Gold Ball Bumping: An Effective Wafer-Bumping Method

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Wafer bumping involves putting a conductive material on each die pad on a wafer to attach it to a package or circuit board forming the first-level interconnect. Bumping has gained popularity due to demand for reduced package size, the need for improved electrical performance, and thermal transfer.

Gold-ball bumping - or stud bumping - can be accomplished with commercially available gold wire bonders using a 1-mil gold wire. In fact, gold ball bumping is an evolution of the 50-year-old wire bonding process. In wire bonding, a gold ball is forced down and thermosonically bonded to a die-bond pad forming the first connection of an integrated circuit (IC) and substrate. With the ball connected, the wire is fed out and attached to a second surface, and then torn off to complete the connection.

In the ball-bumping process, instead of making the second connection with a wire loop and stitch, the wire is removed after the ball is connected to the die. A new ball is formed and the process repeats as necessary on all the die bond pads. Gold-ball bumping can be a one-step process, but can involve two steps if a coining process is needed to planarize the ball bumps.

Once the die is completely bumped, it is flipped and attached to the substrate, providing the first-level interconnect as well as protection for the active die surface. These thermosonic or thermocompression bonding methods are often known as microwelding.

Coplanarity

Coplanarity is a paramount factor in gold bumping for flip chips. To be coplanar, all points must lie on the same geometric plane. In flip chip bonding, coplanarity refers to the height consistency that exists across the top of all bumps. Height variations lead to uneven distribution of forces, die fractures, and open circuits. Once the die is singulated and flipped, it must sit flat with the top and bottom touching the die and package evenly. This means each ball bump must be exactly the same height. If one ball is higher than the other, the shorter one will not touch. Each bump is a signal, and all have to be connected for die to function properly.

Figure 1. Au stud bumps with excellent coplanarity.

"Coplanarity of gold bump height across the entire die is very critical to the thermosonic flip chip die attach process," notes Paul Cheung, Ph.D., engineer, Shuz Tung Machinery Co., Ltd., Taichung, Taiwan, R.O.C., relating his experience performing thermosonic flip chip die attach of LED chips that are ejected from a bumped wafer. "Significant bump height non-coplanarity requires that forces and bond times at die attach be substantially increased to flatten taller bumps and ensure connection of the shorter bumps on each die. When we were able to get ± 2-µm coplanarity of bump height from our new wire bonder, die attach throughput rates increased substantially, even with lower parameter settings, resulting in doubling of yielded throughput at die attach."

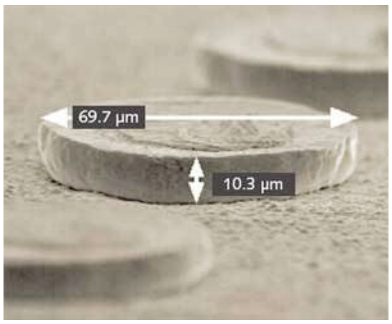

Figure 2. Flattened bump made with a single-step gold-ball bumper.

Figure 2 shows a gold ball bump made in a single-step bumping process. Cheung points out that the way the wire is removed from the bumps influences the coplanarity. The wire bonder Cheung used did not require the extra coining process because it shears the wire to create tail-less bumps (planarBumps) in a consistent, repeatable, single-step process with finished bond height consistency. Eliminating the coining process contributes to increased reliability and throughput.

Figure 3. Ball bump requiring coining.

Figure 3 shows the typical shape of a ball bump created by a wire bonder with a point or peak shape on the top of the ball. This peak was common in gold bumps because the wire is pulled until it snaps just above the ball. Today, more advanced cutting techniques are used to ensure coplanarity controlling where the wire breaks by cutting it off at a specific height.

Work-hardening the wire and breaking it in the heat-affected zone by closing a clamp and pulling the wire off the top of the ball was the standard process for stud bumping. Coplanarity in these bumps was rarely an issue; they were on their way to a secondary "coining" process, which gently flattened the point on the top of the ball, improving the coplanarity of the bumps.

Figure 4. Small- and big-ball problems where I/Os are not connected.

Figure 4 illustrates a small ball on a die that has been flipped. If significant non-coplanarity exists, a higher force and ultrasonic must be applied to bring all the bumps into connection. A die will split or crack if a bump is too big or small because of excess pressure on one bump.

Conductivity
A benefit of bumping is reduced interconnect length. A typical wire length might be 30-mil long, whereas a typical bump connection might be only 2-mil long. This shorter interconnect translates into a lower inductance through the connection path, reducing signal loss. The lower inductance of a bump connection translates into reduced loss and lower power requirements. As frequencies increase, limitations of wire interconnects will force manufacturers using wire bonding to incorporate a bump or flip chip connection. Gold bumps form a gold-to-gold connection, or monometallic bond, providing optimal conductivity and eliminating the need for an additional substrate, or under-bump metallization (UBM), which is the case when solder is used for the bump or plating. A monometallic bond becomes stronger over time, eliminating the need for multiple life-cycle tests. A bi-metallic bond, such as solder, decays over its life. Temperature has an effect on how long it will last.

Gold also has conductive advantages over solder, with an electrical resistivity of 2.19 μΩ-cm as compared to lead (and its alloys), which has an electrical resistivity of 22 μΩ-cm.

Thermal Properties
Temperature is a concern when selecting the method used to attach the gold bumped die to the substrate. A thermosonic microwelding attach process only requires a temperature of 150°C. When thermocompression bonding is used, the process temperature can be as high as 320°C. Therefore, it is important to evaluate the temperature the die can withstand when choosing a method of attach.

Size
Figure 5 shows 250-μm-tall stacked gold-ball bumps. Size is a main reason for bumping die. The entire die and interconnect is essentially reduced to the die size plus the bump height. Packages are becoming smaller, so bumps must be used to maximize the space.

Figure 5. Coplanar 250-μm stacked ball bumps.

Ball bump height depends on the diameter of the ball and the shape. Typically, 40 μm is the lower limit of ball bump height. However, some gold ball bumpers produce a finished bond height of <20 μm and consistency of ±2 μm (at 3 Σ) with 2.5-μm placement accuracy. Upper height limits of over 100 μm can be met if the bond pad is large enough or if ball bumps are stacked.

Reliability
Using gold bumps on a gold substrate reduces thermal coefficient of expansion (TCE) issues encountered when the bumping material is different from that of the substrate. Thermal cycling can cause stresses on the connection. Over the long term, reduced stress translates into better reliability.

Gold bumping is a mature and reliable process. Monometallic gold bonds improve with age and do not suffer the same aging failures as solder processes. It is a clean and can be done easily in-house or by a contract manufacturer. No additional wafer processing is needed beyond wire bonding requirements. Estimated die yield is 99.5%, with a single pass bump having fewer process steps, which translates into higher yield. The consistency gained through coplanar bumps reduces die and substrate stress and pressure.

Conclusion

Coplanarity, conductivity, thermal properties, size, and reliability are weighted concerns for many engineers. The best answer is often gold-ball bumps. Digital signal processors are presently the largest application for gold bumping. LEDs are also attached with a gold bump and flip process. Large wafers with CMOS image sensors and high I/O counts requiring 30 to 40 bumps, and super-high-frequency RF receivers are other applications. Some applications require 550 bumps on a 2-in-long die that can make a connection in a single flip.

Robust connection and high reliability make gold-ball bumping the application of choice for critical medical and space applications. It can also be found in high-end automotive processes such as motion sensing and airbag deployment.

Equipment manufacturers continue to perfect their ball bumping machines to mine the data from the bonding process, and use a closed-loop feedback system to ensure consistent height and accurate placement. Software has been designed to measure bond deformation, and set and maintain upper limits for height and process control.

As companies change to meet RoHS compliance and eliminated lead in their process, gold ball bumping becomes an alternative. In many operations, gold-ball bumping is more cost-effective than other attachment methods such as plating. It is expected to gain popularity for applications where high frequency, reliability, thermal dissipation, and an ultraclean process are required.