Research Article

Intermetallic Phase on the Interface of Ag-Au-Pd/Al Structure

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Three wires, Au, Cu, and Ag-Au-Pd, were bonded on an Al pad, inducing IMC growth by a 155 hr high temperature storage (HTS) so that the electrical resistance was increased and critical fusing current density (CFCD) decreased. Observations of the Ag-Au-Pd wire after HTS (0–1000 hr) indicated that IMC between the Ag-Au-Pd wire and Al Pad was divided into three layers: Ag₂Al layers above and below the bonding interface and a polycrystal thin layer above the total IMC. A high percentage of Pd and Au existed in this 200 nm thin layer, and could suppress Al diffusion into the Ag matrix to inhibit IMC growth. After PCT-1000 hr, a noncontinuous structure still remained between the IMC layer and interface, and the main phase of IMC was (Ag, Au, Pd)₂Al with a hexagonal structure.

1. Introduction

In the past, gold wire was the primary bonding wire used in the packaging industry; however, low-cost copper wires have been increasingly applied due to gold's ever-higher cost. Unfortunately, copper wire cannot fully replace gold wire due to some disadvantages, such as easy oxidation and high hardness [1]. Despite both the prices and hardness of silver wire, which exhibits excellent electrical conductivity, being between gold and copper, the high temperature oxidation problem still exists in silver wire, and the mechanism of the intermetallic compound layer (IMC) on the bonding interface is still unknown. In this study, to enhance the reliability of silver wire in the wire bonding process, 8 wt.% Au and 3 wt.% Pd were added to pure silver to reduce oxidation and inhibit the growth of intermetallic compounds (IMCs).

Research has [2–4] indicated that IMCs form in the bonding interface due to the diffusion mechanism of different metals, which become significant when the temperature increases. After a long-term high temperature storage (HTS), IMCs formed in the bonding interface between the gold wire and aluminum substrate, such as Au₄Al and Au₅Al. In previous research [2], IMCs were found to have high

electrical resistance, and the IMC growth rate of gold and aluminum was ten times that of copper and aluminum. In practical applications, the total electrical resistance ($\Omega_{\text{wire}} + \Omega_{\text{IMC}} + \Omega_{\text{Al pad}} = \Omega_{\text{total}}$) was affected by both of the structure and thickness of the IMCs. It has been suggested that the relationship of the bonding interface electrical resistance and IMC structure of silver alloy wire with aluminum substrate is important [5, 6]. The interface mechanism is able to provide a reference for packaging.

2. Experimental Procedure

In this study, three wires, Ag-8Au-3Pd, Au, and Cu were chosen to compare the variations of total electrical resistance and critical fusing current density (CFCD). HTS at 175°C and 155 hr was the primary method to accelerate the growth of IMC between the wires and Al pad [7]. Leading the directing current into the as-bonded samples was called the directing current test, the circuit mechanism of which is shown in Figure 1. Variations of total electrical resistance ($\Omega_{\text{total}} = \Omega_{\text{wire}} + \Omega_{\text{IMC}} + \Omega_{\text{Al pad}}$) and CFCD of the as-bonded wire with HTS of each wire were compared. The voltage was increased 0.05 V/sec until the wire fused at the CFCD (A/m²).

FIGURE 1: Electrical mechanism diagram of wire bonding interface device.

FIGURE 2: (a) Black line indicates the position of TEM sample by using FIB and (b) shows the shape of the TEM sample.

High temperature storage (HTS) is a reliability test with long duration under high temperature. In order to understand the relation between the electrical resistance and IMC growth after HTS, the Ag-8Au-3Pd wire was bonded on the Al substrate and HTS was executed at 175°C for 250~1000 hours, and IMCs at the interface were observed by focused ion beam (FIB). The 1000 hr HTS specimen was chosen for IMC structure analysis, using FIB to produce a $10\text{ }\mu\text{m} \times 5\text{ }\mu\text{m} \times 40\text{ nm}$ TEM sample, the position of which is illustrated with a black line in Figure 2(a) while the morphology is presented in Figure 2(b). The crystal structure was confirmed by EDS and selected area electron diffraction (SAED).

3. Results and Discussions

3.1. Electrical Properties of Wire Structure. Figure 3 shows the electrical properties of the three devices (wire + IMC + Al pad); before HTS, the Cu device had the lowest electrical resistance and the highest CFCD, while data from the gold and silver alloy wires were similar. After HTS, the resistance

increased and CFCD decreased. The HTS temperature was too low for recrystallization [1, 4], and the IMC characteristics of the interface after HTS were the main factor affecting the electrical properties.

After HTS, the total electrical resistance of the copper device increased due to the IMC (Cu-Al) growth between the copper wire and aluminum pad [8]. The change of electrical resistance on the silver alloy and gold wire was limited because the growth mechanism of IMC was different. Compared to the gold and silver alloy wires, both the resistance and CFCD of the silver alloy wire were better than that of the gold wire. After extending the HTS duration (0–1000 hr) of the silver alloy wire, the IMC growth mechanism and phase structure of the Ag-Al IMC were analyzed.

3.2. IMC of Ag-8Au-3Pd Wire. At room temperature, the bonded interface was continuous, and IMC did not continue to grow, as shown in Figure 4(a). After HTS, the IMC growth characteristics of 250 hr, 500 hr, 750 hr, and 1000 hr were examined, as presented in Figures 4(b)–4(e). IMC grew

FIGURE 3: (a) I-V curve method and the results of (b) Ag-8Au-3Pd, (c) copper, and (d) gold wires.

significantly in the HTS-250 hr process, and the total IMC thickness layer was $1\text{--}1.5 \mu\text{m}$, and did not increase with an increased HTS duration, which indicates that the IMC growth kinetics were suppressed effectively. In addition, IMC had a noncontinuous distribution in the bonding interface and was separated into two layers. When the HTS duration was 500 hr, Kirkendall voids began to form above the IMC [7]. There is strong evidence indicating that IMCs were formed at the zone of maximum pressure at the bonding interface

and diffused up and down progressively to form a coarse-ribbon shaped IMC. Due to Al diffusion exceeding Ag, large amounts of Kirkendall voids appeared by increasing the HTS duration to 500 hr. After HTS-1000 hr, Kirkendall voids could not propagate to form Kirkendall cracks. It is clear that this interface diffusion path was suppressed so that the IMC thickness and Kirkendall voids cannot increase.

The HTS-1000 hr specimen displayed no significant oxidation behavior, which confirms that oxidation resistance of

FIGURE 4: Observations of bonding interface cross-section featured the following conditions: (a) as-bonded interface at room temperature. Intermetallic compounds were grown for (b) 250 hr, (c) 500 hr, (d) 750 hr, and (e) 1000 hr.

FIGURE 5: IMCs below the bonding interface were found to be Ag_2Al (hexagonal structure).

FIGURE 6: IMCs above the bonding interface were found to be $(\text{Ag, Au, Pd})_2\text{Al}$ (hexagonal structure).

TABLE 1: EDS of the three layers of IMC (wt.%).

	Al	Ag	Au	Pd
H phase	60.50%	22.80%	10.89%	5.81%
Upper IMC	43.07%	44.02%	8.25%	4.66%
Lower IMC	37.26%	62.74%		

the Ag-8Au-3Pd wire was improved. The bonding interface was analyzed by TEM and showed that the IMCs were divided into three layers: lower IMC, upper IMC, and the thin film above the total IMC. Figures 5(b)–5(d) and Table 1 offer the selected area electron diffraction patterns and EDS results of the lower IMC, which confirm that the lower IMC was Ag_2Al with a hexagonal structure. Furthermore, Table 1 and Figure 6 indicate that the upper IMC was Ag_2Al doped Au and Pd with a hexagonal structure. This result indicates that both the Au and Pd cannot diffuse into the lower IMC. Notably, a thin film above the upper IMC exists, as shown in Figure 7. In this area, much Al accumulated, which was confirmed as a rich-Al thin

film that had a four-element polycrystalline phase (named H phase) by SAED. More noteworthy is that most of the Al was limited in this H phase and could not form new IMCs. Moreover, the IMC layer could not be thickened after HTS.

4. Conclusion

With a circuit device (wire + IMC + Al pad) and HTS, the electrical resistance and CFCD value of a silver alloy wire were possible to be measured. The IMC interface between the Ag-8Au-3Pd wire and Al pad has three layers: the lower IMC which is hexagonal Ag_2Al , the upper IMC which is hexagonal $(\text{Ag, Au, Pd})_2\text{Al}$, and a rich-Al H phase. The Ag-8Au-3Pd wire has excellent oxidation resistance and the total IMC layer thickness cannot increase when increasing the HTS duration.

Conflict of Interests

The authors declare that there is no conflict of interests concerning the publication of this paper.

FIGURE 7: Small upper polycrystal IMC layers.

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