Choosing the Correct Capillary Design for Fine Pitch, BGA Bonding

Lee Levine, Principal Engineer
phone 215-784-6036, fax 215-784-6402, email: llevine@kns.com
and
Michael J. Sheaffer, Director Technical Marketing
phone 215-784-6411, fax 215-784-6402, email: msheaffer@kns.com

K&S Packaging Materials Group
2101 Blair Mill Road,
Willow Grove, Pa 19090

Abstract

Ball Grid Array Packages (BGAs) present unique challenges to the wire bonding process. They are fine pitch, require long low loops with adequate clearance over voltage and ground bus bar rings, and are built on a laminate substrate. An integrated approach, encompassing upgraded wire bonders and specially designed bonding tools and bonding wire, provides the process capability to meet these technical challenges.

Ball bonded devices having small bond pads with fine pitch between adjacent pads has become the norm for high end QFP and BGA packaging. Devices with pitches of 90 μm have been in production for some time. Devices with 80μm pitch are near production at multiple facilities. Devices with pitches as low as 60μm are in experimental stages with test die.

As semiconductor packages have evolved, and interconnect density has increased, the size of the wire bonds has gotten smaller. As the size has decreased, the need to maintain and improve the strength of the welded cross section of each bond has become a critical factor in process development. In order to maintain an optimum process, each decrease in wire bond size requires the selection and qualification of a new capillary, with design features sized appropriately for the new application.

The use of bottle-necked capillaries, with tip diameter reduced to less than half the diameter of a standard capillary, has been common practice for several years. The issues associated with interference between the capillary and adjacent ball bonds have been resolved. BGA packages requiring lower bonding temperature, however, have introduced new issues. Conventional bottle-necked capillaries have been unable to provide a robust bonding process. New capillary designs, with their moment of inertia optimized for use with higher frequency, adaptive ultrasonic generator systems, provide stronger, more uniform bond strength in all bonding directions and at lower bonding temperatures required by BGA.

A capillary has a large number of significant features and properties. It's tip shape forms the bond while the mechanical properties of the capillary affect the transfer of energy from the ultrasonic transducer into the weld interface. The stiffness of a capillary plays an important role in controlling undesirable bending modes that affect energy transfer during bonding. The surface of the capillary provides the boundary conditions and friction affecting deformation. This paper discusses the role of the capillary, and the effects of capillary design features on bond quality.

Introduction

The BGA package is expected to be the fastest growing semiconductor package during the next 5 years. Estimated CAGR for the period 1996-2001 is 70%[1]. Development of field support and applications has lagged, however, because of the speed at which this package has been accepted.

Because of their intrinsic design, BGAs are technically complex to bond. BGAs are designed for high I/O counts (225-500 leads are common). They demand fine pitch wire bonding (pitches less than 90*mm*, resulting in small first and second bond cross sections) and require long, straight wire loops. Wire lengths of 6 mm are common, and loop shapes must be controlled to provide clearance over ground and power busses located close to the lead tips.

Fine pitch bonding requires the use of a bottle-necked capillary, with a small tip diameter. The small capillary tip and the narrow lead width result in a small bond area for the crescent bond, making the strength of the bond an important concern.

The BGA structure is based on laminate technology. The low glass transition temperature (Tg) of the laminate material requires bonding at lower than normal temperatures. Typical bonding temperature for leadframe devices is 200-230°C; for BGA packages the bonding temperature is reduced to 125°C. A lower bonding temperature generally has a negative effect on the strength and reliability of the crescent bond.

Bonding at Reduced Temperatures.

Bonding at reduced temperatures presents additional challenges to wire bond integrity. When bonding at reduced temperature, acceptable ball bond shear strength can normally be achieved by increasing ultrasonic energy. The strength of the crescent bond, however, is often adversely affected. The use of higher frequency Adaptive USG systems has been shown to provide improved low temperature bonding performance for BGA and other soft substrates.

The system consists of a high performance 120 kHz K&S UNIBODY[tm] transducer and a high frequency capillary driven by a new ultrasonic generating system that adapts to material variations by adjusting ultrasonic output in real time. Figure 1 shows the second bond pull strength for a QFP device bonded at 180°C. There is a significant difference in pull strength between the two bonding directions. The Y direction leads are aligned with the ultrasonic displacement. The X axis leads are perpendicular to the displacement.

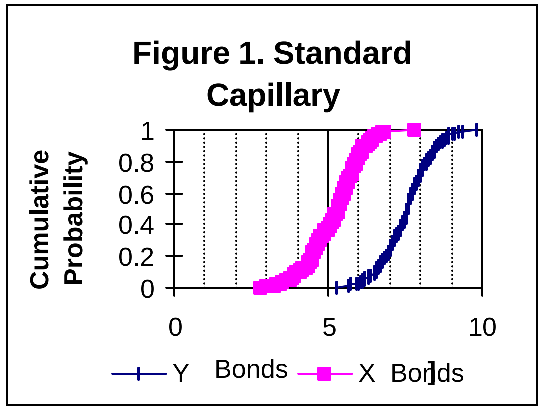


Figure 1. Standard Capillary

Figure 2 shows the same leads bonded with a new high frequency capillary design. The new design has a different configuration above the bottle-necked area. The new capillary is stiffer, which reduces displacement associated with rocking and bending modes. It is easier to insert and remove from the transducer clamp and it has been shown to increase the strength of both the X and Y axis bonds. The result is improvement in the consistency of the crescent bond, changing the pull strength population from a bimodal to a normal distribution.

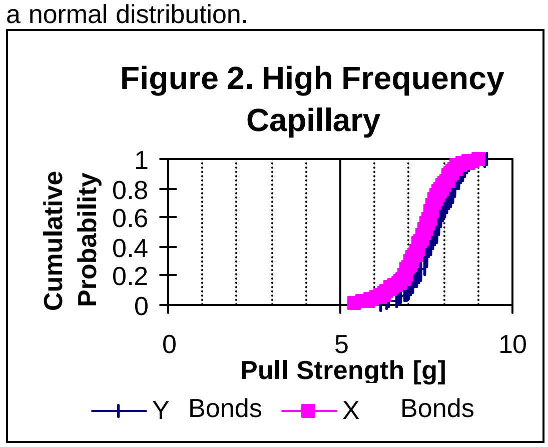
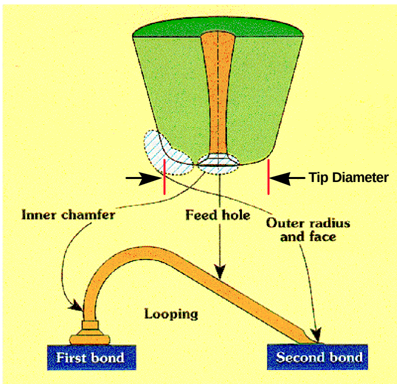


Figure 2. High Frequency Capillary

How Wire Bonding requirements Affect Capillary Geometry.

Figure 3 describes some of the major capillary tip features and how they affect the bonding process. We will discuss these features, and how they are selected to provide strong bonds that meet the demands of fine pitch bonding.

Figure 3. Capillary Parameters that Affect the Bonding Process



Feature	What is Affected
Feed Hole	• Wire Centering • Looping
Inner Chamfer	• Ball Bond Centering • Ball Bond Strength • Bond Size • Looping • Tail Bond Strength
Face Angle & Outer Radius	• Second Bond Strength • Looping
Tip Diameter	• Pitch • Second Bond Strength

In general, design considerations can be grouped into two categories, those that are determined by the constraints of the package, and those that are determined by application specific bond quality requirements.

Computer aided tools are available that model the possible interference between the capillary and adjacent bonds in a fine pitch application [2]. These allow the process engineer to select capillary dimensions that are required by the package. Dimensions include tip diameter, chamfer diameter and bottle-neck height. Other capillary dimensions, such as the face angle of the tip, are application specific and often require evaluation of several sample geometries before an optimized design can be determined.

The capillary face angle is a feature that significantly affects the strength of the second bond. Figure 4 shows a quarter section view through several possible capillary tip configurations. For a standard capillary, producing a full strength second bond with thickness T1, the size and angle of the face might be 8 mils (diameter) and 8° (face angle). From the drawing it can be seen that a small diameter, 4 mil tip capillary with the same face angle would produce a bond that is half the thickness of a standard capillary (T2). This bond would produce lower pull strengths than the thicker bond since the cross-section of the bond is smaller. In general, when capillary tip diameters are reduced, the face angle of the capillary is increased in order to maintain higher pull strengths (T3). In addition, as the tip diameter is reduced, the outer radius (the radius between the capillary face and the cone angle) is also reduced. Reducing the outer radius increases the length of the face, maximizing bond length.

Second Comes First

We have defined a method for applying Designed Experiment techniques (DOE) in new bonding applications [3] for optimizing the bonding process and the capillary. Figure 5 is a schematic of this method. Input from the package design and specifications is used to set limits for the DOEs and to select starting dimensions and features. This method optimizes second bond parameters first, followed by first bond, and then looping. This sequence is used because the quality of first bond is significantly affected by the quality of second bond. Optimizing second bond first provides assurance that the tail bond is optimized.

Figure 4. Capillary Tip Face Angle Quarter Section View

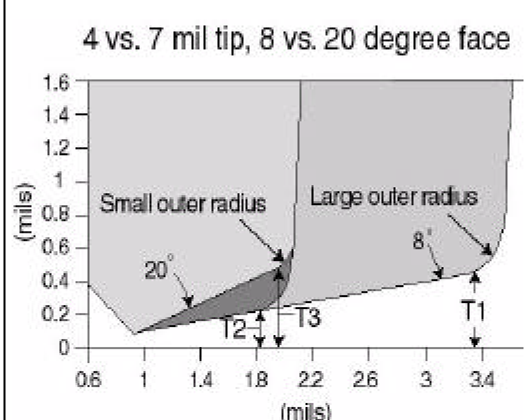
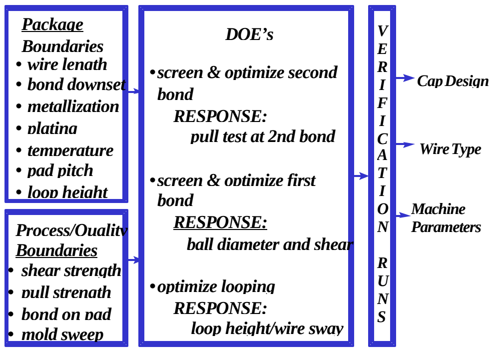


Figure 5. The DOE Method



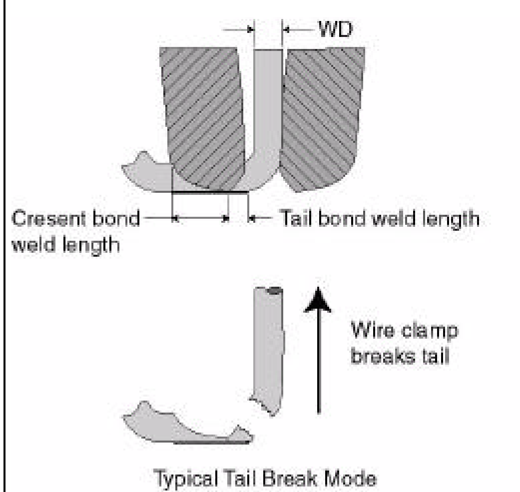
The tail bond is the tack weld temporarily holding the short piece of wire (which will subsequently be used to form the next ball) to the substrate. Getting a good tail bond is a requirement for good ball formation during the firing of the Electronic Flame Off (EFO). Figure 6 shows the weld area of a crescent bond and of a tail bond. Fracture of the tail bond should occur in the region shown. Fracture that occurs by peeling the tail bond into the crescent bond weld area represents a reliability risk.

When optimizing second bond, pull tests are conducted with the hook located as close to second bond as possible. In the case of *Super* Ball Grid Array (SBGA®) devices, the hook is aligned with the inner ground bar ring. On Plastic Ball Grid Array devices, the hook is placed over the ground bar. Locating the hook near second bond changes the resolution of forces so that most of the force is applied to the second bond. This provides a more sensitive method of optimizing the crescent weld area and the tail bond area than can be observed with a mid-span pull test. Since the test forces are more localized, the response is more representative of shifts in second bond strength. The value of the pull strength, when tested in this manner, may differ significantly from pull strengths tested at other locations (mid-span or top of loop).

First Bond Optimization

Following second bond optimization, first bond optimization experiments are conducted. The most important responses for first bond optimization are shear strength/unit area and ball diameter. For fine pitch bonding, the ball size is a limiting factor. It must be small enough to meet 100% on-pad placement requirements. In order to maintain high strength with small balls, high strength/area bonds must be formed. To develop high shear strength/area, bonds must be deformed so that the diameter of the deformed ball extends under the face of the capillary (beyond the chamfer diameter). A reasonable rule-of-thumb for this deformation is that the bond diameter should be approximately 0.4 mils (0.2 mils/side) beyond the chamfer diameter. If the bond is deformed more than this amount, the ball shape will lose uniformity and the variability of the bond diameter will increase. If the bond is deformed less than this amount the high strength will not be developed.

Fig 6. Tail Bond Break Mode



Bond Optimization

ECHIP™ software was used in this study for the simultaneous optimization of several responses

DOE comparing capillary types are often difficult to evaluate, because capillaries are often treated as "categorical" variables. Although differences in means are readily detectable, it is difficult to compare several response surfaces and determine which is more robust. Recently, Micro-Swiss has introduced new software that normalizes and compares several response surfaces [4]. This software makes it possible to determine which response surface has the larger robust working area (i.e., region with second bond pull strength greater than 5 grams). In our comparisons, we look for a capillary with the largest working region. In addition, we would also give preference to a capillary that requires lower bond parameters for an equivalent performance.

Looping

The BGA device has presented a whole new set of looping issues. The device requires long, low, straight loops. There are normally two rings within the second bond periphery. They are used to distribute power and ground. These rings provide a bonding constraint, in that the wires must have a significant separation from them to prevent shorting.

The programmable control parameters on the wire bonder are the dominant variables controlling the shape of the loop. Low drag capillaries, with an inner radius instead of the standard double inner chamfer, are available. The capillary inner geometry, however, plays a minor role in the formation of the wire loop.

Conclusions

Optimized capillary designs improve the bond quality and provide stronger bonds, even when the bonds are small in size and produced at reduced temperatures. New capillary designs improve the robustness and increase the process capability of high frequency bonding by providing a larger process window.

Bibliography

[1] *Worldwide Package Demand by Package Type*, VLSI Research Inc., 1996

[2] CAPDESIGN[tm] software is available from K&S Micro-Swiss

[3] L. Christie, et al., "Integrated Solutions to Bonding BGA Packages: Capillary, Wire, and Machine Considerations", 1997 Proceedings IMAPS, pp 272-277

[4] Micro-Swiss Process Window Analyzer[m] software is available from K&S Micro-Swiss

BIOGRAPHY

Lee Levine received the BS degree in Metallurgy and Materials Science Engineering from Lehigh University, Bethlehem, Pennsylvania, in 1972. Prior to joining K&S, Mr. Levine was Senior Development Engineer at AMP, Inc. and Chief Metallurgist at Hydrostatics, Inc. He is currently Principal Metallurgical Engineer for the K&S Packaging Materials Group in Willow Grove, Pennsylvania, where he has been granted three patents and has 15 publications.

Michael J. Sheaffer is responsible for the operation of the K&S worldwide customer support network for packaging materials. He joined K&S in 1981 and has been actively involved with wirebonder manufacturing and wire bonding processes since 1977. He is author of several technical papers and articles and holds patents in low looping trajectories and bonding dynamics. He received his BS degrees from Drexel University and Millersville University and his MS degree from Ball State University.

SBGA is a registered trademark of AMKOR/ANAM.

ECHIP is a registered trademark of ECHIP, Inc.