Overview of X-Wire™ Insulated Bonding Wire Technology

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Abstract

As the semiconductor industry continues to move towards higher pin counts, finer pitches, multi-row bonding pads and multi-stacked die devices, interconnection through wire bonding becomes a challenge for today's semiconductor packaging processes. X-Wire™ is an insulated (coated) bonding wire developed by Microbonds Inc. that enables complex package designs, enhances package performance, and improves the yield of high-density packaging. This paper outlines insulated bonding wire technologies, based upon X-Wire™, and related complementary packaging and design technologies. The material design considerations for insulated bonding wires and its performance, and packaging and assembly considerations will also be addressed.

Key words: Insulated bonding wire, HDI (High Density Interconnect), Wirebonding, Reliability

Introduction

Insulated bonding wire has long been sought after for high Input/Output (I/O) density wire bonded applications, and a number of attempts have been made in the past have limited success [1-4]. Based on the current International Technology Roadmap for Semiconductors (ITRS) [5], it is forecasted that the number of leads per device will reach as high as 550-990 for cost/performance devices, and 3180 for high performance devices in 2006. A new insulated bonding wire, namely X-Wire™, provides a cost effective means of utilizing the existing wire bonder-based infrastructure, to meet the challenges outlined in the ITRS roadmap.

The following sections outline the basic requirements for the implementation of insulated bonding wire in terms of: (a) material selection and performance considerations of the insulating dielectric coating, which produces the final coated wire known as X-Wire™, (b) integration into existing assembly infrastructure (wire bonders, plasma equipment, molding equipment, etc.), (c) free air ball formation and inter-metallic formation (growth), and (d) bondability of second bond (stitch bond). The brief discussion will extend to packaging related designs, using insulated X-Wire™, and the insulated bonding wire capabilities including yield improvement and new enabled package designs (known as X-Pax™). Preliminary reliability assessment data is also provided.

Material Selection and Performance Considerations of X-Wire™ Insulated Bonding Wire

The following are five key areas of consideration for the development of an insulated bonding wire:

(a) Application considerations (performance requirements)
   i. Axi-symmetric and spherical free air ball (FAB) formation, and stitch bond bondability (able to bond through the coating)
   ii. Dielectric strength must be high enough to preserve insulation properties at device application voltages (e.g. = 5V operating voltages)
   iii. High crack resistance and adhesion to gold so to prevent flake off upon Electronic Flame Off (EFO), wire looping, and bonding processes

iv. Minimal change to the base gold wire properties (e.g. breaking load, elongation etc.) after the coating processes

v. Resistance to common solvents (e.g. alcohols, acetone, and DI water) that may be used during 1^{st} and 2^{nd} level packaging processes

vi. Capable of withstanding temperatures up to 300 °C for short durations (e.g. 10 – 15 sec at 260 °C reflow temperature used for lead free processes)

(b) Physical and chemical considerations

i. Low level of ionics (below 20ppm) in the insulating material

(c) Infrastructure considerations

i. Use of exiting industry standard equipment such as wire bonders

(d) Environmental considerations

i. Low Volatile Organic Compound (VOC), toxic-free during free air ball formation

X-Wire™ is designed to meet the requirements of ITRS future applications for ultra fine wire, high I/O density applications. The maximum recommended operational voltage for the current generation of X-Wire™ (product version called X-Wire™ 2.0), is 5V. This specification covers most of the mid to high digital IC applications, such as 5.0, 3.3, 2.7, and 1.8V.

X-Wire™ is capable of preventing short circuits between bond wires in contact, thereby improving device yield. Specifically, wire sweep during the molding process has been a major challenge for PBGA packages with high-density interconnections. X-Wire™ allows crossing and touching wires, either intentionally and/or induced by wire sweep during the transfer molding process. This capability helps to enable new applications, such as chip-to-chip bonding (Figure 1), complex multi-tiered stacked die (Figure 2a and Figure 2b), System-in-Package (SiP), Package-on-Package (PoP), multi-tier wire bonding (Figure 3), and area array applications.,

Figure 4 shows an example of crossing and touching bonded wires in a device. Direct chip-to-chip wire bonds can be utilized for critical net routing to minimize the inter-chip delay, which may optimize the electrical performance of the package.

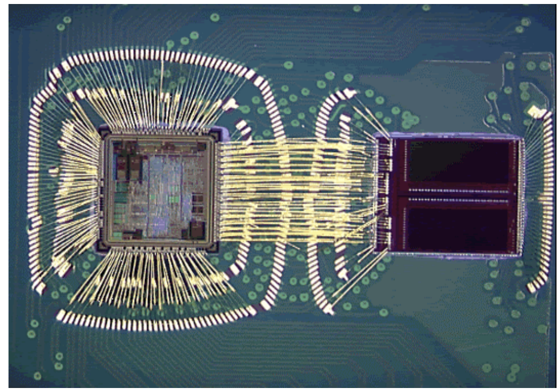
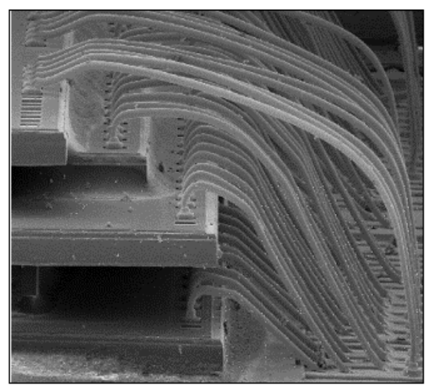
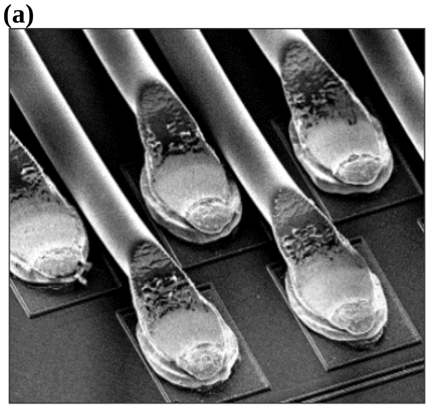


Figure 1. Long Wire Chip-to-Chip Wire Bonding Using X-Wire™. The Inter-Chip Interconnect Bypasses the Substrate Routing and Vias, Enabling the High Speed Performance of the Device.

The inter-chip interconnection bypasses the substrate routing and vias, potentially improving the high speed performance of the device.

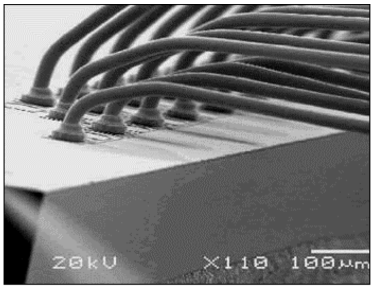


(a)

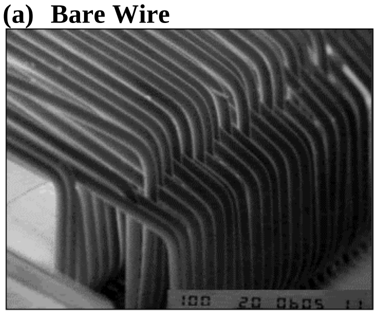


(b)

Figure 2. Stack die. (a) Side View of Bonded Stack Die. (b) In Order to Minimize the Packaging Thickness, Reverse Bonding is Utilized (Stitch-on-Ball).

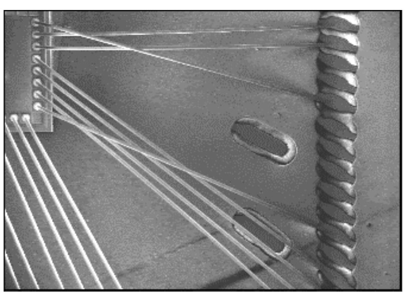


(a) Bare Wire

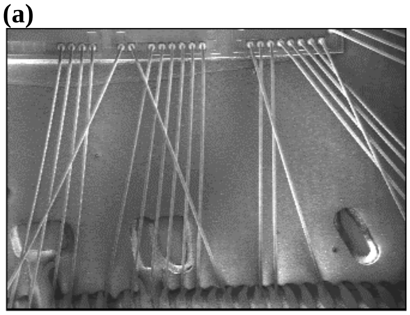


(b) Insulated Wire

Figure 3. High-Density Wire Bonding of (a) Bare Wire - Multi-Tier Wire Bonds. The Interconnect Wire Must be Spaced Carefully, in Order to Prevent Short Circuits. (b) Insulated Bond Wire - Multi-Tier Wire Bonds. The Interconnect Wire can Touch Each Other Without Electrical Shorts, Thereby, Increasing the Wiring Density of the Device.



(a)



(b)

Figure 4. Example of Crossing Wires in the Same Tier using X-Wire™

While bare wires must be spaced carefully, at least one wire diameter apart, in order to prevent shorts. However, X-Wire™ insulated bonding wires can touch each other without electrical short circuits, thereby, increasing the wiring density and layout flexibility of the device.

Wire Bonding using X-Wire™

In order to achieve maximum wiring density, the coating thickness must be thin enough so that the insulated wire does not require an increase of capillary hole diameters (i.e., to achieve the same bond pad pitch capability as for the same diameter of bare wire). In addition, the insulated bonding wire should not leave residue that contaminates the device (chip/substrate surfaces) and/or capillary, or emit VOC during free air ball formation that is harmful to the production environment (see previous section of performance characteristic of X-Wire™).

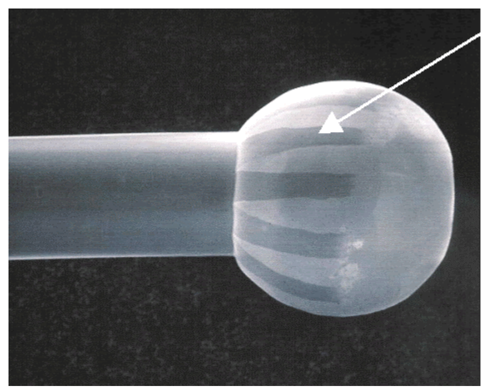
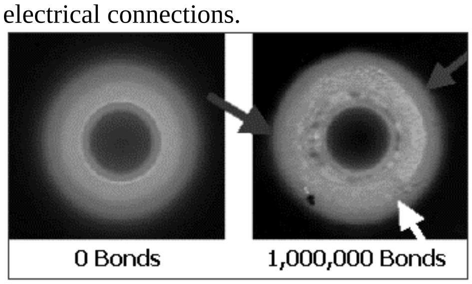
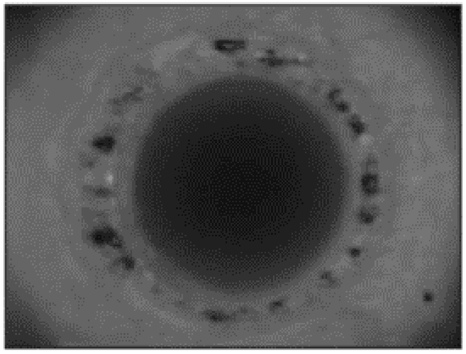


Figure 5. Typical "Water-Melon" Stripes on a Free Air Ball (FAB) of X-Wire™. Note the FAB Bottom is Free of the Coating After EFO Process.

The formation of a successful first bond of X-Wire™ is dependant upon the capability of forming a round symmetric free air. During EFO ball formation, the coating splits into a characteristic and unique "water-melon" stripe pattern part way down the ball (Figure 5), with the bottom half of FAB free of insulated materials in order to form reliable electrical connections.



(a) Capillary Inspected Before and After



(b) Negligible Build Up Observed After 1 Million Bonds

Figure 6 (a). BottomViews of a Capillary Tip Before (Left) and After (Right) 1 Million Bonds.

Figure 6 (b). Higher Magnification View of the Capillary Tip as Shown in Figure 6 (a).

The capillary after 1,000,000 bonds exhibits negligible amount of coating material build up (Figure 6(a) and 6(b)). Figure 6(a) is an image of a standard SPT catalogue capillary at 0 bonds, and the same capillary after 1 million bonds using X-Wire™. It is observed that after 1 million bonds, the capillary shows no coating materials contamination. Figure 6 (b) is a higher magnification image of the capillary hole of Figure 6 (a) showing small amounts of residues, which were picked up from the substrate pads.

Indoor air quality monitoring for VOC emission during wire bonding process was conducted in accordance with Environmental Protection Agency (EPA) test method TO-17 [ref.6]. The EPA TO-17 test consists of sampling air into absorbent tubes followed by thermal desorption and analysis with mass selective (MS) and conventional gas chromatography (GC) detectors". The air samples were collected from two locations using an absorbent; one close to the bond heads (without interfering with the bonding process) and the other one close to the operator's face. Both samples showed that all VOCs measured were well below their respective criteria defined by EPA standards.

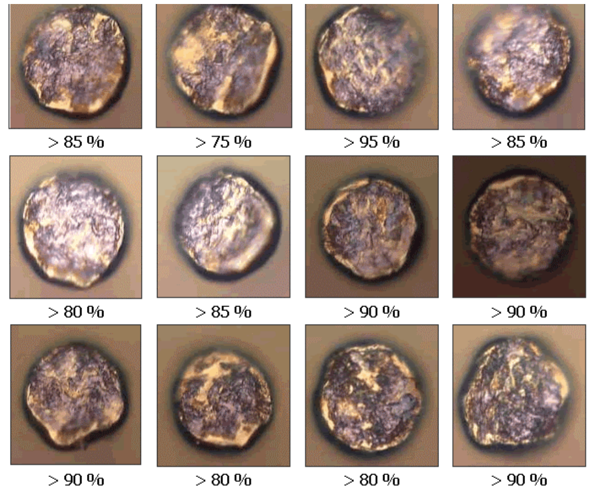


Figure 7. Intermetallic Compound (IMC) Coverage Formation at Zero Hours Using X-Wire™ and Bare Wire All X-Wire™ Samples Exhibit Greater Than 75% of IMC Formation at Time Zero.

Figure 7 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.

The second wire-bond (commonly known as stitch bonding) using X-Wire™ requires bonding through the coating, and utilizes the current standard thermo-sonic wire bonder process. For X-Wire™, the second bond needs different bonding parameters, compared to bare wire, to crack the insulation, The wire bonding window is within standard bonding parameters for stitch bonding, but may be shifted compared to that of bare wire. Generally, slightly lower stitch pull strengths are obtained from X-Wire™ relative to bare wire. Figures 8 and 9 show SEM images of stitch bonds before and after stitch pull test, respectively, showing a good amount of remaining gold from the stitch bond indicates good bonding in the stitch bond region. Figure 10 shows X-Wire™ stitch pull strengths data bonded on a standard bonder (K&S 8028) for 3 different wire diameters, 20, 23 and 25 µm, each bonded on laminated PBGA substrates. All the X-Wire™ diameters showed acceptable pull strength on PBGA laminated substrates (See Figure 10).

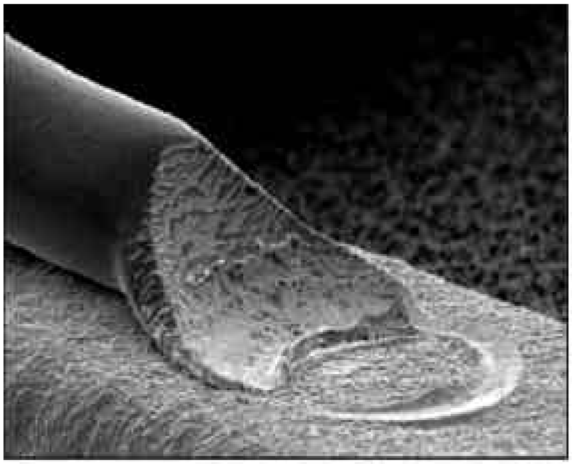
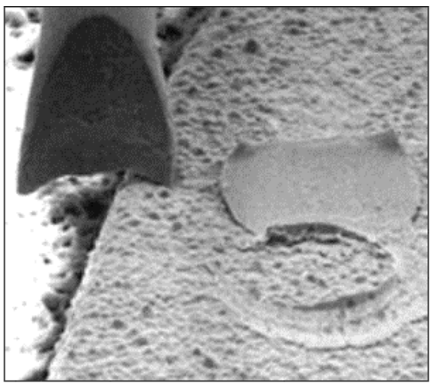
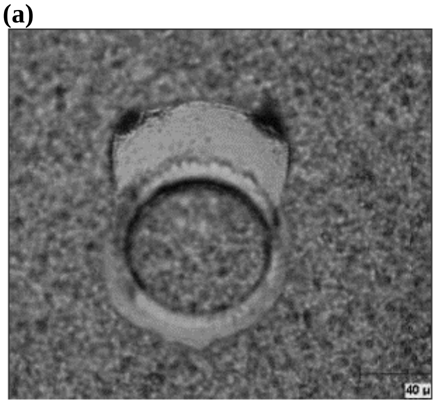


Figure 8. SEM Images of X-Wire™ Stitch Bonds



(a)



(b)

Figure 9. SEM and Optical Images of the Stitch Bonds Remaining after Stitch Pull Test

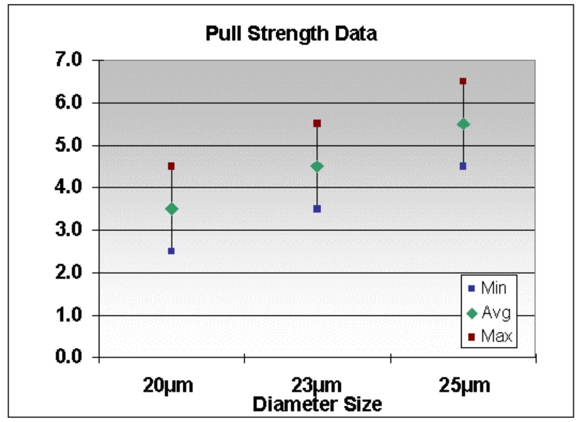


Figure 10. X-Wire™ Pull Strength Data of Three Different Wire Diameters; 20, 23, and 25 µm

X-Wire™ Reliability

The current generation of X-Wire™ (X-Wire 2.0) is designed to withstand the manufacturing process, storage and device operating conditions listed in Table I.

Table I. X-Wire™ Application: Manufacturing Storage and Device Operating Conditions

	Temp. Range	Max. Condition	Notes
Manufacturing Process Conditions	+25 to +260 °C	< 12 sec @ Tpeak = 260°C (solder reflow)	Leadfree (Pb-free) soldering condition
Storage Conditions	-40 to + 85 °C		Molded or encapsulated devices/ assemblies
Device Operating Conditions	0 to + 70 °C		Commercial Level 1 (Internal specification)

Reliability and feasibility studies of X-Wire™ technology were carried out at various industry partners' facilities. The wire bonding was performed at OEM (tier-1) manufacturing facilities with standard production wire bonders such as: ASM Eagle 60, Eagle 60AP, K&S 8028, Maxum-plus and on package types such as PBGA and leadframe.

Table II shows a summary of the reliability test results from a 503 PBGA device. Three lots of the devices were built using two K&S 8028-pps wire bonders. The die in the device consisted of three row bonding pads with bond pad pitch of 90 µm (effective bond pad pitch of 30 µm). The wire bonds were made intentionally in cross-bond format (Figure 11) with 528 touching wire bonds per device using X-Wire™ 30µm gold diameter wire of 99.99% purity gold wire based X-Wire™.

The reliability assessment consists of the following:

(a) JEDEC moisture level 3 as pre-conditioning (JESD-22-A113-B) with modification to Pb-free solder reflow conditions: moisture load @ 30 °C/60% RH, 192 hrs. Solder reflow @ 245 °C, 3 passes.
(b) Temperature Cycle (TC) (JESD-22-A104-A) condition B, -55 to +125 °C; electrical test points at 500, and 1000 cycles.
(c) High Temperature Storage Life (HTS) (JESD-22-A103-A) at 150 °C; electrical test point at 500 and 1000 hrs
(d) Biased Highly Accelerated Stress Test (Biased HAST) (JESD-22-A110-B) 130°C/85%RH/4.0V at 2 atmospheric pressure for 100 hrs.

Table II. X-Wire™ Reliability Test Summary for 503 PBGA

PBGA 503	HAST/Biased (130°C / 85%RH / 4V at 2 atm.)	Hight Temp. Storage (150 °C/1000h)	Thermal Cycle (-55 to 125 °C)
Lot 1	45/45 pass	45/45 pass	45/45 pass
Lot 2	45/45 pass	45/45 pass	45/45 pass
Lot 3	45/45 pass	45/45 pass	45/45 pass

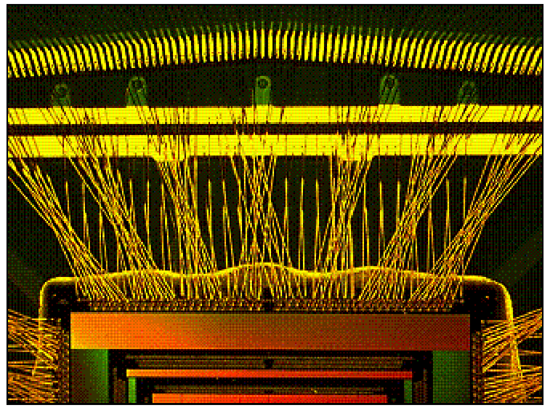


Figure 11. Test Vehicle of 503 PBGA (40x40 mm device) with 528 Wire Bonds in a Cross-Bond Format

Summary

To meet the immediate and future high density interconnection requirement of the industry, Insulated bonding wire technology is a flexible, cost effective way to enable complex package designs, enhance package performance, and improve yield, which are needed. This paper outlines the key technical features of X-Wire™ to date, as well as potential applications using X-Wire™ technology developed by Microbonds Inc. In summary, X-Wire™ technology provides the following benefits:

(a) Dielectric insulating coating on the wire will prevent wire-to-wire shorts.
(b) X-Wire™ is suitable for ultra high density single chip packaging, such as: fine pitch, multi-row wire bonding, and on-chip area array.
(c) X-Wire™ is suitable for multi-chip packaging such as. Stacked Die (SD), System In Package (SiP), and side-by-side chip-to-chip bonding.
(d) X-Wire™ may be used for current manufacturing applications such as: long and corner wirebonds that exhibit wire sweep problems upon molding.
(e) X-Wire™ can enable simplified substrate and the packaging of smaller die.

Conclusions

This paper provides representative test data on X-Wire™ insulated bonding wire technology:

a) Industry wire bond strength specifications on first and second bonds were achieved from 20, 23, and 25µm gold wire based X-Wire™. X-Wire™ shows good ball shape and symmetry.
b) Intermetallic compound coverage of X-Wire™ at time =0 was comparable to that of bare wire and showed to have coverage >75% of the bonded ball area..
c) Test vehicles bonded with X-Wire™ with intentionally crossed and touching wires passed reliability tests (biased HAST, HTS, and TC) after JEDEC moisture level 3 pre-conditioning (JESD-22-A113-B).
d) X-Wire™ is environmentally safe and passed EPA TO17 specifications.

X-Wire™ does not contaminate the capillary even after 1 million bonds.

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