Integral Heater for Reworking High Density Interfaces

Mary C. Massey, William E. McMullen, Ryan S. Berkely
TRW Electronics and Technology Division
One Space Park, 201/4035
Redondo Beach, California 90278
Phone: (310) 812-4321, Fax: (310) 812-4417
E-mail: mary.massey@trw.com
Susheel Dharia, Aki Nomura
Kyocera America, Inc.
8611 Balboa Avenue
San Diego, California 92123

Abstract

A new and distinctive approach to reworking HDI assemblies is presented. The approach involves an integral heater element that can easily be designed into any new custom microelectronics package (ceramic based or plastic). The heater element provides localized heat to facilitate individual package site rework at the board assembly level. The technique enables a significantly improved process over the more traditional method of heating the entire PWB assembly followed by localized hot gas removal of the part. This method can also be used to provide localized heat for solder reflow attachment and removal processes of peripheral leaded and area array packages. This approach provides a more elegant solution to a problem that has challenged industry; salvaging expensive HDI assemblies while reworking individual complex package sites. As package sizes continue to grow for both monolithic and multichip solutions, and as larger, more dense board subassemblies emerge, this technical approach will provide numerous options to facilitate HDI assembly production. TRW has implemented integral heater designs on current space flight hardware.

Key Words: multichip module (MCM), ceramic quad flat pack (CQFP), high temperature co-fired ceramic (HTCC), embedded, integral, interface adhesive bond, refractory metallization

Introduction

Like many other companies during the early and middle 1990's TRW was exploring the potential for using large multi-chip modules to increase digital electronic packaging density. The MCM theme became central to a number of IR&D initiatives intended to foresee and resolve technical issues associated with their introduction into both commercial and military production space hardware. Among the potential problems surfaced was the difficulty of reworking these large packages after they were attached to a PWB.

During the previous decade the size and complexity of spacecraft digital hardware increased dramatically. Board sizes began to exceed 200 in^2 with typical parts counts of 1,000 to 2,000 total components. Though most of these tend to be small IC's and chip discretes there may still be dozens of exceptionally large high cost components such as custom ASICs and stacked memory ICs. To facilitate independent front-back routing the PWB may be dual sequentially laminated or some other even more complex multilayer geometry which itself represents a sizeable investment. The high parts costs and limited availability of replacements requires that rework of a single suspect component be performed with high confidence that the PWB and the other parts on it will not be injured during removal and replacement.

Background

Dissipation of heat is a common problem associated with all modern high-speed digital electronics. The problem is exacerbated by the increased thermal density of MCMs where the whole purpose is to closely co-locate multiple functions, typically in the form of large ASIC die and/or memory modules. The problem is further magnified in space where no air is available for convection cooling and virtually all component-level thermal management is necessarily conductive.

Typical space hardware practice is to attach high power dissipation components directly to the PWB surface using a thin interface adhesive bond.

The PWB is designed to carry heat energy away to spacecraft radiators via ground planes, thermal vias, and various other elements. The better these features are implemented, the lower will be the component junction temperatures, thus improving their reliability. As a result it takes quite a bit of heat to raise the temperature of a component very much above the temperature of the PWB to which it's attached.

Prior to the advent of the large MCMs the standard rework approach was to heat the suspect component such that the interface bond temperature was raised above Tg (the glass transition temperature). Once Tg was reached a mechanical preload was applied using a jaws tool. This tool employs a pair of wedges driven beneath the package and forced together by a drive screw so as to lift the part from the board. During rework the operator maintains essentially constant drive screw pressure. At a sufficiently high temperature, the adhesive begins to creep, thus permitting the eventual removal of the package. Careful application of this technique generally resulted in component removal without collateral damage to the PWB or other components.

The earlier success of the combination of hot air and the jaws tool was predicated on relatively small parts (less than 2 in^2) which, with their large body to cavity size ratios, were readily able to transfer heat from their top to their bottom surfaces. Even prior to obtaining first samples, TRW's proposed standard for a 10 in^2 MCM (Figure 1) appeared to be incompatible with the established rework method based on size alone. Compounding the problem was the fact that the MCM was virtually all cavity, seriously impairing top to bottom heat transfer by placing a gas-filled pocket between the lid and the package base.

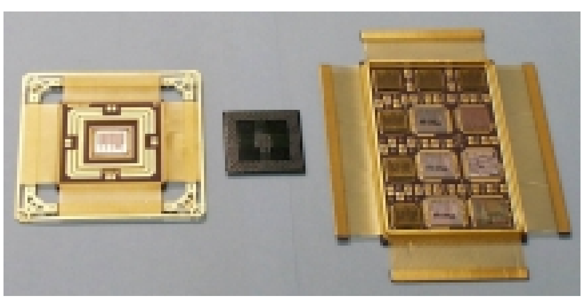


Figure 1. Various IC Packages: CQFP, PBGA, MCM

Embedded Heater Concept

Numerous solutions for reworking MCMs were explored; none of which were completely successful. An example was the attempt to substitute thermoplastic for the thermoset adhesives used previously. Elaborate assembly fixtures were created to apply and maintain the requisite high and perfectly balanced front-to-back pre-load forces necessary during high temperature adhesive re-flow. But practical implementation of these fixtures in a production environment ultimately proved intractable and there was still the problem of how to raise the delta-T across a bond joint sufficiently high to effect component removal.

It seemed that what was needed was a method of creating heat within the bond joint itself. An upper limit power dissipation requirement for rework of around 400 watts (or about 40 watts per in^2) was extrapolated from operational delta-T's across IC-attach bond joints. Targeting this much power appeared to place a significant challenge on whatever means of locally generating heat might be employed. Originally this was pictured as some type of serpentine resistance wire embedded in the bond joint. But thermal design considerations dictated a relatively thin bond on the order of 10 mils, placing an unacceptably delicate diameter constraint on the wire. Moreover, there seemed no practical means for establishing and maintaining the shape of a dense serpentine pattern during assembly, and any attempt to maintain a uniform altitude within the bond joint made the task even more daunting. Related concepts such as electromagnetic induction heating coils were interesting but deemed impractical because of the hundreds of local circuit elements which would also be subject to induction.

A first breakthrough occurred when it was realized that nichrome alloy (as used in toaster elements) was obtainable in thin foil sheets which could be photo-etched into any desired pattern. A "brick tiling" pattern was proposed for an embedded heater element and a spreadsheet model created to tune its electrical resistance by varying widths and ratios within the pattern. With 400 watts as an upper power dissipation goal, practical consideration was given to the voltage/current ratio voltage. Safety for both the operator and the high-cost components dictated maintaining reasonably low voltages well below 50 volts. At the same time, the resistance and current carrying capability of package features such as feedthru vias and also of temporarily attached rework leads placed practical limitations on current. Consideration was also given to the capabilities of the readily available power supplies on hand. In the end the heater element resistance was tailored to approximately 1 ohm so as to provide 400 watts max at 20 volts x 20 amps.

Embedded Heater Tests and Observations

Samples of the foil heater design were fabricated and their resistance was confirmed at approximately the 1-ohm targeted value. Trial runs were made using a non-conductive adhesive to attach dummy MCMs consisting of 2.5” x 4.0” slabs of alumina to a test PWB. This board included thermally accurate features such as ground planes and thermal vias found in “real” space hardware. Temporary power leads were connected to the exposed protruding ends of the foil heater element, power was applied, and the dummy MCMs were readily removed without damage to themselves or the PWB using the jaws tool. These first demonstrations of the embedded rework heater were initially deemed a resounding success.

Follow-up to these early successes indicated there were still some significant unresolved problems. An inherent limitation of a “bare” embedded heater is its incompatibility with electrically conductive adhesives. Conductive (typically silver-filled) epoxy attachment is sometimes mandatory for electrical operation of certain types of high-speed digital, RF, or mixed RF and digital components. Embedding the heater within the bond joint under factory floor conditions proved moderately labor intensive and operator dependent, and accessing exposed lead attachment points with “real” leaded components was problematic. Despite these considerations, intellectual property (IP) protection was optimistically initiated with the launch of a patent search.

Rumors had reached our team that another company may already be holding patent rights to a heater element built into a PWB. This was apparently directed at operational temperature control, and in fact seemed unsuitable for rework in that heat was injected on the wrong side of the bond joint. Our optimism took a sudden downturn, though, when a separate patent surfaced [1], this one for an etched nichrome foil heater element for embedding in component-attach bond joints! This patent, in conjunction with other embedded heater difficulties, once again sent the TRW team “back to the drawing board”. Schemes for including pyrotechnic materials in the adhesive were weighed against fast-acting bacterial nutrients, but the most attractive option that surfaced was the generation of heat within the package itself.

Integral Heater Concept

A second breakthrough occurred with the realization that the standard processes used for creating high temperature co-fired ceramic (HTCC) substrates involved refractory metallization. A check with suppliers revealed their sheet resistances as normally implemented were compatible with the creation of a practical heating element. With this information it was possible to set up a spreadsheet to calculate a serpentine pattern’s electrical resistance based on width and space parameters. Preliminary calculations were very encouraging and sample parts were designed and ordered from Kyocera America, Inc. in San Diego, California.

Kyocera’s multilayer HTCC technology is the most reliable packaging technology available for the microelectronic industry. Applications include high-density substrates for multichip module applications and T/R modules etc. Kyocera uses a green sheet (unfired alumina tape) metallization concept followed by lamination and co-firing. The conductor lines and other metallization patterns are formed with refractory metal, such as tungsten by screen printing on alumina green sheets layer-by-layer. In the green state, electrical connections are made from one layer to the next through via holes, which are punched and then filled with refractory metal prior to lamination. Following the co-firing process, the multilayer structure becomes a monolithic body containing buried refractory metallization. Whenever required, metal parts such as seal ring, leads, etc. are attached with AgCu braze. Then all the exposed metal and metallization surfaces are covered with the appropriate plating.

Incorporation of an integral heater design employs the same refractory metallization as used in the co-fired packages. The heater lines were printed using the same technology used to print the conductor lines. By using design rules consistent with the published design guidelines, the package was manufactured with the standard manufacturing methods used at Kyocera. The unique feature of this design was using the W conductor ink with 13 mΩ per square resistance. In this design, the heater lines were purposefully made very long. By controlling the line length, the heat generated may be altered. In overall scheme of things, the cost impact at the package level is insignificant as compared to the completed module cost.

Initial MCM samples were 2.5” x 4” x 0.1” HTCC substrates which included an internal metallization layer approximately 10 mils above the bottom surface. The serpentine pattern for the heater element and the top layer package artwork is shown in Figure 2. Locating the heater adjacent to the package base maximized heat transfer to the adhesive while avoiding interference with the routing of circuitry layers above. It was noted that the heater layer artwork could be readily modified to accommodate thermal or electrical ground vias to the package’s bottom surface. Solder pads were located in the corners on the top surface and interconnected to the heater layer with the same type of filled vias normally used throughout a standard HTCC package. This overall approach was especially appealing because of its adherence to standard vendor processes already invoked in the "real" MCMs. The heater element became just another layer of artwork and all other attributes of the MCM package were unaffected from vendor package fab through PWB assembly.

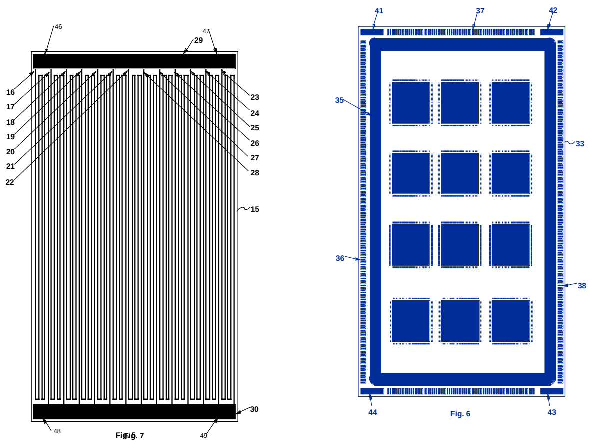


Figure 2. Integral Heater for 16-Layer MCM Package

Integral Heater Tests and Observations

Initial qualitative observations of the new "Integral Heater MCM" were highly encouraging. The packages readily exceeded 100°C in air (wetted-finger-hiss-test) and subsequently exceeded approximately 215°C (soldered-leads-fall-off-test). Higher temperatures were believed achievable using a different solder alloy at the leads but at some point there is the threat of seriously damaging the PWB. Temperatures below 200°C were felt appropriate for reworking preferred adhesives on glass-polyimide boards.

A rework trial site was prepared by attaching one of the samples to a thermally accurate glass-polyimide multilayer dummy PWB as done earlier with the foil heaters. This time, however, the parts were attached using a silver-filled epoxy. A thermocouple was attached to the top surface of the substrate and both current and voltage were monitored. Initially 7 volts were applied, resulting in a power dissipation of approximately 40 watts. Values for voltage, current, and temperature were recorded over time and the results are plotted in Figure 3. The curve has a classic charge rate shape where dT/dt is related to power dissipation. Inflections indicate where the applied voltage (and hence the power) was stepped up when the temperature was observed as becoming asymptotic at too low a value. The second voltage step to 10 volts resulted in a temperature of approximately 160°C with 180°C being reached in the third step to 11 volts or a power dissipation of 85 watts ($P = E^2/R$).

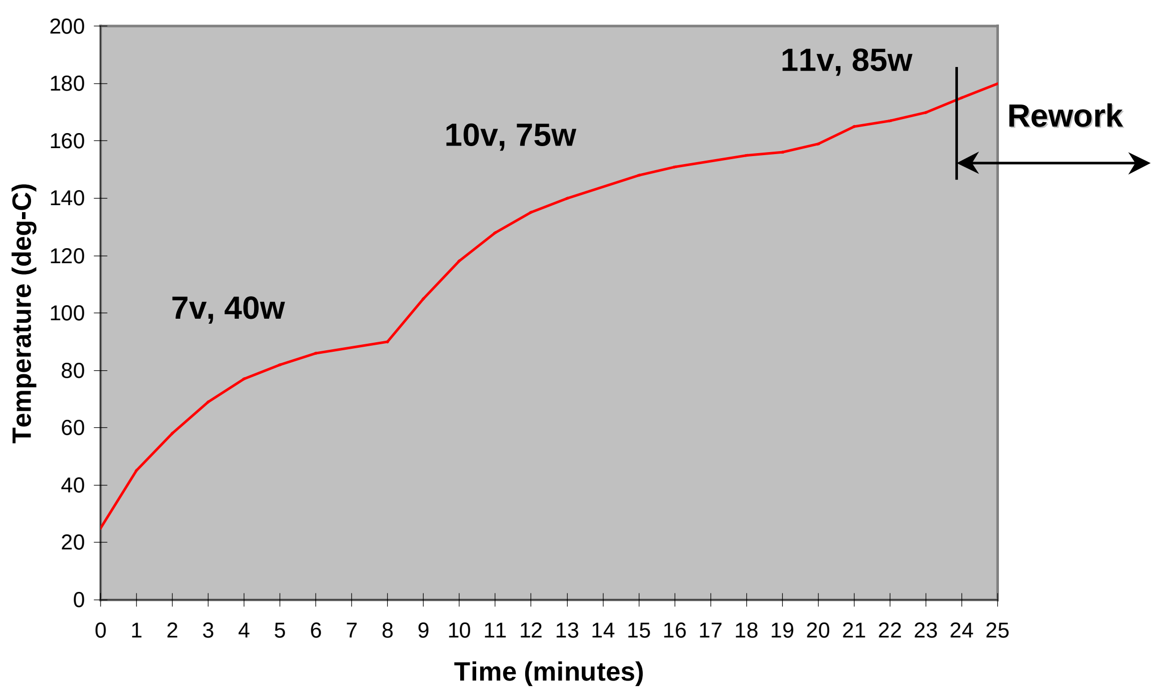


Figure 3. Integral Heater Thermal Transient, MCM Removal from PWB Rework Trial

Once the epoxy's glass transition temperature (Tg) was reached, the jaws tool was used to apply and maintain mechanical preload forces. Under these conditions the epoxy began to creep, and the part could be removed without incident. As the bond line was forced to deteriorate the temperature started to climb rapidly signaling the appropriate time to remove power.

The adhesive used in these first experiments had a high thermal conductivity and a relatively high Tg, well over 100°C. In spite of these conditions the temperature of the surrounding PWB areas remained relatively cool, demonstrating the merits of the integral heater approach.

In a subsequent trial, an integral heater MCM was attached using a non-conductive epoxy whose thermal conductivity was approximately one tenth of that in the initial trial. Based on the earlier observations 11 volts was applied at the outset and the temperature was observed to rise noticeably faster, reaching approximately 180°C in less than 8 minutes. Figure 4 shows a picture of the first integral heater MCM and its bonding site subsequent to the failure of the silver-filled epoxy bondline. Note that the bondline encompassed nearly the entire mounting surface. Had this been an actual PWB assembly, attempting to remove the MCM using a hot plate or a convection oven either would have failed or would have resulted in serious damage to solder joints on adjacent components. On the other hand, a hot gas rework station could not transfer sufficient heat to the component bondline to reach rework temperatures. The integral heater in the MCM circumvents these problems.

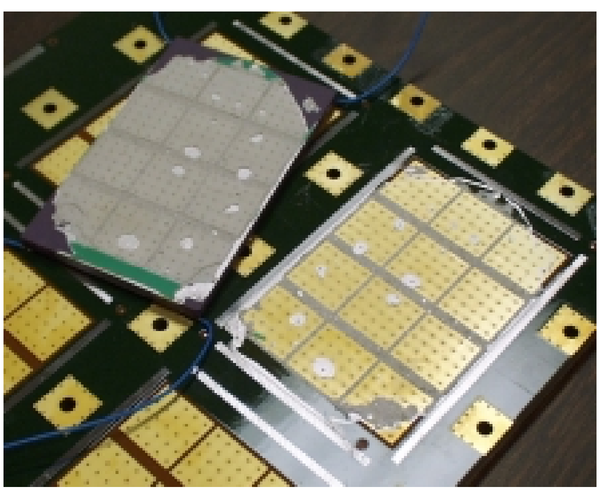


Figure 4. Successful Rework using Integral Heater

CQFP Application

One of the early MCM insertion targets was a commercial SATCOM program that was facing size-weight problems. But subsequent to the proposal these problems were substantially resolved by the introduction of finer-line ASIC geometry and consequently all the MCMs were replaced with lower cost single die ceramic quad flatpacks. A standardized 352-lead package was adopted and considerable effort was expended to ensure compatibility across the entire family of ASIC die. The requirement to customize a previously existing CQFP-352 to fit this large die presented an opportunity to insert the integral heater in a production application (Figure 5).

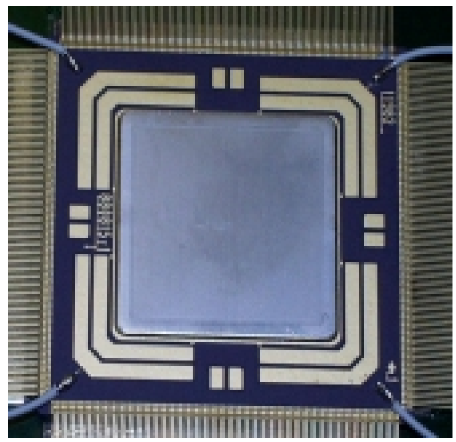
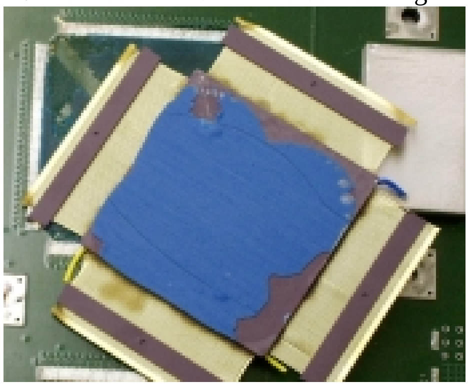


Figure 5. 352-Lead CQFP with Integral Heater

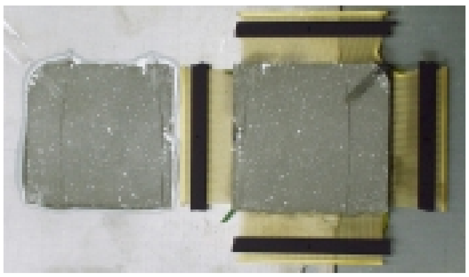
With a body size of only 3.5 in^2, the maximum heater power dissipation was scaled down from the 400 watts originally targeted for the 10 in^2 MCM. Keeping the upper voltage limit at around 20 volts and again aiming for a worst-case requirement of 40 watts/in^2 resulted in a desired heater element resistance in the vicinity of 3 ohms. As done with the MCM, an appropriate artwork pattern was created using the same standard HTCC refractory metallization processes as the rest of the package. This was implemented on the next-to-outside bottom layer and vias were used in all four corners to provide connection points on the topside of the package body.

Samples of the Integral Heater CQFP-352 have been evaluated for ease of rework and the results are similar to those obtained with the MCM. Figure 6 A and 6B illustrate the CQFP rework trials using various interface bond adhesives. Specific production rework process parameters are currently being established for these devices.

A. Non-Conductive Adhesive Bonding



B. Silver Filled Conductive Adhesive Bonding



Figures 6AandB. 352-CQFP Rework Trials

Other Applications

An internal heater can be used to melt solder joints attaching a ball-grid array (BGA) to a PWB. Preliminary explorations indicate they may provide a practical means for fusing solder balls during the installation of replacement BGAs. At lower power integral heaters readily generate sufficient heat to cure most interface-bonding adhesives. This application enables the installation of replacement components using a method that avoids the exposure of a complete electronics assembly to high cure temperatures.

Conclusions

Integral heaters facilitate the removal of large electronic parts from expensive PWB assemblies, and provide a much more elegant solution to a delicate and challenging part removal process. The concept has been successfully demonstrated on functional packages and has been patented [2]. The heater raises the adhesive bondline's temperature while minimizing the exposure of the remaining assembly to elevated temperatures. For this reason, the integral-heater approach is likely to do less than damage than more conventional methods. Of course, the heater must be part of the package design. Incorporation of an integral heater into an existing electronic component requires a package redesign. For large expensive subassemblies with large components, this may represent a cost-effective approach to rework.

References

[1] Martinez et al., "Adhesive Heater and Method for Securing an Object to a Surface", U.S. Patent 5,624,750, April 1997

[2] Berkely et al., "Integral Heater for Reworking MCMs and Other Semiconductor Components", U.S. Patent 6,031,729, February 29, 2000

Acknowledgements

The authors would like to acknowledge the contributions made by the following individuals to this effort: S. VanLiew, G. Pinneo, and J. Lau.

Mary C. Massey is the Internal Research and Development Manager of Advanced Digital Packaging for TRW. Her research supports insertion of advanced electronics products for the Space and Electronics Group. Mary received a B.S. degree in Chemical Engineering from the University of Colorado in Boulder in 1983. She is an officer of the International Microelectronics and Packaging Society, and holds two packaging related patents.

William E. McMullen is a TRW staff engineer. He has a B.S. in Engineering (UCLA, 1981) and a Ph.D. in Physical Chemistry (UCLA, 1985). Before moving to TRW, he worked as a postdoctoral researcher at the University of Chicago (1985-1988) and as a faculty member at Texas A&M University (1988-1996).

Ryan S. Berkely is the senior mechanical engineer for the Advanced Processor Product Line at TRW where his original concept development contributions earned him a TRW Chairman's Award for Innovation. Ryan received a B.S. degree in Industrial Technology-Electronics from California State University at Long Beach in 1977. Of his 34 years of electronics experience, the past 23 have been with leading state-of-the art design teams. He holds two packaging related patents.

Susheel Dharia is the Manager of Special Projects at Kyocera America, Inc. in San Diego, CA. Susheel received a Bachelors and Masters degree in Ceramic Engineering from Alfred University.

Aki Nomura is the Manager of the Design Group at Kyocera America, Inc in San Diego, CA. Aki received a degree in Mechanical Engineering from Tokyo University 1973. Aki joined Kyocera in 1977 in the multilayer group in Japan.