Al_2O_3-Coated Bonding Wire with Electrical Insulation & Promoted Adhesion

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Abstract
Conventional bond wires composed of Au, Ag, and Cu don't meet market demands for strong adhesion, electrical insulation, and corrosion passivation due to their conductive metallic surfaces. We propose a solution through the application of a ceramic (Al_2O_3) coating at nanometer scales on these metal wires, thereby improving their adhesion to encapsulation, electrical insulation, and resistance to corrosion. We used ALD (Atomic Layer Deposition) methods to coat Au and Ag metal wires with diameters ranging from 18um to 48um (0.7mil~1.9 mil) with Al_2O_3. Our paper details the innovative processes we used to incubate the idea of Al_2O_3 coating on conventional bond wires, focusing on wire bondability and dependability. Our findings demonstrate enhanced electrical insulation between crossing wires and increased reliability related to the wires' adhesion to encapsulation.

Key words
Adhesively-Promoted Wire, Al_2O_3 Coating, Bonding Wire, Insulated Wire, Nano Ceramic, Passivated Wire

I. Introduction

Bonding wires are composed of conductive metals of Au, Ag & Cu with excellent electrical conductivities for transmitting power and signals to wafer chips. Wire metals do not provide electrical insulation, adhesion promoter and corrosion passivation. Adhesion between metal wires is extremely weak, which is responsible for wire cut failures during thermal cycling (Fig. 1). Organic coating for electrical insulation does not satisfy bondability and manufacturability, and it is complex to apply very thin organic coating on metal wires. Automotive packages require enhanced reliability of packages under harsh conditions. LED and power packages are susceptible to wire cut failures.

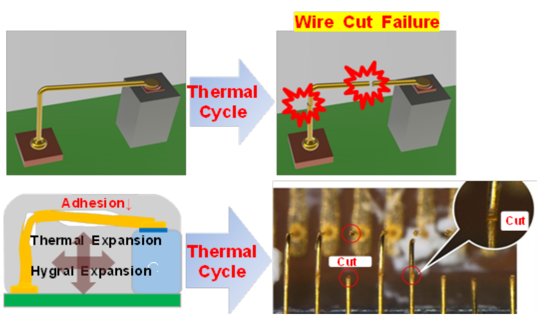

Fig. 1. Bonding wire cracking between bonding wires and encapsulation

Wire bonding technology has been used for a wide range of semiconductor packages, ranging from LED packages requiring 2 wire loops to NAND flash memory packages requiring thousands of loops on stacked dies. Consequently, various requirements were imposed on wire metal types, wire diameters and bonding methods in terms of bondability, reliability and manufacturability. These requirements placed limitations on wire metal types of Au, Ag, Pd and Cu for the most of cases. Fine-pitch applications require electrical insulation of ultra-thin bond wires in terms of space-wise restrictions [1]. Recent automotive packages of LED and power devices require enhanced reliability performances of packages in terms of the reliability of relatively-thick bond wires. Reliability of power packages are challenged by greater power capacity and larger temperature spans, since those bond wires possess conductive metal surfaces. Those surfaces do not allow strong adhesion to polymeric encapsulation, electrical insulation and corrosion resistance. Those new requirements are challenging to satisfy, on the top of existing requirements of bondability and reliability.

In this work, we introduce and propose an optimum solution for aforementioned challenges and requirements, by making use of nano ceramic coating on the surfaces of metal bonding wires. The ultimate goal is to satisfy the requirements on bond wires in terms of adhesion-related reliability, electrical insulation and anti-corrosion passivation.

II. Experiments & Results

We introduced Al_2O_3–coated bond wires for providing adhesion strength and excellent insulation for Au and Ag bond wires, respectively [2]. Ultra-thin Al_2O_3 coating as thin as 10nm was deposited on the wire surfaces using batch-type ALD deposition systems for excellent conformal coating (Fig. 2(a)). TMA (Tri-Methyl Aluminum), a precursor for Al_2O_3 is inexpensive and commercially abundant. Since ALD methods create the deposition of a single layer of atoms per cycle with excellent coating uniformity, we fabricated 1~20nm Al_2O_3 coatings on metal wires with an increment of 1nm thickness, especially for OCB (Off-Centered Ball) experiments. SEM and TEM showed excellent coverage and uniformity of Al_2O_3 coatings on wires.

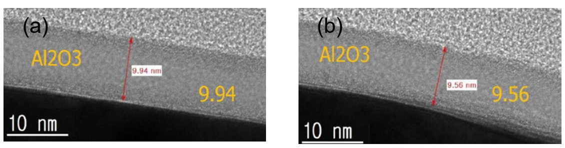

Fig. 2. Al_2O_3 coating on wires: Thickness = 10nm

A. Elec. Insulation for DRAM PKG & Camera Module

Preliminary Al_2O_3 insulation testing was conducted on curled or bent bonding wires which were wound around cylindrical bars having the diameters of 1~4mm in Fig. 3. Bending induced plastic deformation to the wires and resulted in permanent wire curls. The 1st wire was aligned from point 1 to point 3 and the 2nd wire was placed on the top of the 1st wire after being aligned from point 2 to point 4. Good insulation was observed for all of the wires. Au wires of 0.7mil and 1.9mil were coated with 10nm-thick Al_2O_3 insulation.

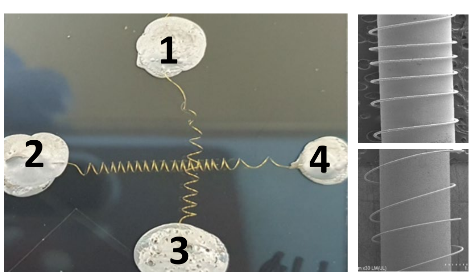

Fig. 3. Wire-cross insulation test for curled wires with Al_2O_3 coating around cylindrical bars

Two wire loops with 10nm-thick Al_2O_3 coating on 1mil-thick Au wire were crossed using a wedge bonding method in Fig. 4. The excessive loop bending cases in Fig. 4(d) did not exhibit electrical insulation while as good insulation was observed for most of wire cross cases in Fig. 4(b) and (c).

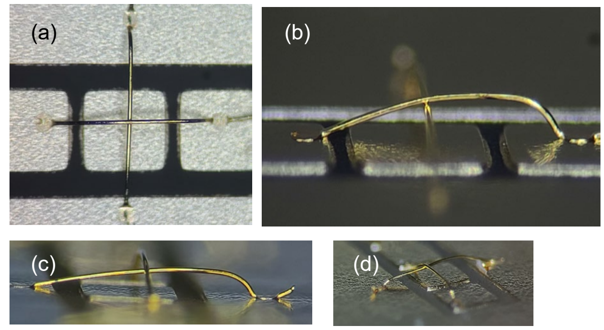

Fig. 4 Wire-cross insulation on Al_2O_3 coating (a) Top view (b) Front view (c) Good insulation (d) Fail insulation

We show electrical insulation performances of Al_2O_3-coated bond wires at wire levels and package levels, respectively. The wire diameters of DRAM packages and camera modules are 0.7mil with 6nm-thick Al_2O_3 and 0.9mil with 10nm-thick Al_2O_3. Al_2O_3-coated bonding wires of 0.7-mil diameters with 6nm Al_2O_3 coating were applied to NAND memory packages (Fig. 5). Due to the large wire population in NAND packages, wires were assembled in parallel direction and allowed to touch with each other. After all the package processes were completed, electrical testing was performed to both Al_2O_3 coating and no coating cases.

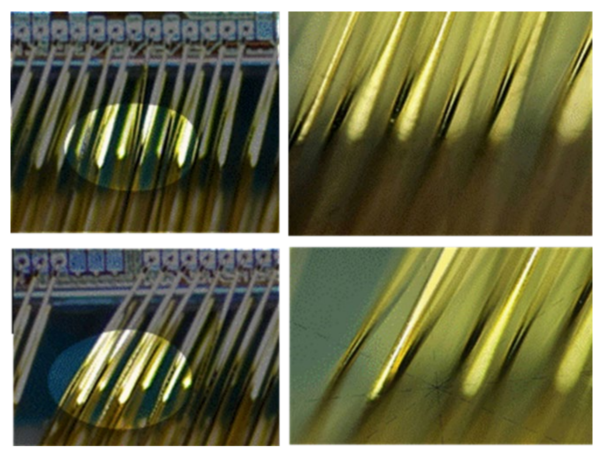

Fig. 5. Al_2O_3-coated bonding wires of 0.7 mil diameter with 6 nm in DRAM packages

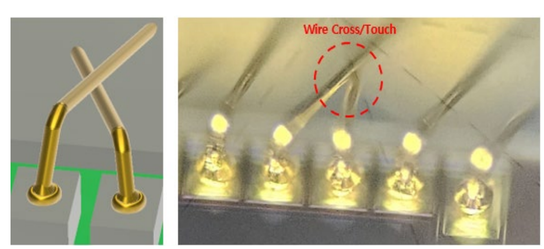

Fig. 6. Al_2O_3-coated bonding wires of 0.9mil diameters with 10nm Al_2O_3 coating were applied to smartphone camera modules

The yield was found 100% for Al_2O_3 coating and 85% for no coating cases.

Al_2O_3-coated bonding wires of 0.9mil diameters with 10nm Al_2O_3 coating were applied to smartphone camera modules (Fig. 6). Wire looping was modified so that wires crossed with each other. After the module assembly was completed, no short was found by electrical testing.

Breakdown voltages were found 8V for 10nm-thick Al_2O_3 coating on Au wires in Fig. 7. Gradual increase in voltage was applied to wire cross of two wires until breakdown or explosion occurred.

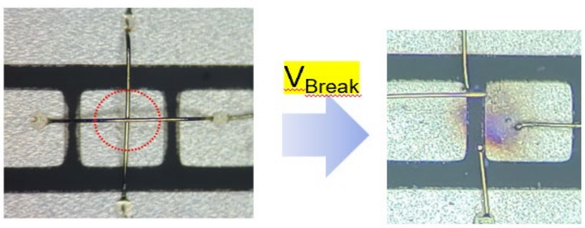

Fig. 7. Breakdown voltage test Al_2O_3-coated wire contact

B. Adhesion & Long-Term Reliability

Al_2O_3 coating on bond wires introduce two new interfaces in terms of adhesion. The 1st interface is between bond wires and Al_2O_3 coating, and the 2nd is between Al_2O_3 coating and encapsulation. We investigated the adhesion associated with the 1st interface of bond wires and Al_2O_3 coating. Since it is complex to induce debonding of the Al_2O_3 film at nm scales from the metal wires, adhesion tests were conducted by depositing 500nm-thick Al metal layers on the surface of Al_2O_3 coating in Fig. 8(a) in a similar manner to the typical fracture test methods such as DCB (Double Cantilever Beam) tests. Wedge bonding methods applied mechanical stresses to induce debonding of the Al_2O_3 film on the wires. Strong adhesion between metal wires and Al_2O_3 coating is essential since wire bonding force provides mechanical force to create this interfacial cracking. Consequently, Al_2O_3 coating did not debond under wedge bonding stresses in Fig. 8(c) in a similar way to strong interfacial fracture toughness reported previously [3, 4].

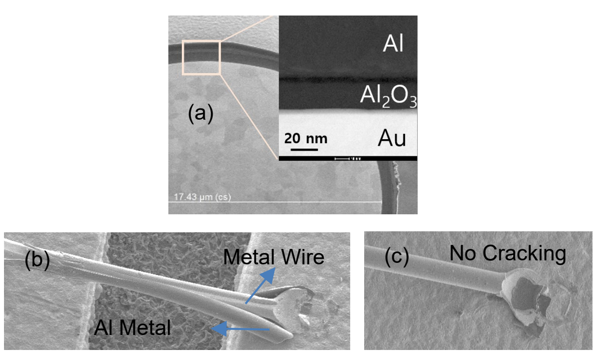

Fig. 8. Promoted adhesion between wire & Al_2O_3 (a) Al coating on Al_2O_3 (b) Before chemical cleaning (c) After

Al_2O_3-coated Au wires were used for replacing 1.7mil Au wires for automotive packages that were susceptible to reliability issues in Fig. 9. The diameter of bare Au wires was required to increase to 1.8, 1.9 and 2.0mil for enhancing lifetime of packages, while that of Al_2O_3-coated Au wires was reduced to 1.5 and 1.2mil. ATC (Accelerated Thermal Cycling) loading (-65℃~150℃) was applied to both conventional and Al_2O_3-coated wire types. TC reliability failures were recorded in Fig 9(a). Al_2O_3-coated Au wires of 1.2 and 1.5mil diameters were found more reliable than 1.7mil bare Au wires in terms of the failure mode of wire cut described in Fig. 9(b). Al_2O_3-coated Au wires did not exhibit wire-cut failures even over 2000 cycles of ATC until our intentional stopping.

(a)

Wire	Dia (mill)			Al_2O_3	TC (cyc)
Bare Au			1.7	0	1.4k
Al_2O_3	1.2	1.5	1.7	20nm	No Fail: >2k

(b) (c)

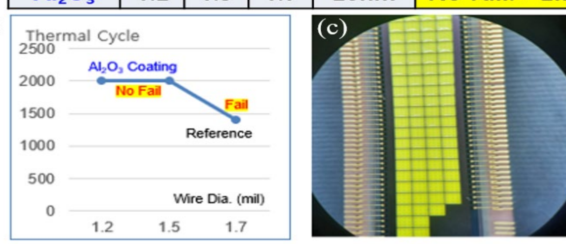

Fig. 9. Reliability associated with adhesion between bonding wires and encapsulation of high-end LED package

C. Bondability & OCB

We present bondability data including OCB (Off-Centered Ball) that was found extremely sensitive to Al_2O_3 coating thickness, and present the optimum Al_2O_3 thickness for bondability (Fig. 10 & Fig. 11).

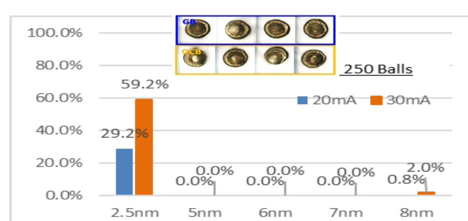

Fig. 10. OCB vs. Al_2O_3 thickness of 0.7mil Au wires (250balls)

Au wires with 1.1, 1.5 and 1.9mil thickness were coated with Al_2O_3 thicknesses from 6 to 15nm (Fig. 12). No significant difference was observed for all the cases in terms of bonding strength. Note that Al_2O_3 did not degrade bonding interfacial strength and IMC [5, 6, 7].

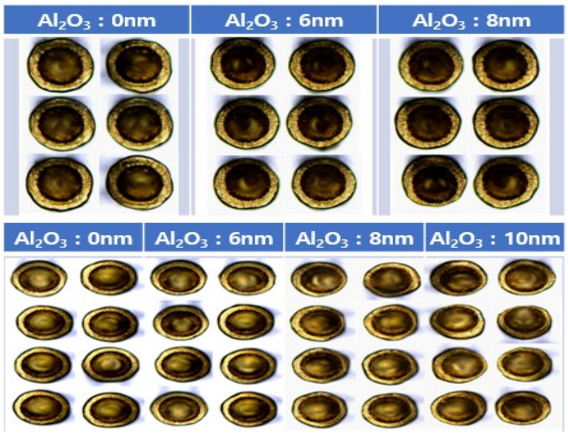

Fig. 11. OCB vs. Al_2O_3 thickness of Au wires (1.1 & 1.9 mil

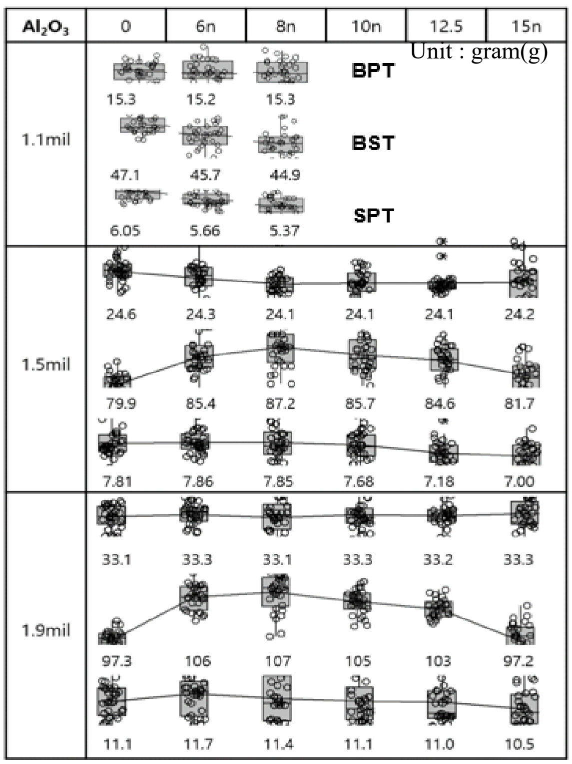

Fig. 12. Mechanical testing(in grams) on Al_2O_3-coated bond wires with thickness from 1.1 to 1.9mil. BPT(Ball Pull Testing), BST (Ball Shear Testing) and SPT(Stitch Pull Testing)

We propose off-centered ball mechanisms by introducing TBMZ (To-Be-Melt Zone) that experiences oxidation at high temperatures during ball formation contrary to HAZ (Heat-Affected Zone) after ball formation in Fig. 13. Even within a brief time, the TBMZ surface undergoes oxidation, with the thickness of this oxide layer contingent upon the wire material type. When the TBMZ

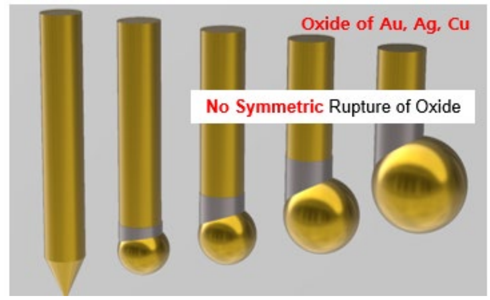

Fig. 13. OCB mechanisms at TBMZ

oxide layer remains small and thin, there are no issues with OCB. However, if this oxide layer becomes thick, it does not gradually break down during ball formation. In Fig. 14, unlike the left-hand side oxide layer, which remains intact, the right-hand side oxide layer has already degraded. Consequently, symmetry and axisymmetric are no longer preserved. We applied artificial oxide (Al_2O_3) coating to the surfaces of bond wires, which prevent the oxidation during ball formation in Fig. 14.

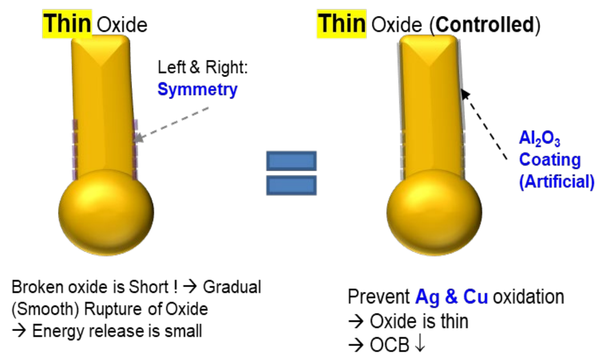

Fig. 14. OCB Mechanism Postulate: Oxide Thickness at TBMZ

III. Conclusion

Our Al_2O_3-coated bonding wire is the first ceramic coating to bonding wires, which provide electrical insulation, adhesion promoter and corrosion passivation to packages. Al_2O_3-coated bonding wires allow wire touch and cross of fine-pitch packages in order to reduce the form factors in various packages such as memory packages and camera modules. The promoted adhesion due to our Al_2O_3-coated bond wire enhances the lifetime of the high-reliability packages such as automotive LED products and power electronics.

We demonstrated bondability associated with nano-scaled Al_2O_3 at the interfaces. We show no bondability degradation associated with Al_2O_3 coating on bonding wires. ALD deposition method was developed for mass production of Al_2O_3 coated bonding wires.

References

[1] Zhong, Z.W. Overview of wire bonding using copper wire or insulated wire. *Microeletronics Reliability* **51**, 4-12 (2011)

[2] Park, S. et al. Insulated, passivated & Adhesvively-Promoted Bond Wire Using All-in-One Al_2O_3 Coating. *IMAPS Symposium* (2022)

[3] Evans, A.G. et al. Interface adhesion: effects of plasticity and segregation. *Acta Materialia* **47**, 4093-4113 (1999)

[4] Liu, J. et al. Fracture behavior of an epoxy/aluminum interface reinforced by sol-gel coatings. *J. Adhesion Sci. Technol.* **20**, 277-305 (2006)

[5] Xu, H. et al. Behavior of aluminum oxide, intermetallics and voids in Cu-Al wire bonds. *Acta Materialia* **59**, 5661-5673 (2011)

[6] Kim, H.G. et al. Microstructural evaluation of interfacial intermetallic compounds in Cu wire bonding with Al and Au pads. *Acta Materialia* **64**, 356-366 (2014)

[7] Park, S.J. Au-Less, Ni-Less & Roughness-Less PCB Cu Surface Treatment Using All-in-One Al_2O_3 Passivation. *71st Electronic Components and Technology Conference* (2021)