CASE STUDY:

GOLD PLANAR BUMPS FOR FLIP CHIP BONDING WITH CHALLENGING SPECIFICATIONS

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INTRODUCTION

The semiconductor packaging industry continues a relentless pursuit to make smaller packages with higher throughput. The industry demand for smaller components requires manufacturers to adapt by developing new processes. Achieving consistent, quality Au Planar bumps has been a challenge that the industry has been trying to meet for years. In this case study, we explore these shrinking specifications of wire bonding requirements in regards to ball bump mashed ball diameter and top heights for flip chip applications and how to achieve them.

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SPECIFICATIONS & CHALLENGES

The customer presented a specification that demanded a grouping of bonds of 60 micron mashed ball diameter with a top height of 17 microns while targeting a mashed ball height of 15 microns. These bumps would then be bonded on a wafer to be used for flip chip applications.

> *Ball bumps with a height to diameter ratio of only 1/3 are typically very difficult to create; bonding tools clog, they are out of specification, or there are frequent user assists.*

These dimensions are quite difficult to accomplish because the ratio between the diameter and height is so extreme. The required height is considered very low for the desired diameter. Additionally, the top height in relation to the mashed ball height are very close in height and the tolerances are low. Essentially, the customer requested a bump with a planar top. Additionally the groups of bumps should be co-planar.

A ball bump is the first bond of a wire where the termination occurs just above the bond, not a stitch bond in another location. Typically, ball bumps have the appearance of a Hershey kiss. The height of the ball bump is about 75% of its diameter and the termination point is where the cross section transitions into the wire diameter. Not only can ball bumps be used as an interconnect, they are also used to secure the stitch of a bonded wire. They can be placed on top of the stitch or below the stitch, as seen in the picture. This operation provides a stronger stitch bond. We will be taking a closer look at how ball bonds are used as interconnects.

Ball bumps are made by bonding the ball then shearing the top of the bump along an axis with the bonding tool. The shear motion is responsible for the top height and the top levelness. Producing wide and flat ball bumps with heights less than 2/3 the diameter require shearing at thicker parts of the bump. Ball bumps with a height to diameter ratio of only 1/3 are typically very difficult to create; bonding tools clog, they are out of specification, or there are frequent user assists. When the bonding tool clogs, the user is required to interact with the machine to fix the wire, which can take minutes.

Top Height (TH): 17um +/-2um
Mashed Ball Height (MBH): 15um +/-2um
Mashed Ball Diameter (MBH): 60um +/-5um
Top Diameter (TD): 50um +/-3um

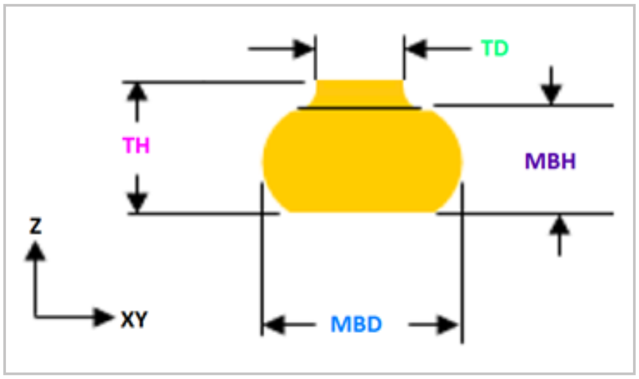

Figure 1: Customer requirements were very difficult. Image is not to scale.

When trying to reduce the top height, the capillary is forced to shear into a larger cross section of the ball. Instead of shearing the ball at the top of the Hershey kiss where it is easy, the machine must shear at a lower portion where the cross section is larger. As the shear height is reduced, there tends to be an increase in EFO errors.

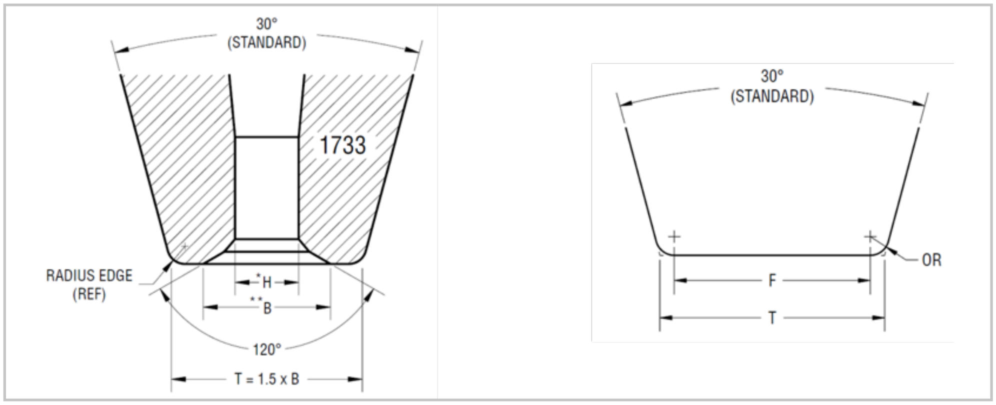

Figure 2: Standard capillary on the left vs the flat face capillary used for coining on the right. Images courtesy of CoorsTeck Gaiser

After the bump is sheared, the wire gets stuck in the capillary and does not produce wire for the machine to form another ball. This causes a column buckle in the wire above the capillary. To overcome this error, a user must interact with the machine and reset the wire, which can take minutes.

ACHIEVING THE SPECIFICATIONS

In working to meet the customer demands, Palomar looked at three different methods to achieve the specifications for the planar bumps.

01 STANDARD SHEAR MOTION

02 ADVANCED SHEAR MOTION

03 TWO-STEP COINING PROCESS

01 STANDARD SHEAR MOTION

The standard shear motion is done along one axis of the ball bump and is completely capable to achieve the desired specifications in the large majority of cases. In our case, we used the Y-axis. The planar bumps are an exception and even more so when trying to achieve the stringent customer specifications. When cutting into the thicker part of the bump using the standard shear motion, it has a higher chance to clog the capillary, which requires user assistance, thereby slowing the throughput.

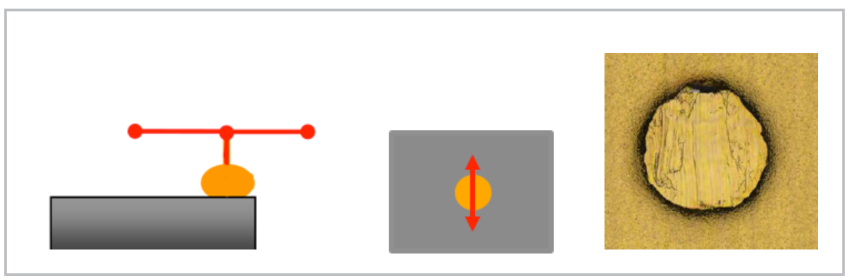

Figure 3: Standard shear motion required too many user assists and produced inconsistent results

02 ADVANCED SHEAR MOTION

The advanced shear motion is a bidirectional standard shear motion starting with the X axis followed by the Y axis. It is intended to weaken the wire in multiple areas before applying the final shear to terminate the bond. There were less user assists but the advanced shear motion did not reduce them to an acceptable amount.

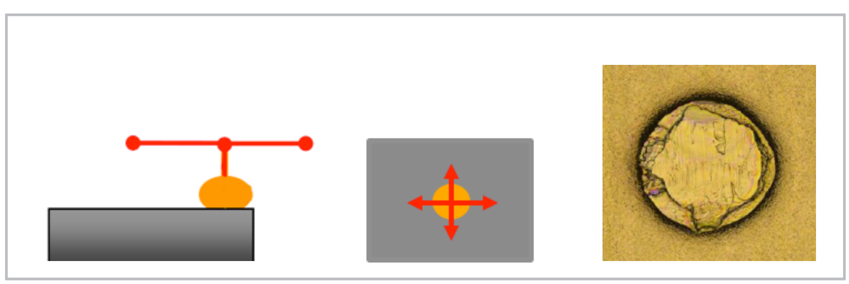

Figure 4: Advanced shear method did not significantly reduce user assists to achieve the specifications

03 TWO-STEP COINING PROCESS

Coining is a two-step process in which the initial ball bonds, which may be out of spec, are bonded again to bring them within specification. This process takes ball bumps that may not be acceptable and bonds them again to flatten them, changing the top height and potentially the mashed ball diameter. Applying the right amount of gold on the surface and flattening it is optimal. With the coining process, the volume deposited on the wafer by the ball bump pass is important so they can be coined to the correct shape. Coining after bonding is slower compared to standard bonding but they provide a better overall throughput due to the reduced user interaction caused by clogged bonding tools.

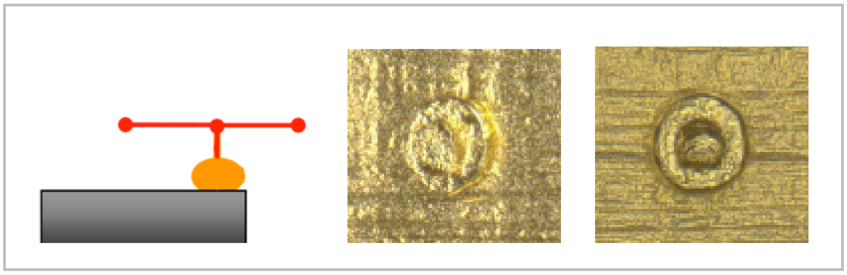

Figure 5: The first step creates a repeatable process with little to no user assists

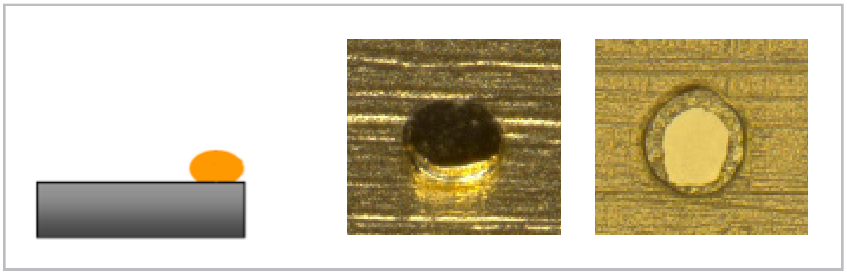

Figure 5: The first step creates a repeatable process with little to no user assists

During the first step, it is crucial to have the correct volume deposited on the substrate by making a very consistent free air ball. The first step of the coining process is simply bonding consistent ball bumps. There is no longer a need to have a low height to diameter ratio and aggressive shear parameters. The process becomes a very standard process and very rarely requires any user assists.

The second step of the coining process is to bond the bumps again using a flat coining capillary. This deforms the pre coined bumps and puts them within specification. By doing so, the top also becomes planar. This process does not have any user assists due to there not being any wire.

A great advantage of coining is that multiple bumps can be coined at once. By doing so, all the bumps that have been coined in a group will have planar tops that are coplanar to each other. This co-planarity becomes very important in flip chip applications where you can coin all the bumps on a chip at once. For small die sizes, they can be accomplished directly on the ball bump bonder as shown in figure 7.

In flip chip applications, the ball bumps are used as the interconnect between the chip and the substrate. When bonding a chip with these ball bumps to a substrate, typically a eutectic reflow process would be used. The bumps can be used as structural support for chips bonded to a substrate. The bumps can also be utilized as spacers if the chip needs to be a very specific height away from the substrate.

For this customer, the bumps are utilized as an interconnect and a spacer. The bumps were bonded on a VCSEL wafer. After the wafer is bumped it would be diced and bonded to another substrate. VCSELs require a fixed distance from other components; typically a lens. The bumps provide a fixed and repeatable height that could be specified for a particular focal point.

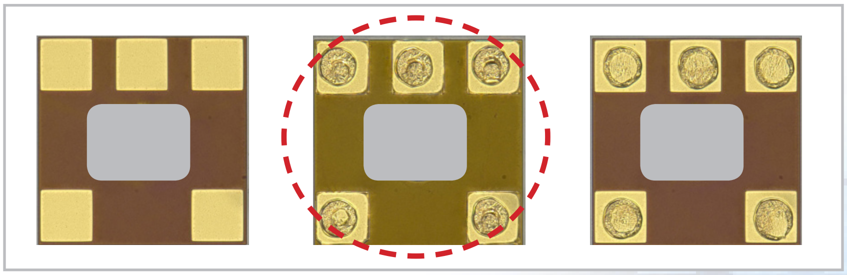

Figure 7: The red line is representative of the tip diameter of the coining capillary used to coined the group bumps on the VSCEL

CONCLUSIONS

The coining process provided consistent, repeatable results that met the customer specification. Over 35 VCSELs were measured with an average ball diameter of 62.1 um.

Top Height	Measured	Specification
Minimum	15.7 um	15.0 um
Maximum	18.6 um	19.0 um
Range	2.9 um	4.0 um
Average	16.91 um	17.0 um
Standard Deviation	0.61 um	N/A
Samples	175 bumps	N/A

APPENDIX:

DEFINITIONS:

Free air ball (FAB) – is essentially an unbonded ball bond. This is important because it controls the amount of volume of gold that goes into the ball bond. This is typically adjusted to meet a specific diameter and/or height of the first bond.

Electronic flame off – the energy that goes into the exposed wire under the capillary and melts the wire into the free air ball. To form a consistent free air ball, the EFO must be consistent as well as the amount of wire it flames off.

Coining – a secondary process that flattens an already bonded ball bump. This process takes ball bumps that may not be acceptable and bonds them again to flatten them so they reach a certain top height (In some cases all of the bumps on the die can be coined together to produce bumps that are coplanar to each other.

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