Bonding Tool Design Choices for Wire Bondable CSP and μBGA® Packages

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Biography

Lee Levine received a BS degree in Metallurgy and Materials Science Engineering from Lehigh University, Bethlehem, Pennsylvania, in 1972. He is currently Principal Metallurgical Engineer for Kulicke & Soffa Packaging Materials, Willow Grove, Pennsylvania. He has been granted four patents and has 18 publications. He is a senior member of IEEE and IMAPS. Prior to joining Kulicke & Soffa, Mr. Levine was Senior Development Engineer at AMP, Inc. and Chief Metallurgist at Hydrostatics, Inc.

Ilan Hanoon received a BS degree in Mechanical Engineering from the Technion - the Technical Institute of Israel, in 1989. He is currently a Senior Process Engineer for Kulicke & Soffa Industries Inc. in Willow Grove, Pennsylvania. Prior to joining the Willow Grove facility, Mr. Hanoon was a Product Engineer in Micro-Swiss LTD, a Kulicke & Soffa company, where he specialized in bonding tool design, manufacturing and applications.

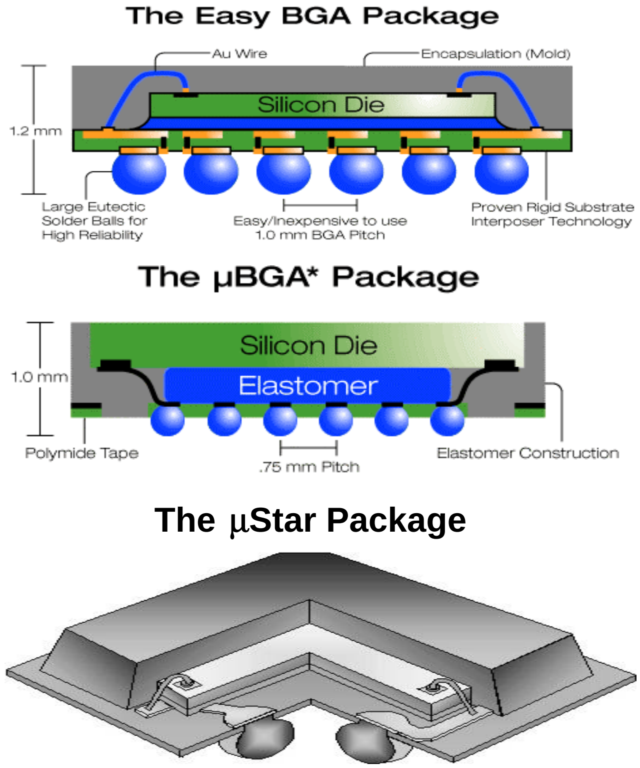
Sigalit Robinzon received her B.Sc. degree in Mechanical Engineering from the Technion-Israel Institute of Technology, in 1989. She joined Micro-Swiss application and R&D Lab in 1995, and currently is the head of the application and R&D laboratory. Prior to Micro-Swiss, Sigalit was a Thin Film Process Engineer at National Semiconductor. Sigalit is focusing on the development of next generation bonding tools while implementing advanced diagnostic, modeling and analysis techniques.

Abstract:

CSP packages are expected to grow to over 5 billion devices by 2003, with over 85% being wire and lead bondable. As process architecture becomes smaller, with smaller features requiring more precise bond placement, bond size becomes smaller and packages become more fragile. Yet process yields and reliability must be maintained if these packages are to remain cost competitive. Robust manufacturing, with tested machine, materials, and tooling, provides the necessary process capability. Integrated process solutions, jointly optimizing machinery, tooling, and materials, provides a significant advantage in improved process capability (C_{pk}). As chip scale manufacturing transitions, from the start-up lab to the factory, process infrastructure must be developed. This paper discusses wire and lead bondable CSPs, and the bonding tool design requirements for robust manufacturing processes.

Presently, three types of CSP designs dominate the marketplace [1]. Two of them are wire bondable, the third requires a lead bond. All are produced using wire bonding equipment, bonding a single interconnect/cycle with a special

Figure 1. CSP Package Types



- **Laminate interposer**
- **Wire bond**
- **Flash DRAM, RDRAM**

- **Flex interposer**
- **Lead bond**
- **Flash DRAM, RDRAM, SDRAM**

- **Flex interposer**
- **Wire bond**
- **Flash DRAM**

purpose tool. Figure 1 shows the designs and their applications.

Process Description

The MBGA (Easy BGA shown for reference) and the µSTAR® BGA use conventional wire, bonded with special looping software and a special bottle necked capillary that enables positioning of second bond very close to the die edge. Die placement and adhesive dispensing requirements are significantly tighter than for other package types -- a strong adhesive fillet must be formed without contaminating the wire bonding area that is in close proximity to the adhesive.

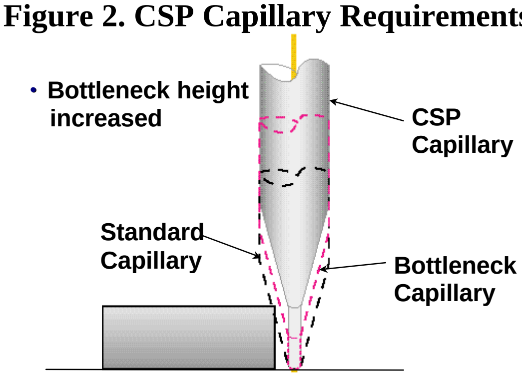
The µBGA® design is bonded using a modified wire bonder called a lead bonder. Bonding is accomplished without wire and with a special tool, material handling systems and software. The software controls and manipulates the leads through a unique set of machine motions that separate the lead from its carrier, move it to the bond location and ultrasonically weld it to the die.

The bonding tool plays a crucial role in the success of each of these processes. This paper describes the processes and provides design guidelines for choosing the correct tool.

Wire Bondable CSP Bonding Tools

CSPs require second bond locations very close to the die edge. This proximity presents special tooling and bonding challenges. Figure 2 illustrates the special capillary requirements for wire bondable CSPs. The height of the bottle

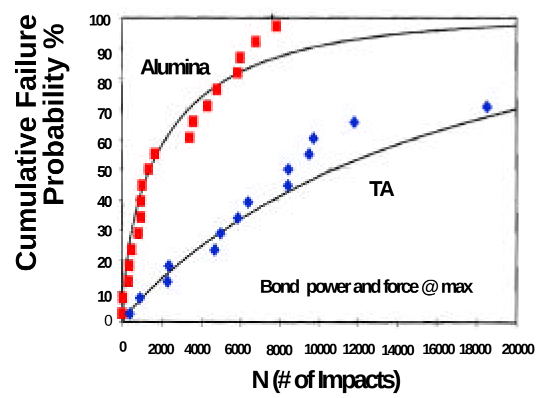
Figure 2. CSP Capillary Requirements



neck region must be greater than normal, because the capillary cannot contact the die edge during the looping motions or bonding. As a result of the additional height and constraints on internal geometry, the bottle neck section is longer and thinner. This results in some regions of the capillary having wall thicknesses of less than 25 µm, challenging the strength of conventional high purity alumina. New higher-strength materials, such as zirconia toughened alumina (TA), have higher strength and greater fracture resistance, resulting in significantly longer life. Figure 3 shows the results of an accelerated fracture test on capillaries of the same design but made of different materials. Using a K&S 1488 wire bonder, set at maximum force and ultrasonic bond energy, capillaries were allowed to impact a hard surface until they fractured. Twenty capillaries of each material were tested. For the standard alumina material, 100% of the sample failed in less than 9,000 impacts. For the toughened alumina, 70% of the sample failed in 19,000 impacts. This demonstrates the improved strength and fracture resistance of the new material. In addition, the new material has a significantly finer grain size, allowing the production of tools with smaller features and better surface finish. All Micro-Swiss fine pitch and CSP capillaries are now manufactured from the new material.

Capillary design has a significant impact on the success of a wire bondable CSP process. The specification of a capillary with feature dimensions appropriate for a robust fine pitch wire bonding process has been well documented [2,3]. Models are available that enable the packaging engineer to choose optimal capillary dimensions based on the package constraints. The models demonstrate that for fine pitch bonding, the capillary tip diameter is controlled by the bond pad pitch of the die. The bond pad size is used, in conjunction with required knowledge of the wire bonder's placement accuracy and ball size variation, to calculate the chamfer diameter required to produce a high shear strength ball bond. The capillary face angle is the feature that produces a high strength second bond. Second bond strength is sensitive to boundary conditions (temperature, material, plating, etc) and normally

Figure 3 Fracture Toughness of Zirconia Toughened Alumina vs Conventional Alumina



the face angle requires optimization through use of designed experiments (DOEs).

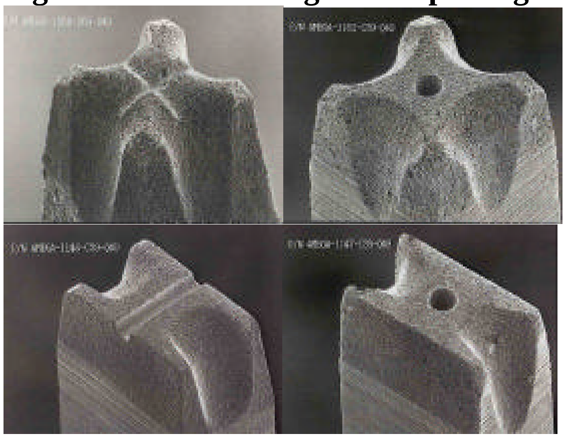
Low temperature (125-150^{0}C) bonding required by flex or laminate packages presents additional challenges. High frequency adaptive ultrasonic systems provide improved bond quality and are a requirement at these low bonding temperatures. Plasma cleaning of the substrates prior to bonding, and DOEs for process optimization, have been shown to be mandatory [4].

Lead Bonding:

As stated previously, lead bonding of µBGA packages requires enhanced machine motion controls that provide higher precision lead placement accuracy and improved Z axis positioning. Additionally, the shape and size of the tool funnel plays a significant role in controlling the lead position during the machine motions. This integrated combination (optimized tool and machine) enables the process to achieve the bond placement accuracy and Z axis trajectory control that is required to produce reliable bonds with smooth, low stress lead shapes.

The shape of the lead profile has a significant effect on the reliability of the package through thermal cycling. Smoothly dressed lead shapes are able to accommodate the stresses generated by thermal expansion and cycling without exerting excessive forces on the bonds; tight loop shapes transmit the forces and exert stresses on the bonds resulting in failures. Tool design for μBGA bonding has a significant effect on the shape and therefore the reliability of the bonds.

Figure 4 Lead Bonding Tool Tip Designs



Lead bonding tool designs can be grouped into two package related configurations. Figure 4 shows the two major design types. The square designed tips (upper) are designed for packages that have leads in two axes. Leads on each of the four device edges are grasped and manipulated by side walls on the appropriate edge of the tool. Unidirectional tip shapes (lower) are designed for packages that have leads in only one axis. Tool side walls are only required on two sides of the tool in this configuration. The optimum configuration should be based on application specific testing.

Lead Bonding Tool Features:

Ultrasonic Response: The design of the tool-shank and tip must be such that the tip of the tool is at an antinode and therefore resonates at maximum amplitude when the system vibrates at ultrasonic frequency. It is important to correctly set up tool length and clamping location for optimum machine output and repeatable bonding behavior.

Materials: For Au plated Cu leads the most common choice is Titanium Carbide (TiC) based material. For bare Cu leads, contamination builds up rapidly, making Tungsten Carbide (WC) a better choice. Coated tools are normally produced on WC base material.

Tool Tip Coatings for Longer Life The lifespan of WC CSP tools is largely determined by build- up of lead material (Au, Cu) on the tool face (surface properties) and not by wear mechanisms (bulk properties). Studies were conducted to determine coating materials that reduce buildup and thereby increase lifespan. A unique high voltage Titanium Nitride (TiN) sputtering method was developed. The advantages of this process are:

- TiN coating increases the surface hardness 30% (from 1,760 to 2,420 Vickers) and both reduces the Au/Cu built-up rate and improves wear resistance.
- Tool life-span is increased significantly (more than 50%).
- Sub-micron amorphous coating thickness can be well controlled so that it is within the tip dimension tolerance (thickness tolerance of +/- 0.05 μm).

Foot Geometry: Conventional grooved designs represent the majority of the tools being used, however, the dimple tool (a flat foot with a small dimple in the center) is showing excellent potential.

A recent study compared four different WC μBGA tool tip designs in terms of the overall bonding performance. The study used 40 lead, 16 MB flash memory devices with 50 μm wide by 18 μm thick gold plated Cu leads. Figure 4 shows the four tool tip designs.

The results of the study were:

Unidirectional Tip Shape (Lower): Both feature designs, the dimple (right) and the cross groove (left), have demonstrated similar performance, however, the dimple design provides lower lead deformation, with equivalent strength and consistency (C_{pk}).

Square Tip Shape (Upper):

The dimple feature was found preferable, showing both:

- Higher pull strength and higher consistency (C_{PK}).
- Lower wire deformation.

Back Funnel: This feature provides the lead capturing capability that is required for the manipulation of the lead. Its design is determined by the width and thickness of the lead in the region that will be within the tool during manipulation by the bonder. During the manipulation motions the lead must slide longitudinally within the funnel. Since the lead width normally tapers, the funnel width specification should be approximately 15 μm wider than the initial, widest region it is to grasp. This enables the taper to slide easily through the funnel as it is shaped by the bonder motion..

Back Radius: the BR should be as large as the geometrical constraints allow because the heel of the lead bond is the location with the highest stress concentration, and the tool BR, together with the lead shaping capabilities of the bonder, serve to reduce those stresses.

Effective Foot Length: This is a combination of the foot and the BR. The choice is a trade-off between large bonding area, large BR and avoiding passivation damage, cracking of the glass passivation layer surrounding the bond pad metallization window.

Summary & Conclusions :

CSPs are expected to compete directly with flip chips as solutions for the high frequency, high I/O packaging. Technology development will depend on the establishment of competitive manufacturing and materials infrastructures. The availability, ease of use and proven reliability of wire bonding equipment and tools, as well as the infrastructure of trained personnel, further advances the potential for growth. Additional enhancements to further decrease packaging cost are still required, however, before CSPs can compete successfully with other types of advanced packages.

References:

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