Advanced Ultra-Low-Loop Wire Bonds

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Abstract

Stacked die, die-to-die, and multi-tiered package demand has driven the development of over 20 premium-process wire bond loop shapes. A high-productivity, ultra-low loop, with <70µm loop height, is one example. The array of loop shape solutions from which a packaging engineer can choose has grown substantially, with new shapes being developed as new demands are identified. Continuous wire bonding developments increase the process productivity, flexibility and versatility.

Introduction

The market for advanced, stacked die packages continues to grow. In 2005, over 750 million cell phones were produced, with 2006's forecast estimated at over 850 million [1]. Each will incorporate at least one stacked die package (there were 996 million stacked die packages in 2005) [2]. With the drive for even more advanced features, including the Internet, e-mail, music and television incorporated within the "cellular" system, today's stacked die packages are in production with as many as eight dice [3]. Packages with as many as 12 levels are in development stages.

Figure 1. Stacked Die Configurations

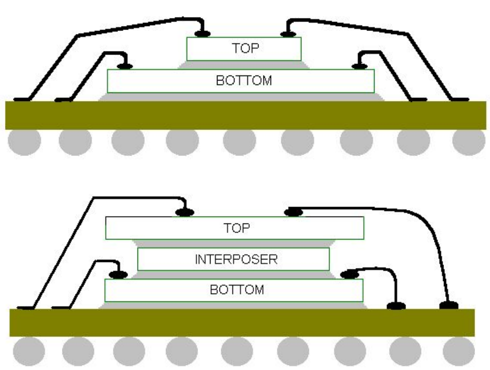


Figure 1 shows examples of the two basic stacked die package configurations: pyramid and cantilevered. Both configurations facilitate die mixing and matching for System-in-Package (SIP) capability. Increasing the cantilever length increases manufacturing flexibility. However, thin, cantilevered die makes manufacturing more difficult. During wire bonding, the cantilever dice deflect and spring back, making bonding difficult to setup and control. Thinned die must be carefully polished to eliminate grinding cracks that can propagate, resulting in fracture.

Figure 2. Advanced Stacked Die Package with Die-to-Die Bonding

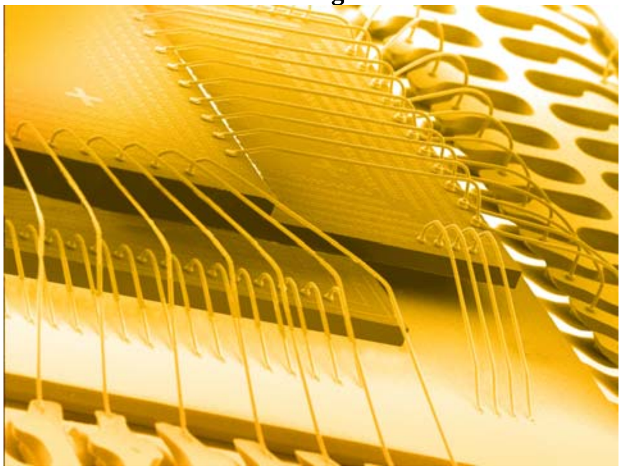


Figure 2 shows an advanced, stacked die package with four die levels and three wire loop shapes, including die-to-die bonding. Die–to-die bonding saves substrate space and costs while decreasing interconnect length. While these package types are currently challenging wire bond capabilities, new advances are providing the necessary process improvements.

Interconnection between these levels is predominantly performed by wire bonding. Only wire bonding offers the manufacturing flexibility and low costs capable of filling this role. The advanced looping controls provided by today's automatic wire bonders allow for flexibility and adaptability that other technological processes cannot provide. The ability to shape a wire bond loop, with well-controlled bends and kinks, has been in continuous development for over 12 years [4], [5]. The first worked loop shape patents were granted in 1993 [6]. These shapes led the way to the development of CSP shapes. With the addition of bends in the wire near the second bond, designed to provide buss bar clearance, BGA looping was developed. Now, with the advent of multiple level stacked die packages with thin profiles, the industry is driving to new, even lower loop height levels. Today's state-of-the-art wire bonders may offer the capabilities to support as many as 20 Premium Process Loop Shapes. Additional new loop shapes are continually being developed to accommodate packaging design requirements.

Recently, new forward loop shapes have been introduced that can produce heights of <75µm without sacrificing throughput. Achieving these ultra low loop shapes is very important for the lowest die of a stacked die, especially when the wires are underneath an overhanging cantilever. More die layers need to be integrated into thinner and thinner packages. Production die, commonly thinned to 100µm thickness, are now down to 75µm. Even 50µm die are being introduced into mass production. Thin cantilever die deflect during bonding, resulting in additional process control challenges because simultaneously loop shapes must be made lower while the variation in loop height must be reduced.

Equipment

Wire bonders move in smooth, continuous, coordinated motions, with all three axes (X, Y and Z) moving simultaneously. Wire is fed through the capillary and bent by the machine motion to provide the required shape. Motions are calculated on the fly and adjusted so that each machine axis travels along a precisely calculated trajectory. Motion trajectories must be controlled and coordinated to within only a few microns of tracking error. A few microns variation can significantly affect loop shape and repeatability. Wire payouts and bends need to be adjusted on the fly to account for changing wire lengths caused by die placement variation. All this needs to be accomplished while bonding up to 16 wires/second at acceleration rates exceeding 12Gs in XY and 150Gs in Z. The latest wire bonding equipment employs new, faster, and more accurate servo controls, which enable more repeatable looping and more complex shapes.

The simplest, standard wire bond loop employs four separate motions from the ball bond to second bond. The formation of more complex loop shapes may employ more than 12 motions. Kinks, bends, flat segments and smooth curved portions are all formed by programmable loop parameters within the software. Wire lengths are controlled and adjusted based on both the modeled loop shape and actual calculated distances between the ball and second bond. As each die is indexed to the bond site, the machine vision system uses pattern recognition to locate the die and leads. Machine intelligence, then, corrects the location of each bond and adjusts the metered wire length for repeatable loop shape and height.

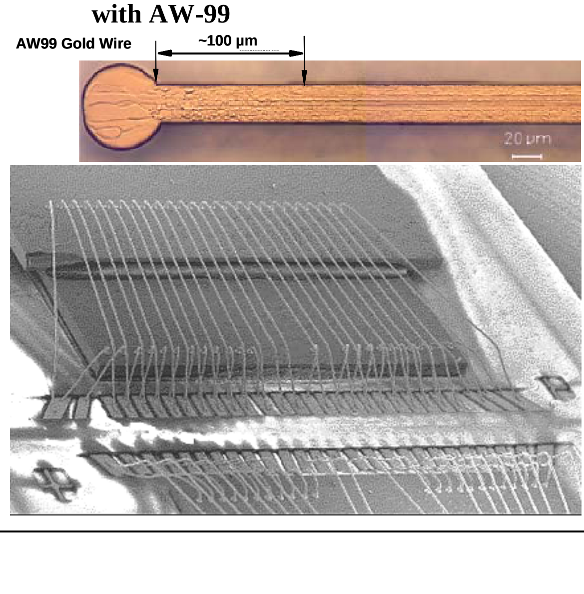
Wire and Wire Properties

Wire and its' properties play a significant role in a wire bonder's ability to produce accurate, repeatable loops. Wire properties have undergone continuous improvements, over the years, to enable the production of longer, lower, straighter loops required by today's packages. Gold bonding wire is normally specified as 99.99% (4-9's) purity, while chemistry within the residual 100ppm impurities is carefully controlled to provide the required mechanical and electrical properties. New alloys, such as K&S's new Radix wire, that have recently been introduced to the market, are in the high 3-9's range to provide improved long-term reliability in very fine pitch (<50µm ball diameter) applications without significantly sacrificing electrical properties.

Ball formation is accomplished by the firing of a spark that melts the wire tip. Wire adjacent to the molten ball, the Heat Affected Zone (HAZ), undergoes rapid heating and cooling as the heat from the melting process is transferred from the ball up the wire. Wire within the HAZ recrystallizes, forming new grains with different mechanical properties than the rest of the wire. The mechanical properties of the HAZ will always be lower strength, stiffness and higher ductility. During the looping process, much of the bending will naturally occur within the HAZ. Wire chemistry can play an important role in providing a short HAZ, with high strength and ductility. A short HAZ will provide lower, more repeatable loops. Figure 3 shows a metallurgical cross-section through the ball for a newly introduced K&S wire entitled AW99. This is an example of a wire with higher strength and stiffness developed for advanced wire bonding.

Bonder motions within the HAZ can be used for cold working and bending functions. Standard wire bond loops use a reverse motion in the HAZ to bend the wire away from second bond initially, cold working the HAZ. When the looping trajectory bends the wire in the HAZ back into a vertical position, the cold worked HAZ will be stiffer and the wire loop will be more erect than it would have been without the cold work from the reverse motion. Other motions can be used to provide additional bends in the wire, providing useful shapes. These shapes can provide additional standoff near second bond, as required in BGA packages, with power and ground rings in the vicinity of second bond or provide flat (parallel to the die surface) portions of the loop with sharp bends descending to the second bond, as in the CSP or worked loop. Wire stiffness needs to be optimized so that these bends can be maintained uniformly. New wire types are being developed to provide both a high stiffness above the HAZ and a soft ball for improved bondability.

Figure 3. Metallographic cross-section showing Heat Affected Zone (HAZ) and Loop Example with AW-99



Capillaries

Capillaries transfer ultrasonic energy to the bond and control weld size and shape. Their internal and external shapes and dimensions provide the necessary features that form the bond. They also are a source of friction during wire feed. K&S has developed the ARCUS capillary [7] that specifically addresses the looping challenges associated with today's increasingly popular stacked-die applications. While conventional bonding tools contribute little to the looping process, the ARCUS is designed and manufactured as a more efficient tool that positively affects the looping response in challenging packages. When implemented in the wire bonding process, this unique bonding tool provides greater control in wire loop height and shape stability, significantly reducing looping failures typically found on wires formed with a conventional capillary. With ARCUS, there are higher assembly yields, less defects and more units-per-hour.

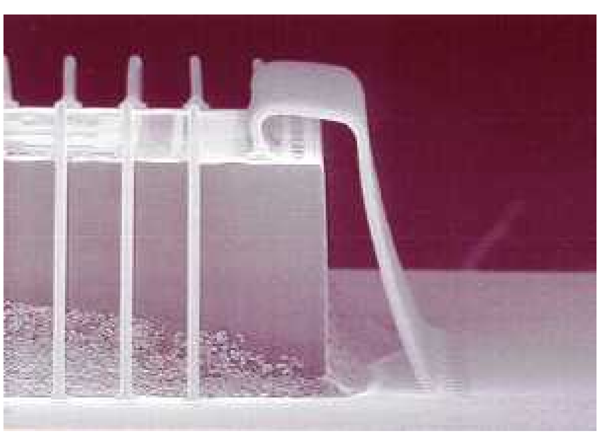
Loop Shaping

The main reasons for shaping a wire loop are to provide clearance and avoid interference (electrical short circuits) from adjacent wires as well as the die or substrate. In addition, bending cold works the wire, changing its mechanical properties. Specific bending motions, such as Reverse Motion bending (bending first away from and then toward second bond), are used to control final loop height and shape. Shaping can generally be divided into two categories based on the quantity and type required.

Worked Loop and Chip Scale Loops

Worked (WL) and Chip Scale (CSP) loops have a flat portion of the loop that is approximately parallel to the die surface. They have controlled loop height and can have a steep kink approach angle (>60^0). These loops are used for long inboard bonds (DDR 2 memory in FBGA packages) and for applications where they must span over lower wire layers in multi-tiered packages. The worked loop has been shown to have superior thermal cycling performance in hermetic applications where the outer kink can absorb the strain of thermal cycling better than the HAZ in a standard loop shape.

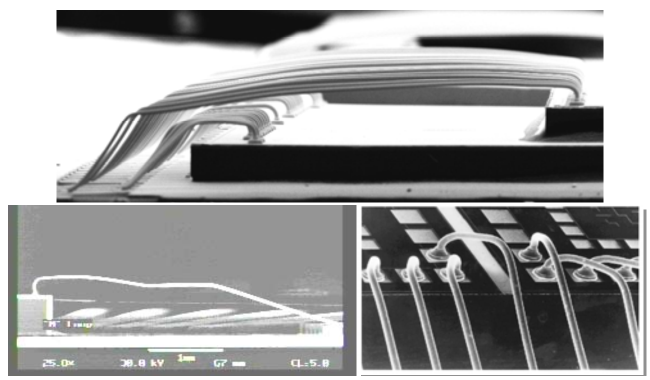
Figure 4. Worked Loop Family



BGA Looping (BGA, BGA 2, BGA3, BGA4, BGA5)

BGA looping is a high-productivity loop with a programmable kink near the second bond that provides standoff over ground or power rings in BGA packaging. It can be shaped laterally and vertically with variants such as the "J" loop, the "M" (Multi-Bend) loop, and "Spider" loop. When tailored with lateral curvature, it has been shown to reduce sweep due to mold flow by as much as 46% in long loop, difficult-to-mold applications. Employing a "tail" or "last-kink" shaping near second bond is typically used when a loop with a very high angle approach is required to avoid obstacles, such as wires from lower levels of a stacked die device. The loop versatility makes it an ideal solution for every layer of a stacked die application. Figure 5 shows a selection of BGA loops.

Figure 5. BGA Looping



Wire shaping has substantial influence on the productivity of the wire bonding process. In general, each bend adds 10%-20% to the overall wire bond cycle time of the device. Therefore, only the minimum amount of required shaping is recommended for an application. Additionally, excessive shaping can weaken the loop base or neck as well as increase the likelihood of uncontrolled kinking along the wire path.

Formation of Low Loops

The Loop height above the ball dictates the minimum loop height that is achievable. The manner which this is shaped is programmable and subject to trade offs. Figure 6 shows the major classifications for the loop formation and their characteristics. They are listed in order of final loop height (highest to lowest).

Loop Trajectory	location	Minimum Loop Height	Productivity	Overhang Capability	2nd Bond Approach Angle
Normal Loop	**edge**	>100 um	Fastest	Good	<45 degree
BGA5 or FFL	**long Inboard**	>100 um	Slower (10-15% slower than Normal Loop)	NA	<45 degree
ULL Loop (normal)	**edge**	< 80 um	Fastest	Good	<45 degree
ULL Loop (folded)	**edge**	< 70 um	Slower (10-15% slower than	Good	<45 degree
SSB2	**edge or Inboard**	< 50 um	Slower (25-30)% slower than Normal Loop)	not as good	>45 degree

Traditional Loop Base

Typically, traditional or normal loop profiles are used to form loops with desired heights of >100µm. Little or no Reverse Motion must be used to form low loops (< 100µm) using traditional looping trajectories. This will allow the wire loop to naturally bend (about the HAZ, depending on the application), forming a low-profile shape and minimizing, the amount of damage to the neck region. This technique is best applied to edge pads using the Standard Loop, but can be used for inboard pads as well, with the addition of shaping in the wire span.

Long in board loops

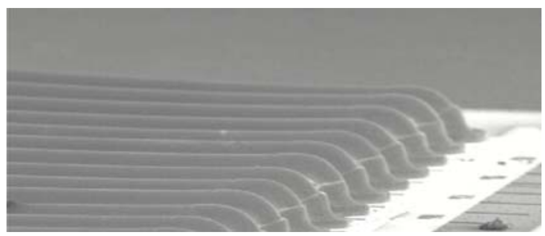
The formation of long inboard loops requires a looping profile that put multiple bends in the wire. The BGA5 trajectory or the BGA5 trajectory can put up to 4 bends into the wire. This stiffens the wire and allows for long inboard profiles that are needed for DRAM or top die applications where the kink is far from 1st bond. Typical loop heights can range from 80-100 µm using 25µm wire.

Figure 7. Long In board with BGA5

ULL – Ultra Low Loop

This technique produces a new, highly productive loop shapes for the lower levels of thin, stacked die packages. Using the Z-axis to form shapes that minimize loop heights. This achieves very low loops (<80µm), without damaging the neck (HAZ) region. The actual height depends on the application and materials. Figure 7 is an example of loops formed using this method.

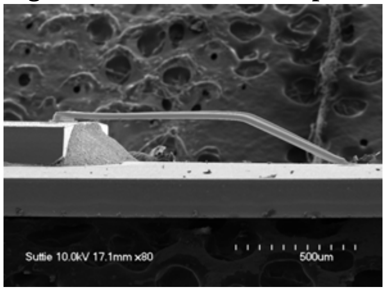
Figure 8. ULL (Normal)



ULL Folded

The last type of loop base provides the lowest forward bonded loop height. With this technique, the capillary face descends and folds a portion of the wire loop down near the ball surface providing the lowest height. However, the deformation is aggressive and can result in lower, more inconsistent pull test results (especially as the capillary tip becomes smaller). Typical loop heights achieved with this technique can be below 75 or even 70 um, using 1 mil wire.

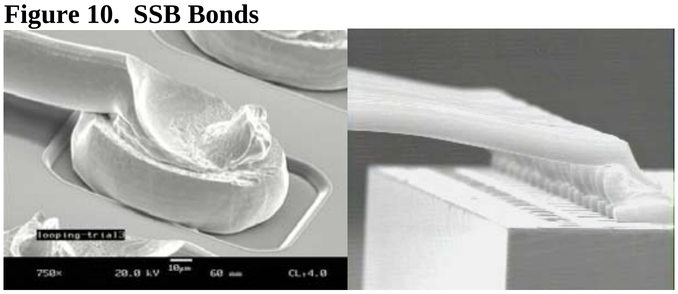
Figure 9. ULL Folded Loop



Stand-Off-Stitch Bond (SSB)

The reverse bonded SSB bond is composed of three bonds. First, a ball is welded to the die and the wire is terminated. The wire can either be terminated as a simple flat or inclined surface (Accu-Bump) or with the Flex-Bump that provides additional standoff (clearance), when needed. After the bump is terminated, a new ball is formed and bonded, with the second bond placed on top of the initial bump. Because they require three bonds, SSB loops are slower than most other bond shapes and impact productivity. Figure 10 shows an example of SSB bonds with Accu-Bump and. Flex-Bumps.

Figure 10. SSB Bonds



Conclusions

The demand for stacked die, die-to-die, and multi-tiered packages has produced a wide array of loop shapes from which the packaging engineer must choose. As packaging developments define new requirements, equipment makers, wire and capillary producers have worked together to provide advanced tools that meet packaging demands. As new packages are developed, the lessons learned in current developments will be applied to providing better, more productive solutions for leading-edge technology.

Bibliography

[1] Advanced Technology Research, October 2005

[2] Electronic Trend Publications, February 2005

[3] F. Carson, “3D Packaging Developments and Trends” *Advancing Microelectronics*, V33:1, Jan 2006, pg 14-18

[4] L.Levine, M. Sheaffer, “Wire Bonding Strategies to Meet Thin Packaging Requirements, Part I,” *Solid State Technology*, March 1993

[5] W.J Holdgrafer, M.J. Sheaffer, and L.R. Levine, “Method of Making Low Profile Fine Wire Interconnections,” U.S. Patent 5,111,989 (5/12/1992)

[6] W,J.Holdgrafer, L.R. Levine, and D.L. Gauntt,“Method of Making Constant Clearance Flat Link Fine Wire Interconnections,” U.S. Patent 5,205,463, (4/27/1993)

[7] Y. Alcobi, “Stacked Die & Multi-tier Applications” *Advanced Packaging*, Oct 2005, pg 10-12