Morphology of Ball Bonds at <50µm Pitch

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Abstract

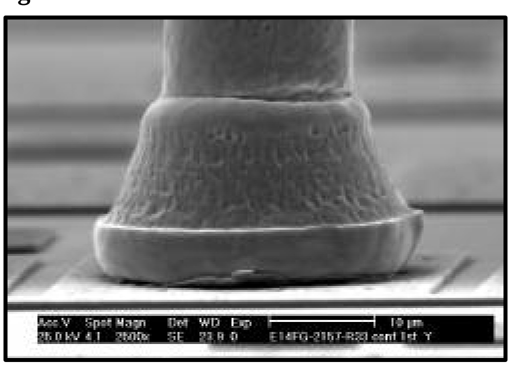
Ball bond morphology has changed significantly, driven by the continuing trend toward finer pitch and denser packaging. Previously, the ball bond was large, often 75-90µm in diameter with wire diameter at 25-30µm (aspect ratio 3). Current leading-edge 40µm pitch packages have a ball diameter of 31µm, with a wire diameter of 17µm (aspect ratio 1.8). The decrease in the aspect ratio of ball/wire has led to changes in the failure mode of high-quality ball bonds when they are destructively pull tested. Previously, a ball lift was an unacceptable failure mode, even if the pull strength was at an acceptable level. Now, fractures occur within the Al bond pad metallization at pull strength levels that correspond to the full tensile strength of Al. Under these circumstances, high strength lifts should be an acceptable (even desirable) failure mode. Acceptance criteria need to be modified to reflect this condition.

Key words: Interconnection, wire bonding, intermetallic reliability

Introduction

Ultra-fine pitch bonding, with pad pitch below 50µm and using wire diameters of <25µm, is now entering large volume manufacturing. New, Contained Inner Chamfer capillaries (CIC) are being employed to optimize this bonding process. Figure 1 shows a photo of a ball bond produced with a CIC capillary. In this design, the internal chamfer angle is steeper than a conventional bond, with the ball almost totally contained within the chamfer. This configuration enables production of smaller diameter bonds than those typically produced with a conventional capillary design - without sacrificing any strength. When compared with standard capillary designs, CIC capillaries enable the use of a larger diameter wire for the same ball diameter. With current processes for < 50µm pitch requiring the use of <25µm wire diameter, this capability is becoming a requirement. Larger diameter wire is stronger, stiffer and easier to use within a high-yield manufacturing environment.

Figure 1 Contained Ball Bond



In the past, wire bonding processes were characterized with a cross sectional area of the intermetallic weld that was several times larger than that of the wire. Figure 2 shows an example of this condition in a standard pitch ball. In this bond, the cross sectional area of the weld interface is 10 times larger than the wire. The weakest segment of wire is the Heat Affected Zone (HAZ): the recrystallized section above the ball that is affected by the heat of the spark that melts the wire and forms the ball. In addition, the strength of the intermetallic alloy is higher than that of either the wire or the aluminum bond pad. Under these conditions, the expected failure mode during a destructive wire bond pull test is a fracture within the HAZ. It is the weakest link. For standard pitch ball bonds, bond lifts, whether occurring during the pull test, shear test, during bonding or after reliability testing, are an unacceptable failure mode. It is required that the intermetallic be stronger than the HAZ.

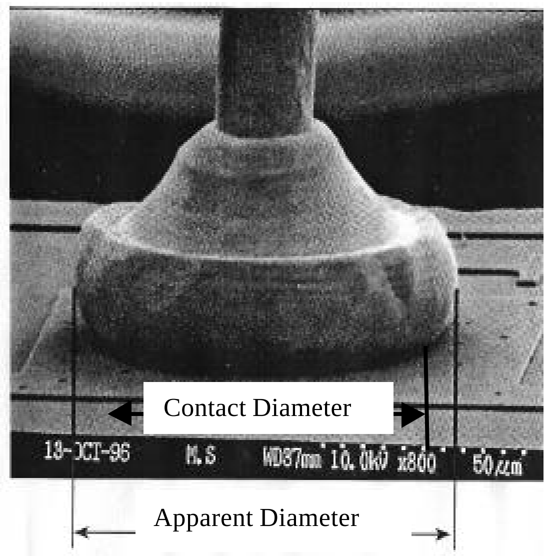


Figure 2. Definitions

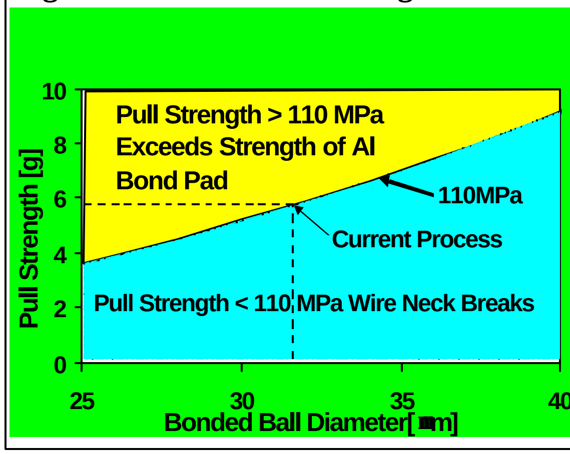
Definitions

Figure 2 is a photo of a standard ball bond with both the Apparent Bond Diameter and Contact Diameter defined. Bond diameter is usually measured as part of a production/quality control test. Typically, diameter is measured using an optical microscope positioned above the ball. Since the ball surface is not cylindrical, the outside diameter is not a vertical surface, but a squashed sphere with an edge radius. Using a tilt position to view the ball from the side, a SEM analysis easily reveals the ball curvature. However, a SEM analysis is too slow to conduct when considering the large number of samples required. An optical measurement, even with its limitations, is adequate. But it is important to realize that contact diameter is significantly smaller - approximately 90% that of the optically measured diameter.

Critical Pull Strength

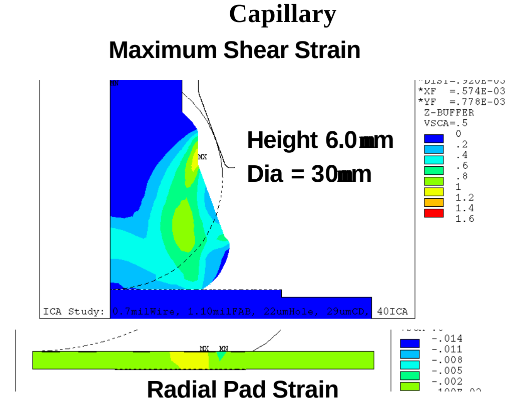
In addition to curvature reducing the contact diameter of the ball, not all of the interface is initially bonded. Dittmer[1], et.al, demonstrated that initially, high strength bonds, with good high temperature storage behavior, have an approximately 77-85% Intermetallic coverage (IMC). Taking both the radius

Figure 3. Critical Pull Strength



of curvature (90%) and IMC (77%) into consideration, a good estimate of intermetallic coverage area is approximately 65% of the ball bond, as measured optically. Figure 3 shows a graph of the critical pull strength value. Critical pull strength is the value where the strength of the weld exceeds the tensile strength of the Al bond pad metallization (110MPa). Ultra-fine pitch ball bonds with a wire diameter of <25µm and using CIC capillaries, meet these conditions. Fracture of the Al bond pad during initial pull testing is a common failure mode. Old guidelines for acceptable quality must change to accommodate this new reality. High strength pull test results, with bond lift as a failure mode, should be accepted at pitch below 50µm.

Figure 4 Ball and Bond Pad Strain for CIC Capillary

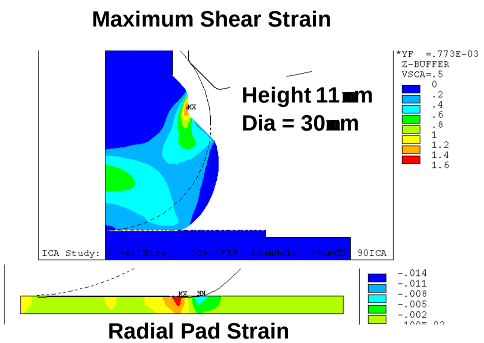


Modeling

Finite element modeling helps explain the mechanics of deformation using the new CIC capillary. Balls were first deformed to the desired target diameter, then strains within the ball and the Al bond pad were plotted. Figures 4 and 5 compare these strains for both the CIC and standard capillaries. Important conclusions reached during this analysis were that peak stresses within balls deformed by the CIC capillary were significantly lower, even when a higher force was used to generate the deformation. This has a significant effect on process capability. Ultra-fine pitch bonding requires the application and control of a very low bonding force (approximately 10 grams). The capability to bond at slightly higher force, with equivalent deformation, improves process capability and productivity because machine velocity can be increased without over deforming bonds.

The CIC capillary also reduces radial bond pad strain. This further improves process capability because thin bond pads associated with ultra-fine pitch devices are less likely to fracture during bonding if they are strained less.

Figure 5 Ball and Bond Pad Strain for Standard Capillary

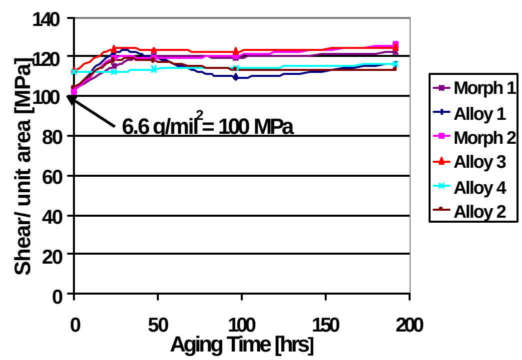


Intermetallic Reliability

The long-term reliability of high quality wire bonds is determined by the growth of the intermetallic weld between the ball bond and the Al bond pad. During initial bond formation, a very thin layer of Au-Al intermetallic is formed. This intermetallic is analogous to the weld nugget formed by other welding processes. As with other welds, the intermetallic alloy is generally stronger and more brittle than either the Au or Al of which it is composed. Also similar to other welds, it is often the boundary interfaces separating intermetallic and base metal phases, which are the focus of reliability studies, as failures, most often occur at these interfaces.

After initial bonding is complete, growth of the 5 possible Au-Al intermetallic phases occurs through diffusion. The most important process variables that control diffusion reactions are time, temperature, and the concentrations of the reacting materials. Some secondary effects that may effect diffusion are dopant levels in the wire and bond pad, atmosphere, ionic concentrations and fire retardants in the molding compound. Typically, diffusion will consume the entire volume of Al bond pad under the ball within 24 hours at temperatures higher than 150^0C. Figure 6 shows the effect of aging ball bonds at 175^0C for up to 200hr. The strength of the ball bond interface, in shear/area (MPa) is not significantly affected by HTS. Figure 7 graphs pull strength for up to 1000 hr storage at 175^0C. Note that pull strength degrades significantly under these conditions.

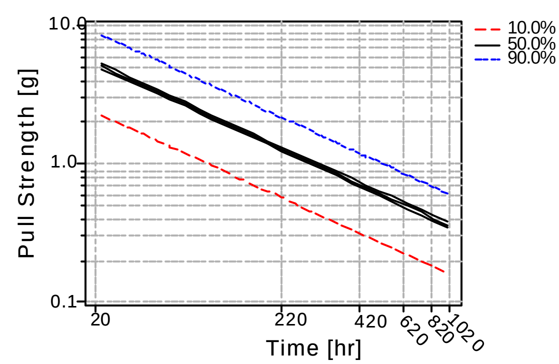
Figure 6 Effect of High Temperature Storage (175^0C) on Ball Bond Shear Strength



Temperature and reactant availability determine the distribution of the 5 possible Au-Al phases that can form. The region directly under the Au ball is rich in Au, promoting the formation of the Au rich phases (Au_5Al_2 and Au_4Al). Around the ball perimeter, where there is more Al available from the bond pad, the Al rich phases are more likely to form ($AuAl_2$). The Au_5Al_2 phase has the fastest growth and is the predominant observed phase.

Figure 7 Degradation of Pull Strength with HTS (175^0C) Aging

Fitted Arrhenius for Pull Strength

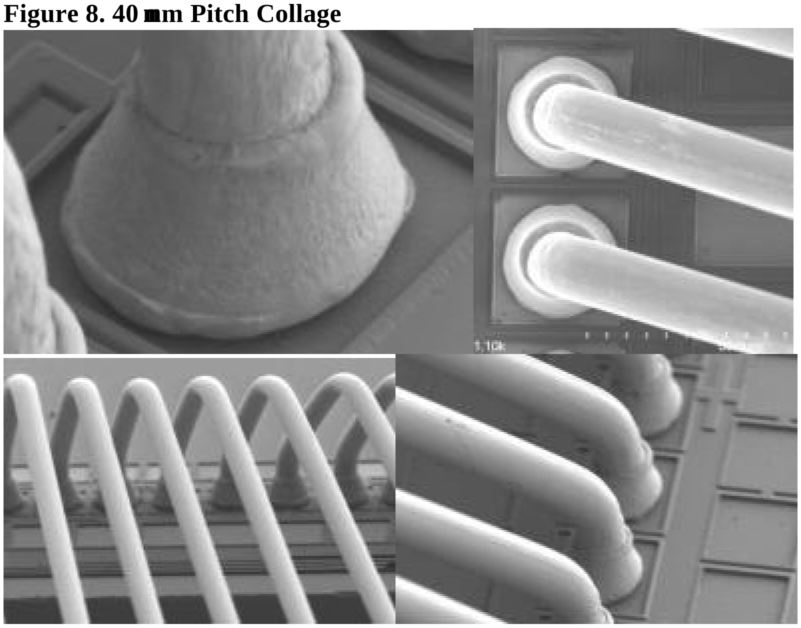


The use of thin bond pads, with buried Ti barrier layers to limit intermetallic growth, has been shown to provide high reliability structures that withstand high temperature storage testing at 200^0C for 1000hr[3].

Looping

Loop shape, height, straightness and trajectories all play an important role in the ultra-fine pitch process development. The development of machine trajectories capable of meeting these requirements at the high speeds and at accelerations necessary for high volume production is critical. Figure 8 is a collage of photos from a 40µm pitch bonding process. The capillary used was a CIC4, from Kulicke & Soffa Bonding Tools. The bonding wire was a 18µm diameter AW-99 alloy, also from K&S Bonding Wires. Stronger, stiffer (higher Young's Modulus) wires have been developed for ultra-fine pitch bonding. They enable the precise bends and repeatability of loop shape by controlling the length of the HAZ. Figure 8 shows the precise, repeatable looping required for ultra-fine pitch bonding.

Figure 8. 40 µm Pitch Collage



Conclusions

As the industry progresses along a path described by Moore's law and mapped by the ITRS Roadmap for Semiconductors, wire bonding continues to keep pace with industry requirements. Process control depends upon determining and measuring critical parameters. Each time we move to a new node, or begin work on a new, finer pitch process, we must first identify the challenges, then work to describe and quantify them. Once this is accomplished, we can begin to find solutions and metrics for the technical challenges required to control them. The challenges associated with production of 40µm pitch wire bond assembly have been formidable, but they will soon be overcome and manufacturing will begin. New, finer pitch requirements will bring more future challenges.

Bibliography

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