NEPP Workshop at NASA Goddard
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PEM update and Cu Bond Wire Update- Documentation and Data

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INTEGRA
TECHNOLOGIES

PEM TASK Team Update

Team Composition

Under SAE G12

- **Chairs**
  - Sultan Ali Lilani - Integra Technologies (Chair)
  - David Locker – US Army (Team Lead – Avionics / Terrestrial PEMs)
  - Rod de Leon – Boeing (Team Lead – Space)

- **Members**
  - 30 members attend weekly meetings (65+ members in distribution list)
  - Representatives from Boeing, Lockheed, NG, Harris, L-3, Aerospace, NASA, Marshall Space, JPL, Aerospace, Rocketdyne, Army, Air Force, Honeywell, SWRI, Rockwell, DLA, BAE, Integra Technologies, etc.
  - Good Representation from OCMs: TI, ON, Intel, LTC, Xilinx, ADI, IR

- **Meetings: Bi-Weekly (started 2/25/2014)**
  - Alternate weekly meetings between Space and Avionics / Terrestrial

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The Need

Item	Comments

Why PEM Task Team?	1. No one comprehensive flow exists that OEMs can use for plastic COTs; specially for Avionics / Terrestrial applications. For Space; NASA has PEM-INST-001comes closest to what industry uses. There are many other flows that various OEMs use and significantly differ from PEM-INST-001
	2. PEM-INST-001 and other flows are written around Microelectronics. However; we see PEM usage for Discrete devices also.
	3. Cost and schedule is a concern by users. Upscreening and additional qualification is costly
	4. Address some of the existing tests used for screening and qualification that are not clear:
	    1. CSAM - controversial - some use it extensively; some don't at all
	    2. Burn-In – Dynamic vs. static burn-in not clear. Discrete BI not addressed
	    3. Outgassing, Construction Analysis not addressed in various flows
	    4. Should pre-conditioning be used for life test samples?

What are the challenges?	1. Space and Avionics / Terrestrial have different needs and requirements 2. QML and non-QML users have different risk aversions 3. OCMs have a tough time supporting low volumes; varied requirements 4. Risks and OCM's assertion that they have made great advancements in Quality and Reliability of the various existing flows (Class N flow, COTs, Automotive and EP products) are not clearly understood.
What are the goals of the industry task group?	1. Step 1: Create a common flow for that the Space and Avionics /Terrestrial can use and OCMs can support. Use COTs as much as possible 2. Step 2: At some point, address QML PEMs for Space.
Current Status	Two sub-teams established: 1. Avionic / Terrestrial sub-group 2. Space sub-group

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Progress / Accomplishment at 10,000 Foot Level

- **Both Sub-Groups are making progress**
  - Space – Screening flow completed; qual flow almost completed
  - Agreement on Avionics group focus – Screening flow almost completed. Qual flow discussions going on
- **DPA Inputs for PEMs**
  - David Locker led several months of focused meetings on PEM DPAs including Cu bond wire
  - Inputs provided to JEDEC Committee for DPA (Michael Cozzolino)
- **Still a microelectronic focus**
- **To be released as a G12 guideline document**

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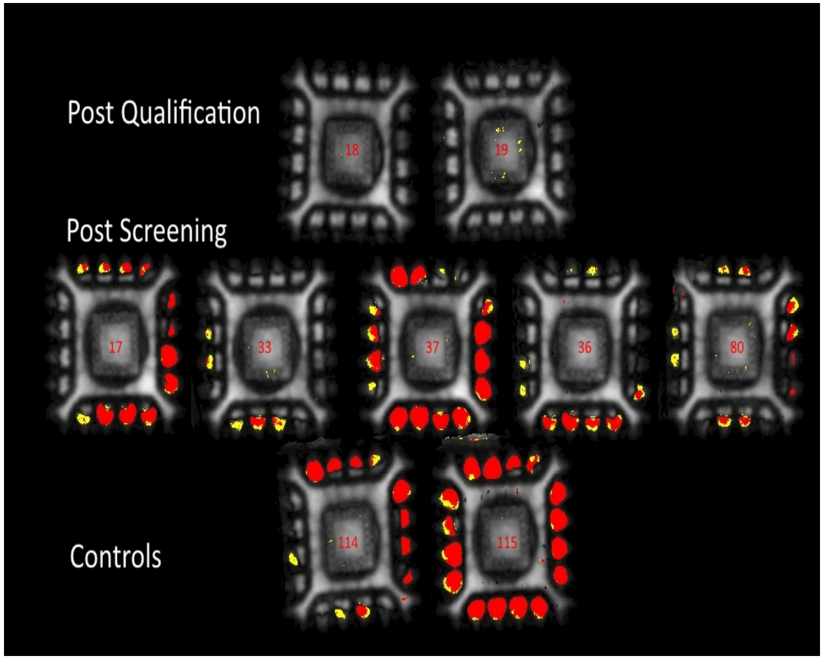
A Case of False Positive CSAM

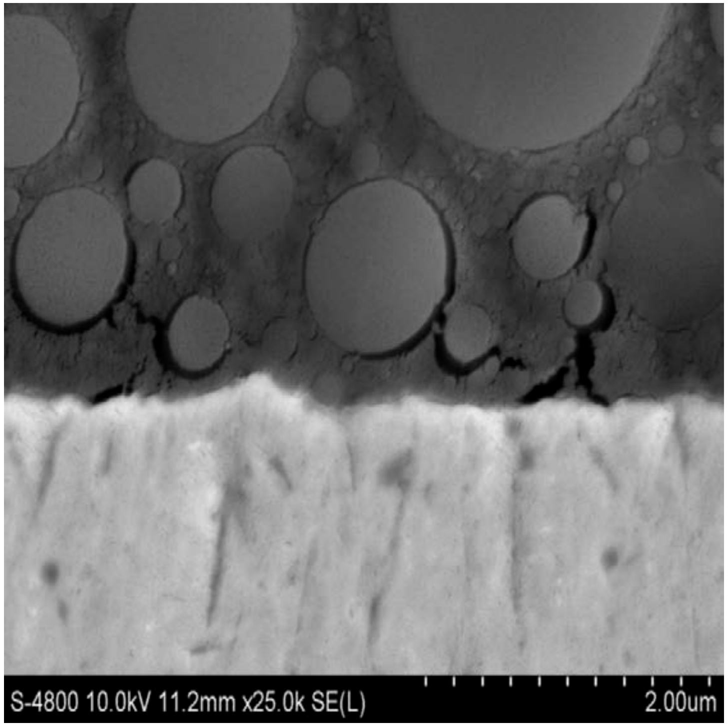
Background

- **Device:NB6N14SMNG**
- **Package: 16 QFN**
- **Problem**
    - **Post Screening samples subjected to Qualification per NASA PEM-INST-001**
    - **Pre-Qualification CSAM revealed delamination on 33/36 devices in the area of wire bonds.**
    - **Post- Qualification CSAM on 22 parts had no delamination or electrical test failures.**
    - **2 Control samples did not change from pre-qualification to post-qualification indicating that the CSAM setup was unchanged.**
- **Qualification Tests:**
    - ✓ **Pre- Conditioning - JESD22 Method A113 68 hours, +85 ° C, 60% RH).**
    - ✓ **1000 hours Life Test at 105C**
    - ✓ **-55 to 125C Temp Cycle – 200 Cycles**
- **CSAM Images: Taken per PEM-INST-001; section 5.3.3**



- **Post screening Images**: Delamination indications on the leads
- **Post qualification Images:** No signs of delamination
- **Control units Images:** Delamination

Post Screening Cross Section



- Interface between the molding compound and the lead finger.
- This is not a traditional delamination but rather a change in the molding compound.
- Separations between the molding compound and the filler material can be seen.

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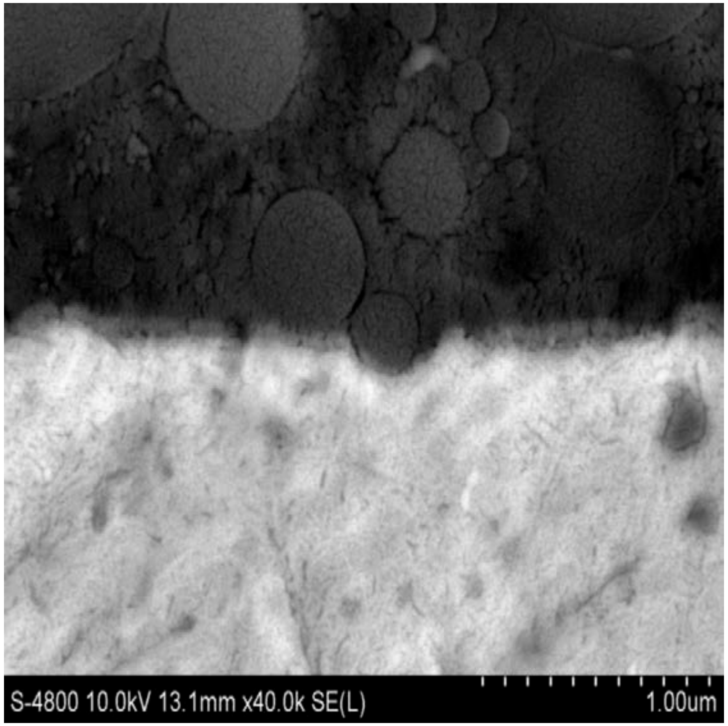
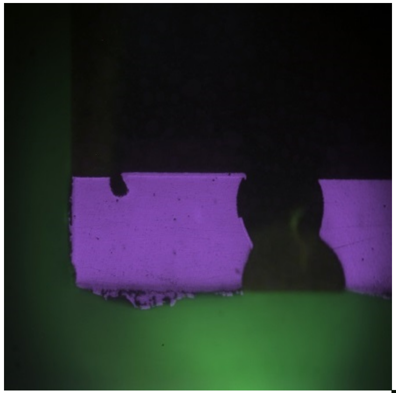
Post Screening Cross Section



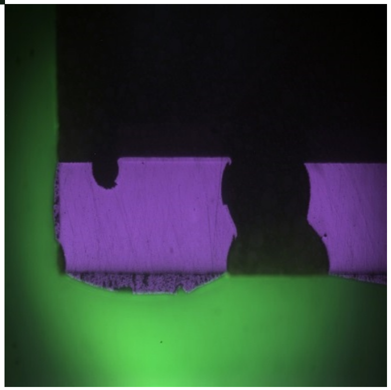
- Some residual separation between the filler material and the molding compound can be seen.
- No delamination was observed between the lead finger and the molding compound.

Dye Penetrant Test



Dye Penetrant Post Qualification

No Dye penetrated to the internal package interfaces on either the post screening or post qualification samples.

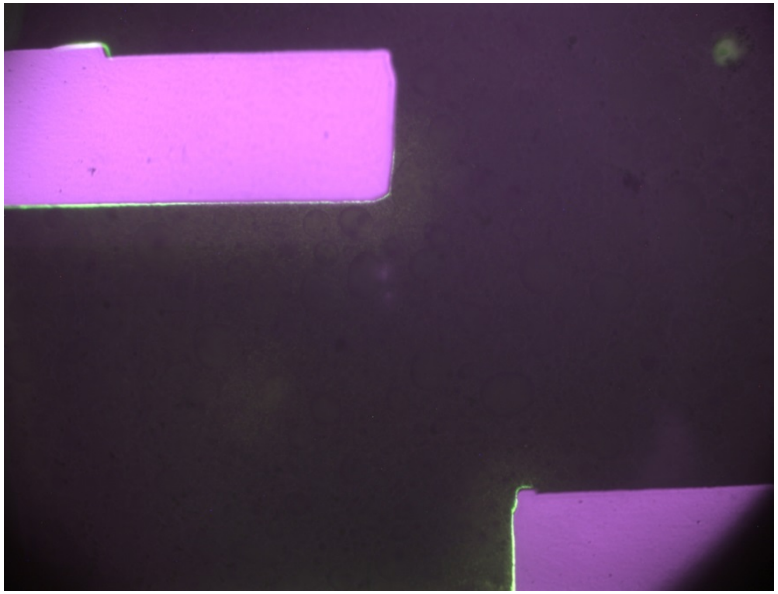


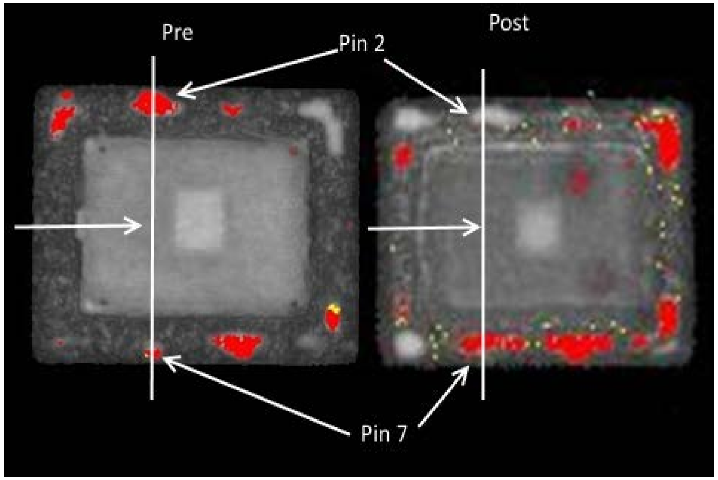
Dye Penetrant Pre Qualification

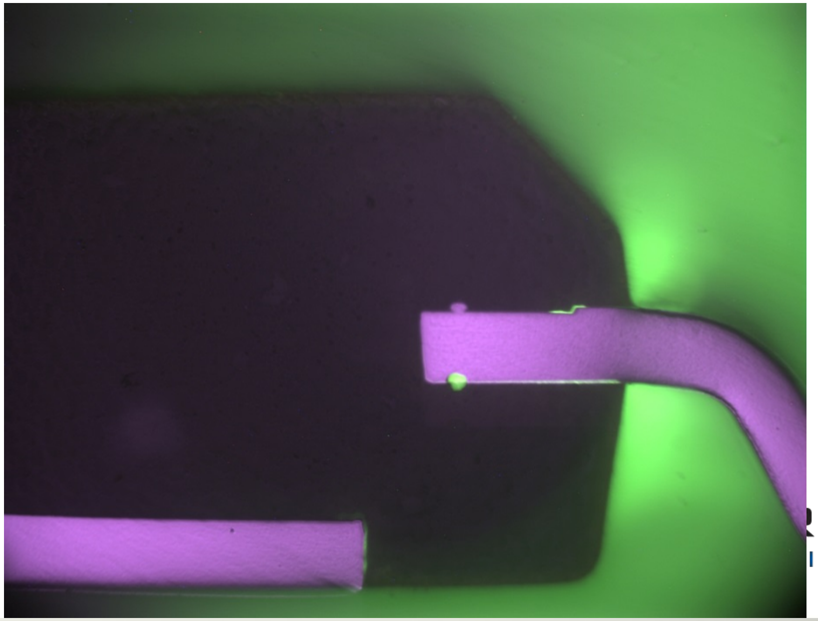
No path for moisture ingress was observed in post screening or post qualification samples.

Example of Water Ingress Masking Delamination in CSAM

Pin 7 (Die Penetrant shows delamination)







Pin 2 (Die Penetrant shows delamination)

Some Thoughts

- Initial concern was that interface was too much compromised and hence; excessive moisture ingression was masking delamination

- Possible change in molding compound characteristic – Is Tg too low that 235C reflow effects it slightly to change surface filler arrangements? Need to study

- Need to verify delamination using cross section – Useful and inexpensive method

- Note JEDEC-J-STD-020D

  6.2 Criteria Requiring Further Evaluation Delamination is not necessarily a cause for rejection. To evaluate the impact of delamination on device reliability, the semiconductor manufacturer may either meet the delamination requirements shown in 6.2.1 or perform reliability assessment using JESD22-A113 and JESD-47 or the semiconductor manufacturer's in-house procedures. The reliability assessment may consist of stress testing, historical generic data analysis, etc. Annex A shows the logic flow diagram for the implementation of these criteria.

  If the SMD Packages pass electrical tests and there is delamination on the back side of the die paddle, heat spreader, or die back side (lead on chip only), but there is no evidence of cracking, or other delamination, and they still meet specified dimensional criteria, the SMD Packages are considered to pass that level of moisture sensitivity.

Cu Bond Wire TASK Team Update

Under SAE G12

- **Leadership**
  - Jeff Jarvis (Chair) – US Army Aviation and Missile Research, Development, and Eng. Center
  - Sultan Ali Lilani (Co-Chair) - Integra Technologies

- **Members**
  - 30 members attend weekly meetings (65+ members in distribution list)
  - Representatives from OCMs: TI, Xilinx, ST Micro etc.
  - Users: Boeing, Lockheed, NASA (MFSC, Goddard, JPL), Navy, AF, Aerospace, NG, Navy Crane / MDA, DLA, Army, Boeing, Space X, Rockwell etc.
  - Test Labs (Analytical Solutions, Hi-Rel Lab, DPACI)
  - Others (Golden Altos, SEMTECH, e2V)

- **Meetings:** Twice a month (started June 2015)

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1. Basis of "copper wire bond" projects going on within the "high reliability" industries.

- Characterize Copper Wire Bond Properties
  - Critical Decapsulation Process: Laser preferred
  - Initial state Physical analysis (MIL-STD-1580)
    - Q006, Mold compound (pH, Cl-), Wire material
  - After documented stresses
  - Utilize AEC Q006 methodology
    - CSAM, wire pull, ball shear, bond cross-sections, functional
    - Additional info in MIL-STD-1580, JESD22-B116
- Characterize Environmental Accelerated Stresses
  - Environmental monitor and quals
  - Controlled operational stresses
  - Determine stress acceleration factors
  - Focus on Copper, but also consider Silver wire

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2. Trying to gather test and inspection from manufacturers and users especially based on AEC Q006A. Looking for "rigorous" documented data that can be utilized for current/future standards development.

- Cu wire stress test qualification results
- Wire pull/ball shear – mean, min, max, standard deviation
- CSAM images before/after stressing
- Electrical/ATE functional/parametric test results before/after stress tests
- Cross-sections of ball/wedge bonds

3. Data gathered to date on Cu-wire Failures in test and the field.

- Lifted bond wire in iNEMI testing and non-commercial field applications (no pictures to share)
- Cracked silicon under Al bond pads (see cratering information and pictures)
  - Should not have active circuitry under pads for Cu wire
- Parameter failures and hard failures from Cu-wire-bond issues. FA analysis shows suspect stitch bonds (FA not available for distribution)
- Cracked/open wire above ball bonds, fielded CCA (see picture)
- Cracked wire at stitch bond in application production/testing (see picture)
- Crack in the stitch bond during application production/testing (see picture).
- Cu-wire corrosion failures Au & Cu wire of same part type (see pictures).
- Stitch bond failure, specific delamination on lead frame

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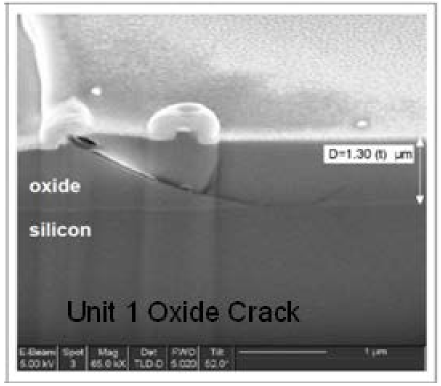
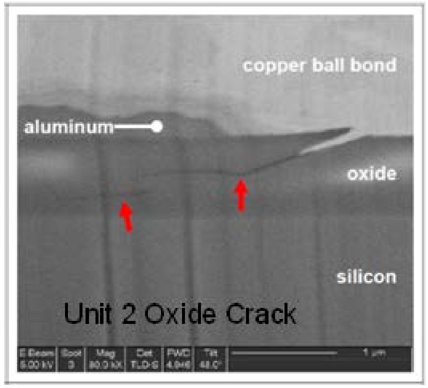
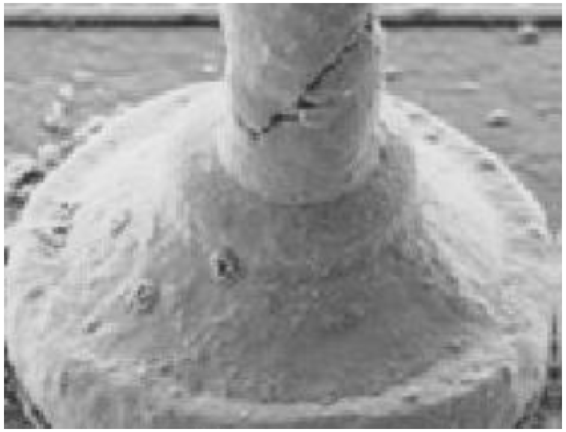
4. Micro-cracking and pad cratering

- Only direct cause understood at present
- Two returned components destructively examined
- Microampere level current leakage was within the device, based on initial failure analysis of returned part.
- Crack was found through oxide layer at pin bond pad internal to part, likely incurred during wire bond to pad.
- Crack can provide conductive path to adjacent bond pad causing current leakage
- Short between pins affected voltage levels
- Other shorts affected performance

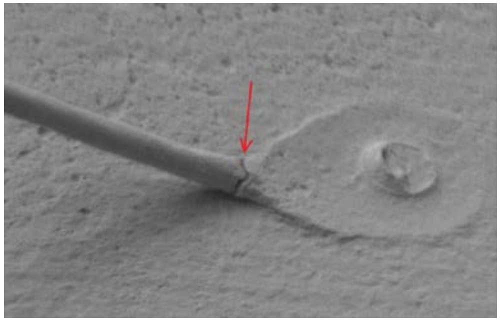




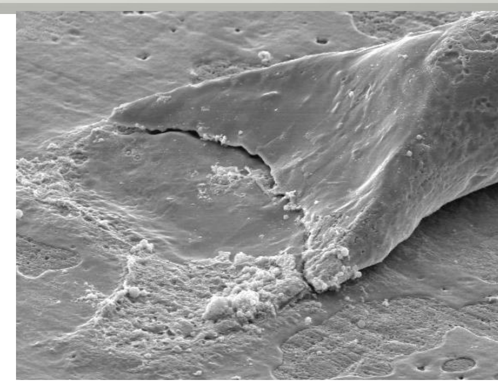
Cratering/pad structure micro cracking



Wire break above ball bond, cause intermittent field failure



Stitch Bond Cracking

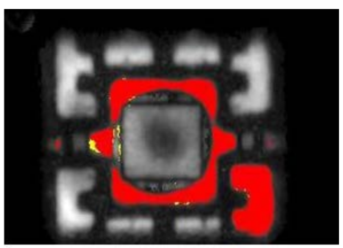


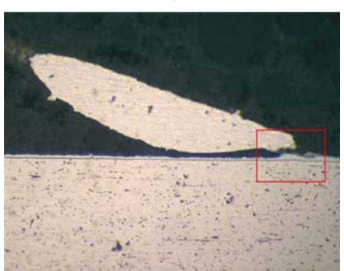
Break in wire at heel of stitch/wedge

Break through the stitch/wedge bond area

Delamination contribution to stitch bond failure

Corrosion on Cu-wire versus Au-wire, same part type, same board, manufacturer switched to Cu-wire and user did not know it.





Delamination contributing to potential corrosion and stitch/wedge break

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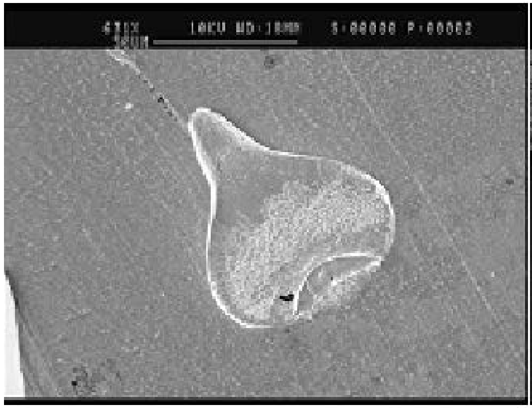
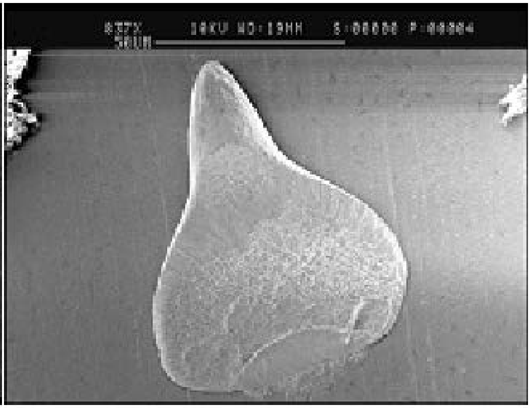
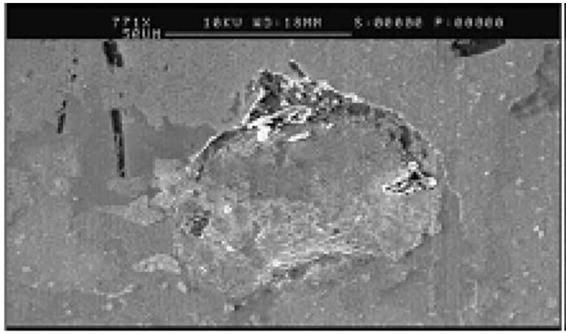
Corrosion on stitch/wedge, Au-wire versus Cu-wire



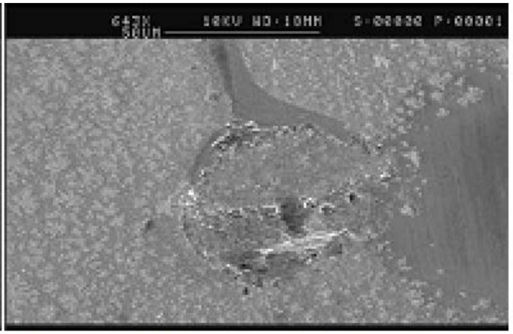
[redacted] SEM image of the gold stitch bond in [redacted] No corrosion was noted.



[redacted] SEM image of the gold stitch bond in [redacted] No corrosion was noted.



[redacted] SEM image of the copper stitch bond in [redacted] Note the corroded copper.



[redacted] SEM image of the copper stitch bond [redacted] Note the corroded copper.

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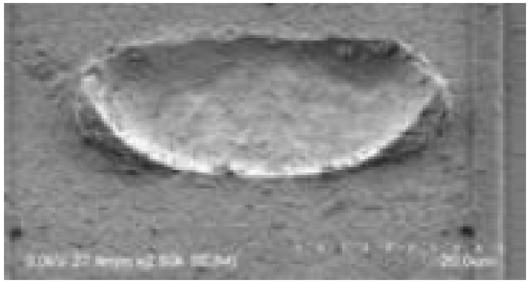
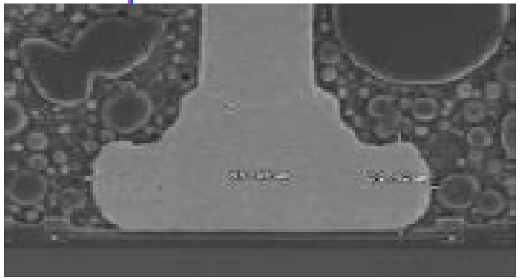
In addition to the ongoing data collection, we are working to develop Cu-wire evaluation criteria to distinguish/identify potential field reliability suspect parts. Looking at "typical" and "optimized" conditions versus "non-typical" and "non-optimized".

Optimized Parameter



Optimized Process



Optimized splash and effective ball bond area giving "typical" shapes. Still defining "non" conditions.

Cu Bond Wire Study at Integra and ASI – An Update

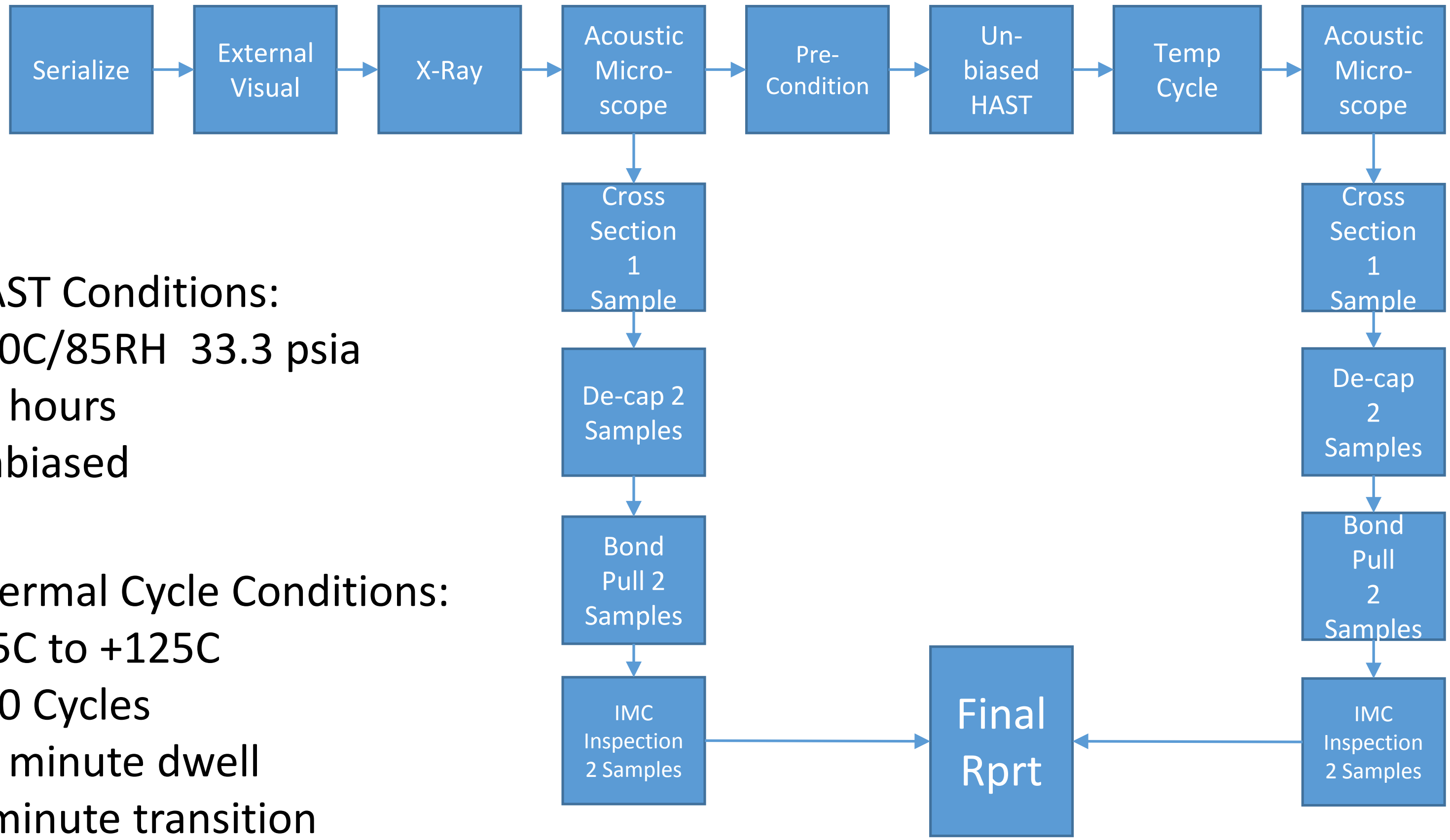
Phase 1

- Perform evaluation of Cu Wire without bias stresses
- Intended to gather some basic information
- Stresses utilized were unbiased and were common for typical qualifications for package changes

Phase 2

- Perform evaluation of Cu Wire with bias stress
- Utilizes biased HAST to more rapidly age the intermetallic bond.
- Temp Cycle utilized to stress the bonds and accelerate the process of work hardening and intermetallic bond issues.
- Increased Sample size

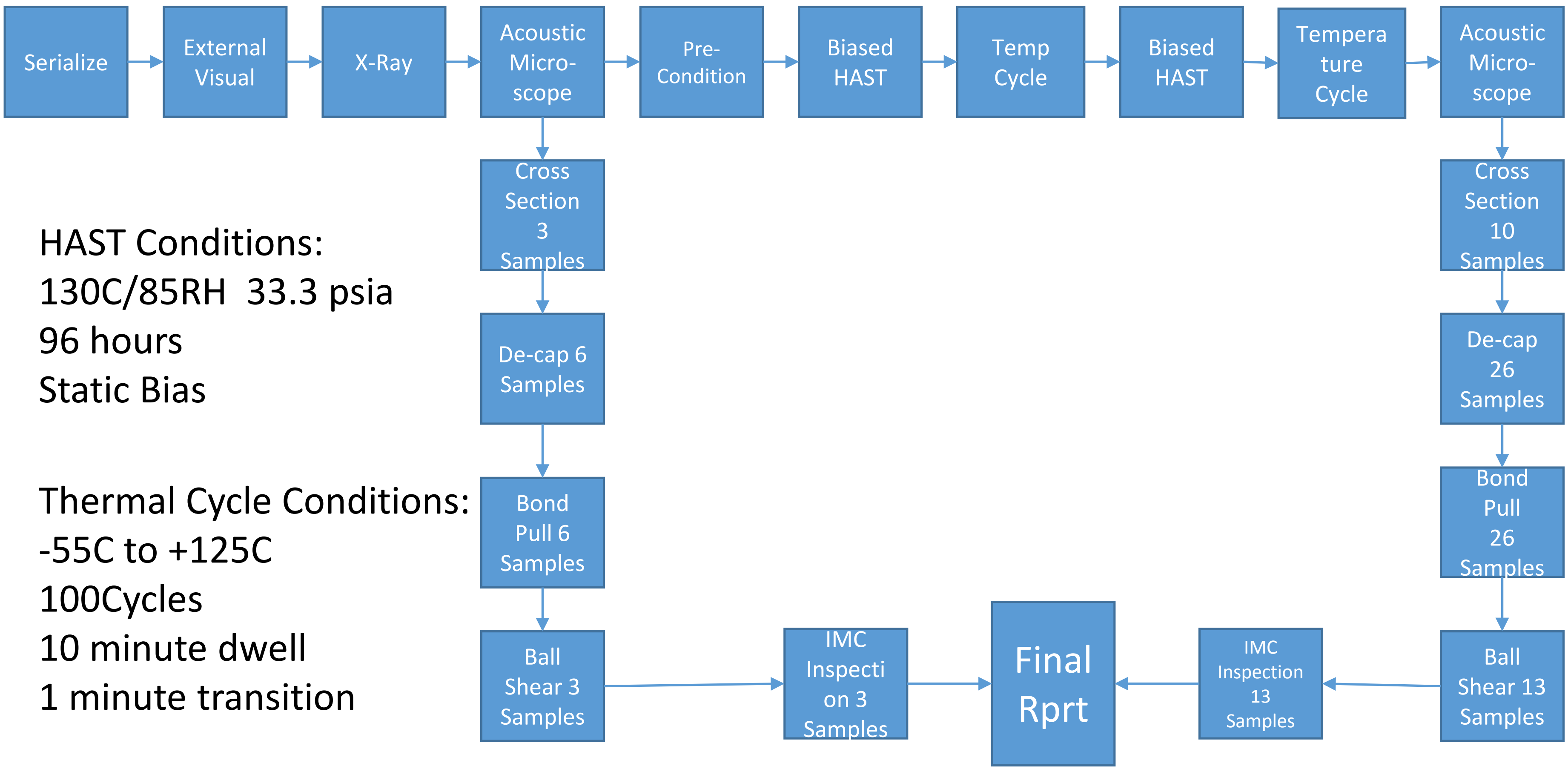
Process Flow for Phase 1



HAST Conditions:
130C/85RH 33.3 psia
96 hours
Unbiased

Thermal Cycle Conditions:
-55C to +125C
100 Cycles
10 minute dwell
1 minute transition

Process Flow for Phase 2



HAST Conditions:
130C/85RH 33.3 psia
96 hours
Static Bias

Thermal Cycle Conditions:
-55C to +125C
100Cycles
10 minute dwell
1 minute transition

Data for Phase 1

Sample Devices

Part Number	Manufacturer	Date Code	Bond Material	Bond Pad Material
74FCT162245ATPVG	IDT	1402	Cu	Al
TPS51116RGET	Texas Instruments	1038	Cu	Cu/Ni/Pd
M74VHC1GT50DFT1G	On Semiconductor	1421	Cu	Al
BAS70-04LT1G	On Semiconductor	1448	Cu	Al

It has been observed during analysis that PCN data is not always accurate for determining when parts actually transition to copper. Because of this, all devices were chosen base on historical analysis data indicating that the manufacturer had transitioned their product to copper.

Two additional devices were candidates, however, the date codes received were prior to the manufacturer's transition to copper.

With limited data on sample sizes and stress level:

1. IMC was found to be 6% greater pre to post stress
2. Aluminum Splash was observed
3. Bond lifting was observed with location dependency
4. IMC
   a. Au/Pd IMC was much thinner than Au/Al – IMC was not measurable due to thickness and slow diffusion with this metal stack
   a. IMC seen on all other devices

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Summary

Lot Numbers	Discussion of Results
74FCT162245ATPVG	• More work needs to be done to identify the cause of the bond lifts. Since these appear to be location dependent, it is recommended that phase 2 specifically look at those locations in cross section. • Because we have location dependent bond lifts this part is a prime candidate for phase 2. The identification of weaker bond interfaces combined with additional stresses may well yield outlier data to be used for future selection of parts. • IMC was found to be 6% greater pre to post stress with no cracking or voiding detected. Aluminum splash was seen during internal visual inspection and cross section inspection. • During Phase 2 sample sizes will increase for cross section and IMC inspection allowing better insight into the cause of bond lifts and provide more quantifiable date to support cause identification..
TPS51116RGET	• Au/Pd IMC was much thinner than Au/Al IMC seen on all other devices. • While the area did change from the pre-to-post stressed parts the sample size was too small to make any assumptions about the parts. • Phase 2 sample sizes have increased and will provide statistically significant sample sizes.
M74VHC1GT50DFT1G	• No indications of bond quality issues were noted. • This part will be eliminated from phase 2 as it exhibits the same formation as the other On Semiconductor device.
BAS70-04LT1G	• No indications of bond quality issues were noted. • Phase 2 sample sizes will increase to provide a more statistically significant sample size and additional aging.

With Biased HAST

Bond Pull Data

TPS51116RGET					
Pre		Post		Post Phase 2	
Min	18.4135	Min	18.2446	Min	13.0257
Max	29.3736	Max	33.6069	Max	23.2201
Mean	23.0359	Mean	25.9858	Mean	17.5127
STDev	3.01775	STDev	3.26181	STDev	1.35318
Number of Bonds	50	Number of Bonds	50	Number of Bonds	475
Bond Lifts	No	Bond Lifts	No	Bond Lifts	No

IMC Data

TPS51116RGET (Ball)						TPS51116RGET (IMC)					
Pre		**Post**		**Post Phase 2**		**Pre**		**Post**		**Post Phase 2**	
Min	2.45	Min	2.43	Min	2.59	Min	1.88	Min	1.93	Min	1.98
Max	2.82	Max	2.89	Max	2.88	Max	2.57	Max	2.9	Max	2.62
Mean	2.65	Mean	2.63	Mean	2.74	Mean	2.19	Mean	2.24	Mean	2.35
STDev	0.08	STDev	0.08	STDev	0.06	STDev	0.14	STDev	0.21	STDev	0.1
Number of bonds	50	Number of bonds	50	Number of bonds	174	Number of bonds	48	Number of bonds	49	Number of bonds	94
Average Area	5.59	Average Area	5.44	Average Area	5.91	Average Area	3.77	Average Area	3.94	Average Area	4.33
				% IMC area Change Pre-to-Post					15%		

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Phase 2 Qual Work Is Continuing

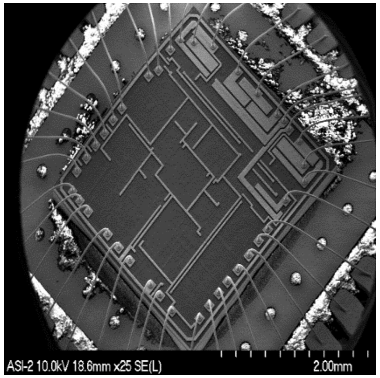
- Phase 2 Sample Size increased to 45 pieces per device type
- Parts will follow the phase 2 flow from slide 4. Major differences include.
  - Increased sample size for cross section and Post IMC inspection.
    - Specifically look at bond issues seen in phase 1 as well as inclusion of more bond analysis.
  - Ball shear added
    - Ball Shear directly relates to the IMC strength where bond pull will only capture gross defects.
  - Increased HAST and T/C with included Bias for HAST.
    - Biased HAST is necessary to accelerate the galvanic reaction the parts will see during normal operation.

Copper Wire Bond De-Encapsulation

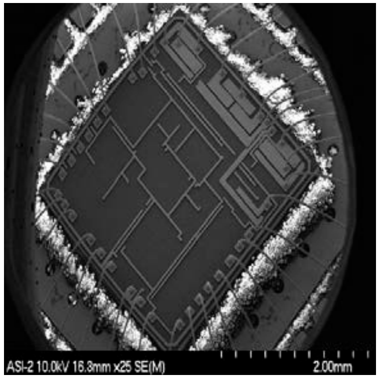
Types of Decapsulation Techniques for Copper Wire Product

Type	Effectiveness
Wet Chemical	Higher potential to attack the Cu bond wires
Plasma	No acid used; does not attack Cu bond wires but attacks certain oxides. Process varies with type of plasma used. Not enough data available
Laser + Wet Chemical	Lower potential to attack Cu bond wire but still needs optimization of Laser and wet chemical process

Full Chemical De-encapsulation



Laser/Chemical De-encapsulation



- Both methods yielded similar values for maximum and average bond pull
- Laser/Chemical process improved minimum bond pulls
- Both methods must be tightly controlled to avoid damage to the devices
- Laser/Chemical process is more automated reducing variability

Total Wire Bond Count:	190
Minimum wire pull strength:	6.967
Maximum wire pull strength:	13.855
Average wire pull strength:	11.609
Standard Deviation:	1.1690

Total Wire Bond Count:	190
Minimum wire pull strength:	8.6953
Maximum wire pull strength:	13.773
Average wire pull strength:	11.627
Standard Deviation:	0.903

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Purpose

- **Provide update on laser ablation capability and its release to production.**
- **Comparison between full chemical de-encapsulation and laser ablation/chemical de-encapsulation process.**
  - Provide Pros and Cons for each technique
  - Provide Data for expected outcomes for future projects
- **Identify any cautions about the use of laser ablation or full chemical de-encapsulation of copper wire bonded parts.**

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Laser Ablation Capability Update

- **Control Laser FALIT equipment was installed at Analytical Solution in early May.**
- **Proof of Laser de-encapsulation process was developed.**
  - Phase 1 – Compare and contrast laser ablation/chemical De-encapsulation with full chemical de-encapsulation. (Complete)
    - Leverage experience from F/A engineer who previously worked with laser ablation equipment.
  - Phase 2 – Develop a complete understanding of variable settings with the laser ablation equipment and how each variable can affect the final outcome. (Ongoing)
    - Equipment Variables
      - Power
      - Q
      - Duty Cycle
      - Raster Rate
    - Device Variable
      - Mold Compound
      - Pre vs post environment mold compound changes
- **Several devices have been successfully de-encapsulated already.**

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Phase 1

Obtain Devices

Mount Devices

Bake Devices

Full Chemical Decap	Laser Ablate Entire Device
Visual and SEM Inspection	Chemically Remove Residual Molding Compound
Document Worst Case Bond on Die	Visual and SEM inspection
Document Worst Case Bond on Lead Frame	Document Worst Case Bond on Die
Document Worst Case Wire	Document Worst Case Bond on Lead Frame
Bond Pull	Document Worst Case Wire
	Bond Pull

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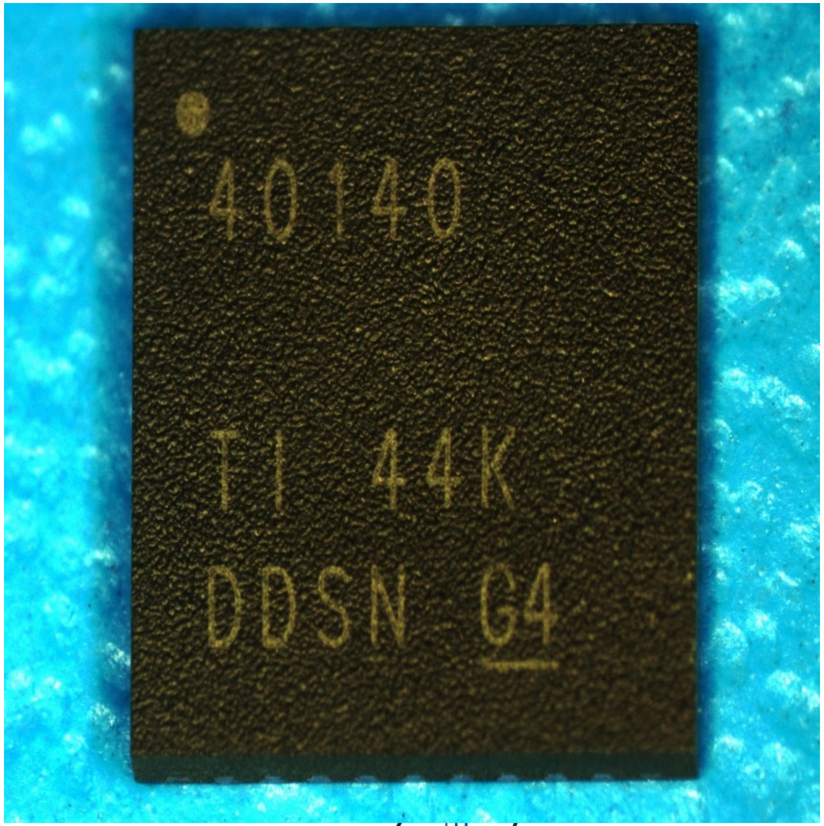
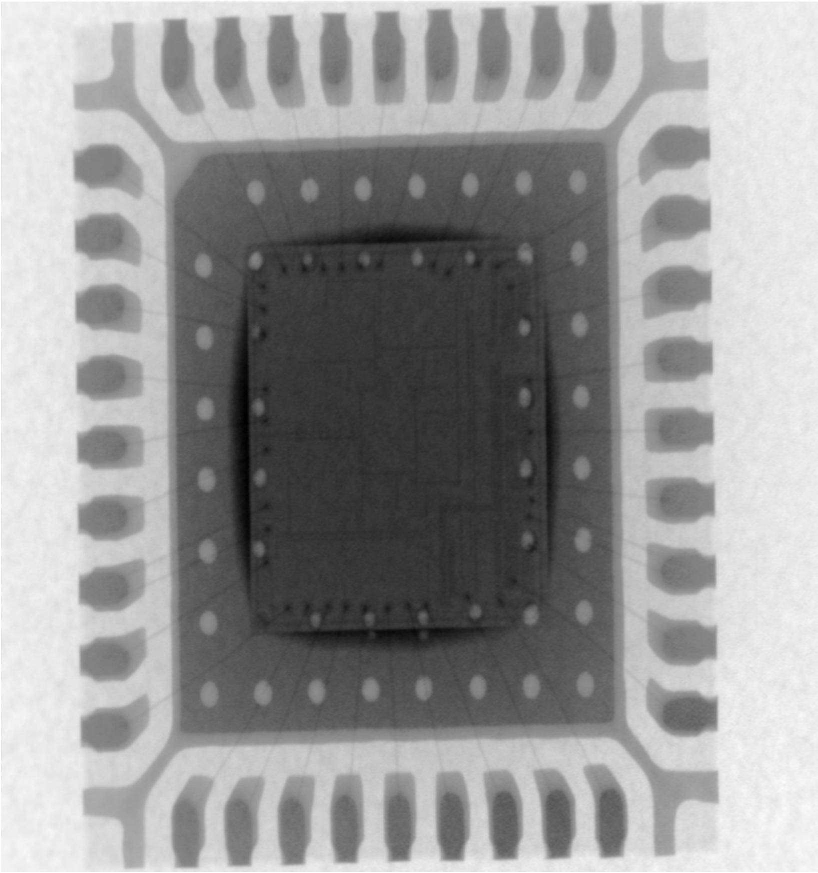
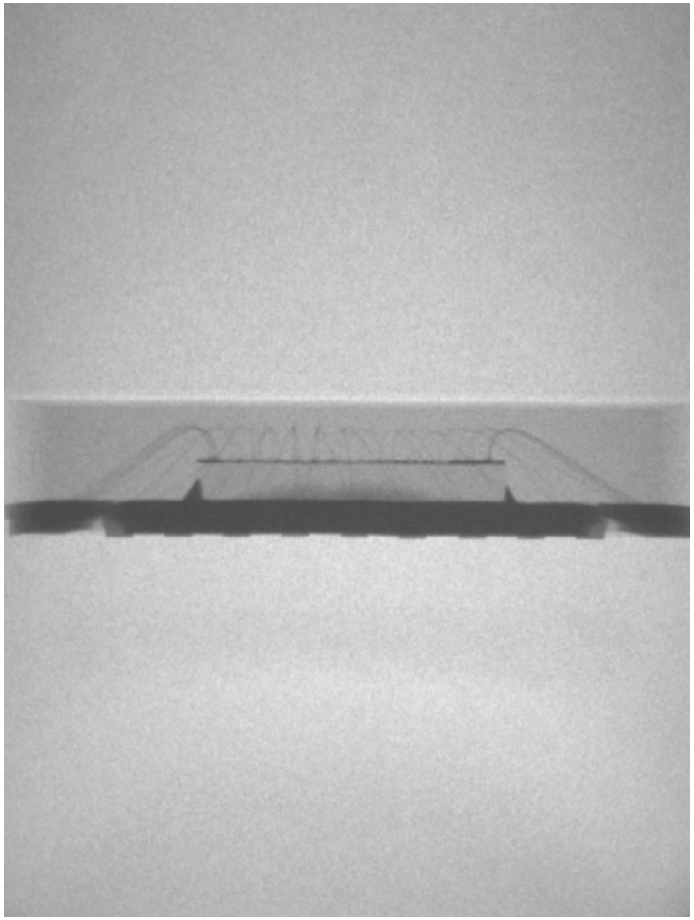
- Part Number: TPS40140RHH
- Device Description: Dual or 2-Phase, Stackable Controller
- Package: VQFN 36
- Wire Bond Material: 1 mil Copper
- Number of Wire Bonds: 38
- All Devices used for this study were from a single lot.

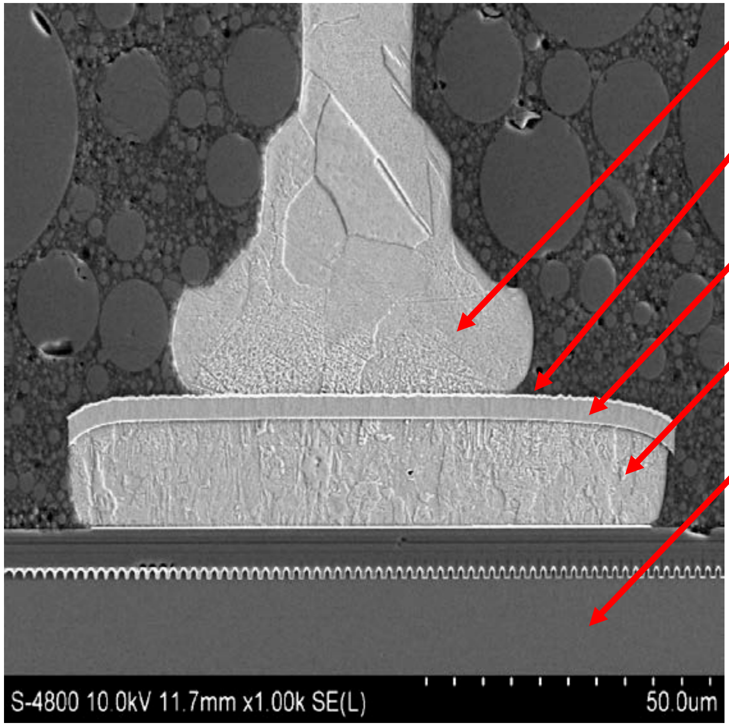


X-Ray Image of a Typical Device





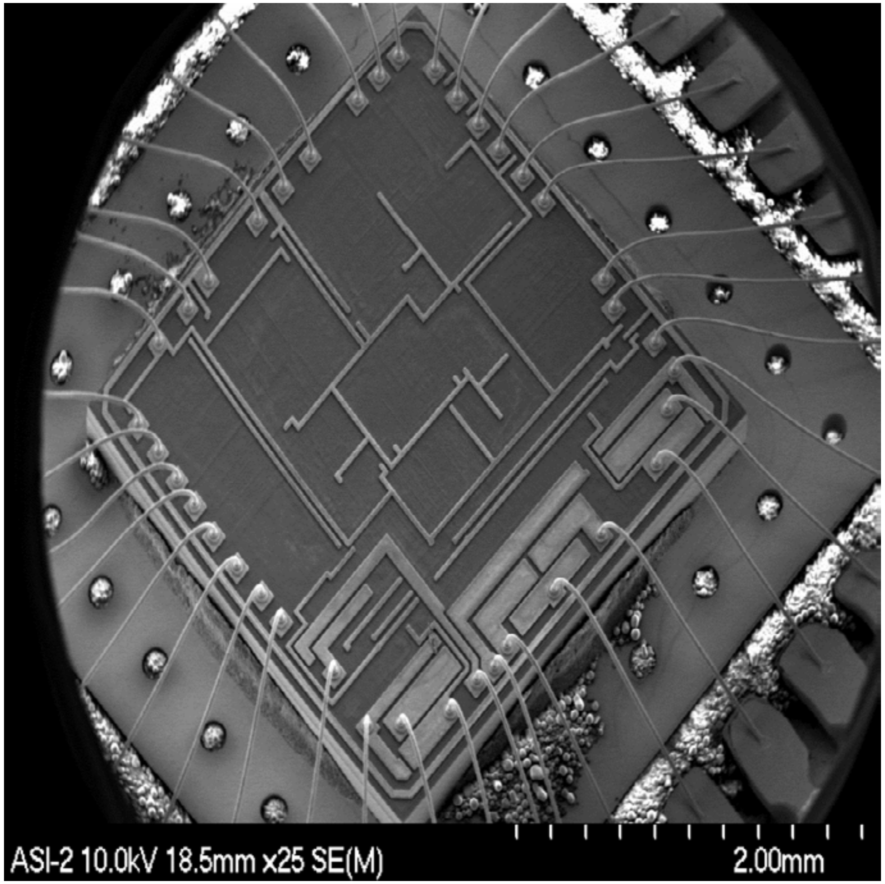
Bond Stack on Die



- Copper Wire Bond
- Palladium Finish
- Nickle Barrier
- Copper Bus
- Die

INTEGRA TECHNOLOGIES

ASI's Full Chemical De-capsulation



- **Pros**
  - Very high degree of repeatability with a 98% success rate first pass.
  - Removes molding compound from under the wires completely
  - No risk to passivated metallization
- **Cons**
  - Risk of etching wires and wire bonds
  - Risk of etching un-passivated metallization
  - Reduction in epoxy die attach strength
  - Must be adjusted for every device type
  - High acid use driving cost of acid and acid disposal up
  - Safety concerns with the high usage of acid.
  - Process window must be tightly controlled.

INTEGRA TECHNOLOGIES

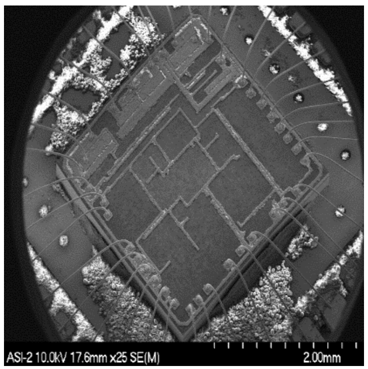
ASI's Full Chemical De-capsulation (continued)

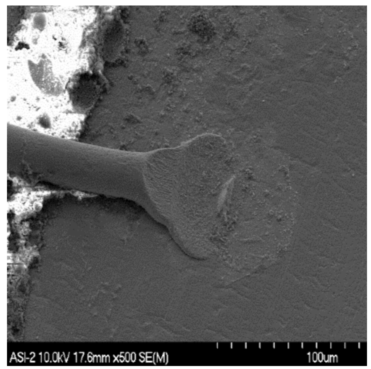
- Acid Mixture
  - 2 parts 90% Nitric
  - 1 part 96% Sulfuric
- Acid Temperature
  - Room Temp
- Beaker
  - 80 ml graduated
- Stir Plate and Rod
  - Speed of stir plate is adjusted until the vortex of the fluid mixture is approximately ¼ of the mixture in depth.

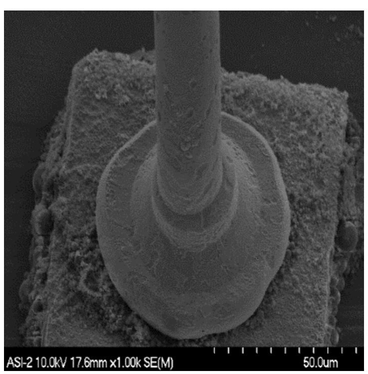
- Process
  - Mount and Bake Parts
    - Solder on high carbon steel substrate
    - Clean all flux residue
    - Vacuum Bake parts
      - 100C
      - 8 hours minimum
  - Mix Acid
  - Suspend part in acid 4 minutes
    - Inspect Device for damage
    - Not all molding compound will be removed from around the wire bonds at this point.
  - Dispose of Acid and mix new batch
  - Suspend part in acid 1 minute
    - Inspect Device for damage and completeness of de-encapsulation.
      - If de-encapsulation is not complete reduce acid exposure time to 15 seconds and repeat until full de-encapsulation is obtained.

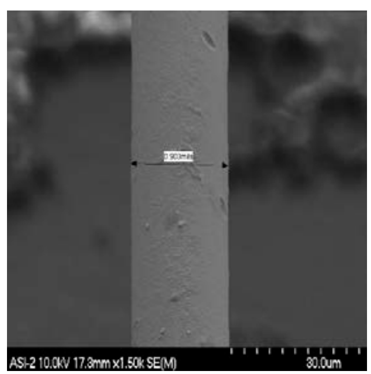
ASI's Full Chemical De-capsulation (continued)

- **S/N 1**



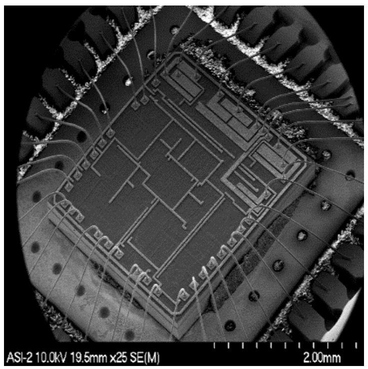


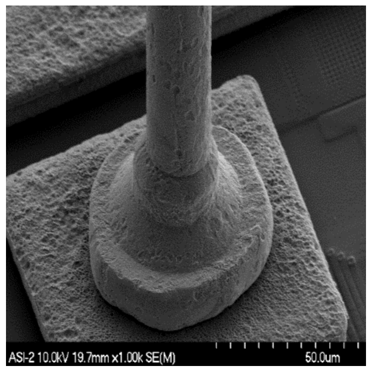


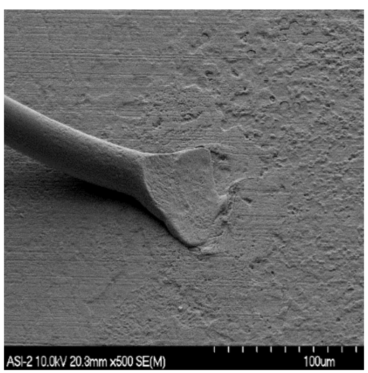


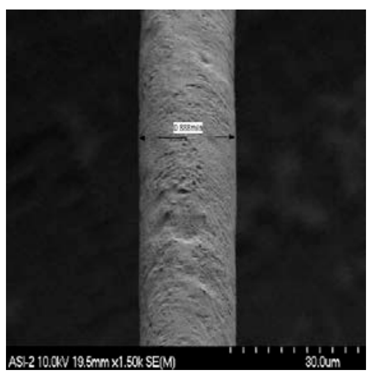
Wire Size:	**0.903 mils**
Wires Pulled:	38
Minimum Wire Pull:	9.430 grams
Maximum Wire Pull:	13.055 grams
Average Wire Pull:	11.940 grams

- **S/N 2**







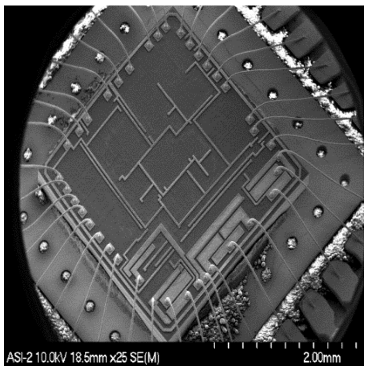


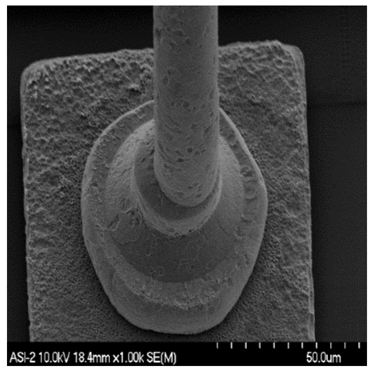
Wire Size:	**0.888 mils**
Wires Pulled:	38
Minimum Wire Pull:	6.967 grams
Maximum Wire Pull:	12.305 grams
Average Wire Pull:	10.537 grams

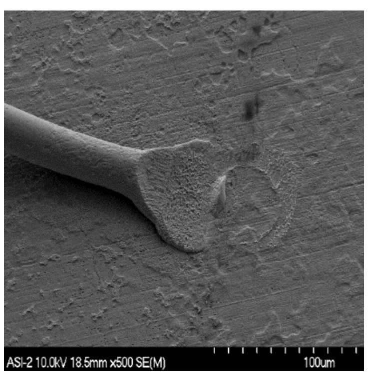
INTEGRA TECHNOLOGIES

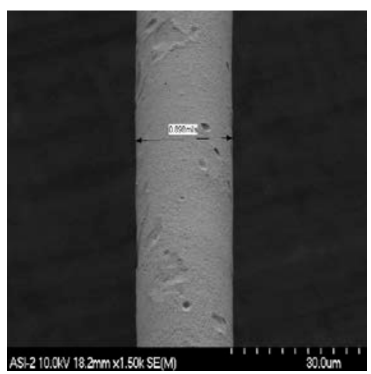
ASI's Full Chemical De-capsulation (continued)

- **S/N 3**



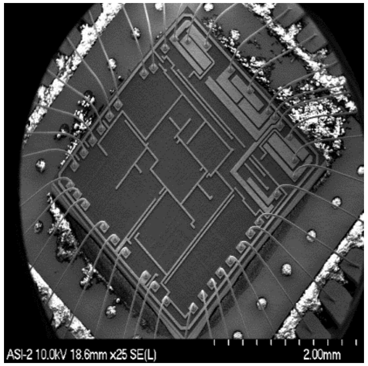


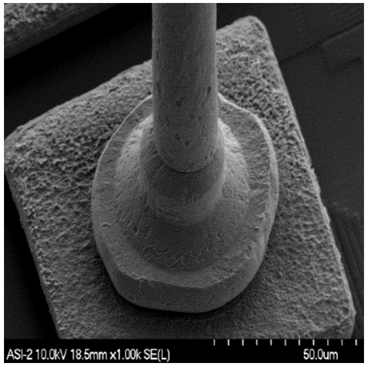


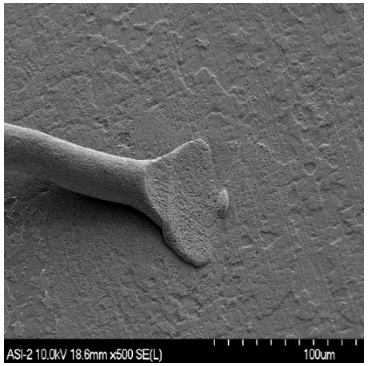


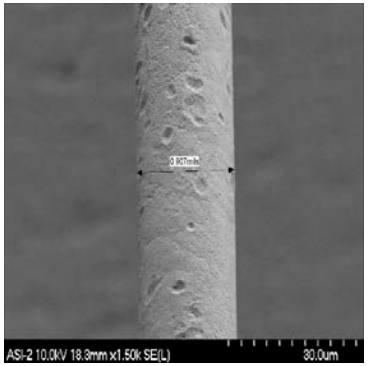
Wire Size:	**0898 mils**
Wires Pulled:	38
Minimum Wire Pull:	10.431 grams
Maximum Wire Pull:	13.856 grams
Average Wire Pull:	11.907 grams

- S/N 4







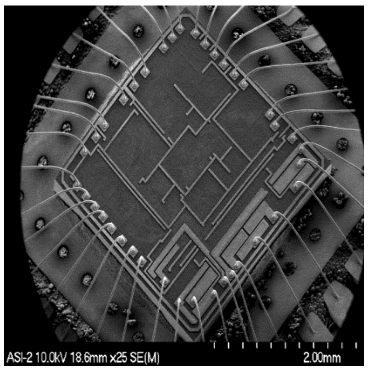


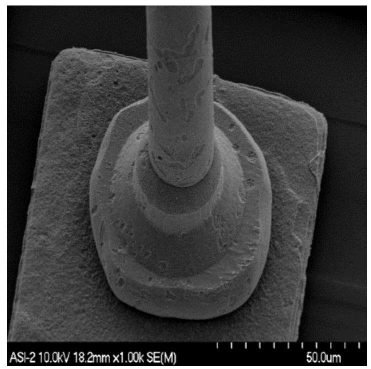
Wire Size:	**0.907 mils**
Wires Pulled:	38
Minimum Wire Pull:	9.249 grams
Maximum Wire Pull:	13.687 grams
Average Wire Pull:	11.789 grams

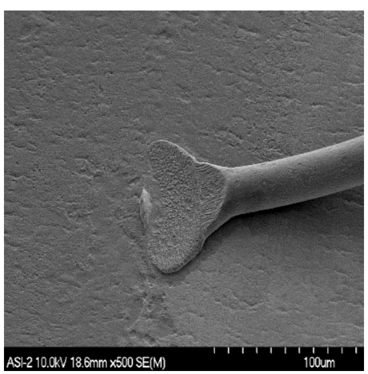
INTEGRA TECHNOLOGIES

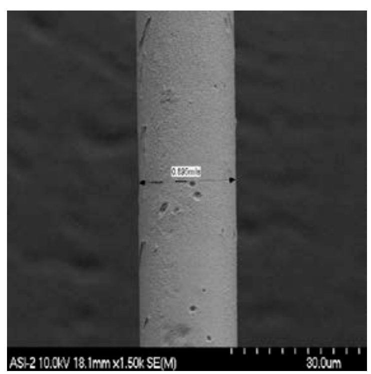
ASI’s Full Chemical De-capsulation (continued)

- S/N 5



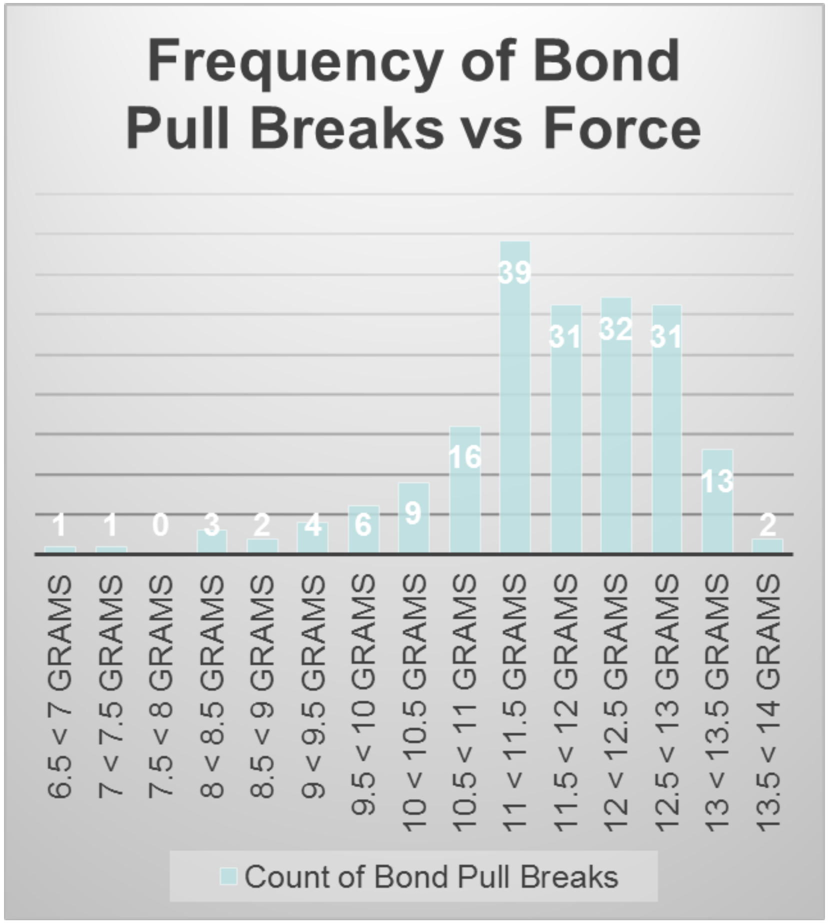






Wire Size:	**0.895 mils**
Wires Pulled:	38
Minimum Wire Pull:	9.410 grams
Maximum Wire Pull:	13.471 grams
Average Wire Pull:	11.874 grams

INTEGRA TECHNOLOGIES



Total Wire Bond Count:	190
Minimum wire pull strength:	6.9672
Maximum wire pull strength:	13.8559
Average wire pull strength:	11.60943
Standard Deviation:	1.169049

- **Full Chemical De-encapsulation is repeatable.**
  - Five devices for this analysis
  - Over 100 copper wire bonded devices over the last month have been successfully de-encapsulated utilizing this method.
  - Wire size due to etching is reduced by approximately 0.1 mils utilizing this method.

- **Bond pull data distribution**
  - No wire pulled below 2 X gold limit
    - Gold limit for 1 mil wire is 2.5 grams
  - 90 % of bond wires broke at the mid span.
    - All low pull strengths were mid span breaks
  - 9.5 % of bond wires broke at the neck down of the ball bond.
  - .5% (1) bond wires broke at the bond on lead frame.

INTEGRA
TECHNOLOGIES

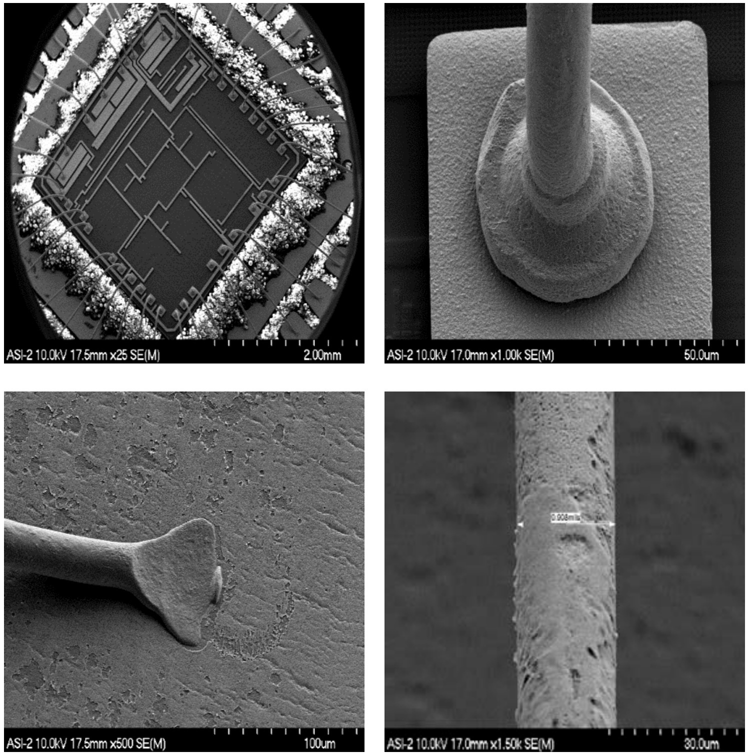
ASI's Laser / Chemical De-encapsulation

- Acid Mixture
  - 2 parts 90% Nitric
  - 1 part 96% Sulfuric
- Acid Temperature
  - Room Temp
- Beaker
  - 80 ml graduated
- Stir Plate and Rod
  - Speed of stir plate is adjusted until the vortex of the fluid mixture is approximately ¼ of the mixture in depth.

- Process
  - Mount and Bake Parts
    - Solder on high carbon steel substrate
    - Clean all flux residue
    - Vacuum Bake parts
      - 100C
      - 8 hours minimum
  - Laser Ablate Device
    - Power setting: 30%
    - Q: 30
      - 4 passes over entire area to be opened.
      - 5 passes excluding area over the die
  - Mix Acid
  - Suspend part in acid 1 minute
    - Inspect Device for damage and completeness of de-encapsulation.
      - If de-encapsulation is not complete reduce acid exposure time to 15 seconds and repeat until full de-encapsulation is obtained.

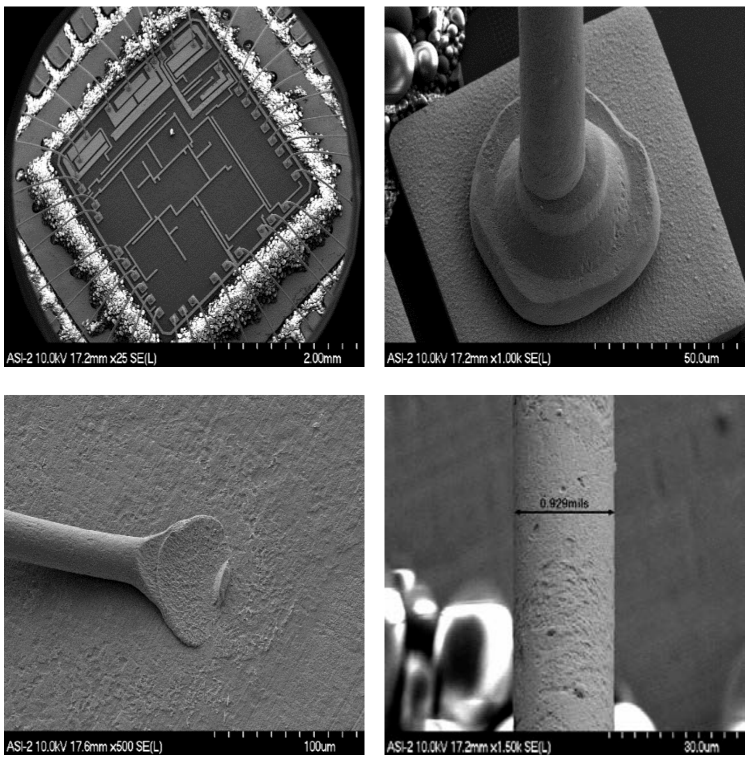
INTEGRA TECHNOLOGIES

- S/N L1



Wire Size:	**0.908 mils**
Wires Pulled:	38
Minimum Wire Pull:	8.884 grams
Maximum Wire Pull:	13.067 grams
Average Wire Pull:	11.701 grams

- S/N L2

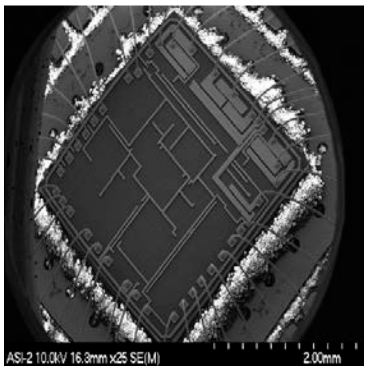


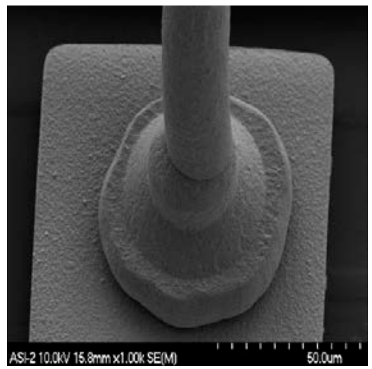
Wire Size:	**0.929 mils**
Wires Pulled:	38
Minimum Wire Pull:	9.434 grams
Maximum Wire Pull:	13.110 grams
Average Wire Pull:	11.453 grams

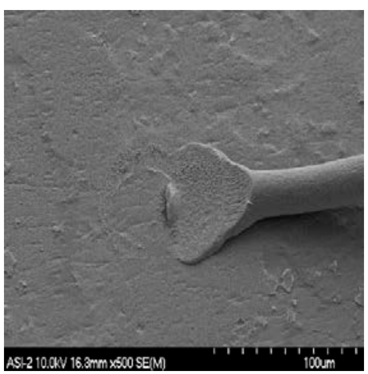
INTEGRA TECHNOLOGIES

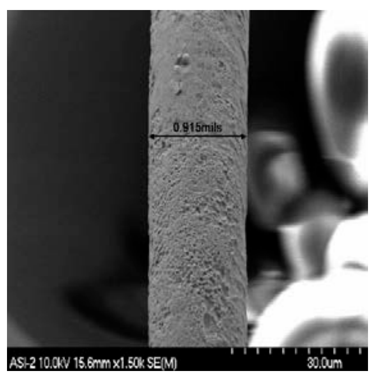
ASI's Laser / Chemical De-encapsulation (continued)

- S/N L3



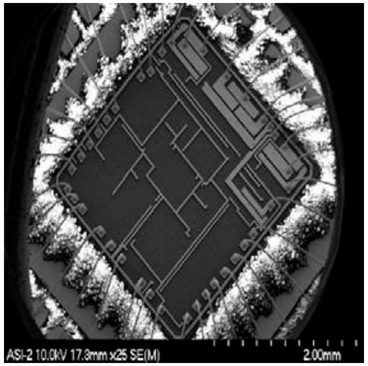


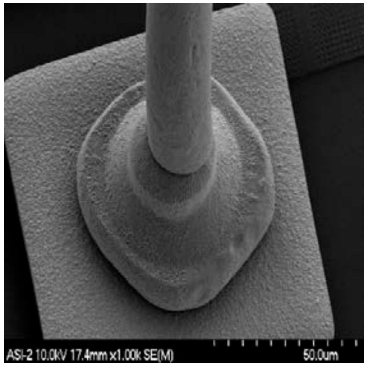


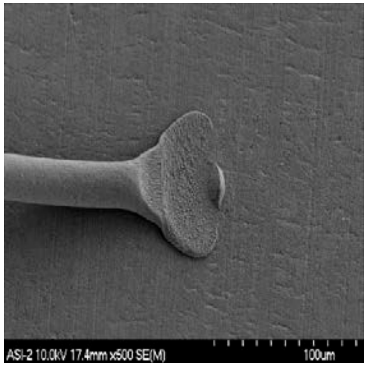


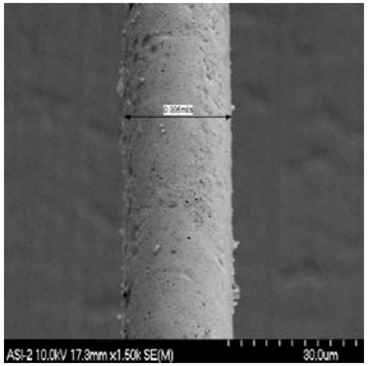
Wire Size:	**0.915 mils**
Wires Pulled:	38
Minimum Wire Pull:	8.695 grams
Maximum Wire Pull:	12.481 grams
Average Wire Pull:	11.027 grams

- S/N L4





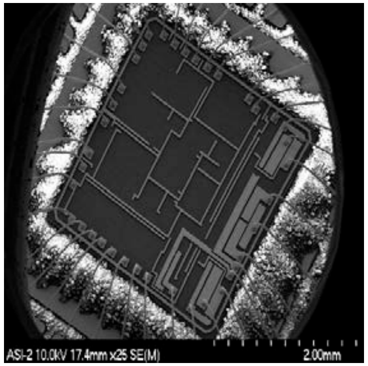


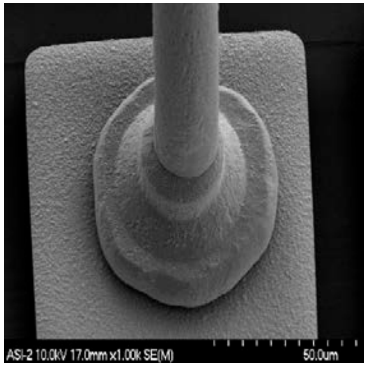


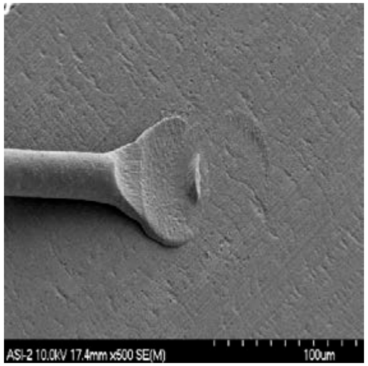
Wire Size:	**0.996 mils**
Wires Pulled:	38
Minimum Wire Pull:	10.141 grams
Maximum Wire Pull:	13.475 grams
Average Wire Pull:	11.979 grams

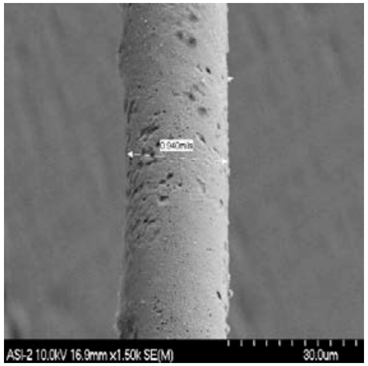
INTEGRA TECHNOLOGIES

- S/N L5



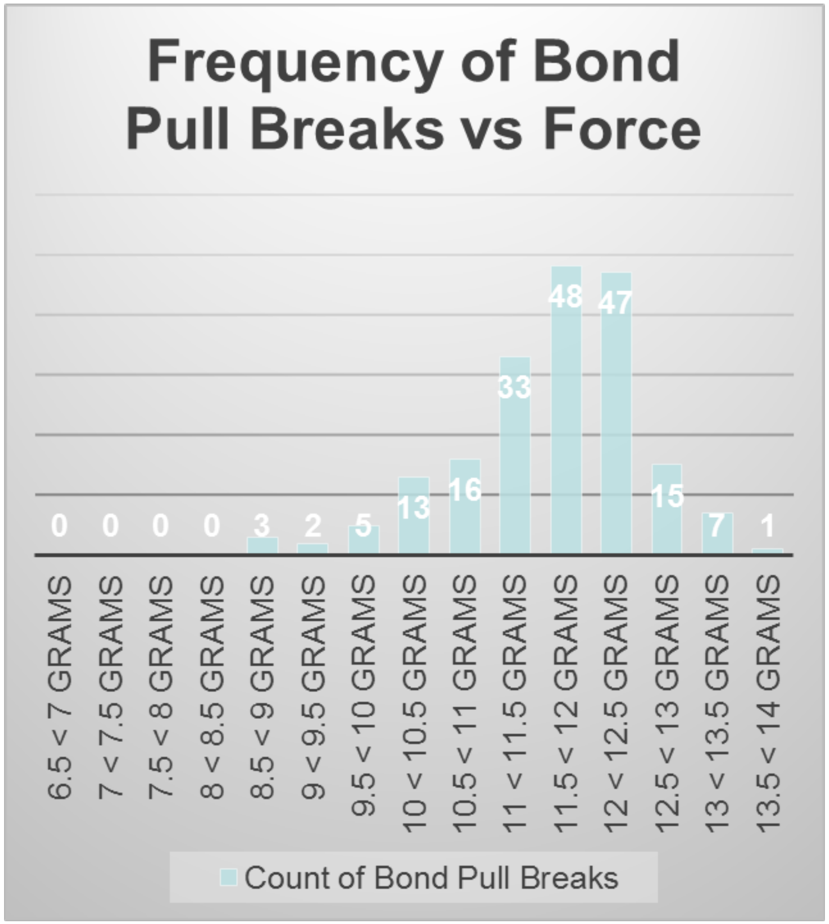






Wire Size:	**0.940 mils**
Wires Pulled:	38
Minimum Wire Pull:	10.070 grams
Maximum Wire Pull:	13.773 grams
Average Wire Pull:	11.977 grams

ASI's Laser / Chemical De-encapsulation (continued)



Total Wire Bond Count:	190
Minimum wire pull strength:	8.6953
Maximum wire pull strength:	13.773
Average wire pull strength:	11.627
Standard Deviation:	0.903

INTEGRA TECHNOLOGIES

ASI's Laser / Chemical De-encapsulation (continued)

- **Laser/Chemical De-encapsulation is repeatable.**
  - Five devices for this analysis
  - Bond wire reduction reduced to .07 mils utilizing this method
  - Lead frame plating was noticeably better preserved.
  - Condition of bond pad and overall wire bonds were better preserved.

- **Bond pull data distribution**
  - No wire pulled below 2 X gold limit
    - Gold limit for 1 mil wire is 2.5 grams
  - 80 % of bond wires broke at the mid span.
    - All low pull strengths were mid span breaks
  - 20 % of bond wires broke at the neck down of the ball bond.
  - No stitch bond breaks observed.

Over-all Conclusion

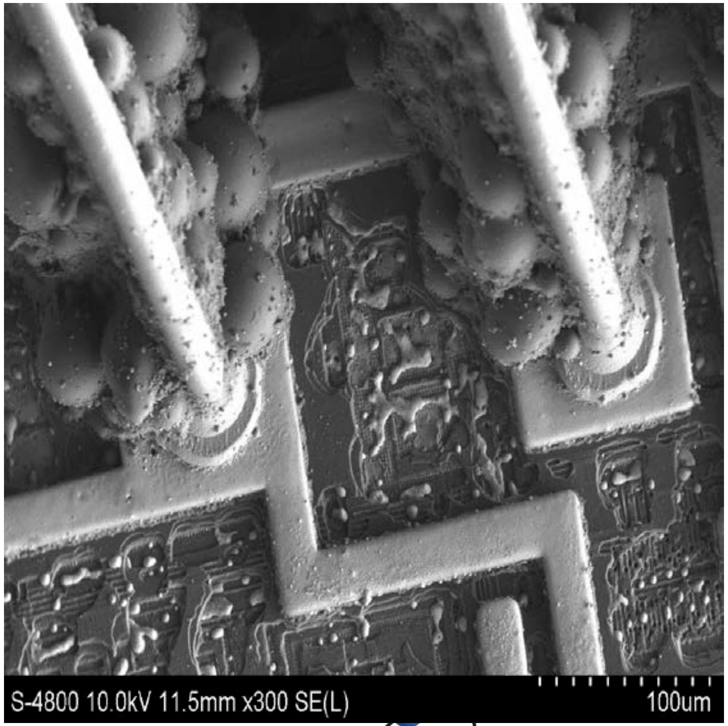
- Laser/chemical process resulted in tighter distribution.
- Average and maximum breaking force was similar for both methods but minimum breaking force was higher when laser/chemical process was used.
- Both methods resulted in bond pull strengths above the 2X limit of gold bond wires.
- Laser/chemical process resulted in cleaner opening with less damage to bond pads, lead frames and overall wire bonds.
- Either process needs setup parts to optimize de-encapsulation.
- Tight controls are needed for either process as both utilize Acid as part of the process which can and will attack the copper wire bonds.

INTEGRA TECHNOLOGIES

Caution

- Laser/chemical process is not the be-all-end-all. Parts are still subjected to acid which can etch and damage wire bonds, lead frame or bond pads.
- Laser can cause damage to both the bond wires and the die if performed improperly.
- Either method requires tight controls and active participation of engineering to mitigate damage that may be induced.

Die damage caused by laser overexposure



INTEGRA TECHNOLOGIES

Copper Wire Back-Up Slides

Phase 1 Inspection Criteria

Tests	Qty	Test Conditions	Purpose	Accept Reject Criteria	Notes:
External Visual	10	MIL-STD-883 Method 2009	Determine pre-existing condition of parts.		
Pre Stress - X-Ray	10	MIL-STD-883 Method 2012	General Construction		
Pre Stress - SAM	10	IPC/JEDEC J-STD-035	General Material Continuity and Baseline	C/JEDEC J-STD-020 paragraph 6.1-6.2.	
Pre Stress – Cross Section	1	Internal Process	Metal stack of bond interface with measurement of IMC and confirmation of Cu wire bonds		
Pre Stress – De-encapsulation and Internal Visual	2	MIL-STD-883 Method 2010	Examination for device quality. Examination of de-encapsulation quality.		De-encapsulation process is proprietary and is optimized to minimize attack on Cu wire
Pre Stress – Bond Pull	2	MIL-STD-883 Method 2011	Primarily looking for week IMC.	2 X gold wire limit for specific size wire.	Investigate any bond lifts for IMC or Cratering issues.
Pre Stress - IMC Inspection	2	Company Proprietary	Ball Bond and IMC area by location.		This is a proprietary process and optimized to minimize attack on the IMC.

Phase 1 Inspection Criteria (continued)

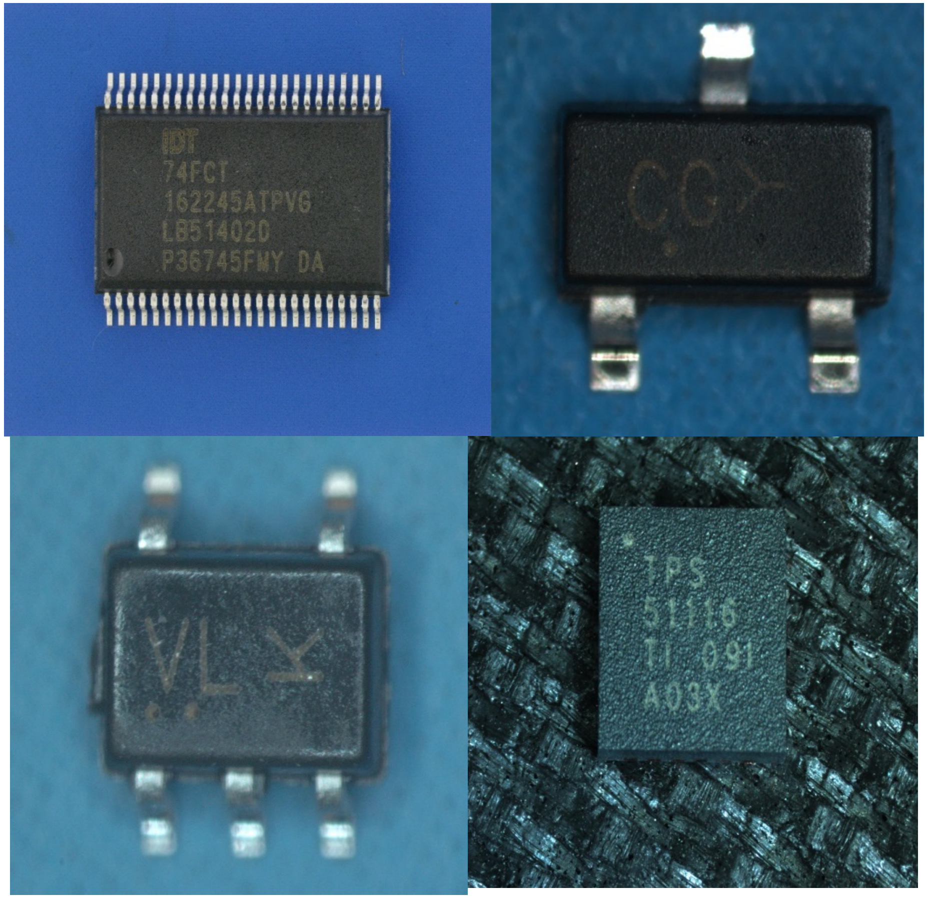
Tests	Qty	Test Conditions	Purpose	Accept Reject Criteria	Notes:
Pre-Conditioning	7	JESD-22-A113F Devices were treated as MSL 3	Initial conditioning of parts to simulate PWB attachment.		
Unbiased HAST	7	JESD22-A118 Condition A	Accelerated Aging and moisture loading.		
Temp Cycle	7	JESD22-A104E Condition B	Mechanical stress of bond wires and wire interfaces.		
SAM	7	IPC/JEDEC J-STD-035	Compare to baseline.	IPC/JEDEC J-STD-020 paragraph 6.1-6.2.	
Post Stress – Cross Section	1	Internal Process			
Post Stress – De-encapsulation and Internal Visual	2	MIL-STD-883 Method 2010	Examination for device Induced issues. Examination of de-encapsulation quality.		De-encapsulation process is proprietary and is optimized to minimize attack on Cu wire
Post Stress – Bond Pull	2	MIL-STD-883 Method 2011	Primarily looking for week IMC.	2 X gold wire limit for specific size wire.	Investigate any bond lifts for IMC or Cratering issues.
Post Stress - IMC Inspection	2	Company Proprietary			This is a proprietary process and optimized to minimize attack on the IMC.

Summary of Results on all 4 lots

Lot Numbers	Ext. Vis	Pre- X-ray	Pre-SAM	Pre-Bond Pull	Pre-IMC	Post-SAM	Post Bond Pull	Post-IMC	Comparative Analysis
74FCT162245AT PVG	Pass	Pass	Pass	*	Pass	Pass	*	Pass	No significant degradation or growth of IMC.
TPS51116RGET	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	No significant degradation or growth of IMC.
M74VHC1GT50D FT1G	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	No significant degradation or growth of IMC.
BAS70-04LT1G	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	No significant degradation or growth of IMC.

Bond lifts were identified for part number 74FCT162245ATPVG. One pre-stress and one post-stress device exhibited bond lifts on pins 12 and 15. Minor cratering was seen.

Initial Conditions of the Parts



- Devices were purchased from Authorized distributor.
- All devices were inspected and found to be in good condition.
- No indication of improper storage that might effect reliability study.
- Minor oxidation was seen on the leads post stress.
- No cracks or package related defects were noted post stress.

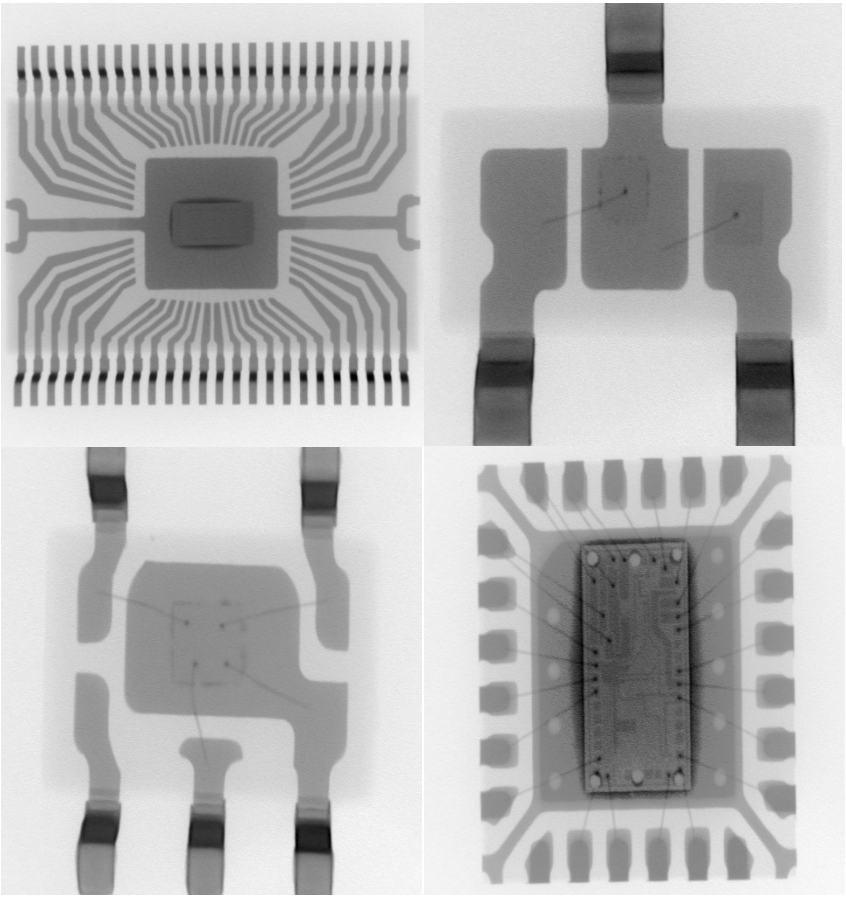
INTEGRA TECHNOLOGIES

External Visual Inspection Results – Pre-Stress

	M74LVHC1GT50DFT1G		BAS70-04LT1G2		74FCT162245ATPVG		TPS51116RGET	
	QTY In	QTY Out	QTY In	QTY Out	QTY In	QTY Out	QTY In	QTY Out
Foreign Material	10	10	10	10	10	10	10	10
Construction Defects	10	10	10	10	10	10	10	10
Leads	10	10	10	10	10	10	10	10
Package Body	10	10	10	10	10	10	10	10
Lot Disposition	Pass		Pass		Pass		Pass	

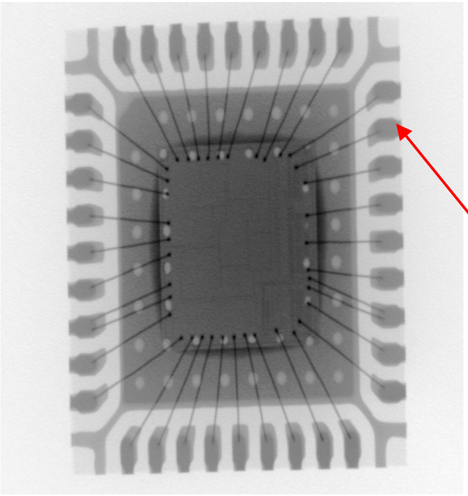
INTEGRA TECHNOLOGIES

X-Ray Results



- All devices were inspected and found to be acceptable.
- Copper wire bonds were noted in X-Ray and confirmed in cross section

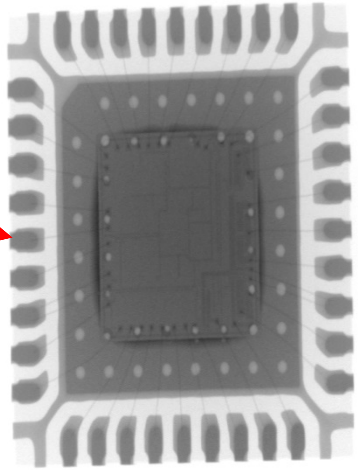
X-Ray (Gold Copper Comparison)



Gold Wire bonds
Gold has higher radio density making it darker when viewed in X-Ray.

- Image to the left shows copper vs gold wire bond comparison. Both parts are TPS40140RHH. Top part has gold bond wires and was built in the 5th month of 2011. Bottom part is copper wire bonded built in the 9th month of 2013.

Copper Wire Bonds
Copper has lower radio density making is lighter when viewed in X-Ray.

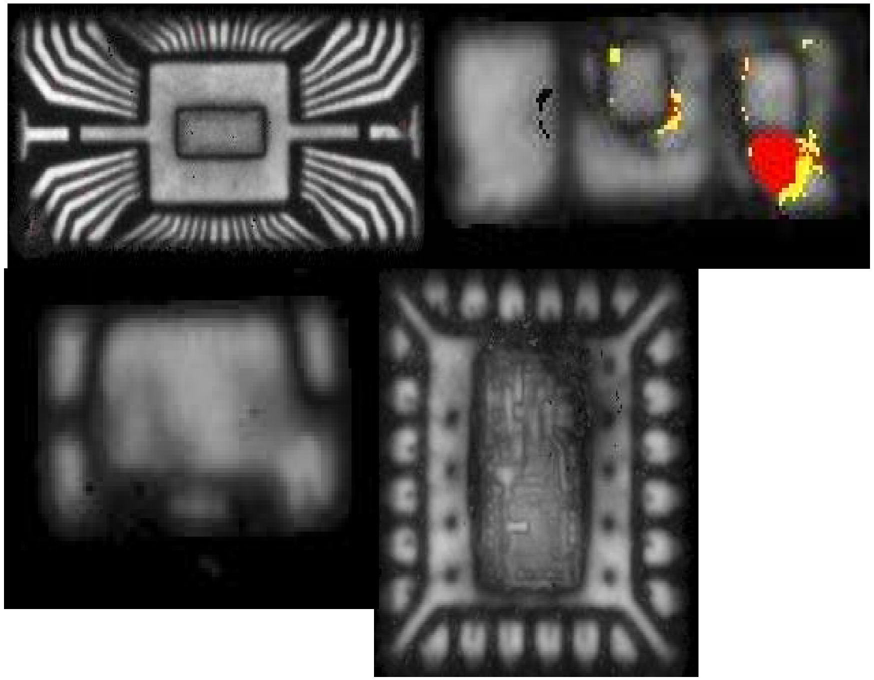


INTEGRA TECHNOLOGIES

X-Ray Results Pre-Stress

	M74LVHC1G T50DFT1G		BAS70-04LT1G2		74FCT1622 45ATPVG		TPS51116R GET	
	QTY In	QTY Out	QTY In	QTY Out	QTY In	QTY Out	QTY In	QTY Out
Extraneous Material	10	10	10	10	10	10	10	10
Element Condition	10	10	10	10	10	10	10	10
Wire Bonding	10	10	10	10	10	10	10	10
Wire Sweep	10	10	10	10	10	10	10	10
Lot Disposition	Pass		Pass		Pass		Pass	

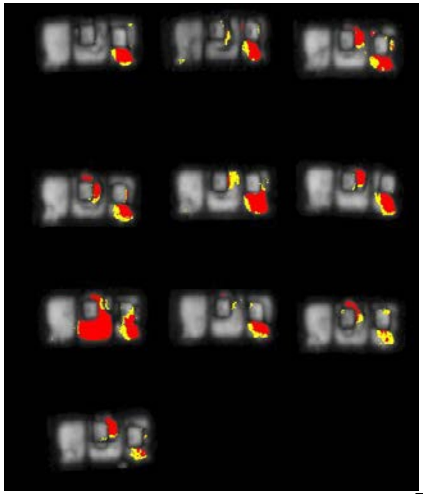
Scanning Acoustic Microscopy

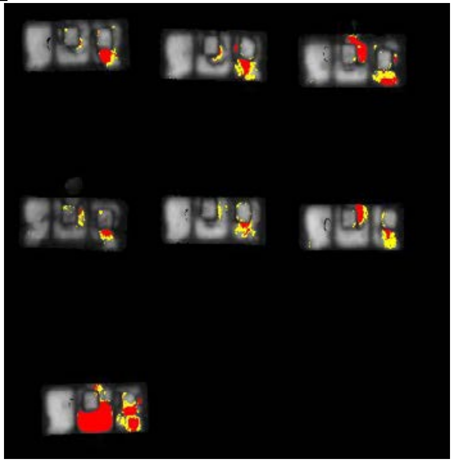


- Molding compound to lead frame showed some areas of delamination which is consistent with what was noted on previous lots.
- No delamination was noted on the active surface of the die.
- Delamination was worse after stress as expected. No cracks in the molding compound were identified.

INTEGRA TECHNOLOGIES

Scanning Acoustic Microscopy (continued)





- Worst case was BAS70-04LT1G.
- Delamination indications were present pre and post stress.
- Delamination change was less than 5% from pre-to-post.
- Pre-stress upper left image. Post-stress lower right. S/N 8-10 were used for pre-stress cross section, bond pull, internal visual inspection and IMC Inspection.

SAM Inspection Results

M74LVHC1GT50DFT1G

S/N	Inspection Results	PASS / FAIL	S/N	Inspection Results	PASS / FAIL	% Change
1	C5	Pass	1	C5	Pass	1%
2	C5	Pass	2	C5	Pass	1%
3	C5	Pass	3	C5	Pass	1%
4	C5	Pass	4	C5	Pass	3%
5	C5	Pass	5	C5	Pass	1%
6	C5	Pass	6	C5	Pass	5%
7	C5	Pass	7	C5	Pass	1%
8	C5	Pass				
9	C5	Pass				
10	C5	Pass				

BAS70-04LT1G2

S/N	Inspection Results	PASS / FAIL	S/N	Inspection Results	PASS / FAIL	% Change
1	C5	Pass	1	C5	Pass	0%
2	C5	Pass	2	C5	Pass	1%
3	C5	Pass	3	C5	Pass	2%
4	C5	Pass	4	C5	Pass	1%
5	C5	Pass	5	C5	Pass	1%
6	C5	Pass	6	C5	Pass	1%
7	C5	Pass	7	C5	Pass	1%
8	C5	Pass				
9	C5	Pass				
10	C5	Pass				

74FCT162245ATPVG

S/N	Inspection Results	PASS / FAIL	S/N	Inspection Results	PASS / FAIL	% Change
1	A	Pass	1	A	Pass	0%
2	A	Pass	2	A	Pass	0%
3	A	Pass	3	A	Pass	0%
4	A	Pass	4	A	Pass	0%
5	A	Pass	5	A	Pass	0%
6	A	Pass	6	A	Pass	0%
7	A	Pass	7	A	Pass	0%
8	A	Pass				
9	A	Pass				
10	A	Pass				

TPS51116RGET

S/N	Inspection Results	PASS / FAIL	S/N	Inspection Results	PASS / FAIL	% Change
1	A	Pass	1	A	Pass	0%
2	A	Pass	2	A	Pass	0%
3	A	Pass	3	A	Pass	0%
4	A	Pass	4	A	Pass	0%
5	A	Pass	5	A	Pass	0%
6	A	Pass	6	A	Pass	0%
7	A	Pass	7	A	Pass	0%
8	A	Pass				
9	A	Pass				
10	A	Pass				

SAM Inspection Criteria

A. No Anomalies

B. JEDEC J-STD-020D Failure Criteria

1. Internal Crack that intersects a bond wire, ball bond, or wedge bond.
2. Internal Crack extending from any lead finger to any other internal feature.
3. Internal crack extending more than 2/3 the distance from any feature to the outside of the package

C. JEDEC J-STD-020D Criteria Requiring Further Evaluation Metal Lead Frame Construction

1. Delamination on Active Surface of the die.
2. Delamination on any wire bonding surface.
3. Delamination change >10% along any polymeric film bridging any metallic features that is designed to be isolated
4. Delamination/cracking >50% of the die attach area in thermally enhanced packages or devices that require electrical contact to the backside of the die.
5. Surface-breaking feature delaminated over its entire length.

D. JEDEC J-STD-020D Criteria Requiring Further Evaluation Substrate Based Package

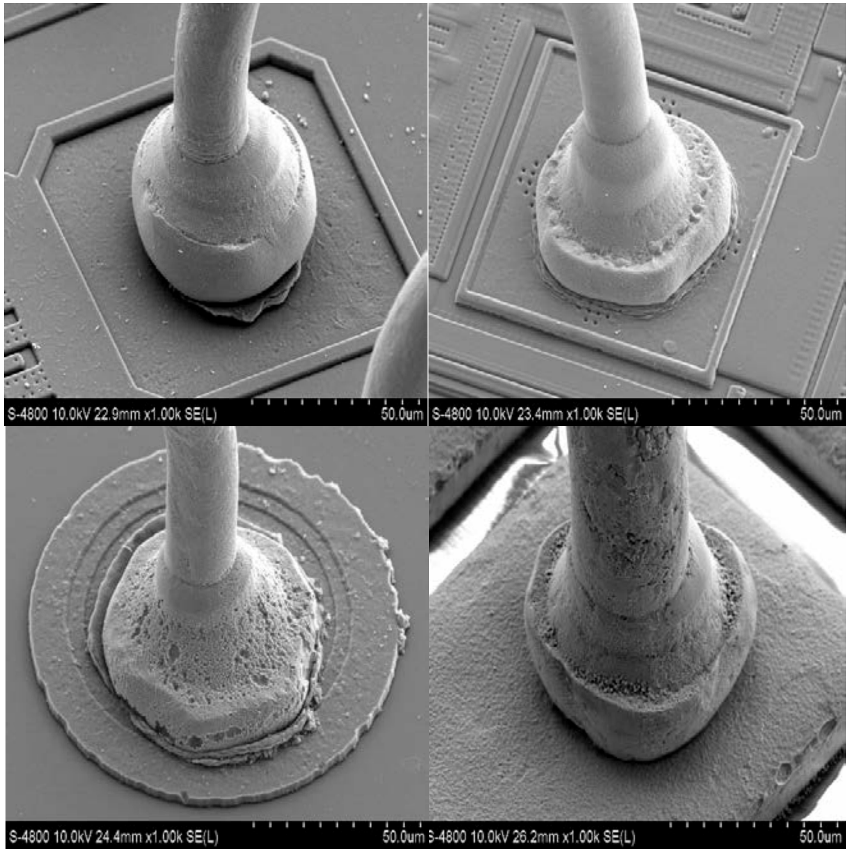
1. Delamination on the active side of the die
2. Delamination on any wire bonding surface.
3. Delamination change >10% along the polymer potting or molding compound/laminate interface
4. Delamination change >10% along the solder mask/laminate resin interface
5. Delamination change >10% within the laminate
6. Delamination/cracking change >10% through the die attach region
7. Delamination/cracking between under fill resin and chip or under fill resin and substrate/solder mask
8. Surface-breaking feature delaminated over its entire length.

E. MIL-STD-883/2030 Failure Criteria

1. Contact area voids > 50 percent of the total intended contact area
2. A single void which exceeds 15% percent of the intended contact area, or a single corner void in excess of 10 % of the total intended contact area
3. When the image is divided into four equal quadrants by bisecting both pairs of opposite edges, any quadrant exhibiting contact area voids in excess of 70% of the intended quadrant contact area

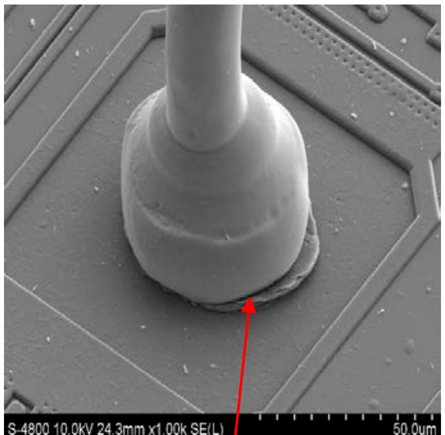
INTEGRA TECHNOLOGIES

De-Capsulation

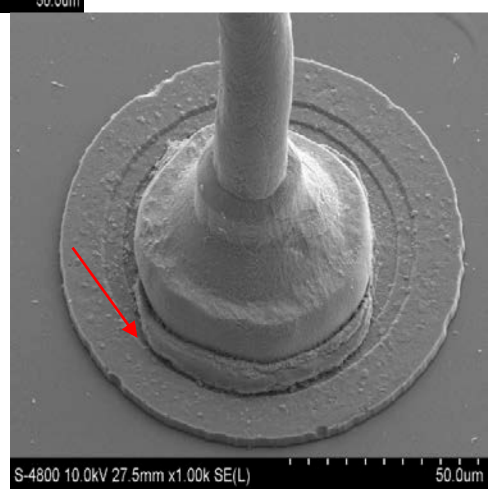


- No single method is best when de-encapsulating copper wire bonded parts.
- Analytical Solutions utilizes several methods based on observations seen in cross section.
- Some degradation of the copper wire bond is expected during de-encapsulation. This degradation must be minimal to properly evaluate bonding.

INTEGRA TECHNOLOGIES



Aluminum Splash



- No device exhibited quality issues.
- No differences visually identified pre-to-post stress.
- Bonds remained relatively in tact. Some minor attack was noted.
- Aluminum splash was seen on all devices with copper-to-aluminum interface. See left image.

Internal Visual Results

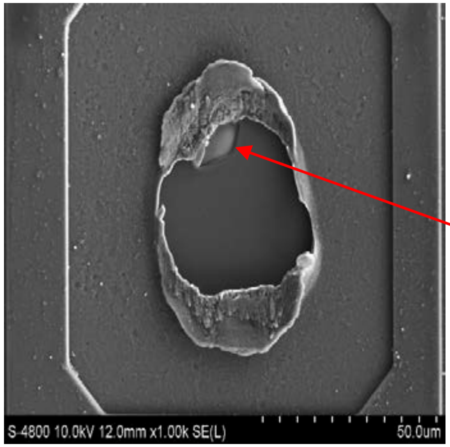
Pre/Post Stress	M74LVHC1GT50DFT1G		BAS70-04LT1G2		74FCT162245ATPVG		TPS51116RGET	
	QTY In	QTY Out	QTY In	QTY Out	QTY In	QTY Out	QTY In	QTY Out
Die Condition	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2
Bond Condition	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2
De-encapsulation Quality	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2
Internal Wires	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2
Lot Disposition	Pass		Pass		Pass		Pass	

Bond Pull Data

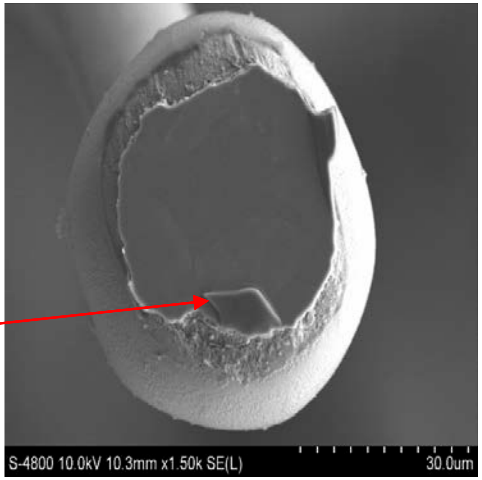
M74LVHC1GT50DFT1G				BAS70-04LT1G2				74FCT162245ATPVG				TPS51116RGET			
Pre		Post		Pre		Post		Pre		Post		Pre		Post	
Min	9.9077	Min	9.1773	Min	10.0604	Min	7.9913	Min	4.38	Min	4.6416	Min	18.4135	Min	18.2446
Max	11.1957	Max	12.468	Max	11.588	Max	9.4953	Max	9.88	Max	9.6367	Max	29.3736	Max	33.6069
Mean	10.31854	Mean	11.11228	Mean	10.85465	Mean	8.871925	Mean	7.706979	Mean	8.613078	Mean	23.03589	Mean	25.98575
STDev	0.38173	STDev	1.116476	STDev	0.63974	STDev	0.563751	STDev	1.362938	STDev	0.816796	STDev	3.01775	STDev	3.261812
Number of bonds	8	Number of bonds	8	Number of bonds	4	Number of bonds	4	Number of Bonds	96	Number of Bonds	96	Number of Bonds	50	Number of Bonds	50
Bond Lifts	No	Bond Lifts	No	Bond Lifts	No	Bond Lifts	No	Bond Lifts	Yes	Bond Lifts	Yes	Bond Lifts	No	Bond Lifts	No

Bond lifts occurred on 74FCT162245ATPVG on S/N 9 pre stress and S/N 2 post stress. Bond locations were 12 and 15 on both devices. Bond pull limit for Gold is 1.5 grams. 2 X Failure criteria for copper would be 3 grams.

Bond Pull (Lifts on 74FCT162245ATPVG)



Cratering



Residual
Silicon

- Worst Case bond lift from with minor cratering. Bond 15 from S/N 2.
- This device type exhibited the worst aluminum splash during internal visual inspection and cross section inspection.
- Failure was between aluminum pad and silicon.

INTEGRA TECHNOLOGIES

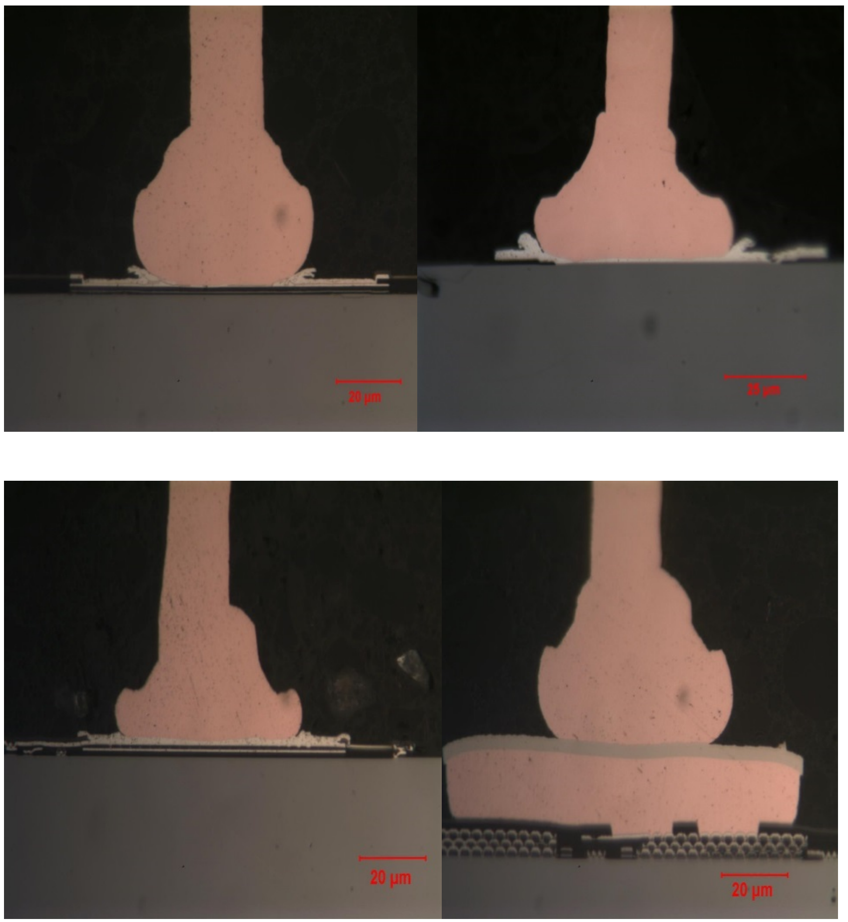
Comparison of Pull Data for Bond Lifts

74FCT162245ATPVG				
	Pre	Cratering ?	Post	Cratering?
Location 12	4.48	No	4.64	No
Location 15	8.29	No	8.83	Yes

- While not every device showed a location dependency there does seem to be a dependency on this device type.
- With the larger sample size in phase 2 and the addition of ball shear these site dependencies can be better documented and explained.
- Pre data is from S/N 9 and Post data is from S/N 2
- No other bond lifts were noted.

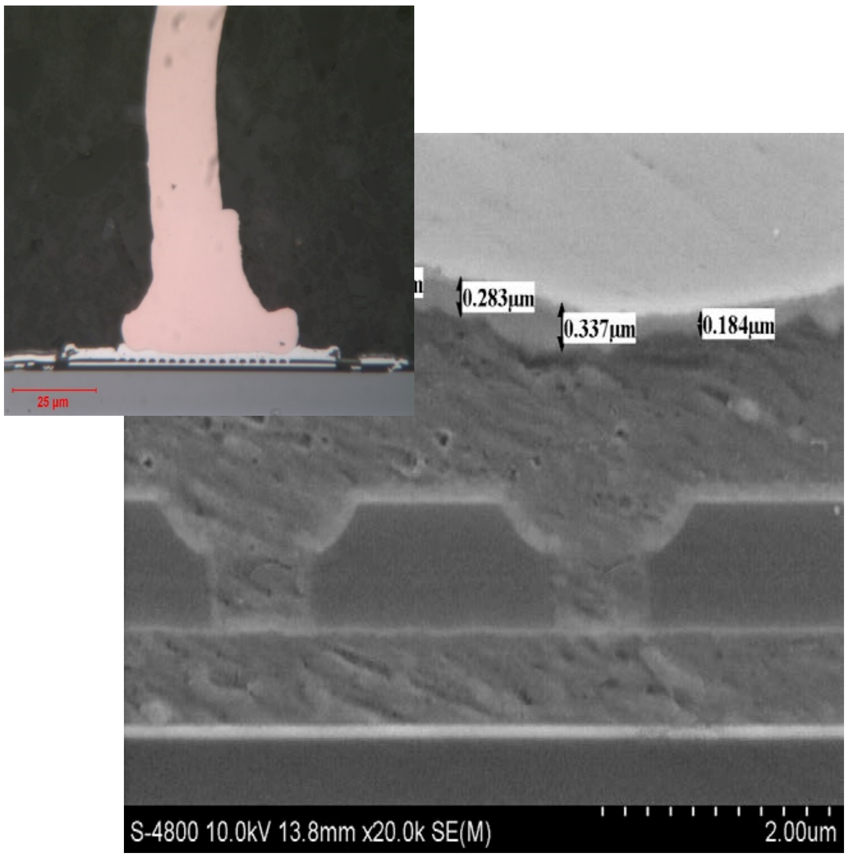
INTEGRA TECHNOLOGIES

Cross Section



- Cross section was performed to obtain the following:
  - Confirm use of copper wire bonds
  - Determine the metal stack up
  - Measure the intermetallic pre and post stress
  - Identify any additional concerns about the devices that might affect the outcome of the experiment.
- No cratering was present
- Bonds were well formed
- Aluminum splash was present but appeared to be acceptable.
- No visible change from pre-to-post at this magnification.

INTEGRA
TECHNOLOGIES



- Cross Section and measurement of IMC.
- No cracking or voiding of IMC was observed on any device.
- IMC growth was observed with Cu/Al interface but was not observed on Cu/Pd interface.
- IMC was not able to be measured on Cu/Pd interface.
- Only 1 bond per device was analyzed. Additional samples will be analyzed in Phase 2.

INTEGRA TECHNOLOGIES

IMC Inspection Cross Section Data

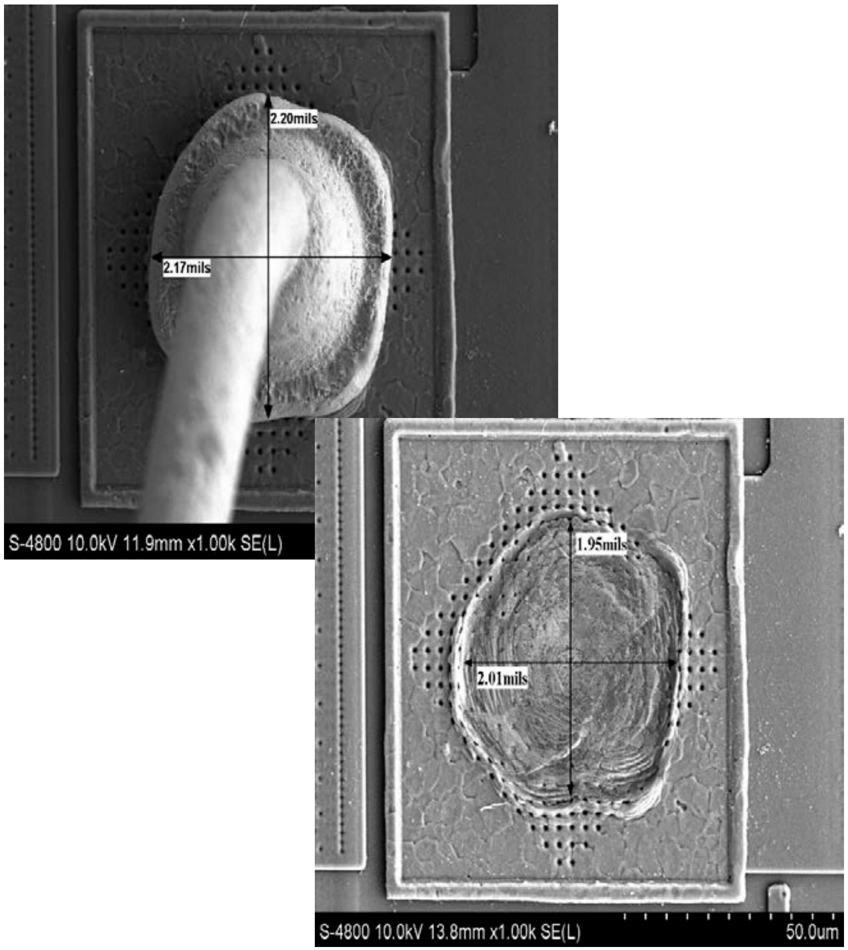
M74LVHC1GT50DFT1G				BAS70-04LT1G2			
Pre	um	Post	um	Pre	um	Post	um
Average	0.0873	Average	0.2284	Average	0.15	Average	0.1776

74FCT162245ATPVG				TPS51116RGET			
Pre	um	Post	um	Pre	um	Post	um
Average	0.1431	Average	0.126	Average	0	Average	0

- Au/Pd intermetallic on the TPS51116RGET was not measurable due to thickness and slow diffusion with this metal stack.
- While there appeared to be an increase with the On Semiconductor parts there appears to be a decrease with the IDT device.
- Larger sample sizes are required to obtain a statistically significant indicator of rate of growth. This will be accomplished in phase 2.

INTEGRA TECHNOLOGIES

IMC Inspection Etched



- Method used to remove copper wire bonds was a proprietary process developed at Analytical Solutions.
- Exposure time of the etch varied between 1 and 5 seconds.
- Not all bonds were removed but greater than 80% of bonds removed from each device.
- Area of intermetallic in relation to the ball bond was compared between pre and post stress and was determined to be between 2% and 6% greater on post stress devices.

INTEGRA TECHNOLOGIES

Statistical Analysis of IMC Area Pre-to-Post

M74LVHC1GT50DFT1G (Ball)				M74LVHC1GT50DFT1G (IMC)				BAS70-04LT1G2 (Ball)				BAS70-04LT1G2 (IMC)			
Pre		**Post**		**Pre**		**Post**		**Pre**		**Post**		**Pre**		**Post**	
Min	2.10	Min	2.17	Min	2.00	Min	1.95	Min	2.43	Min	2.41	Min	2.35	Min	2.29
Max	2.40	Max	2.38	Max	2.24	Max	2.29	Max	2.57	Max	2.58	Max	2.49	Max	2.52
Mean	2.29	Mean	2.26	Mean	2.11	Mean	2.13	Mean	2.50	Mean	2.50	Avera ge	2.41	Avera ge	2.45
STDev	0.08	STDev	0.06	STDev	0.07	STDev	0.10	STDev	0.05	STDev	0.06	Stdev	0.05	Stdev	0.07
Numb er of bonds	8	Numb er of bonds	8	Numb er of bonds	8	Numb er of bonds	8	Numb er of Bonds	4	Numb er of Bonds	4	Numb er of Bonds	4	Numb er of Bonds	4
Avera ge Area	4.11	Avera ge Area	4.02	Avera ge Area	3.51	Avera ge Area	3.50	Avera ge Area	4.91	Avera ge Area	4.92	Avera ge Area	4.55	Avera ge Area	4.70
				% IMC area Change Pre-to-Post			2%					% IMC area Change Pre-to-Post			2%

TPS51116RGET (Ball)				TPS51116RGET (IMC)				74FCT162245ATPVG (Ball)				74FCT162245ATPVG(IMC)			
Pre		**Post**		**Pre**		**Post**		**Pre**		**Post**		**Pre**		**Post**	
Min	2.45	Min	2.43	Min	1.88	Min	1.93	Min	2.04	Min	2.06	Min	0.18	Min	1.50
Max	2.82	Max	2.89	Max	2.57	Max	2.90	Max	2.36	Max	2.34	Max	2.00	Max	2.07
Mean	2.65	Mean	2.63	Mean	2.19	Mean	2.24	Mean	2.17	Mean	2.18	Avera ge	1.70	Avera ge	1.77
STDev	0.08	STDev	0.08	STDev	0.14	STDev	0.21	STDev	0.05	STDev	0.05	Stdev	0.16	Stdev	0.10
Numb er of bonds	50	Numb er of bonds	50	Numb er of bonds	48	Numb er of bonds	49	Numb er of Bonds	96	Numb er of Bonds	96	Numb er of Bonds	93	Numb er of Bonds	94
Avera ge Area	5.59	Avera ge Area	5.44	Avera ge Area	3.77	Avera ge Area	3.94	Avera ge Area	3.68	Avera ge Area	3.74	Avera ge Area	2.27	Avera ge Area	2.46
				% IMC area Change Pre-to-Post			4%					% IMC area Change Pre-to-Post			6%