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DESIGN OF A LOW COST WIRE BOND TAPE BALL GRID ARRAY PACKAGE

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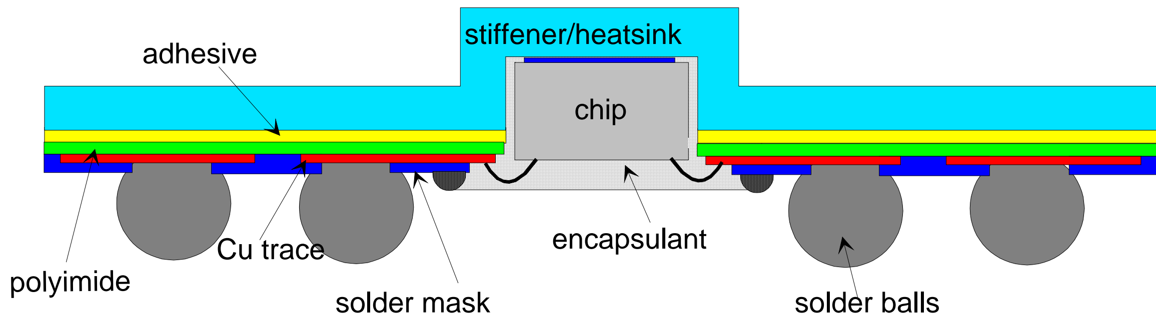
ABSTRACT
Tape ball grid array (TBGA) packages offer many of the advantages of plastic BGAs, namely, excellent durability, improved board space utilization, and ease of surface mount assembly along with the associated yield improvements. TBGA packages go a step further, however, and offer the added benefits of improved signal integrity, better heat dissipation, and extendibility to higher pin counts. This paper will outline the design and material selection process to produce a low cost TBGA which allows the wire bonding of a die. This type of package offers an attractive solution for applications requiring mid to high i/o capability and good electrical and thermal properties. Preliminary results have demonstrated the feasibility of wire bonding to this package at temperatures up to 200°C.

INTRODUCTION
The gain in popularity of ball grid array (BGA) packages is due to a number of significant advantages which BGAs have provided over conventional packaging techniques such as quad flat packs and pin grid arrays. As the need grows for higher i/o, BGA packages become more desireable due to their smaller real estate requirements[1]. In addition, BGA are relatively low cost with good to excellent electrical and thermal characteristics[2]. Perhaps the key advantage of this package style is the ease of board level assembly. The relatively coarse pitches typically associated with BGA packages (1.27 and 1.5 mm) allow for routine solder paste deposition and placing of the component. In fact, many types of BGA packages can be placed up to a half pad off center (typically 0.012”) and will self align upon reflow of the solder balls[3]. The result is defect levels in card assembly less than 2 ppm compared to 48 ppm for 0.5 mm pitch QFPs[4]. The inability to easily inspect the BGA solder joints and repair defects are potential concerns that are being addressed in the industry through better assembly process control and the implementation of methods for removing and replacing defective BGA components[5,6].

There are currently three primary types of BGA packages on the market, each identified by the substrate material used. These are ceramic (CBGA), plastic (PBGA) - made with an epoxy based circuit board material and tape (TBGA) which is constructed from flexible circuitry - typically copper traces on a thin polyimide substrate. Each BGA type has characteristics which make it attractive for certain segments of the market. For example CBGA packages exhibit excellent electrical and thermal characteristics but have a relatively high cost, and as a result, are generally used for high performance die. The typical PBGA has moderate electrical and thermal properties, is relatively low cost, and has good environmental reliability. These packages are typically finding use in lower i/o applications (<225 i/o) for low to mid performance die[7]. The TBGA packages currently being offered in the market are intermediate in cost, have excellent electrical and thermal characteristics as well as excellent environmental reliability[8]. This package style is therefore attractive for use with mid to high performance die.

The most common TBGA packages are currently made with costly double metal sided flexible circuitry as the substrate and only allow die attach by thermal compression bonding or flip chip (C4). Although these constructions provide outstanding electrical characteristics, their cost can limit the use of these packages to higher level applications. A need exists in the industry for a low cost TBGA package which allows wire bonding of a die since a vast infrastructure currently exists for wire bonding. Such a package would be an attractive low cost alternative for low to mid range die. This paper details the design and material selection process undertaken to provide a low cost wire bondable TBGA package.

WIRE BOND TBGA STRUCTURE
Although there are currently no TBGA packages being offered which permit wire bonding of a die, there are a number of companies striving to produce such a construction. The common approach is to adhere the backside of the flexible circuitry to a cavity backed stiffener and wire bond from conductive pads on the flex to the die, as shown in Figure 1. The drawback to this design is the requirement for a solder mask to prevent wicking of the solder balls along the conductive traces. The tolerance required to define uniform sized solder ball pads can prohibit the use of inexpensive screen printing methods for applying the solder mask. Although photodefinable epoxy based solder masks can be used, this can be a time consuming and expensive process, since strips of parts must



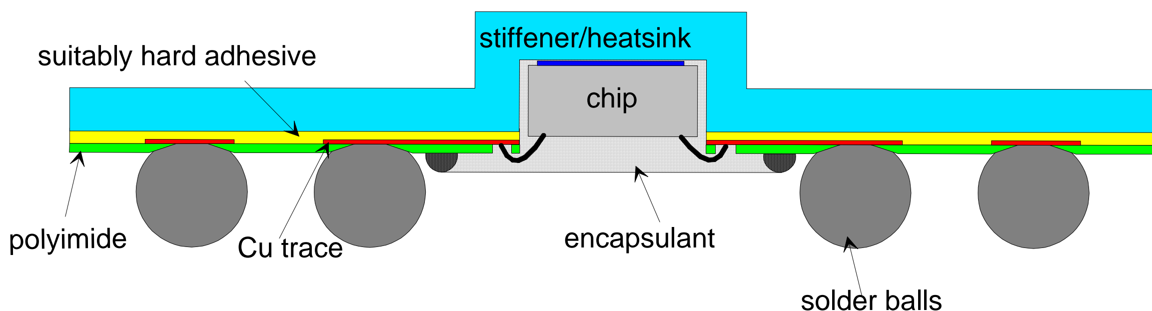
The typical method is to adhere the backside of the circuit to the stiffener and add a solder mask.
Figure 1

be coated followed by elevated temperature drying for up to 30 minutes, exposing, developing, and finally curing at elevated temperature, once again for up to 30 minutes. Other methods, such as laser ablating a solder mask can also be rather costly. Since the target market for wire bond TBGA is low to mid performance die, it is essential that the package be provided at costs low enough to compete with plastic quad flat packs which currently hold the largest share of this market.

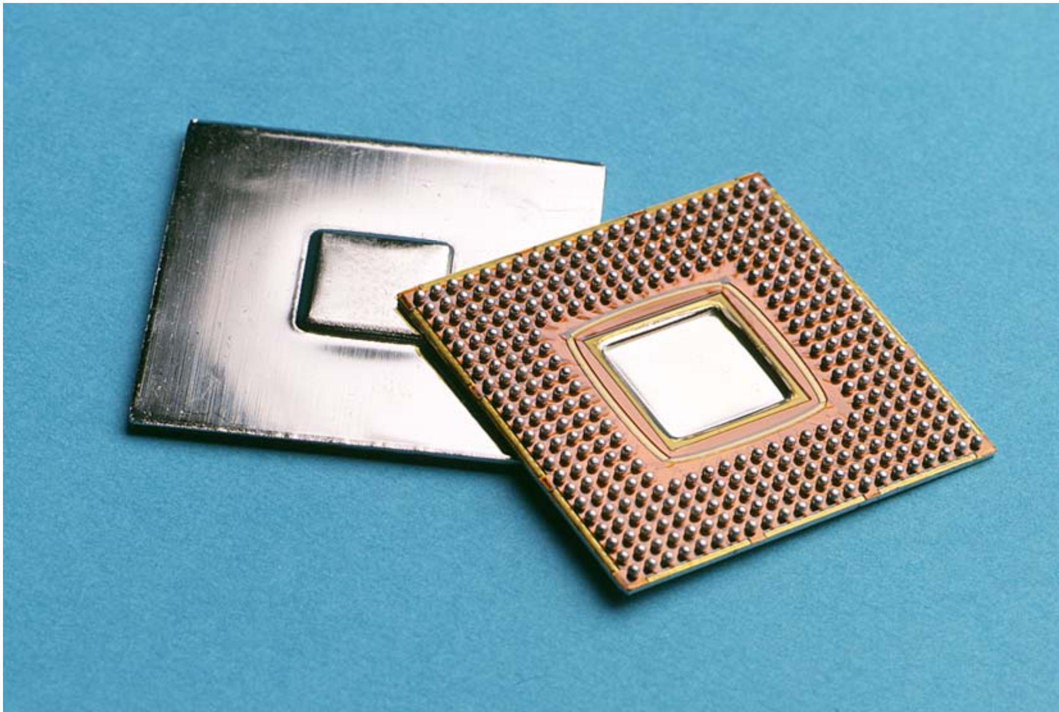
The approach discussed in this paper is to use inexpensive single metal layer flexible circuitry which is inverted such that the polyimide substrate serves as the solder mask, as shown in Figure 2. This design is made possible with the use of adhesiveless flex in which the solder ball pads are defined with a very accurate and consistent chemical etching process. Since numerous other features on the tape require etching, such as the inner window for the die, the etching of the solder ball pads adds no additional processing. Consequently, use of the polyimide substrate as the solder mask is essentially free. With this design configuration, the die is placed in the stiffener cavity and wire bonded to pads which are attached to the stiffener with an adhesive. A photograph of a prototype wire bond TBGA is shown in Figure 3. The bond pads are exposed through a window in the polyimide substrate and are thus held firmly in place to prevent any possible misalignment. A metal tie bar at the center eliminates the need for electrically bussing each solder ball pad to the outside for gold plating and thus frees up space for routing. The tie bar can be easily removed by coarse mechanical punching.

PRODUCT CHARACTERISTICS

The prototype wire bond TBGA chip carrier designed to prove feasibility was 29 mm square with 340 solder balls and 328 wire bond pads. The wire bond pads were 100 µm wide and separated by a 44 µm space. The pads were situated in an arc 2.2 mm (90 mils) from the edge of the die to keep the wire length to less than 2.5 mm (100 mils). A cavity was formed in a nickel plated copper stiffener to accommodate an 8.8 mm die (0.5 mm thick). Since the stiffener also acts as a heat spreader, excellent thermal dissipation can be achieved. In addition, the close proximity of the metal circuitry to the stiffener (approximately 25 µm) allows a fraction of the heat to be dissipated through the adhesive layer and into the circuit board. The thin adhesive layer offers an advantage from an electrical standpoint as well. Inductance values ranging from 1.8 - 4.9 nH (for the shortest and longest traces) were measured on the one metal layer TBGA package laminated with the PI adhesive[9]. These values were only slightly higher than those measured on an identical two metal layer TBGA (1.7 - 4.7 nH)[9]. This effect is believed to result from the close coupling of the stiffener which provides many of the same benefits as a ground plane, but at no additional cost.



The flexible circuit is oriented so that no solder mask is required.
Figure 2.



29 mm wire bond TBGA with 340 i/o.
Figure 3.

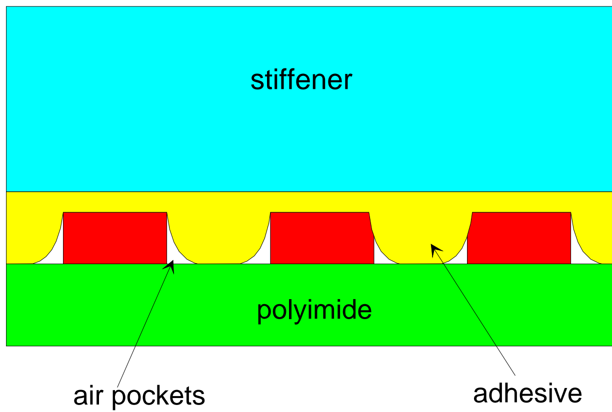
The carrier, without the die, weighs 4.9 grams and is 1.8 mm in height. Eutectic solder balls, 30 mil in diameter, were reflow attached to the package with a rapid low cost mass reflow process. Due to the high temperature capability of the adhesives used in this design, high temperature 10Sn/90Pb solder spheres can also be directly reflow attached to the pads (at temperatures up to 350°C). The TBGA chip carrier described in this paper can be delivered in strip form in a cartridge suitable for wire bonding, similar to that of a PBGA strip. The current capabilities for manufacturing flexible circuitry with the additive process are shown in Table 1.

ADHESIVE ISSUES

The most difficult challenge to overcome in making this design feasible was the identification of a suitable adhesive system. Obviously, the first requirement was that the adhesive be sufficiently rigid at the elevated temperatures required for wire bonding (typically 150-200°C) to prevent absorption of the thermosonic bond energy. Significant vibration of the bond pad during the bonding process can cause inadequate wire scrubbing and result in weak bonds. Another important requirement is that the adhesive have the correct viscosity to flow into all the spaces between circuit traces to prevent formation of air pockets or voids beneath the tape, as illustrated in Figure 4. Conversely, the adhesive must not flow to the extent that it covers up or contaminates any of the bond pads. In addition, the material must have good adhesion to polyimide and to gold plated circuitry even after exposure to high temperature and humidity conditions. Finally, the adhesive must have a low level of ionic contaminants to prevent shorting by metal migration and must not have the capability of diffusing onto the surface of the bond pads.

Table 1. Flex circuit production capabilities.

Feature	Current Manufacturing Capability	Proven in Lab and Scaling to Manufacturing
min line width	40 μm	25 μm
min space width	40 μm	25 μm
min pitch	80 μm	50 μm
surface metal	Au, Au/Ni, Sn	Pd
substrate type	50 μm H film 25 or 50 μm E film	
via etching	solventless etching	laser



Flow properties of the adhesive must enable filling in of spaces between signal traces.
Figure 4.

Numerous adhesives were evaluated before a suitable one, which satisfied all the previously stated requirements, was identified. In the end thermoplastic polyimide was determined to be ideal for this purpose. The particular adhesive evaluated had a glass transition temperature near 220°C and was laminated at temperatures near 350°C. The PI adhesive is forced up between traces to fill in any voids but does not flow over the bond pads. Upon cooling, the adhesive becomes a non-tacky semi-rigid film which provides a stable surface on which to wire bond. In addition this adhesive has low moisture absorption (<1%) and the level of ionic contamination was measured to be <1 ppm for Cl^-, Na^+, and K^+ ions.

Evaluation of Wire Bond Feasibility

An investigation was undertaken to prove the feasibility of wire bonding to this structure. The first round of bonding experiments were performed by an outside source using a Hughes 2A60II wire bonder using 32µm (1.3 mil) diameter gold wire with an elongation of 4-6% and a minimum pull strength of 14 grams . The bonding conditions for this first series of tests were determined by setting the stage temperature to 170°C and slowly increasing the force, time, and power level until acceptable bonds were achieved ('acceptable' was defined by bond pulls resulting in wire breaks). The bonding process was not optimized so that samples with various conditions could be compared. For example, samples with 1.5µm (60µ") of gold were compared to samples with similar gold thickness but with a 1.5µm nickel underplate to determine whether the hard underplate was necessary for acceptable bonding. The bonding conditions shown in Table 2 were used for all the samples. Since it was felt that some users might desire to bond at even higher temperatures, bonding at 200°C was also evaluated.

Table 2. Wire bonding parameters

Force	Time	Ultrasonic Power	Overtravel
25 grams	25 msec	45 mV	5 µm

The integrity of the bonds was determined by pull testing which was performed using a Dage BT22 wire pull tester with a 125µm (5 mil) diameter hook. Results of the first test series is shown in Table 3. A minimum of 12 bonds

Table 3. Wire bond pull strength results with 1.3 mil gold wire**.**

Sample #	Sample Type	Bond Temp °C	Pull Strength (grams)
1	60µ" gold bonded w/ PI adhesive	170	mean = 15.8 stand dev = 2.5
2	"	170	mean = 14.9 stand dev = 1.0
3	60µ" gold w/ 60µ" nickel w/ PI adhesive	170	mean = 14.3 stand dev = 1.0
4	"	170	mean = 14.1 stand dev = 1.9
4	"	200	mean = 14.2 stand dev = 2.5
5	60µ" gold w/ PI and 4 mil PSA	170	mean = 15.9 stand dev = 1.1
5	"	200	mean = 15.0 stand dev = 1.1
6	"	170	mean = 15.1 stand dev = 1.4
6	"	200	mean = 14.7 stand dev = 0.8

* minimum tensile strength of the gold wire was 14 **grams**

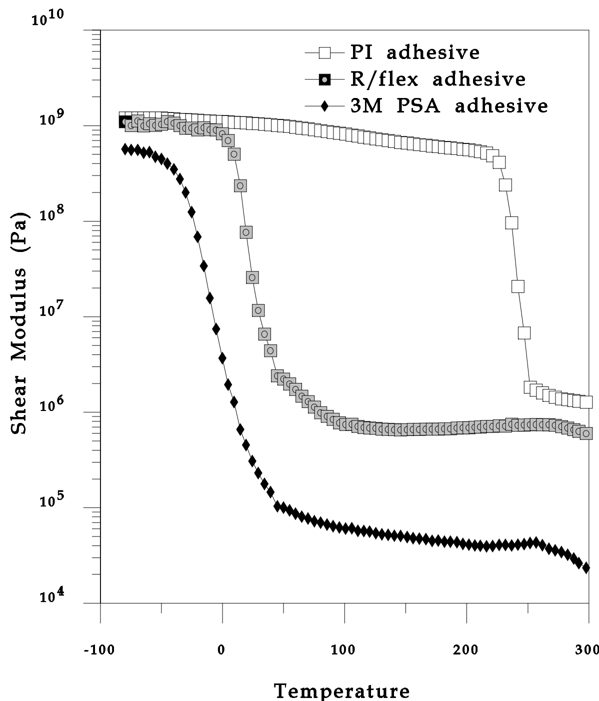
were tested at each condition. Nearly all of the pulls resulted in wire fractures and the mean strengths were above the minimum breaking strength of the wire. Therefore, it appears that bonding to this structure is not a problem at either 170 or 200°C. The results also seemed to indicate that the nickel layer was not required from a hardness standpoint. However, most users would still likely desire the nickel underlayer as a diffusion barrier to prevent copper contamination of the gold.

Adhesive Effects on Solder Joint Reliability

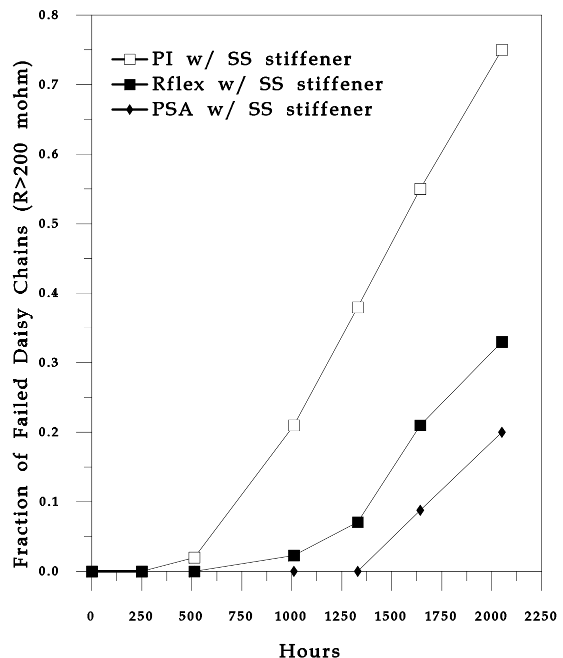
Reliability testing of solder joints using thermal cycling has indicated that the rigidity of the adhesive layer between the flex circuitry and the stiffener plays an important role in the durability of the solder joints. To demonstrate this effect, samples were constructed with three types of adhesives, the most rigid being the thermoplastic PI adhesive with a T_g of 220°C, followed by R/flex 1500 (a thermosetting modified acrylic adhesive) with a T_g of 20°C. The most compliant of the adhesives was an acrylate pressure sensitive adhesive (PSA) with a T_g of -20°C. The graph in Figure 5 plots the shear modulus values of these adhesives vs. temperature and thus gives a better indication of the adhesive compliancy at the temperatures involved in thermal cycling and in wire bonding. The rigidity of the PI adhesive up to 220°C shows why this material performs so well in wire bonding.

The TBGA test vehicles were designed to have small 200µm (8 mil) diameter pads on which to attach 610µm (24 mil) eutectic solder spheres. These parts were reflow attached to test boards and thermal cycled from -55°C to 125°C with a 55 minute ramp and a 20 minute dwell. The small pad size and extreme conditions were used to induce early failures so that comparison results could be attained within a reasonable period of time. The test vehicle was designed to allow 4 point resistance reading of rows of daisy chains. The samples constructed with the PI adhesive showed first evidence of solder joint fatigue after 500 hours of testing while the R/flex samples survived 1000 hours before resistance increases of over 200 mΩ were recorded. Of the adhesives evaluated the PSA samples performed best, with first failures detected at 1600 hours, as shown in Figure 6.

Test vehicles with larger solder ball pads ranging in size from 400 to 600 µm are currently being cycled to determine the expected life of these packages constructed with the PI and Rflex adhesive materials. These daisy chain test vehicles were 29 mm in size and had 340 solder balls. As of this writing over 1000 cycles from -40 to 125°C have been completed on 49 packages with the results shown in Table 4. A failure was defined by a resistance change of 1Ω. No solder joint failures have yet been detected in any of the samples tested. These included samples with 400, 500, and 600µm pads and PI adhesive,; elliptical shaped pads (400 x 600 µm) with PI adhesive, and 500µm pads with



Adhesive modulus vs. Temperature (°C).
Figure 5.

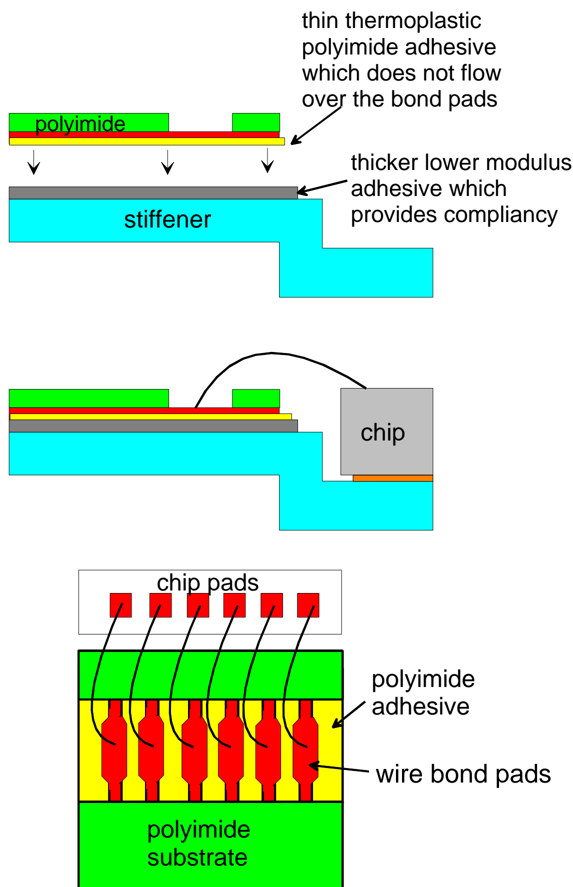


Effect of adhesive rigidity on solder joint durability during thermal cycling.
Figure 6.

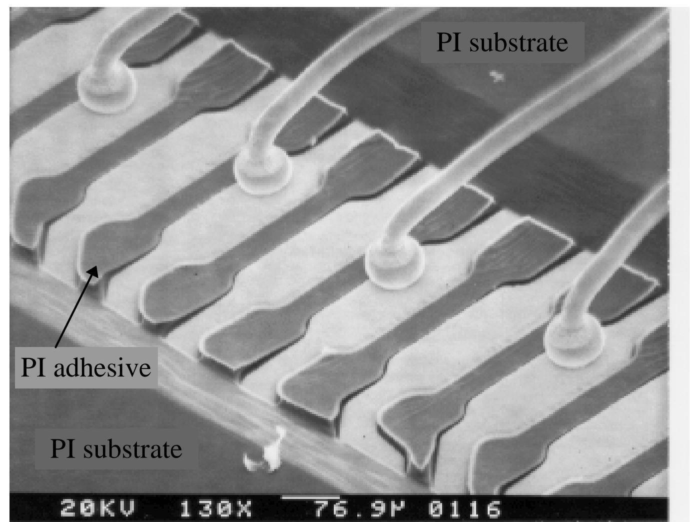
Rflex adhesive. Three samples with the 500 µm pads and PI adhesive did exhibit high resistance readings, however die penetrant analysis and cross sectioning of the solder joints did not reveal any fatigue cracks over 50 µm in length. Further cross sectional analysis revealed the high resistance readings were instead due to via barrel cracking on the test circuit boards. Similar findings were observed during thermal cycling of plastic BGAs after 1885 cycles in a paper by Mawer et al.[10] Testing will continue until at least 50% of the components fail.

The larger test pads along with the associated higher solder ball shear strength appear to provide the required reliability. However, if greater reliability is desired a PSA adhesive can be inserted between the PI adhesive and the stiffener, as shown in Figure 7. To demonstrate the ability to bond to this more compliant structure, samples 5 and 6 in Table 1 were bonded at the same conditions as the previous samples. As can be seen, the PSA adhesive did not adversely affect the wire bonding capability.

A number of ball bonds on these samples are shown in Figure 8. The PI adhesive can be seen to flow up around the pads slightly but not flow onto the pad surface. In fact, contamination of the pads was not observed under any of the lamination conditions attempted. At the same time, the PI adhesive flowed well enough to fill in all the voids beneath the flex circuitry. Cross sections of ball bonds on a pads supported by PI only and PI on PSA are shown in Figure 9. As can be seen the pads did not bend downward from the force of the wire bond process which suggests that the rigidity of the adhesive layers was more than adequate.



A compliant adhesive can be inserted between the stiffener and the PI to improve the reliability.
Figure 7

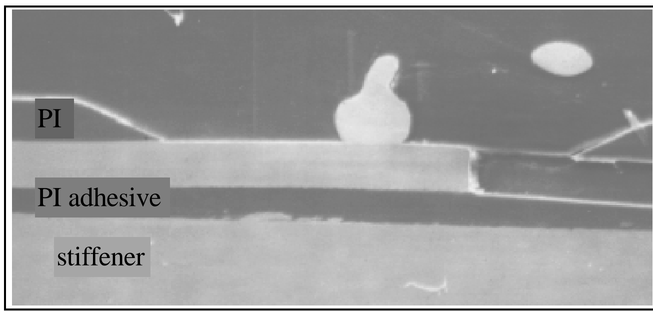


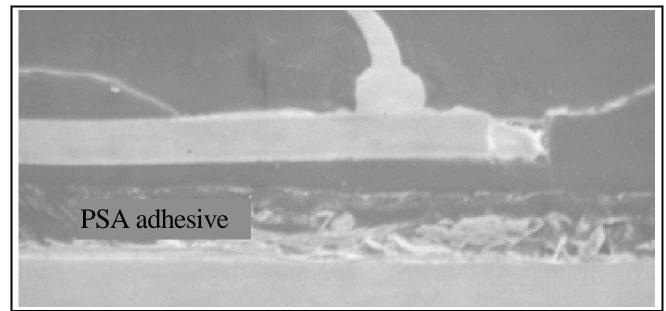
TBGA wire bond pads with gold balls bonded to them.
Figure 8.

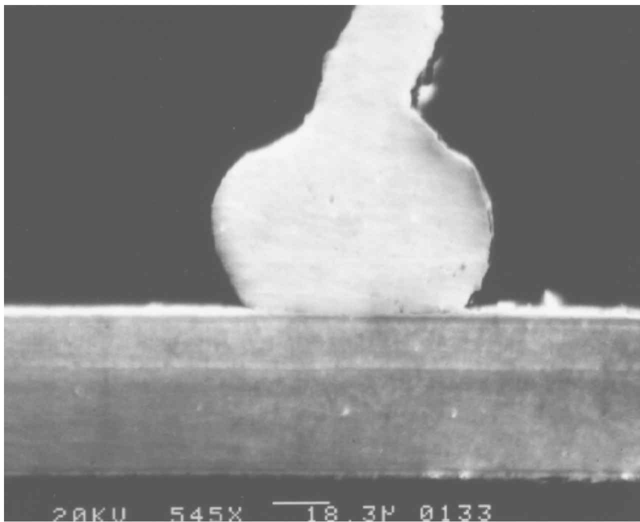
Table 4. TBGA test plan and results.

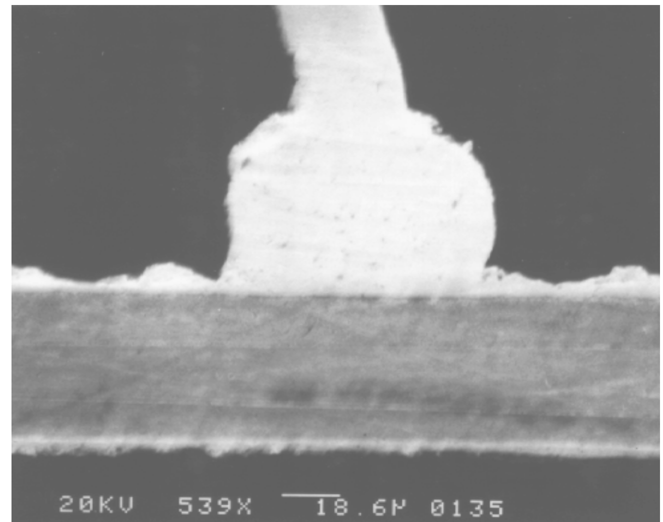
# Samples	Pad Size	Adhesive	Test Conditions	Results to date
12	400µm (16 mil)	PI	-40/125°C	1010 cycles; 0 failures
12	500µm (20 mil)	PI	"	1010 cycles; 0 failures
8	600µm (24 mil)	PI	"	1010 cycles; 0 failures
8	400 x 600 oval	PI		1010 cycles; 0 failures
9	500µm (20 mil)	R/flex	"	1010 cycles, 0 failures
12	400µm (16 mil)	PI	0/100°C	1016 cycles, 0 failures
12	500µm (20 mil)	PI	"	1016 cycles, 0 failures

*stainless steel stiffeners were used for all samples









(a) (b)

Cross sections of ball bonds on pads with a) PI adhesive and b) PI adhesive with a 100μm layer of PSA beneath. Note there is no bending down of the pads from the bonding process suggesting adequate adhesive rigidity.
Figure 9.

Table 5. Wire bond parameters.

Bond type	Temp °C	Force grams	Time msec	Energy mV
Ball	all	30	90	110
Stitch	150	40	120	230
Stitch	170	50	180	200
Stitch	190	70	200	200

Table 6. Results of bonding 1.0 mil gold wire to TBGA samples**.**

Temperature °C	Mean Pull Strength (stand dev) Ball on Pad	Stitch on Pad
150	6.6 grams (1.2)	7.3 grams (0.7)
170	6.6 grams (0.9)	7.1 grams (1.7)
190	7.3 grams (0.8)	7.5 grams (0.7)

*min breaking strength of wire was 5 grams

Further Wire Bond Evaluations

Additional bonding experiments were performed with fine pitch 1.0 mil (25μm) gold wire at temperatures of 150, 170, and 190°C. In this experiment both ball bonds and stitch bonds were evaluated. The optimum bonding parameters for the ball bond were determined at the intermediate temperature of 170°C and all samples were bonded at these conditions with good results. The stitch bonds were optimized at each temperature with the conditions shown in Table 5. The bond pads were cover plated with 60μ" gold over 60μ" nickel. All samples were constructed with a 100μm thick layer of PSA adhesive between the PI adhesive and stiffener since this was considered the worst case situation for wire bonding. Results of bonding to these samples is shown in Table 6. In all cases the mean bond strength was well above the 5gram minimum breaking force of the wire. Therefore, it appears that ball and stitch bonding to this structure with fine pitch wire is feasible at temperatures up to 190°C. However further investigations will be performed to demonstrate reproducibility.

MOISTURE SENSITIVITY

Six samples constructed with the PI adhesive were tested for popcorning following JEDEC standard test method A112. These packages were subjected to the most severe condition (level 1) which consisted of soaking in 85°C/85% RH for 168 hours followed by exposure to two IR oven reflow profiles to 220°C. The amount of moisture absorbed by the package (not including the stiffener or solder balls) was only 0.8% by weight. Examination of the parts revealed no cracks in the PI or any delamination of the circuit from the stiffener. Therefore, at this point the package does not appear to be sensitive to moisture. However, further moisture sensitivity testing will be performed on samples with encapsulated die to verify that no delamination or cracking occurs in the encapsulant. If a package passes level 1, it is classified as not moisture sensitive and does not require dry packing or baking. A non moisture sensitive BGA would be a significant advantage at the board assembly level.

Table 7: Peel strength of PI adhesive.

Substrate	Peel Strength (kg/cm)	Peel Strength (lb./in)
ED Copper	3.6	20
Steel	2.5	14
Kapton HN	1.1	6
Kapton E	0.7	4

ADHESION STRENGTH

The peel strength values of thermoplastic PI to a number of substrates (provided by the supplier) are given in Table 7. Peel testing using a 90° peel at a rate of 6.3 cm/min was performed to verify these values. The peel strength to Kapton E film was instead determined to be 1.0 kg/cm (5.6 lbs/in). The improved adhesion was believed to be due to the surface treatment caused by the method of additive film processing. Steps such as sputtering and etching of the tie layer on the PI substrate is known to disrupt the highly oriented skin on the film. Exposure to 1000 hours at 150°C and 1000 cycles of thermal cycling (-55/125°C) did not degrade the peel strength. However, 1000 hour exposure to 85°C/85RH did cause the adhesion to drop slightly to 0.7 kg/cm (4 lbs/in). No delamination has been observed in any samples constructed with PI adhesive, R/flex 1500, or 9460 PSA adhesives after being subjected to 1000 thermal cycles, 1000 hours of 85°C/85RH, or 1000 hours of 150°C aging.

CONCLUSIONS

A low cost TBGA package which allows the wire bonding of a die offers an attractive solution for applications requiring mid to high i/o capability and good electrical and thermal properties. The TBGA package design discussed in this paper provides these characteristics by making use of less costly single metal flexible circuitry, eliminating the need for a solder mask, and allowing efficient mass reflow attach of solder balls. A suitable adhesive was identified which enabled wire bonding at temperatures up to 200°C. The system thus far looks very promising, however, additional work is required to qualify this package as a fully characterized system ready for mass assembly. Full characterization of the wire bondability of this package will take place in the coming months and additional data will be presented at the conference.

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