EFFECT OF Au COATING THICKNESS ON ELECTROLYTIC MIGRATION AND DISSOLUTION OF Au COATING ON Ag BONDING WIRE

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ABSTRACT

Electromigration is the movement of ions in a semiconductor substrate or thin film layer causing a localized depletion of ions in one layer. This ionic movement opens microstructure vacancies and creates high-density areas, which further leads to increased resistances or the acceleration of dendrite formation outside of the wire. This study focuses on the investigation of electrolytic migration of Au coating on Ag wire.

Tested in this study are wires in 1.2mils and 1.5 mils bonded on gold (Au) bond pads. The diffusion of Au on Ag and vice versa is analyzed using Scanning Electron Microscopy Energy Dispersive X-ray Spectroscopy (SEM-EDX,) and Silver Electromigration Analysis following ASTM F1996-06. Adhesion of wires on leads and dies are analyzed through shear test and wire pull. While reliability testing of wires are done through Temperature Cycling (TMCL) Test, High Temperature Storage Life (HTSL), Highly Accelerated Stress Test (HAST) and Controlled Temperature Humidity Bias (C-ThB).

SEM-EDX analysis showed that the diffusion of gold (Au) to Silver(Ag) reached a range of 100-180 nm of Ag, while Ag dendrites grew up to 5 ums in height outside of the wire.

Microcracks and wire lift-off are also observed but adjustment on ball-aspect-ratio helped resolve the concern. Electromigration of Ag and Au are common occurrences in Au coated Ag wires and thin films. To reduce risks of electromigration, it is recommended that a diffusion simulation be done to determine the depth of migration and the thickness of Au necessary to serve as barrier layer for Ag migration.

1. 0 INTRODUCTION

The development of the new microelectronic products brought researchers and inventors the challenge of providing good efficiency, low cost, and reliable bonding wires.

Since Au wires were introduced, attempts in replacing it as an interconnect technology are bogged down by issues in the reliability of the bonding wire. The quality of Au and purity contributes to changes in the products' efficiency and product performance. This, along with the compatibility of the bonding wire with the die attach material, the substrate, and the epoxy molding compound are critical interfaces which imposes other reliability concerns.

To increase bonding reliability and keep pace with miniaturization, different research and development groups for semiconductor devices introduced the addition of trace elements in Au, Ag and Cu wires to resolve corrosion, adhesion and electromigration concerns. Some of the most common trace elements are Boron, Titanium, Yttrium, Palladium, Nitrogen, are added to inhibit or start the growth of intermetallic or void formation. The diffusion of these trace materials is dependent on the base material to which it is added, the amount of trace material added and the temperature to which it is subjected to, defining the speed of electromigration.

2. 0 REVIEW OF RELATED WORK

Failure due to electromigration is a reliability concern for integrated circuits. This phenomenon of ion migration shrinks the interfaces of the metal layers, reducing the interconnect structure of vias or connecting wires causing electrical failures.

In a study made by Tse and Lach [1] the electromigration of wire bonds caused the occurrences of wire failure after continuous run 10^5 A/sq cm at 80 deg Celsius. These researchers analyzed the diffusion rates using the Nernst-Einstein equation [2,3].

The Nerst-Einstein equation is calculated to provide a direct current conductivity as a function of the ionic diffusion coefficients.

$$\sigma_{dc} = \frac{e^2 C\, D_\sigma}{k_B T} \qquad \text{(Eq1)}$$

Deriving from this, the ionic motion, which is proportional to the atomic diffusivity, the maximum diffusion coefficient can be obtained from

$$D = D_0 \exp\left(\frac{-E_A}{k_B T}\right) \qquad \text{(Eq 2)}$$

Where: Do = maximum diffusion coefficient
E_A = activation energy
K_B = Boltzmann's constant and
T = temperature.

To correlate this to the lifetime of the conductor before electromigration failure, Black's equation is utilized.

$$MTTF = AJ^{-n} \exp\{Ea/ kT\} \qquad \text{(Eq. 3)}$$

Mean Time to Failure (MTTF) [4,5] of a system is the expected time that a system will operate before the first failure occurs.
Here, A is a scaling factor (dependent on the geometry and parameters) and J is the current density.

3.0 METHODOLOGY

In this study, the team processed 1.2 mils and 1.5 mils of Au coated Ag wires, wire bonded on gold bond pads. Both the FAB and the wires interfaces on the leads, active and passive dies are validated to investigate both the interfacial bonds that connect them and the mechanical strength of the interfacial bonds.
High Magnification Microscopes, Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray EDX) are utilized in the imaging of the wires surface, cross-sections, and interfaces.
Silver electromigration on gold and vice versa are evaluated experimentally following the ASTM 1996-06 standard, which served as the basis for the basic values utilized in the diffusion simulation.

To evaluate the susceptibility of the wires for electromigration under dc voltage potential ASTM F1996-06, Standard Method for Silver Migration was followed. Wires from suppliers A and B are cut in 6 cm length, attached on a glass slide with 0.6 mm gap. Distilled water 0.5 uL was added in between the wires before a pulsing voltage is allowed to pass through the wires for five minutes.

Placket-Burman statistical analysis was utilized to obtain the recommended Au wire thickness that could inhibit whisker formation.

Chosen wire type and thickness are process end-to-end sample runs are also made to understand potential reliability issues of the change. Samples are subjected to Temperature Cycling (TMCL) Test, High Temperature Storage Life (HTSL), Highly Accelerated Stress Test (HAST) and Controlled Temperature Humidity Bias (C-ThB).

4.0 RESULTS AND DISCUSSION

The surface morphology of the wire types from the two suppliers along with the thickness of the wires' Au coating are measured and validated using SEM at 6500X magnification and 10000X magnification.

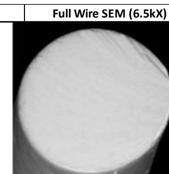
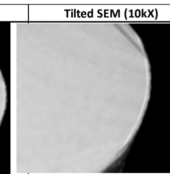
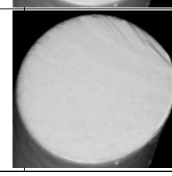
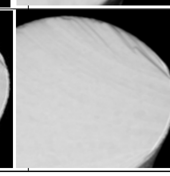
Supplier	Measured Au thickness	Full Wire SEM (6.5kX)	Tilted SEM (10kX)
A	110nm		
B	176 nm		

Fig 1. Samples SEM-EDX of Supplier A and B 1.5 mils SEM.

The thickness of the gold in the Au coated Ag wires are obtained and measured in five sample sites of the 5km spool provided by the two suppliers measured 3X per site, showing 40% higher Au coating thickness from supplier B than from supplier A.

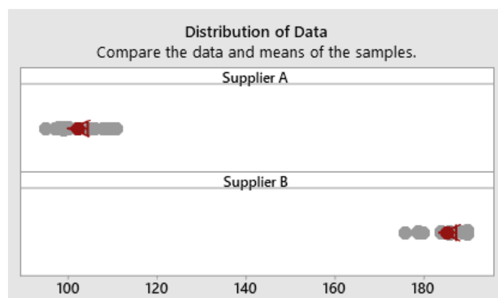


Table 1. Distribution of Au thickness measured on five samples of 1.5mil Au coated Ag wires from Supplier A and B.
SEM analysis of the ball bonded on Cu leads and Au bond pad showed no interfacial crack or bonding failure at zero hour.

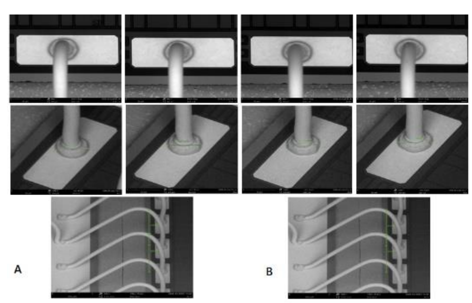


Fig 3. Comparison of ball bonding on leads and bond pad of the ACA wire from supplier A and supplier B.

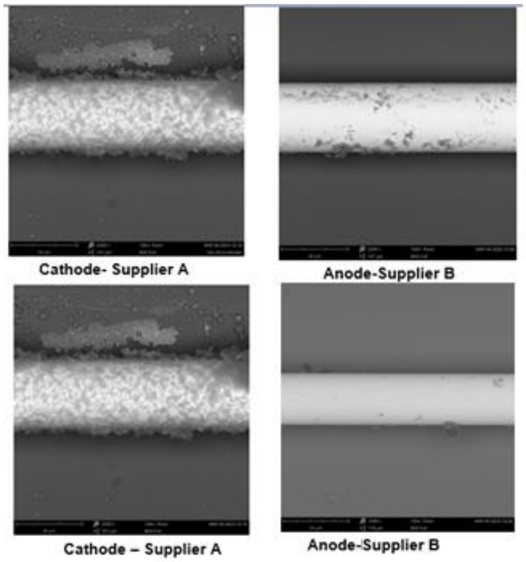
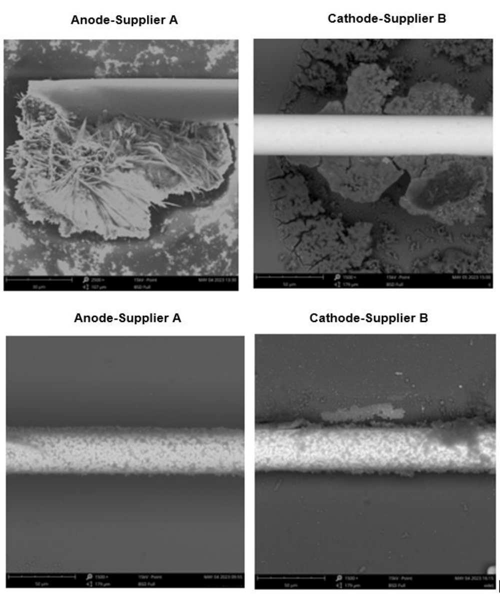


Fig 4. Wire surface image after the electromigration simulation.

1-5um Ag whiskers are observed on supplier A cathodic bonding wire compared with supplier B after five minutes of applied pulsed voltage. Extending this to ten (10) minutes provoked dendrite extending up to thirty (30) ums.



5.0 CONCLUSION

Results of the provoked electromigration of ACA wires showed consistent formation and growth of Ag dendrites and whiskers on surfaces of the wire. Finer and smaller whiskers are observed on supplier B wires compared with MKE wires. Common to both are the fast growth of whiskers on the area with wire scratch (possibly due to the thin layer of Au remaining on the scratched area). Although scratches on wires are not an issue on Au wires, this is a concern on Au coated wires as Au serves as the barrier to Ag ‘s electromigration.

6.0 RECOMMENDATIONS

It is recommended that the optimization of the wire bond parameter (higher bond temp or power to meet the equilibrium phase transformation of Au coated Ag wire) are utilized to reduce the concern on the surface scratch.

It is recommended that a thicker Au-coat on Ag wires twice that of the current Au coating be made to lower the risk or a wire with a barrier layer should be added to reduce the risk of electromigration.

7.0 ACKNOWLEDGMENT

The authors thank the support of Ampleon management in the completion of this paper and SEIPI.

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9.0 ABOUT THE AUTHORS

The authors are employees of Ampleon under Back-end Technology and Global Quality Engineering with the below credentials.