Robust Wirebonding of X-Wire™ Insulated Bonding Wire Technology

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Abstract

As the semiconductor industry continues to move towards high pin count, fine pitch, multi-row and multi-stack devices, wire bonding becomes an increasing challenge for today's semiconductor packaging processes. Insulated wire bonding technology has been identified on the 2006 ITRS Roadmap for Semiconductors[1] as a viable, cost-effective solution to enable complex package designs, enhance package performance, and improve the yield of high-density packaging.

Key words: Insulated bonding wire, Advanced Packaging, Wire bonding

Introduction

In order to successfully implement insulated wire bonding, low cost integration into the existing packaging assembly infrastructure is of utmost importance. In particular, it is a requirement that the insulated wire demonstrate wire bonding performance which meets industry standard wire bond test specifications, when used on existing wire bonding assembly platforms. This paper discusses various methods, techniques and processes that allow insulated wire to be bonded with high yield and reliability. Wire bonder setup, proper capillary selection, as well as correct use of bond parameters, loop parameters, and other advanced wire bond features will be highlighted. Recently, a new insulated bonding wire, called X-Wire™ has proven to be a viable technology addressing these requirements. [2]

Wire Bonder Setup Considerations

In order to begin the development of a stable and robust insulated wire bonding process, the first step is to ensure that your environment for bonding insulated wire has been changed to reflect some minor, but unique requirements driven by the presence of the dielectric coating material.

Firstly, users must ensure that the wire bonder is now properly grounded as the bare wire normally used to provide grounding will now be insulated and can no longer play this role. For the wire bonding systems observed to date, each of the conductive points along the wire path complete the connection to the EFO system. It is believed that the many paths to EFO ground are redundancies in order to guarantee a good EFO return signal for the system to control the EFO arc. By eliminating all of the redundant EFO ground points, the insulated bonding wire can be used without the high voltage EFO system damaging the insulating material or contaminating the components of the wire path on the wire bonders.

Removing the redundant EFO ground connections is generally achieved by identifying, disconnecting and isolating the electrical wires on the wire bonding system. However, the remaining EFO ground connections must be of sufficient quality and durability to provide feedback signals to the EFO system every time the EFO system forms a FAB. Some wire bonder manufacturers have already designed robust, high quality EFO ground systems for their wire spool holders and wire end grounds. However, if the wire spool holder EFO ground is not of high quality, FAB formation problems can occur with insulated wire bonding.

Secondly, the electronic flame off (EFO) system is of critical importance to the successful implementation of insulated wire bonding. This system is responsible for controlling and monitoring the electric arc that is used to melt the end of the bonding wire to form the free air ball (FAB). In order to form the arc, several kilo-volts are applied to the tip of the wire. Once the arc is formed, current flows back into the EFO system through the EFO ground points along the wire path. For most wire bonder manufacturers, these EFO ground points consist of the conductive wire clamp pads, air guide, diverter, wire spool holder, and wire end ground.

Considering that the EFO voltage is several kV, there is sufficient potential for the degradation of the insulating material on the insulated bonding wire. This degradation allows the EFO current to flow through the easiest path to EFO ground, typically the wire clamps. The degradation of insulating material leaves damage on the insulated bonding wire, and can build up on the wire clamp pads. Contamination on the pads, in turn, can impose physical damage to the next section of insulated bonding wire as it is held by the contaminated wire clamp pads. This degradation of the insulating material through the high voltage EFO system can be observed at the wire clamp pads, air guide, diverter, or at any other conductive point along the wire path.

Accordingly, following the equipment manufacturers' recommendations for EFO wand positioning and replacement is important for consistent insulated wire FAB formation and machine to machine portability. A heavily contaminated or damaged EFO wand may not provide a consistent EFO arc for FAB formation.

Thirdly, it is suggested that a new wire clamp assembly be installed and calibrated before beginning feasibility, qualification or production with an insulated bonding wire. A fresh wire clamp insures a flat, high quality surface that is free of contamination build up or pitting for holding the insulated bonding wire.

Most instances of broken or damaged insulation on the wire are traced to using dirty wire clamp pads and or not converting the grounding system of the wire bonder.

An innovative clamp solution which is gaining industry interest is the use of double-jeweled clamp pads, instead of the typical arrangement consisting of one conductive pad and one non-conductive jeweled pad. The double-jewel configuration isolates the clamps from ground and eliminates the possibility of spark erosion. The double-jewel is expected to have longer life for both bare wire and insulated wire applications.

Capillary Selection Considerations

Proper choice of capillary is of significant importance for the development of a stable and robust insulated wire process. The proper choice is again driven by the need to address the presence of the dielectric coating on a previously bare wire.

As with bare wire, there are several tradeoffs required to balance the ideal capillary dimensions for a robust wire bonding process window, with the constraints imposed by package designs. Typical capillary dimensions are well known and documented through the industry, such as the appropriate tip diameter for the bond pad pitch of the die, and the required chamfer diameter for the target bonded ball diameter.

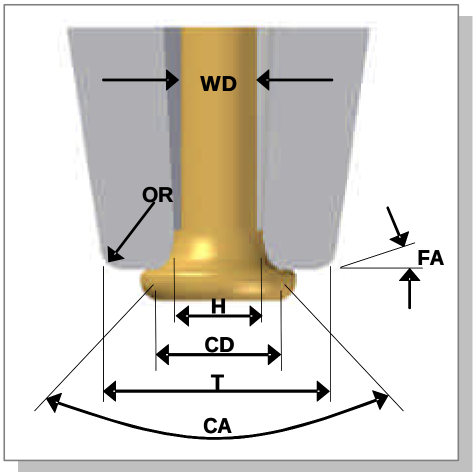

Figure 1: Capillary Dimensions. Source: SPT.

Of significant importance to successful bonding of insulated wire are the relative sizes chosen for hole diameter (H), chamfer diameter (CD), and tip diameter (T), as well as the capillary surface roughness and outer radius (OR). It has been found that to maximize interfacial sliding between the insulated wire and the bonding surface, the interfacial sliding between the capillary face and the bonding wire must be minimized. The roughened or "matte" finish available from most capillary manufacturers helps achieve this. The outer radius helps define the length of the stitch bond. A smaller outer radius will increase the effective length of the capillary face. However, if the outer radius is too small, then the upper limit on stitch bond strength is defined by a small bond cross sectional area or by the onset of heal cracks.

The tip diameter is defined by the bond pad pitch for the application. The capillary selected must be able to bond a ball bond without touching an adjacent ball bond, as this will lead to damaging the adjacent wire surface, disturbing looping, and potentially reducing the ability to form a strong first bond for the current wire. The capillary chamfer diameter is critical for achieving a strong first bond, as it is responsible for centering, gripping, and shaping the first bond during the application of force and ultrasonic power. The hole diameter of the capillary is dependent on bonding wire diameter and looping performance. The hole diameter must be sufficiently large to allow the wire to feed through the capillary without significant drag between the wire and inner capillary surfaces. However, the hole diameter must also be sufficiently small such that looping motions of the wire bonder can form the required loop shape.

For wire bonding an insulated bonding wire, particular attention must be paid to the above dimensions. The hole diameter should follow the recommendations in Table 1. When using a hole diameter that is too small, the looping motions can create damage to the thin dielectric coating. This damage is typically a scraping of the insulation, exposing bare gold wire that may lead to device failure through electrical shorting.

	Insulated Wire Diameter		
	25um	**23um**	**20um**
Hole Diameter	>32um	>28um	>24um

Table 1: Recommended minimum capillary hole diameters.

The relative sizes of hole diameter, chamfer diameter and tip diameter define the ratio of capillary surfaces available to form the stitch bond and the tail bond. The difference in radius between the chamfer diameter and the hole diameter defines the length of the tail bond. This tail bond is what secures the insulated wire to the bonding surface until the capillary ascends to the defined tail length. As the wire clamps close, the tail bond breaks at the bonding material, and allows the continuous ball bonding process to continue. Because there will be insulating material between the bonding surface and the bonding wire, this dimension should be slightly larger than for bare wire. From the authors' experience, robust bonding parameters and a wide bonding process window exist when the dimensions are chosen in accordance with Table 2. It is recommended that the chamfer diameter be increased to meet the recommendations, as opposed to reducing the hole diameter below the previously suggested values. The final dimension to consider is the difference in tip diameter and chamfer diameter, which defines the length of the stitch bond. This should be increased by using the largest tip for the bond pad pitch and looping heights.

	Insulated Wire Diameter		
	25um	**23um**	**20um**
Tail Length (CD – H)/2	>5um	>3.5um	>2um

Table 2: Recommended tail lengths.

Bonding Parameter Considerations

The ball bonding cycle typically consists of forming a first bond between a bonding wire ball and a die pad, shaping the bonding wire to form a desired loop profile, then forming a second bond between the wire and the lead finger, next forming and breaking a tail of bonding wire, and lastly using the EFO arc to melt the tip of the bonding wire tail to form a ball. In order to achieve a robust wire bonding process with insulated wire, there are some minor but critical changes to the parameters typically used with bare wire bonding.

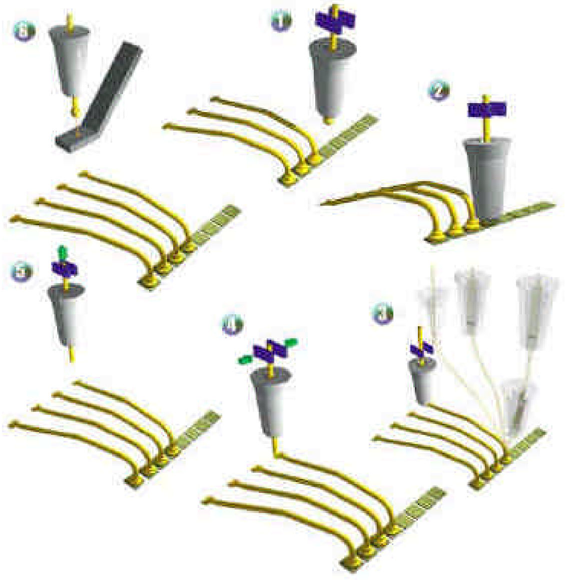

Figure 2: The ball bonding cycle. Source: SPT

First bond considerations

The first bond utilizes ultrasonic power and force over a prescribed period of time to shape and weld the first bond into place. Of all the stages of the ball bonding process, this step in insulated wire bonding is the most similar compared to bare bonding wire. Experience has shown that slightly decreasing ultrasonic power and force achieves the typical strength, shape, IMC and reliability targets required by the industry. Without slightly decreasing ultrasonic power and force, it has been observed that insulated wire will have more deformation than the same bare bonding wire alloy under equivalent first bond parameters. An example of first bond parameters (power, force, time,) for an ASM Eagle 60 wire bonder with a standard PBGA application is shown in Table 3. Other important parameters, such as contact force and search speed are not shown.

Wire Size (μm)	BPP (μm)	Bond Power	Bond Time	Bond Force
25.0	80	55-65	10	12-18
23.0	60	50-60	10	9-14
20.0	55	45-55	10	6-10

Table 3: Example of first bond parameters for insulated wire bonding.

Looping considerations

Looping is of critical importance in standard wire bonding with bare gold bonding wire, as the loop profile for each group of wires must be planned carefully to prevent electrical shorting. With bare wire, electrical shorting can occur between adjacent wires (wire sway, leaning wires), between tiers of wires (tight loops, domed loops), and between wires and the microchip(s) in the package. These electrical shorts may exist immediately after wire bonding, or may occur due to mold compound flow patterns during encapsulation of the microelectronic package.

Using an insulated bonding wire can eliminate most of the previously mentioned shorting risks, when used in a recommended manner.

During wire bond loop formation, aggressive reverse motions occur early in the looping motions, and are primarily responsible for the loop height and loop shape over the ball bond, as well as cold working the HAZ of the wire for improved stiffness. As with bare wire, care must be taken to avoid wire neck damage, as this can lead to mechanical failure of the wire during mold flow stresses or over the life of the device. With an insulated bonding wire, these aggressive capillary motions can also damage or remove the insulating material in the region close to the ball bond. For very low loop heights, in the author's experiences to date damaging the insulating material is currently unavoidable. However, in most applications the location of the damage to the insulating material is typically not a concern because the damage is not in a region where wires will touch in any event.

During looping motions, the capillary rises above the microchip surface while the bonding wire is anchored by the first bond. As the capillary slides up the wire, it is common practice to have some ultrasonic energy vibrating the capillary to help reduce friction. This setting is commonly referred to as USG 'bleed'. With an insulated bonding wire, this ultrasonic vibration can cause the wire to strike the side of the capillary, leaving periodic marks in the insulating material. It is advised to reduce the ultrasonic vibrations of the capillary from standard bare bonding wire setting to approximately 0 to 10% of the standard setting. The insulated material has a relatively low friction coefficient.

For longer wire spans, as the capillary slides up the bonding wire, certain movements are required to form kinks or bends in the bonding wire. These kinks are critical for standard bare wire bonding as they are designed to maintain loop to loop consistency and to resist wire sweep by increasing the stiffness of the loop structure. For insulated bonding wire, these kinks may be areas where the insulating material can become damaged or removed by aggressive contact with the capillary. This damage is typically minor compared to that which can be caused by the reverse motions immediately above the ball bond. To maintain insulating material integrity, it is suggested to minimize the number of kinks, and if kinks are necessary, to use a larger radius bend as opposed to a sharp kink. As previously mentioned, it is recommended to reduce USG bleed parameters that control capillary vibration during kink formation in order to minimize the risk of damage to the insulating material. Reducing unnecessary kinking motions made possible by the use of insulated wire also saves overall bonding time as the looping span process can consume up to 70% of the time used in a typical bonding cycle.

Second Bond Considerations

The second bond formed during the ball bonding process must achieve two requirements; firstly to form a strong stitch bond to secure the wire loop over the life of the device, and secondly to form a tail bond to secure the wire tail until it is meant to be broken. Capillary geometry, bonding material properties and cleanliness can all impact the second bond process stability and the size of the process window.

For an insulated wire, the presence of the insulation can inhibit second bond formation unless certain recommendations are considered. Using typical bare wire parameters for an insulated wire will result in a significantly weaker stitch bond than bare bonding wire. In addition it will be difficult to get the tail bond to hold until the tail is ready to be broken if bare wire parameters are used. In order to achieve parameters that result in strong second bonds, insulated wire second bond techniques will be discussed which improve both stitch bond and tail bond strengths.

In all cases, the goal of a strong second bond with insulated wire is achieved by exposing the core bonding wire to the bonding material. To date, it has been found that this can occur through the use of three methods: (1) using high contact velocity, (2) using high force, and/or (3) by scrubbing the wire and the bonding surface interface.

In the first strategy - using high contact velocity, the insulated wire is rapidly deformed between the capillary and the bonding material. In order to achieve this, the wire bonder parameter that controls the capillary velocity at the time of contact is typically set 50% to 100% higher than that used for bare bonding wire. This initial high rate of deformation cracks the insulating material on the insulated wire properly exposing the core bonding wire for welding to the bonding material.

A second strategy used to achieve the goal of exposing the core bonding wire to the bonding material is to use a typical capillary velocity, but to also apply high force and low power for a short period of time as soon as the wire bonder detects the wire is in contact with the bonding material,. This initial force or contact force may be 100% to 200% higher than a typical bonding force for a bare bonding wire process. The duration of this high force period is generally 1 to 3 milliseconds, and ultrasonic power is 20 to 40% of typical second bond power settings. The goal of this method is to achieve 80% of the second bond deformation very quickly, and then to use the bonding parameters to optimize the conditions for forming a weld joint between the bonding surface and the exposed core bonding wire.

Another strategy for forming a robust second bond is to scrub the bonding wire on the bonding material. This technique relies on mechanical abrasion of the insulation to expose the core bonding material. Each wire bonding system has proprietary methods to control capillary motions to generate a scrubbing motion. If used correctly, the stitch bond of an insulated bonding wire can achieve 80 to 90% or greater of the strength of a bare bonding wire stitch bond, without a material increase in the bond time.

For difficult materials to bond on, or if stronger second bonds are required, then there are two further techniques the authors have experienced for optimization. After forming an initial second bond, many wire bonding systems can move 2 to 10 microns towards the ball bond and then repeat the second bond stage. With correct parameters for the repeated second bond, the stitch bond length can be increased and shape better controlled for a wider cross sectional area at the heel, thus improving stitch strength. Another method available is to weld a ball bump over the stitch bond, known as a security bond. This method can also significantly increase the stitch bond strength of an insulated bonding wire, but at the cost of a longer bonding cycle time. This cycle time may be offset however by the reduction in time achieved by simpler looping considerations made possible by insulated wire.

Free Air Ball Formation Considerations

Free air ball (FAB) formation characteristics vary significantly between typical bare bonding wire and insulated bonding wire. With a typical bare bonding wire, FAB parameters are optimized to obtain the required FAB diameter, most consistent FAB diameter, and minimum HAZ length.

When comparing a typical bare wire to an insulated wire, the first significant observation is that for equal parameter settings, the insulated wire will yield a larger FAB. Figure 3 shows a comparison of Microbonds' X-Wire^{TM} and the same bare used to make X-Wire^{TM}.

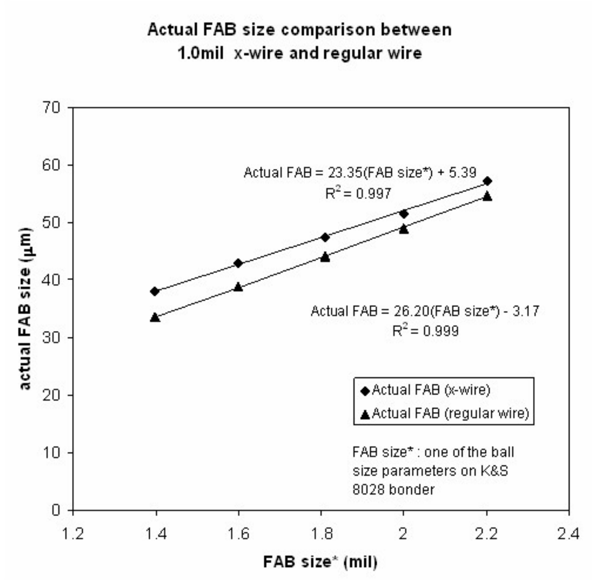

Figure 3: Comparison of FAB diameter between X-Wire^{TM} and bare bonding wire.

The second significant observation is that of the behavior of the insulating material around the location of the FAB. Some previous insulating materials were known to melt up the wire to approximately the HAZ or beyond and agglomerate into a large polymer bead [3]. The material invented by Microbonds for the X-Wire^{TM} product has the insulating material split into watermelon stripes of relatively regular width around the FAB. .

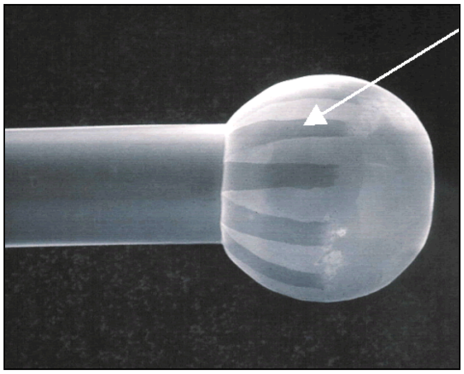

Figure 4: Free Air Ball (FAB) formation of insulated bonding wire, showing characteristic 'watermelon' striping pattern.

In order to achieve the best combination of FAB diameter, FAB diameter consistency, and minimal insulating material on the bottom of the FAB for insulated wire, several shifts in FAB parameters away from typical bare wire FAB parameters have been observed to be successful. The first and largest change, relative to bare gold bonding wire, is to use a lower EFO current. Using 25um diameter bare wires as an example, depending on the wire bonder manufacturer, the EFO current will be in the order of 30 to 40 milliamps for a bare bonding wire. For an insulated wire, the optimum EFO current is generally in the range of 20 to 28 milliamps. This shift will require an increase in the EFO time setting, and for insulated wire, depending on the target FAB diameter, this will be in the order of 800 to 1200 microseconds.

The vertical distance between the top of the EFO wand and the tip of the bonding wire is generally defined as the EFO Gap. In most applications, for insulated wires, the gap setting should be 20 to 40% closer than for bare wire. Significantly changing the EFO Gap may lead to golf clubbed FABs where the FAB has solidified asymmetrically, inconsistent FAB diameters, wire bonder errors regarding an inability to form an EFO arc or improper EFO arc formation, and potential for insulating material residues on the bottom of the FAB.

Automatic Wire Welding Detection Systems

The automated wire bonders supplied by many manufacturers have the ability to determine if a first bond, stitch bond and/or a tail bond has lifted at an inappropriate time. Although the working nature of these systems is highly proprietary to each wire bonder manufacturer, it has been observed that some changes in settings may be necessary to accommodate an insulated bonding wire.

In the instance of false error messages, whereby there was a good weld formed but the wire bonding system generated an error message, the following suggestions can help. If there is a threshold or sensitivity setting, it has been observed that a reduction to approximately 20 to 40% of the bare bonding wire setting can eliminate the false error messages yet allow true error messages for an insulated bonding wire. It has also been observed that reversing the polarity of a DC based detection system can also eliminate the false detection error messages.

Future Developments

With the release of X-Wire™ insulated bonding wire, development of wire bonding and packaging techniques is evolving rapidly among the supply chain, the packaging assemblers and the IDM end-users. Key developments anticipated, and in progress, include: Optimized capillaries, Stand-off Stitch (SSB) bonding, Second bond strength enhancers, FAB formation techniques, Bonder

Software, Quality control techniques, and Insulated Copper Bonding Wire.

Conclusions

Insulated bonding wire has been a long sought after roadmap technology for advanced packaging applications. In particular, because insulated bonding wire extends the lowest cost, flexible wire bonding infrastructure, it can be used immediately to solve yield problems in manufacturing, as well as to enable complex future package layouts. Smooth integration of the insulated bonding wire into the assembly environment is critical to realizing the economic benefits of the technology. In particular, the wire bonding process is the important first process step which the insulated wire must be compatible with. Important differences between using X-Wire™ insulated bonding wire and standard bare gold bonding wire have been discussed, including specific techniques and parameters which have been shown to date to yield the best results.

References

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