Very Fine Pitch Wire Bonding: Re-Examining Wire, Bonding Tool, and Wire Bonder Interrelationships for Optimum Process Capability

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Biography

Lee Levine received the BS degree in Metallurgy and Materials Science Engineering from Lehigh University, Bethlehem, Pennsylvania, in 1972. He is currently Principal Metallurgical Engineer for Kulicke and Soffa's 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 and Soffa, Mr Levine was Senior Development Engineer at AMP, Inc. and Chief Metallurgist at Hydrostatics, Inc.

Abstract:

Through continuous improvements, wire bonding remains the dominant interconnection method. The demand to reduce die size and increase functionality, conserving valuable silicon real estate and increasing the number of interconnects, continues. This has accelerated a decrease in the pitch and size of interconnects. Today's leading edge production devices are gold ball bonded with 60 μm (bond pad) pitch and wedge bonded with 50 μm pitch. In the near future gold ball bonding will approach 40 μm pitch and wedge bonding will approach 30 μm .

As the pitch and size of the interconnections (bond pads) has decreased, the interrelationship of the various process inputs on each other has increased. To provide the longer wire spans and lower loops, many fine pitch devices now require both new, higher performance 99.99% gold wire alloys and capillaries with tighter tolerances. The new wire alloys provide increased strength and stiffness for achieving strong straight loops with below 25 μm diameter wire. Capillaries with tighter tolerance control and improved ceramic materials are necessary because the capillary tip diameter is extremely small for very fine pitch bonding. Small tips are more fragile and require tighter tolerances to achieve a robust bonding process, because the variation in the diameter of small ball bonds is more critical. Wire bonders must provide better bond placement accuracy and more repeatable ball formation because of the smaller bond pad opening sizes resulting from finer bond pad pitch.

New manufacturing techniques and advanced inspection methods also are required for achieving robust very fine pitch processes. Normal process variation resulting from standard materials specification tolerances is no longer acceptable; tightened tolerance specifications are required. To meet this requirement, bundled solutions, with wire, capillary and wire bonders developed and tested together, can be tuned to synergistically provide a more

robust process than would otherwise be achievable.

This paper will focus on the interdependence between wire, capillaries and the wire bonder. Understanding these interrelationships can help the assembly engineer increase process capability and improve manufacturing robustness in very fine pitch applications.

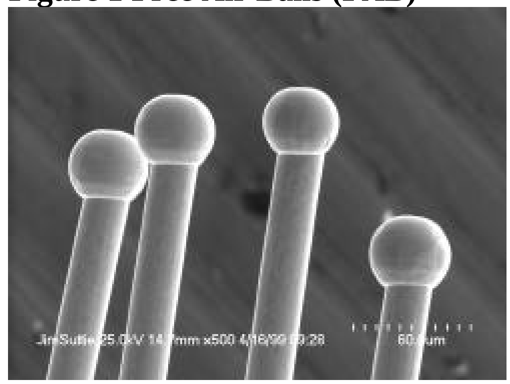
Data:

Tolerances on the critical dimensions of capillaries and wire play a crucial role in achieving a stable robust process. Table 1 shows these tolerances. In order to improve our understanding of the role that materials tolerances play on wire bond process capability, a series of Designed Experiments (DOEs) was conducted. Wire and capillaries were chosen within the limits of the tolerances, to determine whether the tolerances would provide robust process capability. The DOEs studied two wire alloys, 5 wire diameters, and 4 combinations of capillary chamfer and hole diameter (within the tightened capillary tolerance specified for capillaries bonding <70 μm pitch devices). For each material treatment combination, a DOE was run using the two wire bonder programmable parameters having the most significant effect on ball size and shear strength: ultrasonic power and ball size (the programmed size of the undeformed ball).

Table 1 Materials tolerances for Fine Pitch Bonding (60-70 μm)

	Feature	Tolerance
Wire	**Diameter**	**3%**
Capillary [mils]	**Tip Diameter**	**+/- 0.1 mil**
	Chamfer Diameter	**+0.1 / 0 mil**
	Hole Diameter	**+0.1 / 0 mil**
	Outer Radius	**+/- 0.1 mil**

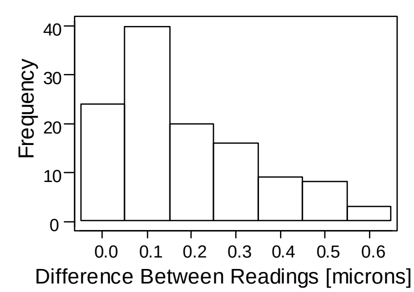
Figure 1 Free Air Balls (FAB)



Gage Capability:

As we move towards finer pitch processes the dimensions that we measure and control are also becoming smaller. The SIA Roadmap defines Metrology as a key element in the technology path. The development of measurement tools and methods must come first in the evolution of a process[1]. In these experiments the resolution of dimensional differences as small as 0.5 μm are important. Since the wavelength of visible light ranges from 0.4-0.7 μm the ability to resolve 0.5 μm with light microscopy is an issue. Older technical literature, before the advent of ccd cameras and electronic imaging

Figure 2 Differences between repeated measurements of the same ball [absolute values].



tools, sets the resolution limits for light microscopy at approximately 1 µm[2]. Therefore, gage capability is a critical requirement, because without good gage capability incorrect conclusions could occur.

A Nikon QC4000 system with 500X magnification was used in these experiments. The QC 4000 system augments the light microscopy with software enhancement of the ccd image. Tools for measuring circles or other features use multi-point data fitting techniques and pixel analysis to determine edges of a feature, and find the best fit. The software enhancement provides significantly better resolution than light microscopy by itself.

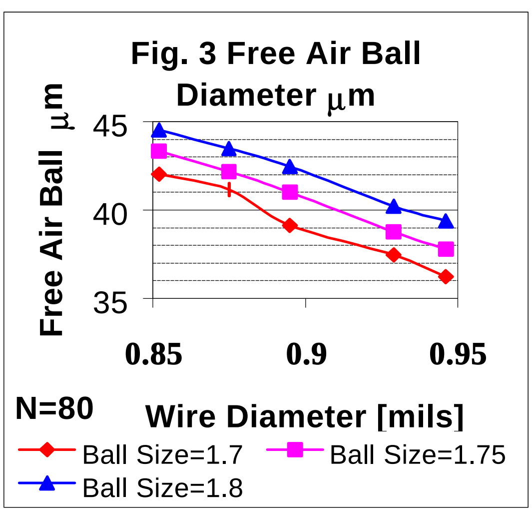
To test whether this system would provide acceptable measurement discrimination and confidence, a gage capability study (GR&R) was conducted. The study measured the diameter of 40 unbonded balls (free air balls) from 4 parameter setting groups (10 each) in series. Figure 1 shows the FABs on the test device. Each series of balls was measured 3 times. Differences between the repeated were analyzed to determine systemic error. Figure 2 is a histogram of the absolute value of the differences. Our conclusions were as follows:

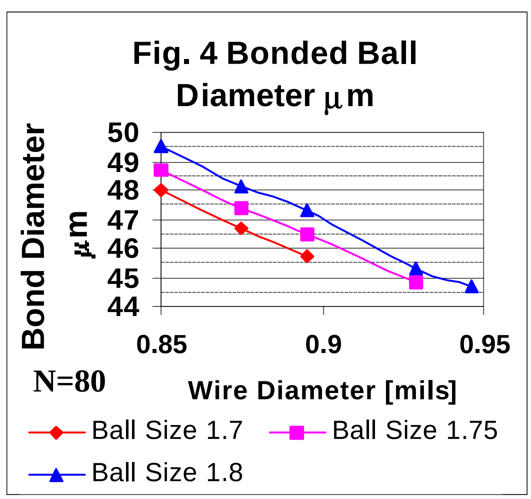
1) For averages of 10 or more samples we could discriminate differences of 0.5 µm confidently.
2) Differences of 0.3 µm or less are within the systemic noise and were considered insignificant.

Wire:

The diameter tolerance for bonding wire is defined by ASTM F-72 as +/-3% of the nominal diameter[3]. For 25 µm wire this represents a tolerance range of 1.5 µm. Earlier studies have shown that differences between spools of the same nominal wire diameter can produce significantly different FAB diameters[4]. A DOE was run to determine the effect of wire diameter tolerance. Figure 3 shows the effect of variation in wire diameter on the FAB diameter. For wire spanning the entire range of ASTM F72-95, we would expect the variation in wire diameter to contribute 3-4 µm variation to the FAB diameter. For wire held within a more reasonable range of 3%, the expected variation in FAB diameter would be approximately 1.5-2 µm.

DOEs to determine the effect of wire diameter variation on the size of the bonded ball were also conducted. Figure 4 shows the results of these DOEs. The effect of variation in wire diameter on





FABs manifests itself in variation in the diameter of bonded balls. Because bonded balls can also vary in height, the variation is slightly less for bonded balls than for FABs. Wire diameters spanning the entire +/-3% of the ASTM specified range would contribute approximately 3 µm variation to the bonded ball diameter. Wire diameter kept within a more conservative 3% range would contribute less than 1.5 µm variation to the bonded ball diameter. Even this lesser variation represents approximately 40% of the error budget allowable for very fine pitch bonding and may require reduction at pitch below 50 µm.

In this experiment we also tested two different 99.99% wire alloys. The results were that the effect of wire alloy was insignificant. Differences in behavior and in trends were the same for both alloys.

Capillaries:

Capillaries for 70 µm or lower pitch have a tightened tolerance of +0.1/-0 mils on both the hole and the chamfer diameter. By holding the tolerance to the upper side of nominal for both dimensions it is possible to avoid the combination of a large hole and a small chamfer diameter producing a capillary with too small an inner chamfer. Capillaries with too small of an inner chamfer produce short tail defects resulting in unnecessary machine stoppages. In this experiment we tested all four of the combinations of hole and chamfer diameter to determine whether they would have a significant effect on final squashed ball diameter or shear strength. The conclusion was that within this tightened tolerance range they did not have a significant effect.

Machine:

Machine requirements for very fine pitch bonding are being addressed by new machine generations and by upgraded systems. Very fine pitch bonding requires improved bond placement accuracy. This entails better placement resolution, better pattern recognition and imaging resolution, and more repeatable ball size control. Dual magnification optics, with higher magnification for finer pitches, also increases accuracy. New higher precision Electronic Flame Off (EFO) units with improved mechanical electrode designs enable more precise spark control and reduce variation of the ball diameter.

In our experiments we targeted a 45 µm ball with 5.5 g/mil^2 shear strength. Long-term aging tests of the gold/aluminum intermetallic demonstrate that in small diameter ball bonds a threshold strength level of 5.5 g/mil^2 provides excellent long-term reliability[5,6]. The most significant process variables affecting bonded ball diameter in this study were programmable ball size and ultrasonic power. Figures 5 and 6 show the effect of these parameters on both bonded ball diameter and on shear strength/area (g/mil^2).

Figure 5 Bonded Ball Diameter

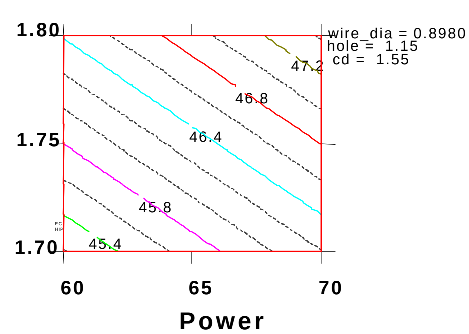
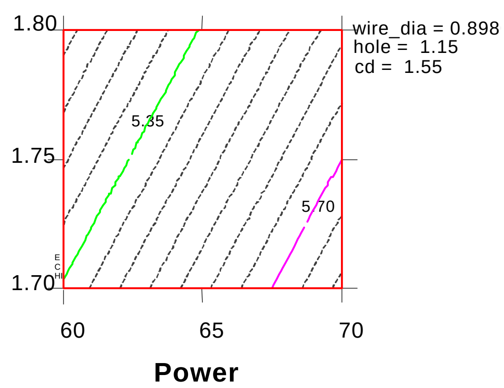


Figure 6. Shear Strength [g/mil^2]



Conclusion:

As pitch becomes finer the tolerances required for all of the wire bond process components become tighter. This requires continuous reevaluation of process and materials specifications in order to assure robust processes

For devices of 60-70 µm the current tolerances for capillaries provide acceptable process capability. Although wire tolerances as specified by ASTM F-72-95 are inadequate, a tighter tolerance range of 3%, provides acceptable process capability.

As pitch reduces to 50 µm and below new, tighter tolerances for wire and capillaries, along with continuous wire bonder improvements, will be required.

References:

[1] Semiconductor Industry Association Roadmap, v14 *Metrology*, pg 179

[2] Kehl, G.L., *The Principles of Metallographic Laboratory Practice*, McGraw-Hill, New York, 1949, pg 90-95

3] ASTM F-72-95, *Standard Specification for Gold Wire for Semiconductor Lead Bonding*, American Society for Testing and Materials, Philadelphia, Pa

[4] W. Qin, J. Brunner, and M. Eshelman, "Factors in Free Air Ball Formation for Fine Pitch Applications," Proceedings HDP/MCM Denver, April 6-9, 1999, pg 254-259

[5] K. Dittmer, S. Kumar, and F. Wulff, "Intermetallic Growth in Small Ball Bonds," Proc. SEMICON Singapore, Test, Assembly & Packaging, May 5, 1998, pg 267-272

[6] K. Dittmer, S. Kumar, and F. Wulff, "Influence of Bonding Conditions on Degradation of Small Ball Bonds due to Intermetallic Phase (IP) Growth," Proceedings HDP/MCM Denver, April 6-9, 1999, pg 403-408

Acknowledgments:

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