Glass-Insulated Bonding Wire Scales to Support advances in Miniaturization

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ABSTRACT

The semiconductor industry is facing a major challenge today – it must adapt to the constant need to miniaturize, and in order to accommodate this major trend the entire ecosystem must adapt and evolve. While the current standard materials and tools make it possible to scale down to a certain level, it is simply not enough.

Although there are efforts to make smaller wires, wire makers, wire drawing equipment and tool makers are working toward a boundary of existing methods. When wire diameter is successfully reduced, more issues correlated with wire uniformity and production control of the low required tension during the drawing process appear, these may result in low yield and higher cost. Another limiting point is the drawing die which experiences yield issue and high erosion at the very small diameter.

It is clear that there is a need for smaller wire diameter to support advances in miniaturization. There are, however, intrinsic challenges of physics that may limit the ability to manufacture and use such wire, most of which are related to the mechanical strength, and concerns about wire stability and shorting.

This presentation will explore the question of bonding wire scalability, and will discuss a possible solution. Data will be provided to show how glass coated wire may effectively address issues related to the mechanical strength and stability of wire and enable relaxed chip design rules while providing a smaller effective wire diameter on smaller bonds.

Keywords: micro bonding wire, wire manufacturing, wire properties, diameter, scalability

INTRODUCTION

Miniaturization and scalability continue to be a major trend in the semiconductor industry, and they necessitate that the entire manufacturing infrastructure adapt and evolve in order to grow. To facilitate growth and greater miniaturization, it is important that the entire industry works together to attain the new development targets including that of wire bonding.

Miniaturization of bonding is critically correlated with the number of bond pads that must be placed per unit area. In the case of ball bonding, each bond pad must fully accommodate the ball bond within the bond pad, without encroaching onto adjacent bond pads. The ball/pad reduction factor applied in the industry is typically between 70-80%.

Next in line of correlation is the FAB during the process of bonded ball formation. Typically, the FAB is about 10-20% smaller than the bonded ball, due to the squashing of the latter during bonding. At the moment, the limiting factor for this FAB diameter is the wire diameter, assuming a typical BSR (the ratio between the FAB diameter over the wire diameter) is about 1.6-2.0. Assuming the smallest wires currently in mass-production are about 0.6mil (15um) the FAB is about 24-30um, bonded ball about 29-33um and bond pad about 33-36um, and bond pad pitch at best 35-38um.

Table 1 correlation between process stage (BPP) and needed bonding wire diameter to facilitate FAB formation [Harmann]

year of mass production			2005	2007	2009	2013
process / BPP	50	40	35	30	25	20
Bonded Ball Diameter	40	32	29.5	22.5	18.75	15
FAB diameter	32 .4	31 .0	27.0	18.7	15.6	12.5
wire diameter (at FSR=1.6)	20	19	17	12	10	8
wire diameter (at FSR=2.0)	16	16	14	9	8	6

Assuming that ITRS roadmap suggests the bond pitch should be down to 20um in 2013, then wire manufacturing still requires a large leap to get there. Back-calculating indicates the need for wire of 8-10um in diameter. All major wire bonding plants are running about 0.7mil copper wire (18um) and having plans to qualify 0.6mil (15um) within the next year or two. One of the critical factors for not seeking more aggressive targets is the lack of availability of a bonding wire of lower diameter and the entire infrastructure that supports such a process, including bonding machines and capillaries.

Current standard materials and tools make it possible to scale down to a certain level, but attempting to go beyond that leads to the figurative brick wall. Capillary manufacturers are producing caps for 0.6mil wire in mass production having a hole diameter of about 21um. There have been attempts to go as low as 15um, accommodating 0.5mil wires, mainly for Au wire bonding. For copper wire bonding designs, the sizes, to date, have been typically slightly larger.

Wire bonding infrastructure is so extensive that no other chip-interconnection technology can displace wire bonding in the foreseeable future, although other technologies, particularly flip chip, will experience increasing utilization. Increasing miniaturization of electronic circuits has put relentless pressure on wire bonding technology to (1) increase yields (<5 ppm defects); (2) decrease pitch (<30 μm for ball bonds) and (3) provide the lowest possible and ever decreasing cost.

SCALING WIRES – WHY HASN'T IT BEEN DONE BEFORE?

Although there are efforts to make smaller wires, wire makers, wire drawing equipment manufacturers and tool makers were all approaching a boundary with existing technologies. When wire diameter is successfully reduced, more issues correlated with wire uniformity and production control of the low required tension during the drawing process appear. These may result in low yield and higher cost. Another limiting point is the drawing die which experiences yield issue and high erosion at the very small diameter. Furthermore once the wire is drawn to the final stage it has dramatically work hardened and must be recrystallized by an annealing process, which is typically done at about 30-60% of a metals melting point at which, in return, it loses significant strength, which introduces further breaks – lower yield and higher cost. In order not to break the wire or stretch it (which would weaken its mechanical performance) annealing tension must be controlled at <0.5g which is much less than the tension control capability of the typical dancer arms and pulleys supplying the tension. Here new technologies would be needed to facilitate wire drawing and annealing processes for cost effectiveness.

WIRE PROPERTIES

Even if the wire can be successfully drawn, with great difficulty, and likely excessive cost, the next level of challenges will surface – the properties of the wire itself. As diameter decreases, strength decreases as a square function (0.5 mil is 25% the strength of 1 mil).

Figure 1 RMW wire compared to human hair

Assuming an average copper wire, having a tensile strength of about 200MPa, the force needed to break the wire is only about 10g, making a 0.5mil wire only about 2.5g. Such a low material strength is very difficult to manually handle, and even posing issue to testing strength during the application. The stiffness is a fourth power (0.5 mil is 1/16 the stiffness of 1 mil (stiffness= deflection under a load). This poses many issues to the handling and the application of the wire. In general, elastic modulus is not the same as stiffness. Elastic modulus is a property of the constituent material; stiffness is a property of a structure.

Another inherent issue with lower wire diameters is the electrical performance. Naturally, the current carrying capacity is lower with lower diameter. This needs to be taken into consideration by the packaging designers. Recently there has been a new wire introduced that encases traditional copper wire in glass coating.

Below is a look at how that wire scales vs. traditional copper wire.

If wire properties are not sufficient, the wire will not hold its shape and will sag under its own weight. Here again a stiffer solution might help. Thinking outside the box, the ability to ignore the issue of adjacent wire shorting would ease this pain. However, usually increased strength is correlated to increased hardness, which is detrimental to the

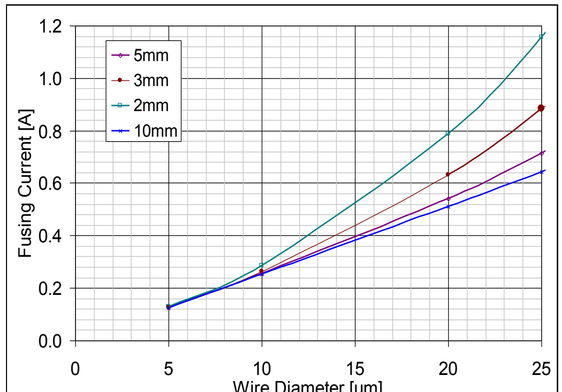

Figure 2 Fusing current (based on calculation) for wires of different wire diameter and testing length

bond. The first bond poses a larger risk of cratering

or bond pad deformation. The second bond poses the risk of lower strength values based on lower deformation and respectively a lower bond area. However, in glass coated wire, some of the strength comes from the glass layer, providing a geometric support. The hardness test shows that the copper core is even softer than a typically highly annealed copper wire, as seen on table 3.

Table 2 comparison of breakload (grams) values for soft, normal and glass coated wire assuming 200, 300 and 400Mpa respectively (RMW wire is referred to as composite, because the glass is a structural member of the wire.)

wire diameter	normal copper wire	soft copper wire	RMW glass composite
25um	9.8	14.7	19.6
20um	6.3	9.4	12.6
15um	3.5	5.3	7.1
10um	NA	NA	3.1
5um	NA	NA	0.8

Table 3 wire hardness values of selected technologically available materials; *refers to the copper core

	wire hardness
normal copper wire	90-100
soft copper wire	85-95
RMW glass composite	75-85*

In normal bonding wire, we need high elongation in copper to ensure sufficient ductility to make a strong second bond. However in case of glass coated wire, the EL/BL of the wire includes the glass, but the glass is not part of the first or second bond. So the wire EL will not be high, however the copper core is still very ductile. From the tensile test chart in figure 3, one can see that the glass plays an initial part of providing strength and limiting ductility, after further elongation, the glass will eventually crack and give way to the extension of the copper.

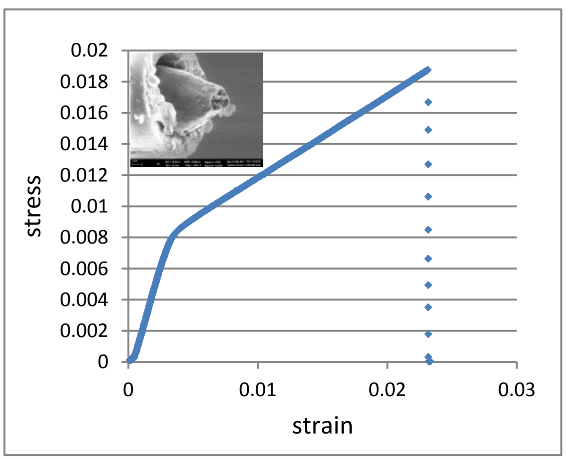

Figure 3 Tensile Test chart of RMW glass coated wire, SEM image of failure mode

HOW THE TECHNOLOGY WORKS

Let's look at the next step, the wire's use in the wire bonder. Users are having difficulty threading the wires and only highly experienced users are able to thread a 0.6mil wire though the wire path and into the capillary, without breaking it.

Further reduction in wire diameter will decrease visibility and more dramatically, decrease the stiffness of the wire, which makes threading more challenging. A wire that is in its geometry stiffer than usual wire would make this process easier.

The next issue is related to the loop formation. A wire is supposed to keep its loop shape, which was imparted from the bonder trajectory during the loop formation (which is most of the time highly advanced with various forward and backwards motions).

The next step in the process is typically the molding process where the wires are heavily exposed to mechanical stress/sweep. Mold compound viscosity and melt front velocities require scrutiny.

Another consideration on the infrastructure is the use of wire bonding capillary as a tool for the bonding machine. Typically made from ceramic, they are currently only available in mass production down to a diameter of about 15um. They are getting increasingly difficult to make, but since there was no wire to drive the dimension, not enough effort has been applied to open these boundaries.

WHY GLASS-INSULATED WIRE WORKS

It is clear that there is a need for smaller wire diameter to support advances in miniaturization. There are however intrinsic challenges of physics that might limit the ability to manufacture and using such wire. Most of the issues are related the mechanical strength, and concerns about wire stability and shorting.

Figure 4 A typical wire bonding capillary, here shown with FAB

It seems natural to think about an insulated wire eliminating worry about shorting. Glass coated wire provides such an

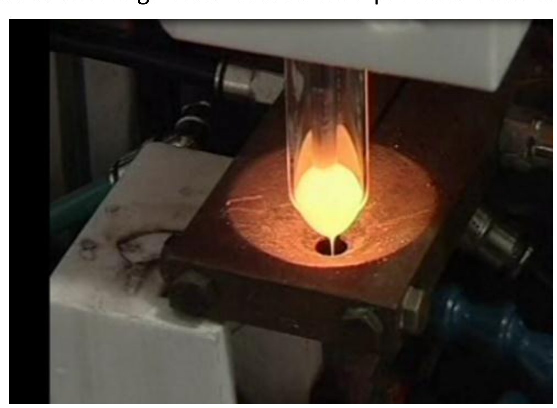

Figure 5 RMW wire pulling machine, induction unit

insulation and slightly inaccurate looping can be accommodated.

The issue of strength (or stiffness in this case) can also be addressed with the glass coated wire. Glass having an inherently higher strength compared to copper, acts not only as a surface layer, but as an active element providing mechanical support to the wire. This leads to much higher strength and stiffness values compared to a bare copper wire, (or any kind of coated wires, be it conductive or insulating).

Looking at the wire manufacturing process from a simplistic view, one could ask: How logical is it to cast the wire at a very large diameter, just to draw it down to a small diameter?

A solution whereby wire can be manufactured directly out from the melt covered by a glass coating is currently being tested and optimized for bonding wire applications. A schematic drawing is shown in figure 11, however dimensions are not to scale and the actual glass layer thickness is about 1um on a 20um wire.

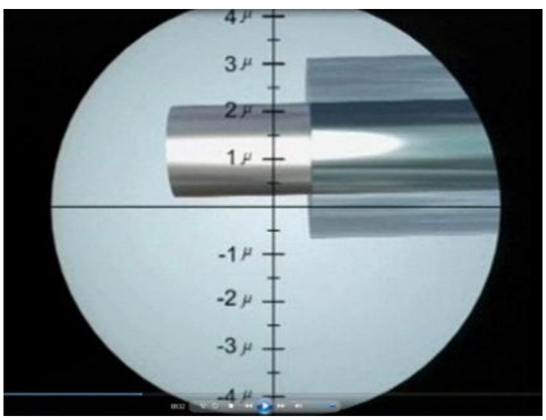

Figure 6 Schematic geometry of a glass coated wire (not to scale)

Glass can greatly increase wire strength and stiffness, yet still provide a smaller, effective wire diameter on smaller bonds. Based on the manufacturing method, a full coverage of glass can be ensured, which in return ensures insulation. In addition floor and shelf life are no longer a limiting factor since there is no exposure of copper.

IMPLICATIONS FOR THE INDUSTRY

The implications of highly scalable glass coated wires on the semiconductor industry are still yet to fully be understood. Insulated wire that allow some instances of wire touching grants greater freedom of chip design. This, combined with the scaled down wires should enable placing more wire on less chip "real-estate" thus keeping up with, or possibly even keeping in advance of the trends of added functionality while increasing miniaturization.

Further, extensive testing is needed in order to discover the full potential and boundaries of this type of wire.

LITERATURE

- G. Harmann
- ITRS Roadmap
- K&S capillary catalogue
- SPT capillary catalogue
- Internal market study

ACKNOWLEDGEMENT

The author would like to thank Dr. Jeffrey Seuntjens and Mr Steven Creswick for their technical feedback, discussion and review, as well as the industry partners SPT, ASM, ITE and tpt for their experimental support

ABOUT THE AUTHOR

Dominik Stephan is the Director for Application and Product Marketing in RED Micro Wire in Singapore. Dominik has been in the field of bonding wire since 2003 with leading manufacturers of bonding wires where he held various positions. He has developed several successful bonding wire products and published many relevant technical papers in local and overseas conferences and journals. Dominik holds a degree in mechanical engineering NUS, Singapore.