Effect of Metallization on the Microstructural Evolution of Microbump under Electric Current Stressing

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Abstract

Microbumps with different metallizations for soldering were investigated for microstructural evolution after long time current stressing at 1×10^4 A/cm². The metallizations applied include Cu and Cu/Ni UBM on the chip side, while OSP-Cu and ENEPIG/Cu on the substrate side. The limiting solder (Sn1.8Ag) volume of the microbump were all converted to IMC after the current stressing test for the OSP-Cu. The metallization combination determines the types and the formation behavior of the compounds.

1. Introduction

The application of microbump allows miniaturization of interconnects. The volume of the bump is reduced by $2 \sim 3$ orders when applying $10 \sim 20 \,\mu$ m microbump instead of conventional 100 μ m flip chip solder bump. The fine pitch interconnects are thus possible with the application of microbump. The small joint height may alleviate the crack formation according to Blech products [1]. The producing of microbump is incorporated with Cu pillar which will alleviate the Joule heat concern of the high current density in the small solder volume. However, the small solder volume causes the concern of rapid transformation of the solder into intermetallic compound (IMC) under high current density. Metallization combinations were investigated in this study for its effect on the IMC conversion of the microbump solder joint.

2. Experimental

The microbump structure investigated is presented in Figure 1 which shows that the bump height is 30 μ m, the diameter of microbump and copper pillar is 75 μ m, the pillar height is 40 μ m. The solder is Sn1.8Ag. The UBM consists thin Ti adhesive layer, thin Cu on the Ti for plating conduction need. A UMB with Ni layer (3 μ m in thickness) between Cu pillar and solder was also applied for comparison. The substrate metallization includes OSP-Cu and OSP-Cu with ENEPIG (electroless Ni(P)/ electroless Pd/immersion Au) layer. Electrical current stressing was conducted at a current density of 1.0×10^4 A/cm² under 125°C for various durations of 24hr, 100hr, 200hr, 300h. The microbump was ground and polished to the maximum diameter to reveal the microstructure variations.



OSP Substrate

TiCuCu UBM

Fig. 1 The schematic of the microbump structure.

3. Results and Discussion

Electromigration is known to induce polarity effect on a flip chip solder joint. The cathode metallization will dissolve while intermetallic compounds (IMC) will accumulate on the anode side [2,3]. Fig. 2 presents the microstructure of Cu/Ni/Sn1.8Ag/ENEPIG/Cu solder joint after current stressing for 24h - 300h. The short time, 24h, current stressing induced the formation of Ni₃Sn₄ on both ends of the joint due to the appearance of Ni metallizations. All of the IMCs including Ag₃Sn, (Au, Pd, Ni)Sn₄, and (Ni, Cu)₃Sn₄ were formed during reflow. The joint still consists large volume fraction of solder even after 24h of current stressing. A longer current stressing up to 300h caused the growth of IMCs in the joints. Meanwhile, voids are observed between IMCs. The formation of voids is ascribed to the molar volume difference induced by IMC formation. The molar volumes of Ni, Sn, and Ni₃Sn₄ are, respectively, 6.6, 16.3, and 75.3 cm³/mol [4]. The formation of Ni₃Sn₄ involves a 11.3% of volume shrinkage. The molar volumes are 71.13 cm³/mol for PdSn₄ and 75.25 cm³/mol for Ni₃Sn₄. The compounds conversion actually involved (Pd, Ni)Sn4 and (Ni, Cu)3Sn4 will exhibit 9.65% -22.3% of volume difference [5]. Polarity effect is also observed after current stressing. Thick IMC exists at the anode side while crack appears at the cathode side after 300h of current stressing.



Fig. 2 The microstructure of Cu/Ni/Sn1.8Ag/ENEPIG/Cu after current stressing for (a)24h (b)200h (c)300h

The adoption of OSP-Cu instead of ENEPIG/Cu on the substrate changes the IMC to Cu₃Sn on the cathode side and (Cu, Ni)₆Sn₅ on both sides after short time, 24h, of current stressing, Fig. 3(a). Ni is supplied from the Ni metallization on the anode side. It is seen that the OSP-Cu dissolves vastly after long time of current stressing. The cathode Cu was massively consumed. The Cu₃Sn layer grew at the cathode but the Ni₃Sn₄ layer remains thin at the anode side. In the meantime, the solder gradually converts to (Cu, Ni)₆Sn₅ during the progress of current stressing. Void also appears during the transformation of solder to IMC. A void exists in the right hand region of Fig. 3(b) evidences the behavior of volume shrinkage during conversion of solder to (Cu, Ni)₆Sn₅. The entire solder joint was converted to IMCs with occupying the major joint volume. It has been reported that Cu₆Sn₅ grew faster than Cu₃Sn. In the structure of OSP-Cu without Ni barrier layer the current stressing accelerates the dissolution of Cu into solder and thus promotes the formation and growth of Cu₆Sn₅ with Ni inclusion.

4. Conclusions

The metallization of solder joint significantly influence the formation of IMC during current stressing. The solder joint with OSP-Cu on the cathode side will convert all the Sn1.8Ag



Fig. 3 The microstructure of Cu/Ni/Sn1.8Ag/OSP-Cu after current stressing for (a)24h (b)100h (c)200h (d)300h

solder to $(Cu, Ni)_6Sn_5$ IMC after long time of current stressing. The polarity effect of current stressing was observed with the ENEPIG-Cu metallization while not the OSP-Cu.

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