Assembly Using X-Wire™ Insulated Bonding Wire Technology

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Insulated Bonding Wire is a new technology which is rapidly gaining acceptance as a viable solution for assembling higher pin count, finer pitch, multi-row and multi-stack devices. Because insulated bonding wire extends the capabilities of the low cost wire bonding assembly infrastructure, it has been identified on the 2006 ITRS Roadmap for Semiconductors, as a cost-effective solution to enable complex package designs, enhance package performance, and improve the yield of high-density packaging.

In order to successfully implement insulated wire bonding, the technology must integrate readily into the packaging and assembly infrastructure and supply chain, which encompasses wirebonding as well as end-of-line processes such as plasma and molding. This discussion will highlight various methods, techniques and processes developed to date that allow insulated wire packages to be assembled with high yield and reliability using current production equipment.

Insulated Wire Bonding

The semiconductor industry has been seeking a viable insulated wire bonding solution for almost as long as wirebonding technology has been available. The benefits of insulated wire bonding have been well known and clear for many years:

Summary of Insulated Wire Benefits

1. Leverages proven expertise in wirebonding to achieve lowest cost/highest performance I/O's by facilitating multi row, area array and stacked die.
2. Allows use of the Z dimension as well as wasted space created by parallelism of bare wires.
3. Conforms to proven bare wire assembly processes with minimal disruption.
4. Facilitates movement to finer diameter gold wires as well as to copper interconnects.
5. Decreases yield loss due to wire sweep or complex package layouts.

Integration and Assembly of Insulated Bonding Wire into the Wire Bonding Infrastructure

It is important to note that in order to attain the benefit of insulated wire, integration into the existing infrastructure should be backwards compatible and relatively straightforward, with low capital cost investment. To that end, it is important to discuss new process windows that are required to successfully implement insulated bonding wire technology in the packaging and assembly environment.

Insulated Bonding Wire – Diameter and Alloys

Currently the insulated wires that are available for commercial use are gold-based alloys, in diameters of $20\mu m$ and larger. The proprietary coating process for X-Wire is 'additive' meaning that it can be applied to any alloy, including special doped bond wires, copper bonding wire, and finer diameters gold bonding wires.

Wire Bonding Considerations

With the proper knowledge and correct use of wire bonding parameters, insulated wire bonding can achieve bond strength equivalent to bare bonding wire.

Ball Formation and 1st Bond

Generally, the ball bonding of insulated wire achieves ball shear values comparable to non-insulated wire bonding. However, optimization of the FAB may be quite different. Insulated wire FAB formation focuses on selecting the correct parameters such as: tail length, EFO current, EFO gap, and EFO time.

A unique attribute of X-Wire™ insulated wire is the characteristic 'watermelon' striping pattern on the free air ball, after ball formation, as seen in Figure 1. When done properly, the bottom of the ball is predominantly clean; however, the top surface of the ball contains remnants of split coatings.

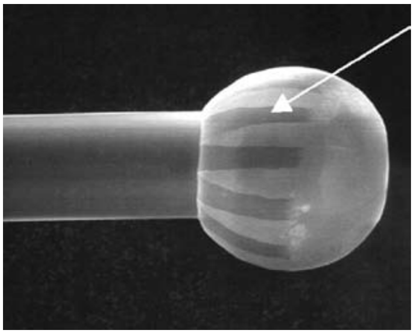

Figure 1. Free Air Ball (FAB) formation of insulated bonding wire, showing characteristic X-Wire™ 'watermelon' striping pattern.

The most notable difference for insulated wire is EFO gap (the gap or distance between the end of the wire and the top of the EFO wand) and EFO current. In general, insulated wire requires shorter EFO gap and lower EFO current relative to bare wire to achieve optimum FAB quality.

Stitch Bond Optimization

Second bond or stitch bond, has been the historical weak point of earlier insulated wire technologies. Therefore, much of the development of X-Wire™ insulated wire has been focused on providing a coating material which easily cracks, but only at the second bond, using the available wirebond ultrasonic energy and other second bond parameters, as required.

Standard techniques for making a strong second bond have been developed to work with the coating's native ability to crack at the desired time and place. Techniques include: (1) applying high initial bonding force with low ultrasonic energy,

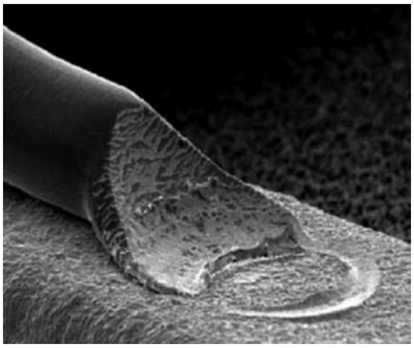

Figure 2. Stitch bond formation of X-Wire™ insulated bonding wire, showing cracking of coating at second bond.

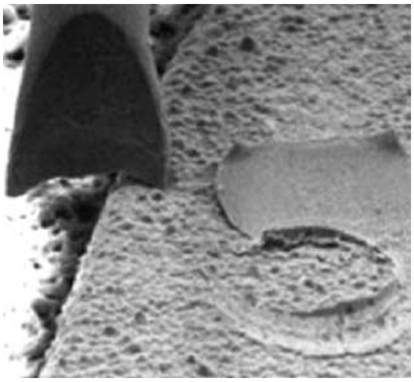

Figure 3. Example of acceptable stitch bond strength for X-Wire™ insulated bonding wire, after peel test. *Wire bonding courtesy of ASM Pacific.*

(2) applying high initial impact during touch-down, and (3) providing slight scrub motion during second bond to increase the level of coating removal for very high strength bonds, or surface finishes that are difficult to bond.

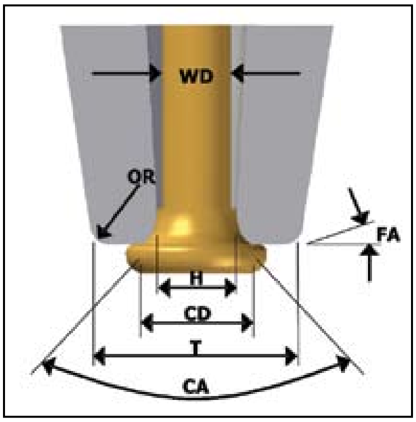

Figure 4. Capillary Dimensions. *Source: SPT.*

Capillary Selection

Because X-Wire™ uses stock catalog capillaries, selection of a suitable capillary for insulated wire is similar to bare wire, with a few minor considerations: (1) hole size, (2) outside radius, and (3) tip finish. Unnecessarily large capillary hole size is not recommended. A smaller hole size is preferred for coated wire. The smaller hole does not scrape insulating coating during looping process, and maximizes the capillary area in contact with the stitch bond. The capillary tip finish recommended is a matte for insulated wire as compared to a polished surface for bare wire. Recent advancements in capillary surface finishing, such as the Stitch Integrator™ capillary from SPT, allow for even further improvement in a robust stitch bond.

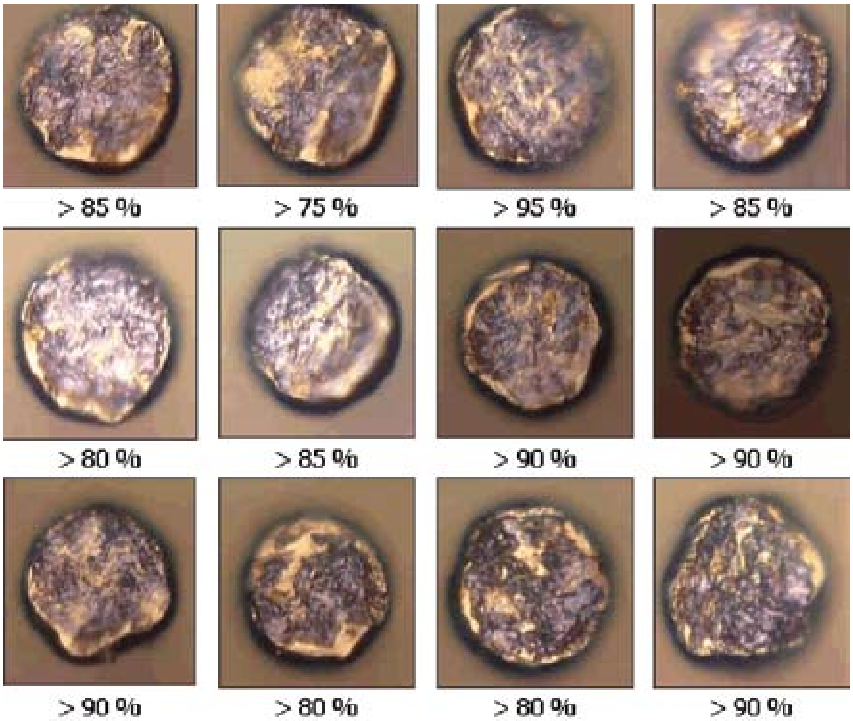

Figure 5. Inter-metallic (IMC) formation of insulated bonding wire bonds.

IMC Testing

Figure 5 shows 12 optical images of the bottom of etched X-Wire™ bonded balls at time = 0. Inter-metallic compound (IMC) coverage on the first bonds formed with X-Wire™ is shown as the dark regions and the percentage coverage of dark region was calculated for each image. The aluminum metallization on the chip pads used in this study was about 0.7 microns thick with 1% silicon and 0.5 % copper. IMC of all the X-Wire™ bonds observed at zero hours exhibits values greater than >75 % coverage.

Wire Looping

An important attribute of insulated bonding wire is the ability to allow wires to touch during bonding or during molding as a result of aggregate molding stresses. This capability alleviates some of the previous requirements of precision looping algorithms and special stiff bond wire alloys, which have been implemented to minimize wire sweep. With insulated wire it has been found that, for the same wirebond connection, fewer kinks are required and preferred and overall cycle time is reduced.

Design Rules for Insulated Wire Layouts

Insulated Wire allows wire routing configurations which were previously prohibited, effectively removing restrictions on current bare wire bond design rules. However, insulated wire must be used with care to take advantage of the flexible routing properties while avoiding potential limitations.

Acceptable Bond Layouts

The current version of insulated bonding wire, known as X-Wire 2.5™, allows wire touching and crossing, wire sweeping, long wires and wires beyond current exit angle restrictions. Examples of the type of acceptable layouts are illustrated in Figure 6.

As mentioned, it is also important to understand layouts which are not currently recommended for insulated wire bonding. Because insulated wire allows wires to touch, wire configurations which are very dense become possible. In these cases, the wires may become trapped in place and exposed to higher than normal stresses from mold flow – particularly filler flow. Therefore, it is recommended that the wires not be trapped, or hard 'pinned', during bonding, which should not be the case during normal bonding.

In understanding the current boundaries, two new concepts are defined for insulated wire: (1) Wire pinning, and (2) Wire stacking. Wire pinning occurs when a second wire is bonded down onto a first bonded wire to cause significant deflection on the first wire, restricting the freedom of motion of the first wire bonded. Wire

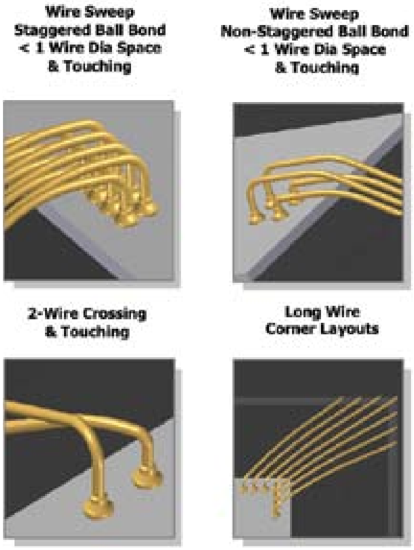

Figure 6. Example layouts and design rules for acceptable insulated bonding wire packages.

stacking is defined as three or more wires bonded such that they are in contact, with the all of contact point being within a tight region. Readers will observe that forces which pin the insulated wires which come close to the forces required to cause a good second bond may cause the insulation to be violated to the point of risk of shorting. Future product releases of X-Wire will remove these deflection restrictions allowing even more design layout flexibility. Examples of wire pinning and stacking are shown in Figure 7.

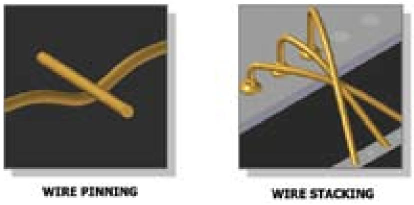

Figure 7. Examples of future layouts of insulated bonding wire, defined as wire pinning and stacking.

Plasma Cleaning of Insulated Wire

After the wirebonding process, organic packages may be subjected to a plasma cleaning step prior to transfer molding. This step is implemented to clean activate the substrate surface which will promote adhesion of the mold compound and reduce the risk of mold-to-substrate delamination. (X-Wire™ has been tested to confirm a lack of delamination in molded X-Wire™ packages) Therefore, it is important to find plasma recipes and configurations which are compatible with the coatings on the insulated wire.

Through various studies and experiments, it has been found that for insulated wire, pure argon gas is preferred over other commonly used gas mixtures, such as argon-oxygen or argon-hydrogen. Alternate gases are also currently in development to further expand the process windows for insulated wire compatibility.

A secondary important factor is the shelf configuration and uniform distribution of plasma. Due to the inherently unstable nature of plasma energy, it is found that in some cases the plasma may be not evenly distributed within a large chamber. In order to minimize this effect, it has been found there are preferred shelf configurations to smooth out the plasma distribution and minimize 'hot' spots. This configuration, using argon gas, allows the insulated wire to be used at typical plasma parameters, such as those shown below:

Equipment	March PX-1000
Gas	Argon
Power	< 400 W
Pressure	100-260 mT
Time	< 400 s

In-line plasma processing systems, such as the I-Trak™ from March Plasma, are becoming a popular alternative to batch processing. Such systems allow individual strips to be shuttled in and out of the plasma station, via automated strip handling conveyors. From a process standpoint differences are the small size of the chamber, and the shorter duration of plasma exposure. The small chamber size allows for a more uniform plasma energy distribution across the strip, which is preferred.

Transfer Molding of Insulated Wire

As mentioned previously, insulated wire provides the benefits of allowing wire touching without the risk of shorting, when used correctly. The design rules of the previous section providing guidelines for recommended layouts should be followed for the current version of X-Wire™ insulated wire, release 2.5. Future roadmap releases will expand the bonding deflection and other process windows.

In terms of molding compound compatibility, insulated bond wires have been tested with the most popular mold compounds from Nitto Denko and Sumitomo. Green compounds have also been tested and are highly recommended.

In terms of process conditions, it is advised to follow standard procedures currently in place for high yield molding. Insulated bonding wire is coated and prevents shorts due to wire sweep; however, it is not recommended to increase mold transfer pressures and lower transfer times beyond what is the norm for bare wire.

Reliability Testing

A range of reliability testing has been performed on X-Wire™ insulated wire by IDM, assembly sub-contractors and supply chain companies. The insulated wire has shown to have high reliability per JEDEC standard specification. A few examples of typical testing, and results for insulated wire, are shown in Table 1.

Conclusion

Selection of packaging technology involves making difficult tradeoffs between economic and technical factors. For newer technologies, infrastructure integration costs are often the deciding factor in the timing of adoption. Insulated bonding wire is a roadmap technology that can lower interconnect cost, while providing the desired benefits. New process windows have been developed and detailed, which allow X-Wire™ insulated bonding wire to be used on existing packaging assembly lines.

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Acknowledgement

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	Assembly Subcontractor	ASIC Designer
Package Type	MAP BGA	PBGA
Package Size	14 x 14mm	40 x 40mm
Package I/O	409	503
Pre-conditioning	JEDEC L2 / 260C	JEDEC L3 / 245C
High Temp Storage	1000hr @ 150C	1000hr @ 150C
HAST	130C / 85%RH, 100hr Unbiased	130C / 85%RH, 100hr 4V
Thermal Cycling	-65C / +150C 1000 cycles	-55C / +125C 2000 cycles

Table 1. Insulated Wire Package Reliability.