Gas-free & nano Al_2O_3-coated Ag bonding wire for replacing Au wire

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Abstract

Ag and Cu wires require forming gas environment during wire bonding contrary to Au wires due to surface oxidation at high temperature. Au is the only noble metal not requiring passivation against oxidation, being most expensive metal. H_2 gas in forming gases is hazardous and expensive. For replacing Au wire and forming gas, we propose a passivation solution using the application of a ceramic (Al_2O_3) coating at nanometer scales on Ag bonding wires. We used ALD (Atomic Layer Deposition) methods to apply Al_2O_3 coating on Ag metal wires with diameters ranging from 0.7 to 1.0 mils. We present bondability and reliability data followed by workability test at 200,000 continuous bondings. Al_2O_3 coated Ag wire satisfied all of the package level requirements from camera module manufacturers.

Key words

Al_2O_3 Coating, Ag Bonding Wire, Passivated Wire, Insulated Wire, Nano Ceramic

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I. Introduction

Forming gas has been essential requirements for replacing Au bonding wires with Ag or Cu wires since spherical FAB (Free Air Ball) formation is hindered by oxidation of wire surfaces [1]. It is only Au metal that prevents excessive oxidation during FAB formation processes at high temperatures, whereas all the other metals are susceptible to OCB (Off-Centered Ball) induced by oxidation. Cu oxidation was mitigated by electroplating thin Pd coating on Cu wire, which led proliferation of Pd-coated Cu wires in semiconductor industries. However, even Pd-coated Cu as well as Ag alloy wires also requires forming gas. Typical forming gas is a shielding or cover gas consisting of 95% N_2 and 5% H_2. H_2 gas is an environmentally hazardous element, which requires gas purging control. Copper oxidization can be prevented by providing sufficient shielding gas during the FAB formation. The bondability is determined by the slip area at the bonding interface, and the transfer from the slip area to entire slip is controlled by the levels of the bonding force and ultrasonic power. The initial temperature of the preheated chip can improve the atomic reaction [2]. Alloying Ag and Cu metals do not prevent OCB since alloying elements are metallic materials.

The oxidation of TBMZ (To-Be-Melt-Zone) may be one of the major causes for OCB [3]. TBMZ is a zone near a molten ball of bonding wire metals, being susceptible to rapid oxidation during FAB formation. The metal composition of TBMZ must not experience rapid oxidation during ball formation. On the top of oxidation resistance, the resulting IMC (Inter-Metallic Compound) types must satisfy strict long-term reliability requirements at harsh environments. For example, adding Au coating on Cu or Ag wires may introduce new adverse types of IMC with existing metal types of the wires and substrate pads. Only a few IMC types have satisfied semiconductor reliability requirements so far. As a result, this coupling between OCB and IMC created daunting technical challenges when developing a new bonding wire technology. The Cu and Ag wires embedded in encapsulation are also susceptible to dendrite short issues due to Cu and Ag ion migration even over mm length scales under moisture conditions for fine pitch applications.

Diffusion barriers are required to prevent the surfaces of Cu and Ag wires from ion migration. Al_2O_3 ALD was previously studied as gas diffusion barriers on polymers [4, 5]. As another solution, electroplating of an oxidation-resistant metal on Cu wire was conceived to prevent surface oxidation [6]. Experiments revealed that electroplating of 0.1-lm-thick Ni, Pd Ag or Au on Cu wire increased bond strengths, but produced problematic ball shapes except the Pd-plated Cu wire, which could produce the same ball shape as that of Au wire. Temperature humidity bias, temperature cycling and pressure cooker tests confirmed that the Pd-plated Cu wire demonstrated excellent bondability and reliability.

Bonding wires are composed of conductive metals with high electrical conductivities for transmitting power and signals to wafer chips. Wire metals do not provide 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. In this work, we introduce nano ceramic coating on the surfaces of Ag bonding wires (Fig. 1), which provide passivation against excessive Ag oxidation during FAB formation processes for eliminating forming gases. We present bondability, reliability and workability performances of our Al2O3-coated Ag wire. Al2O3 coating also provides electrical insulation to Ag wires as well (Fig. 2).

II. Experiments & Results

We introduced Al_2O_3–coated bonding wires for providing passivation for Ag bonding wires. 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. 1). 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. The diameters of 0.7, 0.8 and 1.0mils were investigated for fine pitch and camera module applications, respectively. No forming gas was used during FAB formation.

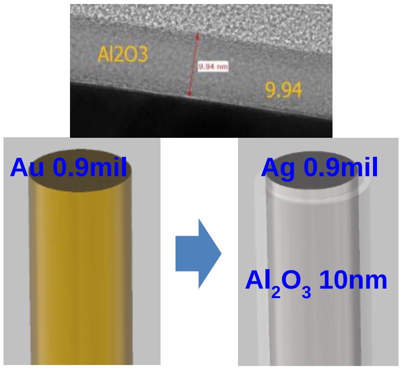

Fig. 1. Al2O3 coating on Ag wire for replacing Au wires

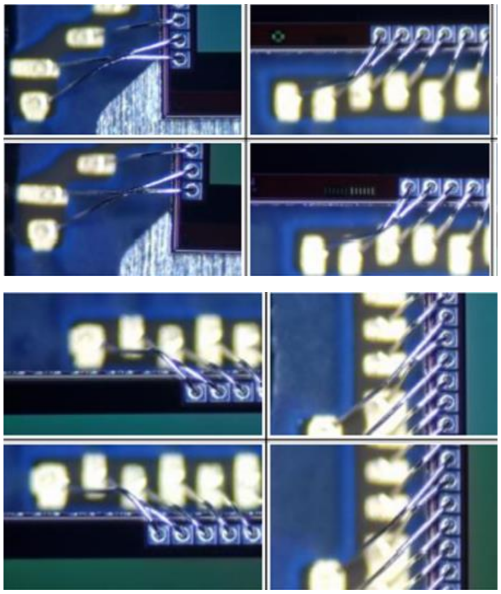

Fig. 2. Wire touch is allowed due to Al2O3 insulating coating in camera modules: no electrical short

A. *Bondability & Reliability*

Bondability testing was performed for FAB formation and bonding strength. Round balls and stitch bonding are shown in Fig. 3. 7nm-thick Al2O3 coating was used as passivation and round balls were obtained, which is different from conventional Ag wires without forming gas. Ball pull, ball shear and stitch pull strengths were found equivalent to conventional Ag wires with forming gas in Fig. 4.

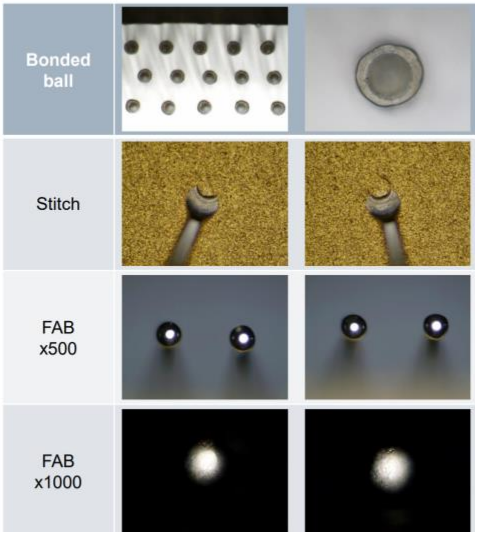

Fig. 3. Ag wire (1mil) with 7nm Al2O3 coating

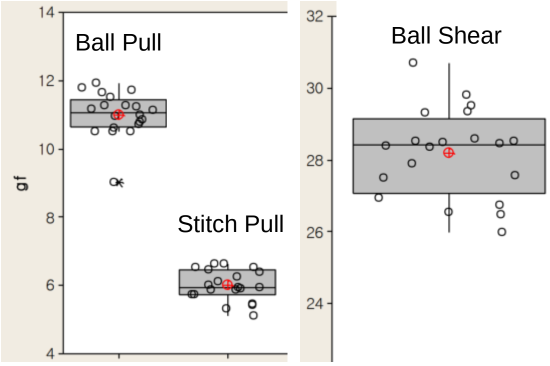

Fig. 4. Ag wire (1mil) with 7nm Al2O3 coating

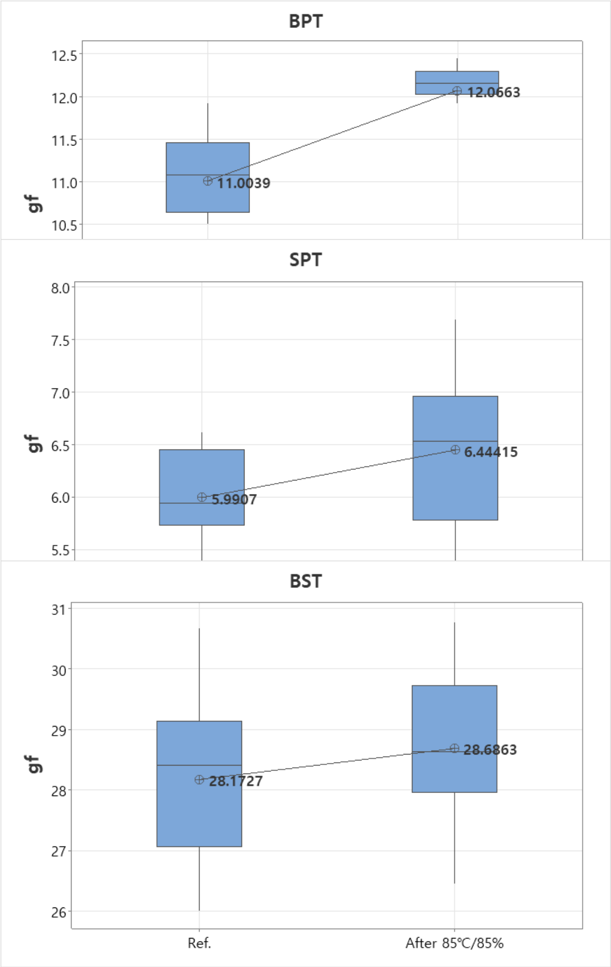

Fig. 5. Reliability after 85%/85℃ for 120hrs

0.9mil wire diameter and 10nm-thick Al2O3 coating was used for reliability performances in Fig. 5. Wire bonding was exposed to the condition of 85%/85℃ for 120hrs, which is a standard for camera module application. Ball pull, ball shear and stitch pull strengths increased after reliability conditioning, which indicated the increase of IMC strengths.

B. *Workability*

Al_2O_3 coating on bond wires were tested for workability that is continuous bonding requirements for large bonding-wire population such as memory packages. Workability is a crucial requirement for mass production. Short tail failure is a premature failure of tail bond at stitching bonding, and induces bonder stoppage, not allowing continuous bonding operations. 0.7 and 0.8mil diameters of Al2O3-coated wires were tested. The goal of 200,000 bonding operations without bonder stoppage was achieved for both diameters (Fig. 6-7). Tail bond pull strengths after 5,000 and 100,000 and 200,000 bonding operations were measured, and no reduction of tail bond strength was observed. Tail bond strength increased for both wire diameters. Stitch pull strength did not change with the number of bonding operations in Fig. 8. Loop heights

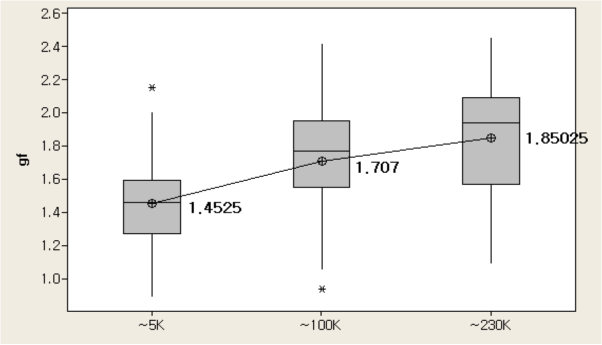

Fig. 6. Tail bond pull of 0.7mil Ag with 5nm Al2O3 for preventing short tail

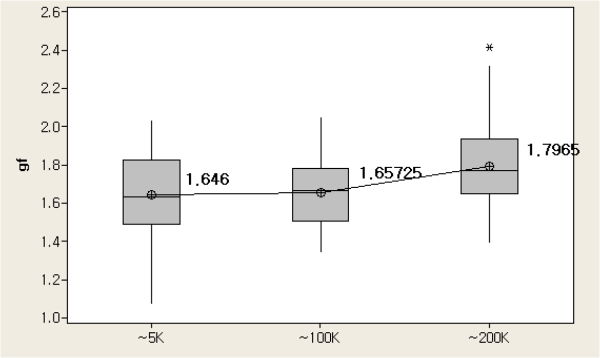

Fig. 7. Tail bond pull of 0.8mil Ag with 5nm Al2O3 for preventing short tail

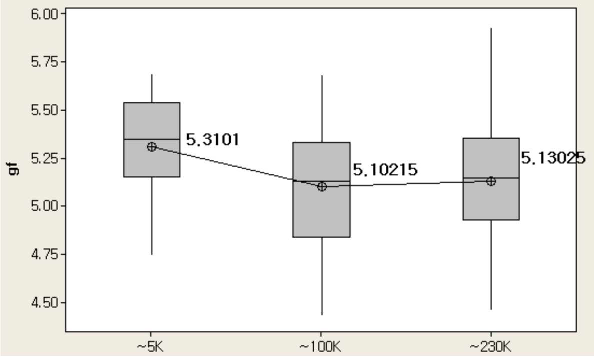

Fig. 8. Stitch pull of 0.7mil Ag with 5nm Al2O3 for preventing short tail

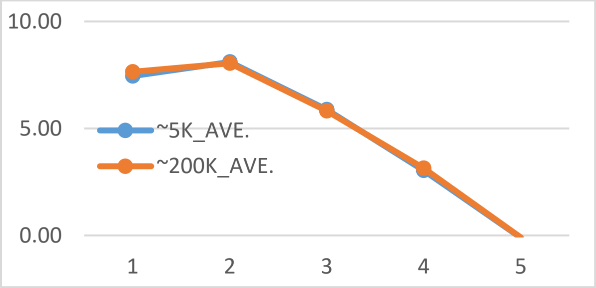

Fig. 9. Loop heights after 200,000 bonding operation did not change.

were measured at 5,000 and 200,000 bondings, and found equivalent to each other in Fig. 9.

C. *Package Test: Camera Module*

Al_2O_3 -coated Ag wires were applied to camera module packages of 2 manufacturers. More than 100 modules were assembled and a number of tests were performed including reliability: thermal shock, high temp & high humidity, accelerated life test, tumble test, manual drop, cold storage, side ball drop, rear strength, blue dot, flange plating corrosion test, push test. Al_2O_3 -coated Ag wires satisfied all of requirements. Electrical insulation was also proved by enforcing wire touch, and no electrical short was observed in Fig. 2.

III. Conclusion

Our Al_2O_3-coated bonding wire is the first ceramic coating to bonding wires for providing passivation to the wire surfaces. Al_2O_3 coating on bonding wires allowed bondability at 1st and 2nd bondings. The increasing bonding strength after reliability indicates stable IMC strength over time. We demonstrated 200,000 continuous bondings for workability during mass production. Package-level tests using camera module satisfied all of the requirements including reliability. This allows replacing conventional Au wires with Al_2O_3-coated Ag wire for cost reduction purposes.

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