Gold Coated Silver Bonding Wire and its Consistent Reliability Performances

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Abstract

Thermal aging of gold-coated silver bonded ball with aluminum bond pads exhibited a stable interface without Kirkendall voids until 4000 hours at 200°C for an un-molded device tested under vacuum. Ball and stitch pull remains nearly the same for aging periods from time zero to 4000h at 200°C. Ball shear showed a slight increase in strength and remained constant until 4000 hours of aging. The growth of aluminides at the bond interface is about 4.5µm for 4000 hours of aging.

The electrical resistance of the bonded ball remains the same until 4000 hours at 175°C for an epoxy molded device, molded with 5 to 7 pH green epoxy molding compound containing low chlorine and sulfur. Interestingly, the bonded ball interface of epoxy molded device sustained 480h on biased Highly Accelerated Stress Test (bHAST) at +20V bias, 130°C, 85%RH. The bonded ball interface is stable until 1000 hours on unbiased HAST (uHAST) at 130°C, 85% RH as well. Cross-sectional observations of the bonded balls revealed the presence of intermetallic phases at the bond interface. However, formation of Kirkendall voids or crack propagation due to galvanic corrosions are absent.

Key words
Bonding wire, thermal ageing, high temperature storage, epoxy molded device, bHAST, uHAST

I. Introduction

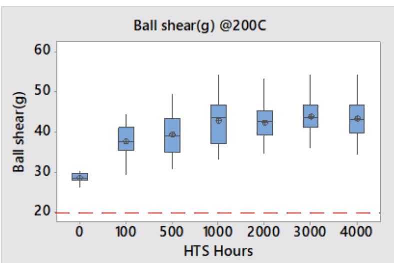
The reliability of a bonding wire is considered the utmost factor to apply in microelectronics devices. Bare and doped gold wires perform well on corrosion-resistant evaluations (unbiased and/or biased HAST/PCT, THB) while suffering from rapid growth of intermetallics and Kirkendall voids on thermal aging (High Temperature Storage (HTS)). Coated and alloyed copper wire reveals a stable interface on thermal aging yet suffers from interfacial galvanic corrosion. Alloyed silver wire behaves the same as copper with galvanic corrosion. In general, during galvanic corrosion, chlorine, and sulfur ions in the epoxy molded compounds (EMCs) attack the bond interface along with moisture. EMCs developed for copper and silver-based bonding wires limit chlorine and sulfur below 20ppm formulated with ion-catchers, demonstrates longer reliability life of copper/silver bonded balls. The present study reports the findings on the reliability behavior of gold-coated silver bonding wire for longer (extended) test durations, and the performances are consistent and similar to previous test evaluations [1-6].

II. Experimental Results

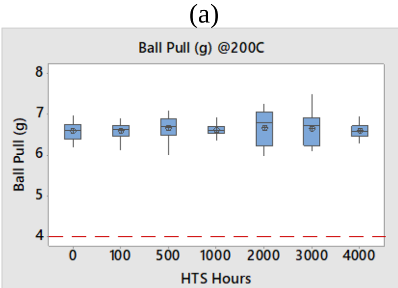
Alloyed silver core was continuously cast using an induction furnace under high vacuum (greater than 10^{-4} torr). At an intermediate wire drawing stage for a diameter between 100 and 500µm. The silver wire core was plated with noble metals, further drawn to fine wire size (15 to 50µm), annealed, and vacuum packed for bonding. Bonded ball and free air ball (FAB) were processed with a Kulicke & Soffa - iConn Wire Bonder under atmosphere without purging protective or inert gases, firing 50 to 70mA EFO current, targeting 1.55-2.0 BSR, and maintaining 760µm (30mil) wand gap. Coated-silver wires were bonded on BGA2x2. Ball/stitch pull, and ball shear were tested using a DAGE 4000-plus Bond Tester. FABs and bonded balls were observed in a Zeiss Sigma Model Scanning Electron Microscope (SEM) for spherical shapes and off-centered balls. Furthermore, the FABs and bonded balls are cross sectioned as per standard metallographic practice, and images were recorded at high magnification metallographic microscope and SEM.

III. Results and Discussion

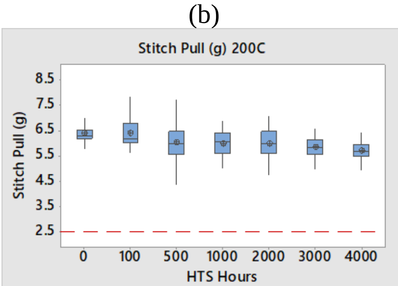
Reliability tests HTS, uHAST, and bHAST were conducted for unmolded and epoxy-molded test device samples. Fig.1 reveals ball and stitch pull values of unmolded wire bonds, and thermal aging under ultra-high vacuum (greater than 10^{-5} torr) remains nearly the same from time zero to 4000 hours. Due to the growth of intermetallic compound at the bond interface, ball shear strength increases until 1000 hours aging and then remains constant up to 4000 hours of aging (Fig.1a). Fig.2 shows the cross-sectioned images of the thermally aged, bonded balls from 500 hours to 4000 hours. The interface is stable for 4000 hours of aging with slow growth of intermetallic layer to a thickness from 3 to 5.2µm without the formation of Kirkendall voids (Fig.2). On ball shear, cracks run in the soft Al bond pad below the thick and hard intermetallic layer (Fig.3a).



(a)



(b)

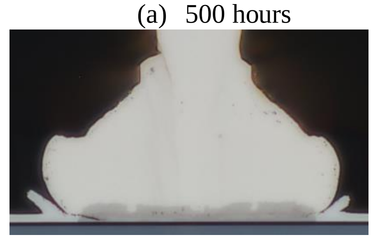


(c)

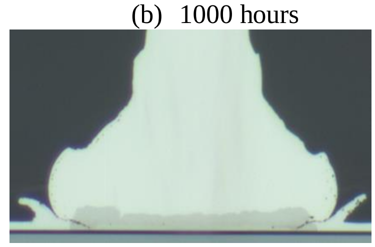
Fig.1 Ball shear and ball/stitch pull of gold-coated silver wire bonds after thermal ageing at 200°C up to 4000 hours (unmolded device bonded with 20µm Ø wire and tested under ultra-high vacuum (10^{-5} torr)).

On wire pull, neck break failure mode is noticed (Fig.3b), indicating that bond interface is strong without any failure related to Kirkendall voids. Similarly, on stitch pull, the "horse-shoe" bond interface is strong, cracking at the stitch-wire intersection (Fig.3c), indicating that ultrasonic stitch weld is good even after thermal aging for 4000 hours.

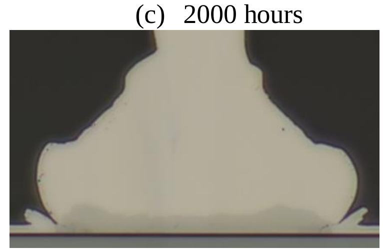
(a) 500 hours



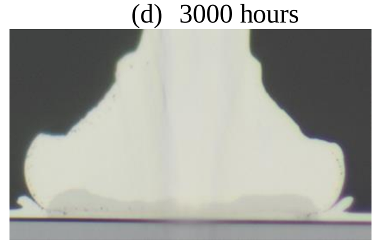
(b) 1000 hours



(c) 2000 hours



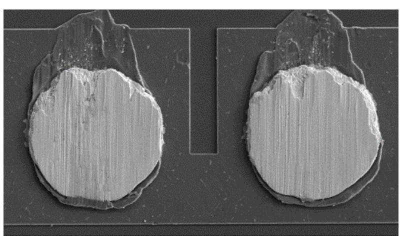
(d) 3000 hours



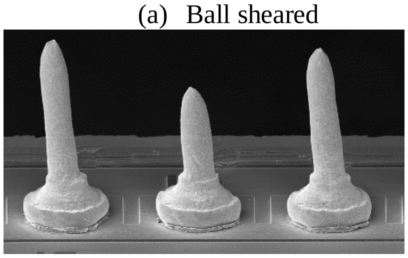
(e) 4000 hours

Fig.2 Cross-sectioned (mag.1kX) metallographic view of a bonded ball after thermal aging at 200°C for varying periods.

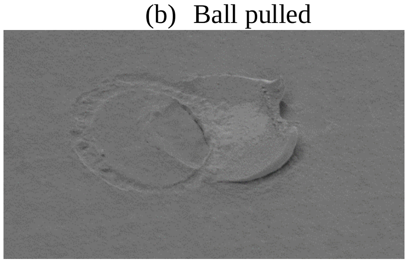
For longer reliability life of the gold-coated silver wire bonds, gold coverage along the periphery of the FAB is vital in addition to the alloy design of the silver core. From Fig.4, it is evident that gold wets the silver core of the FAB surface and spreads along the FAB periphery to tip (SEM-EDX dot mapping, yellow dots represent gold (Fig.4)). This leads to enriched gold-silver alloy along the outer layer of the bonded ball on both the right and left corners. Where, to a certain extent, diffusion of chlorine and sulfur ions from environment into the bond interface is protected [3-6]. Gold coating thickness is optimized in the design of the wire bonding performances. The product data sheet defines the range of weight percent (wt.%) between 3 and 4 to the overall composition of the wire (core and coating). The weight percent is analyzed using Inductively Coupled Plasma mass spectrometer (ICP). Any weight percent lower and higher than this range possesses inferior gold coverage, impacting reliability life. A lower percent of gold plating creates inadequate gold to cover the FAB periphery, and a higher percent of gold plating causes higher diffusion of gold into the silver core causing poor wetting of gold on the FAB surface to FAB tip. Furthermore, time zero bonding interface welding area is important to influence longer reliability life. Commonly, formation of greater than 70% intermetallic phases at the interface is practiced for time zero bonding of gold-coated silver ball bonds. Since intermetallic phases form at nanometer scale needs pre-thermal treatment at 200°C for 2 hours to evaluate the time zero bonding condition [7].



(a) Ball sheared



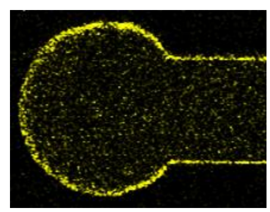
(b) Ball pulled



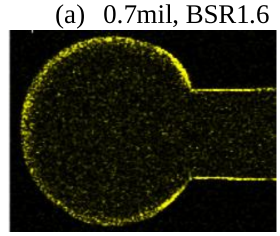
(c) Stitch pulled

Fig.3 SEM observations on the failure mode of ball shear, ball, and stitch pulled unmolded device samples after 4000 hours of thermal aging.

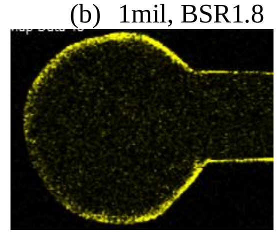
With regards to the epoxy molded device, bHAST, uHAST, and HTS tests are conducted for the molded units using green epoxy molding compound with 5 to 7 pH, and with low chlorine and sulfur content. Table.1 reveals the electrical measurement of daisy-chained device wire bonded to thin aluminum bond pads of 0.6µm thickness. Though the Automotive Electronic Council (AEC) 2X stress test requires 192 hours of bHAST, the study shows it passes until 480h for gold-coated silver wire bonds, which is as good as the performance of the gold wire bonds. Similarly, on thermal aging (HTS), AEC 2X stress test demands 4000 hours at 150°C. However, the evaluation reveals it passing until 4000h at 175°C and 150°C (refer to Table.1). Even though the AEC 2X stress test as per AEC-Q006 & AEC-Q100-RevH is recommended for copper, the bonding wire industry follows the same criteria for silver alloyed wires and now referred to gold coated silver wire successfully passing the 2X stress test. The sample size is limited in this laboratory-based evaluation to a strip with 5 devices. Microstructural observations of the cross-sectioned units reveal thick intermetallic layer growth of about 3.5µm for HTS sample and finer for uHAST and bHAST tested devices. However, Kirkendall voids or cracks related to galvanic corrosion are absent (Fig.5). Cross-section of the failed units for extreme test periods 1056 hours of bHAST (+20V, 130°C, 85%RH) revealed chlorine at the bond interface along the crack with oxidized aluminum, thus confirming the failure is due to galvanic corrosion at this test condition.



(a) 0.7mil, BSR1.6



(b) 1mil, BSR1.8



(c) 1.2mil, BSR2

Fig.4 Gold coverage on free air ball surface, processed for the varying ball to FAB size ratio (BSR) and wire diameters.

IV. Conclusion

Among the reliability studies, the first and foremost test conducted is high-temperature storage (HTS) of the un-molded device at 200°C, where gold coated silver wire bond reveals stable ball/stitch pull and ball shear until 4000hours of storage. The slower rate of silver-aluminide formation is noticed in the range from 3 to 5.2 µm, and Kirkendall voids are absent.

In addition, the epoxy molded device with 5 to 7 pH green epoxy molding compound (low chlorine and sulfur), and bonded with gold-plated silver wire bonds passed the reliability tests, revealing same electrical resistance until the end of the test periods:

- HTS – up to 4000 hours at 175°C
- Biased HAST – up to 480hours (+20V, 130°C, 85%RH)
- Unbiased HAST - up to 1000hours (130C, 85%RH)

A cross-section of all the passed reliability tested devices revealed an absence of Kirkendall voids and cracks related to galvanic corrosion.

Thermal Ageing (HTS), hours								
Periods		0	250	500	1000	2000	3000	4000
4N Au	150°C	10/10 tested devices, all passed up to 4000 hours						
Au coated Ag wire								
4N Au	175°C							
Au coated Ag wire								

Unbiased HAST (130°C, 85%RH), hours					
Periods	0	96	192	576	1056
4N Au	10/10 tested devices, all passed up to 1056 hours				
Au coated Ag wire					

Biased HAST (+20V, 130°C, 85%RH), hours						
Periods	0	96	192	288	384	480
4N Au	10/10 tested devices, all passed up to 480 hours					
Au coated Ag wire						

Table.1 Electrical measurements revealed pass of HTS, uHAST and bHAST tested devices (daisy chained) on epoxy molding.

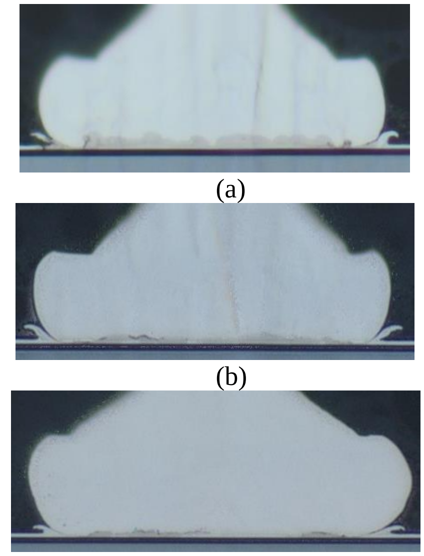


Fig.5 Cross-sectioned metallographic view of an epoxy molded bonded ball tested for the conditions: (a) thermal aging at 175°C for 4000 hours, (b) uHAST at 130°C, 85%RH for 1056 hours, and (c) bHAST at +20V, 130°C, 85%RH for 480 hours.

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