NASA Lead-Free Solder Body of Knowledge
Appendices

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Appendix A

Lead-Free Document Summarization Table

Appendix A: Lead-Free Document Summarization Table

Focus	Objective	Scope	Conclusion(s) Summary	Reference
1. JCAA/JG PP Vibration Report	Vibration testing was conducted by Boeing Phantom Works (Seattle) for the Joint Council on Aging Aircraft/Joint Group on Pollution Prevention (JCAA/JG-PP) No-Lead Solder Project	Thirty test vehicles (in two batches of 15 test vehicles each) were subjected to the vibration test conditions. The input power spectral density was increased during the test at 60 minute intervals in an effort to fail as many components as possible within the time allotted for the test.	On the "manufactured" test vehicles, the lead-free solders under test sometimes performed better than the eutectic tin/lead control. For example, Sn3.4Ag1.0Cu3.3Bi was the best performer with the ceramic leadless chip carriers (CLCC's) and Sn0.7Cu0.05Ni was the best performer with the PDIP's (with both NiPdAu and matte tin component finishes). On the "reworked" test vehicles, SnPb generally outperfomed the lead–free solders on those components that were reworked. For BGA's that were reworked, SnPb balls assembled using flux only always outperformed SnAgCu balls assembled using flux only. In the latter case, the final SnAgCu solder joints contained approximately 0.3% Pb contamination from the residual SnPb left on the pads after removal of the SnPb component. For the PDIP's that were reworked (U23 and U59, NiPdAu finish), SnPb solder was also the best performer. This is in sharp contrast to the results from the "manufactured" vehicles where the Sn0.7Cu0.05Ni wave solder alloy was the best performer, followed by the SnAgCu alloy and then SnPb. These results may be partly due to the negative effect that small amounts of Pb have on the reliability of Sn0.7Cu The results of this study suggest that for some component types, lead-free solders are as reliable as the currently used eutectic SnPb solder with respects to vibration. Unfortunately, this study also demonstrated that with other component types, the leadfree solders failed before the Sn/Pb control. Although this does not mean that lead-free solders can not be used in high reliability electronics, it does imply that models for calculating the actual field lifetime of lead-free solder joints on certain component types will need to be developed and validated using actual vibration test data (from this and other studies).	JCAA/JG-PP No-Lead Solder Project: Vibration Test Tom Woodrow Associate Technical Fellow Electronic Materials Technology Microsystems & Electronics Technology Boeing Phantom Works
2. RELIABI LITY OF PB-FREE AND MIXED SYSTEM ASSEM BLIESA VIONIC	The intent of the study is to provide the avionics industry with reliability data that addresses Pb-free and mixed system assemblies.	Thermal cycling was performed from -55°C to 125°C with a 10-minute dwell at cold and 15-minute dwell at hot extremes. Maximum ramp rate was 10°C per minute as measured on test vehicles.	- From a purely manufacturing standpoint, the only difference that exists between boards assembled with SnPb, Pb-free, or mixed solder systems, is that reflow temperatures must match the solder paste alloy. - Thermal cycling results agreed with much of the previously published literature in that the reliability of Pb-free and mixed systems is at the very least comparable to reliability of SnPb systems. - The only discrepancy arose in that the PBGA352 and fleXBGA144 SnPb-paste mixed system configurations exhibited the best reliability results	MANUFACTURING AND RELIABILITY OF PB-FREE AND MIXED SYSTEM ASSEMBLIES (SNPB/PB-FREE) IN AVIONICS ENVIRONMENTS Dave Nelson, Hector Pallavicini Raytheon Company

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S				McKinney, Texas USA SMT-CD
3. LFS Defense Industry	Paper Presentation	The lead-free initiatives have resulted in two high-level issues of concern to aerospace and defense equipment manufacturers (hereon in referred to as OEMs): 1. Development and implementation of lead-free production lines and 2. Effects of buying lead-free products (COTS from suppliers.	The NEMI effort would appear to be adequate for the 95.5Sn3.9Ag0.6Cu alloy. However, in a COTS insertion world, within a global economy, the chances are significant that some components and assemblies will contain other lead-free interconnection materials. As such, OEMs would need a methodology to validate these other materials. The methodology would need to include the optimum amount and types of properties (e.g. thermal shock, thermal cycle, vibration, etc.) for suitable assessment. Only by having such a process in place can product and system performance be ensured to the customer community.	THE LEAD-FREE SOLDER ALTERNATIVES ISSUE: A DEFENSE INDUSTRY PERSPECTIVE Anthony J. Rafanelli Raytheon Naval & Maritime Integrated Systems-MS 369
4. LF Conversion – Military & Aerospace	Extensive bibliographic research has been performed on lead-free soldering and lead-free component finishing, as well as participation in various conferences and workshops on the subject	The authors' interest in the industry movement to introduce lead (Pb)-free electronic assemblies arises from the role that the Best Manufacturing Practices Center of Excellence (BMPCOE) plays in promoting best practices throughout the U.S. industrial base as well as the additional work it performs in support of military program managers in areas of systems engineering and risk management.	Most new lead-free components have been tested in limited environments and for limited duration; their life cycle reliability is an unknown parameter (therefore a risk factor) for most applications, particularly for military and space applications. The conversion to lead-free components will have virtually no beneficial effect on the environment with the "replacement" compounds being significantly more toxic than the current compounds. The marketing behind electronic "Green" products needs to be exposed for what it is, and the technical difficulties posed by lead-free conversion need to be better analyzed before proceeding with conversion. More life cycle reliability data is needed in the event that marketing forces prevail and conversion continues.	The Impact of Lead-Free Conversion on Military and Aerospace Applications Authors: Charlie Minter BMPCOE/Willcor, Constantin Rauta BMPCOE/CSC and Nick Tambakis BMPCOE/CSC

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5. LF microelectronics - aerospace	The commercial microelectronics industry is rapidly implementing Pb-free assembly strategies and it should be mostly Pb-Free within the next decade. This trend is driven by existing and proposed legislation in Europe and in Japan, which has already lead a number of firms (including AT&T, IBM, Motorola, HP and Intel) to adopt Pb-free implementation programs. This is another sign that the microelectronics industry has become truly global.	In this paper we provide a snapshot of the commercial industry trends and how they may impact electronics in the aerospace environment. Impacts will be felt in the areas of: reliability, assembly methods, cost drivers, supply chain selection and alternate materials selection.	No problem was encountered during the printing process with Pb-free paste. The printing was uniform for all PWBs. • A longer delay was required for the first three pastes during the reflow process. This was due to the higher melting temperature of the solders. • Although the solder fillets appeared to be generally good, the solder joint appeared grainier than those formed by Sn63/Pb37 solder. • Sn95.5Ag3.8Cu0.7 and Sn96.2Ag2.5Cu0.8Sb0.5 passed 100 cycles from-55°C to +125°C with no signs of cracking observed. 20	Implications of Pb-Free Microelectronics Assembly in Aerospace Applications Andrew. A. Shapiro1,2†*, J. Kirk. Bonner1, Oladele A. Ogunseitan3, Jean-Daniel M. Saphores4, Julie M. Schoenung5 1 Electronic Packaging and Fabrication Section Jet Propulsion Laboratory
6. LFS Joint Reliability	Solder joint reliability of ceramic chip resistors assembled to laminate substrates has been a long time concern for systems exposed to harsh environments such as those found in automotive and aerospace applications	In this work, the thermal cycling reliability of several 2512 chip resistor lead-free solder joint configurations has been investigated Thermal cycle -40 to 125C and -40 to 150C	- The eutectic SAC alloy (95.5Sn-3.8Ag-0.7Cu) has similar reliability to standard 63Sn-37Pb for testing from -40 to 125C - 63Sn-37Pb joints dramatically outperformed the lead-free Sn-Ag-Cu alloy joints for the more extreme -40 to 150 testing - Quaternary variations of the lead-free SAC alloy (Sn-Ag-Cu-X), which include small percentages of bismuth and indium, can be used to enhance the -40 to 150C thermal cycling fatigue resisitance relative to standard 95.5Sn-3.8Ag-0.7Cu	THERMAL CYCLING RELIABIYLT OF LEAD FREE CHIP RESISITOR SOLDER JOINTS – **DRAFT**- Bozack, Evans CAVE

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7. LFS – Accelerated Temp Profiles	This paper investigates these increased processing times required for high volume manufacturing of lead-free electronics. A study of typical process capacity and real throughput capacity is presented. The study evaluates high volume electronics manufacturing ranging from small circuit assemblies (e.g. cell phone) to large circuit assemblies (e.g. automotive and computers) and investigates a series of “best” reflow profiles to accelerate the standard lead-free process window to meet a targeted manufacturing capacity using an automated profiling system.	A test vehicle is then fabricated using this defined process window and tested for quality (solder voiding and appearance) and solder joint reliability (accelerated life testing). The designed test vehicle includes components from a large physical distribution including: small and large BGAs, QFNs, and any type discrete components. During assembly, virtual profiling is used to document any deviations to the process profile window. The quality and reliability data are presented within this publication and failure analysis is included to determine the capability of this proposed profile. To perform this investigation a series of high volume products were selected from several electronics manufacturers. From these modules a matrix of reflow profiles were	This work provides several significant contributions for the issue of accelerated profiles for lead-free analysis. First, a general range of expected time differences between products reflowed with SnPb profiles versus SnAgCu profiles are defined. Since most of these products are high in thermal mass compared to typical industrial designs, these results may be considered worst case. In addition, this experiment illustrates that accelerating profiles for many applications can continue to yield solder joints with acceptable quality. This experiment also shows how design specific the acceleration of reflow profiles are when considering lead-free solders. Finally, this experiment illustrates how a prediction and monitoring system for reflow profile evaluation can be used to significantly improve the performance of an electronics manufacturing operation.	Understanding the Impact of Accelerated Temperature Profiles on Lead-Free Soldering John L. Evans, Julius Martin, and Charles Mitchell Auburn University Auburn, University, AL Bjorn Dahle KIC Thermal Profiling San Diego, CA Presented in the ECWC 10 Conference at IPC Printed Circuits Expo®, SMEMA Council APEX® and Designers Summit 05

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		developed for SnPb and SnAgCu to estimate the range of additional reflow time needed for SnAgCu. Since this research focused primarily on the worst case scenario, modules with high thermal mass were selected for this experiment.2,3.		
8. LF Device Reliability	Slide Presentation	SnAgCu = Higher melting point (~217C), but better fatigue life than Eutectic SnPb	- SnAgCu is Most Reliable for TSOPs = assembled to electroless nickel immersion gold boards cycled from – 55 to 125C - Lead-free is more reliable than Sn-Pb (TSOP, resistor,CBGA,PBGA,CSP) = thermal cycle data, 0 to 100C and -40 to 125C Life Comparison of Pb and Lead-free solders = Depending on stress/strain levels developed in the ATC conditions - Life of lead-free solder is longer for lower stress/strain conditions. But, it is the opposite for higher stress/strain condition. For a specified stress level, higher strain rate means more damage accumulation and shorter life.	2nd Level Reliability for Pb-free devices Stephen H. Pan SAC Meeting
9. Solder Joint Reliability	Quantitative analysis of solder joint reliability data for lead-free Sn-Ag-Cu (SAC) and mixed assembly (SnPb + SAC) circuit boards based on an extensive, but non-exhaustive, collection of thermal cycling test results	Life of area-array assemblies with: 1) SAC balls and SAC or SnPb paste; 2) SnPb balls assembled with SAC or SnPb paste.	- When SAC test results are inferior to SnPb test results, the higher slope of SAC fatigue life correlations suggests that SAC assemblies may still outperform SnPb assemblies under mild enough thermal cycling conditions - There is a definite lack of reliability test data under mild conditions - Test results over a wide range of test cycles are mixed for area-array assemblies using SAC balls and SnPb paste requiring a careful reliability assessment - Test results are also mixed with a strong effect of thermal cycling conditions on cyclic life trends for area-array assemblies using SnPb balls and SAC paste. Under conditions 0°C to 100°C, or even milder, these assemblies appear less reliable than conventional SnPb area-array assemblies.	Lead-Free and Mixed Assembly Solder Joint Reliability Trends Jean-Paul Clech, Ph.D. EPSI Inc.
10. Solder Joint Reliabilit	Research finds bulk alloy properties are not a meaningful predictor	Reviewing some of the acknowledged test regimes and their	- Different SnAgCu alloys possess similar reliability characteristics. - SnPb solders exhibit a higher fatigue life than lead-free solders under more extreme conditions (high temperature and strain ranges). Under less extreme conditions (lower	Assessing Solder Joint Reliability in Pb-Free Assemblies

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y	of reliability.	results provides a real-life picture of lead-free reliability.	temperature and strain ranges), lead-free solders display up to double the fatigue life of SnPb alloys. - Adding up to 5% bismuth may improve reliability, provided there is no lead contamination that could cause the formation of a low-melting SnPbBi phase.	Steve Dowds Henkel Electronics Circuits Assembly DECEMBER 2004
11. Solder Joint Reliability	This study focused on the board level reliability of lead free replacements for all significant package families: Ball Grid Array's (BGAs), Chip Scale Packages (CSPs) and leaded packages.	LFS Assembly Sn/3.9Ag/0.6Cu, OSPsurface finish Thermal cycle 0 to 100°C & -40 to 125° C	Assembly: - The high temperature reflow did not cause delamination in the packages assembled. - X-ray inspection after assembly indicated no opens and shorts. Therefore, the lead-free solder paste on the OSP surface finish is acceptable. - Reflow of the lead-free alloys using a nitrogen-less convection oven is possible. - The assembled boards did not exhibit warpage issues. - All the components assembled had electrical continuity. - Existing equipment sets are capable of processing leadfree assemblies reliably. Tests: - For the tested components, no failure was observed after 880 cycles between 0 to 100°C and after 475 cycles for the testing range between –40 to 125°C for both the control Sn/Pb paste and Sn/Ag/Cu paste. - The interim results suggest that there is no difference in the reliability among the various lead-free solder joints tested.	BOARD LEVEL RELIABILITY OF LEAD-FREE PACKAGES Swaminath Prasad, Flynn Carson, G.S. Kim & J.S. Lee – ChipPAC Inc. Patrick Roubaud & Gregory Henshall – Hewlett Packard. Sundar Kamath & Alexander Garcia – Sanmina Corp. Robert Herber & Ronald Bulwith – Alpha Metals Inc. SMT-CD
12. Solder Joint Reliability	In this paper we investigated thermal fatigue mechanisms of solder in temperature cycling tests with the goal of developing a shortened technique for temperature cycling tests	A temperature cycling test was performed using a temperature profile that was -40°C to 125°C with a 30 minute dwell at the min and max temp; Test vehicle: CSP component, Ni-Au surface finish, Sn-Ag-Cu & SnPb solder alloys (no-mixing)	For Sn-Ag-Cu lead-free solder repetitive stress during a temperature cycling test was the cause of finer crystal grains and the occurrence of cracks, and that heat itself had little influence	Thermal Fatigue Mechanisms of CSP Solder Joints on PWB Hironori Ohta, Jissou Research Laboratories & Nozomu Nishimura, Mobile Terminals Division
13. LFS – High	Sn-Ag-Cu alloys arc lcading candidatcs for	The PCB thickness was 0.8uun and also the	Two system solders were developed. One is Sn-Ag-Ni-P. The other was Sn-Ag-Cu-P. Sn-Ag-Ni-P system has a balance of thermal cycling, bend. drop. and intemal void	High Solder Joint Reliability with Lead Free

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Joint Reliabilit y	lead free solders. However. Sn-Ag-Cu alloys were not satisfied to meet sever custoiner requirements. At first, optimum silver **wt%** was investigated to gct the balance of drop, thermal cycling: bend test perfonnancc and solder internal voids. Additives including Ni, Col Au_ P. Ga. Cu and Sb **mas** subsequently studied while obsewing reliability performance. Based on the rcsulls of board Icvcl reliability tests_ new lead free solder has been developed.	solder pad finish used either O.ObumAn/3um" or OSP. -40/125 "C was used with a ramp time of 5 minutes and a dwell time of 10 minutes Drop cmiage holds board under tests. Ladder assembly supports the linear guide rails. Anvil assembly is the impact point of drop carriage. The supported assembly aligns the ladder assembly Figure 4 shows the drop test apparatus.	test performance. On the other hand, Sn-Ag-Cu-P system has a significant advantage for drop test performance. The combination of Cu and P significantly reduce intermetallic compound thickness.	Solders Maszuini Amagai". Yoslulaka Toyodd", Takeslu Tajimat3 The Wcst Industrial Part_ 17-Miyukigaoka. Tsukuba-Shi. IbarakiPref. 305-0841 ~ Japan: SC Package Development. Tsukuba Technology Center. Texas Instruinents_ Japan
14. SAC Solder Joints – Creep Data	The study of shear stress and strain in solder joints of electronic assemblies is of interest for the development of analytical models that describe the shear deformations of solder joints due to the global thermal expansion mismatch between components and circuit boards or other	This paper compares shear creep data from several laboratories with the objective of consolidating compatible datasets under different stress and temperature conditions. Reasons for differences between datasets are also discussed	While the proposed creep models require further validation, especially at cold temperatures where there is a lack of creep data, it is hoped that the results of this comparative analysis are of use to developers of lead-free solder joint stress/strain analysis and reliability prediction models.	Comparative Analysis of Creep Data for Sn-Ag-Cu Solder Joints in Shear *Jean-Paul Clech*

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	substrates			
15. LFS Creep Models	This paper presents the application of physically-based, obstacle-controlled creep models to the analysis of steady-state creep rates for eutectic SnPb and seven leadfree solders: Sn58Bi, Sn0.7Cu, Sn3.5Ag, Sn4Ag, Sn3.8Ag0.7Cu, Sn3.5Ag0.75Cu and Sn2.5Ag0.8Cu0.5Sb.	Using the two-cell creep models, creep contour charts were generated to quantify the contribution of competing creep mechanisms to the total creep rates. The patterns of creep contour lines are quite different for Sn37Pb and Sn3.8Ag0.7Cu, a reflection of vastly different creep mechanisms. The Sn3.Ag0.7Cu creep contour chart suggests a transition from one mechanism to another that is highly temperature related. The transition occurs at about 75°C, in agreement with microstructural and creep rate analysis conducted by Vianco et al. (2004) on Sn3.9Ag0.6Cu solder.	Obstacle-controlled creep models have been developed for Sn37Pb and seven lead-free solders: Sn58Bi, Sn0.7Cu, Sn3.5Ag, Sn4Ag, Sn3.8Ag0.7Cu, Sn2.5Ag0.8Cu0.5Sb and Sn3.5Ag0.75Cu. The obstacle-controlled creep models resolve many anomalies that have been observed in the analysis of lead-free solder creep data using power-law or "sinh" models. With the use of a simple, multiplicative calibration factor, the models allows for bridging tensile, shear and compression test results, as well as strength, creep and stress-relaxation data, and thermal cycling stress/strain measurements. In the case of Sn3.5Ag, the model allowed for bridging ceramic chip carrier joint creep data to flip-chip joint creep data in shear.	AN OBSTACLE-CONTROLLED CREEP MODEL FOR SN-PB AND SN-BASED LEAD-FREE SOLDERS Jean-Paul Clech EPSI Inc. Montclair, NJ, USA jpclech@aol.com
16. SAC Alloy Joint Thermal	Two similar resistor packages, one with SAC alloy (Sn95.5Ag3.8Cu0.7)	TTheset Vreeshisitcolre sd aensidg nS aims polfe Pthree psaarmaeti otny pe as used by the	Thermal mechanical strains in the leadfree SAC alloy and near eutectic tin-lead solder joints are evaluated using DSC technique for resistor packages. Following selected solder material constitutive models, the approach devised for strain partitioning has led to the separation of the elastic, plastic and creep strain from the measured total	SAC AND SnPb SOLDER JOINT THERMAL STRESS AND STRAIN CHARACTERIZATION

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Stress	joints and the other with eutectic tinlead joints, are tested under similar thermal profiles. The total strains in the joints are measured against temperature variation by applying Digital Speckle Correlation (DSC) technique. With the measurements obtained in an area of about 20 by 30 µm near the corner of solder fillet, the average strain is calculated in each case. Time, temperature, and stress dependent deformation of the interconnect materials are analyzed based on the materials' constitutive laws.	National Electronics Manufactures' Initiative (NEMI) for Pb-free reliability research projects. In order to measure the solder joint strains at desired locations, the samples are cross-sectioned, as illustrated in Fig. 2. The feature dimensions are as listed in Table 1. The two types of the ceramic resistor package used in this research differ only in the joint solder materials, of which one is the leadfree SAC alloy (Sn95.5Ag3.8Cu0.7) and the other the eutectic tin-lead (Sn63Pb37). The cross sections are polished, photographed and deposited with thin layers (below 10 µm thick) of black and white speckles. Fig. 3 shows the pictures of the joint area with and without the speckles coverage.	strain. The analysis does confirm that the creep strain is the dominant deformation mechanism. It also gains some insights into the comparison of the behavior between SAC and tin-lead joints under thermal load. In particular, the following points are worth addressing: Both SAC alloy and eutectic tin-lead show similar deformation trends under similar temperature profiles. • Creep deformation is the dominant deformation mechanism for both solder joints and stress relaxation starts during the ramp up period and continues during the rest of the test including high temperature dwell. • SAC alloy experiences higher shear strain, shear stress and creep strain rate than tin-lead solder.	FOR RESISTOR PACKAGES Guihua Shi, Ming Zhou and Hua Lu Department of Mechanical and Industrial Engineering Ryerson University Toronto, Ontario, Canada hlu@acs.ryerson.ca
17. Solder	The lead-free solder-	Emphasis is placed on	- For both the 256-pin and 388-pin PBGAs, the shear creep strain in the lead-free	HDPUG's Design for Lead-

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Joint Reliabilit y High Density Packages	joint reliability of the high-density packages, 256-pin PBGA (plastic ball grid array), 388-pin PBGA, and 1657-pin CCGA (ceramic column grid array), on PCB (printed circuit board) subjected to temperature cycling is investigated.	the time-history creep responses such as the shear stress and shear creep strain hysteresis loops, shear stress history, shear creep strain history, and creep strain energy density of the lead-free solder joints of these packages on PCB while they are subjected to temperature cycling. The lead-free results will be compared to those with Sn-Pb solder joints.	solder joints is lower than that in the tin-lead solder joints. - For both the 256-pin and 388-pin PBGAs, the creep strain energy (the area under the creep hysteresis loop) in the lead-free solder joints is lower than that in the tin-lead solder joints. - Consequently, the thermal-fatigue life of the lead-free solder joints is expected to be longer than that of the tin-lead solder joints. - Again, this is based on the assumption that the material constants (and ®)are the same for the lead-free and the tin-lead solders. - For either lead-free or tin-lead solder joints, the creep strain energy density of the 388-pin PBGA is larger than that of the 256-pin PBGA. Thus, as expected, the thermal-fatigue life of the smaller package (225-pin) is longer than that of the larger package (338-pin).	Free Solder Joint Reliability of High-Density Packages APEX-CD
18. Lead-Free Design – High-Density Packages	The High Density Packaging Users Group (HDPUG) has conducted a substantial study of solder joint reliability of high-density packages using lead-free solder. The design, material, and assembly process aspects of the project are addressed in this paper.	Evaluate the solder joint reliability of lead-free Sn3.8Ag0.7Cu solder joints compared to eutectic Sn37Pb solder joints under thermal cycling. Determine the reliability impact, if any, of different board finishes using SnAgCu solder. Evaluate paste-in-hole (also called pin-in-paste) performance using SnAgCu solder.	Surface mount assembly using lead-free solder pastes identified challenges or differences relative to SnPb assembly in reflow profiling, voiding, wetting, and transition to lead-free. Also, the SnPb balled PBGAs soldered using lead-free solder paste exhibited higher levels of voiding. The design for reliability, thermal cycling test and data analysis, and failure analysis of the lead-free solder joints of high-density packages are reported in29,30,31 respectively.	HDPUG's Lead-Free Design, Materials and Process of High Density Packages Joe Smetana, Alcatel USA Rob Horsley Celestica Limited John Lau Agilent Technologies
19. LFS Reliabilit y –	A test program was started in 2000 at Boeing for the evaluation of the	One lead-free solder was tested for reflow operations	The components used for the lead-free reliability testing were 1206 chip resistors whose end terminations were finished with tin/0.7%copper. As for the lead-free solders, the reflowed tin/3.8%silver/0.7%copper was not as	Reliability and Leachate Testing of Lead-Free Solder Joints

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Leachate testing	reliability of lead-free solder joints.	(tin/3.8%silver/0.7%copper) and one solder was tested for wave soldering operations (tin/0.7%copper). Three lead-free circuit board finishes were also tested: immersion silver; electrolytic gold on top of nickel; and an OSP (organic solderability preservative). The thermal cycle (actual board temperature) was from –55°C to +125°C with 15 minute dwells at each temperature extreme and a ramp rate of 7°C per minute. The thermal cycling was continued for 4380	reliable as eutectic tin/lead on any of the lead-free board finishes and other solders will need to be identified that have greater long-term reliability. The CTE of ceramic components, such as chip resistors, is much less than the CTE of most circuit boards and the mismatch between the component and the board applies a lot of stress to the solder joints. Since chip resistors are used on many circuit boards, they may be the "weakest link" where lead-free solders are concerned. suggests that tin/0.7%copper is a good candidate to replace eutectic tin/lead for surface mount wave solder operations.	Thomas A. Woodrow, Ph.D. The Boeing Company Seattle, WA
20. Solder Joint Reliability High Density Packages - Data Analysis	Temperature cycling test and statistical analysis of various high-density packages on PCBs with SnCu HASL, NiAu, and OSP finishes are investigated in this study	In this study, the reliability of lead-free solder joints of high-density packages subjected to temperature cycling is investigated. Emphasis is placed on the determination of the life distribution of these lead- free solder joints. Also, the test data are analyzed with certain	- The quality (mean life) of lead-free solder pasted 1657CCGA solder joints on NiAu PCB is better than that on SnCu HASL PCB with 83% confidence. - In 98 out of 100 cases, the mean life of 1657CCGA solder joints with lead-free solder paste on NiAu PCB is better than that on OSP PCB. - The SMC lead-free solder joints on SnCu HASL PCB is better than that on NiAu PCB with 89.39% confidence. Also, it is better than the SMC SnPb solder joints on OSP PCB with 99.89% confidence. - The SMC lead-free solder joints on NiAu PCB is better than the SMC SnPb solder joints on OSP PCB with 98.81 % confidence.	Reliability Testing and Data Analysis of High-Density Packages™ Lead-Free Solder Joints APEX-CD

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		levels of confidence.		
21. Solder Joint Reliabilit y- Flip-Chip	From a reliability point of view, there has been interest in the improved thermal fatigue resistance of lead-free solder interconnects.	Flip-chip assemblies on FR-4 (high Tg material) with three different underfill materialsSn63Pb37, Sn96.5Ag3.5, and Sn95.5Ag4.0Cu0.5 bumps Thermal cycles -55 to 125C and -55 to 150C	- Lead-free solders have obviously better high-temperature as well as low-stress creep resistance than Sn59Pb40Ag1 solder - SnAgCu solder is more creep resistance at low stresses and less creep resistant at high stresses - Deformation of the solders is a different function of stress, strain rate, and temperature; the performance should be highly dependent on the temperature and induced stresses in the real joints - **These solders can be expected to perform differently for different package types**	Reliability Assessment of Flip-Chip Assemblies with Lead-free Solder Joints Schubert, Dudek, Jung Fraunhofer Institute for Reliability and Microintergration
22. Effect of Ni on SnCu	While the Ni-stabilized Sn-0.7Cu alloy is now well established as a viable lead-free solder in large scale commercial printed circuit board assembly the effect of Ni is not yet fully understood. It is likely that the effect is related to the preferential incorporation of the Ni into the crystal structure of the Cu6Sn5 intermetallic but this effect needs to be further quantified and related to the observed behaviour in production soldering. In this paper the results of DSC and microstructural analysis are reported and the	However, the primary recommendations of the industry consortia in Japan, Europe and the USA were alloys based around the tin-silver-copper eutectic. There were several factors which influenced that choice. One factor was the melting point of the tin-silver-copper eutectic (217°C), which is some 10°C lower than that of the tin-copper eutectic. At that stage in the development of lead-free soldering technology it was considered important to choose an alloy with a melting point as close as possible to that of the	The properties of the nickel-modified tin-copper eutectic lie somewhere between those of tin-lead and those of the tin-silvercopper alloys. The strength is higher than tin-lead but lower than tin-silver-copper but ductility is greater than tin-silvercopper and comparable with that of tin-lead. In a series of experiments with additions of nickel ranging from 0.01 to 1% it was found that within a certain range of nickel levels there is a dramatic change in the way the alloy behaves in freezing and in the microstructure of the alloy (Figure 4). This discovery is protected in most countries by patents held by Nihon Superior Co., Ltd.1	The Effect of Ni on the Microstructure and Behaviour of the Sn-Cu Eutectic Lead-free Solder Keith Sweatman and Tetsuro Nishimura Nihon Superior Co., Ltd. Osaka, Japan Presented in the ECWC 10 Conference at IPC Printed Circuits Expo®, SMEMA Council APEX® and Designers Summit 05

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	possible connection with the performance of the solder proposed.	tin-lead eutectic it would be replacing (183°C).		
23. LFS – chip size package	To put the lead free solder to practical use, reliability of solder joint should be clarified. To understand its reliability, the following must be considered: components of solder materials, various conditions in the practical use such as PWB surface-finishment, placing conditions, applied stresses and **so** forth.	The CSP has size 12 X 12mm, 0.8" pitch, 14X 14 array as shown in Fig *1* . As surface finishment of PWB, organic solderability protector (OSP) on Cu and Au plating are selected. As solder materials, Sn-3.5Ag-0.75Cu, Sn-2.5Ag-0.5Cu-l.OBi, Sn-7.8Zn-3.OBi, Sn-37Pb (abbr. SnAgCu, SnAgCUBi, SnZnBi, SnPb, respectively) was selected. The CSP was mounted on a FR-4 test board. The assembled board was passed in the reflow oven at over 230 "C peak temperature.	It is cleared that placing condition and PWB surface-finishment caused large effect for reliability of thermal fatigue and mechanical fatigue, respectively. We got the result that CSP placing condition, PWB surface finishment greatly gave more effect **on** reliabiiity ***of*** the lead-free solder joint than solder materials. The work helps us to clarify the influence of	Reliability of Lead Free Solder Joint by Using Chip Size Package **T. Hirano,** K. **Fukuda,** K. Ito, T. Kiga, Y. Taniguchi Packaging Product Engineering Dept. PNC, ***SOW*** CORPORATION
24. LFS - Flip-Chip Reliabilit y	Reliability of a ternary Sn/Ag/Cu alloy for flip-chip solder joints	Sn/3.5Ag/0.7-1.0Cu -40 to 125C thermal cycle 150C 1000 hours temp storage die shear	63Sn/Pb solder bumps showed signs of grain coarsening, the SnAgCu solder bumps exhibited no structural change	Flip-Chip Reliability: Comparative Characterization of Lead-Free (Sn/Ag/Cu) and 63Sn/Pb Eutectic Solder Balkan, Patterson, Burgess Kulicke and Soffa
25. Flip-Chip	The competitive market	This Flip-Chip package	Leadfree or leaded Flip-Chip packages have been developped by STMicroelectronics	AN1235

Focus	Objective	Scope	Conclusion(s) Summary	Reference
Packages	of portable equipment, notably the mobile phone market, is driven by a challenging development of highly integrated products. To allow manufacturers of portable equipment to reduce the dimension of their products, STMicroelectronics has developed packages with reduced size, thickness and weight in the form of the Flip-Chip	family has been designed to fulfill the same quality levels and the same reliability performances as standard semiconductor plastic packages. That means these new Flip-Chip packages have to be considered as new surface mount devices which will be assembled on a printed circuit board without any special or additionnal process steps required.	for electronic applications where integration and performance are the main concerns of designers.	APPLICATION NOTE FLIP-CHIP: PACKAGE DESCRIPTION AND RECOMMENDATIONS FOR USE © 2004 STMicroelectronics - All rights reserved
26. Flip-Chip - interconnect	In a flip-chip package, lead is used in passive component termination finish (SnPb plating), SnPb solder paste for connecting die/land-side capacitors to the board, ball grid array (BGA) solder balls and a high lead-bearing solder bump on silicon that is connected to substrate using eutectic SnPb solder (first level interconnect or FLI).	The solder paste selected for this development was Sn4.0%Ag0.5%Cu (SAC405 Alloy). The Sn-Ag-Cu family of solders is becoming the mainstream lead-free alloy choice of the industry. This solder has a melting point of 217°C, which is 34°C higher compared to the eutectic SnPb solder, which melts at 183°C. Due to the high melting point of SnAgCu solder, components	The key failure modes identified during the development of lead-free flip-chip BGA packages were substrate delamination, underfill to substrate adhesion, die side cap attach process and the reliability of lead-free solder joint. Similar to the industry reports,[3] large Ag_3Sn plates were observed on SAC405 solder, which changes solder joint failure to brittle mode. The joints with SAC305 solder joints did not have large Ag_3Sn plates. In our experiments, we discovered that in SAC405 solder, the formation of Ag_3Sn plates can be controlled by slowing the cooling rate of reflow process.	Lead-Free Second Level Interconnect On Flip-Chip Packages (1/12/2005) Future Fab Intl. Volume 18 By Vivek Gupta, Intel Corporation YT Chin, Intel Corporation

Focus	Objective	Scope	Conclusion(s) Summary	Reference
		may be subjected to up to 260°C temperature during the board assembly and rework processes.		
27. LF Flip Chip Interconnect	This paper discusses the characteristic properties and board level reliability of an advanced flip chip underfill encapsulant using a lead-free alloy (Sn-3.8Ag-0.7Cu) composition. No electrical failures or underfill delamination is observed after 4000 thermal shock cycles from -55°C to +125°C. Results from failure analyses are presented for both flip chip on board and flip chip in package configurations.	Material Characterization: The underfill material was characterized for thermo-mechanical properties using Thermal Mechanical Analyzer (TMA) and Dynamic Mechanical Analyzer (DMA). The TMA scan was run from -40°C to 300°C at a heating rate of 5°C per minute. The glass transition temperature, Tg and the CTE were determined from the first heat of the scan. The CTE below the Tg was measured from -25°C to 25°C. The CTE above the Tg was measured from 200°C to 250°C. The DMA scan was run from 25°C to 300°C at a heating rate of 5°C per minute.	We have presented the characteristic properties and reliability performance of an advanced flip chip underfill encapsulant that is assembled using a ternary lead-free alloy, 95.5Sn/3.8 Ag/0.7Cu. This lead-free alloy is also known as LF2 within the microelectronics industry. We have shown that such an underfill with lead-free interconnection can be used in applications for flip chip on board (FCOB) as well as flip chip in package (FCIP) where moisture preconditioning of the assembled flip chip parts is required followed by multiple reflow cycles to peak reflow temperatures of 260°C. This particular underfill is seen to perform well after Mositure Sensitivity Level 3 (30°C/60%RH/192 hours) conditions followed by three successive reflows to a peak reflow temperature of 260°C.	CHARACTERIZATION AND RELIABILITY PERFORMANCE OF AN ADVANCED UNDERFILL ENCAPSULANT FOR LEAD-FREE FLIP CHIP INTERCONNECTION Kalyan Ghosh Electronics Technology Lord Corporation Cary, NC, USA kalyan_ghosh@lord.com Guoyun Tian NSF Center for Advanced Vehicle Electronics Auburn University Auburn, AL, USA
28. LF Flip Chip	This study examines fluxes for their ability	The test component was a 14.4 x 14.4 mm flip	This study evaluated a number of material sets for Pb-free processes. The tacky flux and underfill systems are designed for the flip-chip packaging process. The movement	FLIP-CHIP UNDERFILL AND FLUX RESIDUE

Focus	Objective	Scope	Conclusion(s) Summary	Reference
Under fill	to provide a reliable and consistent interconnect in a Pb-free flip-chip reflow process. Fluxes tested were used as tacky-fluxes; some were formulated to be used as tacky fluxes, some as the basis for Pb-free solder pastes. After initial evaluation, parts were conditioned and reliability was assessed to determine JEDEC level 3 with a 260oC reflow compatibility.	chip with polyimide passivation. The bump pattern was a full array of 3840 bumps at a pitch of 225 _m. There were two Pb-free alloys used as bump metallurgy: Sn/3.5 Ag/0.5 Cu and Sn/3.0 Ag/1.0 Cu. The substrate was a four layer BT laminate at a thickness of 1 mm. The solder mask was PSR4000 AUS5, and the surface finish on the pads was electroless nickel/immersion gold (ENIG).	to a Pb-free process affects the moisture level rating of packages and devices [5]. One of the materials that impact this JEDEC moisture level rating is the underfill. This study shows that there are compatible flux residue/underfill systems suitable for Pb-free processes. Flux systems G, L, N, and P are more compatible to different underfill material sets than others.	INTERACTION IN A Pb-FREE PROCESS Brian J. Toleno, Ph.D., George Carson, Ph.D., and Michael Todd Henkel Loctite Electronics Industry, CA, USA
29. LFS Reflow - PBGA	This paper will document the activities of a cross functional team formed within Motorola to develop the materials and processes to produce Pb (lead) free leaded and PBGA (Plastic Ball Grid Array) packages for the assembly of integrated circuits to circuit boards using Pb free solder paste. Results of component and board level reliability are	Components selected for evaluation of SnAgCu solder paste were the 357BGA 1.27mm pitch, two 48TSOP 0.5mm pitch – one with a Cu (copper) leadframe and one with an Alloy42 leadframe and a 2512 ceramic chip resistor. Weibull plots of these parts and boards under test. For a part temperature profile of -40 to 125 C, the part dwell times are 15	Board solderable surface finish does not make a statistical difference. Based on these results, there appears to be no significant difference between the various solder compositions. Motorola supports the NEMI recommendation3 of Sn/3.9Ag/0.6Cu solder paste. solder paste as a control. They are being stressed with –40°C to 125°C air to air and –55°C to 125°C liquid to liquid thermal cycles. As of this writing, the 388 PBGA with SnAgCu balls has survived 5000 cycles at –40°C to 125°C without failure at the interconnects. The material combinations and SnAg and SnAgCu balls for BGA packages appear to be an acceptable substitute for SnPb. Alternate lead finishes for peripheral packages are under investigation.	Development of Lead-Free Peripheral Leaded and PBGA Components to Meet MSL3 at 260° C Peak Reflow Profile Geoff Swan, Alan Woosley, Nick Vo and Thomas Koschmieder Motorola PCS

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	presented.	minutes at the extremes, and 15-minute ramps between the two extremes.		
30. LFS – Drop Test	Sn-Ag-Cu alloys are leading candidates for lead-free solders. However, Sn-Ag-Cu alloys were not enough to meet sever board level reliability Kirkendall voids in lead-free solder joints could be reduced tremendously after adding Ni and In to SAC	Sn-Ag-Cu-Ni-In lead-free solders and it's procedure are described .8mm diameter solder balls were attached to .0mm solder pads of 1.6mm thick FR-4 board using a resin flux Solder alloy balls were attached a 12x12mm BGA package which consisted of 289 solder balls	Drop test performance is dependent on Kirkendall voids and Cu3Sn layer growth. After Indium 0.2 wt% and Nickel 0.04 wt% werre added to Sn-1.0Ag-0.1Cu solder, the solder alloy could improve drop test performance by 20% after 150C thermal aging process, compared to Sn-1.0Ag-0.5Cu-P. Furthermore, it was found that Sn-1.0Ag-0.1Cu-0.2In-0.04Ni solder did not increase solder internal voids compared to Sn-1.0Ag-0.5Cu-P	High Drop Test Reliability: Lead-Free Solders Amagai, Toyoda, Ohnishi SC Package Development, Tsukuba Technology Center, TI
31. LFS-Chip Scale Assembly - Reliability	Fine Pitch BGAs (FP-BGAs) and CSPs are increasing in popularity, particularly for portable electronics Current trend to lead free solder balls and assembly	- 10 CSP attachment sites per side. - Immersion Ag finish - Multicore LF300 lead-free solder paste (95.5%Sn/3.8% Ag/0.7%Cu, type 3) - Lead Free Reflow profile	Sn/Pb and Sn/Ag/Cu Comparable, Except Sn/Ag/Cu Better Than Sn/Pb with Capillary	Assembly and Drop Test Reliability of Lead Free Chip Scale Packages R. Wayne Johnson Yueli Liu, Guoyun Tian, Shyam Gale, & Pradeep Lall Laboratory for Electronics Assembly & Packaging - Auburn University
32. LF assembly, reliability – chip-scale package	This paper discusses the reliability testing results of a lead-free version of the micro SMD, National Semiconductor's Wafer Level-Chip Scale	The experimental matrix consisted of 3 variables, namely solder bump metallurgy (Sn/Pb and Sn/Ag/Cu), solder paste metallurgy (Sn/Pb and	Lead-free bumped micro SMD is compatible with SMT assembly processes using the high peak temperature of 260oC for reflow. Standard Sn/Pb solder bumped micro SMD packages can be successfully assembled with a lead-free board mounting process. A homogeneous lead-free flow (lead-free bumps and lead-free paste) has been confirmed as the most reliable combination. This is expected due to the higher strength of Sn/Ag/Cu lead-free solder compared to Sn/Pb solder.	Lead-Free Wafer Level-Chip Scale Package: Assembly and Reliability V. Patwardhan, N. Kelkar, and L. Nguyen National Semiconductor Corporation

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	Package (WL-CSP).	95.7Sn/3.6Ag/0.7Cu), and reflow profile used (220oC peak and 260oC peak). Standard FR-4 test boards were used for assembly.		
33. Hot Air LF Rework	Hot air rework profiles were developed for BGA package sizes from 15 to 37.5mm, soldered on Immersion Silver (ImAg), Organic Surface Protectant (OSP) and Nickel- Gold (NiAu) PCB surface finishes. The BGA package solder balls were all Sn/Ag4.0/Cu0.5, attached to electroless nickel immersion gold at the package interface.	Two types of socket were available from two vendors using different ball metallurgies. The first socket utilized a Sn/Ag3.5 alloy with a melting point of 221°C and the second socket used a Sn/Ag3.0/Cu0.5 alloy with a melting point of 217°C. A Design of Experiments (DOE) was run on the first socket with the Sn/Ag3.5 alloy. The 2^3 factorial looked at Time above Liquidus (TAL), peak temperature and Critical Ramp Rate (CRR), the rate between 205-215°C. The two TAL settings were 30 seconds and 200 seconds, the two peak temperature settings were 230°C and 250°C and the two CRR	A significant number of lead free packages and sockets have been reworked on boards with multiple surface finishes and board thicknesses. No major issues were discovered. An overall yield of 97% was achieved with approximately 500 packages reworked over a two year period using the LF Rework Process developed in this study.	HOT AIR LEAD-FREE REWORK OF BGA PACKAGES & SOCKETS Alan Donaldson & Raiyo Aspandiar Intel Corporation Hillsboro, Oregon, USA alan.w.donaldson@intel.com raiyo.f.aspandiar@intel.com

Focus	Objective	Scope	Conclusion(s) Summary	Reference
		settings were 0.30°C/secind and 0.75°C/second.		
34. LFS Rework and Assembl y	A cross-company workgroup was formed to develop a baseline lead-free manufacturing process using the NEMI tin-Silver-Copper (Sn3.9Ag0.6Cu) alloy for medium to high-end computer products.	The overall project was divided in 3 phases. Phases 1 and 2, the lead-free assembly and rework process development studies, were finished toward the end of Q3 2003. Test boards for the process qualification (phase 3) have been assembled. The accelerated thermal cycling experiments are in progress at the time of the publication of this paper.	An assembly and rework process for medium to highend lead-free computer products has been developed by a cross-company NEMI workgroup. Close to 900 PCAs have been assembled, including 100 qualification boards, using existing industrial equipment and procedures. The initial lead-free SMT process gave acceptable yields but more development needs to be done for the wave solder process. The many challenges that face lead-free rework include process tool thermal stability and operational capability. Much learning is still required to improve the manufacturability and reduce the cost associated with inspection and yield loss.	Development of Baseline Lead-free Rework and Assembly Processes for Large Printed Circuit Assemblies Patrick Roubaud1, Jerry Gleason2, Charlie Reynolds3, Ken Lyjak4, Matt Kelly5, Jasbir Bath6 1Hewlett Packard, Grenoble, France
35. LF Rework Challeng es	During rework, a component is subjected to multiple thermal cycles to remove and replace the component as well as in preparation of the rework site. With the use of lead-free components, the assemblies are subjected to multiple thermal cycles at higher temperatures than those required for	Several factors affect the yield of a BGA/CSP rework process. They can broadly be divided into four categories, including the materials involved, the methods adopted to perform the rework operation, the equipment and tooling utilized, and the operator(s) performing the rework.	The results of the thermal cycling reliability evaluation of Package A, Package B, and Package C illustrated a "robust" lead-free and tin-lead CSP rework process. All the reworked lead-free assemblies have been subjected to2500 air-to-air thermal cycles from 0-100°C, in 20- minute cycles, without any failures. Only one failure of a component replacement. The component temperature should be controlled to prevent any moisture-related damage. Baking the components at 125°C for six to eight hours removes excess moisture from the components. Baking the PCB assembly before rework should also be considered based on the temperature sensitivity of the components on the assembly.	CHALLENGES IN LEAD-FREE REWORK Arun Gowda Electronics Manufacturing Research and Services Department of Systems Science and Industrial Engineering

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	eutectic tin-lead.			
36. Rework LFS Assembly	SMT Magazine Article	Rework is an important part of the volume manufacturing process for lead-free PCB assembly, especially true during the initial transition period when every part of the supply chain goes through the learning curve. However, the issue of rework persists throughout the product lifecycle due to the need for warranty repair.	Lead-free solder rework has been found to be more difficult because the lead-free solder alloys typically do not wet or wick as easily as the Sn/Pb solder; a clear example is seen with QFPs. In spite of these differences, successful rework methods (both manual and semiautomatic) have been developed with lead-free solders (Sn/Ag/Cu or Sn/Ag) for all types of components, such as discrete components, area-array packages, etc., using flux gels, flux pens, wire-core solder, etc. Most of the rework equipment for Sn/Pb can still be used for the lead-free solder. In terms of logistics, during the transition period it is key that solder irons and materials (wirecore solder, flux gels, etc.) for lead-free soldering be marked clearly. Operators must be trained in lead-free rework processes and inspection. More rework and higher materials cost will have some direct impact on cost.	Dongkai Shangguan, Ph.D., Flextronics. Surface Mount Technology (SMT) June, 2003
37. LF BGA Rework	A study was conducted to see if proper solder joint reflow conditions could be achieved during rework of large lead-free BGA's while respecting component body qualification profiles specified in the industry standard, IPC/JEDEC J-STD-020B. A target profile was developed based on the upper limit requirements specified in Table 5-2 of the 020B document.	In general, larger BGA's pose a greater challenge in rework due to their thermal mass, various material makeup and complex structure. Ideally, large lead-free BGA test vehicles would be used, but at the time of the investigation none were readily available. Instead, boards using large SnPb BGA devices were used. As these experiments dealt purely with analyzing	Approximately twenty iterations of adjusting the rework equipment time and temperature settings were required to closely match the theoretical profile for the first component, the CBGA. An additional seven profile iterations were required to adjust this profile to accommodate the BGA. Note no changes were made to gas flow rates or nozzle types during profile development.	AN INVESTIGATION INTO LEAD-FREE BGA REWORK WITH CONSIDERATION TO PROFILE REQUIREMENTS OF IPC/JEDEC J-STD-020B Peter Verbiest Advanced Manufacturing Technology Group Jabil Circuit, Inc. San Jose, CA, USA

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	Several thermal profiles were developed and optimized to meet the target profile for two different large BGA's, on an equipment set that is normally used for tin-lead BGA rework.	thermal behavior, no functionality of the component or board was required so the use of SnPb vehicles was deemed acceptable. No visual inspections for delamination or destructive analyses (e.g. cross-sections) of the components were planned.		
38. LF Rework - NEMI	Numerous investigations have been performed on the assembly of lead-free electrical components onto printed circuit boards using lead-free soldering materials. Few have explored the reworkability of these lead-free assemblies. Array packages are one of the more challenging types of component for rework. For this work lead-free and tin-lead PBGA, uBGA and CBGA component were evaluated. The rework process included removal, site redressing, and part replacement using hot	Rework development was conducted on the NEMI Payette reliability test vehicle. The board is shown in Figure 1 (topside) and 2 (bottomside). Most of the components reworked were on the topside. The bottom side has one PBGA544 component and some TSOP and 2512 chip components. Board specifications are shown below: High Temp Laminate FR4 (Tg: 170°C) Surface Finish: Imm Ag and Electrolytic NiAu Board Thickness: 0.093" and 0.135" Board Dimension:	For the PBGA544**,** the rework profiles stayed within all of the targets. The overall tin-lead and lead-free rework process for the PBGA544 component went very well on both 93mil and 135mil thick NEMI Payette boards. No problems were noticed with either board surface finishes. Rework profile time was around 6 minutes for SnPb rework and 8minutes for SnAgCu rework for 135mil thick boards. For the uBGA256, the rework profiles for SnPb and SnAgCu were successfully used to rework various sets of NEMI Payette assemblies. No major issues were found for these reworked uBGAs. Rework profile time was around 7 minutes for SnPb rework and 9 minutes for SnAgCu rework for 135mil thick boards.	LEAD-FREE AND TIN-LEAD REWORK DEVELOPMENT ACTIVITIES WITHIN THE NEMI LEAD-FREE ASSEMBLY AND REWORK PROJECT Jasbir Bath and Mike Wageman, Solectron Corporation; Quyen Chu and Nabel Ghalib, Jabil Circuits; Alan Donaldson, Intel Corporation Jose Matias and Eddie Hernandez, Hewlett Packard Corporation

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	air convection rework equipment.	16.5" x 7.25" Number of copper layers: 14		
39. LF Rework CSP	One main issue associated with lead-free assembly and rework using lead-free solder alloys such as tin-silver and tin-silver-copper is the comparatively high melting temperatures (~220°C) of these alloys compared to the eutectic tin-lead alloy (183°C). The peak reflow temperatures for many lead-free solders are approximately 240°C-250°C as compared to tin-lead soldering temperatures of 210°C-220°C. This increase in reflow temperatures makes it necessary to re-evaluate the component and PCB materials for multiple reflows at leadfree temperatures. The assembly and rework processes need to be optimized to ensure that the integrity of the component and	Three different packages were considered in this study. Two CSP packages utilized lead-free solder alloy balls and one had eutectic tin-lead solder balls. Table 1 gives the details of the components. Package A has non-solder mask defined component pads while Package B and C have solder mask defined pads on the component side. All the three packages are mechanically equivalent samples with daisy-chained structures obtained for evaluation purposes. The test vehicle used for this study was a 62.0 mils thick multilayered FR-4 board with electroless Ni / immersion Au finish. The board contained assembly sites for three CSPs adjacent to each other.	The fine-pitch nature of CSPs, the low standoffs, lead-free processing temperatures, and the inconsistency associated with the rework process make the rework of lead-free CSPs a challenging task. The capabilities available on the rework machine being used for lead-free CSP rework are very important. The efficiency of the heating process is dependent mainly on the heating system of the rework station and the nozzle design. In depth evaluation of the rework station is necessary prior to actual operation [8]. The main capabilities that a rework station should possess for lead-free rework should include [5]:	LEAD-FREE REWORK PROCESS FOR CHIP SCALE PACKAGES Arun Gowda and K. Srihari, Ph.D. Electronics Manufacturing Research and Services State University of New York, Binghamton, New York 13902 Anthony Primavera, Ph.D. Consortium Manager, Universal Instruments Corporation Binghamton, New York 13902 -0825.

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	Printed Circuit Board (PCB) materials is not compromised.	Three pad sizes of 11.0 mils, 13.0 mils, and 15.0 mils were located on the PCB. The electrical continuity and resistance of the three sites and each of the sites can be determined through a series of probe pads on the test vehicle.		
40. LFS Area Array Packages	Depending on the applications in this paper the most suitable solder alloys for area array packages (flip chip, CSP, BGA) will be presented. First reliability results will be shown as well.	For reliability testing thermal cycling was performed between -55°C and +125°C. The first screening of the lead free solders for flip chip applications are focused to select potential and promising candidates for further more detailed studies. In comparison to eutectic Sn/Pb solder five different alloys Bi/Sn, Sn/Bi/Cu, Sn/Ag, Sn/Cu, Au/Sn are selected and investigated in this paper (see scope of our work – phase a).	The results show that the combination of chemical bumping and solder paste printing for flip chip assembly is very flexible and a reliable technique. In this paper first promising results using different lead free solders could be achieved.	LEAD FREE SOLDERS FOR AREA ARRAY PACKAGING J. Kloeser, Ch. Kallmayer*, E. Jung, P. Coskina*, R. Aschenbrenner and H. Reichl Fraunhofer Institute FhG/IZM-Berlin
41. LF BGA Assembly	Though development work on lead-free components is increasing, research on	Could a flip-chip ball-grid array (FCBGA) with 780 I/O be successfully assembled	Visual and X-ray analysis did not show an advantage of using one reflow profile over another. Macro images of the cross sections also did not show any significant distinction, nor did the thermal cycling tests. All boards were failure-free at up to	Lead-Free BGA Assembly By Sam Yoon and Roy Wu, Altera Corp.; and Jasbir Bath, Chris Chou and

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	lead-free components with high I/0 counts has been fairly limited.	with lead-free solder at a peak reflow temperature below 260 C? How would lead-free solder affect joint reliability? How would it affect rework? We conducted a study to find out.	3,500 cycles.	Samson Lam, Solectron Corp.
42. SAC Solder - BGA	Based on a comparison of different ball materials for BGA / LFBGA / CSP components the quality of interconnections will be discussed followed by any reliability results. The damage mechanism for LFBGA components on different board finishes is not quite understood. Further demands from mobile phones are the drop test, characterizing interface performance of different package constructions in relation to decreased pad constructions and therefore interfaces.	Solder ball materials tested in the trials were SnPb and SnAgCu attached to the interposer of LFBGA components (ball attach temperature 200 °C for SnPb and 230 °C for SnAgCu). Related to the ball attach parameter the interface formed in the first level must be analyzed first as a precondition to answer the question of interface formation, especially the formation of intermetallics responsible for the performance required.	It was found, that the degradation of interfaces in reflowed interconnects will be influenced much stronger by intermetallics with different metallurgical and mechanical properties and voids close to interfaces. Both are formed in the reflow procedure and depend also on the number of reflows for the specified product. From the metallurgical point of view more data are required depend on the package constitution, specially the interconnect materials and the finishes on terminations and diffusion barriers required.	INTERFACE DESCRIPTION AND FAILURE MECHANISM OF SNAGCU SOLDERS IN BGA PACKAGES H.-J. Albrecht Siemens AG Berlin, Germany hans-juergen.albrecht@siemens.com
43. LF BGA Packages – Solder fatigue	The objective of these studies is to gather basic information related to the reliability	The study was conducted using two ball grid array (BGA) components, one a	Compared to conventional components, lead-free components have a superior resistance to solder-joint fatigue failure regardless of the type of solder paste used in card assembly (Sn-Pb or lead-free). The superior fatigue life observed in lead-free solder joints confirms the expectations	SOLDER FATIGUE RELIABILITY ISSUES IN LEAD-FREE BGA PACKAGES

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	risks of lead-free solder joints. In addition to the all-lead-free situation that arises when both the component and the card-attachment operation are lead-free	BGA, and the other a CSP. Reliability of the solder joints was evaluated in terms of their resistance to failure under thermal cycling from 0 to 100 C. Conventional and leadfree daisy chain components were obtained from suppliers. The components were attached to daisy chain test cards using two solder pastes, conventional Sn-Pb eutectic and lead-free Sn-Ag-Cu	based on fatigue/creep resistance data and melting point characteristics of the SAC lead-free alloy. Further evidence of this superiority is found in the high level of deformation found in large solder balls. For the "mixed" case where lead-free components are assembled with eutectic Sn-Pb solder paste the fatigue life is lower compared to similar components assembled with leadfree solder paste.	Pedro Chalco IBM
44. LF Packaging	Slide Presentation	Inform about STM / Philips SC / IFX (E3) activities on lead-free packaging	SnAg3.0-4.0Cu0.5-1.0 is the most applied range Good solderability with Pb free solders Offered by all major suppliers Limited backward compatibility with SnPb solders (board apply process to be adopted) The combination lead-free BGA/SnPb-paste can be processed with a minimum temperature of 230°C (at the ball). Solder joint reliability is improved compared to SnPb-balls For BGA packages SnAgCu is the chosen metallurgy	Lead-free packaging for semiconductor devices E3 presentation Infineon Technologies / ST Microelectronics / Philips Semiconductors June 2003
45. Thermo-Mechanical Fatigue Reliability Pb-Free Ceramic Ball Grid	there has been a need to develop Pb-free solders for fine pitch CBGA applications.	In order to better understand the behavior of SAC CBGA under conditions of stress induced by thermal mismatch strains, experimental electrically testable	All the SAC alloy test vehicles produced well-controlled fatigue life as indicated by the small sigmas. In general, our testing has found that a typical sigma for BGA fatigue life is approximately 0.2. The SAC alloy also has almost twice the fatigue life of the dual alloy Sn/Pb structure, for the same form factor.	Thermo-Mechanical Fatigue Reliability of Pb-Free Ceramic Ball Grid Arrays: Experimental Data and Lifetime Prediction Modeling Mukta Farooq, Lewis Goldmann, Gregory Martin, Charles Goldsmith, Christian

Focus	Objective	Scope	Conclusion(s) Summary	Reference
Arrays		hardware has been built with various values of chip carrier body size and thickness, board thickness and I/O pitch. A temperature range of 0 to 100°C and a frequency of 2 cycles per hour were used as the ATC stress parameters,		Bergeron IBM Microelectronics, Inter Connect Packaging Development
46. LFS Thermo-Mechanical Analysis-Flip-Chip	This work is intended to provide a quantitative estimation of the accumulated inelastic strain of two different lead free solder alloys, namely, Sn3.5Ag and Sn3.8Ag0.5Cu.	A viscoplastic constitutive model is used to analyze the thermally induced inelastic deformation. The trends obtained from modeling results have a good agreement with the experimental data found in literature.	- During a moderate thermal cycle (0 to 100ºC), the induced creep strain in the SnAgCu solder alloy is 2.4 times lower than that of the eutectic SnPb solder. - In a more severe thermal cycle (-40 to 125ºC), the accumulated creep strain of SnAgCu solder alloy is just 1.6 times lower compared to the tin-lead. - This difference is due to the higher stresses generated in the lead free solders combined with the lower creep resistance of lead free solders at low temperatures.	THERMO-MECHANICAL ANALYSIS OF A CHIP SCALE PACKAGE (CSP) USING LEAD FREE AND LEAD CONTAINING SOLDER MATERIALS M. GONZALEZ, B. VANDEVELDE and E. BEYNE
47. SnAgCu – board-level reliability	In this paper, a chip scale package assembled on board test and a notebook motherboard surface mount assembly were used to investigate the characteristics of Sn-3.0Ag-OSCu solder alloy from three different companies. One eutectic tin-lead solder was included for	Thermal cycling test follows the MIL-STD-883E (condition B) : Holding at 125% for 10 minutes and then transfer (in 5 minutes) to -55°C and also holding 10 minutes was defined as one thermal cycle. 46 I/O lead-free *fl* - BGA CSP with daisy-	In this study, all samples of chip scale package assembled on test board passed the electrical test even after 2500 cycles thermal cycling test. Sn-Pb and lead-free Sn-3.OAg-OSCu solder joints with OSP and electroless Ni *I* immersion Au surface finish possesses acceptable board-level reliability. All the components with joints serious cracked are made by ceramic- based chip. One reason is that from lead-free process with higher reflow temperature, the thermal sensitive components, such as ceramic chip resistor, had more residue stress after cooling down. Another reason maybe due to CTE mismatch between the component and motherboard, heating and cooling of the components cause thermal stress, because there is insufficient expansion for the ceramic chip components to reach the same expansion with substrate.	Board-Level Reliability of Lead-free SnAgCu Solder Joint Jim-Shu Wu*"', Shan-Pu Yu*, I-Hsuan Peng', Jong-Lih Wang", and Brooks Chung**, *Packaging Process Technology Div.,Advanced Packaging Technology Center, ITRI, Taiwan

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	comparison.	chained was chosen as the test vehicle. The component size is 5 . 7 6 ~ 7.87mm'. The *fl* - BGA solder bumps with 0.325mm ball diameter, 6x8 bump matrix, and 0 . 7 5 1 ~ 1 bump pitch made by Sn-3.2Ag-0.5Cu lead-free solder. One 63Sn-37Pb and three companies (named A, B, and C) Sn-3.0Ag-OSCu solder pastes were used to evaluate the reliability of solder joints. The FR-4 PCB with OSP and electroless Ni / immersion Au surface finish on Cu pad were used as the test board.		
48. PBGA Warpage	A series of board assembly studies was conducted for 1.0mm pitch plastic ball grid array packages (PBGA) over a broad range of package body sizes and die sizes. X-ray and C-SAM analysis were performed to check for solder ball shorts and evidence of any assembly related	A total of 9 test packages were evaluated in this study. All test devices were over-molded plastic ball grid array (PBGA) type packages having 1.0 mm BGA ball pitch and ranging in body size from 23 x 23 mm to 37.5 x 37.5 mm as shown in Table 1. The die size ranged from 5 x	PBGA package body warpage has been shown to increase with ingressed moisture content and peak reflow temperature, as required for Pb-free SMT assembly applications. In addition, PBGA package body warpage was found to increase with package body size and decreasing silicon die size. Larger PBGA packages (35 mm square and greater with 1.0mm solder ball pitch) were found to pass traditional moisture/reflow classification testing, but were found to fail board assembly due to solder ball shorts as a result of excessive package body warpage.	PLASTIC BALL GRID ARRAY PACKAGE WARPAGE AND IMPACT ON TRADITIONAL MSL CLASSIFICATION FOR PB-FREE ASSEMBLY B.T. Vaccaro, R.L. Shook, E. Thomas, J.J. Gilbert, C. Horvath, A. Dairo, G.J. Libricz Agere Systems Allentown, PA, USA

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	package delamination, respectively. The technique of thermal shadow moiré was employed to measure package body warpage response as a function of temperature and ingressed moisture content.	5 mm to 11 x 11 mm and in one limiting case, the package was manufactured with no silicon die. The package substrates consisted of 4 metal layer, Bismaleimide Triazine (BT) laminates ranging in thickness from 0.56 to 0.61 mm, which was dependent on the particular package body size.		bvaccaro@agere.com
49. LF PBGA – board level reliability	The present study is intended to evaluate the board level reliability of PBGA assemblies under thermal and mechanical loading. The main objective is to characterize the reliability of Pb-free solder joints with various assembly conditions. For the purpose of benchmarking, specimens with conventional Sn-Pb eutectic solder are tested in parallel as well.	The test boards used in the present study were a 6-layer (4 internal Cu layers) FR-402 (Tg: 140°C) printed circuit board (PCB). The total board thickness was 1.6 mm (62 mils). The solder pads on the test board were non-solder mask defined. JESD22-A104-B Condition G. The testing temperature range was from -40°C to 125°C. The period was one hour per cycle. The dwell time at the low temperature and the high temperature was 15 minutes,	From the TC test results, it is observed that the Pb-free solder joints (95.5Sn-3.9Ag-0.6Cu) have a much longer thermal fatigue life than the conventional eutectic solder (63Sn-37Pb). Besides, it is identified that the solder joint thermal fatigue life of smaller package (27x27 mm) is longer than that of larger package (35x35 mm). Furthermore, among the cases with Pb-free solder, the comparisons indicate that the 95.5Sn3.9Ag-0.6Cu solder joints with 96Sn-2.5Ag-0.5Cu-lBi solder paste performs better for the lower peak reflow temperature (240°C) while the 95.5Sn-3.9Ag-0.6Cu solder joints with 95.5Sn-3.9Ag-0.6Cu solder paste performs better for the higher peak reflow temperature (26OOC). Note that these observations are consistent for both package sizes.	Evaluation of Board Level Reliability of Pb-free PBGA Solder Joints Shi-Wei Ricky Lee and Ben Hoi Wai Lui Electronic Packaging Laboratory Department of Mechanical Engineering

Focus	Objective	Scope	Conclusion(s) Summary	Reference
		respectively. The ramp time was 15 minutes with an 1 l"C/min ramp rate.		
50. Lead-Free Packages – Board Level Reliability	The purpose of this study is to understand the board level solder joint reliability of the packages (SOIC,PBGA,FBGA) built with lead-free alternatives.The units assembled to daisy chained boards will be subjected to thermal cycling test to understand the solder joint reliability.	The lead-free solder paste used for assembly is Qualitek LF217 with an alloy combination of Sn95.5Ag4.0Cu0.5. The temperature cycling of SOIC and PBGA parts will be conducted at Gintic. The test condition for SOIC and PBGA will be • -55/+125 o C to 1000 cycles • 10min ramp & 10 min dwell • The temp cycle for FBGA will be conducted in AMD Singapore. The test condition for FBGA is • –40/+125 o C to 1000 cycles • 3min ramp 17min dwell	Comment: Assembled FBGA units were cross-sectioned for inspection. The wetting of joints was found to be good. The joint geometry was good which measured an average stand-off height of 10.5mils. -The lead-free solder joint performance were as good as or better than the Sn/Pb solder joint. -At location, where a crack in the mould or peel off of the mould occurred, solder joint was inspected and found to be good. -Most of the solder joint failure mode was between the solder ball and the PCB pad. (More than 95% of the balls were attached to the package)	Board Level reliability of Lead-free packages (Interim Report) Ashok Anand & YC Mui
51. Solder Joint Reliability High Density Packages	Failure analyses of the leadfree and SnPb solder joints of high-density packages such as the PBGA (plastic ball grid array) and the	In this study, failure analyses are investigated on some of the components from the temperature cycling test reported in.2 These	The failure locations and failure modes of the solder joints of the PBGA and CCGA packages compare very well with the temperature cycling test and the finite element analysis results.	HDPUG's Failure Analysis of High-Density Packages' Lead-Free Solder Joints APEX-CD

Focus	Objective	Scope	Conclusion(s) Summary	Reference
Failure Analysis	CCGA (ceramic column grid array) soldered on SnCu HASL (hot-air solder leveling) ENIG (electroless nickel-immersion gold) or NiAu, and OSP (organic solderability preservative) Enteek PCBs (printed circuit boards) are presented.	components are: (1) 208PBGA (plastic ball grid array); (2) 256PBGA; (3) 388PBGA; and (4) 1657CCGA (ceramic column grid array).		
52. Effect of Bi on SAC	The solder materials used to make the solder joints for this study are: eutectic Sn-3Ag-0.5Cu solder, Sn-3Ag-0.5Cu-1Bi solder, Sn-3Ag-0.5Cu-3Bi quaternary solder. In order to study the microstructures evolution and the growth kinetic of IMC, aging the solder joints isothermally in resistance oven at 150 ± 5 □ with different periods of 0 50 100 250 500 1000hours. The result show that: the morphology of IMC become from scallop-like to planar in aging process, the mean	The solder materials used to make the solder joints for this study are: (1) eutectic Sn-3Ag-0.5Cu solder alloy, (2) Sn-3Ag-0.5Cu-1Bi and (3) Sn-3Ag-0.5Cu-3Bi quaternary solder alloys. Compositions as well as the values of solidus and liquidus of these solders are listed in table 1. It is found that the value of solidus temperature decreases with increasing Bi content, while the liquidus temperature is not sensitive to Bi content	1. The morphology of IMC becomes from scallop-like to planar in aging process. 2. The thickness of IMC in Bi-bearing solder joint is thinner than Sn-Ag-Cu solder joint's. 3. The addition of Bi can reduce the growth rate of IMC in soder/Cu interface. 4. The hardness of solder is very small contract with the IMC's, while the difference of hardness between Cu substrate and the IMC is less.	The effect of Bi on the IMC growth in Sn-3Ag-0.5Cu solder interface during aging process Lin Qi, Jie Zhao, Xiu-min Wang and Lai Wang (Dalian University of Technology, Dalian, P. R. China, 116024)

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	thickness of IMC layer solder joints is found to increase linearly with the square root of aging time, namely the growth of IMC controlled by atom diffusion, the IMC growth rate decreased as Bi content increased, for the solders discussed above the comparative IMC growth rate sequence from fast to slow is Sn-3Ag-0.5Cu > Sn-3Ag-0.5Cu-1Bi > Sn-3Ag-0.5Cu-3Bi.			
53. LFS Reliability – Trace amounts of lead	The effects of trace amounts of lead (<1%) upon the reliability of the six solders was also evaluated since accidental or intentional mixing of lead and lead-free solders will occur during the transition to lead-free.	The lead-free solders tested were: Sn3.8Ag0.7Cu; Sn3.4Ag4.8Bi; Sn3.5Ag; Sn0.7Cu; Sn3.4Ag1Cu3.3Bi; and 58Bi42Sn. Eutectic tin/lead solder was used as a control. A test vehicle was designed to accommodate ten dummy daisy-chained LCCC20 (leadless ceramic chip carrier) components on the topside. The test vehicles were	Boeing's test program was able to identify several solders that appear to have reliability equal to or greater than eutectic tin/lead. It was also shown that trace amounts of lead contamination improves the reliability of Sn3.8Ag0.7Cu and Sn3.5Ag but degrades the reliability of Sn0.7Cu and the bismuth–containing alloys. In the case of 58Bi42Sn, the effects of the lead contamination were catastrophic. Reflowed Sn3.8Ag0.7Cu, Sn3.5Ag and Sn0.7Cu solder joints are less reliable than eutectic tin/lead. Sn3.4Ag1Cu3.3Bi is more reliable than eutectic tin/lead (with a much better first failure number and an equivalent characteristic life number). Based upon the reliability test results, Sn3.4Ag1Cu3.3Bi appears to be a good candidate to replace reflowed eutectic tin/lead in high reliability electronics. The current study also suggests that trace amounts of lead can increase the reliability of Sn3.8Ag0.7Cu and Sn3.5Ag but decreases the reliability of Sn0.7Cu and the bismuth–containing solders. The effects of trace	The Effects of Trace Amounts of Lead on the Reliability of Six Lead-Free Solders Thomas A. Woodrow, Ph.D. The Boeing Company

Focus	Objective	Scope	Conclusion(s) Summary	Reference
		assembled by a vapor phase reflow soldering process. After assembly, the test vehicles were thermally cycled and the failure rates of the lead-free solder joints were determined by electrically monitoring the solder joints during the test.		
54. LFS Balls – SnPb Paste and Process	Slide Presentation	"What happens when you reflow a BGA component that contains SAC solder alloy solder balls in a Sn63 solder alloy reflow process temperature profile using Sn63 alloy solder paste?"	In general the joint was of poor quality with several voids and a crack across the bottom pad. SAC ball did not totally reflow and the solder broke from HASL board material. What happens is that we get SAC on top of the ball and various intermetallics below. Significant edge irregularities on the ball look like they could have caused the crinkled surfaces that Lety got on her BGA photos.	PbfreeBGA SolderballIssues September 2004 D. Hillman Rockwell Collins
55. Solder Joint Reliabilit y SnPb / Pb-free solder mixing	The team's focus was on the solder joint, comparing the tin-silver-copper alloy to eutectic tin-lead	Test vehicle utilized 6 component types. Pb-free solder Sn4Ag.5Cu and Sn3.9Ag.7Cu. Immersion silver board finish. For some test vehicles Pb and Pb-free solder mixing was allowed. Thermal Cycling: -40C to 125 C and 0C to 100C Three-point bending	- Testing using both temperature conditions showed that solder joints formed from combinations using Pb-free balls, component finish and paste alloy performed equivalent to or better than the SnPb/SnPb benchmark. - Results for the SnPb/Pb-free combinations were mixed, most performed equivalent, 2 performed worse and 1 performed better - All results obtained demonstrate that Pb-free solder joints are equivalent or superior to the SnPb benchmark - Much work still remains to be done with regards to process optimization	Are Lead-Free Solder Joints Reliable? John Sohn Circuits Assembly June 2002

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		Electrochemical migration		
56. Solder Joint Reliabilit y SnPb / Pb-free solder mixing	the effect on joint reliability of mixing alloys likely to be used in production and rework during the transition to lead-free soldering technologies. SnPb, SnPbAg, SnCu, SnAgCu and SnAgBiCu alloys were used in a range of mixtures to make surface mount joints.	The reliability of the joints was assessed using thermal cycling with continuity monitoring, and shear teiting.	- The results indicate that when solder alloys are mixed the resultant joints exhibit a general improvement in first failure reliability as compared with those soldered using the single alloys. This finding suggests that concerns about mixing of alloys in rework situations, may be unfounded. - Using the plots in this report the likely effect on reliability of reworking joints with a lead free alloy can be predicted - Mixed alloy joints in this study generally gave better or equal first failure performance relative to the original alloys	Reliability of Mixed Lead and Lead-Free Alloys: Simulating the Effect of Reworking Electronic Assemblies Alan Brewin, Christopher Hun4 Milos Dusek & Jaspal Nottay Materials Centre National Physical Laboratory Teddington, hfiddieux UK. TWII QLW
57. Solder Mixing SAC Paste SnPb Balls	In the transition period from Lead-bearing solder to Lead- Free solder, four metallurgical combinations will be in use: Lead-Free solder with Lead-Free components, Lead-bearing solder with Lead-bearing components, Lead-Free solder with Lead-bearing components, and Lead-bearing solder with Lead-Free components.	In this study, BGA locations on electroless Ni/ immersion Au (ENIG)-finished boards were reflowed with Sn-3.8Ag- 0.7Cu or Sn-37Pb solder balls using Sn-3.8Ag-0.7Cu or eutectic Sn-Pb solder pastes. Some boards were aged at 150 °C for 310 hr, 480 hr, and 2160 hr.	- Large and small spherical voids made with flux: Sn- 3.8Ag-0.7Cu solder joints, with both Sn-3.8Ag-0.7Cu and Sn-Pb balls are more affected by these voids than Sn-Pb solder joints. The flux formulation is responsible for this type of void formation. - After reflow and aging, LF - LF and mixed cell solder joints are stronger than SnPb - SnPb joints. This is attributed to the reinforcement effect of eutectic intermetallic particles and thinner (in case of LF – LF joints) intermetallic layers.	SOLDER JOINT FORMATION WITH Sn-Ag-Cu AND Sn-Pb SOLDER BALLS AND PASTES Polina Snugovsky, Zohreh Bagheri, Matthew Kelly, Marianne Romansky Celestica International Inc. SMT-CD
58. BGA ball solder	Electronic Magazine	Most lead-free BGAs are shipping with Sn-	The eutectic Sn-Pb solder will melt at approximately 183°C, and then begin dissolving the SAC ball as the furnace temperature rises. If the ball does not melt,	Component Technology By Leo Higgins

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mixing		Ag-Cu ("SAC") solder balls. The ternary eutectic composition is approximately Sn-3.5Ag-0.9Cu (wt. %), with a melting point of 217°C. The solder ball composition is commonly Sn-3.5Ag-0.75Cu, or Sn-3.8Ag-0.7Cu (wt. %), or a very similar chemistry. Presently, it may be possible to find lead-free BGAs with different SAC chemistries, Sn-3.5Ag eutectic or Sn-0.7Cu, among others, so it is critical to know the BGA ball chemistry. When using Sn-Pb eutectic solder paste to surface mount a lead-free BGA with typical SAC solder balls, it is important that the BGA balls melt during the reflow process.	upon cool down it is likely that the interface between the SAC ball and the frozen eutectic Sn-Pb, modified by partial dissolution of the SAC ball, will contain voids. Making sure that the SAC balls are all heated to an approximate minimum temperature of 225° to 230°C, since the typical solder ball composition is not the SAC eutectic, will ensure the BGA balls will melt and mix with the Sn-Pb eutectic solder, greatly increasing the probability of a void-free interface.	ASAT Holdings Ltd. Lead-Free Magazine
59. LFS Joints – Contamination Risks	Since the melting point of the preferred lead free alloys tin-silvercopper (SAC) alloys is 217°C they offer the possibility of a	The design of the circuit included a double-sided flexible circuit; with SOIC's mounted on both sides of the flex, creating a	Traditional problem solving techniques including fishbone diagrams, analytical failure analysis, and root cause analysis were all used to resolve this problem. Concerns about process were quickly reviewed and determined not to be the root cause for the failures. Focus was quickly placed on the growth of a thick intermetallic layer as the cause of the failures, rather than as another symptom. More careful examination of the cracking and it's propagation would most likely have resulted in	LEAD CONTAMINATION RISKS IN LEAD FREE SOLDER JOINTS FOR HIGH TEMPERATURE APPLICATIONS Mark Privett, Brian J.

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	single product for both low and high operating temperature assemblies. Although there have been numerous studies on the reliability of lead-free alloys, there are still questions regarding their suitability for high temperature applications particularly where lead contamination will occur [1-3]. This paper focuses on a case study in which failures occurred in solder joints produced from tin-lead terminated components and SAC387 (Sn 3.8Ag 0.7Cu) lead free solder.	balanced circuit. SOIC's were slightly offset from each other. The flex circuit was finished in Electroless Nickel Immersion Gold (ENIG). SOIC's were constructed with Cu leads and SnPb (80/20) tinning. Flex circuits were assembled with a FR4 backer for added stiffness, installed in a rigid nylon housing. A connector was selectively soldered onto one end of the circuit.	an earlier conclusion that the material was reflowing after crack propagation or reflowing to cause the crack formation.	Toleno, Ph.D., Neil Poole, Ph.D. Henkel Loctite Electronics Industry, CA, USA Hector Steen, Ph.D. Henkel Loctite Electronics Hemel Hempstead, Hertfordshire, United Kingdom
60. LFS Balls - BGA	Slide Presentation	Product testing on tin-silver-copper balls	During reflow process, a faster intermetallic growth rate was found for SnAg/Cu compared to eutectic SnPb During thermal aging at 150 and 170 oC , a faster intermetallic growth rate was found for SnPb, but no clear intermetallic growth was observed for SnAg/Cu Failure shear stresses decrease as aging time increase for both SnPb and SnAg/Cu Better high temperature performance for SnAg/Cu than SnPb	Tyco Electronics Eric Verhelst Lead-Free Implementation Roadmap Oct 2002
61. LFS failure modes – BGA – PCB materials	Here in this study, the mechanical reliability of BGA with lead-free solder on different PCB materials including traditional FR4	Sn95.75Ag3.5Cu0.75 solder alloy was used due to its increasing acceptance in the electronic industry	The PBGA assembly with Pb-free solder on halogen-free exhibits higher reliability than the assembly with Pb-free solder on a traditional FR4 material The matching between the lead-free solders and PCB materials including halogen-free material and FR4 material are very important	Research on Failure Modes of BGA Assemblies with Lead-Free on Different PCB Materials Qi, Liu Motorola

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	materials and new environmental halogen-free materials was studied			
62. Soldering Capability – Forward & Backward	For a transitional period, leaded and lead-free technologies already coexist, either by having leaded packages mounted with lead-free paste or by having eutectic Sn/Pb paste used with lead-free components.	The present situation, with the on-going conversion of leaded electronic components and board mounting processes to Lead-free finishing and mounting processes leads us to consider three new cases (as summarized Customers who use leaded solder on lead-free components (backward compatibility) Customers who use lead-free solder (and a 30 to 40°C higher soldering temperature) on leaded components (forward compatibility) Customers who use lead-free solder on lead-free components	Lead-frame Package Solder Joint Reliability Tin-Bismuth coated units soldered with Tin-Lead may show unstable solder joint reliability due to the very low melting eutectic of Tin-Bismuth-Lead (92°C). The use of TinBismuth coating with standard Leaded solder alloys is not recommended. It may however be validated by the customers for specific applications. The solder joint reliability of components with Tin and NiPdAu coatings has been shown to be similar or better than that of components with Tin-lead coating. BGA Package Solder Joint Reliability Lead-free solder joint reliability, versus thermal cycling, is improved compared to SnPb balls. STMicroelectronics components, lead-free or leaded, are fully compatible, from the soldering process, and quality and reliability stand-points, with both lead-free or leaded solder pastes. The only exception is for lead-free BGA using leaded solder process (since the reflow temperature could be too low for melting the lead-free solder balls).	AN2034 APPLICATION NOTE Soldering Compatibility (Backward and Forward) © 2004 STMicroelectronics - All rights reserved
63. LF Electrodeposits – in SnPb solder	Reviews solderability qualification experiments performed on these new coatings to demonstrate backwards compatibility of lead-	Experiments reported here use SnPb solder with SnPb and lead free surface finishes to compare solderability performance	Pure tin plated components show excellent solderability and are backwards compatible with SnPb solder processes 93/7 SnPb deposits initially wet faster that pure tin. However as the test proceeds the pure tin deposits exhibit a greater wetting force than the 93/7 Sn/Pb deposits	Solderability of Lead Free Electrodeposits in Tin/Lead Solder Dr. Robert D. Hilt Tyco Electronics

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	free plating with SnPb reflow solder processes			
64. Solder Joint Reliability	Collect and compare board level reliability data for BGA type packages, Investigate the effect of Sn/Ag/Cu composition on reliability, Investigate the acceleration factors for different temperature cycle conditions, and Select the Pb free Solder ball alloys for BGA type packages. The objectives were met by partnering with industry groups such as NCMS and by conducting internal evaluations.	The reliability of 9 different Pb free solder joints is compared with the Sn/Pb eutectic solder using two types of BGA packages. Three different temperature cycling conditions (-40 to 125oC, 15 minutes ramps and dwells; -55 to 125oC, 2 minute ramps, 13 minutes dwells; 0 to 100o C, 10 minute ramps, 5 minute dwells) were used	- All Pb free alloys performed better than Sn/Pb alloy for these packages - Three slightly different compositions of Sn/Ag/Cu alloy were evaluated as part of this study. Generally all three alloys showed similar behavior and with no significant difference in reliability. The data supports the general industry recommendation that this alloy can be used as a possible replacement for Sn/Pb alloy. - A comparison between two different cyclic test conditions indicates higher acceleration for the Pb free alloys over a wider temperature range, implying significantly higher reliability at field level conditions for Pb free alloys. - Based on this study and supporting data from the industry, Sn/4.0Ag/0.5Cu alloy has been selected as the preliminary replacement for Sn/Pb alloy for BGA type packages. Further studies are underway to finalize this selection.	Reliability of Lead-Free Solder Connections for Area-Array Packages Ahmer Syed Amkor Technology, Inc
65. LF Reliability Testing	The University of Massachusetts at Lowell has brought together many Massachusetts/New England firms to collaborate on the manufacture and testing of lead-free printed wiring boards (PWBs). The results of the first set of experiments, published in 2001, showed that zero-defect soldering is achievable	Reflow Atmospheres a. Air b. Nitrogen. (Nitrogen was supplied by Air Products and Chemicals and contained 50 ppm Oxygen) 3. Solder Pastes all 95.5Sn-3.8 Ag-0.7Cu (NEMI recommended) from three different suppliers (A, B and C), all incorporating no-clean fluxes. Flux formulations	*For SOICs with Tin Component finish*, no statistical differences whether leaded or lead free with all factors and levels, using solder supplier B and air. *For SOICs with NiPdAu finish* • Thermal cycling is not significant for pull tests. • 2 Surface finishes were borderline significant prior to cycling (HASL/Higher and ENIG/lower) But all surface finishes are equivalent after • Only the solder suppliers are significantly different (surface finish and nitrogen are not significant) • Results did not change statistically after thermal cycling, regardless of solder supplier • Only ENIG changed statistically (better) between leaded and unleaded boards, when using B solder supplier and reflowed in air. Note that in pull tests prior to thermal cycling, ENIG was significantly lowe than the rest, shown earlier.	Reliability Testing Results of Surface Mounted Lead Free Soldering Materials and Processes Sammy Shina University of Massachusetts Lowell, MA Liz Harriman and Greg Morose Massachusetts Toxics Use Reduction Institute (TURI) Lowell, MA Richard Anderson, Helena Pasquito and George

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	with lead-free materials. Following thermal cycling, the PWBs were visually inspected and the leads were pull-tested for reliability analysis. They compared favorably to a baseline of lead soldered PWBs A follow-on design of experiments was created in 2002 and a second set of test PWBs was made and tested in 2003. Three lead-free solder pastes based on Sn/Ag/Cu alloys were reflowed using either air or nitrogen with five PWB surface finishes, four component types with two types of component finish. Visual inspection and pull testing were performed and published as completed in APEX, SMTI and IEEE conferences. This paper summarizes the testing results and introduces further research plans in volume manufacturing of lead free PWBs for	proprietary according to each supplier. 4. Component Lead Finishes a. Matte tin, tin plating, Tin/Silver/Copper, Nickel/Palladium/ Gold (NiPdAu), and Nickel/Gold. b. tin/silver/copper balls for BGA 5. Sn-Pb eutectic solder PWB using the solder treatments as control PWBs.		Wilkish M-A/COM Tyco Electronics Lowell MA Presented in the ECWC 10 Conference at IPC Printed Circuits Expo®, SMEMA Council APEX® and Designers Summit 05

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	the phase III testing sponsored by the EPA.			
66. Solder Joint Reliabilit y	SAC Alloy Review	Sn-3.8Ag-0.7Cu; -55 to 125 C Sn-3.0Ag-0.5Cu; -55 to 125 C Sn-3.0Ag-0.5Cu; -40 to 125 C	- Sn-3.8Ag-0.7Cu = confidential - Sn-3.0Ag-0.5Cu = confidential - Sn-3.0Ag-0.5Cu = equivalent or better MTTF and slope then SnPb	Email from Daniel F. Baldwin, Ph.D. ENGENT, Inc.
67. Solder Joint Reliabilit y	Slide Presentation	LFS PCB Assembly	- Lead-free (SAC) joints are more reliable than SnPb joints, **in some cases YES, in other cases NO** - Conclusion is "component" dependent - Conclusion is "cycling condition" dependent - Pb-free solders have creep rates up to **100 times** smaller than for SnPb = Too small dwell times results in incomplete creep: test results are too positive	Techwatch seminar "PCB assemblage" Bart Vandevelde IMEC
68. Solder Joint Reliabilit y Thermal Cycle	The purpose of this research is to establish the performance of Pb-free solder joints under thermal fatigue and investigate the failure modes	The reliability of a lead-free solder (Sn3.8Ag0.7Cu) was compared with that of tin-lead solder (Sn63Pb) using two test vehicles: (i) resistor 2512 and (ii) PBGA 256 (plastic ball grid array). The ATC test conditions were 0-100oC temperature range, 10-14 °C/min ramp rate and 6 minute dwell times (Fig. 2). To verify the thermal profile, several thermocouples were	The test results show that Pb-free soldered resistors had a longer fatigue life compared with SnPb soldered resistors, although Pb-free resistors had more defects, such as inferior wetting and asymmetric solder joint thickness at the two ends of the resistor. The followed conclusions can be drawn from the current ATC tests: - The cracks usually initiated at the interior end of the solder joints, then propagated to the fillets for both SnPb and Pb-free resistors. - For Pb-free assembles, voids in solder joints play an important role in thermal fatigue failures. Early failure occurred in solder joints with larger voids.	ACCELERATED THERMAL CYCLING OF TIN-LEAD AND LEAD-FREE SOLDER JOINTS Y. Qi, H. R. Ghorbani, and J.K. Spelt Department of Mechanical and Industrial Engineering University of Toronto SMT-CD
69. Low Cost Lead-	Sn3.9Ag0.6Cu alloy for reflow soldering and	In practice, many test methods should be	From extensive research efforts to replace Sn37Pb, SnAgCu seems to be the most popular system despite the cost of silver composition. The Sn0.7Cu solders may be	Low-Cost Lead-Free Solder for EE Industries

Focus	Objective	Scope	Conclusion(s) Summary	Reference
Free	Sn3.5Cu or Sn0.7Ag for wave soldering. The selections were based on environmental hazards posed by the materials, the environmental risk of acquiring the materials, long-term availability of the materials, its cost relative to tin-lead, and it's amenahility to forming a two-component alloy. However, these selections have still to be proved that they can replace SnPb solder completely. It is also noteworthy that other organizations suggested different materials with different compositions.	carried out to explore the mechanical properties of the lead-free solders. The tests of interest are such as mechanical tensile and shear strength measurements, creep test and fatigue test. The strength of the solder alloys is a measure of the ability of interconnects to be compliant to the imposition of strain. The work of Frear et al. **[I21** showed that Sn37Pb and Sn0.7Cu solder bumps have similar values of shear strength while the Sn3.8Ag0.7Cu **is** 20% stronger. The Sn3.5Ag solder alloy has the greatest shear strength at ***25%*** greater than Sn0.7Cu. The shear failure for all joints tested occurred solely through the solder. Eutectic Sn3.5Ag, and the companion SnAg(X) alloys (including tin-silver-copper), have shown susceptibility to brittle	developed for wave soldering situations in which alloy cost is of particular concem and the low melting alloys as SnAgBi type may be ***used*** for surface mount consumer products. The reliability of SnAgCu, in particular, appears to be equivalent to that of SnPb.	*C.* Thanachayanont and N. Ramungul National Metal and Materials Technology Center 114 Paholyothin Road, Klong 1, Klong Luang, I 2 120 Pathumthani, Thailand Phone: +66-2564-6500 Fax: +66-2564-6501 E-mail: chanchm@nitec.or.th

Focus	Objective	Scope	Conclusion(s) Summary	Reference
		interfacial delamination in tensile [I31 and shear tests [I41 for surface mount interconnects.		
70. Low Cost Lead-Free Alternatives	In this paper we consider two main lead free solder pastes for reflow, the most commonly used being SnAgCu (SAC) which has a higher melting point than the Tin-lead eutectic solder, and 58Bi42Sn which has a lower melting point than the tin-lead eutectic solder. The main reason to study the use of a low melting point solder is that certain components that have a package with low Tg (Glass Transition Temperature) resin cannot withstand 240oC or higher temperature during reflow, therefore SAC cannot be used. In addition, with a low melting point solder, it is possible to continue to use FR1 as used in conventional tin-lead	For this study, a combination of (1), (3) and (4) are evaluated via the choice of the test vehicle and evaluation of the FR1 vs. FR4 materials. With a well controlled process, the temperatures are maintained uniform inside the oven to within +/- 3oC and hence this parameter was not a critical issue in this study. This study looked at 2 different board materials: FR1, and FR4. FR-1 is a paper phenolic based material while the FR4 is an epoxy woven glass based material. FR-1 with a lower flexural modulus and higher coefficient of thermal expansion will have a relatively higher warpage compared to FR4 (See Table 2). Nearly 200 samples	The low melting point lead-free solder, 58Bi42Sn, revealed excellent solder durability comparable to the traditional Sn-Pb and SAC for a consumer application whose maximum temperature is limited to a maximum of 75oC. In addition the lower reflow temperature makes this an attractive candidate compared to the popular SnAgCu solder allowing one to use FR1 instead of FR4. The optimal configuration was reliable after double-sided surface mount reflow followed by wave-solder with SAC. This configuration has the advantage of being a low cost option and has a reflow temperature lower than 63Sn37Pb solder. SnAgCu also had a similar performance compared to SnBi, however the PCB started exhibiting blistering and delamination above 250oC reflow temperature. Moreover, the board geometry starts becoming sensitive to warpage with higher reflow temperatures. More study has to be conducted to prove that this is not an issue for the intended application.	Low Cost Lead Free Solution Evaluation for Electronic Consumer Applications Krishna Darbha and Nicoletta Sangalli Microsoft Corporation Redmond, WA Presented in the ECWC 10 Conference at IPC Printed Circuits Expo®, SMEMA Council APEX® and Designers Summit 05

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	process. We also consider two different PCB materials FR1 and FR4 with two different coating materials, OSP (organic solderability protectants) and NiAu. We want to evaluate whether FR1 can be used with SAC, and if the OSP coating is more or less reliable than NiAu for a commercial application where the maximum temperature does not go above 75oC including shipping conditions.	were made for each PCB type and the reliability tests were conducted as per Table 3. -40 to 85oC, 200 cycles, more than 300 samples to evaluate SnBi reliability -40o C to 85oC for 500 cycles, more than 200 samples to evaluate PCB, plating finish and SAC/SnBi reliability		
71. Low Temp LFS	The High Density Packaging Users Group Consortium (HDPUG) has conducted a study of process development and solder joint reliability of high-density packages on printed circuit boards (PCB) using a low melting temperature lead-free solder (Sn-57wt%Bi-1wt%Ag). The design, materials, and assembly process aspects of the project are discussed in this study. The components	In this study, a lower melting point lead-free solder, Sn-57wt%Bi-1wt%Ag, is studied. There are a number of niche assembly applications that cannot withstand the processing temperature range of 230 to 260oC required for SnAgCu assemblies. For example, optical components with plastic lenses depend on the opacity and stability of epoxies to meet their optical transmission	BiSnAg is an alternative Pb-free alloy for printed circuit assembly applications that have temperature constraints that prevent the use of SnAgCu. Concerns regarding the brittleness, availability, use and environmental impact of the BiSnAg alloy are tradeoffs that have been discussed. A design for reliability of the PBGA256 with SnAgCu solder balls and SnBiAg solder paste has been performed for the understanding of its thermal behavior and failure locations. Twenty test boards have been built, eight lead free, and eight SNPB "controls" plus two each for shock and vibration tests. It was found that the assembly process of the SnBiAg lead-free test boards is very robust and the assembly yield is almost 100%. Results of temperature cycling test and shock & vibration tests are reported in the companion paper.20	Design, Materials, and Assembly Process of High-Density Packages with a Low- Temperature Lead-Free Solder (SnBiAg) Jerry Gleason, Valeska Schroeder andGregory Henshall Hewlett-Packard Company Palo Alto, CA John Lau and Walter Dauksher, Agilent Technologies, Inc. Santa Clara, CA Bob Sullivan High Density Packaging Users Group

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	studied include several SMT package types and various lead configurations. The assembly process addresses the low-temperature lead free assembly process, inspection and analysis of these boards and packages. A companion paper, "Reliability Tests and Failure Analyses of High-Density Packages with a Low-Temperature Lead-Free Solder (SnBiAg)" is also published in these Proceedings.	and alignment specifications. Non-glass optical materials tend to darken or crack when exp osed to high processing temperatures. Lead free solders for low cost electronic packaging, including BiSn, have been investigated as early as 1994.5		Scottsdale, AZ Presented in the ECWC 10 Conference at IPC Printed Circuits Expo®, SMEMA Council APEX® and Designers Summit 05
72. Fillet Lifting	Cookson Electronics Slide from Website	Through Hole Fillet Lifting - Causes	Caused by solder fillet cooling before the board; the board contracts away from the fillet as some solder on the board side is still pasty Cosmetic rather than a reliability issue Made worse by lead-tin coatings Lead-rich area stays fluid later, allows fillets to lift off Avoid by using lead-free components and rapid cooling board	http://www.cooksonelectronics.com
73. Plated Through Hole Performance	This paper will discuss the effects on the platedthrough- hole (PTH) performance and epoxy-based laminate material properties caused by the higher temperature assembly reflow profiles required for the new NEMI	A program was undertaken to evaluate the response of three epoxy-based systems to the higher temperature reflow profile, which will be required by the NEMI 95.5Sn/3.8Ag/0.7Cu alloy. The authors	The higher temperature NEMI reflow cycle using forced air convection caused discoloration of all three of the laminate systems evaluated. It is unknown if using a nitrogen purge would alleviate this situation. Coloration change is not the only indicator of performance reduction. There was little coloration change seen in the comparison of the baseline versus the standard reflow boards, yet the standard reflow boards show a slight drop in PTH performance for the FR-4 laminate and a significant drop for the PPO/epoxy. Merix has seen this performance reduction in other unrelated IST studies. The Tg (TMA) and Z-axis CTE (TMA) values were not affected by the NEMI alloy reflow temperature, except for a drop in Tg for the high Tg laminate. A general rule	EFFECTS OF NEMI SN/AG/CU ALLOY ASSEMBLY REFLOW ON PLATED THROUGH HOLE PERFORMANCE John J. Davignon Randy Reed Merix Corporation Forest Grove, Oregon Journal of SMT October

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	95.5Sn/3.8Ag/0.7Cu alloy. PTH performance was evaluated by the Interconnect Stress Test (IST) method.	chose the NEMI alloy because its use is supported by a large group of OEMs, and it will allow for a phased transition into a complete lead free product. This alloy will allow a small percentage of lead (from the packaged component leads) to enter the solder joint without concern for a low melting tertiary phase. Several other alloy choices are available with slightly lower temperature requirements (lower eutectic temperatures).	of thumb used by industry is a 5°C change to certify a true shift in Tg. The T-260 results showed some decrease in the PPO/epoxy laminate and only a slight change in the FR-4 laminate. A general rule of thumb used by industry for acceptable results is a value that exceeds 5 minutes. Both pure epoxy laminates evaluated were not able to withstand the higher T-288 test. The epoxy laminates carbonized during the heat up cycle.	2000
74. LF Paste-In-Hole	This paper will present the results of the board design and process optimization for PIH using lead-free solder**.** The work focuses on the relationship between a number of design and process variables and the PIH solder joint quality. These variables include: (1) Stencil design (Thickness, aperture	The test vehicle includes a range of different components. Printed circuit boards (PCB) were made of FR-4 laminate material, using two surface finishes, i.e. organic solderability preservative (OSP) and electroless Ni/immersion Au (ENIG or Ni/Au). Three board thicknesses were	In this work, various PCB variables, stencil apertures, solder paste printing methods and parameters, and component types and insertion methods, have been evaluated for the PIH technology, for both Sn/Pb and lead-free solders. PCBs with thicknesses of 1.0mm & 1.6mm, with both ENIG and OSP surface finishes, have been tested successfully using metal squeegee. Overall, PIH can be a good alternative to wave soldering, when cost, PCB and stencil design, and component selection are properly taken into consideration.	BOARD DESIGN AND PROCESS OPTIMIZATION FOR PASTE-INHOLE USING LEAD-FREE SOLDER Gerhard Pfennich & Harald Fockenberger Flextronics Althofen, Austria Leow Ching Tat & Terence Ho Flextronics Malaysia

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	shape and dimension) (2) Printing parameters (Pressure, speed, squeegee angle, stroke, and separation) (3) Printing method (Squeegee, closed-head)	used for the study (1.0, 1.6 and 2.3 mm). The screen printer used was equipped with a TCU (temperature controlling unit) which kept the temperature of the printer under controlled conditions. Reflow profiles used for each paste were established by following the manufacturers' recommendations.		Dongkai Shangguan, Ph.D. Flextronics San Jose, CA, USA
75. Thermal Cycle Testing	Test PTH and SMT boards for component failures using lead-free solders	SMTs and PTH Components tested on boards using several lead-free solders SMT (Solder types- SnPb, SnAgCu, SnCu, SnBi), (Component Finishes - SnPb, NiPd, Sn, SnCu) and (Board Finish - HASL, OSP, Ni/Au) PTH (Solder types - SnAgCuSb), (Component Finishes - SnPb, NiPd, Sn, SnCu) and (Board	No significant interaction of component finish, solder alloy and PWB finish variables as demonstrated by overlapping thermal cycle population mean data. Only two component types recorded statistically significant thermal cycle failure values (LCCC, Area Array Components) Failure distributions for LCCC and Area Array types found to be similar to other industry studies. Solder paste alloy, component finish, and PWB finish variable combinations statistically non-significant for the LCC components. All other component types / Pb-free finishes passed 2000 thermal cycles failure free. PTH - Zero thermal cycle failures recorded for solder alloy, component finish and PWB finish variable combinations after completing 1700 thermal cycles. - PLCC recorded 2 and SMC recorded no thermal cycle failures during testing Component, finish and PWB finish variable combinations resulted in minimal impact. Solder paste alloy variable combination had a statistically significant effect on ANSIJ-STD-001 Class 2 & Class 3 joint geometry. Thermal cycle test results demonstrated feasibility of utilizing existing soldering processes and Pb-free materials to achieve ANSIJ-STD-001C Class 2 and Class 3 solder joint geometries capable of meeting avionics use environment expectations.	Lead Free Components Focus Group -

Focus	Objective	Scope	Conclusion(s) Summary	Reference
		Finishes - HASL, OSP) Temperture Range: (-55C - 125C) - 2000 Thermal Cycles		
76. LFS Low Cycle Fatigue	Low-cycle fatigue (LCF) tests on as-cast Sn-3.5Ag, Sn-3Ag-0.5Cu, Sn-3Ag-0.5Cu-1Bi, and Sn-3Ag-0.5Cu-3Bi solders was carried out	a noncontact strain-controlled system at 20°C with a constant frequency of 0.1 Hz.	The addition of Cu does not significantly affect the fatigue life of eutectic Sn-Ag solder. However, the fatigue life was significantly reduced with the addition of Bi. The fatigue life of the present solders is dominated by the fracture ductility and can be described by the ductility-modified Coffin–Manson's relationship. Steps at the boundaries of dendrite phases were the initiation sites for microcracks for Sn-3.5Ag, Sn-3Ag-0.5Cu, and Sn-3Ag-0.5Cu-1Bi solders, while for Sn 3Ag-0.5Cu-3Bi solder, cracks initiated along both the dendrite boundaries and subgrain boundaries in the dendrite phases.	Low-Cycle Fatigue Behavior of Sn-Ag, Sn-Ag-Cu, and Sn-Ag-Cu-Bi Lead-Free Solders CHAOSUAN KANCHANOMAI,1 YUKIO MIYASHITA,1 and YOSHIHARU MUTOH1,2
77. LF Sn3.8Ag 0.7Cu – Joint Propertie s	Mechanical propelties for 95.5Sn-3.8Ag-0.7Cu solder alloy were derived from bulk specimen tensile test and lap shear solder joint tests specimen.	The tensile tests were carried out at three temperatures (25OC, 75OC and 125OC) and at three different strain rates (5 . 6 ~ 1 0 ~ **s.',** 5.6~10.' And 5.6~10-~s-~). Shear tests were carried out at three temperatures (25T, 75°C and 125T) and at three different displacement rates (OSmm/min, **O.OSmm/min** and ***0 . 0 0 5 d m i n)***	The specimen gave the highest strength at the fastest displacement rate and at room temperature of ***25OC*** (0.61Tm). The lowest strength occurs when the specimen is subjected to the slowest displacement rate at elevated temperature of 125°C **(0.8lTm).** The microstructure of Sn-3.8Ag-0.7Cu solder in bulk solder specimens bad elongated Sn rich phases with needle-like rods of *Ag$n* intermetallics. The microstructure of the solder joint specimen had globular Sn rich phases with particles of *Ag&* intermetallics. The elements detected in the intermetallic layer above the Cu pad and Ni barrier layer indicates a complex intermetallic compound The mechanical properties of tensile and shear test are highly dependent on temperature and strain rates. The mechanical properties of Sn-3.8Ag-0.7Cn solder alloy will decrease with an increase in temperature and with lower strain rate. Using the von Mises relationship between tensile and shear stress, the yield stress and UTS show good agreement between the hulk solder and solder joint test results.	Bulk Solder and Solder Joint Properties for Lead Free 95.5Sn-3.8Ag-0.7Cu Solder Alloy John H.L. Pang, B. S. Xiong, C. C. Neo, X. R. Bang, T.H. Low Nanyang Technological University, School of Mechanical and Production Engineering Nanyang Avenue, Singapore 639798
78. Solder Joint	This paper will describe experiments performed	Two different PBGA substrate manufacturers	- PBGAs with SnAg spheres performed a minimum of 2ξ better than SnPbAg in the two automotive thermal cycling conditions. It is expected that different results may be	AUTOMOTIVE PBGA ASSEMBLY AND

Focus	Objective	Scope	Conclusion(s) Summary	Reference
Reliability	to determine the interconnect reliability of a 1.0 mm pitch, four perimeter row, 324 PBGA for automotive applications with lead-free (tin-silver) versus conventional (tin-lead-silver) solder spheres. Additionally, assembly was carried out with lead-free versus eutectic solder paste for both sphere types.	were evaluated and the test boards used had an immersion nickel/electroless gold surface finish. The assembled boards were thermal cycled in both –40 to 125 and –50 to 150°C until failure to compare lifetime of the four sphere and paste combinations. Solder joint failures were detected with continuous in-situ electrical monitoring and then verified with dye penetrant. Additionally, solder ball shear testing versus 125 and 150°C bake out to 1,008 hrs was performed on lead bearing and lead-free solder balls.	seen at less severe cycles (i.e., 0 to 100°C). - Unlike packages with standard SnPbAg spheres, those with SnAg spheres retained solder ball shear strength and the more desirable ductile or bulk solder failure mode out to 1,008 hours at 125 and 150°C. Since the intermetallic bond layer between the package pad and solder ball is principally SnNi for both alloys, the reason for this is unclear. - For Pb-free spheres, the SnNi intermetallic appeared to grow at the same rate in both 125 and 150°C. Whereas the growth rate in the Pb-containing PBGAs baked at 150°C was 2.6· than at 125°C.	BOARD-LEVEL RELIABILITY WITH LEAD-FREE VERSUS LEAD-TIN INTERCONNECT Andrew Mawer and Kim-Marie Levis Motorola Semiconductor Products Sector SMT-CD
79. Solder Joint Reliability (PCB)	Identify the effects of thermo-mechanical stress on Sn-Ag-Cu and Sn-Zn-Bi solder with different lead finishes (Sn-10Pb, Ni/Pb/Au plating).	Perform several reliability tests: high temperature tests, thermal cycle tests, and combined thermal-vibration tests. Following tests, investigated the causes of degradation by checking solder joint	Our investigations indicate that the same level of reliability can be obtained with SN-AG-Cu solder as with conventional Sn-Pb eutectic solder. PCBs in mass production prototypes with Sn-Ag-Cu solder held up successfully under a minimum of 3,000 cycles in thermal cycle tests and a minimum of 20,000 hours in field reliability testing.	Reliability Testing and Failure Analysis of Lead-Free Solder Joints under Thermo-Mechanical Stress. Hirokazu Tanaka, Yuuichi Aoki, Makoto Kitagawa and Yoshiki Saito. (ESPEC CORP.) 2004

Focus	Objective	Scope	Conclusion(s) Summary	Reference
		strength and observing solder joint cross-sections. After initial testing, Sn-Ag-Cu solder was used in mass production prototype PCBs. These were subjected to a variety of reliability tests and carried out three years of field testing.		
80. SMT Solder Joint Reliability	Test a real-world PCB assembly using lead-free solders.	Goal is to test a complex PCB using commercially available lead-free solders. Lead-free solders included in this study are: SnAg, SnAg3.0Cu0.5, SnAg4.0Cu0.5, SnAgCuBi, SnAgCuSb, and SnZnBi. Eutectic SnPb is also incorporated in the experiment for control purposes. Surface finishes include HASL (SnCu), ENIG, Immersion Sn, Immersion Ag, and OSP. Accelerated thermal testing (AATC and LLTS). Reliability analyses on these	Length of thermal exposure treatment was considerably smaller (1008 AATC and 300 LLTS). Exposure length was not sufficient to calculate MTTF. Advanced means of monitoring accelerated tests must be employed to make sure that consistent failure data is collected. Lead-pull testing revealed that Pb-free solder alloys provide comparable solder joint strength to SnPb. Thermal shock reduced the strength due to coarser intermetallic layer. However, the strength of Pb-free joints, even after thermal shock test, was comparable to that of SnPb solder. Failure modes appear to depend on the geometry of a joint, the solder alloy used, and the type of lead termination. BGAs and uBGAs showed significant amount of coarsening. However, they did not show proportionate growth in the intermetallic layer thickness, which stresses the necessity of longer thermal exposure. Study did not reveal any failed joints in case of PLCCs or QFPs, and a very small number of failures for R0603s and R0805s.	A Reliability Comparison of Different Lead-Free Alloys and Surface Finishes in SMT Assembly. Jignesh Rathod and Daryl Santos, PhD. (Binghamton University) Prashant Chouta, Joe Belmonte and Alan Rae, Ph.D. (Cookson Electronics)

Focus	Objective	Scope	Conclusion(s) Summary	Reference
		boards include electrical resistance, lead-pull tests, nail tests, cross-sectioning and micrographs.		
81. LF Solder Paste	Since it is commonly considered that a Pb-free process is more difficult to control (due to more constraints on the printing and reflow), the use of statistics becomes even more essential in the evaluation of solder pastes. Without proper statistical techniques, it is difficult to accurately assess and rank the performance of various solder paste candidates.	Board assembly facilities have limited time to conduct the evaluation. Since there are dozens of Pb-free solder pastes available on the market, it is necessary to narrow the search prior to conducting an extensive physical evaluation. The following elimination criteria are suggested: 1. Solder Paste Lot-to-Lot Consistency: Most solder paste manufacturers will provide potential customers with specific quality documentation for multiple lots (5-10 suggested) of a given solder paste.	Implementing Pb-free solder pastes in inevitable. Properly evaluating Pb-free solder pastes is essential. The proposed 4-step evaluation process provides a systematic approach, while also minimizing the time and resources required. This effective and concise approach allows for complete assessment of the solder paste performance and ensures that the best solder paste is selected. Since 50 – 70% of all postreflow defects can be attributed to the stencil printing process, a significant amount of time for the evaluations should be spent on that process.	SOLDER PASTE EVALUATION TECHNIQUES TO SIMPLIFY THE TRANSITION TO PB-FREE Timothy Jensen Indium Corporation of America Utica, NY, USA tjensen@indium.com
82. LF Paste Evaluation	To meet the challenges of lead-free soldering, a method to evaluate the performance of lead-free solder pastes will be explored. Identifying	Three surface finishes were selected for testing, electroless nickel-immersion gold (NiAu), immersion silver (ImAg) and	Once the paste has been selected, additional process development is still needed. Accelerated life testing should be performed to verify the process and design will meet the end use requirements. Rework equipment will need to be evaluated to determine if it is capable of preheating the PCA sufficiently and reaching the higher melting point. Component selection will also be important not only for selecting the appropriate finish but also for thermal limitations for reflow soldering with the higher	LEAD-FREE SOLDER PASTE EVALUATION Michael Havener Benchmark Electronics Winona, MN, USA Robert Farrell

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	the optimal water-soluble and no-clean chemistries is the objective of this testing. Existing tin-lead pastes will also be evaluated as a comparison and to determine if the lead-free chemistries can meet or exceed tin-lead performance. The evaluation process will start with the selection of materials and test vehicle followed by three test phases to down select the candidate pastes. Testing will evaluate printing performance, solder spreadability and solder joint formation.	organic surface preservative (OSP). These finishes are expected to be the most prevalent for lead-free soldering. A pure tin over bare copper component surface finish was used for the lead-free solder alloys and a tin-lead component surface finish was used for the tin-lead solder alloys. Pure tin is not a recommended finish due to tin whisker mitigation. All testing was performed at multiple sites to factor in differences in equipment and processing technique. Multiple inspectors were also utilized at each site.	melting point alloys. Inspectors will need to be trained for inspecting the lead-free solder joints. Automated inspection machines will need to be evaluated to determine their capabilities for lead-free inspection.	Benchmark Electronics Hudson, NH, USA
83. LF Paste – Phase II	A test board with extensive lead-free packages and thermal and mechanical test features to emulate volume and highend server and telecommunication products was designed.	Test vehicle (TV) with representative package types, 2400FCBGA1.0mm, 800PBGA1.0mm, 1000CBGA1.0mm, QFP, SOIC, PLCC, CSP, RN, LTCC, fuse, crystal, press-fit, PTH	To cope with the lead-free process and product initiatives, two TV with advanced test feature were selected. Extensive paste & flux evaluation and reliability test will be conducted. A logical approach is implemented to include raw paste and flux material evaluation. First, the wetting, slump, viscosity, and solder ball were conducted on a bare Cu coupon to screen nine NC and eight OA lead-free solder pastes along with their equivalent SnPb baselines. The wettability, printing, slump, residue, flux penetration and solder quality were conducted on three surface finishes: OSP, Imm Ag, and Ni/Au. Finally, microstructure and pull strength on PQFP along with BGA ball shear were also performed. The quantitative methodology we implemented in this	LEAD-FREE PROCESS TRANSITION-PHASE II: PASTE PERFORMANCE ASSESSMENT BY SURFACE FINISH AND MECHANICAL STRENGTH CORRELATION Robert Farrell, Steve Beck,

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	Physic property such as component clearance, layout density, stack-up layer, anti-pad, thermal strap thermal management, component orientation, mirror and shadow effect, surface finish and process variables in paste printing, reflow and wave will be extensively studied in Phase III.	etc as shown in Figure 1 were laid out with Daisy Chain (DC) structure to achieve real-time reliability monitoring and failure analysis isolation. The TV lay out has 28 stack-up layers between Polyclad dielectric 370 HR Novelac material with Tg of 1750C intertwined with 1 and 2 oz copper foil on thickness of 150 mil and dimension 18x20". Surface finishes OSP, Imm Ag, Ni/Au will be benchmarked to HASL. Interconnect Stress Test (IST) will be performed and used as a fab via and trace to via reliability tracking mechanism in the early stage of Incoming Quality Analysis (IQA) before and after the reflow processes.	paste characteristic study and including correlation to surface finish and high strain rate mechanical strength indicated the following summary.	and Richard Garnick Benchmark Electronics, Inc. NH, MN, AL, USA Paul P.E. Wang, Ph.D., Keith Graveling, Heidi Reynolds, Ph.D., and Ken Kochi Sun Microsystems, Inc. Newark, CA, USA and United Kingdom
84. LFS Paste – Solder joint integrity	the Lead Free Movement has taken center stage in the electronics assembly industry	Another important alloy is the Sn/Ag/Cu system. Sn/Ag/Cu is also on the list of the JEIDA lead free roadmap. In addition, the European	Recent work with candidate lead free alloys indicate a significant improvement in reliability over Sn/Pb. The creep rate is dependent on alloy composition and microstructure and is strongly temperature dependent. Because Sn/Ag and Sn/Ag/Cu have similar microstructures, they behave similarly during isothermal aging and creep testing.	Integrity of Solder Joints from Lead-free Solder Paste Angela Grusd Heraeus Inc.

Focus	Objective	Scope	Conclusion(s) Summary	Reference
		Brite-Euram Consortia recommended Sn/Ag/Cu as the general purpose solder. The Sn-Ag-X lead free solders offer superior creep resistance at room temperature and 100°C as compared to Sn-40Pb.		
85. LFS Reliability	This paper discusses reliability issues related to lead- free printed circuit board interconnects.	This paper reviews the published literature on the use and reliability of lead-free solders and devices. The literature review is complemented by experimental results for lead-free flip chip applications.	In the case of assembly of lead-free flip chips, solder joint properties were still found to depend on the reflow profile (peak temperature and time above the liquidus temperature). The ultimate shear strength of Sn/Ag/Cu (SAC) joints on Ni/Au-coated substrate pads proved very sensitive to small changes in peak temperature and time above liquidus.	Reliability Of Lead-Free Solder Interconnects - **A** Review Sandeep Tonapi GE Corporate Research and Development Albany Sunil Gopakumar *SUNY* Binghamton
86. LFS – BGA - Vibration	In this paper, a new method was proposed for evaluating the high-cycles fatigue strength of BGA (Ball Grid Array) packages with Pb-free solder and Pb solder due to a vibration.	To confirm whether the solder ball of a Pb-free and a Pb behaves elastically or not within the range of **l0-25Hz,** a FEM analysis was performed with Two-step full and sub-modeling. Both results coincide with each other well. The test data of the vibration fatigue for Pb-free and Pb packages were	The effect of frequency on a high cycles vibration fatigue life of Pb-kee and Pb package can be ignored within a range of 10-25Hz.	Vibration Fatigue Reliability of BGA-IC Package with Pb-free Solder and Pb-Sn Solder Young-Bae *Kima,* Hiroshi Noguchi", and Masazumi Amagaib a Faculty of Engineering, Kyushu University, 6-10-1 Hakozaki, Higashi-ku, Fukuoka-shi, Fukuoka 812 8581, Japan New package Development (NPD) Department, Texas

Focus	Objective	Scope	Conclusion(s) Summary	Reference
		classified by the nominal shear stress and an Effective Von **Mises** stress which was calculated by FEM.		Instruments Japan, 4260 Aza Takao, Oaza Kawasaki, Hiji-Machi,
87. Solder Joint Reliabilit y Assembl y - Compatib ility	Report presents the results of an evaluation of the compatibility of some lead-free alloys with other materials currently used in PCB assembly (flux systems, lead-tin solder, board and component finishes), and the consequential effects on the joint reliability	Test boards were generated under a matrix of assembly conditions (three component termination styles, five board finishes, and three solders), and subsequently comparative data were acquired following thermal exposure of the boards (-55 to + 125C for up to 2200cycles.	- For the larger components i.e. 2512-type resistors, there is a larger strain range to be accorrunodated by the solder joints which is better achieved with the traditional SnPb solder than with the new SnAgCu alloy. On the other hand when the strain range is smaller (i.e. with 0603-type resistors or SOICS) the lead-free alloys can perform as good as, or better than, the traditional SnPb solder. - There appears to be a benefit from adding Bi to the SnAgCu solder. The presence of the bismuth in strengthening the lead-free solder joints arises via solid solution, hardening (for <1% Bi, it is present at interstitial sites), and via precipitation of interrnetauic particles (for >I% Bi) - Not surprisingly, as the number of cycles was increased the strengths of all the joints decreased as the grain structures coarsened. However, the rate of strength reduction of joints made using SnAgBiCu solder was much less than observed for the other two solders. It was observed that the lead-free alloys produced brittle ruptures in comparison to the ductile splits observed with the lead-containffig solder.	Compatibility of Lead-free Solders with PCB Materials Milog Dugek, Jaspal Nottay and Christopher Hunt Materials Centre National Physical Laboratory TeMngton, Middlesex, LTK, TWI I OLW
88. Solder Joint Reliabilit y Assembl y	In with paper, environmentally benign solders were discussed related to the ability of interaction to different surface finishes on package and board side, investigated for compatibility with existing process parameters and to discribe the baord level reliability compared to conventional solder materials.	The paper outlines lead-free paste analysis in comparison to conventional solder paste for conventional SMD components as well as chip size packages. The important points of interest are the discription of processability related to existing SMD proccess and the knowledge about the board level reliability.	- Alloys SnCu0,7, SnAg3,5 and SnAg3,8Cu0,7 have wetting, electrical, thermal and mechanical characteristics at least as good as SnPb. - Reliability results were obtained for conventional SMD devices and area array components, which indicate that the use of SnAgCu under conventional reflow conditions can be succesful	BOARD LEVEL RELIABILITY OF LEAD FREE SOLDERED INTERCONNECTIONS H.-J. Albrecht Siemens AG, ZT MF 6 SMT-CD

Focus	Objective	Scope	Conclusion(s) Summary	Reference
89. Solder Joint Reliability Assembly	In this paper, environmentally benign solders were discussed related to the ability of interaction to different surface finishes on package and board side, investigated for compatibility with existing process parameters and to discribe the baord level reliability compared to conventional solder materials.	Including the Ideals activities SnAgCu alloys (pastes) were tested related to wetting, spreading, dissolution, reflow profile optimization, 3-dimensional defects in comparison with organic vehicles used in the solder paste, interaction to conventional and lead-free finishes on package and board side, intermetallic formation and fatigue properties.	- SnAg3.8Cu0.7 was investigated in combination with conventional components and area array components. In general, lead-free component finishes are still under development. - Initial reliability results were obtained for the standard leaded devices, which indicate that the use of SnAg3.8Cu0.7 solder in combination with Cu-OSP-, immersion Sn and Ni-Au-finishes on the board side has the potential to replace conventional solders under the given test files. Lead-free finishes for PCB are readily available. - No major modifications of the standard reflow equipment is required. Peak temperatures between 230°C (Nitrogen) and 240°C (normal atmosphere) can be applied. The increased minimum reflow temperature will require new steps in the package qualification.	BOARD LEVEL RELIABILITY OF LEAD-FREE SOLDERED INTERCONNECTS ON CONVENTIONAL AND AREA ARRAY COMPONENTS H.-J. Albrecht, K. Wilke Siemens AG, CT MM 6 SMT-CD
90. LFS Assembly - Compatibility	Volume manufacturing in lead-free solder PCB assembly is a complex undertaking for the industry.	This paper will review the compatibility issues in volume manufacturing of lead-free solder PCB assembly, including materials compatibility (including solder and PCB), component compatibility, process compatibility, equipment compatibility, design compatibility, and quality and reliability compatibility. The cost for compatibility is also	However, for very large components and components with a very large CTE mismatch with the substrate (such as ceramic body components on FR4), and/or under very severe thermal cycling conditions, the SAC alloy may not always be as reliable as the Sn-Pb solder. The acceleration factor is different for SAC and Sn-Pb, i.e. 1000 cycles under the same thermal cycling conditions means different actual field reliability for SAC and Sn-Pb, because the acceleration factor depends on materials properties which are different for SAC and Sn-Pb. Complicating the picture further is the use of different solder alloys on the same board (such as SAC for reflow and Sn-Cu for wave soldering).	STUDY OF COMPATIBILITY FOR LEAD-FREE SOLDER PCB ASSEMBLY Dr. Dongkai Shangguan Flextronics

Focus	Objective	Scope	Conclusion(s) Summary	Reference
		discussed.		
91. LFS Assembly	This paper will focus on several topics critical to the implementation of lead-free soldering	These topics include the impact of Tin-silver-copper as the alloy of choice for leadfree assembly both with respect to component and solder joint reliability, temperature exposure, and lead-free finishes. Results from the recently completed NEMI Lead-free Solder Project, the author's own work and other published data are discussed.	A higher ratio indicates improved thermal cycling performance at the more benign test condition relative to the more extreme condition. Sn-Ag-Cu performs better relative to Sn-Pb at the less extreme cycling conditions. Pb contamination in lead-free solder joints can adversely affect reliability of leadfree alloys. Many components are compatible with lead-free assembly, and the biggest roadblock is to have all components compatible with the assembly process as well as the composition limits.	Lead-free Solder Assembly: Impact and Opportunity Edwin Bradley Motorola
92. SMT and PTH Assembly	Assessment of assembly process at American Competitiveness Institute	SMT - Screen Printing, Rapid Component Placement, Reflow Process PTH - Flux Application, Wave Soldering.	SMT - Feasible to manufacture with Pb-free solder. Pb-Free solder joints appear different (grainy dull appearance) Pb-Free solder do not wet as well (more aggressive flux or using nitrogen should improve wetting). PTH - Feasible to manufacture with Pb-free solder. More dross associated with Pb-free solder (nitrogen my reduce dross). Pb-free solder joints appear different. Pb-free solder do not we as well. (more aggressive flux or using nitrogen should improve wetting. Screen Printing - equivalent to SnPb solders Component Placement - equivalent to SnPb solders Reflow - Higher reflow temperatures (240-260). More active flux needed to promote wetting. Recommended use of nitrogen to improve wetting. Wave - Higher pre-heat temperatures. More active solder flux required to promote wetting. Recommended us of nitrogen to improve wetting. Joint Appearance - Grainy Dull Finish. Pb-free do not wet as well as SnPb.	Lead Free Components Focus Group -
93. LFS – BGA – Au	Gold embrittlement is another important issue for BGA applications	Solder joint reliability comparison of SdAglCu alloys with,	- Board 1e;el reliability of solder joints using SdAglCu alloy improved fiom 25 to 1 OO%, depending upon the component type and the test cycling condition, - The SdAglCu alloy may eliminate the Au embrittlement problem associated with	Reliability and Au Embrittlement of Lead Free Solders for BGA

Focus	Objective	Scope	Conclusion(s) Summary	Reference
Embrittlement	that must be considered.	SdPb eutectic **for** fleXBGA package. TC1: -40 to 125"C, 15 minutes ramps and dwells TC2: -55 **to** 125'C, **2** minute ramps, 13 minutes dwells, 2 TC3: 0 to 1OO"C, 10 minute ramps, 5 minute dwells	BGA type packages.	Applications Ahmer Syed Amkor Technology, Inc
94. SAC Alloy – Deformation & Crack Growth	This paper analyzes the performance of both SACand eutectic Sn–Pb solder alloys on Kulicke&Soffa's (K&S') *Ultra* CSP® wafer level package (WLP) at a thermal cycling (TC) test. The *Ultra* CSP standard Al/Ni–V/Cu under bump metallurgy (UBM) system was used to analyze if this UBM system with SAC solder would produce acceptable reliability in the TC test.	Boards assembled with both the SAC and eutectic Sn-Pb *Ultra* CSP 50 units were put into a TC test of 40 to 125 C, for 1 h/cycle (15 min. for dwell and transition time as well). The resistances of the R1 and R2 daisy chains were measured every 100 cycles (hours).	The Weibull life of the SAC *Ultra* CSP was equal to or higher (18%) than that of eutectic Sn–Pb. SAC solder joints produced relatively sharp cracks, which implies that there was not a large-scale deformation accompanied with the crack growth. This indicates the SAC solder is much harder (or stiffer) in the low temperature regime and much more creep-resistant during the high temperature regime.	Solder Joint Reliability and Characteristics of Deformation and Crack Growth of Sn–Ag–Cu Versus Eutectic Sn–Pb on a WLP in a Thermal Cycling Test Deok-Hoon Kim, Peter Elenius, and Scott Barrett
95. Leadless CSP	This paper addresses the assembly and reliability of 0.5 mm pitch leadless Chip Scale Packages (CSP) on .062" immersion Ag	Solder paste was deposited by printing through a 5 mil thick laser cut stencil using a 250 mm metal squeegee angled at 60°. The	Commercially available leadless CSPs were readily assembled onto high-T_g boards with Pb-free solder paste. Assembly reliability appeared quite sensitive to the proper optimization of the PCB pad and stencil aperture design, presumably through a minimization of the scatter in solder joint volume and voiding. It follows that further reduction in voiding through materials selection and process optimization may offer additional benefits. In general, lifetimes in excess of 1000 cycles between 0_oC and	ASSEMBLY AND RELIABILITY ISSUES ASSOCIATED WITH LEADLESS CHIP SCALE PACKAGES Muffadal Mukadam1,

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	plated printed circuit boards (PCB) using Pbfree solder paste. Four different leadless CSP designs were studied and each was evaluated using multiple PCB attachment pad designs. Assembly was performed by stencil printing solder paste over the PCB pads, placing components with a high-speed placement machine, and reflowing in a forced convection oven. Vision issues were encountered during the placement process and a "video model" was required to place certain leadless packages.	quality of the print deposits was assessed by visual inspection using an optical microscope after every print. Four different aperture designs were considered for each package. Not surprisingly, the transfer efficiency varied with the ratio between the exposed PCB surface area and that of the aperture sidewalls in the usual fashion. Extensive clogging was observed in a number of cases, notably for three out of the four designs tried for package A which lead to insufficient paste deposition. As we shall see later, this had significant consequences, not only in terms of the risk of opens but also for the assembly reliability.	100oC seem achievable with these packages on 62 mil thick boards. However, we caution that two assemblies involved low-level Pb contamination of the no-Pb solder joints. The effects of this are expected to depend on the relative volumes, reflow profile parameters and subsequent thermal history, as well as assembly mechanics and detailed accelerated test parameters.	Michael Meilunas2, Peter Borgesen, Ph.D.3, K. Srihari, Ph.D.1 1Electronics Manufacturing Research and Services State University of New York at Binghamton Binghamton, NY 13902 2Process Research Engineer Universal Instruments Corporation Binghamton, NY 13902-0825 3Manager – Area Array Consortium Universal Instruments Corporation Binghamton, NY 13902-0825
96. Solder Joint Reliabilit y PBGA	This paper will describe experiments performed to determine the interconnect reliability of a peripherally leaded	The assembled boards were thermal cycled in both -40 to 125 and -50 to 150°C until >50% failure to compare	- From a solder joint reliability perspective, PBGAs with no-Pb solder balls performed better than those with eutectic in the two thermal cycling conditions studied. - All combinations of Pb-containing and Pb-free paste versus solder balls assembled successfblly using a profile that ensured reflow of all alloys present. In addition, the	Assembly and Solder Joint Reliability of Plastic Ball Grid Array with Lead-Free Versus Lead-Tin Interconnect

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	1.0 mm pitch, 324 PBGA with lead-free (tin-silver) versus conventional (tin-lead-silver) solder balls.	lifetime of the lead-based and lead- free material.	elements were generally well dispersed within the solder joints for all combinations.	Kim-Marie Levis and Andrew Mawer Motorola Semiconductor Products Sector
97. LF CSP Flux and Reflow	The present paper addresses the effects of reflow profile, pad metallurgy, and amount of flux on the assembly of flip chips with lead-free solder bumps onto organic substrates. Special attention was paid to the 85.9Sn/3.1Ag/10In/1.0 Cu alloy, which has a relatively low melting point of 197oC. Good wetting and a robust collapse could, however, not be achieved with flip chip relevant no-clean fluxes developed for eutectic Sn/Pb, even with peak reflow temperatures approaching 250oC. In fact, both 95.5Sn/3.5Ag/1.0Cu and 95Sn/5Sb were seen to perform much better at such temperatures.	Wetting and solder joint collapse was studied under two substantially different conditions, soldering to a blanket OSP coated copper surface and to individual contact pads on substrates designed to match the die, respectively. In both the cases, the flip chip solder bumps were first dipped into a thin film of a tacky flux on the Thin Film Applicator (TFA) on the GSM placement machine. Numerous different flux film thicknesses between 0.5 and 2.5 mil were considered. Four different no-clean fluxes (A, B, C, and D) from three different suppliers were investigated. The materials were chosen because they were known to work well for eutectic Sn/Pb on both	The small dimensions involved makes it difficult to develop an optimized solder based flip chip assembly process without ensuring full collapse of the joints to their equilibrium shape in mass reflow. All three lead free alloys considered here was found to require more flux than eutectic Sn/Pb to ensure this. In fact, the wetting properties of the Sn/Ag/Cu/In alloy were not very good and robust collapse could not be achieved with any of the three no-clean fluxes tested. Unless dedicated fluxes can be developed to alleviate this, the alloy is therefore not attractive for general flip chip assembly in spite of the relatively low melting point. The Sn/Ag/Cu and Sn/Sb alloys did perform almost as well as eutectic Sn/Pb with peak reflow temperatures around the 250oC. Indications are that the former can be also be used at somewhat lower temperatures, making it the more attractive candidate from the perspective of assembly.	Effects of Flux and Reflow Parameters on Lead-Free Flip Chip Assembly Sandeep Tonapi1 Doctoral Candidate Peter Borgesen, Ph.D. 2 Manager, Area Array Consortium K. Srihari, Ph.D. 1 Professor, Department of Systems Science and Industrial Engineering 1 - Thomas J. Watson School of Engineering and Applied Science State University of New York at Binghamton Binghamton, New York 13902-6000 2 – Universal Instruments Corporation PO Box 825 Binghamton, NY 13902-0825

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		OSP and Ni/Au coated copper surfaces, and because they would ‘roll’ well on the TFA without forming obvious ‘tracks’ or thickness variations.		
98. Solder Joint Reliability PBGA & CSP	In this paper, the results of accelerated thermal cycle (ATC) testing of Pb-free solder joints are described; the effects of thermal aging on intermetallic growth and joint strength have been reported previously [2].	In this study, accelerated thermal cycling (ATC) tests were performed. The test boards had organic solder preservative (OSP) surface finish and were populated with SMT leadfree components. The solder paste used in the SMT process was Sn-4Ag-0.5Cu in a water-soluble formulation. The components assembled included a PBGA and a CSP. Four lead-free solder ball metallurgies (Sn-Ag, Sn-Cu, Sn-Ag-Cu and Sn-Ag-Cu-Bi) have been evaluated on the PBGA.	- Sn-Ag-Cu solder joints are more reliable in thermal fatigue than comparable Sn-Pb eutectic joints. - Sn-Ag-Cu joints fail by thermal fatigue through the solder, just as Sn-Pb joints do. Intermetallic compounds, surface irregularities and voids have not contributed to any of the failures examined in this investigation. - The relative improvement of Sn-Ag-Cu solder joints over conventional Sn-Pb joints depends on the thermal cycle conditions and package type. The relative improvement of the Pb-free joint life ranged from 1.4 to 2.3, depending on package type and thermal cycle profile. - Assembling conventional PBGAs, with Sn-Pb solder balls, using Pb-free solder degraded the thermal fatigue life compared to a completely Pb-free joint. However, the performance was no worse than that of a completely Sn-Pb joint. Further study of the effects of Pb on Sn-Ag-Cu solder joints is required to confirm.	THERMAL FATIGUE RESISTANCE OF Pb-FREE SECOND LEVEL INTERCONNECT Patrick Roubaud, Greg Henshall - Hewlett Packard - Palo Alto, CA patrick_roubaud@hp.com , greg_henshall@hp.com Ronald Bulwith - Alpha Metals - Jersey City, NJ rbulwith@alphametals.cookson.com SMT-CD
99. LFS – CSP – Surface finish	The reliabilty of chip scale package using lead-free solder process was studied in this	The impact of reflow process, peak reflow temperature ranging from Tm+5C to Tm+40	All packages assembled using SAC396 can meet IPC-9701 From the results of thermal cycling, only CSP24, CSP308 and QFP208 can meet the telecom application requirement of IPC-9701 OSP outperformed ENIG as PCB surface finish for lead-free process	Reliability of CSP/Lead Free Solder Joints with Different Surface Finishes and Reflow Profiles

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	paper	and the dwell time ranging from 30 to 90 were investigated Sn3.9Ag0.6Cu		Xie, Geiger, Arra Flextronics
100. Surface Finishes for QFP	The purpose of this study is to evaluate three different QFP lead finishes using steam age preconditioning. This evaluation is based on solder joint strength measured by lead pull test. The effects of steam age preconditioning on solder voiding, wetting, fillet formation, and solder joint strength is included. This paper also summarizes the details of the QFP assembly build and process characterization using visual inspection, X-ray, and cross-sectional analysis. Furthermore, microscopic examination of the fracture surfaces following the lead pull tests was performed	Fig. 1 provides the test matrix. Three QFP component lead finishes (i.e. Sn, SnCu, and SnPb), two solder alloys (Sn/37Pb and Sn/3.0Ag/0.5Cu), and three different steam age preconditioning levels (0 hr, 1 hr, and 8 hr) were evaluated. A 62-mil thick FR-4 based printed circuit board with MacDermid immersion Ag pad finish was used throughout the study. Three QFP components were assembled on each test board. All the three QFP sites contained non-solder mask defined pads measuring 12 mils x 80 mils. The QFPs evaluated were 0.5mm pitch, 208 I/O devices with gull wing leads. Dimensional variations between the lead designs are summarized in Table 1. The Sn	A discussion of QFP assembly and lead pull study was presented in this paper. The combination of lead finish and solder paste does affect the lead pull forces. However, it is important to point out that a combination of lead play, off-centering, skew, coupon orientation, void formation, and sample preparation make it difficult to determine the exact reasoning for increase or decrease in lead pull force within the same lead finish (with same preconditioning and solder paste). Also, when comparing alternate surface finishes, the strength of the solder joint will vary depending on the component lead dimensions, solder modulus, intermetallic strength between the component and the solder, fillet formation, and amount of solder voiding, provided rest of the variables remain the same. In this study, Sn and SnCu lead finishes showed higher lead pull forces with Sn/3.0Ag/0.5Cu solder paste whereas SnPb lead finish showed higher lead pull forces with Sn/37Pb solder paste. Sn and SnCu lead finishes showed comparable lead pull forces whereas SnPb lead finish showed lower lead pull forces compared to Sn and SnCu lead finishes.	Proceedings of IMECE'03 2003 ASME International Mechanical Engineering Congress & Exposition Washington, D.C., November 16-21, 2003 IMECE2003-42846 Study Of Alternate Surface Finishes For Quad Flat Packs Muffadal Mukadam /State University of New York at Binghamton, NY. Michael Meilunas/Universal Instruments Corporation, Binghamton, NY. K. Srihari/ State University of New York at Binghamton, NY.

Focus	Objective	Scope	Conclusion(s) Summary	Reference
		(100%Sn) and SnCu (98.5%Sn, 1.5%Cu) plated components contained Cu as the leadframe base metal, while the SnPb plated devices contained alloy 42 (Ni/Fe).		
101. BGA Solder Joints – Impact Reliability	The purposes of this study are to clarify the dynamic behavior of BGA or CSP packaging subjected to an impact loading, and to establish a simple analytical method of impact reliability assessment for solder joints.	In order to take dynamic material properties into account, a high deformation speed tension test and a vibration test were camed out to obtain the strain rate dependence of yield stress and Young's modulus of solder materials and PCB. A 3-D analytical model of PCB mounted with a BGA chip was used to simulate the impact behavior of BGA packaging, and explicit-based FEM code LS-DYNA was used to carry out the dynamic analysis. Sn-3.5Ag-0.75Cu	The impact reliability of solder joints is affected by the falling posture of the PCB. If the horizontal posture of the PCB can not be controlled, remarkable unct:rtainty about the failure life will be caused, and the maxirnum life may increase to be equivalent **1.0** the cycle to failure of a test with half its falling height.	Dynamic Behavior of Electronics Package and Impact Reliability of BGA Solder Joints Qiang YU*, Hironobu KIKUCHI*, Shinya IKEDA*, Masaki SHIRATORI*, Manabu KAKINO**, Noriyuki FUJIWARA" *Department of Mechanical Engineering and Materials Science Yokohama National University
102. LF Fine Pitch Wafer CSPs	Assembly yields and the long-term reliability of fine pitch WLCSPs are much more	Two daisy-chained WLCSP designs were evaluated for this experiment. Design A	A reasonably robust paste printing process window for 0.4mm pitch area array devices exists. Paste printing is possible with .004” and .005” stencils. Recommendations include using type III solder paste and .010” square apertures in .005” stencil or .009” squares in .004” stencil. The process window for 0.5mm pitch	LEAD-FREE AND TIN-LEAD ASSEMBLY AND RELIABILITY OF FINE PITCH WAFER LEVEL

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	sensitive to assembly parameters than larger pitch devices. For example, it will be shown that 0.4mm pitch devices require relatively small stencil apertures with strict dimensional tolerances in order to avoid solder bridging during the assembly process. Furthermore, it is conceivable that 0.4mm pitch paste assembly cannot be successfully implemented with a stencil that is much more than .005" thick.	is a 192 I/O 0.4mm pitch package containing a 16x16 solder joint matrix depopulated to a four row perimeter array. Solder ball diameter is approximately .010" and the balls are attached to the package body by .0078" diameter pads. Design B is a 98 I/O 0.5mm pitch package containing a 10x10 depopulated solder joint array. Solder ball diameter is approximately .012" and the balls are attached to the package body by .011" diameter pads. Both devices were acquired with 96.5Sn/3.0Ag/0.5Cu and 63Sn/37Pb solder balls.	printing is even larger and can easily accommodate .006" stencils without resulting in solder bridging. Flux dipping is an acceptable alternative to paste printing, but expect a 30% reduction in thermal cycle reliability due to decreased joint standoff. Pb-free assembly in an air reflow environment is possible for flux dipping and paste printing WLCSP assembly. An air atmosphere will result in less collapse than a nitrogen environment thereby producing greater standoff heights. The reliability of an air assembly is statistically similar to that produced by a nitrogen assembly.	CSPs Michael Meilunas1, Muffadal Mukadam2 & Peter Borgesen1, Hari Srihari2 1Universal Instruments Binghamton, New York, USA 2Binghamton University Binghamton, New York, USA
103. Solder Joints – Impact Reliability	The impact toughness of solder joints was evaluated quantitatively by means of a miniature Charpoy test	Shear rate was 1m/s Solder balls were SnPb, SnAgCu, SnZn, SnZnBi Cu immersion Au/electroless Ni-P pads	The SnAgCu joints had higher tendencies to break at the interface in the impact test than the shear test SnAgCu solders was liable to fracture at the interface by the impact test because of higher bulk strength	Impact Reliability of Solder Joints Date, Shoji, Fujiyoshi UCLA
104. Solder	The Quad Flat Pack	Temperature range for	Although the results on the QFN-EP packages were positive, the study also presented	QUAD FLAT PACK NO

Focus	Objective	Scope	Conclusion(s) Summary	Reference
Joint Reliability Quad Flat Pack	No-Lead Exposed Pad (QFN-EP) package was first implemented at Motorola for wireless applications. The package has tremendous potential due to its low profile, small footprint, low inductance, and low cost.	the experimental cycling was from –40 C to 125C with 15 minute dwells at extremes and 15 minute ramps between extremes	the importance of carefully selecting and evaluating both package and the PCB designs.	LEAD (QFN) BOARD LEVEL RELIABILITY STUDY FOR AUTOMOTIVE APPLICATIONS Pamela O'Brien1 and Thomas Koschmieder2 1Motorola Inc. SMT-CD
105. LFS SMT Component Reliability	This paper discuses some of the results, empirical and theoretical, of various studies	This paper will primarily focus on ten metallurgical and reliability aspects	No one drop-in substitute exists where nothing but the solder material needs to be changed. Several formulas are available, each with different process requirements and each with different material properties.	LEAD-FREE SOLDERING FOR SMT COMPONENTS; A REVIEW OF PROCESSING AND RELIABILITY ISSUES Frank Liotine
106. LF Processing – Heat Sensitive Components	Reflow temperatures are increasing due to lead-free adoption at the same time that we are assembling devices with more heat-sensitive components – optoelectronic modules, displays, MEMS and complex ICs. This paper reviews technologies to manage these heat sensitive components and describes a new technology to protect these sensitive components and allow	Based mainly on solder joint robustness, the National Electronics Manufacturing Initiative (NEMI) recommended one of the SAC (tin-silver-copper) alloys to its members [1]. However, the melting temperatures of the SAC variations are about 40 degrees Celsius higher than the tin-lead eutectic incumbent alloy. This requires a similarly higher reflow peak	The cap clearly had a cooling effect for all three reflow profiles. Also, charging the cap with an evaporation agent led to significant increases in cooling capability. Figure 2 shows the thermocouple readings when an uncharged cap is used for cooling (no evaporation liquid). Starting at the upper left, the first chart shows the low temperature profile (1300C peak temperature) with a thin circuit board. In this case, the cap has a minimal cooling effect, with only about 100C between the exposed thermocouple (pink line) and the thermocouple under the cap (blue line). Going left to right across the top row, the next chart shows the same setup, but with a thicker board. Because of the greater thermal mass, the exposed thermocouple does not get as hot. The cooling effect is about the same.	PROCESSING HEAT-SENSITIVE COMPONENTS IN LEAD-FREE AND OTHER CONDITIONS Brian Lewis, Prashant Chouta, and Adam Singer Cookson Electronics Inc. Jersey City, NJ, USA asinger@cooksonelectronics.com Alan Rae Nanodynamics Inc. Buffalo, NY, USA arae@nanodynamics.com

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	them to be processed under normal reflow, wave and rework conditions.	temperature, which requires improvements in the other (non-solder) materials being used.		
107. LF – Optimizing Stencils	Because stencil printing has such a large influence on first pass yield, and lead-free alloys have different wetting properties than their lead-bearing counterparts, the authors have undertaken a study to identify stencil aperture geometries that optimize desired SMT characteristics. The concern of the lower spread of lead-free alloys on some alternate surface finishes is explored. Aperture designs that maximize pad coverage while minimizing defects like midchip solder balls are offered.	Spread characteristics of the solder pastes can be studied by two methods. The first method involves printing a circular deposit of known area on bare metallic substrate, reflowing the sample, and measuring the area covered with solder post-reflow. The ratio of the postreflow area to that of the original printed area gives a measure of the spreading of the paste and an indication of wetting for the particular board finish on which it was measured. An alternative solder spread/wetting test involves printing pairs of uniform thickness (40 mil) solder paste stripes onto an array of uniform thickness (30 mil), equally spaced	The optimum apertures found for minimizing the formation of mid chip solder balls is the radiused inverted homeplate design with aperture proportions of 20%-60%-20%. This aperture did not produce any tombstones. To gauge wetting and spread capability of solder pastes, the cross-print pattern was found to be superior to the spread ratio test. QFP data was inconclusive. It is recommended that this type of test be performed in production environments to capture a greater sample size the systemic noise associated with high volume manufacturing operations. Further studies are recommended to characterize tombstone behavior, particularly with different lead-free alloys.	OPTIMIZING STENCIL DESIGN FOR LEAD-FREE SMT PROCESSING Ranjit S Pandher Chrys Shea Cookson Electronics Assembly Materials Jersey City, New Jersey, USA

Focus	Objective	Scope	Conclusion(s) Summary	Reference
		traces on the board.		
108. LF 0201 Assembly	The trend towards smaller, faster and cheaper electronic devices has led to an increase in the use of 0201 and even smaller sized passive components. The size advantages of 0201 components make it a popular choice among design engineers but not among manufacturing engineers. From a manufacturing perspective, the size of the 0201 package poses significant challenges to the printed circuit board (PCB) assembly process.	The test vehicle consisted of 240 non-solder mask defined rectangular pads with dimensions and spacing as shown in Figure 1. The pads were equally distributed in the horizontal and vertical orientations (Figure 2). Five different types of test vehicles, with the same pad layout, with varying pad finishes (HASL, Ni/Au, pure Sn, immersion Ag and OSP)	The study carried identified a number of key factors controlling the 0201 assembly defect rate. Solder beading, tombstoning, and skewing were the major defects that were observed on 0201assemblies. One significant finding was the low occurrence of tombstoning defect- a few occurrences were for Sn/Pb solder paste with antitombstoning on ImAg PCB surface finish. No Occurrence with lead-free solder paste. Solder Beading was the most prominent defect, about 20%, whereas other defects combined were about 5%. Solder beading defect formation depends upon the wetting quality of the surface finish which in turn depends upon the wetting angle. Thus, solder beading defect can be controlled by reducing reflow ramp-up rate and also by controlling	EFFECT OF SOLDER PASTE AND SURFACE FINISH ON 0201 ASSEMBLY PROCESS DEFECTS Rahul A. Newasekar and S. Manian Ramkumar Center for Electronics Manufacturing Rochester Institute of Technology Rochester, NY, USA smrmet@rit.edu Reza Ghaffarian, Ph.D. Jet Propulsion Laboratory, California Institute of Technology Pasadena, CA, USA reza.ghaffarian@jpl.nasa.gov
109. LF – Processing 01005 Components	paste printing, component placement and reflow soldering for 01005 components will be investigated, based on our previous experience with 0201 size components. Component spacing down to 100 µm is included in the	An array of land patterns (Figure 2) for 01005 was designed and incorporated on a test vehicle (Figure 3) that was already being laid out, to enable the trials. The overall size of the test vehicle was 170 x 145 x 1.0 mm, but the test structure for	It is possible to design and manufacture products with 01005 components. The overall process will be similar to 0201. The pad design C has yielded good results with ptimized processes. Solder paste printing will require It is possible to design and manufacture products with 01005 components. The overall process will be similar to 0201. The pad design C has yielded good results with ptimized processes. Solder paste printing will require possible to feed 01005 activity of the flux. Further work timize the process for reflow in air.	PCB DESIGN AND ASSEMBLY PROCESS STUDY OF 01005 SIZE PASSIVE COMPONENTS USING LEAD-FREE SOLDER Fredrik Mattsson Flextronics Linkoping, Sweden David Geiger & Dongkai Shangguan, Ph.D.

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	experiments. Shear strength testing, cross-sectioning, and light microscopy as well as Scanning Electronic Microscopy (SEM) are used to examine the results.	an array of 816 component sites for 01005 only used a small portion of the test vehicle. The test vehicle, 1mm thick, had six copper layers and FR-4 laminate core material.		Flextronics San Jose, CA, USA Todd Castello Flextronics Youngsville, NC, USA
110. SMT Processing and Lead-Free Components	Phase 1 - Solderability of Pb Free Components Evaluate solderability performance of component Pb-free finish types and compare a variety of other process factors (SnPb, surface finish, flux, types of component, profiles of wave and reflow. Characterize effects of reflow profile parameters on solderability of components with select Pb-free lead finish types. Phase 2 - Lead Free Solder Technology Transfer Qualify lead free assembly processes and technology transfer.	First phase is to characterize, analyze and qualify the solderability of lead free terminations in eutectic solder SMT processes for a wide variety of lead free terminations and eutectic solder systems. The second phase will deliver a comprehensive lead free SMT process solution to participating customers. Lead free process solution will be installed and qualified on a specified SMT line.	This is a proposal. No work has begun as of January 2005.	Lead Free Process Solution Including Qualification, Installation and Transfer Engent - Matt Perry, Michelle Keys.
111. Optimizi	In this paper, a	The Sn-Cu alloy has	Due to the inherently inferior wettability of the lead-free solder as compared with the	Optimization of Lead-Free

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ng LF Processin g	comprehensive review is provided on the optimization of soldering processes (including reflow, wave soldering, and rework), for different component types, different PCB sizes and finishes, and in different soldering atmospheres (air and nitrogen). The impact of key process parameters on the process yield is discussed in comparison with the Sn-Pb soldering process, and methodologies for optimizing the lead-free soldering processes are outlined. Component compatibility issues are also discussed.	generally been found to be inferior to SAC in terms of wettability, dross formation, and reliability under typical loading conditions; however, its much lower cost as compared with SAC makes it an attractive alternative alloy for wave soldering, especially for cost sensitive products. Even though most manufacturers may prefer to use the same alloy for all of the solder interconnects on the entire board (including reflow and wave soldering), there are products in volume production today which use SAC for reflow and Sn-Cu for wave soldering on the same board; as such, methods for inspection, rework, and accelerated testing must be compatible for both alloys. Several variants of the Sn-Cu alloy have also been introduced, including silver (Ag), nickel (Ni), and other elements as	Sn-Pb solder, lead free solder has generally been found to generate more defects of voiding, tomb-stoning, solder beading, bridging, and misalignment. It takes considerable efforts to achieve the same yield for lead-free solder as for Sn-Pb solder, especially for wave soldering. Therefore, process optimization is critical for volume manufacturing with lead-free solder. In this paper, a comprehensive review has been provided on the optimization of soldering processes (including reflow, wave soldering, and rework), for different component types, different PCB finishes, and in different soldering atmospheres (air and nitrogen)	Soldering Processes for Volume Manufacturing Dongkai Shangguan, Ph.D. Flextronics International San Jose, CA Presented in the ECWC 10 Conference at IPC Printed Circuits Expo®, SMEMA Council APEX® and Designers Summit 05

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		alloying additions.		
112.LF Processing	For paste characterization, SIR, Corrosion, slump, solder ball, printing, wetting, strength, IMC and microstructure were evaluated. Tremendous amount of control variables, are factored into a Design Of Experiment to assess the paste printability. Four different categories of control parameters from stencil tooling (aperature, thickness), paste (type, stirring time, usage dwell time), printer (speed, snap off, cleaning frequency), and operation environment (process humidity and temperature) were treated as main effects and interactions were orthogonally studied.	A test vehicle2 with major representative package types, FCBGA, PBGA, CBGA, QFP, SOIC, RN, passive, press-fit, PTH etc as shown in Figure 1 were laid out with Daisy Chain (DC) structure to achieve the following goals. PCB was 14 and 26 stack-up layers and Polyclad dielectric 370HR Novelac material with Tg of 1750C intertwined with 1 and 2 oz copper foil on thickness 93, 150 and 197 mils and dimension 16x20.875". Symmetry stack-up is designed into the layer structure to reduce PCB warpage as shown in our earlier study by Shadow Moiré emulation and FEM simulation3.	A few test vehicles with advanced features for extensive paste & flux evaluation and reliability tests on representative package types and solder joint were designed to proactively cope with the Lead-Free initiative. Among all the critical characteristic tests, SIR, corrosion, and slump were performed first to screen for potential electrochemical and printing concerns. Then solder & flux wetting, paste cold and hot slump, solder ball, and printing efficiency tests were examined to provide the interconnect foundation for package-solder and pad system. Finally, high strain rate pull test on 208QFP and shear test on R2010, microstructure, and IMC structure were analyzed. A quantitative score rule was defined to differentiate the overall performance of each raw material.	LEAD-FREE PROCESS AND PRODUCT TRANSITION* Phase II. Paste Characteristic Study by Response Assessment and Printing Optimization by Taguchi Method Paul P.E. Wang, Ph.D., Gary Huang, Ken Kochi, Heidi Reynolds, Ph.D., and David Love Sun Microsystems, Inc., USA. Hana Hsu, Jerry Peng, Peng Sun, Anching Chien, Leimo Chen, Jakal Weng, C.G. Tyran, S.K Chiu, and C.J. Lin Mitac International Corp. Hsin-Chu, Taiwan.
113.LF Component Finishes	While electroplated pure tin is a component surface finish that has existed in the electronics industry for	Much of the literature supports the theory that growth of tin whiskers is related to internal stress. It has been	With no widely accepted method to determine if tin whiskers will grow and no published and accepted model for tin whisker formation many questions remain unanswered. Tin whiskers can develop in a short time period or after many years. The success of any mitigation strategy such as new plating chemistries, conformal coat, lead diffusion and robotic solder dip needs to be evaluated for each type of	LEAD-FREE COMPONENT FINISHES – PROBLEMS AND MITIGATION Joseph Zaccari

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	decades, there is a well-known phenomenon related to pure tin plating, known as “tin whiskers.” Tin whiskers are conductive, pure tin crystals that spontaneously “grow” from an electroplated pure tin surface.	shown that the external application of compressive stress can cause the growth of the whiskers. To understand the development of whiskers it is important to consider all aspects of the total system.	application.	Corfin Industries LLC
114. Component Solderability Evaluation	To compare solderability results of Pb free terminations using the most common industry standard techniques Compare solderability test results using SnPb and SnAgCu solders Predict board level solder joint an thermal cycling performance based on the solderability testing results to determine the applicability of the test methods	Dip & Look Wetting Balance Surface Mount Simulation (CPT) Test Vehicles: (SOIC, LQFP, PDIP, CDIP, pad TSSOP, SSOP, MLF, TO-252, TO-99 can) Termination Finished: (SnPb, SnCu, Sn, NIPd (4 layer), NiPdAu (3 layer) Solders: (SnPb, SnAgCu)	Dip and Look - For SnPb and SnAgCu solder, all component finishes except NiPd(Au) exhibited good solderability In general, results were in good agreement between the SnPb and SnAgCu testing methods. Wetting balance - Components exhibiting degraded wetting times and forces when using SnAgCu solder versus SnPb (PDIP, LQFP, SOIC, TO-252) Components with similar wetting times and forces for SnPb and SnAgCu solders (To can, CDIP). For both SnPb and SnAgCu solders, results degraded after steam aging for many components and finishes. SnPb solder results at 0 hour predict good board assembly performance (All components, all finishes) SnAgCu results predict potential solderability problems at the board level (SOIC, TO-252, all finished tested), (PDIP, SnCu and Sn finishes). Surface Mount Simulation - All lead finish types exhibited acceptable wetting (SnPb, Sn, SnCu and NiPd finishes), (both for 0 hour and steam aged samples) Results predicted that this package should form good solder joints during board assembly and perform acceptably during thermal cycling (for both SnPb and SnAgCu systems)	Lead Free Components Focus Group -
115. LFS Reliability - SMT Power	A power cycling in-test monitoring system has been constructed to test the reliability of eight	The assemblies included SnAg3.8Cu0.7 and SnAg3.8Cu0.7X solder joints on OSP-	Yield stress measurements of the bulk SACX alloy suggested superior fatigue resistance to SPA solder alloy. However, SACX soldered assemblies did not show increased fatigue life over 5000 power cycles, compared with SPA soldered assemblies.	The Effect of Power Cycling on the Reliability of Lead-Free Surface Mount Assemblies

Focus	Objective	Scope	Conclusion(s) Summary	Reference
Cycling	different lead-free surface mount assemblies.	Cu (organic solderability preservative on Cu), electroless NiAu, immersion Ag and immersion Sn board metallizations. All assemblies experienced up to 5000 power cycles of ambient to 100 C with a 15 min dwell at each temperature.		Elaine Davitt, Frank A. Stam, and John Barrett, *Senior Member, IEEE*
116. LFS - Constitutive Behavior	Therefore, in this study two lead-free solder alloys (Sn96.5Ag3.5, Sn95.5Ag3.8Cu0.7) and two lead-containing solder alloys (Sn63Pb37, Sn59Pb40Ag1) were investigated and compared with each other in order to give an estimation of the reliability enhancement of the new lead-free soldering technology.	Constant-load creep tests were performed on the bulk specimens at temperatures from 20 °C to 180 °C. The steady-state strainrates span seven orders of magnitude ranging from 10^{-11} s^{-1} to 10^{-4} s^{-1}. For the experiments on real flip chip solder joints a test	Stronger differences as on the Sn96,5Ag3,5 solder were found between the Sn95,5Ag3,8Cu0,8 bulk solder and the Sn95,5Ag4Cu0,5 flip chip solder (Fig. 22). At the reference temperature of T = 20 °C the creep behaviour Sn95,5Ag3,8Cu0,8 bulk solder could have been subdivided into a low-stress behaviour with n’ = 2,6 and a high stress behaviour with n’ = 10.	Constitutive Behaviour of Lead-free Solders vs. Lead-containing Solders - Experiments on Bulk Specimens and Flip-Chip Joints S. Wiese (1), A. Schubert (2), H. Walter (2), R. Dudek (2), F. Feustel (1), (1) Dresden University of Technology, Semiconductor & Microsystems Technology Laboratory
117. Solder Joint Reliability Pb / Pb-free mixing	The fatigue properties of Sn3,5Ag0,7Cu have been investigated in this work with	- Sn3,5Ag0,7Cu lead-free solder. These boards were then temperature cycled between $125^{o}C$ and $-15^{o}C$. - Sn3,5Ag0,7Cu lead-free solder alloy has	Sn3,5Ag0,7Cu has fatigue properties during mechanical cycling which are better than those of the best traditional lead containing samples tested previously. It has however, been shown that a contamination of 2%-5% Pb can be detrimental to the lifetime of Pb-free solders[7]. - It has been shown that the Pb-free solder joint reliability is considerably reduced by the contamination of low Pb contents from metallisations. The mechanism by which this takes place is different from that previously suggested involving the low melting point of the Pb-containing phase.	FATIGUE PROPERTIES OF Sn3.5Ag0.7Cu SOLDER JOINTS AND EFFECTS OF Pb-CONTAMINATION James Oliver, Margareta Nylén, Olivier Rod, Christofer Markou

Focus	Objective	Scope	Conclusion(s) Summary	Reference
		been mechanically cycled to compare with the traditional SnPb solders.		Swedish Institute for Metals Research SMT-CD
118. Solder Joint Reliability Pb / Pb-free mixing	The question of what happens to a lead-free solder joint if it becomes contaminated with lead is important because during the transition to lead-free soldering it is very likely that tin/lead parts will still be used in a great deal of production.	In order to determine Sn/Ag/Cu alloys' durability when exposed to lead, Sn/Ag4/Cu0.5 was tested for mechanical reliability with a 0.5% and 1% contamination of lead.	- Lead-free alloys can suffer decreased reliability when contaminated with lead. - Low Cycle Fatigue Testing = Sn/Ag4/Cu0.5 passed the testing requirements. However, when contaminated with 0.5% lead, the alloy lasted only approximately 50% of the cycles as the alloy without lead contamination and failed the test. Furthermore, when contaminated with 1% lead, the cycles to failure were again reduced by 50%, which constituted another failure. - 40° to +125°C testing = important to note that assemblies that mixed Sn/Pb balls with Sn/Ag/Cu paste fared significantly worse than either the all lead-free or all Sn/Pb assemblies in terms of % cum. failures. This data reiterates to potential reduced reliability of mixing lead parts with lead-free solders.	A STUDY OF LEAD-CONTAMINATION IN LEAD-FREE ELECTRONICS ASSEMBLY AND ITS IMPACT ON RELIABILITY Karl Seelig and David Suraski AIM, Inc. SMT-CD
119. Solder Joint Reliability Pb / Pb-free mixing	An effort is being made by Intel to evaluate the technical feasibility of Sn-Ag-Cu BGAs attached with eutectic Pb-Sn solder paste to printed circuit boards and the impacts of that material combination to solder joint reliability.	This paper presents the results of solder joint reliability evaluation of VFBGA (very fine pitch ball grid array) and SCSP (stacked chip scale package) Pb-free packages attached to Printed Circuit Boards (PCBs) with eutectic Pb- Sn pastes. The packages were assembled under various reflow profiles using standard Pb-Sn assembly conditions.	**- Normal SMT assembly yields were observed.** 0.5mm pitch VFBGA and 0.8mm pitch SCSP BGA Pb-free packages were assembled with eutectic Pb-Sn paste under Intel recommended reflow profiles. Yields were above 99.2% yield at on both OSP and electro-less Ni and immersion Au PCB surfaces. **- This data suggests that board level reliability goals are met for Pb-free balls using Sn-37Pb paste on OSP board surface finish under certain process conditions.** These conditions are when the Sn-Ag-Cu BGA ball completely melts and mixes with Sn-37Pb paste. The goals are defined as statically less than 5% failure at 800 temperature cycles and mean drops to failure is equal or better than control Sn-37Pb solder joints. **- "Black pad" on electro-less Ni-Au and other board defects affected the data in this experiment.** The Sn-Ag- Cu BGA balls and Pb-Sn solder paste assemblies are high risk (worse than Sn-Pb joints) under mechanical shock load when board defects are present.	SOLDER JOINT RELIABILITY OF Sn-Ag-Cu BGA COMPONENTS ATTACHED WITH EUTECTIC Pb-Sn SOLDER PASTE Fay Hua1, Raiyo Aspandiar4, Tim Rothman2, Cameron Anderson3, Greg Clemons3, Mimi Klier2, 1Intel Corp., Materials Technology Operation, 3065 Bowers Ave., Santa Clara, CA 95054 2Package SMT-CD
120. Solder	At Intel, Backwards	8 layer, standard FR4	**- Assembly Yield =** 100% yield was observed for all the wbPBGA builds.	SOLDER JOINT

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Joint Reliability Pb / Pb-free mixing BGA	Compatibility is defined as a lead free package (lead free terminals) or component that is capable of being solder attached to a Print Circuit Boards (PCB) using eutectic Sn/Pb paste under Intel recommended SnPb reflow profiles and process parameters while the final solder joints statistically meet or exceed current board level reliability goals.	boards were used in this study to simulate the projected product conditions. SnPb HASL and Entek. Plus OSP surface finishes were used on the PCBs. Each PCB had 6 wbPBGA land patterns, all of identical daisy chained design. All package BGA balls were Sn-4.0Ag-0.5Cu (SAC405) Pb-free solders.	- **Thermal Cycling Results =** Assembly of Sn-4.0Ag-0.5Cu BGA packages attached with eutectic SnPb solder paste reflowed at the higher peak temperature (¡Ý217 °C) on OSP and HASL boards. VARIED RESULTS BASED ON PACKAGE TYPE - Assembly of Sn-4.0Ag-0.5Cu BGA packages attached with eutectic SnPb solder paste reflowed at lower peak temperature (208°C) on OSP and HASL. = all the solder joints of Sn-0.4Ag-0.5Cu BGA attached with eutectic SnPb paste meet the board level reliability goal in 0.5mm pitch vfBGA and 0.8mm SCSP packages on OSP surface finishes, the solder joints processed at 208°C peak	RELIABILITY ASSESMENT OF Sn-Ag-Cu BGA COMPONENTS ATTACHED WITH EUTECTIC Pb-Sn SOLDER Hua1, Raiyo Aspandiar2, Cameron Anderson3, Greg Clemons3, Chee-key Chung4 , Mustapha Faizul4 Intel Corporation SMT-CD
121. Solder Joint Reliability High Temperature Processing	The goal of our investigations were the tests to produce lead-free soldered electronic boards with conventional equipment and to find out the limits for lead-free soldering.	The thermal cycling test for simulating the aging of the lead free solder joints were performed from – 40°C to 125°C for 30 minutes of each. The simulation of a continuous working temperature were simulated in a thermal storage for 500 hours and with 150°C.	The evaluation of the lead-free solder pastes using thermal stress is still going on. So far no defects could be detected after 950 cycles –40°C/125°C. The higher permanent working temperature seems to be not a problem for the investigated lead-free solder materials. No failure could be obtained after 500h thermal storage at 150°C.	RELIABILITY OF LEAD FREE SOLDER JOINTS ON MANUFACTURING CONDITIONS Th. Herzog , K.-J. Wolter, Th. Zerna Electronics Technology Laboratory Dresden University of Technology SMT-CD
122. Solder Joint Reliability Cooling Rates	Leadless chip resistor (LCR) assemblies were manufactured using both traditional tin-lead (Sn37Pb) and lead-free (Sn3.8Ag0.7Cu)	The leadfree test vehicles were assembled using three different cooling rates: 1.6°C/sec, 3.8°C/sec, and 6.8°C/sec. They	- The test results indicated that these lead-free solder joints had better creep-fatigue performance than the tin-lead solder joints. - The LCR built with the medium cooling rate showed the longest fatigue life compared with the resistors built with the normal cooling rate of 1.6°C/sec and the higher cooling rate 6.8°C/sec. - The results indicated that poor wetting increases strains throughout the joint	Accelerated Thermal Fatigue of Lead-Free Solder Joints as a Function of Reflow Cooling Rate Y. QI,1 A.R. ZBRZEZNY,2 M. AGIA,3 R. LAM,1 H.R.

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	solders.	were then exposed to accelerated thermalcycling (ATC) tests between 0°C and 100°C with a 10–14°C/min ramp rate and a 5-min dwell time.	significantly, which is in accordance with the ATC results.	GHORBANI,1 P. SNUGOVSKY,4 D.D. PEROVIC,2 and J.K. SPELT1,5
123. Cooling Rate – SnAg Solder	The tensile behavior and microstructure of bulk, Sn-3.5Ag solders as a function of cooling rate was studied. Cooling rate is an important processing factor that affects the microstructure of the solder and therefore significantly influences mechanical behavior. Controlled cooling rates were obtained by cooling specimens in different media: Water, air, and furnace. Cooling rate significantly affected secondary dendrite arm size and spacing of the Sn-rich phase, as well as the aspect ratio of Ag3Sn. Sn-rich dendrite arm size and spacing were smaller for water-cooled specimens, than in air-cooled specimens.	High purity cast ingots of Sn 96.5-Ag 3.5 wt% (Indium Corporation, Ithaca, NY) were used in this study. Impurity analysis of the solders, shown in Table 1, showed a trace amount of impurities. The ingots were machined into rectangular blanks and reflowed in an aluminum mold coated with graphite. A thermocouple was placed at the bottom of the solder to determine the cooling rate in the solder. Samples were heated at 240oC (approximately 20°C above the eutectic point of the solder) for 20 seconds and cooled in different cooling media: Water, air, and furnace. The cooling rate was measured from peak temperature to 150 °C,	Increasing cooling rate decreased the Sn-rich phase secondary dendrite arm size and spacing. Faster cooling rates resulted in a fine dispersion of Ag3Sn, while slower cooling rates resulted in needle-like Ag3Sn. Cooling rate did not affect the Young's modulus of the solder, although a decrease in Young's modulus with increasing fraction of porosity was observed. The experimental data showed good agreement with the model by Ramakrishnan and Arunachalam [21]. Water cooled samples exhibited the highest yield strength and work hardening rate, due to the very fine Sn-rich dendrites and fine Ag3Sn particles within the eutectic. The combination of needle-like Ag3Sn and the Sn-rich matrix in furnace-cooled samples resulted in fibrous co-deformation of the phases, yielding the highest ductility for all cooling rates studied. The ultimate tensile strength was similar for all samples due to nearly ideal elastic-plastic behavior of the solder. Stress relaxation mechanisms, primarily by grain boundary sliding, were predominant at relatively large strains in the furnace cooled samples.	Effects of Cooling Rate on the Microstructure and Tensile Behavior of a Sn-3.5 wt.% Ag Solder F.Ochoa, J.J. Williams, and N. Chawla Mechanical Behavior of Materials Facility Department of Chemical and Materials Engineering Arizona State University Tempe, AZ, 85287-6006

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		since previous work by the authors [12, 13] has shown that no significant change in microstructure is observed below		
124. LF Process Window	The purpose of this document is to report the results of a design of experiment (DOE) used to determine the process window for a typical surface mount 0402x4 resistor network. The factors of the DOE include solder paste alignment in the X and Y directions and part placement in the X and Y directions. The result of the process window DOE determined the placement of a 0402x4 resistor network to be a circle, centered at the CAD location with a diameter of 2 mils to attain a process capability index (Cpk) of 1.50.	Process capability can be determined for the entire process and for the individual steps within the process. It is often useful to examine the individual steps in the process and determine the capability of each step. Machine capability (Cp) is a measurement of the spread, and the process capability index (Cpk) is a measurement of how well the distribution is centered. The machine capability indices are defined as, As the process varies away from the process center, the defect rate increases. The circled region on Figure 5 represents the process window at an acceptable defect rate or process capability index. The defect rate	The solder paste alignment was found to be the more critical design variable, followed by placement accuracy design variables. Since there is a strong interaction between the paste alignment and placement accuracy, the smallest process window defines the overall process window. The results of the process window DOE of the placement of a 0402x4 resistor network were determined to be a circular region centered at zero with a diameter of 2 mils to attain a process capability index of 1.50. The solder paste and placement interaction that was found to be most significant for the bridging solder defect response was between the Paste Y and Place Y interaction. This interaction was also responsible for determining the process window.	PROCESS WINDOW STUDY DETERMINING THE DEFECT-FREE PROCESSING WINDOW FOR SMALL SURFACE MOUNT COMPONENTS USING A RESPONSE SURFACE DESIGN OF EXPERIMENT Michael Johnston Micron Technology Inc. Boise, ID, USA msjohnston@micron.com

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		increases rapidly as the process capability decreases. (See Figure 3.)		
125. Sn-Ag based solder joints – dwell times – thermo mechanical fatigue	Thermomechanical fatigue (TMF) caused by the mismatch in the coefficient of thermal expansion (CTE) between solder and substrate gradually degrades the mechanical properties of solder joints during service.	Solder joints fabricated with eutectic Sn-Ag and Sn-Ag solder with Cu or Ni were subjected to TMF between _15°C and _150°C with dwell times of 115 min at high-temperature extreme and 20 min at low-temperature extreme. Characterization of surface damage and residual-mechanical strength of these solder joints were carried out after 0, 250, 500, and 1,000 TMF cycles.	Quaternary alloys containing small amounts of Cu and Ni exhibit better TMF performance than binary and ternary alloys under TMF cycling with longer dwell times at high-temperature extreme. The design of solder joints in electronic packages requires a good understanding of the mechanisms that control the deformation under the service environment. However, the dominant mechanism, which contributes to TMF, has not yet been fully identified.	Effect of Dwell Times on Thermomechanical Fatigue Behavior of Sn-Ag–Based Solder Joints J.G. LEE1 and K.N. SUBRAMANIAN1,2
126. LFS Alloys – Grain Boundaries	Grain-boundary deformation is the primary failure mode observed in solder joints. Understanding the effects of alloy composition variations and cooling rates on microstructural stability and deformation processes will allow development of	The effects of these variables on grain-boundary character were investigated in a pure-tin ingot and a reflowed sample; ingots of Sn-3.5wt.%Ag and Sn-3.8wt.%Ag-0.7wt.%Cu; and solder balls with 1.63-wt.% or 3-wt.% Ag. The microstructure was	After aging (150°C for 200 h), the fine-grained polycrystalline microstructure in both pure-tin specimens grew considerably, revealing preferred misorientations and ledge formation at grain boundaries. Aging of the alloy ingots showed only slight grain growth caused by precipitate pinning.	Grain-Boundary Character and Grain Growth in Bulk Tin and Bulk Lead-Free Solder Alloys A.U. TELANG,1,3 T.R. BIELER,1 J.P. LUCAS,1 K.N. SUBRAMANIAN,1 L.P. LEHMAN,2 Y. XING,2 and E.J. COTTS2

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	improved joints.	characterized using orientation imaging microscopy (OIM).		
127. Solder Reaction Across Solder joints	Slide Presentation	With the electronic devices being continuously scaled down, solder reaction is becoming one of the major concerns for packaging reliability. _ Due to the Pb-free requirement, new surface finishes have appeared in the market and more are being studied. _ Persistence of the Black Pad problem results in the application of OSPCu or bare Cu. _ Local effects of solder reaction on joint reliability has been extensively studied, but its effects on the other side of the joint is relatively new to the industry.	Ranking of dissolution rate of metals corresponds to that of saturation solubility of the metals, with Au being the fastest and Ni the slowest. _ Dissolution rate of metals in the eutectic SnAg solder is higher than in the eutectic SnPb solder. _ Dissolved metals may diffuse across the solder joint during reflow process, altering the solder reactions on the other side of the joint and thus influence the joint reliability. _ When assessing solder joint reliability, influence from the other side of the joint should also be considered if the surface coatings are different on the two sides.	Influence of Solder Reaction Across Solder Joints Kejun Zeng FC BGA Packaging Development Semiconductor Packaging Development Texas Instruments, Inc
128. LF – Digital X-Ray	The effects on the PWB production process of having to introduce new	With such a change in the materials and methods used for PWB	The improvements made to the capabilities of x-ray inspection systems over recent years, offers the opportunity for better and subtler inspection of PWB joints. In particular, the enhanced sensitivity of digital x-ray systems now provides an	USE OF DIGITAL X-RAY IMAGING AS A PROCESS CONTROL

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	lead-free solder material; needing higher reflow oven temperatures, an altered printing process and possible use of different board finishes, requires consideration of continuous process control monitoring. For example, it has been observed that the new lead-free materials tend to exhibit higher levels of voiding than their tin/lead counterparts, which may impact in-field reliability. This is in addition to potential faults initially implementing a lead-free process may cause. To help ensure production quality control, x-ray inspection is often considered a crucial part the test regime.	assembly, the use of x-ray inspection has increased dramatically. This is because of x-ray's ability to inspect samples non-destructively, during production and ahead of repair and rework. X-ray is particularly useful on devices with optically hidden joints, such as BGAs, flip chips and CSPs. In addition, it is also because of x-ray inspection's ability to look within all joints of the board to confirm and quantify voiding levels, ahead of making any process adjustment for optimum PWB manufacture.	opportunity for a clearer investigation, and continuous monitoring, of the level of voiding within all PWB joints. As a result, there is now firm evidence of at least two types of voiding that can occur within BGA balls. The first void type being the established 'process control' voids of air bubbles trapped within the bulk of the solder ball, formed during the SMT process. The second void type being so called 'Champagne Voids', where many small air bubbles are located at the ball to pad interface.	TOOL FOR LEAD-FREE PWB ASSEMBLY David Bernard Dage Precision Industries Fremont, CA, USA d.bernard@dage-group.com Nick Hoo & Dominic Lodge Soldertec/Tin Technology St. Albans, Hertfordshire, United Kingdom nick.hoo@tintechnology.co m
129. LF PBGA X-Ray	The effects of lead-free solder paste (Sn3wt%Ag0.5wt%Cu) and lead-free solder ball (Sn4wt%Ag0.5wt%Cu) of a 1156- pin PBGA (plastic ball grid array)	The standard 1156-pin PBGA package as shown in Figure 1 is made with the Sn37Pb solder balls. On the other hand the lead-free 1156-pin PBGA is	Based on 5DX tests, the effects of lead-free solder balls and solder paste of a 1156-pin PBGA package on their solderjoint x-ray inspection have been obtained. The assembly process of the PBGA with Sn4Ag0.5Cu solder balls on PCB with OSP surface finish reflowed with the Sn3Ag0.5Cu solder paste has also been provided. Furthermore, the test set-up, procedures, and methodology for determining the parameters (solder diameter and solder thickness) of 5DX tests have been presented.	3D X-RAY TESTS AND ANALYSES OF LEAD-FREE PBGA (PLASTIC BALL GRID ARRAY) PACKAGE SOLDER JOINTS J. Lau

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	package on their solderjoint x-ray inspection are investigated. Emphasis is placed on the determination of the difference (shift) of the x-ray measurement parameters (e.g., solder diameter and solder thickness) between the lead-free and tin-lead (Sn37wt%Pb) solder joints.	made with the Sn4Ag0.5Cu solder balls (Figure 1). The diameter of these solder balls is the same: 0.63+0.07/-0.13mm. The ball pitch for both cases is 1mm. The BT (bismaleimide triazene) substrate thickness for both cases is the same and is equal to 0.56+/-0.06mm. The PCB (8 layers) is made of FR-4 fiber-glass laminate materials and is: 280x200x2.4mm. The surface finish of the copper pad is OSP. The assembly process of the test boards is very robust and is with regular equipments		Agilent Technologies, Inc. Santa Clara, CA, USA john_lau@agilent.com J. Chu, Ph.D., W. Chen, R. Khaw, M. Cheng, Ph.D., and J. Lee Foxconn International, Inc. San Jose, CA, USA
130. LFS – Microstructure, PBGA	Slide Presentation	Effect of Surface Finish Effect of Multiple Reflows Materials Materials BGA Solder Composition Sn-3.8Ag-0.7Cu (SAC) Surface Finishes Cu/OSP Au/Ni(P) Au/Pd/Ni(P)	Surface finish plays a dominant role in determining the microstructure, mechanical properties, and possibly the reliability of BGA solder joints. IMC growth is faster on Cu than on Au/Ni or Au/Pd/Ni surface finish. Microhardness of solder joints is more affected by surface finish, and less affected by reflow cycle. The microstructure of BGA joints changes with reflow cycles, affected by the dissolution of surface finish layers.	Interfacial Reactions, Microstructure and Mechanical Properties of Pb--Free Solder Joints in PBGA J S. K. Kang, W. K Choi, D.-Y. Shih, P. Lauro, D. Henderson*, T. Gosselin*, D. N. Leonard** IBM Research Division oints in PBGA Laminates

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131. LFS Joints Microstructure	For these statements we've investigate the solder joint formation of different solder alloys on different PCB metal finishes after reflow soldering. As alternative lead-free solders we've examined the ternary alloy SnAg3.8Cu0.7, SnAg3.5, SnPb36Ag2 and the cupper-rich solder alloy SnAg0.2Cu1.0. As a result the differences in the texture and intermetallic zone of solder joints for all alloys and PCB finishes were detected by metallurgical cross sectioning, EDX and visual inspection.	A special test board demonstrator was used to find out some more about the reliability behavior and their influences of different lead-free alloy compositions. The demonstrator test boards for the reliability investigations were manufactured with two different metallization (*Figure 1*) as followed: - *Electroless Nickel/Immersion Gold (ENIG):* • layer thicknesses: Ni = 4-8 µm; Gold > = 0.05 µm • phosphor content in the Ni = 7-10 % - *Electroless Tin (Sn):* • Layer thicknesses: Tin (Sn) > = 0, 8 µm.	The solder alloy with SnAg3.5 and SnAg3.8Cu0.7 are technologically very well controllable for the standard pitch up to 0.4 mm and make with grain size 3 optimal printing parameters possible. From view of the reliability evaluation after accelerated thermal shock aging the results to 1000 cycles are almost similar to those from tin-lead solders. For 2000 cycles the behaviour of tin-lead seems to be a little bit better in reliability performance then SnAg3.5 and SnAg3.8Cu0.7, but the differences are very small. For application temperatures to 125°C above all SnAg3.5 and the near-eutectic SnAg3.8Cu0.7 represents an acceptable alternative to the tin lead.	INVESTIGATIONS OF THE MICROSTRUCTURE OF LEAD-FREE SOLDER JOINTS AND RELIABILITY BEHAVIOR BY THE EXAMPLE OF CHIP RESISTANCE COMPONENTS Th. Herzog, K.-J. Wolter Electronics Packaging Laboratory Dresden University of Technology D-01062 Dresden, Germany
132. LFS Joints - Microstructure	The changes are caused by differences in solderability, compatibility, material properties, higher reflow temperatures, and flux chemistries. Either alone or when coupled with optical	ACI recently performed a study to investigate many of the issues of implementing lead-free soldering. While the study focused on processing changes and issues, the results yielded information	Care must be taken when evaluating lead-free acceptability and solder joint geometry because of the variability in physical properties. Industry standards for the various alloys are not yet available. Higher reflow temperatures and different physical properties of the alloy may change the failure mechanism of the joints and surrounding areas. Additionally, investigations should include an expanded area when evaluating cross-sections.	MICROSTRUCTURE BEHAVIOR OF LEAD-FREE SOLDER JOINTS Blaine L. Partee American Competitiveness Institute (ACI)

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	and X-ray inspection methods, microsections can provide crucial information needed to make smooth transitions to lead-free solders.	about the microsectioning and evaluation of lead-free solder joints.		
133. Components – Matte tin lead finish	For a company to transition from tin lead to lead-free involves resolving a number of technical and logistics issues. This has been documented earlier for National Semiconductor	This paper will report on the solder joint reliability of matte Sn used as a finish for leaded packages. Package selection, PCB design, solder wettability, selection of reflow profiles, and effect of reflow temperature will also be discussed.	This study has shown that matte Sn components exhibit comparable board level reliability to that of SnPb. In addition, the following was concluded: NiAu boards exhibited better wetting characteristics than did OSP boards. SnAgCu paste showed equal wetting onto SnPb and Sn components. No significant difference was seen between standard and linear reflow profiles in terms of wettability of SnPb and lead-free solder pastes. The 230oC profile did not completely reflow the lead-free solder pastes, although this did not translate directly to a weakening of the solder joints.	Board Level Reliability of Components with Matte Tin Lead Finish L. Nguyen, R. Walberg, L. Zhou*, and T. Koh* National Semiconductor Corp.
134. Solder Joint Reliability Component Finish	Reliability of the solder joints made between the Pbfree Sn-Ag-Cu alloy and these component terminal finishes is essential.	In this study, we investigated the reliability of SMT solder joints made with Sn-3.8Ag-0.7Cu solder and leaded components with a variety of surface finishes: pure Sn, Sn-3Cu, and Sn alloyed with Bi in concentrations of 1, 3 and 6 weight percent.	- Growth of the Cu_3Sn + Cu_6Sn_5 layer at the interface between the copper PCB pad and the solder is slightly slower for the Pb-free joints than for conventional Sn-Pb joints, even though the initial layer thickness is slightly greater for the Pb-free joints - The strength and toughness of the Pb-free joints is greater than or equal to that of conventional Sn-Pb joints for all of the terminal finishes studied. - Such conditions are unlikely to occur in service. Thus, based on these findings, it appears that any of the Pb-free terminal finishes will produce joints with Sn-Ag-Cu solder that have room temperature strength and toughness values at least as good as conventional Sn-Pb joints, even after aging in service. - Few, if any, failures have been produced by accelerated thermal cycling using a 60-minute, –40 and +125 °C profile up to 3185 cycles.	IMPACT OF COMPONENT TERMINAL FINISH ON THE RELIABILITY OF Pb-FREE SOLDER JOINTS Gregory Henshall, Patrick Roubaud, Geary Chew Hewlett-Packard Co. SMT-CD
135. Solder Joint	Mechanical properties of Sn/Ag/Cu solder	The test vehicle contained 75 different	- The lead pull and drop test methods used in this work have yielded consistent results. It was shown that the lead coating material has a significant impact on both	CHARACTERIZATION OF MECHANICAL

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Reliability Component Finish	joints in combination with different component lead coating materials (Ni/Pd/Au, Sn/15%Pb and Sn/2%Bi, and Sn) were studied in this work using a lead pull test and a free fall drop test.	components but this study was focused on the QFP208 type of packages. The daisy-chained QFP208 packages, all having a copper leadframe, were tested with four different lead coating materials: Ni/Pd/Au, Sn/15%Pb, Sn/2%Bi and 100% matte Sn (wt-%).	the pull and drop test performance of the resulting solder joints. - Better wetting and thus larger interfacial area between the lead and solder improves the strength of the joints in both tests. In this study, the wetting of Sn/Ag/Cu solder on Sn/2%Bi and Ni/Pd/Au coated leads was shown to be better than on Sn or Sn/Pb coated ones; This may be due to the coating material as well as the surface roughness. $(Cu, Ni, Pd)_6Sn_5$ IMC layer formed between the solder and Ni/Pd/Au coated leads is stronger under the combination of tensile and shear loading used in this study than the $(Cu, Ni)_6Sn_5$ IMC layer formed between the solder and copper leads, but significantly more brittle under the drop impact loading. The difference may be caused by the intrinsic properties of this layer type but also by its lower thickness.	PERFORMANCE OF SN/AG/CU SOLDER JOINTS WITH DIFFERENT COMPONENT LEAD COATINGS Minna Arra Flextronics International SMT-CD
136. LF Component Finish	Slide Presentation	Pure tin (matte) plating is the leading candidate to replace widely used tin/lead finishes. Legislative pressures in Europe (WEEE, RoHS) are driving the lead-free conversion in response to perceived environmental and health hazards related to lead. Japanese manufacturers have also adopted a lead-free stance. Pure tin is know to cause reliability problems due to tin whiskers.	COTS components may compromise quality in high reliability applications Pure-tin plated component leads are susceptible to whisker formation Failures due to tin whiskers are a real world problem. All current mitigation strategies have limitations	Lead-Free Component Finishes Problems and Mitigation Joe Zaccari Military Programs Manager 2004 IEEE MRQW February 3 – 4, 2004
137. Solder Joint	This paper investigates flip chip reliability for	Ingots of various SnAgCu alloys were	- The liquidus temperatures of the near eutectic SnAgCu alloys increase with increasing copper concentration. From the viewpoint of bumping and assembly	THE EFFECTS OF COPPER CONTENT ON

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Reliability SnAg bumps / Cu content	near eutectic SnAgCu bump as a function of copper concentration. Both reflow experiments and DSC analysis were used to determine the maximum amount of copper that could be added to the eutectic SnAg alloy without impacting its reflow characteristics.	prepared by adding copper up to twenty percent (20%) by weight into eutectic SnAg. Samples were heated above 500ₒC for 30 minutes to assure complete alloying of all three elements. The ingots were used as the samples for reflow experimentation and DSC analysis.	reflow, near eutectic SnAgCu alloys with copper concentration up to 4wt.% could be treated as eutectic SnAgCu. - Near eutectic SnAgCu bumps have performed significantly better than eutectic SnPb bumps in HTS and HTOL tests. Up to 24 and 7 fold improvement in reliability have been observed in HTS and HTOL tests respectively.	THE RELIABILITY OF Sn-Ag BASED BUMP ALLOYS IN FLIP CHIP APPLICATIONS Shing Yeh Delphi Delco Electronics Systems SMT-CD
138.LFS Alloy NEMI	Magazine Article Circuits Assembly	Recommendation of an industry standard leadfree alloy: Sn3.9Ag0.6Cu(±0.2%) for reflow and Sn0.7Cu for wave solder	The NEMI Phase I reliability testing showed conclusively that the reliability of solder joints made with the NEMI alloy was equal to or better than tin-lead eutectic for a wide range of components.	NEMI's Lead-Free Alloy Circuits Assembly APRIL 2004 Alan Rae and Carol Handwerker
139.LFS Reliability, Joint – Equation - Model	A set of accclcration niodels for lead-frec solder joints is proposed and discussed in this shidy. Useful equations for the acceleration models, life distribution. and failure m e are also provided. Furthennorc, methods for selecting the acceleration factor are discussed.	In this study, creep responses of the 95.5wtYoSn-3.9\vt%Ag-0.6\vt%Cu lead-free solder joints on a 256-pin PBGA (plastic ball~grid array) assembly subjected to three different temperature profiles: AT = *50:* 100; and 150°C will be determined.	For the PBGA assembly, the maximum stress and creep strain occur near the upper corner of both the lead-free and SnPb solder joints. For the PBGA assembly the <u>stresses in the lead-free solder joint are larger</u> than those in the SnPb solder joints. This is because the <u>stiffness of the lead-free solder is larger</u> than that of the SnPb solder. For the PBGA assembly, <u>the creep strains in the lead- free solder joint are smaller</u> than those in the SnPb solder joints. This is because the creep strain rate of the lead-free solder is smaller than that of the SnPb solder. For the PBGA assembly, the thermal-fatigue life of the lead-free solder joints should be longer than that of the SnPb solder joints. <u>Since the maximum creep strain energy per cycle in the lead-free solder is smaller than that in the SnPb solder joints.</u>	Acceleration Models, Constitutive Equations, and Reliability of Lead-Free Solders and Joints John Lau', Walter Dauksliei, and P;iul Vianco' ' Agilcnt Technologies. Inc.. *530* I Stevens Creek Boulevard
140.Solder	This paper deals with a	The comparison is	- Comparing the induced inelastic strains, the leadfree SnAgCu generally scores better	Thermal cycling reliability

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Joint Reliability Modeling	comparison study between SnPb and SnAgCu solder joint reliability.	based on non-linear finite element modellin. Three packages have been selected: silicon CSP, underfilled flip chip and QFN package.	thanks to the lower creep strain rate. On the other hand for the CSP and flip chip package, SnAgCu scores worse for the more extreme loading conditions when the inelastic dissipated energy density is selected as damage parameter. The main reason is that due to the lower creep strain rate, the stresses become higher for SnAgCu resulting in higher hysteresis loops with more dissipated energy per cycle.	of SnAgCu and SnPb solder joints: a comparison for several IC-packages Bart Vandevelde, Mario Gonzalez, Paresh Limaye, Petar Ratchev and Eric Beyne IMEC
141. SAC Solder Joints Prediction Models	This paper describes in detail the life prediction models for SnAgCu solder joints. The models are based on published	This model has been validated with more than 75 data points and predicts life within 25% in most cases. This proven approach is used here again to develop the life prediction model for SnAgCu solder joints	Better prediction accuracy achieved by using double power law constitutive equation Either accumulated creep strain or energy density can be used for life prediction Creep strain provides better prediction accuracy Energy density captures high stress effects better	Accumulated Creep Strain and Energy Density Based Thermal Fatigue Life Prediction Models for SnAgCu Solder Joints Ahmer Syed Amkor Technology, Inc.
142. SAC Solder Joints Fatigue Life Models	This paper describes in detail the life-prediction models of SnPh(Ag) and SnAgCu solder joints for thermal cycle conditions.	This work deals with the effect of different solder interconnect alloys (Sn59Pb40Agl and Sn95.5Ag3.8Cu0.7) and the effect of different package types (PBGAs, CSPs, Flip Chip on FR-4 with and without underfill) on the fatigue life. Different temperature cycling conditions are applied.	- However, the results suggest that for the same strain level at higher strains, SnAgCu performs better, whereas for the same strain level at lower strains, SnPb(Ag) performs better. - These differences as well as the different creep behaviors of the two solders cause the experimentally observed trend of an improved fatigue life of SnPb solder joints for relatively stiff components and high thermal mismatch induced loads, compared to a better performance of SnAgCu solder for relatively compliant structures and low thermal mismatch induced loads.	Fatigue Life Models for SnAgCu and SnPb Solder Joints Evaluated by Experiments and Simulation A. Schubertt, R. Dudek, E. Auerswald, A. Gollhardt, B. Michel, H. Reicbl Fraunhofer Institute for Reliability and Microintegration, Berlin,

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143. SAC Solder Joints Thermal Fatigue Modeling	Thermal fatigue of solder joints is investigated by means of finite element method (FEM)	Secondary creep laws are given for both SnPb and SnAgCu solders, based on own measurements and literature data. The secondary creep behaviors defined in that way are compared to other date recently published	It was observed that the differences in the creep rate affect the calculation results, i.e. cyclic equivalent creep strain and creep strain energy density, for the PBGA much more than for the ceramic chip resistor. This effect is attributed to the displacement controlled character of solder deformation for chip resistor	Thermal Fatigue Modelling for SnAgCu and SnPb Solder Joints Dudek, Walter, Doering Fraunhofer Institute Reliability and Microintergration
144. Sn-Rich solder joints - creep	Sn-rich solders that have become candidates for use in Ph-free solder joints have anomalous creep hehavior when tested in the form of solder joints. 'Their steady-state creep rates separate into two regimes with different stress exponents (n) . The lowstress exponents range from -3-6, while the higli-stress exponents are 7-12, unusually hieh values.	Creep tests were done on nine-pad single shear creep specimen? with the geometry shown in Fig. I . The substrate pad s i x is about 1.22" x 2.24". The pad metallization on one side was Cu while that on the other side was about 4 pm electroless Ni coated with about 0.13 pui immersion Au. The solder joint thickness was fixed at 160 pm. The shear specimens were reflowed in nitrogen with a peak temperature of 2 3 5 T for Sn-3.5Ag and Sn-3Ag-0.5Cu and 2 4 5 T for Sn- 0.7Cu. Samples were cooled at the rate of 2.7"C/sec, followed	The stress exponent at high stress changes significantly with temperature as temperature drops below about IOO"C, and reaches anomalously high values (n = 10-11) at lower temperatures. These anomalous features suppest thal qualification and design verification tests for Sn-rich solder joints should use geometries and conditions as near as possible to those anticipated in service, until further research clarifies how this complex creep behavior can be understood metallurgically and treated analytically.	Creep Properties of Sn-rich Solder Joints J.W. Morns, Jr.', H.G. Song' and Fay Hua' 'Departnient of Materials Science and Engineering, University of California, Berkeley, CA 94720

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		by aging at 160°C for 4 hours.		
145. LFS – Creep Model	This paper presents the application of physically-based, obstacle-controlled creep models to the analysis of steady-state creep rates for eutectic SnPb and seven leadfree solders:	Using the two-cell creep models, creep contour charts were generated to quantify the contribution of competing creep mechanisms to the total creep rates. The patterns of creep contour lines are quite different for Sn37Pb and Sn3.8Ag0.7Cu, a reflection of vastly different creep mechanisms.	Creep contour charts for Sn37Pb and Sn3.8Ag0.7Cu display vastly different patterns. The creep contour chart for Sn3.8Ag0.7Cu suggest a transition temperature for competing creep mechanisms at about 75°C, in agreement with the microstructural analysis of Vianco et al. (2004) on Sn3.9Ag0.6Cu compression creep specimens.	AN OBSTACLE-CONTROLLED CREEP MODEL FOR SN-PB AND SN-BASED LEAD-FREE SOLDERS Appeared in Proceedings, SMTA International Conference (SMTAI ’04), Sept. 26-30, 2004, Chicago, IL. Jean-Paul Clech EPSI Inc.
146. LFS Thermo-Mechanical Reliability	Chp Resistor 1206 = The solder alloys Sn99Cu1, Sn96.5Ag3.5, Sn96.OAg3 .Cu0.5 were Sn62Pb36Ag2. Chip resistors 1206 were used **as** an example for an SMD component.	Reliability assessment of lead-free solder interconnects through experiments and FE calculations is discussed in the paper, shown on examples like SMD-components and Flip-Chips.	Joint reliability data shows that although the joint reliability can be increased by the use of SnAgCu or SnAg alloys, the degree of improvement is package dependent (Figure 2). The reliability improvement should be better for a more compliant package-board assembly (e.g. PBGA). For package types with high CTE mismatch with the board (e.g. LCCC assembled on FR-4) the solder joint reliability may decrease by using lead-free solders like Sn-Ag-Cu or Sn-Ag	Thermo-mechanical Reliability of Lead-free Solder Interconnects A. Schubert, R. Dudek, R. Doring, H. Walter, E. Auerswald, A. Gollhardt, B. Michel Fraunhofer Institute for Reliability and Microintegration, Berlin, Germany
147. Solder Joint Reliability uBGA Packages	Review of alternative solder alloy compositions, furnish recommendations for solder process	Thermal cycle testing - 40C to 125C: Sn96.3Ag3.2Cu.5 & Sn96.5Ag3.5 solder balls; Sn96.5Ag3.5	- Lead-free solders tested performed as well as the SnPb - The reflow profile for the Pb-free had to be adjusted for proper reflow	Lead-free Soldering for the Attachment of uBGA Packages Tessera Inc.

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	development and review environmental testing requirements comparing eutectic solder to Pb-free solder on a 46 I/O uBGA	solder paste		
148. Solder Joint Reliability (Electroplated SnAg Bumps)	Investigate the degradation mechanisms of commercially available lead-free SnAg bumps using various stress conditions to evaluate their reliability and qualify them for flip chip packaging	The focus lies on the first-level solder bumps, which can be regarded as the final front-end process step when manufacturing a flip hip product. Tests: Therm cycle, HAST, high-temp storage, re-melting, electric current	Electroplated SnAg bumps are a viable solution for lead-free first level flip chip interconnections. Reliability and quality are equal and in some respects superior to traditional eutectic SnPb bumps.	Reliability of Electroplated Lead-Free SnAg Bumps for Flip Chip Applications Bernd Ebersberger, Robert Bauer, Lars Alexa Infineon Technologies
149. LFS Joint Fragility	Recent investigations have revealed that Pb-free solder joints may be fragile, prone to premature interfacial failure particularly under shock loading, as initially formed or tend to become so under moderate thermal aging. Depending on the solder pad surface finish, different mechanisms are clearly involved, but none of the commonly used surface finishes appear to be consistently immune to embrittlement	Recent reports of rapid mechanical weakening of Sn-Ag-Cu solder joints on Cu pads in thermal aging have caused considerable stir in the microelectronics packaging community [4], [5]. The effect appeared to be caused by the growth of Kirkendall voids along the Cu3Sn/Cu interface (*Figure 1*). Extensive voiding was observed after only moderate aging (20-40 days at 100oC)	However, usually soldering of Sn-Ag-Cu to Ni pads leads to the build-up of a (Cu, Ni)6Sn5 layer on top of the Ni3Sn4. Some such structures have been found to be brittle immediately after Sn-Ag-Cu solder alloy assembly, and aging of a Ni3Sn4/(Cu, Ni)6Sn5 structure, albeit in Sn-Pb joints, has been seen to lead to strong voiding and porosity in some instances. Too often, extensive Kirkendall voiding may weaken Sn-Ag-Cu solder joints on Cu pads after only moderate aging, and a seemingly independent embrittlement mechanism was found to occur even without aging although it does still tend to worsen with aging.	Fragility of Pb-free Solder Joints Universal Instruments Corporation

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	processes.			
150. LF BGA Voiding	This paper investigates the impact of the reflow profile on the quality of the lead-free surface mount solder joint. In particular, the impact of the reflow profile on solder joint voiding for lead-free assemblies is analyzed. The critical reflow profile parameters that are responsible for voiding such as preheat temperature, ramp-up rate, and peak temperature were varied within the allowable process limits to verify if the voiding could be minimized.	The main focus of this project is to determine the impact of the reflow profile on solder joint voiding for lead-free assemblies. The goal is to accomplish this by assembling BGAs using reflow profiles with varying preheat temperatures, ramp up rates, and peak temperatures. The analysis would involve x-ray examination to observe the formation of solder voids. Based on the data generated from the x-ray analysis, the effect of these reflow parameters on the formation of voids can be established.	Based on current IPC 7095 guidelines for solder joint voiding, all the varying reflow parameters will meet the 10% criteria stated. Any of the profiles used for this experiment will work well in a production environment for a lead-free process when assembling the above mentioned BGAs. Although there were differences in the results all were below 10% total voiding. The reflow parameters that were observed to be optimal were a medium preheat temperature, a ramp rate of 0.65°C/sec, and a peak temperature of 240°C.	EFFECT OF THE REFLOW PROFILE ON BGA VOIDING IN A LEAD-FREE PROCESS Felix Bruno and Frank Grano Sanmina-SCI Technology Development Center Huntsville, AL, USA K. Srihari, Ph.D. EMRS, SSIE Department, State University of New York at Binghamton Binghamton, NY, USA
151. LF Pad Finish - Voids	This paper will evaluate reasons for the increase in voiding, explore the different PCB pad finishes in use for lead-free and the amount of voiding produced by a controlled soldering process using these surface finishes. With the use of advanced	This paper brings together results from the SMART Group Hands-on Lead-Free Experience 2003 (1), where circuit boards with differing pad finishes were assembled over two days using exactly the same materials, components	By automatically inspecting BGAs on differently finished boards within a digital x-ray inspection system, the total void percentage per ball and the single largest void were calculated. The results highlighted variances in the quantity of voiding depending on which board finish was used. Based on this data, it has been suggested that immersion, tin, immersion silver and lead-free HASL finishes might wish to be considered as preferential for use with lead-free assembly.	DOES PCB PAD FINISH AFFECT VOIDING LEVELS IN LEAD-FREE ASSEMBLIES? David Bernard Dage Precision Industries Fremont, CA, USA d.bernard@dage-group.com Keith Bryant Dage Precision Industries

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	technology including automated digital x-ray measurements, the total amount of voiding, void size and location will be measured and compared.	and conditions. The boards were then reflowed by either standard convection reflow or by vapour phase. For this report, the results using convection reflow only have been included. The results from the vapour phase can be found in reference 1.		Aylesbury, Buckinghamshire, United Kingdom k.bryant@dage-group.com
152. LFS Microvia Voiding	For SnAgCu solders, the voiding rate at microvia was studied with the use of simulated microvia, and was the lowest with 95.5Sn3.8Ag0.7Cu and 95.5Sn3.5Ag1Cu, and increased with further decrease in Ag content. Results indicated that voiding at microvia was governed by via filling and exclusion of fluxes. The voiding rate decreased with decreasing surface tension and increasing wetting force which in turn was dictated by the solder wetting or spreading.	In order to increase the sample size for microvia voiding study, a test was designed so that a large number of microvias were arranged as an area array in a test coupon which was subsequently covered with a thick layer of solder paste. Upon reflow, the solder paste melted and formed a thick layer of molten solder simulating the BGA or CSP solder height. This thick molten solder layer would allow the formation of large voids as those observed in BGA or CSP, as	For SnAgCu solders, the voiding rate at microvia was studied with the use of simulated microvia, and was the lowest with 95.5Sn3.8Ag0.7Cu and 95.5Sn3.5Ag1Cu, and increased with further decrease in Ag content. Results indicated that voiding at microvia was governed by via filling and exclusion of fluxes. The voiding rate decreased with decreasing surface tension and increasing wetting force which in turn was dictated by the solder wetting or spreading. Both low surface tension and high solder wetting prevented the flux from being entrapped within microvia.	EFFECT OF LEAD-FREE SOLDER COMPOSITION ON VOIDING AT MICROVIA Arnab Dasgupta, Ph.D., Benlih Huang, Ph.D., and Ning-Cheng Lee, Ph.D. Indium Corporation of America Clinton, NY, USA askus@indium.com

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		reported in a previous study [11,12].		
153. LFS Voiding Micro via	Microvia technology is a critical element in high density interconnect development. It allows realization of low cost, high density, high speed and miniaturization for electronic devices.	In this study, potential factors such as printing process, solder particle size, metal content, solderability of pads, reflow profile, and flux chemistry which may affect voiding in microvia of lead-free solder joints were investigated. The results and voiding mechanism will be discussed below with optimized conditions recommended. The alloy used is 95.5Sn-3.8Ag-0.7Cu.	- Lead-free soldering does not introduce new voiding mechanism. - Voiding was found to decrease with increasing number of print, increasing flux activity, decreasing solder powder size, decreasing metal content, decreasing peak temperature, and use of linear ramp profile instead of profile with a soaking zone.	VOIDING OF LEAD-FREE SOLDERING AT MICROVIA Dr. Hyoryoon Jo, Benjamin E. Nieman, and Dr. Ning-Cheng Lee Indium Corporation of America SMT-CD
154. LFS - Characterization	In this paper, a chip scale package (CSP) is used to investigate the characteristics of the tin-silver solder alloy. Two surface finishes are implemented on the printed circuit boards (PCBs) to compare the solderability of the altemat. (e	Two lead-free surface finishes were considered for comparing the solderability of the Sn3.5Ag and Sn37Pb solder alloys. The gold over nickel (Ni/Au) and the organic solderability preservative (OSP) surface finishing methods were applied on the four- layer FR-4 test boards. The	The mechanical properties of the tin-silver solder (alloy and the tin-lead solder alloy were investigated by the solderability condition of the alloy with two :surface finishes of the prinkd circuit boards. The results of the three-point bending and component pull tests demonstrated the excellent performance of both solder alloys. It was observed that in these tests the PCB failure occurred prior to the failure of the solder joints. There was no significant difference between the lead-free and leaded solder alloys mounted with the different surface finishes. ‘The variable frequency vibration test found that all test samples passed the requirement of the MIL- ISTD showing that the test samples could be iicceptable for the future use.	Characterization of Lead-free Solder by Reliability Testing R Tzan and 'S-L Chu 'Metallic Devices for Electronics Lab. finspection Automation Technology Lab. Materials Research Labs., ITRI

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	materials. Several testing methods are performed to examine the properties and failure modes of tin-silver solder and t:in-lead solder alloys.	variable frequency vibration test, three-point , and component pull test, and thermal cycle test were performed for each of the four materials combination (Table 1) of the CSP.		
155. LFS Characterization – Mech - Therm	Near-ternary eutectic Sn-Ag-Cu (SAC) alloys are leading candidates for Pb-free solders. The electronics industry has begun to study both the processing behaviors and the thermomechanical fatigue properties of these alloys in detail in order to understand their applicability in the context of current electronic card reliability requirements [1]. These alloys have three solid phases: β-Sn, Ag3Sn and Cu6Sn5	In order to evaluate the effect of cooling rate on the material properties of the SAC alloys, a tri-plate mold was constructed The effect of cooling rate on the physical properties of the SAC alloys was evaluated by testing tensile dogbone samples at cooling rates of 0.008, 0.019 and 16.72°C/sec. Strain rate dependence was also evaluated by pulling samples at 0.1, 1.0 and 10.0 in/min. Depicted in Figures 4-6 are the results of the mechanical property testing as a function of both strain rate and cooling rate for the SAC 305 and 405 alloys.	The test data indicates that strain rate dependence is much more pronounced than the cooling rate for the three cooling rates studied. As the strain rate is increased, the elastic modulus decreases quite rapidly initially then levels off. This trend was observed for both alloys and for all cooling rates. Shown in Figure 6 is the effect of cooling rate at a single strain rate for the SAC solders. The comparatively small change in mechanical properties seems to substantiate the low effect of cooling rate on elastic modulus.	MECHANICAL AND THERMAL CHARACTERIZATION OF LEAD FREE SOLDER Arv Sinha and Joe Kuczynski IBM Server Group Development Rochester, MN, USA sinha@us.ibm.com

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156. LF Manufacturing	Develop a baseline Lead-free manufacturing process for medium to high-end computer products	Assembly, Rework and Reliability	. lead-free rework could be developed successfully on 93mil and 135mil thick boards . Increasing bottom side board preheat was found effective in reducing delta T between solder joint and component body . Component Body Temperatures indicated in J-STD-020B were being conformed to for the three cases shown in Phase 3 . Margin of error to maintain a lead-free minimum solder joint temperature of 230-235°C with maximum body temperature of 245°C-250°C is very . Adjacent component temperatures were being exceeded at 150mils on the board in many cases. . A particular issue was noticed after uBGA rework for an adjacent CBGA: partial double reflow. . Payette boards in Phase 3 have been reworked and will be in ATC reliability testing shortly	Jasbir Bath, Solectron ftp://nemi.org/webdownload/newsroom/Presentations/Lead-free%20Rework030504.pdf
157. PWD Manufacturers Insight - CORETEC	Slide Presentation	PWD Manufactures	In general, composition deviating from the ternary eutectic SnAgCu in Ag content, particularly with a Ag content lower than 3.5Ag, exhibits a greater solid fraction at onset of melting thus results in a lower tombstoning rate, presumably due to a slower wetting speed. On the other hand, composition deviating from the ternary eutectic SnAgCu also exhibits a lower surface tension which results in an easier solder spread or solder wetting, and consequently results in a higher tombstoning rate and a lower voiding. Voids Found with ALL lead-free solders Occur at the interface between solder and pad SAC305 gives lowest voiding Need to avoid cross-contamination of solders > 0.5% Pb will cause reliability issues	How far, how fast? Lead Free 2004 CORETEC
158. Manufacturing	develop and verify a baseline rework process for large and thick lead-free PCAs which are characterized by components with a wide range of thermal masses on large high thermal masse	baseline lead-free manufacturing process using the NEMI tin-Silver-Copper (Sn3.9Ag0.6Cu) alloy for medium to high-end computer products.	The initial lead-free SMT process gave acceptable yields but more development needs to be done for the wave solder process. During the rework development it was found that increasing the bottom side board preheat was helpful in keeping the temperature gradients under control during the rework operations. The many challenges that face lead-free rework include process tool thermal stability and operational capability. Much learning is still required to improve the manufacturability and	Patrick Roubaud1, Jerry Gleason2, Charlie Reynolds3, Ken Lyjak4, Matt Kelly5, Jasbir Bath6 1Hewlett Packard, Grenoble, France 2Hewlett Packard, Palo Alto, California USA 3IBM, East-Fishkill, New York USA

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	cards.		reduce the cost associated with inspection and yield loss.	4IBM, Research Triangle Park, North Carolina USA 5Celestica Inc., Toronto, Canada 6Solectron , Milpitas, California USA ftp://nemi.org/webdownload/newsroom/Presentations/Amsterdam04_rework.pdf
159. LF impacts production	This paper will outline the issues relating to the implementation of a Pb-free solder paste into a standard Sn/Pb manufacturing facility and product. The Pb-free study includes the compatibility and impact on the various manufacturing processes that include, printing, component placement, reflow process, and solder joint quality.	Bare board wetting Component wetting Determining the Product Readiness Production Evaluation and Implementation	A robust Pb-free solder paste must be first qualified for the Pb-free process. The solder paste must have a large process window and capable of uniform performance over a wide range of temperatures, preferably lower temperatures, but also at mid and high temperatures. The components must be carefully chosen and qualified to perform at the higher process temperatures. The PCB finishes and component terminations should be considered prior to initial product assembly and also the possible compatibility issues. The product design must be well thought out and evaluated for a Pb-free process. Modifications may be required to the standard pad geometries to optimize the Pb-free soldering process.	Changing to Pb-free Profoundly Impacts the Manufacturing Production Process Richard Brooks & David Day Indium Corporation of America Vahid Goudarzi
160. LFS Processing	This paper presents the findings of specific investigations of lead free solder alloy processing, solder pastes for reflow soldering as well as solder bathes for flow soldering.	The wetting balance analysis is an usual method for evaluation the ability of processing. Whereas solder bath and globule method with 230-240°C is qualified for standard lead containing solders,	This parameter indicates also effects of specific heat, viscosity, phase transition and evaporating flux solvents. Investigation of current true solder pastes shows, that there are no well and poor wetting lead free alloys, there are only well or poor soldering conditions. The definition of testing method has to correspond with this intention.	INVESTIGATION OF LEAD FREE SOLDER PROCESSING Mathias Nowottnick, Uwe Pape, Klaus Wittke, Wolfgang Scheel Fraunhofer IZM SMT-CD

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		lead free alloys require differing conditions [1]. For testing of great quantities of different alloys the use of solder globules is much easier than solder bathes		
161. Soderability NEMI lead-free rework group investigated and developed lead-free rework processes	development of the rework profile, then test for medium to high-end computer products. The work concentrated on development of lead-free hot air convection rework	Tested PBGA 5444, uBGA256, CBGA 933 and TSOP and 2512 chip 93, 135 mil boards	The increase in rework profile time, from 7 SnPb to 11 minutes of time for SnAgCu,was due to the higher times to reach the rework peak temperature for SnAgCu rework due to its higher melting point and the need to reach a higher topside board preheat temperature with the bottomside heater before engaging the topside nozzle.	Jasbir Bath and Mike Wageman, Solectron Corporation; Quyen Chu and Nabel Ghalib, Jabil Circuits; Alan Donaldson, Intel Corp.; Jose Matias and Eddie Hernandez, Hewlett-Packard Corp. ftp://nemi.org/webdownload/newsroom/ Presentations/SMTAI-04_rework.pdf
162. LF Paste in Nitrogen	The purpose of this study is to evaluate the possible influence of an inerting atmosphere on the residues formation during the reflow process. Five lead-free solder pastes have been selected with various activity levels. Wetting forces and time measurements have been determined with the method developed	The tests were performed with 7 lead-free “no clean” solder pastes that were chosen according to their emergence as the best candidates for reflow applications, the alloys contents of the 7 pastes being close to Sn96,5Ag3Cu0,5. Those pastes have also been selected in order to get a wide range of	First of all, the results presented here confirm the hypothesis that better wetting of highly activated pastes under air, leads to higher residue deposition levels. Thus, on a representative sample of 5 solder pastes, a correlation has been done between wetting performances under air and electromigration phenomena due to contaminants remaining on the board. As a consequence, even if some specific behaviours can not be fully explained and require further investigations, the main trend is that highly activated pastes use leads to the deposition of harmful residues. The effect of these residues on assemblies reliability is also clearly shown thanks to contaminants tests. Moreover, the study reveals that wetting process is clearly improved and better controlled with an inert atmosphere.	Influence of N2 Atmosphere on the Contamination Effects of Lead-free Solder Paste During Reflow Soldering Processes Helene Daniel, Marc Leturmy, Sylvie Lazure, and Thomas Vukelic Air Liquide CRCD Jouy-en-Josas, France Daniel Muller IFTEC Bourg La Reine, France

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	by Air Liquide in 2002 and based on the Malcom SP2 device. This specific and high performance equipment allows simulating the temperature profile of a reflow process and has been adapted to work under controlled atmospheres. This test is then very representative of reflow soldering processes.	wetting behaviours and a representative sample of solder suppliers, named A,B,C, etc. In the whole study, pastes are represented by letters A, B, C, pastes B+ and C+ said by the supplier as being more activated than respectively pastes B and C. The soldering profiles chosen were recommended by solder suppliers. The main characteristics of these pastes can be seen in Figure 3.		Presented in the ECWC 10 Conference at IPC Printed Circuits Expo®, SMEMA Council APEX® and Designers Summit 05
163. LFS Soldering In Nitrogen	But quantitative data regarding the soldering behavior of lead-free solders under various atmospheres are sparse.	In order to investigate the effect of nitrogen inerting on wettability, the solderability of copper wire (1 mm diameter) using various lead-free solder alloys, was measured using a Multicore Must II wetting balance instrument. The wire was cleaned prior to testing using the following sequence:	- Nitrogen inerting can largely compensate for the poor solderability experienced when using lead-free solders. - When using SnAgCu, SnCu and SnAgBi solder alloys good wetting times can be achieved with nitrogen inerting at higher oxygen levels for superheats above 40◦C. In wettability tests, levels of 5,000 ppm oxygen were sufficient.	EVALUATION OF THE COMPARATIVE SOLDERABILITY OF LEAD-FREE SOLDERS IN NITROGEN – PART II Christopher Hunt & Deborah Lea National Physical Laboratory SMT-CD
164. LF Soldering -	Magazine Article	This superheat is part of the process window for reflow, taking into	Clearly, nitrogen inerting can reduce the superheat required by at least 20°C. components become lead-free.5 It is also known that SAC reflow soldering increases the tendency to form voids The	Nitrogen's Effect on Pb-free Soldering Paul Stratton

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Nitrogen		account different heating rates at different joint locations on a particular board. Similarly, the pot superheat current for wave soldering with eutectic SnPb is even higher, around 40° to 50°C. However, when lead-free solders are used, reflow temperatures above 260°C are implied for the same superheat	use of nitrogen inerting reduces this effect considerably, probably by protecting the flux at the higher reflow temperature and permitting it to reduce the oxides in the short time available above the liquidus	**Circuits Assembly** FEBRUARY 2005
165. LFS Reflow Process Nitrogen Effect	In this study, the effect on solder spreading by changing the reflow time, or the time above solder liquidus temperature, was investigated.	Spread tests were conducted for three commercially available solder pastes of no-clean type with an alloy content close to Sn95.8Ag3.5Cu0.7 from three different solder suppliers. An oxygen control system [6] that	- Using a nitrogen atmosphere instead of an air atmosphere when soldering will improve the wetting performance of the solder. - All solders tested showed improved wetting when processed in nitrogen, regardless of the maximum solder temperature. - Voids observed in the BGA225 seemed bigger when soldered in air. Also, the shape of the joints tended to be more irregular after air soldering.	THE EFFECT OF NITROGEN REFLOW SOLDERING IN A LEAD-FREE PROCESS Anders Åström Linde Gas Division SMT-CD
166. LFS Pastes and Reflow	Recently, we conducted a study to qualitatively evaluate several new no-lead solder pastes and reflow techniques. This study built upon	This new study was intended to evaluate the latest no-lead formulations and fluxes as well as improved profile shapes and pad	The SnAgBi alloy from Vendor A was found to have very few voids with bare copper pads (Figure 6) and somewhat higher void occurrence with tin plated pads (Figure 7). Similar results were found with Vendor A's SnAgCu alloy (Figures 8 and 9). However, a considerable difference existed concerning the voids found with Vendor B's SnAgCu alloy	New No-Lead Solder Pastes and Reflow Techniques Jim Raby and David Heller Circuits Assembly MARCH 2002

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	experience we gained from previous studies of no-lead solders and our evolving industry experience.	metallizations. The goal was to reduce the occurrence of unacceptable solder voids. tin/silver/bismuth (SnAg-Bi) and tin/silver/copper (SnAgCu).		
167. LF Reflow – Surface Mount	The LF reflow process is described in greater detail, along with the low and high temperature constraints on processing window. The lowest peak temperature and time above liquidus (TAL) are experimentally determined using designed experiments. Limits are identified for these variables, which in turn define the processing window. The resulting profile is then compared against a traditional eutectic profile, to determine the impact of beat rate and delta temperature, followed by a discussion on power cost adder due to the higher reflow temperature associated	In this paper, the reflow peak temperature and TAL variables will be discussed in greater detail. The limits for peak temperature and TAL are experimentally determined, to develop the process window. The LF reflow profile thus developed is compared against the eutectic Sn/Pb profile to determine impact of beat rate, temperature differential and power cost adder. All boards were assembled using organic solderability preservative (OSP) surface finish using Air for reflow atmosphere. Yield was 100% on all legs. The package of interest was a 1.27mm pitch Ball Grid Array	The LF reflow process has been briefly described, along with some of the challenges associated with it. The lower and upper peak reflow temperatures and time-above-liquidus (TAL) values have been experimentally determined. The experimental results showed that 228C is the minimum required peak reflow temperature with a TAL value of 40seconds. The upper limit of reflow peak temperature is set at 245/250C in accordance with the J-STD 020B specification with a maximum TAL value of 120 seconds. Board delamination occurs at peak temperatures of 260C and TAL >120 seconds, during 2x and 3x reflow cycles. The reflow process window thus covers a peak temperature range between 228- 245/250C. The associated TAL values range between 40 - 120 seconds.	SURFACE MOUNT CHALLENGES WITH LEAD-FREE REFLOW Prawin Paulraj and Norman J Armendariz Intel Corporation Hillsboro, OR, USA

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	with LF processing.	(BGA) component, with 0.75mm solder balls. The size of the component was 37.5mm square. Components were cross-sectioned to measure joint height and perform SEM and microhardness analysis [1].		
168. LF Alternatives - Reflow	Compatibility of those alloys with a variety of representative flux chemistries is considered essential, and is determined for performance in handlingability, including shelf life and tack time, and soldering capability, including solder balling, wetting, and solder joint appearance.	The compatibility between flux and alloy often dictates the performance of reflow soldering, such as solder balling, wetting, processing window, and stability. Since the flux chemistry varies from supplier to supplier, and since the use of more than one suppliers is considered crucial for assuring a steady process, an alloy being compatible with a wider range of flux systems obviously will have a greater prospect to be accepted by SMT industry.	Results indicate that the control 63Sn37Pb is still the most compatible alloy, Compatibility of those alloys with a variety of representative flux chemistries is considered essential, and is determined for performance in handling-ability, including shelf life and tack time, and soldering capability, including solder balling, wetting, and solder joint appearance. Results indicate that the control 63Sn37Pb is still the most compatible alloy, rated 27.1 in compatibility out of a full scale 30 when using warm profile. The primary factor which distinguishes 63Sn37Pb from the rest alloys is the soldering performance, particularly the wetting and solder appearance.	Prospect of Lead Free Alternatives for Reflow Soldering Dr. Benlih Huang and Dr. Ning-Cheng Lee Indium Corporation of America
169. Wave Process	Develop both reflow and wave soldering	In the three years of the project, the candidate	Lead-free soldering technology based on SnAgCu(Sb) and SnBiSbAg alloys is technically and industrially viable.	Synthesis Report for Publication - Project No.

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Development Reflow Process Development Rework and Repair Reliability of Reflow/Wave boards	processes using lead-free solders with low-no VOC fluxes. Devise repair and rework procedures with lead-free flux-cored wire Establish properties of lead-free solders compared with tin-lead eutectic in respect of their mechanical and thermo-mechanical performance.	solders and their matched fluxing systems, board finished and component metallisations were selected and tested in extensive assembly trials. The chosen solders were; SnAg3.8Cu0.7 (96SC / Ecosol TSC / SAC) eutectic alloy for reflow soldering SnAg3.8Cu0.7Sb0.25 (SACS) for general purpose wave soldering use SNBi5.0Sb2.0Ag1+ (SBA+) for single-sided wave assembly	Process window for lead-free wave soldering is within the established region for tin-lead soldering. In wave soldering, fillet lifting in through-hole assembly can be minimized by the use of hyper-eutectic SnAgCuSb alloy. Process window for lead-free reflow soldering is compatible with the majority of current component demands, but may require some components to be re-specified. Reliability of lead-free assemblies is seen to be functionally equivalent to tin-lead in terms of cycles to failure in thermo-mechanical fatigue tests. Tolerance to a wide range of standard board and component finishes has been demonstrated.	BE-95-1994 - Improved Designe Life and Environmentally Aware Manufacturing of Electronics Assemblies by Lead-Free Soldering: "IDEALS". (1996-1999) Marconi Materials Technology (UK) - (James H Vincent, Martin Harrison)
170. SAC used in Repair	Much work has been done involving the introduction of RoHS and WEEE Directives across the European Union and the world. Although the use of Pb is limited in new products and equipment, older Pb-containing materials can continue to be used for repair of existing systems. As time progresses, these older Pb-containing materials	We are presently working with our Repair Facilities to make sure they will be ready to use Pb-free solders well in advance of the RoHS deadline. We foresee a day in which most assembly houses will only work with non-Pb solders, and the easily available components will also be Pb-free. Ultimately there will be little or no	The lead coating now used, and those proposed will wet well enough with SAC solders to pose no wetability problems. The pull strength of the solder bonds is comparable for both solder types. High temperature operation will age either type of solder bond, increasing the intermetallic thickness and reducing the pull strength of the bond. It is possible that the use of a nickel plate under the matte tin finish may slow the degradation of the pull strength. All Lead Coatings Tested Work with SAC Solder •Pull Strength is not Different •High Temperature Degrades Both Types of Solder Connections •No Problems Using SAC Solder and Pb-Free Components to Repair Assemblies	The Use of SAC Solder and Pb-Free Lead Materials in the Repair Scenario Mark Woolley and Jae Choi Avaya, Inc. Westminster, CO Presented in the ECWC 10 Conference at IPC Printed Circuits Expo®, SMEMA Council APEX® and Designers Summit 05

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	will need to be repaired using Pbfree components and solders. This paper addresses the concerns of repair centers, which must rework these boards using Pbfree components and materials.	added Pb in the assembly at all. During the transition, there will be a time in which both Pb-bearing components and Pb-free components will coexist in the manufacturing facility. Manufacturing facilities will be switching from SnPb to SAC solders. It is possible that all combinations of component lead finishes and solders will be able to be found for a short period of time.		
171. Component Reliability	Slide Presentation	LFS PCB Assembly	-Many components need to be re-designed and re-qualified for the higher solder reflow temperatures	Techwatch seminar “PCB assemblage” Bart Vandevelde IMEC
172. PCB Reliability	Slide Presentation	LFS PCB Assembly	The PCB has to withstand higher soldering temperatures; expected problems: micro-via cracking due to thermal expansion mismatch (for sequential build up boards)	Techwatch seminar “PCB assemblage” Bart Vandevelde IMEC
173. LFS DOE - Defluxing	Lead-free alloys under consideration have physical properties, which may directly impact industry standard electronic assembly cleaning	The designed experiment evaluated commercially available lead-free solder paste products and industry standard cleaning materials. The cleaning	Data supports the hypothesis that cleaning is more difficult for Pb-Free assemblies Boards soldered in air were harder to clean The data indicates that the cleaning materials require higher solvency and temperature For assemblies soldered in nitrogen, these process parameters can be relaxed To maintain wetting that is identical to Sn/Pb, and increase of 50°C to the soldering temperature is needed Pb-free solderability is significantly poorer with weaker no-clean and pure rosin	Lead-Free Soldering: DOE Study to Understand its Affect on Electronic Assembly Defluxing Mike Bixenman Kyzen Corporation

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	processes. The purpose of this study is to evaluate how the use of nitrogen versus non-nitrogen reflow atmospheres affect the cleanability of flux residue from RMA, synthetic and water-soluble surface mount solder paste residues.	evaluations were conducted in a controlled application lab while using thermally profiled reflow conditions and cleaning equipment. The response variables used will be qualitative visual inspection of white residue and solder bump appearance. 95.5 Sn/3.9Ag/0.6Cu (SAC)	fluxes Pb-free alloys do not wet as well too lead-free terminations	
174. LF No-Clean	This paper sets out to establish new benchmarks for cleaning no clean surface mount solder paste residues (including the most challenging latest lead free product formulations) by incorporating leading cleaning technologies, the actual impact of different spraying technologies, temperature air vs. nitrogen atmosphere, as major variables. The cleaning evaluations were conducted in a controlled application	Determine the impact of spraying technology and cleaning technology on eutectic and lead-free no-clean formulations. - Establish that „Temperature“ can potentially be a disposable cleaning process variable!	All eutectic and lead free no cleans tested were fully cleanable without additional heating, while soldered under regular atmospheric conditions. - The spraying technology was found to be an important process optimization tool. - Lead-free under nitrogen atmosphere was very easily cleanable under standard process conditions. - Recommendation to future users of no-cleans: Find partners that support and overall process optimization and can integrate mechanical, thermal, and chemical interactions	LEADFREE (NO-CLEAN) - UNHEATED CLEANING? Umut Tosun Zestron America Ashburn, VA, USA u.tosun@zestronusa.com Dirk Ellis Speedline Technologies, Inc. Camdenton, MO, USA dellis@speedlinetech.com

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	technology center while using thermally profiled reflow conditions and cleaning equipment.			
175. Solderability Tests	Lead-free devices, from STMicroelectronics, are warranted to pass the solderability tests, and to form a reliable solder joint with the base material of the circuit board, using Leaded (Sn-Pb) solder or Lead-free (Sn-Ag-Cu) solder.	Solder Lead-free Composition Range (% weight) Tin 94.6 to 96.6 Silver 3.0 to 4.3 Copper 0.4 to 1.1	Through two standard tests ("Dip and Look" and "Wetting Balance"), ST Lead-free devices are warranted to pass solderability tests using Sn-Pb solder or Sn-Ag-Cu solder, and so to meet all the requirements for electronics soldering.	AN2036 APPLICATION NOTE Solderability Tests © 2004 STMicroelectronics - All rights reserved
176. LF Alloy - Tombstone	The mass fraction of solid may be the more essential factor. Surface tension also plays a role, with lower surface tension correlates with a higher tombstoning rate. Tombstoning of SnAgCu can be regulated by the solder composition. A maximal tombstoning rate is observed at 95.5Sn3.5Ag1Cu. The tombstoning rate decreases with increasing deviation in Ag content from this composition, particularly toward the	A 20 cm x 15.2 cm tombstoning board with Cu metallization was employed for tombstoning testing. In each test, 169 of 0402 chips were placed on each test board for each paste, with equal amount of parts being placed on the same board for another paste. To further reduce the possible performance difference due to printing and location, the pastes were printed alternately on these two pair of patterns.	The 95.5Sn3.5Ag1Cu is virtually identical as the true ternary eutectic point 95.6Sn3.5Ag0.9Cu of the SnAgCu alloys [9]. As discussed above, the instantaneous melting behavior of this eutectic alloy is prone to have a high tombstoning rate, as indicated by the maximum tombstoning rate within the SnAgCu alloys studied (see Fig. 3). The DSC of 95.5Sn3.8Ag0.7Cu (see Fig. 7) shows a trace of tail when compared with 95.5Sn3.5Ag1Cu. This is consistent with the findings of Handwerker [10], as illustrated by Fig. 19. The considerable difference in tombstoning rate indicates the significant impact of solid phase at the onset of solder melting.	EFFECT OF LEAD-FREE ALLOY COMPOSITION ON TOMBSTONING Benlih Huang, Ph.D. and Ning-Cheng Lee, Ph.D. Indium Corporation of America Clinton, NY, USA Email: askus@indium.com

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	end of lower Ag content. SnAgCu composition with a Ag content lower than 3.5%, such as 2.5Ag, is more favorable in terms of reducing tombstoning rate with minimal risk of forming Ag3Sn intermetallic platelet.			
177. LF Wetting	This paper reports the findings of numerous studies using quantitative wetting gauges to measure solder paste wetting to the PCB surfaces. Wetting results with various lead free profiles, reflow atmosphere oxygen concentrations and lead free PCB surface metallizations are compared and contrasted for their contribution to maximizing lead free wetting. Although numerous lead free alloys are on the market today, this paper concentrates on the popular SAC	Finding the best process and material set is relatively simple when working with Sn/Pb. There are numerous options of solder pastes in both no clean and water clean chemistries. Board finishes that yield excellent results are plentiful and paste sensitivity to reflow profiles are rare. With lead free we need to re-evaluate all main elements of the process and carefully select the solder paste formulation. To accomplish this we need sensitive and quantitative tools. Failure to accomplish this can result in excess	The best overall profile for the formulation studied is a ramp-to-spike style profile with a slightly extended liquidus time. Profiles with extended liquidus times have proven to be valuable for soldering to tin plated (lead free) components in the field even when using Sn/Pb solder pastes. • Board surface finish had a greater effect on overall lead free performance than the reflow atmosphere O_2 content did. • ENIG was overwhelmingly the best board finish tested with the best wetting and lowest solder voiding. • Immersion tin, with only slightly better wetting than OSP coated copper (Entek), had high solder balling and BGA voiding behavior. • Immersion silver did not demonstrate the strong wetting that ENIG did and produced the highest levels of solder voiding of all of the lead free finishes tested.	Maximizing Lead Free Wetting Richard Lathrop Heraeus Circuit Materials Division Philadelphia, PA Presented in the ECWC 10 Conference at IPC Printed Circuits Expo®, SMEMA Council APEX® and Designers Summit 05

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	(Sn/Ag/Cu) alloy specifically 95.5/4/0.5 in a no clean paste. In addition to wetting, solder defects and voiding are included in the comparisons to reveal the best overall lead free reflow process.	rework due to wetting related defects such as miss-aligned components, tombstones, solder beads and balls.		
178. LFS Wetting Characteristics	For a successful transition to Pb-free manufacturing in electronics assembly, it is critical to understand the behavior of Pb-free solders (in bulk and paste form) and their interaction with the Pb-free printed wiring board (PWB) finishes.	Pb-free assembly requires Pb-free solders as bulk solder alloys (for wave soldering applications), solder paste [for surface mount technology (SMT)] and wire (for hand and repair soldering). In addition to the usage of Pb-free solders, the PWB finishes must be Pb-free for total Pb-free manufacturing.	- NiAu and Ag PWB finishes are the best in a process that involves multiple reflow cycles. OSP did not fare well with any of the Pb-free alloys in all preconditions. - Better spreading was observed when a nitrogen atmosphere was used. - In general, the SnAg solder alloy had the fastest wetting times and slowest was recorded with SnAgBi alloy in the wetting balance tests in all preconditionings. -The difference in spread ratio for SnPb solder is not significantly higher than the Pb-free when compared with the data obtained on the other PWB finishes. There is little difference in the data for air and nitrogen atmospheres suggesting that wetting on Ag boards is independent of atmosphere. There is very little or no effect of multiple reflow cycles on the solderability of Ag boards.	Wetting Characteristics of Pb-Free Solder Alloys and PWB Finishes Sattiraju, *Student Member, IEEE*, Bing Dang, R. Wayne Johnson, *Senior Member, IEEE*, Yali Li, Jeffrey S. Smith, and Michael J. Bozack
179. Wetting Behavior	The overriding objective of the programme was to demonstrate the viability of lead free wave soldering and reflow assembly processes and the associated repair and rework of lead free	Conducted using a wetting balance (Multicore MUST II and GEC Meniscograph Mk 6B) under a variety of conditions, depending on the objective of the experiments	- Surface tension of the lead free alloys is significantly higher than SnPb. This can be inferred from the wetting balance measurements where the contact angle for prealloyed pellets melted onto various surfaces is shown. - Repeating the same measurements with solder pastes based on the alloys masks the effect to some extent. - Repeating the experiments in nitrogen reduced the contact angle by 1-3°. - Wetting times for Pb-free solders are considered short and within reach of the normal process window for mass soldering processes. - Process temperatures/times would have to rise in proportion with the increased liquidus temperature of the alloys.	IMPLEMENTING LEAD FREE SOLDERING – EUROPEAN CONSORTIUM RESEARCH Dr. M. Warwick Multicore Solders Limited

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	devices.		- A small addition of antimony has no apparent effect on wetting performance while larger additions seem to retard wetting.	
180. LFS Wetting Behavior Shear Strength	At this background our work is dealing with different lead free solder pastes to evaluate their process capability and wetting behavior on different pad metallizations.	Therefore we try to evaluate 3 different solder paste materials for the use in electronic reflow manufacturing. For our investigation we've used: *A ternary eutectic alloy of Sn95.5Ag3.8Cu0.7 with a melting point of 217°C,*	The differences of the shear strengths of solder joints are very small between forced convection ore vapor phase soldering for every alloy. There is a higher strength loss after vapor phase between room temperature and T_h=0.75 than for forced convection soldering.	PROCESS CAPABILITY, WETTING BEHAVIOR AND TEMPERATURE DEPENDENT SHEAR STRENGTH OF ALTERNATIVE LEAD FREE SOLDER JOINTS Th. Herzog , S. Rudolph, K.-J. Wolter Electronics Technology Laboratory SMT-CD
181. Thermal Cycle – LFS Joints - Shear	This paper describes work that was to undertake a comparison of accelerated test regimes for lead-free solders. Identical samples were subjected to six different regimes to investigate the effect of thermal excursions, ramp rates and temperature dwells. The most damage to joints was found to be caused by thermal cycling between -55 and 125°C, with a 10°C/min ramp rate and 5-minute dwells. Larger thermal excursions were shown to give faster results	When field failures occur in solder joints, they are generally in components which have a large thermal coefficient of expansion (TCE) mismatch with the substrate on which they are mounted. Therefore, this work concentrated on failures and failure modes within these component types, as these are the structures most likely to fail first in field use. This work utilised ceramic chip resistors, which are **Figure 2:** Test board layout (81 x 65 x 1.6 mm) present in	Comparison of accelerated test regimes for lead-free solders undertaken in this work indicates that the most damage to joints is caused by thermal cycling between -55 and 125°C, with a 10oC/min ramp rate and 5 minute dwells. This regime can be recommended to the electronics industry as a suitable accelerated test regime for lead-free solders. The large thermal excursions of this regime have been shown to give faster results without compromising the failure mode. Increasing the upper cycling temperature and reducing the lower temperature both have the effect of increasing fatigue damage. The work has also shown that slow ramps cause greater damage than longer dwell times.	THE IMPACT OF THERMAL CYCLE REGIME ON THE SHEAR STRENGTH OF LEAD-FREE SOLDER JOINTS Milos Dusek, Martin Wickham and Christopher Hunt National Physical Laboratory Teddington, Middlesex, United Kingdom milos.dusek@npl.co.uk, chris.hunt@npl.co.uk, martin.wickham@ntlworld.com

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	without compromising failure mode.	most electronic assemblies. Due to their alumina bodies, they have a TCE, which is much lower than that in common substrate materials (see Figure 1), and hence are more prone to fail from cyclic strain damage accumulating in the joints.		
182. LFS – Reflow and Wet ability	Solder joints used in electronic applications undergo reflow operations. Such operations can affect the solderability, interface intermetallic layer formation and the resultant solder joint microstructure.	These studies were carried out with eutectic Sn-3.5Ag solders, with or without mechanically added Cu or Ag reinforcements, using Cu substrates. Microstructural analysis was carried out on solder joints made with the same solders using copper substrate.	The wettabilty of gold substrate with eutectic Sn-Ag solder has been shown to be commensurate to that of Pb-Sn solder alloys.4 The wetting characteristics of any particular solder alloy are strongly influenced by the flux used.5,8 In particular, the wetting parameters, such as interfacial tension and wetting rate, of eutectic Sn-Ag solder can be highly variable depending on the choice of flux.5	Effects of Reflow on Wettability, Microstructure and Mechanical Properties in Lead-Free Solders F. GUO, S. CHOI, J.P. LUCAS, and K.N. SUBRAMANIAN
183. Flux Delivery	Spray fluxing is an important factor in lead-free environments. This paper shows the testing that was performed on different types of spray fluxers using different methods of flux applications. To determine the best	Electrovert® Vectra™ wave solder machine, an ultrasonic reciprocating spray fluxer, an Ultrasonic reciprocating bidirectional spray fluxer, and ultrasonic reciprocating air atomized spray fluxer, a	This test has shown that selection of a fluxer is important. There is a difference between fluxers and each fluxer has a different hole fill capability. All the fluxers performed well or at an acceptable lever on larger hole size (20 – 40 mil). The smaller hole size (10 – 15 mil) can differentiate a fluxer's performance. The fluxers that performed well at the smallest hole sizes should also perform well with problem boards, as more flux tend to penetrate the hole around the components. For lead-free soldering of OSP boards, non-rosin VOC free no-clean fluxes performed better on difficult boards. Maintenance requirements were not considered in this testing, but should be taken into account when selecting a fluxer. Serious considerations should be made when choosing flux chemistries. The fluxer should always be tested with the	Lead-Free Flux Delivery and Chemistry Testing Ken Kirby Speedline Technologies Electrovert Camdenton, MO Presented in the ECWC 10 Conference at IPC Printed Circuits Expo®, SMEMA Council APEX® and

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	method of spray fluxing at a pre-determined deposition that yields the best hole fill and to explore new ways to improve the spray fluxing performance.	20" ultrasonic fixed head spray fluxer, a 12" ultrasonic fixed head spray fluxer and an atomized jetted reciprocating spray fluxer. The test vehicle will be an OSP test board without surface mount. Two types of flux will be used in the test. The first flux type will be non-rosin alcohol-based no-clean and the second flux type will be non-rosin VOC free no-clean.	different fluxes under consideration.	Designers Summit 05
184. LFS Assembly Processes & Materials	This study is focused on using different assembly options such as dip fluxing, flux jetting and reflow encapsulate for 200-250um pitch lead-free (SnAgCu) flip chips on FR4 substrates. The impact of different PCB surface finishes (OSP and ENIG), was investigated from an assembly perspective. Different underfill materials including an acid anhydrate based material and two non-acid anhydrate based	This study is focused on the assembly of 200-250um pitch lead-free SnAgCu flip chips on FR4 substrates. The impact of different PCB surface finishes, including OSP and ENIG, were investigated from an assembly perspective. Underfill materials were evaluated for use with leadfree flip chip. Two of the underfill materials are acid anhydrate based materials and the other two are non-acid	Lead-free solder flip chip assembly on FR-4 was demonstrated to be feasible both on ENIG and OSP surface finishes with reflow in a nitrogen atmosphere. The processes, such as fluxing, pick and place, reflow, and underfilling were evaluated to determine which of these combinations would provide better yields. It is clear that nitrogen is needed in a flip chip application to ensure high yields. The self-alignment properties with SnAgCu is the same as or similar to SnPb in a flip chip application. The different surface finishes (ENIG and OSP) showed no difference with both showing selfcentering with misplacement up to 50% off pad. Dip fluxing and flux jetting are two feasible assembly methods for SnAgCu flip chips. This study shows that this specific reflow encapsulate evaluated is not working well as the epoxy gels before wetting is achieved.	Lead-Free Solder Flip Chips on FR-4 Substrates with Different Assembly Processes and Materials David Geiger and Dongkai Shangguan Flextronics San Jose, CA Jonas Sjöberg Flextronics Linköping, Sweden Todd Castello Flextronics Youngsville, NC Presented in the ECWC 10 Conference at IPC Printed Circuits Expo®, SMEMA Council APEX® and Designers Summit 05

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	materials were evaluated for compatibility with the flux and lead-free solder bumps and process. A reflow encapsulate designed for lead-free soldering is also studied from an assembly point of view.	anhydrate based. Some of the acid anhydrates used in the underfill require special permissions in some countries. We have therefore investigated the possibility to replace these materials with non-acid anhydrate underfill materials. Also, one of the processes used was the no flow underfill process where the underfill is applied before pick and place, the flip chips placed and the boards reflowed.		
185. LFS Material Control	A successful transition will require a significant collaborative effort between production, engineering, procurement, and a large number of component suppliers and distributors. During this process one area that should not be overlooked is the actual production floor. After all this is where all the different materials	This includes products that are exempt from the new legislation. Other OEMs will convert all their products to Pb-Free to minimize the cost and complexity of managing two different versions of the same product. As a result the majority of EMS and ODM assemblers will have to manage two different sets of materials and run two	Once the Pb-free materials have been selected and the process has been qualified the major manufacturing issue that remains is that of managing the material logistics. There are many critical aspects of controlling materials on the production floor. The key issues include : - Identify and segregate Sn/Pb and Pb-free materials - Validate Line Setup - Control Moisture-sensitive components - Provide complete material and process traceability These issues can all be addressed with proven and costeffective material control systems, using a combination of barcode and RFID technology.	MATERIAL CONTROL FOR LEAD-FREE MANUFACTURING François Monette Cogiscan Inc. 50 De Gaspe, Suite A5 Bromont, Quebec, Canada, J2L 2N8 E-mail : fmonette@cogiscan.com

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	come together to make the finished product. The assembly line is where the largest number of people are involved and the complexity of their task translates in the highest risk of errors.	different processes side-by-side for a significant period of time. Depending on the strategy being used by the assembler this transition can range from a few months to many years in manufacturing, rework and field repairs.		
186. Solder Performance SAC Alloy Composition	In this study, tombstoning and voiding at microvia behavior were studied on a series of SnAgCu lead-free solders, with an attempt to identify a possible "composition window" for controlling these problems. Eutectic SnPb was included as the baseline.	Part I study, tombstoning behavior was studied on a series of SnAgCu lead-free solders, with an attempt to identify a possible "composition window" for controlling this problem. voiding at microvia was studied on a series of SnAgCu solders, with emphasis on finding a possible "composition window" for controlling this problem. Eutectic SnPb was included as the baseline.	Tombstoning of SnAgCu can be regulated by the solder composition. A maximal tombstoning rate is observed at 95.5Sn3.5Ag1Cu. The tombstoning rate decreases with increasing deviation in Ag content from this composition, particularly toward the end of lower Ag content	
187. LFS Alloys - Heraeus	In recent years, efforts to develop alternatives to leadbased solders have increased	Of these, the most challenging and time consuming is the reliability of alternative	Recent work with candidate lead-free alloys (e.g. Sn/Ag or Sn/Ag/Cu) indicate that they do exhibit improved reliability over SnPb	Lead-free alloys Anton Zoran Miric W.C. Heraeus GmbH, Hanau, Germany

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	dramatically. These efforts began as a response to potential legislation and regulations restricting lead usage in the electronics industry. Lead	solders. The lead-free alloys available cannot be used as a drop-in replacement for the SnPb or SnPbAg		Angela Grusd Heraeus Cermalloy Division, West Conshohocken, Pennsylvania, USA
188. LFS in electronics	In particular, the Sn-Ag-X lead free solders offer superior creep resistance at room temperature and 100°C as compared to Sn-40Pb.	One of the most promising replacement alloys is Sn/4Ag/0.5Cu. This alloy will be discussed in detail.	Recent work with candidate lead free alloys indicate a significant improvement in reliability over Sn/Pb. Figures 2-4 clearly demonstrate a superior creep resistance over Sn/Pb for all lead free alloys tested including Sn/Ag eutectic, Sn/Cu eutectic, and Sn/4Ag/0.5Cu at both room temperature and 100°C	LEAD FREE SOLDERS IN ELECTRONICS Angela Grusd Heraeus Inc.
189. LFS Assembly SAC Alloy Processing	. This paper discusses the commercially available tin-silver-copper alloys and their processing and reliability as well as the world wide level of acceptance, forwards and backwards compatibility, contamination issues, environmental and economic impact.	The world is stating to focus on tin-silver copper as the lead-free alloy of choice	- Sn-Ag-Cu alloys appear to provide an acceptable compromise as a lead-free substitute. At present arange of Sn-Ag-Cu alloys will be used. However, all these alloys appear to be very close in composition and properties The major concerns at the present are: -Individual component and connector survivability in complex assemblies that require a high temperature profile - JEDEC Level 1 245 °C (J-STD-020) may be inadequate for some components Labeling of components as lead-free	Real-Life Tin-Silver-Copper Alloy Processing Alan Rae, Joe Belmonte, Leszek Hozer Cookson Electronics Inc. APEX-CD
190. LFS Assembly - NASA	This paper presents data collected on a recent NASA project to focus on finding suitable alternatives to eutectic	- Four lead-free solder pastes were selected based on an extensive search of the literature. Two PWBs per solder	- No problems were encountered during the printing process with lead free paste. The printing was uniform for all PWBs. - A longer delay was required for the first three pastes during the reflow process. This was due to the higher melting temperature of the solders. - Although the solder fillets appeared to be generally good, the solder joint appeared	HI-REL LEAD-FREE PRINTED WIRING ASSEMBLIES J.K. “Kirk” Bonner, L. del Castillo, A. Mehta*

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	tin-lead solders and solder pastes.	type were assembled using the four different solder pastes resulting in total of eight assemblies. - Ensure that the new lead-free pastes can be successfully assembled. - Based on the results of 1, we will down select from the initial four pastes to two. - Assemble four PWBs per paste (2 pastes) and thermal cycle.	grainier than those formed by Sn63/Pb37 solder. - The daisy-chain continuity measured after reflow was same as that prior to the reflow, meaning there was no opens after reflow.	Jet Propulsion Laboratory California Institute of Technology SMT-CD
191. LFS Assembly NASA - Final Report	JPL focused on the reflow assembly process. The goal of this investigation was to focus on finding suitable alternatives to eutectic tin-lead solders in the event that lead is either curtailed or is no longer available for electronics usage.	All PWBs were assembled in the SMT Laboratory at JPL. Sn-Ag-(Cu-Sb) alloys (pastes 1- 3 in Table 1 above) have melting temperatures in range of 216-221°C, requiring a 25°C increase in peak temperature. Therefore, they were reflowed using a bench-top vapor phase system containing a perfluorocarbon material with a boiling point of 240ºC.	- Overall, processing lead-free PWAs through the assembly did not cause any significant problems. - The solder paste deposition was accomplished with ease and it was uniform as measured by laser measurement system. - Generating of the reflow thermal profile for no lead assembly was somewhat challenging since the reflow temperature is higher therefore the reflow window is smaller (217 oC to 240 oC) compared to Sn/Pb eutectic (183 oC to 220 oC). - Some of the plastic BGAs exhibited delamination after the reflow. The reason being, they were not prebaked, hence they absorbed the moisture resulting in the delamination. Prebaking of the BGAs at 125oC for 24 hours eliminated the delamination.	Pb-Free Solder Alloy Investigation Final Report Dr. Kirk Bonner, Atul Mehta, Dr. Linda Del Castillo
192. LFS in power	Thermal performance of packaged power	Several types of representative samples	Due to a combination of testing conditions and material properties, the lead-free solders, Sn/3.5Ag and Sn/Ag/0.7Cu, sustained the most severe damage as compared	Thermal Performance and Microstructure of Lead

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devices	devices and multichip modules depends largely on the quality of the solder interface between the power semiconductor devices, such as MOSFETs, IGBTs and diodes, and the substrate-heat sink assembly. This project examines the thermal performance of power devices attached using lead-free solders. The objective was to observe microstructural change in large-area solder joints caused by thermal cycling and relate these changes to reliability issues in large-area lead and lead-free solder constructed semiconductor power devices.	were created focused on the study of a variety of solder types. Silicon MOSFET dies are soldered to a direct copper bond (DCB) substrate (tri-layered sample) and wire bonded to adjoining pads isolated from the copper substrates Cross sectioning was performed on all of the sampled for micrographic analysis. These cross sectioned devices were thermally cycled (-55ºC to 100ºC) to accelerate the degradation of this solder layer over an expected lifetime.	to Sn/37Pb solder alloy, The most severe damage was observed at the solder/substrate interface in a simulated power semiconductor device sample due to elevated stresses gradients across the solder layers.	versus Lead-free Solder Die Attach Interface in Power Device Packages Kelly Stinson-Bagby Optical Devices Group Luna Innovations, Inc. Blacksburg, VA Dan Huff, Dimos Katsis, Daan Van Wyk,and G. Q. Lu Center for Power Electronic Systems (CPES)
193. LFS Assembly Pb-free comparison	This paper provides an assembly process comparison of Pb-free alloys with a Sn/Pb alloy using a test vehicle designed to resemble real world manufacturing	Four different Pb-free alloy systems, including two compositions in the Sn/Ag/Cu alloy system, are investigated, and their board level assembly processing characteristics are	- The results of this study showed that, for a printed circuit board consisting of a variety of components with different pitch sizes, it was possible to have a viable printing process for Pb-free pastes within a larger process window. - For any given Pb-free paste and component mix, it would become necessary to optimize the print process for each Pb-free paste. - The SAC305 alloy emerged as the best overall Pb-free alloy in terms of minimal soldering defects under the given assembly conditions. - It seems likely that the narrow process window with a low peak reflow temperature	SMT Assembly Process Comparison of Pb-free Alloy Systems Shafi Saiyed, Daryl Santos, Ph.D. State University of New York at Binghamton Binghamton, NY

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	applications.	compared to the eutectic Sn/Pb alloy for a variety of surface mount components and packages, and through-hole components.	of ~240 °C increases the possibility for defects for Pb-free alloys with slightly higher melting temperatures (e.g., Sn/Ag at 221 °C). - Based on the present results, future development effort towards the optimization of the SMT assembly process parameters for Sn/Ag and similar SAC alloys is warranted, especially with regard to fine-tuning the printing process and reflow profile. - It is possible that under varying degrees of process optimization for any of the different combinations of alloy and surface finish, different performance rankings would become apparent.	APEX-CD
194. LFS Assembly Pb-free build	The Massachusetts Toxics Use Reduction Institute (TURI) has sponsored a consortium of Massachusetts based corporations to investigate lead-free (Pb-free) surface mount soldering technology.	PWB Finishes – Five Treatments– Reflow Atmospheres – Two Treatments Solder Pastes – 95.5Sn-3.8 Ag-0.7Cu- Component Lead Finishes – Four Treatments	These data show it is possible to obtain visually acceptable solder joints using a variety of board finishes, lead finishes, paste formulations and Air/Nitrogen combinations. Visual inspection is often the only means of defect detection other than circuit testing, and the two often verify one another thus indicating a good Pb-free reflow process with high yield can be achieved.	Testing and Analysis of Surface Mounted Lead Free Soldering Materials and Processes APEX-CD
195. LFS SMT Soldering	This paper discusses the mechanical reliability tests of the lead free process, outlines the testing decisions made and the techniques used	The Manufacturing Research Laboratory facilities at UMASS Lowell were utilized to test and analyze the performance of alternatives based on the principles of Design of Experiments. Results were analyzed using statistical techniques resulting in determining whether a particular factor was significant to the quality characteristic being measured.	Results show that the reliability of the lead free joints as measured after 2000 thermal cycles by pull tests have been shown to be of equivalent quality to the lead based solder joints baseline. - It has been shown in this paper that it is possible to obtain a Lead Free soldering process that is defect free and exhibits a better reliability profile than that of the baseline Tin Lead. - Lead-free soldering. For reliability performance, as expressed by thermal cycling, the Tin silver/alloys have shown to be stronger than the tin lead baseline and performed equally well after 2000 thermal cycles.	PROCESS AND MATERIAL SELECTION FOR ZERO DEFECTS AND SUPERIOR ADHESION LEAD FREE SMT SOLDERING Dr. Sammy Shina Hemant Belbase Department of Mechanical Engineering University of Massachusetts Lowell SMT-CD

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		Maximum and minimum temperature. 0 and 100' C		
196. LFS Assemblies Component Temperature	With the transition from eutectic tin-lead solder to higher melt, lead-free Sn/Ag/Cu (SAC) solder alloys, concerns from component and board suppliers, contract manufacturers, and original equipment manufacturers are emerging with respect to component body maximum peak temperatures, and the effects these elevated temperatures have on the assembly, during and after second level processing.	The group decided that four cards should be used for this study with the intent that the mix of cards would cover a large range of components and substrates such that basically all types of SMT assemblies could be covered.	In performing this study we were able to provide to the joint JEDEC/IPC working group that controls J-STD-020 data that supported the proposed reflow profiles for Pb-free soldering processes. The gathered component body temperature data supported the use of two profiles, a 245oC peak reflow temperature for large components and a 250oC value for smaller components.	COMPONENT TEMPERATURE STUDY ON TIN-LEAD AND LEAD-FREE ASSEMBLIES Matthew Kelly, Duilio Colnago, and Vittorio Sirtori, Celestica International Jasbir Bath, Suan Kee Tan, and Lai Hook Teo, Solectron Corporation SMT-CD
197. LFS Assembly Offset Chip	One area of interest that requires additional experimentation and understanding is the ability of the Pb-free alloys to self-center offset components compared to the Sn/Pb alloy. It is generally understood that chip components (primarily 0402, 0603, 0805, and 1206 resistors and capacitors) that have	This research is undertaken to evaluate how well Pb-free solder paste self centers an intentionally offset placed component compared to Sn/Pb lead solder using well-designed experiments. Chip components (R1206, R0805, research is undertaken to evaluate how well Pb-free solder paste self	- The results obtained from Experiment 1 show that for Pb-free alloy a combination of SAC305/ENIG/N_2 shows the best self-centering capability among the various combinations of Pb-free alloy, surface finish, and reflow atmosphere. Shina et al., 2001, have achieved similar results. The superior performance of the above condition is attributed to the better wetting conditions provided by ENIG surface finish and the inert atmosphere during reflow. - SAC405 solder paste shows good wetting behavior with OSP finished boards when reflowed in a nitrogen atmosphere. OSP/SAC405/N2 combination shows maximum component self-centering capability among various combinations of SAC405 alloy, board finish and reflow atmosphere. However, there is little difference observed in processing behavior between ENIG and OSP.	Self-Centering of Offset Chip Components in a Pb-free Assembly Amey Teredesai Binghamton University

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	been placed slightly off center from the printed circuit board's pads will center on the component pads during the reflow soldering operation using standard tin/lead solder alloys.	centers an intentionally offset placed component compared to Sn/Pb lead solder using well-designed experiments. Chip components (R1206, R0805, R0603 and R0402), are used in this research to evaluate self-centering ability of potential Pb-free alloys.		
198. LF - connectors, processes	In connector systems lead primarily exists in some contact platings. Lead may also exist in certain connectors as an alloying element in copper or steel or as an additive in certain PVC plastics.	Migrating to lead free interconnect products requires: 1) lead free plating capability, an understanding of lead free processing and polymers with greater temperature stability than are typically used today.	Trends for solder paste are toward a tin- silver-copper alloy. Trends in wave soldering lines are toward a eutectic composition of tin and copper. Pure tin and tin-copper connector contact platings tested by Tyco Electronics are compatible with both these trends. The platings are also compatible with traditional tin/lead solder alloys.	Achieving Lead Free Connectors and Processes Robert D. Hilty, Tyco Electronics Corporation
199. LFS - Identification and Selection of alternatives to SnPb.	The demands for development of Lead free alloy include characteristics such as: solder ability, cost, temperature range, workability, joint quality, reliability, printability, wettability, control of oxidation, reaction to connector, recycling performance and endurance of	Development of index of existing lead free solders with data points in cost, melting temp, bulk tensile, bulk extensibility, wetting time, wetting stress, wetting spreadability compositional change, shear strength of joint, bulk lifetime, creep of read. Thermal cycle and application (paste	Selecting the best lead free solder is very difficult from the analyzed data and results, but if we have to choose some type of alternative lead free solder, Sn-Ag-Cu-Bi is better when considering the data presented in this study. Should consider the following solders for different applications: Wave - Ag (1~3.5%), Cu (0.3~1%), Bi (<0.3%), Sn (Balance) Reflow - Sn-Zn (Eutectic) and Sn-Zn-Bi (2~3%) Low Melt Apps - Sn-Bi-(Ag)-(Cu) and Sn-Zn-Bi	Lead Free Solder for Environmental Protection. SMIC R&D Report. May 1998. Rikiya Kato, Chief Engineer (Senju Metal Industry Co., Ltd.)

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	material.	ball, wire cored solder) and to compare these to 63/37 SnPb solder.		
200. LF Components - Automotive	To convert these products to lead free versions, we needed to ensure the reliability of the new coatings. Reliability testing included in this report includes: crimp tensile strength, crimp electrical performance, solderability, solder joint reliability, whisker resistance, contact resistance, insertion force, coefficient of friction and durability.	This paper will review some of the qualification efforts undertaken to prove the reliability of lead free connector products. These products have been on the market since February 2003 and have performed reliably in our manufacturing operations as well as at our customers.	The automotive industry faced the conversion to lead free plating earlier than other industries due to the implementation of the ELV directive. Products that have been converted to lead free plating are fully backwards compatible into tin/lead soldering processes and do not require modifications to the thermal profiles or wave soldering conditions to achieve a reliable solder joint.	Lead Free Components in Automotive Applications Robert D. Hilty Tyco Electronics Harrisburg, PA
201. Practical LFS Implementation	Numerous scientific studies have been published regarding lead-free concerns: equipment capability, solder alloy types, component metallization, process chemistries, PWB materials and surface finishes. The scientists and engineers have shown feasibility, and in some parts of the world, full-scale production of lead-free electronics is a reality.	The scientific work that identified lead-free solutions must now be translated into practice on the shop floor. This is a considerable undertaking, given all the variables that exist in a production environment. The goal of this paper is to provide the framework for planning the transitions of individual factories. It combines the experience of several engineers who	2005 will be the year that most assemblers begin building with lead-free processes. There are a multitude of factors to consider when planning the transition to lead-free. This paper provides a listing of the factors deemed most important by engineers from material and equipment suppliers who have been working on lead-free transitions throughout the world. It is intended to provide a starting point for assemblers who are now planning the transition. Appendix A is a synopsis of the considerations in checklist form. Assemblers using the checklist as a planning tool can easily add considerations unique to their situation or delete considerations that do not apply to their process.	Practical Lead-Free Implementation Chrys Shea and Bruce Barton Cookson Electronics Assembly Materials Jersey City, NJ Joe Belmonte and Ken Kirby Speedline Technologies Franklin, MA Presented in the ECWC 10 Conference at IPC Printed Circuits Expo®, SMEMA Council APEX® and Designers Summit 05

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	But many assemblers, particularly those in North and South America, are still formulating their transition plan.	have supported lead-free transitions around the world.		
202. LFS Implementation - automotive electronics applications	Successfully launched a single sided SMT lead free soldering process	Solder Selection: SnAg = 96.5Sn/3.5Ag	- Mechanical properties of the alloy is also well suited for automotive electronics applications. - 96.5Sn/3.5Ag solder alloy is readily available in the form of solder paste, solder bar and core wire solder today.	Visteon Experience on Lead-Free Stephen Wong
203. LFS Implementation Automotive	Delphi Delco Electronics Systems has been working on Lead-free solder since 1993	The alloys were tested at both 0 to lOOC with a 30 minute thermal cycle, and at -55 to +125C with a 72 minutes cycle.	Reflow soldering will probably be implemented first since it requires only a change in paste. A major hindrance at this time is the availability of components qualified at the higher temperatures required for the new SnAgCu alloy. Ultimately, lead-free component finishes will be required for a truly lead- free assembly.	Lead-free Solder Implementation for Automotive Electronics Gordon Whitten Delphi Delco Electronics Systems
204. LFS – Automotive applications	This paper addresses the reliability of a 15mm, 0.65mm pitch MAP BGA for automotive applications using daisy chain thermal-mechanical test vehicles designed for the continuous monitoring of solder balls.	The effects of underfill versus no underfill, lead-free solder spheres versus SnPbAg solder spheres, and lead-free solder paste versus SnPb solder paste are evaluated under two thermal cycling conditions, –40 to +125oC and –50 to +150oC. Cycles to first	Within the combinations of SnPbAg ball with SnPb solder paste and SnAgCu ball with SnAgCu paste, -40 to +125 oC AATC condition performed better than –50 to +150 oC AATC condition For the combination of SnPbAg ball and SnPb solder paste, underfill extended solder joint life (-40 to +125 oC AATC condition). For the combination of SnAgCu ball and SnAgCu or SnPb solder paste, underfill did not improve solder joint life. In –40 to +125 oC AATC and –50 to +150 oC AATC testing without underfill, the cells with SnAgCu ball and SnAgCu paste were better than the cells with SnAgCu ball and SnPb paste.	RELIABILITY OF 15MM, 0.65 MM PITCH MOLD ARRAY PROCESS (MAP) BALL GRID ARRAY (BGA) FOR AUTOMOTIVE APPLICATIONS Patrice Langford* and Thomas Koschmieder Motorola, Inc.

Focus	Objective	Scope	Conclusion(s) Summary	Reference
		failure and characteristic life are reviewed using Weibull plots. Failure analysis and failure mechanisms are also discussed.		
205. LFS Processes – Cooling Rates	This paper evaluates the effect of variable cooling slopes on lead free solder joints. Controlled testing of lead free assemblies subjected to various cooling slopes in both air and nitrogen environments is also discussed. Solder joints will be inspected for solder joint grain structure under differing conditions of aggressive, medium, and mild cooling slopes. Data will be presented on the findings of this study along with suggestions of desirable cooling slopes and reflow system options to best support the reflow cooling profile.	The lead free material utilized for the experiment is a SAC 305 from a worldwide material supplier. Profiles were developed utilizing the material supplier recommended parameters for development. It was noted that in the specification of the material the supplier suggested an aggressive cooling slope from 3-7°C/second from peak temperature with the most aggressive cooling slope preferred. This is an interesting note since other material suppliers have referenced cooling slopes from 2-4°C/second from peak temperature.	Aggressive cooling slopes resulted in smaller, diffused Sn rich dendrites within a finer mix of eutectic grain structures forms.This resulted in a more uniform mix of the material as it solidified. Mild to gradual cooling slopes resulted in longer eutectic grainstructures within longer and layered Sn rich forms. There was no significant visual affect between samples reflowed in an air environment vs. a nitrogen environment in terms of grain structure. Shear strength testing is required in order determine the affects of cooling slopes on solder joint strength.	Effects of Cooling Slopes in Lead Free Reflow Marc Apell, Tad Formella amd Alden Johnson Speedline Technologies, Inc. Franklin, MA Presented in the ECWC 10 Conference at IPC Printed Circuits Expo®, SMEMA Council APEX® and Designers Summit 05
206. Best Practices for LF Assembl	Slide Presentation	This Overview will be of a Successful Implementation at Motorola, Plantation,	SnAg3.9Cu0.6 (+/0.2% for Ag and/or Cu) NEMI: No statistically different process or reliability performance within this range Latest info: SAC305 – Less Tombstoning PWB Finishes	Motorola/Indium Lead-free Efforts & Best Practices for Lead free Assembly Ronald C. Lasky, PhD, PE

Focus	Objective	Scope	Conclusion(s) Summary	Reference
y		Florida, USA	Motorola chose OSP MacDermid & Enthone recommend Immersion Ag	rlasky@indium.com Indium Corporation Dartmouth College
207. LF Environ ment	Depending heavily on efforts to create a lead-free environment in which the usage of lead itself is eliminated to supplement efforts aimed at recycling and reuse	Leaded terminal packages sucha as TSOPs, QFPs and DIPs Solder Ball terminal packages such as CSPs	Leaded packages = alloys of Sn and Bi: 2% Bi concentration, Three layers consisting of NiPdAu Ball terminations = SnAgCu, 3% Ag, .5% Cu	Measures to promote a lead-free environment Sharp
208. Solder ability Pb-Free Finishes Pb-Free Solders	The requirement of using lead-free materials has generated remendous pressure in the electronics industry. In semiconductor leadframe packaging, the tin-lead post plating will be soon replaced by environment-friendly finishing processes. At present, pure tin and some tin alloys have been developed in electroplating for tin-lead. Meanwhile, the industry has renewed the interests in the palladium pre-plated frame (Pd PPF) technology	In this study, we will report the solderability test results on ure tin, tin-copper, tin-bismuth, nickel/palladium and ickel/palladium/GF plated leadframes under as-plated ondition or after 8 hours steam aging using SnCu0.7 and nAg3.8Cu0.7 solders.	- Tin, tin-copper, tin-bismuth, nickel/palladium and nickel/palladium/GF finishes can meet the wetting requirements with lead-free solders. - A higher soldering temperature is needed with SnCu0.7 and SnAg3.8Cu0.7 solders to achieve good wetting behavior. - All the tested lead-free finishes provide required wetting performance at 260°C with SnAg3.8Cu0.7 solder. It has a lower melting temperature compared with SnCu0.7 solder and may be more convenient to use in electronics industry. - The tested lead-free finishes and SnPb10 finish have comparable wetting behavior.	SOLDERABILITY OF LEAD-FREE FINISHES USING LEAD-FREE SOLDERS C. Fan, Y. Zhang and J. A. Abys Lucent Technologies, Electroplating Chemicals & Services SMT-CD
209. LFS	This paper summarizes	Over the past 2-½	Currently, this lead free process has been in production since June 1, 2001. The daily	HIGH VOLUME LEAD

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Production	the steps required to implement a high volume Lead Free SMT process.	years, we have successfully developed the first high volume Lead Free process. The product and process development included solder joint integrity research, product life reliability qualifications and production mistake proofing.	production rate is approximately 7000 units. This process has been successfully implemented without any major issues. Continuous process monitoring and improvement are essential at this stage to further understand the impact on the processing equipment, particularly, the reflow oven. No equipment down time and component failure	FREE PRODUCTION Stephen Wong, Myron Nestor Visteon Automotive System, (Markham Plant) Markham, Ontario SMT-CD
210. LFS Implementation	The overriding objective of the programme was to demonstrate the viability of lead free wave soldering and reflow assembly processes and the associated repair and rework of lead free devices.	The prograrnme was based on industrial scale wave and reflow soldering process equipment and in both cases, nitrogen and air atmospheres were available. The reflow oven was a high specification convection system (Seho FDS 64403.6) and the wave soldering machine was equipped with radiation and forced air convection preheater and a dual wave (Vitronics-Soltec Deltawave 6622 S&V),	- The results reported here reinforce the growing opinion in the industry that the eutectic SnAg3 .8CU0.7 alloy is the best all-round solution for lead free soldering. - The temperature sensitivity of components maybe a barrier to using lead-free solder alloys in some applications, despite the surprisingly low temperatures that may be used.	IMPLEMENTING LEAD FREE SOLDERING CONSORTIUM RESEARCH Dr. M. Warwick Multicore Solders Limited SMT-CD
211. LFS and Adhesives (Presentation)	Development of environmentally friendly materials (lead-free solders and adhesives (ICA, NCA))	Requirements and specifications for substrates, components, interconnection materials, and the	Work performed in IMECAT so far: Development of lead free interconnection materials (LFS and adhesives) Lead free wafer bumping technologies donw to 100micron on 6 inch wafters Dedicated interconnection test chips Basic lead free assembly technologies for 5 industrial sectors	IMECAT: An EC FP5-Frowth Project on the Development and Application of Lead Free Solders and Adhesives

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	and application of these materials for electrical interconnection and assembly for a wide variety of applications	assembly technologies to be developed. Development of the interconnection materials: lead-free solders and adhesives; simultaneously: design and production of test substrates and test chips, procurement of other commercially available (test) components to be assembled Development and qualification of basic assembly technologies; thermomechanical modeling and simulation of the assemblies Using the developed technologies: design, production and testing of functional and/or technology demonstrators.	Remains to be done: Development of ultrafine pitch (60micron) lead free wafer bumping Continuation of comparative study soldered vs. adhesive flip-chip Qualification of the developed technologies (Design), manufacturing and testing of demonstrators Continuation of modeling work, especially for demonstrators	Dr. ir. Jan Vanfleteren IMEC/INTEC/TFCG, Gent (Belgium) (June 2004)
212. Lead-Free Reflow Process Moisture Sensitivity Performance	The increased reflow temperatures that are required for lead-free solders will impact the moisture sensitivity performance of plastic surface mount devices (SMDs). This paper presents the effect of	Moisture/reflow analyses were performed on five different package types as shown in Figure 4. Each device was chosen to represent a specific package family. The moisture/reflow	- In summary, the results of this study indicate that the moisture sensitivity performance is reduced by at least one IPC/JEDEC level when the peak reflow temperature is increased to 260°C. However, the effects of lead-free reflow temperatures on moisture sensitivity performance vary widely based on package type: - The 144LQFP package is able to withstand level 2a stressing at 225°C. At 260°C, the moisture sensitivity performance is reduced to IPC/JEDEC level 3. - The moisture sensitivity performance of low profile fine pitch BGAs is downgraded from level 3 at 240°C to level 4 at 260°C.	THE IMPACT OF LEAD-FREE REFLOW TEMPERATURES ON THE MOISTURE SENSITIVITY PERFORMANCE OF PLASTIC SURFACE MOUNT PACKAGES B.T. Vaccaro, R.L. Shook,

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	lead-free simulated assembly on the moisture/reflow performance for conventional leadframebased products	performance of each family is unique due to differences in assembly materials and/or package thickness and was thus characterized independently.		D.L. Gerlach Lucent Technologies SMT-CD
213. LFS Paste Evaluation	This paper presents the results of an evaluation of lead-free solder pastes of the Sn/Ag/Cu family. Eutectic Sn/Pb alloy solder was included in the study as reference.	Tests carried out included tack test, slump test, solder balling test, printability and wetting on PCB surfaces.	- In overall performance, only one of the lead-free pastes (96.9Sn-2.7Ag-0.4Cu) was equal to the Sn/Pb paste. - It was observed that the tin-lead solder paste wetted both Ni/Au and OSP plated surfaces considerably better than the lead-free solder paste, and the difference was the largest on OSP surfaces. - The Sn/Pb paste did not show any superior performance compared to the lead-free solder pastes in tack, slump, printability and solder balling tests.	PERFORMANCE EVALUATION OF LEAD-FREE SOLDER PASTES Minna Arra Flextronics, Tampere, Finland SMT-CD
214. LFS Paste Comparison	This paper outlines the printing and wetting experimentation and the findings of a lead free solder paste comparison, and identifies one solder paste capable of performing across a wide temperature range of reflow profiles.	The selection is based on testing of three lead free solder paste formulations from three different suppliers. The solder paste must be able to perform on copper with an organic surface protectant in an air reflow atmosphere. Testing was also carried out in a nitrogen atmosphere, as this may be a requirement in some circumstances. The alloy in each case is the same Sn/3.9Ag/0.6Cu, to the NEMI standard make up	- The paste from supplier B passed all of the testing and resulting in solder joints which looked similar to those of the current lead containing solders. - All of the suppliers' paste past all of the printing requirements. - The use of halogen free printed circuit board material, should go hand in hand with lead free solder and requires investigation.	LEAD FREE SOLDER FLUX VEHICLE SELECTION PROCESS Andrew Butterfield1, Valerie Visintainer2, Vahid Goudarzi3 Motorola SMT-CD

Focus	Objective	Scope	Conclusion(s) Summary	Reference
215. LFS Processing Conductive anodic filament (CAF) formation	In this paper, we present evidence for an additional reliability concern for lead-free soldered electronic product. Conductive anodic filament (CAF) formation is a failure mode associated with boards, which either operate or are stored in a humid environment.	This paper compares the number of CAF formed on boards reflowed at 201°C vs. 241°C after aging under 100V bias at 85°C/85% RH for 28 days.	Higher board processing temperatures have been shown to result in increased numbers of CAF for most of the fluxes tested. The 241° C peak temperature represents the wave soldering peak temperature for a typical lead-free solder alloy. Reflow temperatures for solder pastes will be even higher. The flux vehicle used in the watersoluble formulation and the halide activator had different interacting effects.	IMPACT OF HIGHER MELTING LEAD-FREE SOLDERS ON THE RELIABILITY OF PRINTED WIRING ASSEMBLIES Dr. Laura J. Turbini Centre for Microelectronics Assembly and Packaging University of Toronto SMT-CD
216. Laminates for LFS Assemblies	This paper will discuss the development of new resin systems that will withstand the higher reflow temperatures required of lead-free solders, while meeting the expectations of PCB manufacturers concerned with both the ease of fabrication processing and providing cost competitive solutions in today's global marketplace.	The current trend in the PCB industry is towards thicker boards requiring smaller coefficients of thermal expansion (CTE). To achieve this lower CTE and minimize costs, FR-4 resin systems with a T_g in the 170 °C range are currently used. However, current systems have T-260 times in the neighborhood of five to ten minutes. Testing at 288°C, as requested by some OEMs, results in timesto- delamination of essentially zero minutes. The apparent front runner for general soldering, specified by the National Electronic	New resin formulations are being developed that will meet the thermal requirements of the new, lead-free solders. These systems have better thermal properties, drill better and potentially will cure faster. As a result of the preliminary screening trials on laminates, PCBs were fabricated on both of these systems at different PCB manufacturers. Several board designs, ranging from standard test boards to 16-layer, 0.093-inch boards incorporating 0.010-inch drilled holes were built. These boards, along with standard 170°C epoxy boards, were fabricated with standard, conventional processes. However, the cure system used in both new materials is faster than the traditional Dicy curing agent and reductions in lamination cycles of 30 minutes or more are possible. These laminate cycle reductions will be studied at a later date. There were no observed issues with manufacturing circuit boards on these materials. Standard drills and drilling parameters were utilized. Micrographs of magnified (200X) 0.0135-inch hole walls obtained form condition. A micro-sections are compared in Figure 1. Smoother PTHs can be achieved with the new products.	**Laminate Materials for No-Lead Solder Applications** Eric Holman and Terry Smith Isola Laminate Systems La Crosse, Wisconsin Presented at IPC Printed Circuits EXPO® 2001 www.ipcprintedcircuitexpo.org

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		Manufacturers Initiative (NEMI) is the Sn-Cu-Ag alloy[2]. There are variations of this alloy using slightly different amounts of Cu and Ag, with slightly different melting points. With a melting point around 216 °C , reflow temperatures near 250 °C or higher are likely.[2] Some original equipment manufacturers (OEMs) are already specifying higher thermal performance requirements, such as a T-288 test (time to delamination at 288 °C) or multiple solder float exposures at temperatures in excess of 550 °F. This increase in temperature will stress the thermal performance of most current PCB resin systems.		
217. Lead-Free Solder Processing	Develop a reliable Pb-free process utilizing SnAgCu solder paste as a replacement for SnPb solder paste	One of the most serious issues for Pb-free electronics assembly is that peak reflow temperatures are projected to rise to 240	- The peak temperature necessary to achieve sufficient wetting should be 232 °C or above. - New profiling techniques can significantly reduce the time and number of iterations necessary to create new profiles. - Components that are currently temperature sensitive to temperatures above 240 °C can be used in Pb-free processing.	Taking the Pain Out of Pb-Free Reflow Paul N. Houston and Brian J. Lewis Siemens Dematic Electronics Assembly

Focus	Objective	Scope	Conclusion(s) Summary	Reference
		°C to 260 °C.	- It was also shown that the shear strength of the Pb-free solder joints were as good if not better than the solder joint strength of the standard SnPb solder.	Systems Advanced Assembly Technology APEX-CD
218. Lead-Free Solder Processing Observations	The various alternatives of lead free materials, surface finishes and manufacturing processes were evaluated as factors in a set of designed experiments and analyzed, in comparison to a baseline of standard leaded processes and materials, using the quality characteristics of visual, mechanical and thermal testing criteria.	Manufacturing Research Laboratory facilities at UMASS Lowell were utilized to test and analyze the performance of alternatives based on the principles of Design of Experiments. Results were analyzed using statistical techniques resulting in determining whether a particular factor was significant to the quality characteristic being measured.	- Lead-free soldering does exist and with little improvement in the existing process it is possible. However individual process optimization and more investigation is necessary. - Surface finish is the biggest contributor (52%). - Reflow environment improves the quality of solder joints with nitrogen having 10% statistical contribution. - No major difference could be noted in results produced using Soak or linear profile. This concludes that linear profile can very well be used since this spends less time on higher temperature and hence low risk of thermal damage to boards and components. - Use of lead-free solders may have a reduction in throughput due to low belt speed in reflow. - Components have to sustain higher and there is a need for major improvement in this area.	DESIGN OF EXPERIMENTS FOR LEAD FREE MATERIALS, SURFACE FINISHES AND MANUFACTURING PROCESSES OF PRINTED WIRING BOARDS Dr. Sammy Shina Hemant Belbase
219. Lead-Free Solder Processing Observations	Slide Presentation	LFS PCB Assembly	- Higher melting temperature of Sn based lead-free alloys: .T = +30 to +40°C - Smaller temperature process window: SnPb: 30-40ºC above Tmelt versus SnAgCu (SAC): 20-25ºC above Tmelt - Problems which will show up (again): Tombstoning, Bad wetting, Solder beading, Voiding, Bridging, Logistics: avoid mixing SnPb and leadfree assembly, Visual inspection (leadfree have different surface)	Techwatch seminar "PCB assemblage" Bart Vandevelde IMEC
220. Lead-Free Solder Processing Observations	Slide Presentation	Component is a lead-free environment	- For component leads, SnBi is not viable until lead has been removed for the solder process (PbBi low melting phase) - Reflow soldering profiles for lead-free solder require increased heat and longer duration - Lead-free solder alloys have higher surface tension producing slower wetting (improves with N gas environment) - Pb contamination of a Sn-Ag-Cu solder joint can result in melting point and	NEPCON, Brighton 2004 Smart Group Lead-Free Experience 2 Angus Westwater

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			solidification temperatures of <180C	
221. Lead-Free Solder Assembly	Paper Presentation	Lead-free solder assembly overview	- Leaders in lead-free manufacturing today - have consolidated on is SnAg 3.0 Cu 0.5. For wave soldering, which uses more solder at higher temperatures, tests revealed no significant differences in deposited paste volumes between tin/lead and lead-free alloys. - Lead-free materials generally have higher surface tension and do not wet pad surfaces as readily as tin/lead pastes. - Reduction in stencil aperture length of 0.020" less than pad length was required to compensate for the wet-out properties of a tin/lead paste, that reduction in length would be less - approximately 0.002" - for a lead-free paste to achieve comparable printing results. - Normal tin/lead reflow process window of 30C° to 40C° is reduced by as much as 20°C in lead-free reflow. This narrower window requires a well-designed oven with excellent temperature distribution across the conveyor and through the entire reflow sequence - Experiments have shown typical solder temperatures in the range of 265º-270º will give the best results with no-lead solders. This increases the delta T by 5º to 15ºC, which may pose a thermal shock concern for some components.	Clarifying Issues in the Transition to Lead-Free Assembly Cookson Electronics Contact - Krista Fabian, Public Relations Manager
222. LF Processing – Cu Build Up	The Sn/Ag/Cu family of alloys is the leading candidate for a lead-free alternative. The first part of this study was to determine if there is any significant difference between Sn/Ag/Cu alloys when used in automatic soldering equipment in terms of copper build-up in the system. The study compared two Sn/Ag/Cu alloys to determine if at processing temperatures one alloy would absorb	As shown in table 1, Sn/Ag3.0/Cu0.5 dissolves almost double the amount of copper as Sn/Ag2.5/Cu0.8/Sb0.5 does at the same temperature over the same short period of time. From this it is inferred that Sn/Ag2.5/Cu0.8/Sb0.5 is more stable in automatic soldering equipment and should require less initial alloy maintenance. This result is corroborated by studiesi showing the	As shown above, by cooling the pot and removing the precipitate the copper level was lowered down to an acceptable level. Therefore, it is possible to salvage leadfree solder using a similar method as used with Sn/Pb, except that the SnCu intermetallics now sink instead of float, and instead of being skimmed now need to be dragged from the bottom of the pot. The end result is that copper levels can be reduced in a lead-free soldering pot to within acceptable levels.	CONTROLLING COPPER BUILD UP IN AUTOMATIC SOLDERING EQUIPMENT USING LEAD-FREE SOLDER David Suraski and Karl Seelig AIM Cranston, RI, USA

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	less copper than the other alloy.	lower copper dissolution of Sn/Ag2.5/Cu0.8/Sb0.5 versus other lead-free alloys, as shown in fig. 1. It also should be noted that extensive third party testingii has demonstrated that this alloy is a viable choice for the HAL process, demonstrating good coverage and solderability with flatter pads than Sn/Pb.		
223. LFS Assembly Processing	To that end, we recently completed a comprehensive study of surface mount reflow (SMT) and through-hole (TH), including both wave solder and pin-in-paste techniques. We looked at solder alloy, surface finish, flux, etc., from the point of processibility, and then tested every joint electrically and visually, following up with air-to-air and liquid-to-liquid thermal cycling.	To satisfy these requirements, our test vehicle was a 12□□ x 10□□, two-sided, four layered, 0.062□□-thick board comprised of six separate circuits. Each circuit had equivalent SMT component composition such that the board could be sectioned for distribution into the different environmental test chambers. The board laminate material was a high performance FR-4 with a Tg between 175 and 180° C. The bottom side of	In common with other studies, we found no major difference between the alloys and surface finishes. What we did find was that large resistor components (1206) failed frequently due to joint cracking under thermal stress. For complex boards, you will need to use a multi-zone oven – 7-zone and above – with integral flux management and nitrogen capability. Wave solder pots of corrosion-resistant cast iron are fine, but stainless steel components are attacked by lead-free alloys over a period of months. Retrofits of specially coated stainless steel for wear-prone components are available. Nitrogen buys you 100C, allowing you to solder at lower temperatures with a better finish joint but incurring nitrogen cost. The different rate of flux evaporation in nitrogen, as opposed to air, has been blamed for "tombstoning" in some assemblies when 0201 components are reflowed in nitrogen. Much of the work in Europe and the USA has been on 3.8-4.0% silver with 0.5-0.7% copper. Japanese work focused on 3% silver to reduce costs. (In our study, the 3% and 4% silver alloys performed about the same.) All these alloys melt around 217$_0$C. Make sure that your solder manufacturer has cross-licensed the alloys you need to cover the global market.	Practical Processing of Lead-Free Assemblies * previously published in PCB007 June 2002 Issue By Alan Rae, Vice President Technology, Cookson Electronics, Inc.

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		the board was used for the wave soldering experiments (arrangements of components on a single circuit is shown in Figure 1 , with the feed direction into the wave indicated by the arrow). The SMT components included SO16s, SOT23s, 1206 and 0805 chip resistors, and fine-pitch QFP80s. The test vehicles were treated with five different surface finishes, including: Hot Air Solder Leveling (HASL) (Sn/Pb HASL for $Sn_{63}Pb_{37}$ baseline alloy and Sn-Cu HASL for the Pb-free alloys), Electroless Ni/Immersion Au (ENIG), Immersion Tin (I-Sn), Immersion Silver (I-Ag), and Organic Solderability Preservative (OSP). The I-Sn finish was only tested in the reflow study, not in the wave study. The alloys evaluated were tin-lead, tin-silver, tin-copper,		

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		tin-silver-copper with 3% and 4% silver, tin-silver-copper-bismuth, tin-silver-copper-antimony and tin-zinc-bismuth.		
224. LFS Assembly Process	The use of 0201 packages is increasing form year to year as the industry continues to drive towards small, lighter, faster products. Many military applications are demanding miniaturized, high reliability designs	The main factors involved in board design for 0201 components are the pad design and spacing of the 0201 to other components	Robust design for manufacturing guidelines were developed and a reliable process window was obtained for a high speed 0201 assembly process that was proven to provide less than a 100 DPM assembly yield for both eutectic lead tin and lead-free solder assemblies	DESIGNING AN 0201 ASSEMVLY PROCESS FOR HIGH YIELD AND RELIABILITY Dan Baldwin Paul Houston Engent
225. Imaging LFS	Many studies have analysed the impact lead free solder pastes will have on aspects such as joint strength and compatibility within the manufacturing process. Numerous studies using lead-rich materials have already identified the major parameters influencing the mass imaging process. However, the material used to replace the lead	The solder paste samples used in this investigation are shown in Table 1. Two different suppliers for the lead-free materials were chosen to determine if this had any effect on the results. All samples shown in Table 1 are commercially available. Sn96.5Ag3.0Cu0.5 88.5 Sn63Pb37 90.0 Sn96.5Ag3.0Cu0.5 89.5	The results show that the fabrication method has a significant effect on the print process capability. Standard laser cut stencils manufactured by three different methods has demonstrated a large process spread. One major element of this difference is the accuracy not only of the aperture size but also position. Stencils displaying good dimensional and positional capability enable acceptable print results, while those showing poor alignment and aperture dimension repeatability also produce poor results with the print process. To print lead free materials we have discovered that: • An accurately fabricated stencil, which has good aperture dimensional integrity, is paramount. • Stencils fabricated from nickel as a base metal seem to give a more robust and capable process. • Enclosed Head technology increases the process window for lead free materials.	Mass Imaging of Lead Free Materials – What impact does Stencil Technology have? Clive Ashmore DEK Printing Machines City, State Presented in the ECWC 10 Conference at IPC Printed Circuits Expo®, SMEMA Council APEX® and Designers Summit 05

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	(Pb) component changes the solder paste properties and therefore the characteristics of the print medium.			
226. LFS Joint Inspection	This paper is intended to aid in the transition from tin-lead to lead-free solder with reference to automated inspection methods. Specifically, the paper discusses many of the general solder joint differences observed within lead-free assemblies and discusses how this will affect Automated Optical Inspection (AOI) and Automated X-ray Inspection (AXI) in terms of the capability to perform lead-free component and solder joint inspection.	The main purposes of the Lead-Free Qualification Matrix were to identify the activities required to qualify test and inspection equipment as lead-free capable. This would highlight a series of projects and initiatives that must be undertaken to understand the limitations of our current processes when applied to PCBs assembled using leadfree solder. In turn, these projects may highlight capability gaps that must be closed to ensure complete success in the transition process.	The key to the successful implementation of a lead-free process will be the gathering and analysis of data collected from the process. As AOI and AXI will be able to perform effectively on these products, they will be valuable tools, especially during the transition process. As new products are introduced, more information and data will be gathered to further define test and inspection processes and strategies. It may also drive amendments to design for test and assembly requirements.	INSPECTION OF LEAD-FREE SOLDER JOINTS ON PRINTED CIRCUIT ASSEMBLIES USING AUTOMATED INSPECTION TECHNIQUES Andrew Pollock Celestica Manchester United Kingdom apollock@celestica.com
227. LF Manufacturing Inspection	The paper will address issues that will impact defect levels and defect spectrum during the transition to lead-free manufacturing. Since	During the last several years the industry has experimented with many different type of alloys. The USA has mainly converged	The switch to lead-free is a major process change and will impact PCBAs for both products that are mandated to switch to lead-free before July 2006 as well as PCBAs for exempted products. Since not all components will be available in a lead-free version, while others will be available only in a lead-free version, all PCBA manufacturing will be impacted. From a test and inspection point of view, defect levels in many cases will increase significantly and also the defect spectrum is likely	The importance of Test and Inspection when implementing lead-free manufacturing Stig Oresjo Agilent Technologies, Inc.

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	there are exemptions of which product types are mandated to go lead-free, and not all components will be available in lead-free versions there is not a clean path to lead-free manufacturing. Both manufacturers that are forced to go lead-free as well as companies that are exempted will be impacted.	towards the NEMI and SMTA recommendation of 3.9% silver, 0.6% copper and the rest tin. NEMI recommends 0.7% copper and the rest tin for the wave soldering process. Europe mainly is experimenting with tin, 3.4-3.9% silver, and 0.5 – 0.9% copper.	to change somewhat. Higher defect levels and a changing defect spectrum means that more attention to test and inspection is needed.	Loveland, Colorado Robert Ling Agilent Technologies, Inc. Singapore
228. Flip Chip Inspection	This paper will discuss the existing problem of topside ball delamination for the area array packages FCs and CSPs by highlighting passages from recent research publications. The research shown presents important failure analysis data relating to FC and CSP reliability in both a tin-lead and a lea d free soldering process. Finally, an introduction of a new optical inspection technology designed to detect such defects in a non-destructive manner	In any case, the extremely small component side joints of an FC or CSP are at greater risk of failing under mechanical stress. Professor Toshio Nakamura and Gary Yu Gu have conducted extensive research aimed at understanding the failure mechanism by identifying likely fracture modes and potential delamination sites in flip chip packages. Their research entitled **"Mechanical Behaviours of Flip-Chip Packaging"**	This paper has highlighted a very specific defect of component side ball delamination of area array packages, in particular FCs and CSPs, by examining and summarizing current research available on this critical subject. It has become clear that the lead free soldering process will create new process challenges for these components. Simply put, the existing problems of component side delamination will be exacerbated in a lead free process. With this knowledge, therefore, it is essential to implement proper inspection and test procedures in order to guarantee a quality lead free FC and CSP soldering process. Failure to discover such fatal process defects, as highlighted above, will result in in-field failures, and will generate unnecessary warranty and repair costs.	Lead Free Flip Chip and Chip Scale Package Inspection: New Challenges Will Require New Inspection Technologies Mark Cannon and Juergen Friedrich ERSA GmbH Wertheim, Germany Presented in the ECWC 10 Conference at IPC Printed Circuits Expo®, SMEMA Council APEX® and Designers Summit 05

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	will be made.	clearly shows that the upper solder connection is at greater risk of delamination as seen in Figures 3 and 4 below.		
229. Impact Defect Levels	The paper will address issues that will impact defect levels and defect spectrum during the transition to lead-free manufacturing. Since there are exemptions of which product types are mandated to go lead-free, and not all components will be available in lead-free versions, there is not a clean path to lead-free manufacturing. Both manufacturers that are forced to go lead-free as well as companies that are exempted will be impacted. This and other issues will have a big impact on the optimal test strategy. Data of defect levels and defect spectrum from lead-free production will be presented below. The paper will also address different test and	A complicating factor when going lead-free is that lead is in many areas of the PCBA. Lead can be found in the solder paste and solder. Components also have lead on their connection pins and in many cases also internally. In many cases many bareboard finishes include lead. Because lead is in many types of material used on the PCBA and some products are mandated to switch to lead-free, while others are exempted, it will not be a clean switch.1 See Figure 1. These two factors will create many issues that will be addressed. Today we have tin-lead solder and tin-lead components. In most cases it will not be as easy as at once we have	The switch to lead-free is a major process change and will impact PCBAs for products that are mandated to switch to leadfree before July 2006 as well as PCBAs for exempted products. Since not all components will be available in a lead-free version, while others will be available only in a lead-free version, all PCBA manufacturing will be impacted. From a test and inspection point of view, defect levels in many cases will increase significantly and also the defect spectrum is likely to change somewhat. Higher defect levels and a changing defect spectrum mean that more attention to test and inspection is needed. Studies and early experiments show that test and inspection systems and methods are ready for lead-free. Additional data gathering of defect levels and defect spectrum for production lead-free boards is needed.	Test and Inspection as Part of the Lead-Free Manufacturing Process Stig Oresjo Agilent Technologies, Inc. Loveland, Colorado Presented in the ECWC 10 Conference at IPC Printed Circuits Expo®, SMEMA Council APEX® and Designers Summit 05

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	inspection systems' readiness to test lead-free printed circuit board assemblies (PCBA).	lead-free solder and all components are lead-free, see Figure 1, Path A. For the industry that is forced to go lead-free the most likely path is that they switch to lead-free solder paste, but not all components will be lead-free in the beginning, as illustrated in Figure 1, Path B.		
230. LFS Assembly Flip Chip	An assembly process for environmentally conscious low cost flip chip assembly to microvia laminate substances	SnAgCu systems, with the alloying elements ranging from 3.0 to 4.7 percent Ag and .5 to 3.0 percent Cu. The melting temperature of the various alloy compositions do not vary much, they are between 217 and 221C	The lead-free processing window is extremely sensitive to such factors as flux amount, reflow atmosphere, and peak reflow temperature. Under fill adhesion tests indicate higher adhesion of under fill to lead-free solders than to SnPb. The study has demonstrated good reliability with a material set passing 1000 thermal cycles before first failure	PROCESSING AND RELIABILITY OF FLIP CHIP WITH LEAD-FREE SOLDERS ON HALOGEN-FREE MICROVIA SUBSTRATES Dan Baldwin Grant Baynham Engent
231. LFS Materials Solder Balls	Based on a comparison of different ball materials for BGA / LFBGA / CSP components the quality of interconnections will be discussed followed by any reliability results.	Solder balls were used for ball attach on commercially available laminates (pads). To analyse extended TCT requirements the testboards were taken for the test conditions TCT-40/+150, N = 2000 cycles.	To implement Pb-free solder it is to guarantee, that the solder joint formation is in minimum comparable to SnPb. To modify only the ball material for area array devices can't fit the requirements for the whole product.	ALTERNATIVE LEAD FREE BALL MATERIALS WITH IMPROVED INTERFACE PROPERTIES H.-J. Albrecht Siemens AG,
232. Aerospace &	Slide Presentation	The Negative Impact of Lead free Products on	- Environmental justification for conversion to lead-free is invalid - Current replacements for lead-based solder compounds appear to be more toxic and	The Negative Impact of Lead free Products on

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Military Electronics Reliability		Aerospace & Military Electronics Reliability	harmful to the environment - Reliability of products manufactured with lead-free solder and components has yet to be proven in service - Dependence of military / aerospace industry applications on lower reliability lead-free components will result in higher risk - Tremendous costs for conversion to lead-free products	Aerospace & Military Electronics Reliability Andy Kostic, Ph.D. Fellow Northrop Grumman Charlie Minter Technical Risk Manager Best Manufacturing Practices Center of Excellence
233. LFS Alloy Systems Intermetallic Compounds	CAVE Monograph Slide Presentation Formation of intermetallic compounds directly impact long-term reliability of solder joints. Intermetallics are usually brittle and lower the reliability by acting as sources of joint crack propagation	Determine the intermetallic composition, thickness, and growth rate for a variety of Pb-free solder alloys joined to Pb-free board finishes as a function of time under isothermal conditions (150C)	- The growth of intermetallic compounds in the Pb-free solder joints tested is largely governed by ordinary diffusion-controlled growth processes described by classic kinetic theory at 150C - The Pb-free solder alloys tested on Sn, Ag, and OSP form dual intermetallic layers consisting of the n-phase (Cu6Sn5) nearest the solder and the e-phase Cu3Sn nearest the board finish. The results are similar to the Sn-Pb solders on Cu	Identification and Growth of Intermetallic Compounds in Pb-Free Solder Alloy Systems M.J. Bozack and Chad Rodekohr
234. LFS SAC Intermetallic Study	This paper focuses on the intermetallics study of reliability tested solder joints between the Sn-3.5Ag-0.75Cu lead-free solder balls and Sn-plated Cu pads on molded BGAs.	This report addresses the metallurgy and integrity of package-level C5 solder joints using Sn-3.5Ag-0.75Cu with Sn-plated Cu pads. Sn-3.5Ag-0.75Cu was identified as the subject of study because of **its** advantages in reliability, mechanical properties (creep, thermal fatigue	- ***Shear strength superiority of lead-free solder*** - Lead- free solder exhibited superiority in shear strength compared to Sn-Pb-Ag solder after TH, AATC and LLTS. This was because the **3** reliability tests resulted in lead-free solder interface with uniform microstructure and small amount of IMCs formation, - From these observations, it is concluded that the primary concern in reliability of lead-free solder should be related to the annealing and IMCs growth at solder joints.	An Intermetallic Study of Solder Joints with Sn-Ag-Cu Lead-free Solder C.F. Chan (Motorola), S. K. Lahiri (SMA), P. Yuan (Motorola) and J. B. H. How (Motorola)

Focus	Objective	Scope	Conclusion(s) Summary	Reference
		resistance) and solderbility compared to other lead-free alternatives such as the Sn-Cu, Sn-Ag and Sn-Ag-Bi **[2].**		
235. Inter metallic Growth in Pb-Free Solders Solder Reliability Mechanical Properties of Pb-Free Solders (Presentation)	Study intermetallic growth, solder reliability and other characteristics of lead-free solders.	Study Growth of four Pb-Free alloys as a function of time and board finish (at 150C) Examine real-time, in-situ melting, wetting and spreading dynamics of Pb-free solders on three classes of substrate (Ni-Au, Cu, Al2O3) Evaluate stress-strain, creep, fatigue and other mechanical properties of Lead-free solder materials as a function of temperature, thermal cycling, exposure, etc. Provide basic mechanical properties of different Lead-free solder material for finite element analyses. Characterization of Lead-free solders subjected to thermal cycling (93.5Sn-3.8Ag-07.Cu-2.0Bi, 92.35Sn-3.35Ag-1.0Cu-2.0Bi,	Determined intermetallics, characterized interface and wetting for 7 solders on 3 substrates. Determined that air-cooled SnPb samples have higher ultimate tensile strength and higher yield stress. SnAgCu have the higher elastic modulus SnPb water cooled with no reflow samples are the only type that shows a downward plastic deformation, leading to longer strain failure. Solder voids in all solder compositions in as fabricated boards were observed. Sphereodization and coarsening of the second phase was observed after thermal cycling SnBi based alloys have poor reliability with immersion silver finish. SnBi based alloys have better reliability with ENIG finish than with immersion silver finish. The best reliability is obtained with SnPb joints with ENIG plating.	Center for Advanced Vehicle Electronics (CAVE) Intermetallic Growth, Wetting Studies - M.J. Bozack and Chad Rodekohr Lead-free Solder Behavior - Hecham Abdel-Hady, Hongtao Ma Microstructural Characterization - Shyam Gale Joint Reliability - Tushar Shete, N. Islam

Focus	Objective	Scope	Conclusion(s) Summary	Reference
		88.5Sn-3.0Ag-0.5Cu-8.0In, 95.5Sn-3.8Ag-0.7Cu) at (-40C - 150C AATC, up to 5000 cycles) Lead-free solder joint reliability (SnBi, SnBiAg)		
236. Solder Joints High Temperature	The term "high temperature electronics" is used for operating temperatures more than 125°C. For a lower temperature is the application of standard components, substrates and common SnPb-solders possible whereas special solutions are demanded for high temperature electronics.	For a further raise of operating temperature without increasing soldering process temperatures, it is necessary to find other solutions.	Conventional solder joints are limited in operating temperatures, higher melting solder alloys have a number of disadvantages, which can be accepted only in exceptional cases. With improved solders, e.g. reacting solder pastes, it is possible to extend the operating temperature range up to 150°C. Beyond the 150°C are new joining technologies demanded, for example the combined solder and adhesive joint and the use of liquid or liquid/solid solders for interconnections.	SOLDER JOINTS FOR HIGH TEMPERATURE ELECTRONICS Mathias Nowottnick, Uwe Pape, Klaus Wittke, Wolfgang Scheel Fraunhofer IZM Berlin, SMTA-CD
237. SAC Alloy and intermetallic growth	Long-term, solid-state intermetallic compound (IMC) layer growth was examined in 95.5Sn-3.9Ag-0.6Cu (wt.%)/copper (Cu) couples.	Aging temperatures and times ranged from 70°C to 205°C and from 1 day to 400 days, respectively. The IMC layer thicknesses and compositions were compared to those investigated in 96.5Sn-3.5Ag/Cu, 95.5Sn-0.5Ag-4.0Cu/Cu, and 100Sn/Cu couples	In summary, a comparison was made of the IMC layer growth kinetics between the four Pb-free solder/ Cu couples. Only the kinetics of Cu3Sn growth were sensitive to the solder composition and, specifically, the Ag component of those compositions. Development of the Cu6Sn5 layer, which also dominated the total IMC layer growth kinetics, was not sensitive to the solder composition. These trends, together with observations that the total IMC layer thicknesses were comparable between the four solder/Cu couples as a function of aging time and temperature, provides additional evidence that the primary effect of solder composition on solid-state IMC layer growth is in the thickness fraction and growth kinetics of the Cu3Sn layer.	Solid-State Intermetallic Compound Layer Growth Between Copper and 95.5Sn-3.9Ag-0.6Cu Solder PAUL T. VIANCO,1,2 JEROME A. REJENT,1 and PAUL F. HLAVA1 1.—Sandia National Laboratories, Albuquerque, NM 87185. 2.—E-mail: ptvianco@sandia.gov
238. LF BGA	In this paper a study	- The test vehicle	The results of this study show that, for a bare Cu pad- SnAgCu solder interconnect	Effect of Thermal Aging on

Focus	Objective	Scope	Conclusion(s) Summary	Reference
Packages Voids	was conducted to investigate the influence of intermetallic compound (IMC) growth on the solder joint reliability of Pb-free ball grid array (BGA) packages under drop loading conditions.	considered was a chip scale package with bare Cu BGA pads and SnAgCu solder ball. The experiment - Thermal aging of the test board assembly was performed at 125°C for 3, 10, 20 and 40 days to induce solid state IMC growth for solder joints.	system, Kirkendall voiding at the Cu to Cu_3Sn IMC interface is the main mechanism for joint strength degradation under thermal aging. Based on these observations, the Cu-SnAgCu solder interconnect system is not recommended for use in high temperature applications since the interfacial voiding was shown to be detrimental to the shock reliability of the system.	Board Level Drop Reliability for Pb-free BGA Packages Tz-Cheng Chiu, Kejun Zeng, Roger Stierman and Darvin Edwards1, Kazuaki Ano2 1 Texas Instruments, Inc.
239. LFS Assemblies – Investigating Voids	Quite a lot of information has been published about changes in the level of voiding as the industry moves from a lead-based assembly process to a lead-free process.	While this article does not enter into this debate, it will report on the findings of a controlled leadfree study and draw comparisons to current knowledge.	- Voiding increases with the use of higher melting point tin/silver/copper alloys. - The increased surface tension of these materials adds to this phenomenon. - Reflow profiles and cooling rates have a significant influence on voiding and the position of the voids.	Investigating Voids Keith Bryant Circuits Assembly JUNE 2004
240. LFS Wave Soldering Passive Components	Many people are concerned about the future use of Poly(butylene terephthalate) (PBT) connectors with a melting point around 220°C in a wave soldering process with solder-pot temperatures predicted to rise to above 265- 275°C with the introduction of lead-free solders. This study compares the	simulating the lead-free soldering environment by simply increasing the temperature on a wave soldering machine filled with conventional Tin-Lead solder. Corresponding standard pin metallurgy was used in the connectors.	The process windows are getting tighter just when more flexibility is needed by the practitioners of wave soldering in order to achieve good solder joints with the new, higher melting, lead-free solder alloys. We expect that at least some PBT applications will have to be upgraded to higher temperature materials in order to survive lead-free soldering. Many resins like LCP, PPS, and PPA would require costly retooling	THERMOPLASTIC CONNECTOR HOUSINGS IN A LEAD-FREE WAVE SOLDERING ENVIRONMENT Gerald Keep, Kenneth Breeding, and Michael Cliffton Eastman Chemical Company SMT-CD

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	performance of PBT to that of higher melt point alternatives.			
241. LFS Wave Soldering Selective Soldering	This paper describes the use of selective soldering as a viable alternative to wave soldering for lead-free soldering of TH interconnections.	Programmable selective soldering systems shown in Figure 4 use a software-controlled multi-axis environment to control flux deposition, preheating and solder application.	Selective soldering is a viable, cost effective alternative to wave soldering for lead-free soldering of TH interconnections in complex mixed technology PCB assemblies. Confirmation tests have established that sustained topside convection preheat throughout the selective soldering process results in improved solder joint quality.	LEAD-FREE SELECTIVE SOLDERING: THE WAVE OF THE FUTURE Bob Klenke ERSA, Inc. SMT-CD
242. LFS Selective Soldering	For this reason selective soldering becomes more interesting since in this process only the areas that come in contact with the lead-free solder will meet these high temperatures and other parts on the assembly will stay way beyond.	A DOE was performed on a select wave to investigate and quantify which process parameters impact the quality of soldering. The select wave can be applied in applications containing single and multiple through-hole leads, like connectors.	- It requires a structural approach to transfer to lead-free that includes a study of the process in order to determine the optimal settings for an alloy with a higher melting point and different flow characteristics. - Optimization of the parameters, like nitrogen flow, solder wave height and flux contribution needs to be done before the lead-free implementation.	SELECTIVE SOLDERING WITH LEAD-FREE ALLOYS Marc Dalderup, Denis Barbini Vitronics Soltec SMT-CD
243. Selective Soldering SAC	This paper focuses on the effects of board surface finishes and selective soldering process parameters such as drag speed and solderpot temperatures, on the formation and strength of the solder joints. The analysis shows that the process	The components were soldered utilizing a Selectwave fitted with an 8 mm diameter single point nozzle. The solder was actively flowing over the nozzle in a specific direction that opposes the course of the board as it is soldered. The overflow	The purpose of this study was to identify the impact various parameters exert on the solder joint formation and defect level. Trends were observed based on drag speed, board surface finish, solder temperature. Also important was the type of component. On this board three through hole components were included. Each component is characterized by unique finish, thermal properties, pin count, etc… A combination of board level, component level, and process level parameters resulted in a soldering process that is optimized at different parameter levels. The flexibility in automating a soldering process that is adjustable for drag speed, solder angle, dip soldering, and possibly solder temperature can result in optimization of solder joint quality.	SELECTIVE SOLDERING WITH SN3.9AG0.6CU: PROCESS DEVELOPMENT Ursula G. Marquez Vitronics Soltec, Inc. Binghamton, NY, USA Umarquez@us.vitronics-soltec.com Denis C. Barbini Vitronics Soltec, Inc.

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	development and material selection should be optimized per component type. This work was accomplished within the scope of the NEMI Lead Free Assembly and Rework Project.	of the solder is controlled by nozzle design. The 8 mm nozzle is surrounded by a 50 liters per minute, lpm, flow of nitrogen gas. The board was held at an angle of 10° by means of a robotic gripper. In this investigation, the goal was to determine the optimized process for each component.		Stratham, NH, USA Dbarbini@us.vitronics-soltec.com Richard A. Szymanowski Celestica, Inc. Toronto, ON, Canada raszyman@celestica.com
244. Selective soldering is a process for soldering thru-hole components on the bottom side of an assembly. lead free assembly and rework	identify the impact various parameters exert on the solder joint formation and defect level such as drag speed and solderpot temperatures, on the formation and strength of the solder joints.	provide a preliminary understanding in how the wave and selective soldering process are impacted with the use of lead free alloys	Trends were observed based on drag speed, board surface finish, solder temperature. Also important was the type of component. On this board three through hole components were included. Each component is characterized by unique finish, thermal properties, pin count, etc. A combination of board level, component level, and process level parameters resulted in a soldering process that is optimized at different parameter levels. The flexibility in automating a soldering process that is adjustable for drag speed, solder angle, dip soldering, and possibly solder temperature can result in optimization of solder joint quality.	Ursula G. Marquez Vitronics Soltec, Inc. Binghamton, NY, USA Umarquez@us.vitronics-soltec.com Denis C. Barbini Vitronics Soltec, Inc. Stratham, NH, USA Dbarbini@us.vitronics-soltec.com Richard A. Szymanowski Celestica, Inc. Toronto, ON, Canada raszyman@celestica.co ftp://nemi.org/webdownload/newsroom/Presentations/SMTAI-04_selective_soldering.pdf
245. LFS Selective Solder	Lead-free soldering is currently being introduced on a wide	A single, standard solder joint configuration was used	A cost effective robotic diode laser soldering system has been developed and used to successfully solder lead-free and lead-containing solder joints.	AUTOMATED SELECTIVE SOLDERING OF LEAD-TIN AND

Focus	Objective	Scope	Conclusion(s) Summary	Reference
Laser	scale as a response to the current / proposed legislative restrictions on the use of lead in electronics, especially in the Far East and Europe.	to demonstrate a generic experimental approach to minimizing heat input. A small FR4 circuit board was designed specifically for investigations into diode laser soldering. In this case, 96.5%/3.5% tin/silver solder pre-forms were used, melting point 221°C, supplied by Alpha Fry Technologies.		LEAD-FREE SOLDERS - A COMPARATIVE STUDY USING DIODE LASER AND XENON LAMP Syed Naveed1, Anthony Hoult2, and Victor Trotter1 1Spectra Technologies Inc, SMT-CD
246. Lead Free Wave Soldering, Solder joint strength; Solder compatibility	Impact of contamination and limits. Analyze alloys for wave solder, optimize alloy for wave solder	Compared several alloys on single sided and double sided boards.	Lead-free wave soldering has several practical lead-free alternatives. Contamination lowers melting point. Conclusions and Recommendations • Poor Pull Strength is the Result of Lead Contamination and Diffusion of Finish into the Joint Leaving the Exposed Lead Material. • Possible other Causes are Board Warpage, Component Warpage. • Avoid Unintended Double Reflow! – Customer fabricated specific QFP heat sinks to resolve double reflow • Do NOT Mix Tin Lead and Lead Free.	Ursula Marquez Umarquez@us.vitronics-soltec.com Wave Soldering Selective Soldering Reflow Soldering Vitronics Soltec Binghamton, NY October 18, 2003 ftp://nemi.org/webdownload/newsroom/ Presentations/09.pdf
247. NEMI Lead Free Wave Soldering Project	0 to 100 ^{o}C and -40 to 125^{o}C thermal cycling	Build upon work being done in the NEMI Lead Free Assembly and Rework Project Lead Free Wave Solder Process	Tests underway Planning began May 2004, tests scheduled to begin Jan 2005	Bill Bartel, Plexus Stu Longgood, Delphi Jim Wilcox, IBM Kitty Pearsall, IBM Quyen Chu, Jabil Jennifer Nguyen, Solectron

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		development using a limited number of process variables. Characterizing the first pass yield Long term reliability and MTBF Evaluating the norms used today for tin lead and identifying the behavior of lead free. Baseline all tests with atin lead control experiment		Ernesto Ferrer, HP Denis Jean, Plexus Denis Barbini, Vitronics Soltec ftp://nemi.org/webdownload/projects/Wave_Solder_mins070604.pdf
248. LFS Wave Soldering Process Controls	Wave soldering is a relatively simple process to convert to lead-free, but the conversion brings subtle changes that result in a tighter process window.	When wave soldering process parameters operate outside their normal windows, many expensive defects can be produced. The application of appropriate process control techniques can effectively prevent many of these defects.	- The wetting of lead-free alloys to solderable surfaces does not occur as readily as eutectic solder. It is generally accepted that the use of a nitrogen environment improves wetting, and solder pot temperatures for lead-free alloys can be run 10oC cooler with similar solderability results when nitrogen is employed. - Lead-free alloys do not have the same surface tension as lead-bearing alloys, and the peel-off from the wave is not as effective at removing solder bridges. The use of a hot debridging knife can dramatically improve process yields.	LEAD-FREE WAVE SOLDERING – TIGHTER PROCESS WINDOWS NEED TIGHTER PROCESS CONTROLS Chrys Shea Cookson Electronics Assembly Materials SMT-CD
249. Lead-free Reflow Oven and Rework Machine Status	The NEMI lead-free component group conducted a study on reflow temperatures during lead-free soldering to cover the following issues:	For computer related electronics	• Increasing bottom side board preheat was found effective in reducing delta T between solder joint and component body but potential risk of secondary reflow of adjacent components and bottom side components and reliability of board material • Margin of error to maintain a lead-free minimum solder joint temperature of 230-235°C with maximum body temperature of 245°C-250°C (old J-STD-020B standard) is very tight (for some of the best rework development engineers in the industry).	Jasbir Bath, Solectron Corporation Milpitas, CA, USA Tel: (408) 957 2935 Email: JasbirBath@ca.slr.com ftp://nemi.org/webdownload

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	• 1) What is the □T across a typical circuit board and the components • 2) What are the typical processing tolerances for reflow ovens • To assess the impact that reflow equipment has on □T, two oven manufacturers ran experiments with their 10 zone convection ovens. • Hot air convection ovens are the standard reflow equipment used in the industry.		• Adjacent component temperatures were being exceeded at 150mils on the board in many cases. • Payette boards in Phase 3 have been assembled and reworked and are in ATC reliability testing Rework Conclusions • Margin of error to maintain a lead-free minimum solder joint temperature of 230-235°C with maximum body temperature of 245°C-250°C is very tight during BGA/ CSP rework (for some of the best rework development engineers in the industry). New J-STD-020C standard to help to address this. • Adjacent component temperatures were being exceeded at 150mils on the board in many cases for tin-lead and lead-free rework. • Rework Equipment and Nozzles are still in the process of development for lead-free (Generally more difficult to control temperatures in rework that reflow: Need more process manufacturing margin). • Other lead-free BGA/CSP rework techniques such as lazer are still in development • Hand-soldering lead-free rework was conducted successfully • Lead-free mini-pot connector rework is still in development	/newsroom/ Presentations/08.pdf
250. LFS – Intrusive Reflow	As the use of SMT components has increased and the use of through-hole component has decreased (but not eliminated) the use of Intrusive reflow has become a method of soldering the limited quantity of PTH components. Intrusive reflow uses the SMT process to solder the	The experiment was set up using the same criteria used for SnPb solder. As was stated earlier the goal was to determine if the same rules would apply when using a lead-free alloy (SAC). Initial paste volume was set low and then increased as the build progressed. Some of the production parameters:	As stated previously, the main goal of this build was to see if the rules used for SnPb can be applied to the SAC alloy. Based on the results we have seen the same rules currently applied to SnPb based materials can be applied to a SAC based alloy. The use of intrusive reflow, as long as the component can withstand the higher temperature of the process, does produce a solder joint that meets IPC 610 for hole fill as long as sufficient solder paste can be applied to the PCB..	INTRUSIVE REFLOW USING A LEAD-FREE PROCESS Frank Grano and Felix Bruno Sanmina-SCI Technology Development Center (TDC), Huntsville, AL, USA

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	Through-hole components. Solder paste is applied to the PCB, the Through-hole component is inserted into the board, and then it is reflowed along with the SMT components.	• One overall stencil aperture design was used for all boards. Paste height was varied to increase the overall paste volume. • The stencil overprinted the PCB pad in one direction. • A single reflow profile was used for all stencil variations		
251. LF wave soldering - equipment	This paper describes the effects of Sn rich solders in contact with various materials and discusses alternate methods to alleviate this problem.	In cooperation with the Metallurgy Department of the University of Missouri - Rolla, the Sn corrosion effects were studied for stainless steels, coated stainless steels, titanium, cast iron, and other materials. Corrosion effects and test results are presented for each of these materials.	Utilizing the data presented, the person responsible for Wave Soldering operations should be able to make good decisions as to what will need to be replaced in his/her existing Wave Solder machine. The data can also be used as a guide to assist in the selection of the proper materials used in a new machine.	Equipment Impacts of Lead Free Wave Soldering Jim Morris Advanced Development Manager Cookson Electronics Equipment
252. Lead-free Component and Board Temperature Requirements	• Lead-free Soldering Temperatures compared with tin-lead soldering • J-STD-020C and JEITA component temperature rating for lead-free soldering • Lead-free PCB working group activity	For computer related components	Laminate material suppliers and PWB manufacturers should develop/make available higher temperature lead free versions of their products much earlier than may be required by legislation due to the number of tests needed for the bare board and the time taken to conduct product level evaluations. Due to the significant decrease in modulus that typically occurs shortly before the Tg is reached, the cycling temperature should be: at least 10°C below Tg, preferably at 20°C below Tg for better correlation with long term field life reliability.	Jasbir Bath, Solectron Corporation Milpitas, CA, USA Tel: (408) 957 2935 Email: JasbirBath@ca.slr.com ftp://nemi.org/webdownload/newsroom/Presentations/08.pdf

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	and input into standards groups			
253. Sn3.9Ag 0.6Cu Creep Behavior	Aging effects and creep behavior along with microstructure changes in eutectic PbSn and lead-free solder alloy Sn3.9Ag0.6Cu were studied	The aging temperatures were room temperature and 180C. The aging times ranged from as cast up to 35 days	Sn3.9Ag0.6Cu ternary alloy consists of a mixture of eutectic regions of dispersed Ag3Sn intermetallic compounds within a tin-rich matrix surrounding large equiaxed crystals of tin-rich solid solution.	Aging and Creep Behavior of Sn3.9Ag0.6Cu Solder Alloy Xiao, Nguyen, Armstrong University of Wyoming
254. LFS Solder SAC Alloy Analysis	In order to determine what material is best suited to be the standard alloy, the IPC SPVC members have reviewed the most likely candidates in the current list of contenders	To cover that composition range the alloys chosen for testing by the IPC SPVC were: 96.5/3.0/0.5 Tin/Silver/Copper 95.5/3.8/0.7 Tin/Silver/Copper 95.5/4.0/0.5 Tin/Silver/Copper	Based on the results of the tests described above and the statistical analysis of the data gathered the difference between the alloys is not statistically significant. The difference in test procedures, between locations, is of more consequence than the variation in alloys. Significant microstructure changes were observed in the Sn3.9Ag0.6Cu creep specimens. Strong coarsening was observed in the silver and copper containing IMC particles in crept Sn3.9Ag0.6Cu specimens	IPC-SPVC-WP-006 ROUND ROBIN TESTING AND ANALYSIS LEAD-FREE ALLOYS TIN, SILVER and COPPER
255. Sn3.0Ag 0.5Cu - intermetallic growth	This paper describes the formation of intermetallic compounds at the interface and in the bulk of Sn3.0Ag0.5Cu reflow soldered on FR-4 PWBs	After reflow two boards from each plating system were aged at 0.85Tm1 (143.5C) in order to accelerate the intermetallic effects of long term exposure to steady state temperature without degradation of the laminate boards and delamination of the plated pads	The hardness and elastic modulus of ternary intermetallic (Cu-Ni-Sn) in Au/Ni plating are 6.9 GPa (+/-5%) and 163 GPa (+/-4%). These are about 20% higher than binary intermetallic (Cu6Sn5) on OSP plating. The higher hardness in intermetallics indicates the higher possibility of failure related to intermetallic brittleness, which can create the cracks in solder joints. Ternary intermetallics formed in Au/Ni plating have better shear strength but more chance of cracking under mechanical shocks	Study of Intermetallic Growth on PWBs Soldered with Sn3.0Ag0.5Cu Lee, Hwang, Park CALCE
256. Surface	This paper presents	immersion silver is	Immersion silver finish outperformed immersion tin finish in the wettability subject to	SOLDERABILITY AND

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Finish Solder ability - Immersio n Ag	intensive experimental results from wetting balance and solderability tests of immersion silver (I_Ag) and tin (I_Sn) finishes in comparison to those of hot air solder leveling (HASL) and electroless nickel immersion gold (ENIG).	promising. To understand the impact of board handling on the wettability, extensive solderability tests were performed in this paper. It covers hot baking, moisture aging, multiple reflows, misprint and wash. Both reflow soldering and wave soldering were performed to evaluate the solderability	environmental stress. Both finishes can be used in PCB boards with a shelf life over half year.	PROCESS INTEGRATION STUDIES OF IMMERSION SILVER AND TIN SURFACE FINISHES Dongji Xie, Ph.D., FLEXTRONICS, San Jose, CA SMT-CD
257. Surface Finish Immersio n Ag	The interest in new PCB surface finishes is fueled by two drivers, demands for increased functionality/ yield at electronic assembly, and demands for process ease/ productivity at PCB fabrication.	The concept of a metallic solderability preservative was tested with fabricator and end-use customers. The chemical formulations were developed to achieve productivity, cost, and functionality metrics. The metallic finish was tested by independent labs, industry consortia, and by individual customers in order to verify our internal results.	The Sterling immersion Silver metallic solderability preservative process has been developed to provide an inexpensive finish with the functionality of high performance metal coatings. The finish exceeds industry requirements for electrical performance and is capable in applications requiring surface conductivity.	NEW GENERATION METALLIC SOLDERABILITY PRESERVATIVES: IMMERSION SILVER PERFORMANCE RESULTS Donald P. Cullen MacDermid, Incorporated SMT-CD
258. Surface Finish Immersio n Ag	The increase in packaging density has highlighted the limitations of Hot Air Solder Level (HASL)	The use of large, fine pitch components has put increasing importance on component pad	Immersion silver has proven to be an acceptable replacement for HASL for automotive electronic applications. Immersion silver has demonstrated superior moisture and insulation resistance behavior compared to HASL, and modules manufactured with an immersion silver finish have passed all appropriate module validation testing.	EVAUATION OF IMMERSION SILVER FINISH FOR AUTOMOTIVE ELECTRONICS

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	as a Printed Wiring Board (PWB) surface finish due to coplanarity and process variability limitations. These limitations have directed the search for a planar and more consistent surface finish which could replace HASL as a PWB surface finish without major performance drawbacks in terms of storage, manufacturing or module performance.	coplanarity making HASL finishes more and more undesirable. Additionally, the desire and potential regulatory requirement for no-lead electronics precludes the use of a lead based HASL finish. As a consequence, Visteon has been evaluating alternative PWB surface finishes to replace the traditional HASL surface finish.		Robert Gordon, Susan Marr, Dongkai Shangguan Visteon Corporation SMT-CD
259. Surface Finish – Immersion Gold	In this study, the DIG process (Direct Immersion Gold), is investigated. DIG is a process in which gold is plated directly on copper as a surface finish for printed circuit board and package applications. By examining the deposition reaction of the electroless flash gold plating bath, it was confirmed that, copper does not co-deposit with gold and also that the main driving force for deposition is an autocatalytic reaction.	Regarding feature 3) Copper co-deposition; theoretical evaluation was conducted by investigating the oxidation potential of the reducing agent contained in the DIG bath and the deposition potential of copper. Also, by conducting Auger analysis on the deposit, it was confirmed that copper does not contaminate the gold layer. Furthermore, by measuring the amount of dissolved copper and comparing it to the	Many processes are being proposed as a final finishes for printed circuit board and package applications. In this study, a finishing process that can directly deposit gold onto the copper surface by utilizing an electroless plating process has been presented. It was confirmed that it is possible to directly deposit gold on the copper surface with excellent coverage and without creating defects on the copper surface, because the main gold depositing reaction is an auto-catalytic and not a displacement one. Furthermore, by combining a neutral auto-catalytic heavy gold electroless plating bath, a heavy gold layer was deposited directly on the copper surface. The applicability of solder mounting and gold wire bonding on these gold plating layers (flash 50nm and heavy 500nm) directly on copper was demonstarted.	Direct Immersion Gold as a Final Finish Shigeo Hashimoto, Masayuki Kiso, Yukinori Oda, Horshi Otake C.Uyemura & Co., Ltd. Central Research Laboratory Osaka Japan George Milad, Don Gudaczauskas UIC Technical Center Southington, CT, USA Presented in the ECWC 10 Conference at IPC Printed Circuits Expo®, SMEMA Council APEX® and Designers Summit 05

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	In addition the effects of the copper surface roughness and deposition time on the deposit and solderability characteristics were examined.	amount of deposited gold it was clear that the auto-catalytic reaction percentage is >80% of the total depositing reaction, as compared to the immersion reaction. Gold coverage obtained by the DIG bath was examined by anodic electrical current measurement. By comparing a plating layer deposited by a displacement (immersion) type gold plating bath and plating layers deposited by the DIG bath in various plating times, it was demonstrated that DIG exhibits superior coverage as compared to standard immersion gold. Also, gold coverage on test coupons plated under 10 minutes differed significantly from those plated in excess of 10 minutes.		
260. Surface Finish Comparis	Assembly of these devices has necessitated a greater degree of	Package-to-board interconnection reliability testing was	Thermal cycling reliability comparable to that with solder surface can be obtained with immersion silver finish. The possibility of post assembly defects, such as hairline cracks, should be carefully watched and further investigation is required to determine	COMPARISON OF AG, NI/AU, AND SOLDER PWB SURFACE

Focus	Objective	Scope	Conclusion(s) Summary	Reference
on Fine Pitch Components	surface flatness for the printed wiring board (PWB) mounting pads. The standard solder plate and reflow, used successfully for coarser pitch packages, does not produce the flatness necessary to achieve consistently reliable solder joints for many fine pitch packages.	conducted with fine pitch ball grid array assemblies using immersion silver, and immersion gold over nickel PWB surface finishes. Thermal cycling data were generated in the temperature range of –40 to 125°C.	the cause of this post assembly defect. Differences in board level solder joint reliability dependant on surface finish is not unexpected [13]. The strength of the solder joint is dependant on the nature of the metallurgical bond, the intermetallic thickness, and their distribution within the body of the solder joint.	FINISHES ON THE SECOND LEVEL RELIABILITY OF FINE PITCH AREA ARRAY ASSEMBLIES Lon Chase Raytheon Electronic Systems SMT-CD
261. Surface Finish Reliability Comparison	The purpose of this study was to assess the reliability of selected packages, including fine pitch array and leadless packages, on alternative PWB finishes with HASL used as a control.	Packages chosen for this study included a 0.5mm pitch QFP (2), 1.27mm pitch 357 I/O PBGA (2), 0.5mm pitch 84 I/O BGA (3), 0.75mm pitch 28 I/O MLP (2), 0.8mm pitch 32 I/O QFN (3), and EIA2512 0-ohm resistors (10). The thermal profile used in this evaluation was a cyclic –40°C to 125°C profile, with 16 and 10 minute dwells at the top and bottom respectively	The results of this study indicate that the reliability of leadless packages is very design dependent. While one package demonstrates reliability well beyond the requirements for most applications, another is much less desirable.	RELIABILITY COMPARISON OF LEADED, ARRAY, & LEADLESS PACKAGES ON ALTERNATIVE PWB FINISHES Trevor S. Bowers John L. Evans, Ph.D., Michael J. Bozack, Ph.D. SMT-CD
262. LF Ceramic Grid Array	Lead-free interconnect structures have been developed for second-level assembly of ceramic grid array	The SnAgCu alloy with 95.5wt%Sn/ 3.8wt%Ag/ 0.7wt%Cu has emerged as a strong candidate among the	IBM has developed lead-free second-level ball and column interconnects, which offer some performance advantages over their tin-lead counterparts. Lead-free SAC BGA packages on 1mm pitch exhibit higher reliability than existing tin-lead CBGA packages in the same form factor, due to the superior fatigue properties of the SAC alloy. Lead-free CuCGA packages have lower inductance, thereby offering superior	Lead-Free Package Interconnections for Ceramic Grid Arrays Mario Interrante, Jeffrey Coffin, Marie Cole, Isabel

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	packages. For smaller packages where a ball structure provides sufficient thermal fatigue life, a standard lead-free Tin-Silver-Copper (SnAgCu or SAC) ball may be used. SAC CBGA interconnections have been shown to provide better reliability than their predecessor tin-lead dual alloy CBGA interconnections, when tested under accelerated thermal cycling conditions. The results from recent evaluations of CBGA packages will be discussed.	various leadfree consortia, R&D teams, and alloy manufacturers. For commonality with industry direction, a single-melt solder ball structure using this alloy is the leading candidate for a leadfree CBGA interconnect [1]. This alloy has fared well during several evaluations of both 1.27 mm and 1.0 mm pitch test vehicles where the criteria included wettability of the alloy to the I/O pads, the nature of the flux systems required for achieving optimum wettability, the microstructure of the alloy after attachment and successive reflows, the shear strength of the attached balls, and the thermal fatigue life of assembled modules.	electrical performance when compared to high-lead solder columns in certain applications. The improved reliability of SAC BGAs enable card assembly of ceramic packages up to 42.5mm in size, effectively increasing the potential BGA application space. SAC BGA solutions deliver low inductance for lead-free interconnects, but a higher thermo -mechanical fatigue reliability requirement is better suited to the lead-free CuCGA interconnect.	De Sousa*, Mukta Farooq, Lewis Goldmann, Charles Goldsmith, Janet Jozwiak, Tasha Lopez, Gregory Martin, Van Thanh Truong*, David Welsh IBM Microelectronics Division, Interconnect Products 2070 Route 52, MS/87P Hopewell Junction, N.Y. 12533 USA interran@us.ibm.com 845-894-7335 (*) IBM Canada, Bromont
263. LFS Column Grid Arrays	IBM introduced Copper Column Grid Array (CuCGA) interconnect as the lead-free replacement for the	This paper focuses on the development and reliability evaluation of the CuCGA card assembly and rework	Lead-free CuCGA packages were designed with a solder temperature hierarchy to ensure robustness during card assembly and rework. Initial card assembly profiles successfully meet current industry standards for reflow limitations, and placement accuracy was assured. Card rework was successfully demonstrated, resulting in more than 90% of the columns being removed with the package while maintaining peak	LEAD-FREE CARD ASSEMBLY AND REWORK FOR COLUMN GRID ARRAYS Mario Interrante, Brian

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	lead-tin solder column on the Ceramic Column Grid Array (CCGA)	processes. The goal of the process development was to adapt the successful SMT assembly process for CCGA to the developing standards for lead-free SMT processing.	card temperatures of 180-210oC.	Chapman, Marie Cole, Isabel De Sousa*, Chuck Goldsmith, Janet Jozwiak, Tasha Lopez, Wai Ma, Gregory Martin, SMT-CD
264. Leaded, Array, Leadless Components – Alternative PWB Finishes	Increasing customer demands to provide more functionality in smaller electronic devices has consequently driven the urgency to increase I/O density and reduce the size of integrated circuits (IC). This has led to the widespread use of ball grid array (BGA) packages and fine pitch array packages, most of which have pitches ranging from 1.27 mm down to 0.5 mm. More recently, leadless packages such as the Quad Flat Pack No-Lead (QFN) and micro leadframe package (MLP) have provided electronics designers even more options to increase circuit density.	Packages chosen for this study included a 0.5mm pitch QFP (2), 1.27mm pitch 357 I/O PBGA (2), 0.5mm pitch 84 I/O BGA (3), 0.75mm pitch 28 I/O MLP (2), 0.8mm pitch 32 I/O QFN (3), and EIA2512 0-ohm resistors (10). The thermal profile used in this evaluation was a cyclic –40°C to 125°C profile, with 16 and 10 minute dwells at the top and bottom respectively, and a ramp up / ramp down rate of approximately 6.75°C per minute. All nets were monitored continuously with a threshold resistance of 20 ohms using a Keithley 7011 System.	Fine pitch BGA solder joint cracks were observed to run either through the Pb-rich region, or between the Pb and Sn-rich regions. These cracks are believed to be the result of PWB masking problems, and also related to the inherent variance of HASL thickness. With regards to the alternative surface finishes used in this study, there was no evidence that either ImAg or electroplated Ni/Au compromised reliability. The results of this study indicate that the reliability of leadless packages is very design dependent. While one package demonstrates reliability well beyond the requirements for most applications, another is much less desirable.	RELIABILITY COMPARISON OF LEADED, ARRAY, & LEADLESS PACKAGES ON ALTERNATIVE PWB FINISHES Trevor S. Bowers John L. Evans, Ph.D., Michael J. Bozack, Ph.D. ADTRAN, Inc. Center for Advanced Vehicle Electronics

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265. LFS Rework - BGA / CSP	New evaluations will need to be done for lead free manufacturing and rework. The rework cycle is much more difficult than the production cycle.	Generally, BGA has a problem with warping causing bridging in the corners, when air temperature over 300°C is used. This is a condition known as dog earring. Therefore, 265°C to 285°C air temperature is used in the reflow zone as the maximum air temperature.	rework system has to ramp up very fast and down again to achieve this small peak temperature. Component suppliers' maximum temperature, at the component lid, is 265°C, with the most common temperatures ranging from 240 to 250°C. This is very close to the solder temperature which is 225°C - 233°C. In addition, the time above reflow has gone from 60 - 90 seconds for eutectic solder to 15 - 30 seconds for lead free.	REWORK OF BGA/CSP COMPONENTS USING LEAD FREE SOLDERS Paul Wood Metcal SMT-CD
266. PWA / PWB Reliability (Presentation)	Discuss common PWB defects and Industry studies of PWA / PWB.	PWB Defects characterized, including breakouts, barrel cracks, innerlayer separation, corner cracks, etc. Listed IPC Studies	IPC Studies include: IPC TR-578 (Conductor width and PTH reliability), IPC TR-579 (PTH reliability). IPC TR-481 (Multilayer PWB quality), IPC TR-484 (Copper foil ductility), IPC TR-485 (Copper foil rupture strength), IPC TR-486 Interconnect stress test). Determined from collecting information on PWA field failures (70 companies) that chip capacitors were the biggest problem followed by PWB failures.	PWA/PWB Reliability Issues Tom Woodrow - PWA/PWB Meeting - 12/13/2004
267. Area Array Inspection – X-ray	Many aspects of printed circuit board assembly using leadfree solders have been investigated. The aspect to be presented in this paper will be the inspection of the solder joints of area array packages using 2D and 3D X-ray systems. The challenges of X-ray inspection for lead-free solder joints	For this study, an existing test vehicle was used. This board is 152x216mm in size and 1.57mm thick. This twolayer board uses FR-4 for the base material and has a Ni/Au (ENIG) surface finish. It has been used in the past to evaluate the performance of different solder paste.	It can be seen that the differences range from 1% up to 12%. This result is in line with what would be expected from the density difference between the tin-lead and lead-free solder alloys of approximately 12%. Overall, there is no significant difference in the X-ray images of lead-free and tin-lead solder joints. The same settings can generate images that can be analyzed with no major difficulties, even though certain fine-tuning can be done to further optimize the images.	X-RAY INSPECTION OF AREA ARRAY PACKAGES USING TIN-LEAD AND LEAD-FREE SOLDERS David Geiger, Todd Castello, and Dongkai Shangguan, Ph.D. Flextronics San Jose, CA, USA

Focus	Objective	Scope	Conclusion(s) Summary	Reference
	will be discussed in comparison with tin-lead assemblies.	In addition, components can be placed on the board to further examine solder joint formation for a variety of solder joint types.		
268. LFS X-Ray Inspections	This may be because, at worst, some test parameters are no longer valid with the lead-free solders, or, less seriously, the inspection control settings must be varied to accept revised test responses based on acceptable levels for these new materials.	So, in general, the lead is being replaced by tin in these new solders. The immediate effect of this change is to dramatically increase the liquidus temperature of these solders to around 215 – 230°C. As a result, the reflow oven temperatures typically used for SMT production must be raised to a much higher level – around 290°C so as to ensure the solder reflow will occur.	However, as far as x-ray inspection is concerned then existing and future x-ray equipment will be able to see these faults under lead-free BGA and CSPs, as well as within the rest of the SMT components. All that may be necessary is the adjustment of certain x-ray tube parameters to ensure the best image contrast is available to allow for easy analysis.	IMPLICATIONS OF USING LEAD-FREE SOLDERS ON X-RAY INSPECTION OF FLIP CHIPS AND BGAS David Bernard, Dage Precision Industries Inc. SMT-CD
269. LFS Assemblies X-Ray Inspection NASA_JPL	the use of x-ray imaging has become an additional inspection requirement for quality control and detection of unique defects due to manufacturing of advanced electronic array packages such as ball grid array (BGAs)	Extensive work has been carried out by the JPL-led consortia to assist the understanding of technology implementation issues of area array packages for high reliability applications. These issues included process	New inspection criteria for lead-free solder joints and even solder balls in BGAs need to be developed and QA personnel need to be trained, especially for high reliability applications, where visual/optical inspection are often used for acceptance/rejection. AOI also need to be modified to include acceptance criteria for the lead-free features.	VISUAL AND X-RAY INSPECTION CHARACTERISTICS OF EUTECTIC AND LEAD FREE ASSEMBLIES R. Ghaffarian, Ph.D. SMT-CD

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	and chip scale packages (CSPs).	optimization, assembly reliability characterization, and use of inspection tools including X-ray and optical microscopy for quality control and damage detection due to environmental exposures.		
270. RoHS RoHS/WEEE Electronics Manufacturing Overview of Development, and Implementation	Status update on NEMI efforts in –Assembly Process Specifications –Component and Board Marking (including product number change management and labeling standards) JEDEC, IPC –Component Supply Chain Readiness –Materials Declarations –Materials Composition Data Exchange	• Widespread introduction of Pb-free solders in consumer products . • Leading EMS firms have Pb-free capability. • Limited introduction of Pb-free solders in commercial products. • NEMI Survey indicates that, for all component types, 2/3 of suppliers can currently provide Pb-free components that meet thermal specifications. • Lead finishes are still under debate for high reliability applications. • Appears major conversion of supply chain will be in 3-4 Q 2005. • There is no focused industry wide effort to	Tin-silver-copper (SAC) alloy has been extensively evaluated: – Initial work by NCMS and others – Focus of NEMI Phase I efforts – Shown to produce joints more reliable than tin-lead eutectic • Pb-free reflow soldering process is well defined	Chuck Richardson chuck.richardson@nemi.org National Electronics Manufacturing Initiative ftp://nemi.org/webdownload/newsroom/Presentations/RoHS_status.pdf

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		address WEEE which goes into effect in 7/05! • NEMI is active in facilitating the conversion of the supply chain to meet RoHS.		
271. LFS Transition – Cause/Effect	This paper details the results of an Intel investigation of printed circuit board materials, fabrication processes, and design variables and the resulting impact on board reliability after lead-free assembly. Results were baselined against standard tinlead assembly for purposes of comparison. Printed circuit board process and design variables examined included via size, layer count, board thickness, and laminate material. Also examined were the variation within an individual supplier and the variation across multiple suppliers using the same materials. The paper details the test board configurations	The primary objective of all three test boards was to challenge the supplier's high volume capabilities in all aspects of the board fabrication process, and capture limits of both the supplier's capability and the material performance through the test results. All boards were instructed to be built to IPC class 2 copper thickness requirements for each of the via structures. Material selection and stack-up were varied by design, but were dictated to the suppliers for each build. Three lots of 10 panels each were built for each of the supplier builds tested. The three lots were instructed to be from different raw	Drill size, material choice, and board thickness are all design variables that can have an impact on IST via cycles to failure test performance of the board. For a given supplier build lot, drill size and material choice have consistent IST via cycle performance differences between Sn/Pb assembly and Pb-free assembly. The IST via cycle to failure performance differences increase as board thickness increases when the assembly reflow temperature is increased. All these design influences can be significantly impacted by supplier variation if not controlled. The common solution to meet IST via cycles to failure criteria when moving to Pb-free assembly is to switch to a more thermally compatible material for the design. This move may result in little or no improvement in IST cycles to failure if the supplier is unfamiliar with the new material and has transition problems with process adjustments. Some materials , even though they are listed as higher temperature materials / higher Tg materials, are unsuited for Pb-free processing by exhibiting susceptibility to delamination/blistering at these process conditions.	Lead-Free Product Transition: Impact on Printed Circuit Board Design and Material Selection Gary Brist and Gary Long Intel Corporation Hillsboro, OR Presented in the ECWC 10 Conference at IPC Printed Circuits Expo®, SMEMA Council APEX® and Designers Summit 05

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	used in the study, the lead-free and tin-lead assembly profiles to which the boards were subjected, and the test methods employed to collect the data. The test data highlights key trends in the reliability data as a function of changes in the variables tested.	material lots and built at three distinct intervals through the factory to capture as much material and process variation as possible. A summary of the test board conditions is listed below in Table 1.		
272. ACI – Initiatives in LFS	Slides	ACI LFS Overview	Lead-Free solders do not wet as well as SnPb solders . More active solder flux required to improve solder wetting . May require more aggressive cleaning process after soldering . Nitrogen recommended to improve solder wetting Material compatibility between board finishes and Lead-Free solders – Need a better understanding of board finish / Lead-Free solders interactions . Immersion Sn area of interest: Sn whiskering potential . Need a better understanding of board finish robustness – IPC Alternative Finishes Committee is investigating Need more data for high reliability aerospace applications – Lead-Free Components Focus Group, NSMC, NEMI, NIST have performed tests	ACI
273. LFS – Harsh Life	Magazine Article	With the phasing out of military standards, many aerospace electronics systems are produced using COTS (commercial off-the shelf) components such as video boards, disk drives etc. which were designed for applications in the relatively benign environments of	Cookson estimates that the majority of lead-free assemblies will use Sn-Ag-Cu (SAC) alloys with between 3% and 4% Ag and 0.5-1.0% Cu. The reason this alloy is preferred (within this range chemical, physical and electrical properties are very similar) is because of cost, compatibility, performance and the immense amount of work vested in these alloys by programs in Europe (IDEALS), the USA and Japan. The main cross-contamination issue is of lowering the melting point of the alloy. Lead contamination of tin-silver-copper alloys appears not to be critical as long as the joint is homogenous, but Pb concentrations above 0.4% have been shown to enhance fillet lifting in SnCu. In other lead-free alloys such as SnBi, even 0.25% can cause catastrophic joint failure on thermal cycling. Materials management in rework is therefore critical.	HARSH life for lead-free solders Cookson Electronics Electronics Manufacture and Test

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		consumer electronics.		
274. LFS – High strength – High fatigue resistance	Magazine Article	Sn/Cu/In/Ga proves to be an interesting solution for high-strength and high-fatigue-resistant electronics applications.	The lead-free solder Alloy 719 (92.8Sn/ 0.7Cu/6In/0.5Ga) and Alloy 717 (93Sn/ 0.5Cu/6In/0.5Ga) in the Sn/Cu/In/Ga system offer superior strength and fatigue life over 63Sn/37Pb. Fatigue life of Alloy 717 and Alloy 719 is 74 and 196 percent higher than 63Sn/37Pb, respectively. Its melting temperature (209∞ to 214∞C for Alloy 717; 210∞ to 215∞C for Alloy 719) and wetting characteristics are applicable for SMT manufacturing and IC packaging. These compositions are one result of ten years of research and are covered under U.S. patent no. 5,985,212. SMT	High-strength and High-fatigue-resistant Lead-free Solder. Dr. Jennie S. Hwang, Dr. Zhenfeng Guo, Dr. Holger Koenigsmann Surface Mount Technology (SMT) March, 2000
275. LFS Balls – Advanced Alloy	A new alloy for lead-free solder balls is introduced combining the advantages of a smooth surface after production and a uniform reflectivity after the ball attach process. This property significantly simplifies the inspection process during BGA processing.	By adding small amounts of Indium and Lanthanum to the ternary eutectic SnAgCu-alloy a pentary, virtually eutectic composition with a melting point of 214 °C is realised. It is shown that the processability in terms of reflow behaviour and the shear strength of BGA spheres made of this alloy is comparable to or better than that of ternary SnAgCu-balls.	The SnAgCuInLa alloy as introduced is a viable option for lead-free solder balls with some advantages over the binary SnAg and ternary SnAgCu alloy. These are Excellent sphericity, High resistance to mechanical damage, Lower melting temperature (214 °C), Smooth surface after production, Reduced tendency to surface oxidation, Homogenous solidification after reflow, Good inspectability via laser triangulation (coplanarity measurement), High shear strength Board level reliability however must be investigated in detail and results for this will be presented in a future paper.	Advanced Alloy for Lead-Free Solder Balls Marc Dittes*, Hermann Walter** * Infineon Technologies AG, Regensburg – Germany **Pfarr Stanztechnik GmbH, Buttlar - Germany
276. Status of Lead-Free Solder Alloys	THE ISSUE of lead-free soldering has piqued a great deal of interest in the electronics assembly industry as of late.	This paper shall provide a discussion of the direction that the industry is moving (and why), the most viable solutions for board	0.5% and 1% lead-contamination, Tin/Silver/Copper bulk solder alloys do see a reduction in mechanical strength. In addition, studies have shown that lead-contamination does have negative effects on solder joints produced with lead-free alloys.[13] Furthermore, bismuth bearing alloys see an even greater reduction in mechanical and thermal reliability. be met. A great number of ongoing and completed studies concerning lead-free solder alloys are now available. The results of these	The Current Status of Lead-Free Solder Alloys David Suraski and Karl Seelig

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	What once was an issue that seemed too far away to worry about has become a pressing reality. In order to avoid confusion, last minute panic, and a misunderstanding of how the issue of lead-free soldering will affect the industry and individuals users of solders, it is necessary for all suppliers and assemblers to become educated in this matter.	assemblers, and an analysis of the most pertinent and comprehensive alloy comparative test data available.	suggest that the Sn/Cu/Ag based alloys offer the most viable replacement to tin/lead alloys for the majority of applications.	
277. Alternatives to Tin-Lead Solders	World-wide interest in altematives to tin-lead (Sn-Pb) solder and to brominated flame retardants **(BFRs)** continues to grow, in no small part due to the WEEE (Waste Electrical and Electronic Equipment) Directive in the European Union.	This paper briefly summarizes these alternatives and the data collected to-date, which will lead to an improved understanding of the relative merits and drawbacks of conventional verses emerging technologies. Included are discussions of technical performance, end-of-life issues, and life-cycle analyses. A bibliography of published papers, reports, and web-sites is	The alloy that seems to be the most likely general substitute for Sn-Pb is tin-silver-copper (Sn-Ag-Cu). This material is attractive because it has a relatively low melting point (217°C) and initial studies indicate that it has reliability similar to Sn-Pb.	Survey of Alternatives to Tin-Lead Solder and Brominated Flame Retardants Cynthia F. Murphy, University of Texas, Austin Texas

Focus	Objective	Scope	Conclusion(s) Summary	Reference
		provided.		
278. Green Packages	Green packages, i.e. lead-free and halogen-free semiconductor components require the evaluatation of a lot of new materials and processes. Results concerning solder plating, ball attach and the properties of halogen-free mold compounds are introduced.	Infineon Technologies AG as one of the leading manufacturer of semiconductors is commited to environmentally friendly processes and materials. This contribution addresses some results of development activities in the field of green packages, i.e. lead-free and halogen-free semiconductor packages. This paper is on leadfree solder platings and solder balls, halogen-free mold compounds and the processing and properties of all of these. Due to the short time of availability halogen-free substrate materials and solder masks are not addressed in this paper.	Hence it can be concluded that green packages are possible. However, some tasks still remain concerning processes, improvement of some properties, testing and qualification of such invironmentally friendly packages. And last but not least, the huge amount of experience with SnPb-soldering and all the materials and processes tuned to SnPb-technology cannot be adapted to the lead-free world easily. The question of reliability must be considered very seriously to be sure not to replace one risk by anonther. Some of the materials interactions are not well known yet, but the promising results of all the projects world-wide are reason enough to go on.	Green Packages – Requirements, Materials, Results Marc Dittes Infineon Technologies AG
279. Tracing LFS Parts	Magazine Article	As the implementation of lead-free solders increases, it is - becoming evident that labeling, shipping and managing components	Of the component suppliers surveyed, 94 percent are designing components that will meet the RoHS requirements, but only 53 percent intend to assign new part numbers to the lead-free components. Forty-two percent made their plans clear not to issue new part numbers. Instead, they will leave the identification of a part as lead or lead-free to the package labeling or to the manufacturing date range. The real challenge in military applications will be to ensure that all components are clearly identified at all	Lead-free movement complicates electronic parts traceability *Military & Aerospace Electronics* December, 2004 Author(s) : Keith Gurnett

Focus	Objective	Scope	Conclusion(s) Summary	Reference
		may be neither simple nor foolproof.	stages as lead or lead-free. Permitting the two types of components to become mixed in the same reflow environment opens the door for dangerous field failures.	Tom Adams
280. LF process and product transition	As a phase II future study, a Lead-Free test vehicle with advanced testability feature for extensive reliability study on all representative package types and solder joint were designed.	Test vehicle with lead-free major representative package types, FCBGA, PBGA, CBGA, QFP, SOIC, RN, passive, press-fit, PTH etc as shown in Figure 2 were layout with Daisy Chain (DC) structure to achieve the following goals.	The mechanical strength of the lead-free Sn-Ag-Cu solder joint will be greatly enhanced by the homogeneous distribution of the Ag_3Sn and Cu_6Sn_5 through an optimal reflow process and a carefully selected alloy system. The homogeneity of the distribution will (1) reduce the average CTE mismatch between the IMC phases and (2) create more Ag_3Sn-Cu_6Sn_5 interface area such that will then effectively blunt the phase slip and deformation created by external force field as well will enhance resistance to the fatigue failure.	MECHANICAL STRESS CONTROL AND MANAGEMENT IN THE ASSEMBLY PROCESSES FOR Sn-Pb AND Pb-FREE SYSTEM* PHASE II - LEAD-FREE PROCESS AND PRODUCT TRANSITION* Dr. Paul P.E. Wang˙, Hana Hsuø, C.J. Linø, Gary Huang˙, Ken Kochi˙, David Love˙, Dr. Heidi Reynolds ˙, Keith Graveling, and Livia Hu˙
281. LFS Update	Slide Presentation	No “Drop in Replacement” for Sn 63/Pb 37 Higher processing temperatures - 20 to 40C higher Narrower reflow process window - Between liquidus and peak (40 - 20C) Alloy patent issues are now resolved by major suppliers	Sn 3% Ag 0.5% Cu primarily…with other SAC alloys Sn 3.5% Ag, for some automotive and for rework Sn 0.7% Cu (+ Ni, Ag…?) for HASL and low-cost Need to avoid cross-contamination of solders - >0.5% Pb will cause reliability issues Hand-soldering of lead-free alloys requires training - Freeze behavior is different than eutectic - ACI Philadelphia has run training courses Need to selectively apply heat to only the areas that need rework Sn-Ag is probably the universal rework material - Available in wire - No disastrous intermetallics	Lead-free solder Update Salt Lake City April 2003 1 16-18 April 2002 – Commercial Technologies for Maintenance Activities

Focus	Objective	Scope	Conclusion(s) Summary	Reference
		Confusing selection, availability, compatibility of surface and lead finishes - OSP / HASL / ENiG / Ag / Sn Lack of comprehensive database for lead-free		
282. Road to LFS	Slide Presentation	Seiko Epson has thus established goals based on its commitment to protecting the global environment, and is well on the way to making its PCB mounting processes totally lead-free. As a result, the company has devised soldering techniques using lead-free solder that achieve even higher reliability than has been achieved using conventional 63Sn-37b solder. –40°C to 125°C, 15-minute interval	Reliability test results and bonding area sectional views of soldering performed using the Sn-Ag-Cu solder alloys being researched have shown that these lead-free solders have bonding reliability equal or superior to conventional 63Sn-37Pb solder. The results of these tests revealed which alloy has the best bonding reliability based on QE methodology. A factorial effect diagram showed that use of Sn-Ag-Cu solder results in higher bonding reliability than use of 63Sn-37Pb solder. These tests were repeated and their reproducibility was confirmed.	Seiko Epson Corporation
283. LFS Status	An analysis of the current status of lead-free soldering	A much wider awareness and appreciation of the issues now exists, although actions geared towards the transition	The SnAgCu ternary alloy is being promoted as the general purpose, baseline lead-free solder, with good processing and reliability performance SnAgBi type alloys, possibly with the addition of Cu or other improvers are suitable for surface mount applications where service temperatures are not expected to be extreme	Update 2000 Lead-Free Soldering Brian Richards Centre for Materials and Measurement Technology

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		are still at a low level		
284. NEMI Technology Roadmaps: Closing Identified Technology Gaps - NEMI Projects To Eliminate Pb Solder	Roadmap outline	Outline	none	Chuck Richardson SMTAI 2004 ftp://nemi.org/webdownload/newsroom/Presentations/SMTAI04_Richardson.pdf
285. The Reality of Lead-free Soldering	Although it is now widely agreed that there is no drop-in replacement for SnPb solder, there is a range of possible alternatives commercially available. The trick is to choose the right one for any particular application.	However, over the past year there has been an increasing consensus for using one family of alloys, based on SnAgCu, at least for many surface mount applications. The large volume telecommunications industry is one that has targetted this alloy.	But the outlook is bright. Performance data, especially those from the field, though sparse, suggest that the Pb-free solders will provide adequate joints. The reliability of SnAgCu, in particular, appears to be equivalent to that of SnPb.	Dr Brian Richards. BSc MSc PhD. Consultant. National Physical Laboratory, Teddington, Middlesex. TW11 0LW
286. LFS – where is the world going	A review of LFS	The favored Pb-free solder alternatives vary from region to region. However, in general, high tin alloys are preferred, including	However, Sn/Ag/Cu systems are more tolerant toward Pb contamination than Bi-containing systems, therefore are more compatible with existing infrastructure for the transition stage. Pb-free surface finishes for PCBs include OSP, immersion Ag, immersion Au/electroless Ni, HASL Sn/Cu, Sn/Bi, electroless Pd/electroless Ni, electroless Pd/Cu, and Sn.	Lead-Free Soldering – Where The World Is Going Dr. Ning-Cheng Lee Indium Corporation of America

Focus	Objective	Scope	Conclusion(s) Summary	Reference
		Sn/Ag, Sn/Cu, Sn/Ag/Cu, Sn/Ag/Bi, and various versions of those alloys with small amount of additions of other elements, such as Sb. Sn/Ag/Bi systems are used in some Japanese products already.		
287. Moving ahead in LF	Magazine article	If U.S. electronics assemblers want to remain competitive during the next 5 years, they will have to overcome the challenges of lead-free solder. Yet, by some estimates, only 5 percent of North American electronics assemblers are currently using lead-free solder. "The big contract manufacturers...are evaluating lead-free solder in low-volume product lines, but it isn't mainstream yet," says Jim Slattery, vice president of global technology support at Indium Corp. of America (Utica, NY). "Everybody is going to	For surface-mount assembly, tin-silver-copper has emerged as the most popular lead-free alloy, though the exact composition of the alloy varies with the manufacturer. The silver content ranges from 3 percent to 4 percent, while copper content varies from 0.4 to 0.8 percent, says Doug Dixon, product manager for Multicore soldering products with the Electronics Div. of Henkel Loctite Corp. (Industry, CA). "We recommend an alloy of 3.8 percent silver, 0.5 percent copper and [95.7 percent] tin," he says. "Japanese companies prefer 3 percent silver, 0.5 percent copper and [96.5 percent] tin. We believe the alloy with 3.8 percent silver is the only true eutectic [in that family], but that is disputed in the industry."	Moving Ahead in Lead-Free By John Sprovieri / Senior Editor

Focus	Objective	Scope	Conclusion(s) Summary	Reference
		wait until the last minute to implement it."		
288. Global Trends in LFS	Magazine Article	In this study, the impact of lead-free on PBGA, CSP, flip chip, WLCSP and plastic quad flat pack (PQFP) are examined.	Many in the technical community have recently said that Sn-4Ag-0.5Cu, Sn-3.9Ag-0.6Cu and Sn-3.8Ag-0.7Cu are not as reliable as Sn-3Ag-0.5Cu. One of the reasons is that more and larger Ag3Sn platelets are presented in the higher Ag-content solder joints. These platelets degrade solder joint reliability, especially for smaller solder joints (such as flip chips) under isothermal fatigue, mechanical and shock and vibration conditions.	Global Trends in Lead-free Soldering BY JOHN H. LAU AND KATRINA LIU *Advanced Packaging* January, 2004
289. LF Global Trends	Global trends regarding lead-free soldering and technology are investigated in this study. Emphasis is placed on costs, regulations, definitions, designs, materials, processes, tests, inspections, and reliability of components, printed circuit boards (PCBs), tin whiskers, and solder joints.	Useful constitutive equations for various SnAgCu alloys have been given in [1-16] and are tabulated in Table 1. Based on 108 creep data points, as shown in Figure 6, from literatures and IZM's own measurements, Schubert, Dudek, Auerswald, Gollhardt, Michel, and Reichl presented a new creep constitutive equation [7]. At the same time, based on 32 creep data points measured by Sandia, as shown in Figure 7, Vianco, Rejent, Kilgo, Lau, and Dauksher presented another new creep constitutive equation [1, 2].	Global trends of lead-free soldering and technologies have been briefly discussed. Emphasized have been placed on the costs, regulations, definitions, designs, materials, processes, tests, inspections, lead-free substitutes, and reliability of lead-free components, Sn whisker, and solder joints. Important results and recommendations are summarized in the following. Lead-free is not a lie anymore and is here to stay. Either you jump on the lead-free bandwagon or are left behind. (2) Lead-free has been a law in EU since February 13, 2003, and the implementation date is July 1, 2006. China will formally publish her own RoHS on September 18th, 2004 and the implementation date is also July 1, 2006.	UPDATE OF GLOBAL TRENDS IN LEAD-FREE SOLDERING John Lau1 and Katrina Liu2 1Agilent Technologies, Inc. Santa Clara, CA, USA 2Graduate School, Beijing Normal University Beijing, P.R.China

Focus	Objective	Scope	Conclusion(s) Summary	Reference
290. Future aspects for LFS	Besides numerous investigations on technical reliability and processing of lead-free soldering materials, environmental, resources and other sustainability aspects have not been receiving much attention	Materials assessed included SAC305 Sn and Ni/Au PWB surface finish	All assessed lead-free materials aside from the Ni/Au PCB finish, considerably reduce the toxic releases from PCBs into the environment	Lead-free Soldering – Future Aspects of Toxicity, Energy and Resource Consumption Deubzer, Griese, IZM, U of Tokyo
291. Lead Free Productio n, Under the Microsco pe	This report was commissioned by Vision Engineering, world leaders in the development and manufacture of stereo optical systems. Thousands of these systems are currently used to inspect electronic components and processes. With the switch over to Lead Free production, this document will lead you through the optical inspection issues involved, explaining what will change and what needs to be done.	There should be no impact due to lead-free. However if the board is warped after previous reflow steps on a double sided product the quality of the deposits will be affected. Both the definition and the volume of adhesive will be affected. Measuring the size variation of the dots is a simple method of inspection and quality control. If a company uses one reflow machine for both reflow and adhesive curing problems can occur if they do not monitor the temperatures correctly. Reflow for lead-free will be around 240oC,	There should be no impact due to lead-free. However if the board is warped after previous reflow steps on a double sided product the quality of the deposits will be affected. Both the definition and the volume of adhesive will be affected. Measuring the size variation of the dots is a simple method of inspection and quality control. Many companies feel that reflow machines will need to change for lead -free but it depends on the technology level of the system and the throughput speed required for your product. A professional oven with four or five process zones and a process length of 3-4 metres should provide satisfactory results with higher temperatures. The only issue then is the exit temperature of the boards for the required throughput speed and the outer skin temperature of the oven from a health and safety point of view. If you have a higher reflow temperature then the exit temperature will be higher for the same conveyor speed unless additional cooling is provided. Lead-free will probably have more impact on the wave soldering process than any other process, many people were just not prepared for the issues which have become apparent. Alternative high tin content solders have a tendency to attack the stainless steel used in different parts of the ducting and impellers used to form and drive the wave shape. This means that existing solder machines will need to be replaced or parts of the bath replaced. Fortunately most suppliers do have solutions to this equipment problem.	Vision Engineering Lead Free Production, Under the Microscope. Bob Willis

Focus	Objective	Scope	Conclusion(s) Summary	Reference
		adhesive cure will still be between 110-130oC for around three minutes. Often companies do not wait for the process temperature to drop in the oven which can result in voiding of the adhesives, lower bond strength to the board surface and component loss. Some times the voids are visible to the side of the chip components if the adhesive is visible. During wave soldering this can lead in the worst case to solder shorts under chip parts, this is only visible with X-ray or microsectioning.		
292. Road to RoHS	Electronic Magazine Article	The most far-reaching piece of legislation ever to impact the electronics industry, RoHS and WEEE will affect all companies that service or manufacture any products shipped into Europe, and beyond. Similar legislation is	A third, and even more worrisome challenge - as the world's component suppliers begin to comply with RoHS in order to service the needs of the high-volume consumer electronics market, many will discontinue offering non-compliant legacy parts - leaving price premiums or risky last time buys. To complicate matters, test methods for evaluating PCB performance have either yet to be updated or in some cases, developed. Several tests recently conducted have brought these issues to light. Numerous PCBs run through actual lead-free assembly processes exhibited severe blistering and delamination.	By Dan Shea, Chief Technology Officer, Celestica Mar 02, 2005 emsnow

Focus	Objective	Scope	Conclusion(s) Summary	Reference
		also on the horizon in geographies including China and some states in the U.S., such as California and Maine.		
293. LF – Transition - Enviro	This paper will review the key compatibility issues involved, and the strategy for the transition from an EMS/ODM perspective. For RoHS compliance, supply chain compliance and assurance management are a complex undertaking that needs the entire industry to work on. Design for the environment (DfE) and recycling are the ultimate solutions to environmental issues posed by the ever-increasing volume of electronic products. Strategies and methodologies for RoHS compliance management, and product end-of-life management through recycling, will also be discussed.	For lead-free soldering, efforts are being shifted from R&D to implementation, and from developmental labs to the manufacturing floor. Many companies have implemented lead-free on selected products thus far to gain confidence and experience, and these have primarily been with consumer products. Over the next couple of years, it is anticipated that most new product launches will be with lead-free, and long life cycle products need to be designed with lead-free and RoHS compliance in mind.	A holistic approach is needed for the lead-free transition and environmental compliance. The strategy for meeting the challenges of environmental leadership for the transition to WEEE/RoHS compliance and the key compatibility issues involved have been reviewed in this paper. A number of compatibility issues must be addressed in order to make a smooth transition to lead-free, and process optimization and reliability are critical to deepening the lead-free transition. For RoHS compliance, supply chain compliance and assurance management are a complex undertaking that needs the entire industry to work on.	A HOLISTIC APPROACH TO LEAD-FREE TRANSITION AND ENVIRONMENTAL COMPLIANCE Dongkai Shangguan, Ph.D. Flextronics San Jose, CA, USA dongkai.shangguan@flextronics.com

Focus	Objective	Scope	Conclusion(s) Summary	Reference
294. Urgency Lacking on Pb-Free	Electronic Magazine Article	A poll of more than 50 attendees of recent workshops on the business implications of lead-free manufacturing revealed just 18% of respondents are actively working on alternatives to lead. The vast majority – 80% – of those responding is still in the beginning stages of preparations for the phaseout. And none of the respondents indicated they have converted completely (Disclosure: The seminar, An Introduction to Lead-Free, is sponsored by Design Chain Associates and EPTAC in conjunction with UP Media Group, publisher of Circuits Assembly.)	What that doesn't mean, however, is that lead-free solders will cost the same as tin-lead ones. Says Cookson Electronics Assembly Materials president David Zerfoss: "We've put millions [of dollars] into research for lead-free capable materials and there's a price tag for that and the products themselves are inherently much more expensive." Bar solder contains a higher tin content than pastes, leaving some suppliers more exposed to tin pricing volatility. Zerfoss notes the shift from 63-37 to 90-plus% tin means the same joint will require less solder by 20% by weight to make, but the alloy composition by the weight of the bar will be 34% more. Bottom line: More consumption of tin and silver. Quips Zerfoss: "You cannot sell lead-free at the same price. Lead-free ain't free." Adds Koki's Clark; "The assembly industry is going to have to rethink the demands of cost-down policies."	Urgency Lacking on Pb-Free By Mike Buetow Editor & Chief ***Circuits Assembly Magazine*** Guest Commentary Lead-Free Magazine

Appendix B

Current and Future Studies

Appendix B: Current and Future Studies

CALCE

Point of Contact:
Michael Osterman
osterman@calce.umd.edu
CALCE Electronic Products and Systems Center
1103 Engineering Lab Building
University of Maryland
College Park, MD 20742
Tel.: 301-405-5323
Fax: 301-314-9269

Activity	Narrative
CALCE Long-Term Pb-Free Study	Assess and compare the lead-free technology against the lead-based for long-term (10 to 30 years) reliability requirements. Provide recommendations to reduce reliability risks to achieve long-term reliability goal of 10 to 30 years of operating life for the lead-free products.
C05-01 Effects of Manufacturing Variables on Quality and Durability of Lead Free Solder Joints (Continuation of C04-26)	Investigate manufacturing defects in lead free solders, originating from: - Paste deposition process - Reflow process Assess the influence of the manufacturing defects on durability under: - Thermal cycling - Drop Evaluate the feasibility of establishing PoF-based screening process for manufacturing defects in lead free assemblies
C05-02 Accelerated Qualification of SAC Assembly: Combined Temperature Cycling & Vibration	Demonstrate accelerated qualification of Pb-free assemblies under vibration (continuation of C04-02) Demonstrate accelerated qualification of Pb-free assemblies under combined temperature cycling and vibration

Activity	Narrative
C05-40 Durability of Pb-free Electronic Interconnects Under Impact Loading	Investigate the drop-resistance of Pb-free surface mount interconnects using the test methodology developed in C01-29 and C02-14. Compare the durability of Pb-free and Sn-Pb interconnects under impact loading.
C05-03 Reliability of SnAgCu Solder for High Temperature/High Power Assemblies	To utilize constitutive and fatigue models of SnAgCu and SnPb solder to perform a relative reliability assessment of assemblies for high temperature and high power applications. Microstructural evolution and intermetallic issues in SnAgCu will be addressed.
C05-04 Experiments to Validate calcePWA Vibration Model (Pb/Sn & Sn/Ag/Cu)	This project will rely upon a series of carefully run vibration experiments to purposely induce high cycle fatigue failures in a well characterized solder joint. Experiments will be run with both eutectic PbSn as well as the primary SnAgCu lead free alternative. The resulting failure data will be used to validate and improve the underlying high cycle fatigue damage model currently being used in the calcePWA software.
C05-05 Virtual Qualification of Pb-free Power Electronic Assemblies	Identify current limitations and areas of potential improvements for application of virtual qualification on conventional and Pb-free power electronic assemblies. Determine effect of internal resistive heating of large conductors internal to structure and develop approach for considering this effect in simulation. As feasible, plan and implement improvements to address identified limitations.
C05-06 Effect of Temperature Cycle on the Durability Lead Free Interconnects (Sn-Ag-Cu and Sn-Ag) – Continued	Provide critical test data that examines the effect of various parameters of temperature cycling on the durability of Pb-free solder. Initiate tests to determine the temperature cycle effects on durability of SnAgCu solder for various package types and board finishes. Update calcePWA/calceFAST thermal fatigue interconnect failure models based on test results
C05-07 Durability of Reworked Pb-free and Mixed (Pb-free/SnPb) Solders Interconnects	Provide durability information on re-worked Pb-free and Mixed (Pb-free/SnPb) Solder interconnects.
C05-08 Tin Whisker Risk Metric and Mitigation Strategies for Electronic Assemblies	Provide reports and assessments of whisker growth on experiments initiated under C03-30 and C04-07. Define and demonstrate a metric for evaluating the risk of tin finished surfaces in electronic hardware. Examine Sn3Pb versus matte Sn (with and without Ni barrier). Report of the effectiveness of various mitigation strategies for tin finished surfaces in electronic hardware.

Activity	Narrative
C05-09 Characterization of Moisture Absorption and Desorption FBGA Package in Storage and Lead-Free Reflow Soldering Conditions	This project will investigate moisture absorption and desorption in an organic substrate package and their impact on package mechanical reliability in both storage (30C / 60% RH) and lead-free reflow soldering conditions, by both experimental and numerical analysis.
C05-10 Robustness of Ceramic Capacitors Assembled with Pb-Free Solder	To perform flexure testing on ceramic capacitors assembled with Pb-free solder to validate predictive model
C05-11 Reliable Large-Area Pb-free Interconnects for Photovoltaic Cells Reliability and Failure Assessment	Investigate and characterize the electrical interconnect integrity for solar cells and solar modules. Develop alternative processes for improving the interconnect reliability. The environments of interest include moisture, temperature, optical, and mechanical loads.

CAVE

Points of Contact:

Michael J. Bozack, Ph.D.
bozack@physics.auburn.edu
Professor
Surface Science Laboratory
Department of Physics
Auburn University
Auburn, AL 36849
(334) 844-4363 (voice)
(334) 844-4613 (FAX)
http://www.physics.auburn.edu/~bozack/
http://cave.auburn.edu

R. Wayne Johnson, Ph.D
johnson@eng.auburn.edu
Professor of Electrical and Computer Engineering
Director, Peak of Excellence
Auburn University
Auburn, AL 36849
334 844-1880 (voice)
334 844-1898 (FAX)

Activity	Narrative
Pb-Free Reliability Studies (Chip Resistors)	This was a reliability study of chip resistors using five Pb-free alloys + SnPb as a control. The thermal cycling was from -40C to +125C and -40C to +150C. Thermal cycling completed. 5541 cycles to +150C and 5720 cycles to +125C. Microstructure and crack growth evaluated for 2512 type resistors through 5000 cycles. This work was/is being done by the Center for Advanced Vehicle Electronics (CAVE) at Auburn University
Intermetallic Growth in Pb-Free Solders	Experiments to study the growth of intermetallics for four standard Pb-free alloys as a function of time, temperature, and board finish are complete (200 specimens). The goal is to determine the intermetallic composition, thickness, growth rate, activation energies and diffusion mechanism. This work is being done by the Center for Advanced Vehicle Electronics (CAVE) at Auburn University Temperatures were 100C, 125C, and 150C
Mechanical Properties of Pb-Free Solders	This project developed a test specimen preparation procedure that had the same microstructure as reflowed Pb-free solder joints. The stress-strain and creep behaviors of Pb-free solders are being measured as a function of temperature and strain rate. A reliable consistent and comprehensive set of material properties for Pb-free alloys is needed for mechanical design, reliability assessment, finite element analysis, and process optimization of electronic packages. This work is being done by Auburn University
Interfacial Studies of Pb-Free Alloys and Construction of a Library of Pb-Free Wetting Videos	A study of the interfaces between Pb-free solders and board finishes during wetting since wetting and spreading are so crucial to solder joint formation. CAVE continues to extend their library of Pb-free wetting videos. These videos included the SnCu and the SAC alloys being tested in the JG-PP project, at our request. This work was/is being done by the Center for Advanced Vehicle Electronics (CAVE) at Auburn University

IPC

Points of Contact:

John Perry
JohnPerry@ipc.org
Technical Project Manager
IPC
3000 Lakeside Drive # 309S
Bannockburn, IL 60015
perrjo@ipc.org
1-847-597-2818 (P)
1-847-615-7105 (F)
1-847-615-7100 (Main)

Jack Crawford
crawja@ipc.org
IPC Director Certification and
Assembly Technology
847-597-2893 (P)
847-615-5693 (F)
3000 Lakeside Drive, Suite 309
S
Bannockburn, IL, 60015

Fern Abrams
fabrams@ipc.org
Director - Environmental Policy
202-962-0460 (P)

Activity	Narrative
IPC Solder Products Value Council: IPC-SPVC-WP-006	The majority of potential “standard” replacement alloys are composed of Tin, Silver, and Copper with Silver varying between 3 and 4% and Tin varying between 95.5 and 96.5%. The current “front runners” are (in % of Tin/Silver/Copper) the 96.5/3.0/0.5 0 (Japanese) and 95.5/3.9/0.6 (NEMI) alloys. Therefore, it should be expected that, from the cost and performance of the alloy, the Silver content should dominate. Accordingly, any comparison of alloys should be done on a material set that spans the range of Silver content from 3 to 4%. To cover that composition range the alloys chosen for testing by the IPC SPVC were: 96.5/3.0/0.5 Tin/Silver/Copper 95.5/3.8/0.7 Tin/Silver/Copper 95.5/4.0/0.5 Tin/Silver/Copper
IPC-A-610, Revision D with inclusion of lead-free criteria.	IPC-A-610 is the most widely used electronics assembly standard in the world. A must for all quality assurance and assembly departments, IPC-A-610D illustrates industry-accepted workmanship criteria for electronics assemblies through full-color photographs and illustrations. Topics include lead free, component orientation and soldering criteria for through-hole, SMT and discrete wiring assemblies, mechanical assembly, cleaning, marking, coating, and laminate requirements.
IPC-J-STD-001, Revision D with inclusion of lead-free criteria.	J-STD-001D is world-recognized as the sole industry-consensus standard covering soldering materials and processes. This revision now includes support for lead free manufacturing, in addition to easier to understand criteria for materials, methods and verification for producing quality soldered interconnections and assemblies.
IPC-1065, lead-free markings	This handbook has been developed to aid printed circuit board (PCB) manufacturers and users in completing Material Declarations that follow the format and guidance of the Joint Industry Material Composition Declaration Guide.
IPC-1066, lead-free markings	This standard establishes the requirements for a distinctive symbol and labels to be used to identify materials that are lead free (Pb-free) and are capable of providing Pb-free second level interconnects, and for indicating certain types of Pb-free materials and the maximum allowable soldering temperature.

NCMS

Point of Contact:
Paul Chalmer
paulc@ncms.org
Program Manager
(734)995-4911

Activity	Narrative
Printed Wiring Board Resource Center	To reduce the information management burden facing PWB shops so that they can focus their resources on achieving compliance and adopting pollution prevention improvements, the Printed Wiring Board Resource Center was established. It will provide printed wiring board (PWB) shops; industry vendor and suppliers; federal, state, and local environmental agencies; academia; and other interested parties with easy access to relevant, current, reliable, and comprehensive information on pollution prevention opportunities, regulatory compliance assistance, and general business information pertinent to the PWB industry. The Center will emphasize pollution prevention techniques as the preferred method of complying with government regulations and enhancing competitiveness.

iNEMI

Point of Contact:
Dr. Robert C. Pfahl, Jr.
bob.pfahl@inemi.org
Vice President of Operations
International Electronics
Manufacturing Initiative, Inc.
2214 Rock Hill Road, Suite 110
Herndon, VA 20170-4214
United States of America
Voice: +1-703-834-2083; Fax: +1-703-834-2735
Mobile: +1-630-965-2462
Web site - www.inemi.org

Activity	Narrative
Pb-Free BGAs in SnPb Assemblies	The objective is to understand the reliability of the resulting mixed-alloy solder joints. For companies choosing to take the RoHS exemption and continue to manufacture SnPb products beyond July 1, 2006, there will be a growing issue with the lack of availability of SnPb components. Many companies may be compelled to use lead-free BGAs in a SnPb process, for which the process and reliability have not yet been characterized.
Substrate Surface Finishes for Lead-Free Assembly	This new iNEMI project is evaluating the effects of alternative surface finishes for circuit boards and package substrates on Pb-free solder joint reliability. They are conducting comparative four-point bend testing and drop testing of Pb-free BGA components assembled on test boards, with the goal of evaluating several surface finishes for the BGA package substrates. In addition, the team is evaluating a set of circuit board surfaces. In all cases, the iNEMI-recommended SnAgCu alloy will be used for reflow solder paste.

Activity	Narrative
Lead-Free Assembly & Rework Project	The work done by the first iNEMI Lead-Free Assembly Project pointed to the need for additional work to evaluate more complex assemblies with thicker boards and to take into consideration the special challenges of Pb-free rework. A follow-on effort — the iNEMI Lead-Free Assembly & Rework Project — has evaluated thicker boards and the ability to rework a representative mix of components on such boards. Testing began in late 2003 on approximately 100 assemblies, using two board thicknesses (0.093" and 0.135") and a variety of components manufactured with new Pb-free processes. Based on results of its experiments, the project team was able to provide manufacturing environment data to IPC and the JEDEC JC-14.1 committee to help evolve J-STD-020B to the current J-STD-020C standard, which raises maximum Pb-free surface mount package body temperature limits to 245°C, 250°C or 260°C, depending on package volume and thickness.
Lead-Free Wave Soldering Assembly Process	Building on the work of the iNEMI Lead-Free Assembly & Rework Project, this new project will investigate use of the iNEMI-recommended lead-free alloy for wave soldering, characterizing the impact of Pb-free alloys on wave and/or selective soldering processes. Specific activities will include: - Evaluate the through-hole portions of the Payette test vehicle (developed by the Lead-Free Assembly & Rework Project), which was assembled utilizing a lead-free selective soldering process. This will enable the group to report pertinent results quickly and reach consensus for the next stage of the initiative.
RoHS Transition Task Group	The 2002 iNEMI Roadmap highlighted the need for requirements, processes and standards to help the electronics industry address the many supply chain issues surrounding the transition to Pb-free assembly and, more specifically, the requirements of the RoHS and WEEE directives. In late 2003, iNEMI created the RoHS Transition Task Group to further define areas for standardization and to develop implementation projects.
Tin Whisker Accelerated Test Project	This program is working to devise industry-standard tests for predicting tin whiskers. At the end of 2004, the project team had completed 3000 thermal cycles and 7000 hours of temperature and humidity testing in an effort to identify an accelerated test method to help predict the propensity for tin whisker growth. Comparing results with Soldertec of Tin Technology Ltd (Europe), and the Japan Electronics and Information Technology Industries Association (JEITA), the three groups concluded that thermal cycling and high humidity accelerate whisker growth.

Activity	Narrative
Tin Whisker Modeling Project	This project team is attempting to understand why whiskers form, and how to control them. The team has published an annotated bibliography of tin whisker literature, written by project chair George Galyon (IBM), and developed a consensus position on whisker theories. Several theories have been advanced, both within the group and in industry forums, and experiments are being planned to evaluate these theories.
Tin Whisker User Group	The iNEMI Tin Whisker User Group's objectives are to define tin whisker mitigation practices and acceptance testing that can minimize the exposure of tin whiskers in high-reliability applications. In 2004, the User Group released two documents: (1) interim recommendations on lead-free finishes for components used in high-reliability products and (2) recommendations for tin whisker mitigation practices and acceptance testing to minimize the exposure of tin whiskers in high-reliability applications.

Appendix C

NASA Centers' Contact Lists

Appendix C.1: Contacts for Ames Research Center (ARC)			
Name	**Office**	**Phone**	**Notes**
Paul A. Pinaula	Senior Logistics Manager	650-604-5206	Called on 01/26/05--In and out of the office on travel, referred to E.Kristich
Eric Kristich	Logistics	650-604-5137	Left message on 01/26/05; Asked V.Torres to respond
Vivian Torres	Logistics	650-604-5676	Referred by E.Kristich; Message left on 01/26/05; Contacted on 02/01/05--referred to F. Custard (Disposal) and Acquisition
Frank Custard	Disposal	650-604-4058	Referred by V.Torres; Left message on 02/01/05; Returned Call on 02/01/05--Does not have any issues with the switch to LFS, which may actually simplify the disposal process
Grace Ann Weiler	Acquisition	650-604-4685	Referred by V.Torres; No answer on 02/01/05; No answer on 02/02/05; Contacted on 03/09/05--looking for contacts; Left message on 04/01/05--Retired
Nelson Japlit	Supply	Work 650-604-3428 Cell 650-279-9084	Left message on 01/26/05; Message left on 01/26/05; Contacted on 02/01/05--Referred to M.Lacey and T.Reichert
Mark Lacy	Environmental Specialist	650-604-1406	Referred by N.Japlit; Contacted on 02/01/05--looking for contacts; Email received on 02/02/05 with contacts (Doherty, Gonzaga, Mattox, Centeno, Reyna, Schwind)
John Doherty	Supply	650-604-4712	Referred by M.Lacy; Left message on 02/02/05; Left message on 03/09/05
Janice Gonzaga	Supply	650-604-6220	Referred by M.Lacy; Left message on 02/02/05; Left message on 03/09/05
Eric Mattox	Supply -- Sverdrup	650-604-1261	Referred by M.Lacy; Left message on 02/02/05; Message left on 02/10/05; Left message on 02/10/05; Left message on 03/02/05; Left message on 03/09/05
Dave Centeno	Supply -- Johnson Controls	650-604-1620	Referred by M.Lacy; Contacted on 02/02/05--Referred to J. Moudy
Jill Moudy	Supply	650-604-3531	Referred by D.Centeno; Left message on 02/02/05; Left message on 03/09/05
Rudy Reyna	Supply -- L3 Aerotech	650-604-6296	Referred by M.Lacy; Contacted on 02/02/05--gathering info; Left message on 03/09/05; Asked J.Saucedo to contact me

Appendix C.1: Contacts for Ames Research Center (ARC)			
Name	**Office**	**Phone**	**Notes**
Juan Saucedo	Supply (Moffit Field, CA)	Work 650-604-6050 Cell 650-291-0043	Referred by R.Reyna; Message left on 03/10/05; Left message on 03/10/05; Returned call on 03/10/05--Concerned with processing temp differences and tin whiskers; Feels that a change in part number (however small) is essential; Noted that new training would be required; Mentioned MSDS could be used to ensure correct product is received
Terry Reichert	Safety	650-604-0375	Referred by N.Japlit; Left message on 02/01/05; Message left on 02/01/05; Contacted on 02/02/05--will speak with purchasing; Left message on 03/09/05
Michael S. Freeman	NESC Chief Engineer	650-604-4705	Phone number incorrect; Not found in KSC X.500
Michael R. Dudley	Director S&MA	650-604-5046	Called on 03/02/05--Secretary referred to O.Greulich
Owen Greulich	QA	650-604-4117	Referred by M.Dudley secretary; Left message on 03/02/05; Left message with secretary on 03/09/05; Returned call on 03/09/05--looking for contact; Called me on 03/10/05--Spoke with Bill Marsh who has reported to Mike Sampson
Susan Suffel	WTC POC	650-604-1238	Left message on 04/19/05; Returned call on 04/22/05—information previously sent to K.Kessel by B.Marsh
Rosa Tonarelli	Procurement	650-604-6572	Asked to contact me by C.Cunningham; Called me on 02/02/05--looking for contacts; Left message on 03/09/05; Message left on 03/09/05--had forwarded request to S.Malsom
Daryl Wong	Procurement Officer (Acting)	650-604-6889	Left message on 02/01/05; Contacted on 03/09/05--looking into contacts
Connie L. Cunningham	Procurement Officer (Acting)	650-604-5820	Left message on 02/01/05--R.Wong listed as contact in message; Referred me to R. Tonarelli; Asked S.Maulsom to respond

Appendix C.1: Contacts for Ames Research Center (ARC)			
Name	**Office**	**Phone**	**Notes**
Scott Maulsom	Procurement	650-604-1164	Asked to contact me by C.Cunningham; Message left on 02/03/05; Left message on 02/07/05; Returned call on 02/08/05--going to work on the issue; Email sent on 02/08/05--White Paper; Email received on 02/09/05--least, "caffeine free coffee" was allowed to have up to 5% of the usual amount of caffeine in it. Using that same advertising reasoning, "lead-free" solder might not be actually lead-free until there is a standard saying that the words "lead-free" actually means 0.0% lead content. 2. From a procurement point-of-view, clearly defined labeling and parts numbers need to be created for each product to differentiate it from its leaded counter-parts. If the OEM refuses to make such a differentiation, then the local NASA QA departments are going to have to work in concert with the technical people making the purchases to insure that some sort of post-purchase/post-delivery identification system is set up to keep the leaded components separate from the lead-free components. 3. It probably wouldn't hurt to develop a clause or clauses for the FAR and/or the NASA FAR Supplement defining the requirement for contractor's who purchase parts/supplies/components/whatever to establish and maintain some sort of parts/supplies/components/whatever purchasing, receiving, storage and usage system that differentiates leaded/lead-free items from each other. 4. Someone will need to define training requirements for the people who design, maintain, and repair those items where there maybe a mixture of leaded and lead-free components (sort of like we have requirements for ESD or clean room training now) to insure that the people in the field working with these things know what they are doing. 5. Existing clauses, especially those having to do with "buy-green" will need to be updated to reflect the new lead-free soldering material and any components that are created using them. In addition to any clauses, all of the PONs, directives, etc. where it is appropriate to include this new lead-free way of doing business will need to be updated. 6. For those contracts where a supplier has been producing leaded parts/components/systems for a period of time and where a non-leaded part/component would not work for technical reasons, we will probably need to let new contracts directing the supplier to maintain an appropriate amount of leaded spares to cover the reasonable lifetime of the items in the field that may need repairs from these spares.; Replied thank you on 02/09/05; Message left on 03/09/05; Contacted on 03/10/05--said that I did not know that he had been referred to me by R.Tonarelli and thank you again for his help

Appendix C.2: Contacts for Dryden Flight Research Center (DFRC)			
Name	**Office**	**Phone**	**Notes**
Gary Spencer	Logistics Manager	805-258-3322	Phone number incorrect, not found in KSC X.500
VACANT	Supply Manager		
Russ Davis	Procurement	661-276-3326	Left message on 02/01/05; Asked B.Bowman to contact me
Brian Bowman	Procurement	661-276-3329	Referred by R.Davis; Contacted me on 02/08/05--looking for contacts; Message left on 02/15/05--contacted QA who says that LFS is not used therefore not an issue; Left message on 03/02/05; Left message on 03/08/05; Left message on 03/09/05; Contacted on 03/31/05--QA he spoke to was G.May
Gary May	QA	661-276-7498	Referred by B.Bowman; Contacted on 03/31/05--referred to WTC, suggested that GIDEP alerts may be useful; Believes that if leaded is called for in the specs that is what we should receive; NASA needs to be very specific when ordering parts; manufacturers need to ensure that there is segregation of leaded and LF and that they are clearly identified by part number
Michael W. Kehoe	NESC Chief Engineer	661-276-3708	Left message on 04/19/05; Message left on 04/20/05--looking into contacts; Asked B.Davis to contact me
Bette Davis	Industrial Health	661-276-3438	Asked to contact me by M.Kehoe; Message left on 04/21/05; Contacted on 04/21/05--cannot help because she is IH
Lawrence R. Davis	Director S&MA	661-276-2312	Contacted on 03/09/05--secretary referred to B.Davis
Bette Davis	Environmental Health & Safety	661-276-3438	Referred by L.Davis secretary; Contacted on 03/09/05--referred to K. Riley
Kevin Riley	QA	661-276-3862	Referred by B.Davis; Contacted on 03/09/05--referred to H.Trent and H.Winsett
Howard Trent	QA; WTC POC	661-276-2599	Referred by K.Riley; Contacted on 03/09/05--referred to G.Mcguire (MSFC), B.Humphrey (GSFC), M.Sampson (GSFC)
Howard Winsett	QA	661-276-2262	Referred by K.Riley; Contacted on 04/19/05--Is currently following issue and member of IPC; concerned about future supply; contacted supplier who said that they will continue to make leaded paste as a special order for the next several years; suggested that testing be used in the future to verify leaded parts and that a new Q(uality) Attachment be used with Purchase Requests that require manufacturer to certify that it is a leaded part

Appendix C.3: Contacts for Glenn Research Center (GRC)

Name	Office	Phone	Notes
Linda A. Norberg	Supply at Lewis Field	216-433-3027	Left message on 01/26/05; Left message on 03/09/05
Bradley J. Baker	Procurement	216-433-2800	Left message on 02/01/05; Message left on 02/01/05; Left message with secretary on 02/02/05; Left message on 03/09/05; Returned call on 03/10/09--Was unaware of LFS issue and concerns; said that current trend is to purchase "environmentally preferable" products; Solutions could be to make the leaded solder a prominent part of contract, require certification papers, or hire Defense Contract Managers (DCM) to oversee fabrication--the last two can be very expensive
Linda Sekura	Env Preferable Purchasing	216-433-5693	Referred to me by C.Myers; Message left on 02/02/05; Contacted on 02/02/05--looking into contacts; Left message on 03/09/05; Message left on 03/14/05--looking into contacts; Email sent on 04/06/05--referred me to E.Disanto
Eugene Disanto		216-433-5231	Referred by L.Sekura via email; Contacted on 04/19/05--requested email with additional info; Sent email on 04/19/05--White Paper attached
Derrick J. Cheston	NESC Chief Engineer	216-433-3879	Left message on 04/20/05
Vernon W. Wessel	Director S&MA	216-433-2350	Left message on 04/20/05; Returned call on 04/20/05--referred to M.Blotzer
Mike Blotzer	Env Mgmt	216-433-8159 Cell 216-701-0301	Referred by B.Wessel; Contacted on 04/20/05--referred to F.Robinson and J.Reagan
Vincent Lalli	WTC POC	216-433-2354	Phone number incorrect, Not listed in KSC X.500
Gary Gorecki	WTC Alternate POC	216-433-3690	Contacted on 04/20/05--currently hand solders with lead, but unsure of what suppliers are doing, agreed that this is an issue that has to be worked with technical and procurement personnel
Kenneth A. Adams	S&MA Directorate Chief Engineer	216-433-6195	Left message on 04/20/05; Asked C.Berg to contact me

Appendix C.3: Contacts for Glenn Research Center (GRC)			
Name	**Office**	**Phone**	**Notes**
Chris Berg		216-433-6122	Asked to contact me by K.Adams; Message left on 04/21/05; Left message on 04/21/05; Left message on 05/13/05; Returned call on 05/13/05—works with T.Best, but will look into additional contacts
Frank Robinson, Jr.	Chief Risk Mgmt Office	216-433-2340	Left message on 04/20/05; Asked T.Best to contact me
Tim Best	S&MA	216-433-2359	Asked to contact me by F.Robinson; Message left on 04/21/05; Contacted on 04/21/05—will look into issue and send me information
John R. Reagan	Chief Quality Mgmt Office	216-433-2357	Contacted on 04/21/05--felt that T.Best would be the best person to work with
Manuel B. Dominguez	Chief Safety Office	216-433-6735	Contacted on 04/20/05--secretary referred me to C.Greenwell (IH)
Christine Greenwell	Industrial Hygiene	216-433-3105	Left message on 04/20/05
Timothy Ruffner	Diagnostic and Data Systems	216-433-2391	Forwarded my contact info by D.Cheston; Sent email on 05/06/05--listed multiple websites that had additional information, CC'd S.Anzalone on email
Salvatore Anzalone	Diagnostic and Data Systems		CC'd on email from T.Ruffner; Received email on 05/18/05--list of references regarding Tin Whiskers Mitigation Plans

Appendix C.4: Contacts for Goddard Space Flight Center (GSFC)

Name	Office	Phone	Notes
Bob Clark	Supply	301-286-7740	Contacted on 01/26/05--Referred to Quality Assurance
Secretary	Quality Assurance (QA)	301-286-8877	Referred by R.Clark; Left message on 01/26/05; Contacted on 03/09/05--referred to E.Marvray
Esmond Marvray	Quality Assurance (QA)	301-286-6750	Referred by GSFC QA secretary; Left message on 03/09/05; Left message with secretary on 05/13/05
Valorie A. Burr	Acting Procurement Officer	301-286-7522	Contacted on 02/01/05--referred to Fac Mgmt Office
Andrea Holton	Secretary Facilities Mgmt Office	301-286-4416	Contacted on 02/01/05--referred to Env/Safety Office
Env/Safety Office	Environmental and Safety	301-286-7422	Referred by A.Holton; Left message on 02/01/05; Contacted on 03/09/05--incorrect number, no new info available
Robert Kichak	NESC Electrical	301-286-1199	Referred by T.Wilson (KSC); Left message on 03/09/05; Returned call on 03/11/05--Concerned with solder on satellites (extreme thermal cycling with solar rays); Obsolescence risk which can drive up costs; require process control inspections; will look into the issue more
Bob Humphrey	WTC POC	301-286-0106	Referred by H.Trent (DFRC); Contacted on 04/20/05--out of office

Appendix C.4: Contacts for Goddard Space Flight Center (GSFC)

Name	Office	Phone	Notes
Mike Sampson	WTC POC	301-286-3335	Referred by H.Trent (DFRC); Contacted on 04/20/05--there is much confusion in industry about which LF alloys should use, general direction is not to necessarily use the best alloy for the requirement, but use the easiest and most economical; Feels that NASA should wait for industry to sort this out as NASA can cope with the consequences; Is currently receiving pure tin plated (whether asked for or by accident) and doesn't believe that we can avoid pure tin on terminal finishes so risk mitigation is necessary (although there is no way to completely mitigate the risk): most pratical is conformal coatings (experiments have been done that shows that it may help), others are dip coating over tin (difficult to apply evenly and may cause damage), annealing or reflowing finish; Also expressed concerns over COTS boxes (do we trust the manufacturer to meet our requirements or do we disassemble every box to make sure); Also concerned about the lack of direction and leadership within NASA in addressing this problem
Abigail Harper	Acting Director S&MA	301-286-7390	Left message with secretary on 04/20/05; Contacted on 05/13/05—secretary referred me to E.Marvray
Veron M. Brade	Associate Div Chief Procurement Operations Div	301-286-8400	Contacted on 04/20/05--who ever answered referred to J.Debelius
Jim Debelius	Institutional Procurement	301-286-5491	Referred by V.Brade; Left message on 04/20/05; Message left on 04/26/05—referred me to T.McCain
Tim McCain	Maintenance Operations	301-286-5575	Referred by J.Debelius; Left message with secretary on 05/13/05; Returned call on 05/13/05—works in facilities so no concerns

Appendix C.5: Contacts for Jet Propulsion Laboratory			
Name	**Office**	**Phone**	**Notes**
Frank W. Malinowski	Logistics Manager	818-354-4970	Contacted on 01/26/05--JPL teaches soldering classes; Looking for correct contact; Asked J.Rosca to respond
Jim Rosca	Logistics	818-354-4862	Referred by F.Malinowski--school phone number 818-354-4862; Message left on 01/27/05; Called back on 01/31/05--referred to A.Young
Alan Young	Logistics; WTC POC	818-653-4121	Referred by J.Rosca; Left message on 02/01/05; Left message on 02/07/05--requested an email detailing info; Email sent on 02/08/05; Left message on 03/09/05; forwarded email to P.Zulueta
Phillip Zulueta	WTC POC	818-354-1566	Forwarded email by A.Young; Email received on 03/09/05--said that they have no funding to support this work and referred me to F.Mortelliti
Frank Mortellite	EHS Program Mgr	818-354-3080	Referred by P.Zulueta; Left message with secretary on 04/20/05; Left message with secretary on 05/13/05; Asked T.Smith–Araki to contact me
Trish Smith-Araki	Occupational Health	818-354-9893	Asked to contact me by Frank Mortellite; Called on 05/13/05—works in OH reviewing MSDS and ensures training, will provide additional contacts
Jeffery M. Lupis	NASA Management Office	818-354-5619	Left message on 02/01/05; Message left on 02/01/05--referred to J.Kitahara
Jim Kitahara	NASA Management Office	818-354-4112	Referred by J.Lupis; Message left on 02/04/05; Left message on 02/04/05; Left message on 02/08/05; Returned call on 02/08/05--Peter Robles referred me to F.Mortelliti
Sharon Harriman		818-354-8630	Was forwarded info regarding LFS; Message left on 02/14/05; Left message on 03/02/05; Call returned on 03/03/05--JPL has done some testing of LFS for Goddard; referred to K.Bonner
John (Kirk) Bonner		818-354-1320	Referred by S.Harriman; Participating on JGPP/JCAA project

Appendix C.6: Contacts for Johnson Space Center (JSC)			
Name	**Office**	**Phone**	**Notes**
Linda F. Massey	Logistics Manager	281-483-6517	Contacted on 01/26/05--Said that her office didn't deal with that; Referred to A.Williams and J.Zamaitisi
Abrum Williams	Logistics	281-483-2018	Referred by L.Massey; Phone number incorrect, not found in KSC X.500
Joseph Zamaitisi	Logistics	281-483-2260	Referred by L.Massey; Left message on 01/26/05; Call returned 01/26/05--referred to J.Bennett, J.Figert, and R.Dasgubta
Jay Bennett	Structual Eng--Materials	281-483-8925	Referred by J.Zamaitisi; Left message on 01/26/05; Left message on 03/09/05; Message left on 03/11/05--referred to J.Jocabs, E.Sullivan
Jeremy Jacobs	MM&P	281-483-5906	Referred by J.Bennett; Left message on 04/20/05; Left message on 05/13/05; Returned call on 05/13/05—works with E.Sullivan but expressed concerns about repairs, referred to S.Gavin
Susan Gavin	Safety	281-244-2264	Referred by J.Jacobs; Left message on 05/13/05; Message left on 05/13/05; Message left on 05/15/05; Left message on 05/18/05; Returned call on 05/18/05--it is important to distinguish between LF and leaded (via part number, serial number, etc) to maintain trace-ability (for recalls, GIDEP alerts), Material characterization is very important, Must look at "flow down" requirements and procurement documents, Risk from "form, fit and function;" Quality control at the front end of the procurement stage is key
Erica Sullivan	MM&P	281-483-6233	Referred by J.Bennett; Contacted on 04/20/05--referred to B.Cook and D.Beverly
Bob Cook	SM&A; WTC POC	281-244-1903	Referred by E.Sullivan; Contacted on 04/20/05--already receiving LF parts, only know from testing which is very expensive and time consuming; problem with procurement is that unless we are are purchasing military- or space-quality parts we cannot be certain of what we are receiving; usually buy in bulk and there are no specific EEE requirements; currently test lots with scanning electron microscope
Dave Beverly	Engineering	281-483-0250	Referred by E.Sullivan; contacted on 04/20/05--feels that in the near future that it is going to be difficult to procure leaded solder; ordering only mil-quality parts is only a partial solution
John Figert	Structual Eng--Materials	281-483-8919	Referred by J.Zamaitisi; Left message on 01/26/05; Left message on 03/09/06

Appendix C.6: Contacts for Johnson Space Center (JSC)

Name	Office	Phone	Notes
Rajib Dasgubto	Structual Eng-- Materials	281-483-4739	Referred by J.Zamaitisi; Left message on 02/01/05; Contacted on 03/09/05--referred to J.Golden
Johnny Golden	Structual Eng-- Materials	281-226-6710	Referred by R.Dasgubto; Left message on 03/11/05
Karen Wyont	Supply	281-483-6656	Left message on 01/26/05; Returned call on 01/26/05--DynCorp does all procuring; referred to M.Griffith (DynCorp)
Megan Griffith	Procurement -- DynCorp	281-483-8742	Referred by K.Wyont; Contacted on 01/26/05--Referred to A.Baumbach
Allen Baumbach		281-483-7954	Referred by M.Griffith; Left message on 02/01/05, Contacted on 03/09/05--uses leaded solder but has no way of verifying what they have received
Debra L. Johnson	Procurement	281-483-4157	Contacted on 02/01/05--referred to W.Gremillion
Wayne Gremillion	S&MA (Institutional Safety)	281-483-4287	Referred by D.Johnson; Contacted on 02/02/05--looking into contacts; Left message on 03/09/05
David A. Hamilton	NESC Chief Engineer	281-483-8885	Contacted on 04/20/05--secretary referred me to H.Rotter
Hank Rotter	NESC	281-483-8885	Referred by D.Hamilton's secretary; Contacted on 04/20/05--said that B.Kichak (GSFC) is the NESC person to speak with
Yolanda Y. Marshall	Director S&MA	281-483-2422	Left message with secretary on 04/20/05; Asked L.Starns to contact me
Larry Starns	S&MA	281-483-3858	Asked to contact me by Y.Marshall; Message left on 04/21/05; Left message with secretary on 04/21/05; Returned call on 04/21/05--will forward my contact info to his soldering expert; Left message on 05/13/05 because no one had contacted me; Message left on 05/13/05—referred me to B.Cook whom I'd already spoken with
Tamyra Martin	WTC POC	281-483-4502	Phoned on 04/20/05--out of office, requested that correspondance be sent via email; Sent email on 04/20/05; Received email response on 04/21/05—referred me to Workmanship Standards Committee for additional contacts (www.workmanship.nasa.gov)

Appendix C.7: Contacts for Kennedy Space Center (KSC)			
Name	**Office**	**Phone**	**Notes**
Brian Greene	NASA AP2 Program	321-453-3838	Forwarded email on 02/08/05--stated that executive management at Hamilton-Sundstrand decided that all new H-S systems will be LF by 2007 and all legacy systems will be LF by 2012 (that includes all NASA, DoD and commercial customers)
Walt Covington	Logistics Manager	321-861-5476	No longer at KSC, left message at that number on 01/26/05--Pad B Quality is given in the phone message; Left message on 02/02/05; Left message on 03/09/05
Rebecca Denis	Supply	321-867-4104	Contacted on 01/26/05--Out of office until Feb 1, referred to C.Clark
Cathy Clark	Supply	321-867-4451	Referred by R.Denis; Left message on 01/26/05; Returned call on 01/26/05--Office handles NASA Tagged Property only
Dudley Cannon, Jr.	Procurement	321-867-7212	Contacted on 02/01/05--Secretary referred to G.Marsh
Gloria Marsh	Procurement	321-867-7349	Referred by D.Cannon's secretary; Left message on 02/01/05; Contacted on 03/09/05--referred to Reeves, McCarty, Wheeler, Haugervik
Dave Reeves	Procurement	321-867-3999	Referred by G.Marsh; Left message on 03/09/05
Mike McCarty	Procurement	321-867-9340	Referred by G.Marsh; Left message on 03/09/05
Mike Wheeler	Procurement -- SGS	321-476-4012	Referred by G.Marsh; Left message on 03/09/05
Andy Haugervik	Procurement -- Boeing	321-867-6363	Referred by G.Marsh; Left message on 03/09/05; Message left on 03/10/05; Left message on 03/10/05; Message left on 03/11/05; Left message on 04/20/05; Message left on 04/21/05; Returned call on 04/21/05--requested an email with additional info; Sent email on 04/21/05--White Paper and article on LFS; CC'd me on email to G.Burns and S.Balch; Forwarded me email on 04/26/05—no information currently available; Forwarded me email on 04/28/05—there are some discussions taking place at Boeing about why leaded solders must be used on space flight hardware, gathering more data and will reply when complete, Forwarded me email on 05/10/05—included Boeing's corporate position on LF
Timmy R. Wilson	NESC Chief Engineer	321-861-3868	Left message on 03/09/05; Message left on 03/09/05; Contacted on 03/09/05--referred to R.Kichak (GSFC)

Appendix C.7: Contacts for Kennedy Space Center (KSC)			
Name	**Office**	**Phone**	**Notes**
Larry Tucci	Sr Quality Manager S&MA	321-861-3566	Left message on 03/02/05; Call returned on 03/03/05--referred to N.Jambulingam
Natesan Jambulingam	S&MA -- Reliability	321-867-9723	Referred by L.Tucci; Left message on 03/03/05; Returned call on 03/03/05--asked for additional info and will contact me with any info he finds; Sent email on 03/03/05 with White Paper and articles--will keep me posted on any info
Bob Loomis	Sr Safety & Reliability Mgr (S&MA)	321-867-8743	Left message on 03/02/05; Call returned on 03/03/05--referred to S.Brisbin and G.Watson
Steve Brisben	Industrial Hygiene	321-867-6133	Left message on 03/03/05; Call returned on 03/03/05--referred to T.Ross
Tim Ross	S&MA-- Procurement Quality	321-867-2373	Referred by S.Brisben; Left message on 04/19/05; Returned call on 04/20/05--concerned that sub-tier suppliers are not alerting prime contractors to changes; thinks that a safety notice would help; asked that I send him the GIDEP alert
Grant Watson	Industrial Hygiene	321-867-8926	Left message on 03/03/05; Call returned on 03/03/05--referred to R.Ellison
Rob Ellison	Procurement Quality Office	321-861-5384	Referred by G.Watson; Left message on 04/19/05
Sam Haddad	Industrial Relations Officer	321-867-4346	Left message on 02/03/05
Connie Wilcox	Chief Acq Mgmt Office	321-867-7388	Left message on 02/03/05
Mitch Colvin	Lead Acq & Admin (ESO)	321-867-3415	Left message on 02/03/05
Bob Pirkle	Chief MSO	321-867-4989	Left message on 02/03/05; Returned call on 02/08/05--Only issue would be modifying existing contracts

Appendix C.7: Contacts for Kennedy Space Center (KSC)			
Name	**Office**	**Phone**	**Notes**
David Culp	Lead Program Support (MSO)	321-867-4199	Left message on 02/03/05
Steve Parker	Lead Payload & Acquisition (MSO)	321-867-2928	Left message on 02/03/05; Message left on 02/10/05; Left message on 02/10/05; Returned call on 02/10/05--no longer in that area
Marlo Krisberg	Chief OSO	321-867-7318	Left message on 02/03/05
VACANT	Lead Acq & Admin (OSO)		
Laura Rochester	Lead J-BOSC (OSO)	321-476-4027	Left message on 02/03/05
Jeffrey Lamke	Chief & SEB Mgr (LSO)	321-867-9342	Left message on 02/03/05
Terry Crowley	Lead ELV (LSO)	321-867-7696	Left message on 02/03/05; Returned call on 02/03/05--Feels that this is more of a technical issue that should be addressed by those that make the specs

Appendix C.7: Contacts for Kennedy Space Center (KSC)			
Name	**Office**	**Phone**	**Notes**
Victoria Deem	Project Lead USA -- Materials Mgmt, Logistics Planning & Supportability	321-861-5879	Left message on 12/17/04; Message left on 01/04/05; Left message on 01/06/05; Left message on 01/10/05; Returned call on 01/11/05--set up meeting; Meeting on 01/13/05 to discuss LFS and procurement issues; Message left on 01/17/05--Electrical uses NASA-STD-8739 to order sub-assemblies; Left message on 01/18/05; Left message on 02/03/05--asked about procurement flow chart; Email response on 02/03/05--requesting input on flowchart from others; Left message on 03/03/05; Sent email with article on 03/03/05; Email sent on 03/07/05; Left message on 03/08/05; Message left and email sent on 04/07/05--email contained response from Honeywell saying that while at the corporate level they are evaluating LFS and intend to meet EU requirements, their facility at KSC has decided not to go to LF; they are not currently buying any new parts and changes to LF would require EDCP and Honeywell drawings unless that parameter was controlled/changed on a mil-spec drawing; if new parts are purchased, they may want to implement similar lead finish inspections to ensure compatibility with tin-lead soldering and the prohibition of pure tin plating; Sent email on 04/19/05--asking to clarify acronyms; Email reply on 04/20/05--with acronyms; Contacted on 04/20/05--asking who to contact to find out what inspection techniques are being used by Honeywell customers, referred to P.Lafferty
Pat Lafferty	USA Log--MEDS	321-861-6532	Left message on 04/20/05 requesting additional info about what techniques other Honeywell customers are using to detect LFS; Returned call on 04/20/05--looking into contacts; Message left on 04/22/05—found Honeywell contact; Email sent on 04/22/05—referred to M.Bohley (Other Contacts—Honeywell)
Donna Brossard	Project Lead USA Log Planning & Supportability	321-861-5557	Email reply on 02/03/05 regarding flowchart
Mike Toner	USA NSLD (Avionics Lab)	321-799-5957	Contact from V.Deem; Left message on 05/13/05; Returned call on 05/13/05—referred to M.Sees whom I'd already spoken with

Appendix C.7: Contacts for Kennedy Space Center (KSC)

Name	Office	Phone	Notes
Marion Sees	USA NSLD (Senior Engineer)	321-799-7252	Contact from V.Deem; Left message on 03/09/05; Message left on 03/10/05; Contacted on 03/10/05--recommends one-time buy of leaded solder and strict requirements for future purchases; Feels that the Part Number being changed is imperative; Concerned about tin whiskers, elevated processing temperatures, compatibility, and long term durability
Rex Johnson	USA (LES Repairs)	Work 321-861-0730 Cell 321-720-8294	Contact from V.Deem; Contacted on 03/09/05--has no concerns or other possible contacts
Bob Rauch	USA (Ground Ops MMP)	321-861-4569	Contact from V.Deem; Contacted on 03/09/05--expressed concern that because manufacturers may not notify them of the change, there is no visual difference between LF and Leaded and they don't have a system in place to test that they may inadvertantly receive LF
Romie Grant	USA (LCC PC Repair)	321-861-7880	Contact from V.Deem; Left message on 05/13/05

Appendix C.8: Contacts for Langley Research Center (LaRC)			
Name	**Office**	**Phone**	**Notes**
Howard R. Puckett, Jr.	Logistics Manager	757-864-6067	No longer listed at LaRC
Suzanne Melson	Supply	757-864-3571	Left message on 01/26/05; Left message on 03/09/05--on travel
Kimberly G. Stone	Procurement	757-864-2426	Left message w/ secretary on 02/01/05; Asked P.Clark to call me
Autumn Pimperl	Procurement	757-864-2426	Contacted me on 02/02/05--referring me to Supply/Simple Acq via email; Contacted on 04/20/05--previously referred me to P.Clark
Panice Clark	Procurement	757-864-2522	Referred by K.Stone; Contacted me on 02/03/05--Feels that this is not a procurement issue, but a technical issue, Says that it is the responsibility of the end-user to research catalogs before requesting an item be purchased, Looking for technical contacts; Contacted on04/20/05--referred to D.Pierpont
Dave Pierpont		757-864-6305	Referred by P.Clark; Left message on 04/20/05; Message left on 04/22/05; Contacted on 04/22/05—requested additional info; Sent email on 04/22/05—White Paper and article; Message left on 05/16/05—looking into contacts
Dave Jones	Procurement		Replied to phone message via email on 02/17/05--referred to G.Sullivan
Greg Sullivan	Procurement	757-864-3373	Referred by D.Jones; Sent email on 02/25/05--attached White Paper; Left message on 04/20/05
Alan H. Phillips	Director S&MA	757-864-3358	Contacted on 04/20/05--referred to D.Porter
Dan Porter	S&MA	757-864-3374	Referred by A.Phillips; Left message on 04/20/05; Asked D.Pettit to contact me
Duane Pettit	Mission Assurance	757-864-5224	Referred by D.Porter; Message left on 04/26/05; Contacted on 05/13/05—asked for additional info; Sent email on 05/13/05—White Paper and article
Art Hayhurst	WTC POC	757-864-3352	Left message on 04/20/05; Message left on 04/25/05—referred me to WTC website and M.Strickland (MSFC)

Appendix C.9: Contacts for Marshall Space Flight Center (MSFC)			
Name	**Office**	**Phone**	**Notes**
Roy W. Malone	Logistics Manager	256-544-0506	Left message on 01/26/05; Email from M. Strickland states that he no longer works at MSFC--currently Dep Dir of S&MA
Carolyn A. Landry	Supply	256-544-0846	Contacted on 01/26/05--On-site Contractor makes purchases; Referred to L.Marshall
Leigh Ann Marshall	Supply	256-430-4316	Referred by C.Landry; Left message on 01/26/05; Call returned on 01/26/05--referred to D.Jordan and D.Glover
Danny Jordan		256-544-1375	Referred by L.Marshall; Left message on 02/01/05; Left message on 03/09/05
David Glover		256-544-4772	Referred by L.Marshall; Contacted on 02/01/05--referred to D.Adams
Dan Adams	Environmental	256-544-1614	Referred by D.Glover; Contacted on 02/01/05--referred to N.Coffee
Nathan Coffee	Environmental	256-544-6007	Referred by D.Adams; Contacted on 02/02/05--looking into info; Sent email on 02/02/05 with info on the project; Contacted on 03/09/05--in the ENV office so doesn't feel he can be of any help
Stephen P. Beale	Procurement	256-544-0257	Contacted on 02/01/05--secretary referred to K.Whitson
Kim Whitson	Engineering	256-544-0866	Referred by S.Beale's secretary; Left message with secretary on 02/02/05; Returned call on 02/04/05--Believes this is primarily a technical issue, but feels it does have some reach into procurement; Says that non-commercial products should have a description that can be used to determine if it is lead free, but COTS probably will not, making it impossible to readily determine if it is lead free.requested white paper to distribute to eng staff; Sent email with White Paper on 02/04/05
Jan Davis	Director S&MA	256-544-0455	Left message on 04/20/05
Bill Kilpatrick	Director SMO--Engineering	256-544-1000	Left message with secretary on 04/20/05

Appendix C.9: Contacts for Marshall Space Flight Center (MSFC)

Name	Office	Phone	Notes
Anne Meinhold	MSFC PSE&I	256-544-6494	Sent email on 12/15/04--requested that SEA members interested in LFS send me their contact info; Sent email on 12/15/04--requesting info regarding who SEA has spoken to regarding LFS; Called on 01/06/05--regarding who SEA has spoken to regarding LFS; Email response on 01/06/05--lists of reports/presentations given by SEA (forwarded to K.Kessel)

Appendix C.10: Contacts for Stennis Space Center (SSC)			
Name	**Office**	**Phone**	**Notes**
Don R. Griffith	Logistics Manager	228-688-2144	Left message on 01/26/05; Contacted on 03/09/05--referred to M.Carpenter
Marla Carpenter	Logistics Contractor	228-688-1309	Referred by D.Griffith; Left message on 03/09/05; Asked L.Givens to contact me
Larry Givens	Boeing Procurement	228-688-3899	Asked to contacted me by M.Carpenter; Message left on 04/27/05; Left message on 04/29/05; Left message on 05/13/05; Returned call on 05/13/05—hasn't procured solder in many years, but places orders through MSS (contractor) who has the responsibility to ensure that the products meet specification, has used silver solder in some thermocouple applications
Rebecca S. Dubuisson	Procurement	228-688-1636	Contacted on 02/01/05--no longer in procurement, referred to N.Etheridge
Nick Etheridge	Procurement	228-688-2974	Referred by R.Dubuisson; Contacted on 02/01/05--referred to T.Baker
Terri Baker	Support Services Contractor	228-688-3122	Referred by N.Etheridge; Left message on 02/02/05; Returned call on 02/04/05--looking for contacts
Wendy Gerhart	Procurement	228-688-1259	Message left on 03/15/05--SSC currently uses some LFS; Contacted on 04/20/05--clarified that LFS is used in the plumbing shop; looking into other solder uses
Michael D. Smiles	Director S&MA	228-688-2351	Left message on 04/20/05; Asked J.Stealy to contact me
John Stealy	Dep Director S&MA	228-688-2236	Asked to contact me by M.Smiles; Called me on 04/29/05—could not provide any information
James Washington	WTC POC	228-688-1788	Left message on 04/20/05

Appendix C.11: Other NASA Contacts			
Name	**Office**	**Phone**	**Notes**
Mike Puskar	Hamilton-Sundstrand (Suits)	860-654-5130	Contacted on 04/19/05--Working on design for new battery and charger for space suit, having trouble finding leaded parts so is looking into other options; also surveying suppliers and currently has no issues, but concerns about subcontractors who are not aware of the problem; stated that Fairchild has stated that it will be LF by end of year and will not be changing part numbers; Forwarded email to me from B.Cook regarding Paraxylene (XY)
Eric Eichinger	Boeing (Orbiter)	714-372-5197	Contacted on 04/19/05--Previously, they had put together a matrix of what suppliers are currently doing, their policy towards LF, if they understood Boeing requirements, and the process required to change; in general, the responses showed that largely, they didn't understand the change process very well, but were well aware of Boeing's policy of only using leaded parts and felt confident in their ability to comply; steps are currently being taken to look at sub-contractors/suppliers
Mark Bohley	Honeywell	602-822-4438	Referred by P.Lafferty (KSC); Left message on 04/22/05; Message left on 04/22/05; Returned call on 04/22/05—some customers are forcing Honeywell to do inspections to ensure that LF is not used, they use scanning electron microscope (SEM) and portable x-ray fluorescence

Appendix D

Subject Matter Experts

Appendix D: Subject Matter Experts

Company	Name	Contact E-Mail / Group Posted To
?	Dr. Banks	drbanks@mmm.com
?	JD Geissinger	jdgeissinger1@mmm.com
?	Joseph Fjelstad	JosephFjelstad@aol.com
Agilent Technologies	John O'Connell (B.ENG), (AMIEE)	Contact_Us@agilent.com
Arizona State University	Nikhilesh Chawla	nikhilesh.chawla@asu.edu
ARMY	Fred Haber	fred.haber@us.army.mil
ATT?	E. Hakim	e.hakim@att.net
Avaya	?	jab7@avaya.com
Avaya	?	jaechoi@avaya.com
Avaya	?	Woolleym@avaya.com
BAE	Clive Simmons	?
BAE Systems (NY)	Stephan Meschter	stephan.j.meschter@baesystems.com
BEST	R. Cirimele	rcirimele@solder.net
Best Manufacturing Practices Center of Excellence	Charlie Minter (Presentation - ON HAND)	Charlie@bmpcoe.org
Boeing (Spain)	Juan Carlos Campbell	juan.c.campbell@boeing.com
Boeing Seattle	Tom Woodrow	?
CALCE	Michael Osterman	osterman@calce.umd.edu
CALCE	Michael Osterman	osterman@calce.umd.edu
CAVE - Auburn University	Michael J. Bozack	bozack@physics.auburn.edu
Celestica Inc., - Canada	M. S. Kelly	mskelly@celestica.com
ChipPAC	Prasad Swaminath	prasad.swaminath@chippac.com
Corfin Industries	Andrew Bloom	abloom@corfin.com
Corfin Industries	Joe Zaccari	jzaccari@corfin.com
ENGENT	Matt Perry	matt.perry@engentaat.com
Englemaier Associates	Werner Engelmaier	englemaier@aol.com
European Space Agency	?	spfc@esa.int
Flextronics International	Dr. Dongkai Shangguan	Dongkai.Shangguan@flextronics.com
Florida Cirtech	Bob Gilbert	bgilbert@floridacirtech.com
Guidant	?	?
Heraeus Inc	Jon McMaster	mjcmaster@4cmd.com
Indium Corp	Tom Pearson	?
IPC	?	Subscribed to and Posted to IPC's: NoLeadTech
ITT Industries	Alan Leibowitz	alan.leibowitz@itt.com
ITT Industries	Bruce Sander	Bruce.Sander@itt.com

ITT Industries	Kenneth Devitt	kenneth.devitt@itt.com
ITT Industries	Solomon Hui	solomon.hui@itt.com
ITT Industries	Wayne Smith	wayne.smith@itt.com
JPL	Reza Ghaffarian	Reza.Ghaffarian@jpl.nasa.gov
KEMET	Mary Carter Berrios	?
Lockheed-Martin?	Jenny Hwang	JSLHWANG@aol.com
Louisville StorageTek	Allen LG	allenlg@louisville.stortek.com
Louisville StorageTek	Dierk TL	dierktl@louisville.stortek.com
Louisville StorageTek	Grigg DL	griggdl@louisville.stortek.com
Magazine?	Julia Goldstein	Julia.Goldstein@sbcglobal.net
Medtronic	ERMS Customer Relations	ers-internet-custrelations@medtronic.com
Michigan Aerospace	Jane Pavlich	jpavlich@MichiganAerospace.com
Michigan State University	K.N Subramanian	subraman@egr.msu.edu
NASA-ARC	Bill Marsh	?
NASA-ARC	Susan Suffel	?
NAVY	Andrew Ganster	?
NEMI	Bob Pfahl	bob.pfahl@inemi.org
NEMI	Mark Kwoka	?
Northrop Grumman	Andy Kostic	Andrew.Kostic@ngc.com
NPL	Martin Wickham	martin.wickham@ntlworld.com
Phoenix International	R. Kirkeby	rkirkeby@phoeintl.com
Plexus	Kirk Vandreel	kirk.vandreel@plexus.com
Raytheon Company	David Nelson	?
Restronics	M. Hendron	mhendron@restronics.com
Rockwell Collins	Dave Hillman	?
SEANET	G. Bastin	gbastin@seanet.com
Senju Solder	Derek Daily	ddaily@sjmcb.mitsui.com
Smiths Aerospace Electronic Systems	?	?
SMTA - Sandia National Labs	?	?
SMTA - Sandia National Labs	Paul Vianco	?
SMTA - TechScan Compendium	?	?
Solectron	Jasbir Bath	jasbirbath@ca.slr.com
SPIRENT COMMUNICATIONS	J. Dean McIntee	Dean.Mcintee@spirentcom.com
Spirent Communications	John Lane	john.lane@spirentcom.com

Spirent Communications	Steven Dovell	steven.dovell@spirentcom.com
Sun Microsystems	Joel Cargill	Joel.cargill@sun.com
Teradyne	Gregory Montello	gregory.montello@teradyne.com
Thales Group	Arnaud Grivon	arnaud.grivon@thalesgroup.com
TT Electronics	Allan Cole	allan.cole@irctt.com
TWI	Norman Stockham	norman.stockham@twi.co.uk
Tyco Electronics	Dr. Robert Hilty	bob.hilty@tycoelectronics.com
Universal Instruments Corporation	Peter Borgesen	borgesen@uic.com
VHL Aircraft	L. Lanes	llanes@vhlaircraft.com
Vitronics Soltec	Denis Barbini	dbarbini@us.vitronics-soltec.com
Welch Allyn	?	?
Zoll	?	?
Agilent Technologies	John Lau	John_lau@agilent.com
Agilent Technologies	Stig Oresjo	stig_oresjo@agilent.com
CALCE	Qian Zhang, Paul Friesen, Abhijit Dasgupta	?
CALCE	?	leadfree@calce.umd.edu
CALCE	?	research@calce.umd.edu
CALCE	Dr. Sanka Ganesan	sganesan@calce.umd.edu
CALCE	Prof. Michael Pecht	pecht@calce.umd.edu
CAVE - Auburn University	Sattiraju, SV., Dang, B., Johnson, R.W., Li, Y., Smith, J.S., Bozack, M.J, Flowers, G.T., Xie, F., Malucci, R.D.	?
Celestica	Polina Snugovsky	Polina@celestica.com
Celestica Limited	Rob Horsley	rhorsley@celestica.com
Flextronics International	Minna Arra	minna.arra@fi.flextronics.com
Indium Corp	Jim Slattery	jslattery@indium.com
IPC	Anthony Hilvers (VP of Industry Programs)	AnthonyHilvers@ipc.org
Northrop Grumman	Mike Ankrom	mankrom@northropgrumman.com
Raytheon Company	Hector Pallavicini	?
SMTA	?	?
Solectron	Jennifer Shepherd	jennifershepherd@ca.slr.com
Tyco Electronics	Dr. Robert D. Hilty	Bob.hilty@tycoelectronics.com
Tyco Electronics	Eric Verhelst	eric.verhelst@tycoelectronics.com

Tyco Electronics	Tom Ocket	tom.ocket@tycoelectronics.com
VHL Aircraft	Hugh	hugh@vhlaircraft.com
Aim Solder	David Suraski	dsuraski@aimsolder.com
Auburn University Department of Industrial & Systems Engineering Center for Advanced Vehicle Electronics	John L. Evans	cave@eng.auburn.edu
Binghamton Universtity	Amey Teredesai	aterede0@binghamton.edu
Boeing Phantom Works, AIA - LAEWG	Lloyd Condra	lloyd.w.condra@boeing.com
Charcroft Electronics	Edmund Coady	edmund.coady@charcroft.com
Cookson Electronics	Jim Morris	jmorris@cooksonelectronics.com
Cookson Electronics	Krist Fabian (PR Director)	kfabian@cooksonelectronics.com
Department of Mechanical Engineering University of Massachuusetts Lowell	Dr. Sammy Shina Hemant Belbase	Sammy_Shina@uml.edu
Electronics Manufacturing Laboratories, Cal Poly State University	Dr. Jianbiao Pan	pan@calpoly.edu
ESPEC Corp	Hirokazu Tanaka, Yuuichi Aoki, Makoto Kitagawa and Yoshiki Saito	?
Henkel Electronics	Steve Dowds	steve.dowds@henkel.co.uk
IBM Corporation	Donald W. Henderson	donwhend@us.ibm.com
Marconi Materials Technology	James H. Vincent, Martin R. Harrison,	james.h.vincent@gecm.com, martin.harrison@gecm.com
Materials Center - National Physical Laboratory	Alan Brewin, Christopher Hunt, Milos Dusek, Jaspal Nottay,	alan.brewin@npl.co.uk, chris.hunt@npl.co.uk, milos.dusek@npl.co.uk, jaspal.nottay@npl.co.uk
Materials Center - National Physical Laboratory	Milos Dusek, Jaspal Nottay, Chris Hunt	milos.dusek@npl.co.uk, jaspal.nottay@npl.co.uk, chris.hunt@npl.co.uk
Motorola	Patrice Langford	patrice.langford@motorola.com
Multicore Solders	Hector Steen, Malcolm Warwick	hector.steen@multicoresolders.com, Malcolm.Warwick@multicoresolders.com
NIST	Carol Handwerker	carol.handwerker@nist.gov

NIST	T.A. Siewert	siewert@nist.gov
Philips	Peer Langeveld, Erik E. de Kluizenaar	P.Langeveld@philips.com, e.e.de.kluizenaar@philips.com
Raytheon Naval & Maratime Integrated Systems	Anthony Rafanelli	Anthony_J_Rafanelli@raytheon.com
Siemens	Hans-Jurgen Albrecht, Gunnar Petzold	hans-juergen.albrecht@blns.siemens.de, gunnar.petzold@blns.siemens.de
Solectron	Phil Provencal	PhilProvencal@ma.slr.com
University of Missouri - Metallurigical Engineering	Matthew J. O'Keefe	mjokeefe@umr.edu
Univesity of Naples	Antonio Buonomo, Alessandro Lo Schiavo, Fabrizio Rotulo	antonio.buonomo@unina2.it, loschiavo@ieee.org
Witmetaal	Martin Oud, Mohammad Biglari	moud@frytechnology.cookson.com, Mo_Biglari@frytechnology.cookson.com
Aim Solder	?	info@aimsolder.com
Aim Solder	Karl Seelig	kseelig@aimsolder.com
Alcatel	Joe Smetana	joseph.smetana@alcatel.com
Alpha-Fry Technologies	Karen Tellefsen	ktellefsen@cooksonelectronics.com
American Competitiveness Institute	Blain L. Partee	?
ARINC	Roger Goldberg	Roger.Goldberg@arinc.com
Auburn University Department of Industrial & Systems Engineering Center for Advanced Vehicle Electronics	Elliot Crain	?
Auburn University Department of Industrial & Systems Engineering Center for Advanced Vehicle Electronics	Jared A. Davis	?
Auburn University Laboratory for Electronics Assembly and Packaging	R. Wayne Johnson	johnson@eng.auburn.edu
Avantec	Bernard Tournier	btournier@avantec.dehon.com

Balver Zinn	Josef Jost	josef.jost@balverzinn.com
Boeing IDS	Dr. W.L. Procarione	william.l.procarione@boeing.com
BTU International	Karen Walters	Kwalters@btu.com
Cal Polytechnic	Jianbiao Pan	pan@calpoly.edu
Components Technology Institute Inc. (Electronic Components Institute Inc.)	L. Hamiter	LHamiter@cti-us.com
Cookson Electronics	Alan Rae	arae@ced.cookson.com
Cookson Electronics	Chrys Shea	?
Cookson Electronics	Prashant Chouta	?
Cookson Electronics	Tony Ingham	tingham@cooksonelectronics.com
Copendium	?	?
Electronics Manufacturing Research and Services Department of Systems Science and Industrial Engineering State University of New York, Binghamton.	Arun Gowda	arungowda@yahoo.com
Electrovert	Dirk Ellis	dellis@speedlinetech.com
EPSI Inc	Dr. Jean-Paul Clech	?
ERA - RoHS	Paul Goodman	paul.goodman@era.co.uk
Ericsson	Ove Isaksson	ove.isaksson@ericsson.com
Goodrich Control Systems	Bob Newman	?
Henkel Technologies	Hector Steen	hector.steen@henkel.co.uk
Heraeus Inc.	Angela Grusd	?
Hewlett Packard - France	Patrick Roubaud	?
IBM Worldwide Packaging and Test - Microelectronics Division	Marie Cole	?
IDEALs	?	?
Intel	Fay Hua	fay.hua@intel.com
ITRI - Soldertec	Kay Nimmo	kay.nimmo@tintechnology.com
IVF	Dag Anderson	da@ivf.se
Jabil Circuit	Srinivas Chada	srini_chada@jabil.com
JEDEC	Julie C.	juliec@jedec.org
Kester	Peter Biocca	pbiocca@kester.com
Kyzen Corporation	Mike Bixenman	mike_bix@kyzen.com

LEADOUT	Eduardo Dias Lopes (Contact C3P about this)	?
Loctite	Doug Dixon	doug.dixon@loctite.com
Mat-Tech	Erik Brom	e.brom@mat-tech.com
Metcal	Paul Wood	pwood@metcal.com
Metcal Europe	Simon Hawkins	Shawkins@metcal.com
Military & Aerospace Electronics (E-Zine)	Keith Gurnett, Tom Adams	?
MLFC - Air Products and Chemicals, Inc.	Marie Kistler	kistlemd@apci.com
MLFC - Kwalters	Karen Walters	Kwaltersjobs@aol.com
MLFC - Mass. Toxics Use Reduction Institute	Liz Harriman	harriman@turi.org
MLFC - Raytheon Company	David Pinski	David_A_Pinsky@raytheon.com
MLFC - Schneider Electric	Mark Quealy	mark.quealy@modicon.com
MLFC - Texas Instruments	Donald Abbot	d-abbott1@email.mc.ti.com
MLFC - Tyco Electronics	George Wilkish	wilkishg@tycoelectronics.com
MLFC - Tyco Electronics	Helena Pasquito	pasquith@typcoelectronics.com
MLFC - University of Massachusetts	Sammy Smith	sammy_shina@uml.edu
NCMS	?	?
Sanmina Corporation	Tom Bresnan	tbresnan@hadco.com
Semiconductor International	Greg Reed	?
Siemens	Bernd Schwarz	Bernd.schwarz@siemens.com
Siemens VDO Automotive	James R. Thompson, Ping Seto	?
Silicon Pipe Inc.	Joe Fjelstad	josephfjelstad@aol.com
SMART	Eduardo Dias Lopes (Contact C3P about this)	?
SMART - Surface Mount and Related Technologies	?	leadfree@smartgroup.org
SMT Engineering Co	Frank Liotine	?
Solder Products Value Council	?	?
Soldering Technology International Inc.	Jim Raby	jraby@solderingtech.com
Soldering Technology International Inc.	Mel Parrish	mparrish@solderingtech.com
Soldertec	?	?
Technical University of Berlin	Karsten Schischke	karsten.schischke@tu-berlin.de

The Aerospace Corp.	Gary Ewell	gary.j.ewell@aero.org
The Massachusetts Pb-Free Free Consortium (MLFC)	Richard A. Anderson	anderson@tycoelectronics
Tin Technology	?	?
TURI	?	?
Universitat Wien (University of Vienna)	Adolf Mikula	adolf.mikula@univie.ac.at
W.C. Heraeus GmbH - Germany	Anton Zoran Miric	anton.miric@heraeus.com