Integrated Solutions to Bonding BGA Packages: Capillary, Wire, and Machine Considerations

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Abstract

Ball Grid Array Packages (BGAs) present unique challenges to the wire bonding process. They are fine pitch, require long low loops with adequate clearance over voltage and ground bus bar rings, and are built on a laminate substrate. A combined approach, encompassing upgraded wire bonders and specially designed bonding tools and bonding wire, provides a unique opportunity to develop integrated solutions to these technical challenges. A multi-disciplined team is able to drive the optimization process farther and faster than groups that only focus on smaller areas of the process. In K&S applications labs located in Pennsylvania, Singapore, and Israel, engineers and customers have worked together to develop solutions that provide robust, high-yield processes.

This paper will describe the Designed Experiments (DOEs) and developments that have led to the development of high-yield BGA manufacturing processes.

Key words: Interconnections, wire bonding, Ball Grid Arrays, metallization

Introduction

The Ball Grid Array (BGA) package is expected to be the fastest growing semiconductor package during the next 5 years. Estimated CAGR for the period 1996-2001 is 70%[1]. However, development of field support and applications has lagged because of the speed at which this package has been accepted.

Because of their intrinsic design, BGAs are technically complex to bond. BGAs are designed for high I/O counts (225-500 leads are common). They demand fine pitch wire bonding (pitch of 90 microns or less) and require long wire lengths, straight loops, and small first and second bond areas. Wire lengths of 6 mm are common, and loop shapes must be controlled to provide clearance over ground and voltage busses located close to the lead tips. Fine pitch bonding requires the use of a thin necked capillary, with a small tip diameter. The small capillary tip and the narrow lead width result in a small cross-section for the crescent bond, making the strength of the bond an important concern. The BGA structure is based on laminate technology. The low glass transition temperature (Tg) of the laminate material requires bonding at lower than normal temperatures; this generally has a negative effect on wire bond strength and reliability.

Machines and Materials

The two devices used in these experiments were manufactured by AMKOR/ANAM Electronics in their new Philippine factory. The *Super* Ball Grid Array (SBGA®) devices contained an AMKOR test die with 65 µm wide x 75 µm pitch bond pads. The PBGA devices contained a K&S test die with 65 µm wide bond pads on a 80 µm pitch. AMKOR Electronics is a major supplier and developer of BGA devices.

This application study was carried out on a Kulicke & Soffa Model 1488 *plus* ball bonder with an Adaptive USG (ultrasonic power generator) System. The Adaptive USG System was chosen because it provides improved low temperature bonding performance for BGA and other soft substrates. It consists of a high performance 120 kHz K&S UNIBODY™ transducer driven by a new ultrasonic generating system that adapts to material variations by adjusting ultrasonic output in real time. The 1488 *plus* maintains higher bond placement accuracy required for fine pitch bonding.

The capillaries used in this work were manufactured by Micro-Swiss. Experiments to optimize the capillary, and to identify the best combination of tool geometry and materials for high frequency bonding, have resulted in exceptionally high strength/area bonds. This is especially important because the overall cross-section of the bonds has decreased due to fine pitch requirements.

The wire used in this study was 25 µm (1.0 mil) AW14 supplied by American Fine Wire. It is a wire designed and recommended for fine pitch, low-medium long-loop applications. Some of the wires in this study were as long as 8 mm with a range of 6.5 to 8 mm. The wires were not molded.

The devices were plasma cleaned in a Balzers Model LFC-150 plasma cleaner using an Argon Hydrogen plasma. An advantage of the Balzers unit is that it will handle parts in magazines and it can process eight magazines per cleaning cycle.

Description of Work

This paper describes the optimization of the bonding process. Kulicke & Soffa has defined a method for applying Designed Experiment techniques (DOE) in new bonding applications [2]. This method optimizes second bond parameters first, followed by first bond and then looping. This sequence is used since the quality of first bond is significantly affected by the quality of second bond. Optimizing second bond first provides assurance that the tail bond is good. The tail bond is the weld between the short piece of wire, which will subsequently be used to form the next ball, and the substrate. Getting a good tail bond is a requirement for good ball formation during the firing of the Electronic Flame Off (EFO).

When optimizing second bond, pull tests are conducted with the hook located as close to second bond as possible. This changes the resolution of forces so that most of the force is applied to the second bond. The value of the pull strength, when tested in this manner, is less important than the failure mode and appearance of the bond. In the case of the SBGA® devices, the hook is aligned with the inner ground bar ring. On the PBGA devices, the hook is placed over the ground bar. By maximizing the second bond strength in this way, it will still be at a maximum when the pull test is conducted at its normal location during production (mid span).

Following second bond optimization, first bond optimization experiments are conducted. The most important responses for first bond optimization are shear strength/unit area and ball diameter. For fine pitch bonding, the ball size is a limiting factor. It must be small enough to meet 100% on-pad placement requirements. In the case of the SBGA® device with 65 µm bond pads, an average ball size of 57 µm was selected. In order to maintain high strength with small balls, high strength/area bonds must be formed. In this application the minimum acceptable shear strength was 7 mg / μm^2 (4.5 g / mil^2). Optimization of looping completes the application study.

In this series of experiments, the effects of plasma cleaning were of considerable interest. DOE techniques were used to optimize the cleaning process. Pull testing, with the hook located near second bond, was the most important response used in the plasma cleaner optimization.

Capillary Design Considerations for 75 µm Pitch

As bond pad width and the pitch between adjacent bond pads has become smaller, the role of capillary geometry has become more important[3]. Solid model based software design guides simplify the selection of capillaries with dimensions that allow bonding without danger of interference between the capillary and adjacent wires and ball bonds [4].

For this application, the devices had 65 µm bond pads on 75 µm pitch. Using this data, CAPDESIGN™ software recommended that the capillary design needed to produce a high-strength

57 µm average ball diameter would have a 46 µm (1.8 mil) chamfer diameter. In addition, capillaries with a 97 µm (3.8 mil) tip diameter were required to meet the 75 µm pitch requirement.

Although these dimensions were dictated by the pitch requirement, there are other critical dimensions that significantly affect the bonding process. On BGA devices, the second bond is the one which is more difficult. This is a result of:

1. Low bonding temperature, because of the low T_g laminate.
2. The short bond length, because of the fine pitch, small diameter capillary.
3. Contamination (laminate surfaces often contain a variety of foreign substances and plating residues).

Capillaries with a range of face angles were studied to determine the best choice for bonding on the BGA surface. Although normal recommendations are to increase capillary face angle for smaller tip capillaries, this is not always the best course. The best procedure is to test a series of face angles to determine the optimum choice for a specific application. All of the capillaries in the study were selected to have the same dimensions other than face angle so that the face angle response could be studied systematically.

Second Bond Optimization

A series of DOEs using four capillary designs was carried out on both electroless and electrolytic Au plated SBGA® and PBGA devices. The same 17 trial quadratic response surface experiment was run with each capillary and both plating types. All of the capillaries had a 97 µm (3.8 mil) tip diameter designed for 75 µm pitch bonding. The experiments showed that the 15° face performed best on both plating types. Figure 1 shows this data.

During the course of this study, a new proprietary capillary design, significantly different from previous designs, was included. The new capillary was designed specifically for high frequency bonding applications. Comparative tests showed that the new capillary provided higher second bond pull strength, less difference between the averages for the Y and X axis wires, a wider process window, and a significantly better failure mode distribution. Figure 2 shows a comparison of the average pull strength, when the wires were pulled at second bond.

Figure 1 Effect of Capillary Geometry and SBGA® Plating on Pull Strength

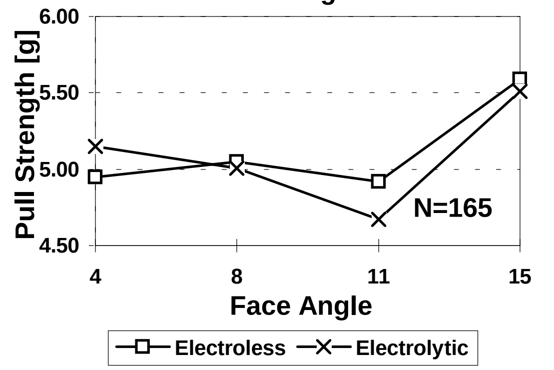
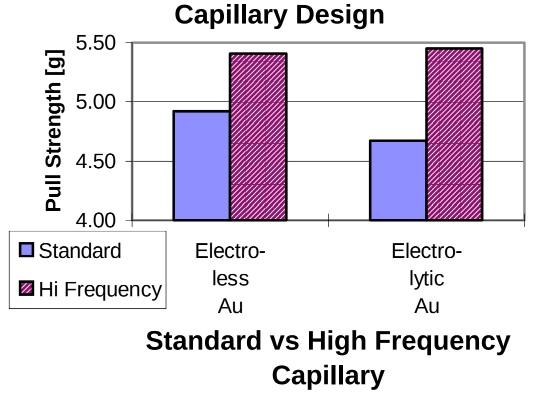


Figure 2 High Frequency Capillary Design



Au Plating

Two plating methods are commonly used for top layer metallization on BGA devices. Electroless plating is often the best method for fine pitch applications, because it does not require a continuous electrical connection for plating to occur as is required for an electrolytic cell. However, electroless plating is normally considered a harder surface to wire bond than electrolytic plating. Electrolytic plating is normally less expensive, and has more uniform surface properties[5]. For each of the capillaries studied, a full set of samples was replicated for both electroless and electrolytic plating. Figure 1 also illustrates this data. There were no significant differences between the bond strengths due to plating. It should be noted that all of the parts in this study were plasma cleaned using the optimized plasma cleaning process and the sample size was small.

Plasma Cleaning Experiments

All devices in this study were plasma cleaned with a Balzers LFC-150. Attempts at bonding devices without initial plasma cleaning resulted in a very large number of defects by opens (failure to form a good ball because of a poor tail bond weld). A DOE on the Balzers LFC150 plasma cleaner was performed. Cleaning variables that were included in the DOE were cleaning time, flow rates of hydrogen and argon gases, arc current and the sweep angle of the arc filament.

An initial screening experiment was performed to identify the most significant factors affecting the second bond pull strength results. From the results of the initial screening it was clear that after 3 minutes of cleaning, no significant improvements were gained by cleaning for a longer time. To improve the resolution and add confidence, the initial experiment was augmented (additional trials were added by a blocked design) into a quadratic design. Figure 3 is a contour plot of the two most significant factors in the quadratic DOE. The results showed that at lower Argon gas flow and higher Arc current the best second bond pull test results would be obtained. All subsequent experiments were plasma cleaned with these optimized settings.

Delay After Plasma Cleaning

Common practice at companies that perform plasma cleaning prior to bonding is to strictly control the time interval between plasma cleaning and wire bonding. In some cases this limit is as low as 2 hours. An experiment was run to investigate this effect. Electrolytic plated PBGA devices were plasma cleaned and bonded with a delay between the two operations. Pull strength near second bond and ball shear strength were both measured. No significant effect was observed due to the delay, however, the sample size was small. Figure 4 shows the results of the time delay experiment.

Figure 3 Average Pull Strength after Plasma Cleaning Electroless Au Plated SBGA®

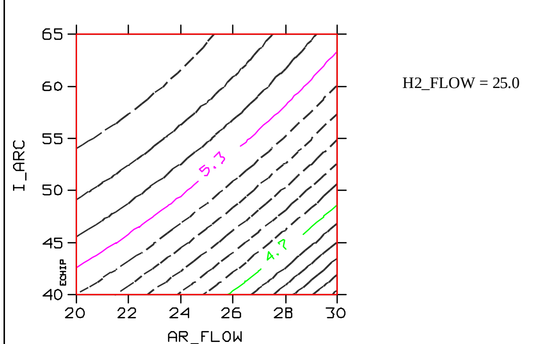
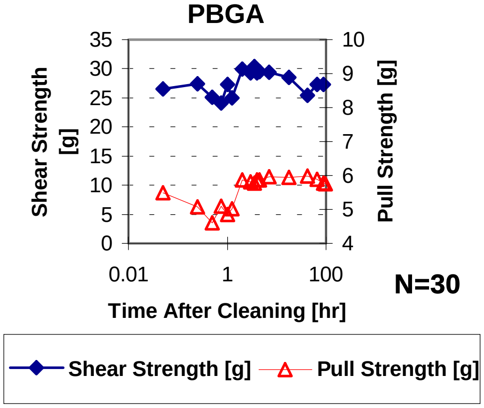


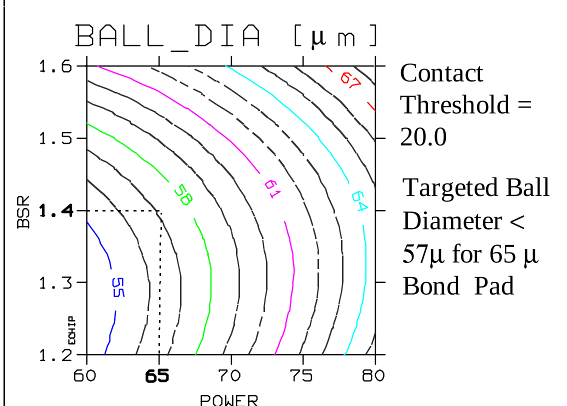
Figure 4 Effect of Time Delay after Plasma Cleaning on Bond Strength of Electrolytic Plated PBGA



First Bond Optimization

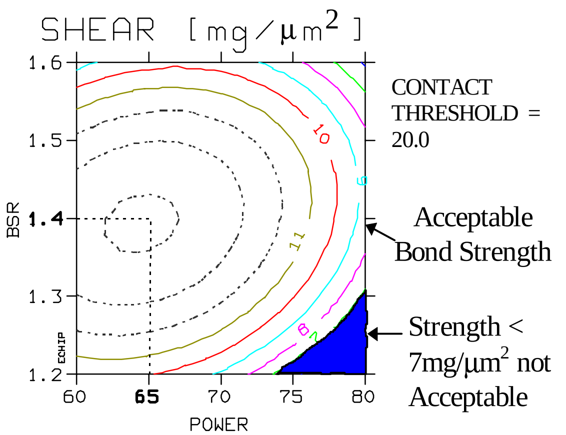
Optimizing the ball bond on a modern ball bonder is largely a matter of working with design and process models to determine which targets to set. Once the targets are determined, response surface modeling of the process is used to map the process and predict the parameters that will meet the targeted responses with optimum strength bonds.

Figure 5 Ball Diameter for Fine Pitch Bonding



After capillary dimensions are specified, it is necessary to run a DOE to model the process. For fine pitch bonding it is necessary to simultaneously optimize several responses. The shear strength must be optimized at a specific ball diameter. In addition, ball height and shape are also important quality criteria. E-CHIP™, the software that was used in this study, is excellent for the simultaneous optimization of several responses

Figure 6 Ball Shear / Area



Figures 5 & 6 illustrate the simultaneous optimization of both the ball shear strength/area and bond diameter to get the best strength at the design specified ball diameter. The most significant process control variables are Ball Size Ratio (BSR, the ratio of the expected free air ball diameter to the input wire diameter), and the ultrasonic power. BSR affects the diameter of the free air ball, the ball that is formed before bonding. Ultrasonic power affects the bonding deformation. In this case there was a very large process window for producing bonds of acceptable strength. Producing a maximum bond strength at the targeted bond diameter requires a well characterized process and the correct specification of capillary feature dimensions.

BGA Looping

The BGA device has presented a whole new set of looping issues. The device requires long, low, straight loops. There are normally two rings within the second bond periphery. They are used to distribute power and ground. These rings provide a bonding constraint, in that the wires must have a significant separation from them to prevent shorting.

Solutions to the BGA looping problems are based on the use of new software algorithms generated by K&S and presently available in Premium Process BGA2 Series looping software. These software solutions add new motion controls that control the way the wire is shaped by the motion of the capillary. The new motions can be used to increase the height of the wire over the power and ground rings. The worked loop shape, a wire with a long flat portion parallel to the die surface and then descending to second bond, has been shown to provide improved thermal cycling reliability. This occurs because, as it cycles, the wire is able to flex at the outer bend, not in the HAZ above the ball [6].

Figure 7 shows the shape of the wire as it descends toward second bond. The wire has a steep angle providing good stand-off distance between the wire and the distribution rings. Figure 8 is a close-up of other wires, bonded to both the leads and the distribution ring. Figure 9 shows worked loops, with a special additional bend in the wire near second bond. This shape is especially important for SBGA®, in which the height of the die surface can be lower than the height of the leads.

Figure 7 Wires Ascending from Second Bond Showing Stand-off Between Wire and Distribution Rings

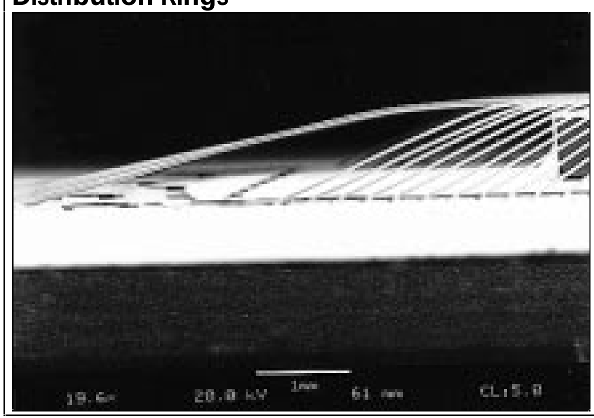
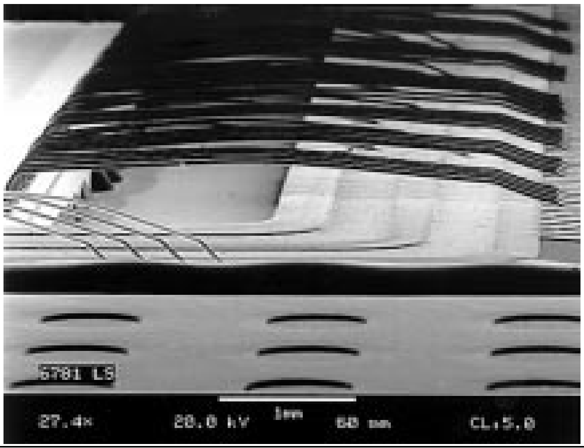


Figure 8 Close-up of Wires Ascending from Second Bond.

Figure 9 Photo of Worked Loop Showing Special Loop Shape Near Second Bond



Conclusions

DOEs have verified that high-yield fine pitch BGA processes are feasible with modern, high-speed automatic wire bonding equipment. The development of fine-pitch BGA packages has become a reality. High volume, robust processes have been established for devices with pitch as low as 70 µm. It was demonstrated that optimized capillary designs improve the bond quality and provide stronger bonds, even when the bonds are small in size. New capillary designs are being introduced that improve the robustness and increase the process capability of high frequency bonding by providing a larger process window.

Developing a successful leading-edge technology of this nature requires considerable understanding of the bonding process, the materials and the equipment. Collaborative efforts between equipment and materials suppliers and the end-use customer or assembly facility greatly enhance the product/process development cycle, increasing both the speed of development and the quality of the end result.

Cleaning BGA devices prior to bonding is a requirement for high-yield BGA manufacturing. Once cleaned the data demonstrated that the devices were capable of a robust process.

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