Advanced Packaging

Wire Bond Technology

THE GREAT DEBATE: BALL VS. WEDGE

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Over the years, microelectronic wire bond process and packaging engineers have debated whether to use ball- or wedge-bond technologies. This has been especially true with RF designs and fine-pitch packaging. There is little debate that ball bonding is faster and more robust; however, due to a need for low-profile interconnects or fine pitch, wedge has continued to dominate key market segments. Another area where wedge bonding typically dominates is when a running stitch interconnect or die-to-die bonding is required. These demands have recently multiplied as advanced LED designs mature.

THE SHORT STORY

The debate of wedge vs. ball bonding continues. Ball bonding is faster and more robust, but, when low-profile interconnects are required, wedge dominates. New methods, such as automatically bonding running-stitch interconnects with ball-bond equipment, suggest ball bonders can compete with wedge bonders.

Background

The first wire bonder, designed in 1957, was a thermocompression wedge bonder. Ultrasonic wedge bonding was introduced in the early 1960s. Thermosonic wedge bonding was first performed in 1970. Several features have remained common among wedge-bonding equipment, such as the wire feeds through the tool and the wire clamp is behind the tool. Today's wedge bonders are vastly different, although the wire still feeds through the tool.

Currently there are two types of wedge-bond equipment. One feeds the wire through the wedge at a 60° angle; the second feeds the wire at a 90° angle. Figure 1 demonstrates a basic 90° wedge-bond process. Because the wire feeds through the wedge tool, both the 1st and 2nd bonds must be orthogonal. This reduces throughput. Further, the wire clamp for a wedge bonder is positioned behind the tool, which significantly increases the keep-out zones required to facilitate second bond and tail tear-off.

The first ball bonder was introduced years later. It used a hydrogen flame to burn the end of the wire (tail) into a ball. Since then key features have progressed. For example, today balls are formed by an electrode that swipes under the tip of the wire to form a ball. Some common features in all ball-bond equipment designs include a wire clamp positioned above the tool (capillary) and a wire that feeds through the center of a ceramic capillary (tool). Figure 1 illustrates both wedge and ball bonding.

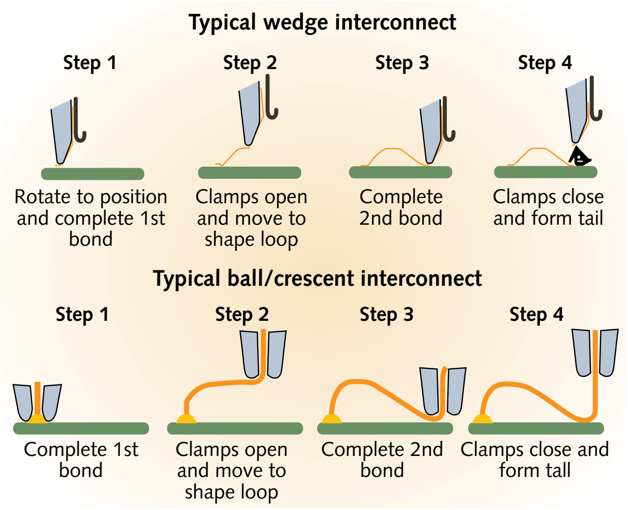

FIGURE 1. Simplified representations of wedge and ball bonding.

Automated wire bonders were introduced in the early 1980s. At that time, the majority of interconnects were made using aluminum wire. As the need for reliability increased, gold wire became more common. As package densities increased, wire interconnect bond pitches decreased. Initially, the solution to fine pitch was wedge bonding because the wedge tool design allows wires to be bonded in close proximity (side-to-side).

Fine-pitch Interconnects

The need to package more in less space has caused ASIC designs to become denser. It was once thought that the best method for interconnecting fine-pitch packaging was through wedge bonds. In the late 1990s, the typical bond pitch decreased from approximately 110 µm to around 90 µm. During that period, the average wedge tool tip was roughly one-third the width of a ball-bond capillary tool tip. Capillary materials lacked robustness to support fine-pitch processes. Since then, improved materials enable fine-pitch designs where tip dimensions of less than 70 µm are not uncommon.

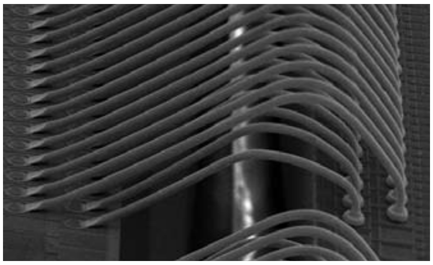

FIGURE 2. 55-µm pitch side view.

Smaller features, higher density, and increased I/O demand finer pitch. In today's fine-pitch environment, any device that would be bonded using a wedge bonder could be bonded faster using ball-bond equipment. Figure 2 depicts 55-µm fine-pitch architecture interconnected by ball bonding using 1.0-mil wire.

IC to IC Interconnects

Designs that require interconnecting from IC to IC (die-to-die) or from a substrate to an IC (reverse bonding) would typically require a wedge bonder. This is because, unlike the capillary tool, the wedge tool does not contact the bond surface. In ball bonding, when a ball interconnect is terminated, more than 50% of the tool contacts the bond surface, which disturbs top-surface metallization.

This can be addressed by creating a security, or safety, bond with a ball bonder by placing a ball bump over the crescent to seal the disturbed metal. Or, a stand-off-stitch (SoS) can be created by placing a bump on the die prior to terminating the second bond (Figure 3). The SoS termination maintains a gap between the wire and IC metallization, protects the active device bond pad metallization, provides a monometallic interconnect for the crescent bond, and yields excellent destructive pull results (wire breaks).

Chain Bonding

The final stronghold for wedge bonding is with RF packaging, where wire interconnects experience parasitic losses due to inductance with adjacent wire bonds, resulting in signal disturbance. In effect, the wire bonds act as discrete inductors. The effect of the wire bonds can be signif-

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icant in RF compared to digital and should be accounted for in the design of the device.

To achieve the benefits of wedge bonding RF devices, while simultaneously maximizing bonding speed, reliability, and reduced keep-out space of a ball bonder, a chain stitch was developed. This section documents the results from an RF test vehicle where the wedge interconnects were replaced using a ball-chain bonding technique. The purpose of this test was to evaluate ball-chain bonding using a mature package design. The part selected was a high-frequency transistor assembly where all package interconnects had been wedge. Due to wedge-bond design guidelines and tool clearances, the wedge transistor assembly (WTA) package required three different wire sizes (1.0 mil, 1.3 mil, and 1.5 mil). Pretest analysis suggested that all wires could be replaced using 1.5 mil ball-chain interconnects, thus reducing several process steps. The evaluation consisted of inspecting customer-supplied materials, performing off-line testing of customer's package layout using gold coupons, performing capillary testing and identifying optimum design, wire bonding customer part and optimizing loop and bond parameters (using visual inspection and wire-pull test), and wire bonding active parts.

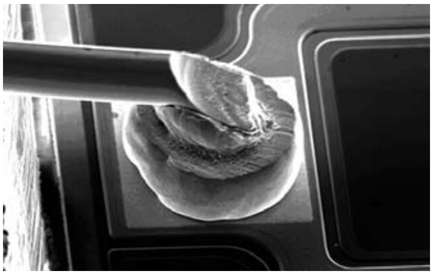


FIGURE 3. SoS crescent bond.

During capillary testing, low-destructive pull-test failures occurred. In each case the low pull value was defined as a crescent break. It was determined that a standard capillary design might not be optimal for chain bonding. This was evident through SEM inspection that showed stress where the wire exited at the crescent.

Based on these results, an alternative capillary design was used that would yield good chain interconnect, but at the same time tear off consistently for the terminating bond. Figure 4 shows a typical chain interconnect bonded with the improved tool design.

To mitigate any hidden issues with respect to this alternate capillary, several interconnect test vehicles were assembled using 1.0 mil wire and subjected to high-temperature bake testing. Each test vehicle consisted of 56 chain interconnects bonded onto a gold thick-film coupon. The bake test consisted of exposing test samples to 300°C for one hour. This accelerated test is roughly equivalent to 1,000 hours at 125°C. Destructive pull tests per Mil-Std-883, Method 2011 were sampled across several test vehicles before and after bake test. Figure 5 tabulates those test results. All of the failures were mid-span wire breaks.

Wedge Emulation with a Ball Bonder Using Chain Bonding

The final step was to process customer-supplied RF transmitter assemblies. Figure 6 illustrates the successful end item results. Chain bonding on a ball bonder allowed successful interconnect of these RF devices using a single-diameter wire, whereas wedge bonding required three different-size wires. There is also no argument that ball bonding is faster and requires less keep-out space.

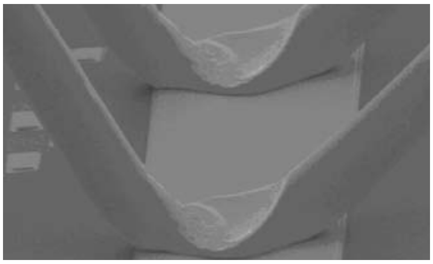


FIGURE 4. Improved chain bond SEM photo.

With the right equipment, running stitches can be made to interconnect RF devices. But what about interconnects that must begin with a wedge? In these examples, each interconnect began with a ball and terminated with a crescent. This is how a ball bonder has always operated, until now.

Software developments allow the user to program an interconnect beginning with a stitch. This process begins with a pre-programmed wire length sticking out below the tool. Next, the bond head completes programmed moves that form the 1st stitch and complete the bond. This process has been successfully demonstrated and shown to comply with the visual standards defined per Mil-Std-883, Method 2017., which states that a wedge bond shall be >1.0× or <3.0× the wire diameter in width.

This technique allows the user to interconnect using wire other than gold. Since there is no ball, bonding with aluminum or even copper wire can be done, just like a wedge bonder. This makes the ball bonder a viable and flexible alternative to a wedge bonder. At this point the only interconnect not yet made using a ball bonder would be a ribbon, but with an adequate capillary design, some form of ribbon bonding should be possible.

Conclusions

Throughout the 1990s, process engineers would buy equipment to develop manufacturing methods. Today, there are fewer process engineers, and customers expect a whole solution, complete with a manufacturable process. This demand drives the need for commonality.

Using a ball bonder and chain bonding can be a good alternative to wedge bonding. Wedge bonding will continue to dominate ribbon interconnecting, but this technique provides the tools needed to address most wire applications.

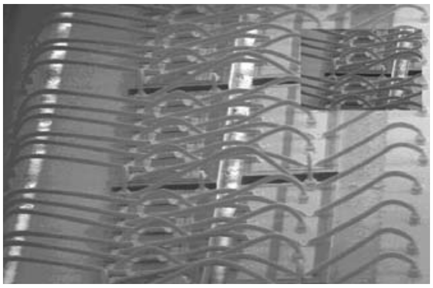
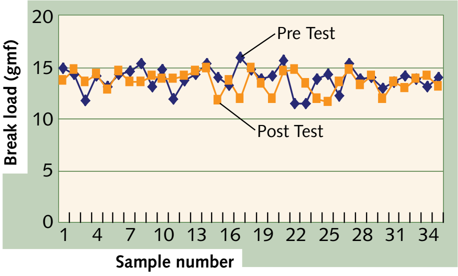


FIGURE 6. Ball bonded transmitter assembly @ 15× magnification.

Photos courtesy of Tyco Electronics Wireless Systems Segment, Power Hybrids Operations.

With the high cost of capital equipment, the need to conserve manufacturing floor space, reduce personnel, streamline operations, and increase time-to-market, being able to perform almost all bonding operations on a ball bonder is an advantage. With the addition of chain bonding to a ball bonder, manufacturers can support applications that require higher frequencies and denser packages without sacrificing throughput and yield. **AP**



	Pre Test	Post Test
Average	13.90	13.61
Max Value	15.92	14.91
Min Value	11.43	11.61
Standard Deviation	1.13	0.979

FIGURE 5. Pre-bake and post-bake destructive pull test results.

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