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Effect of isothermal aging and low density current on intermetallic compound growth rate in lead-free solder interface

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ABSTRACT

This study investigated the effects of isothermal aging and low density current on intermetallic compound (IMC) growth rate and microstructural evolution of lead-free solder interface at a temperature of 398 K. The results showed that the morphology of IMC layers under high temperature aging and current stressing was basically same. The growth rate of IMC at the anode was the fastest. That was because chemical diffusion force and electronic wind acted together to drive the growth of IMC at the anode. The current density was not high enough for obvious polarization effects and crack along the electron flow direction to be observed. Next the mean-time-to-failure analysis was used to calculate the lifetime of ball grid array solder joints stressed electrically. However, the calculated value was much shorter than the true value. Indicating that perhaps the equation needs to be modified when applied to Cu interconnects and flip chip solder joints.

1. Introduction

Some intermetallic compounds (IMC) forming between the solder and substrate are essential for good metallurgical bonds. Thus, the growth of IMC layers during field service influences the strength and mechanical failures of solder joints [1,2]. Thin layers of IMC result in good metallurgical bonds, while excessive thick layers of IMC may undermine the performance and eventually the reliability of the solder joint. Liu et al. [3] reported that the shear and tensile strengths of the flip chip solder joints decreased with increasing reflowing time and IMC thickness. Therefore, it is important to study growth behaviors of IMC layers formed between solders and substrates.

In general, an electronic device during service is subjected to high temperature (up to 373 K) and current stress. The temperature and current, which a device experiences, are main factors for the growth of intermetallic layer. Many previous works showed the effect of thermal aging or current stress on the growth dynamics of IMC in lead-free solders. It is believed that the formation of Cu–Sn IMC during aging is controlled by the volume diffusion or stationary grain boundary diffusion. The thickness of IMC increases linearly with the square root of aging time by Fickian diffusion [4–7]. Gan and Tu [1] investigated the changes in thickness and morphology of IMC forming at cathode and the anode in the Sn3.8Ag0.7Cu/Cu system. The growth of IMC was enhanced by electric current at the anode and inhibited at the cathode. The scallop-to-layer transformation for Cu_6Sn_5 compound took place much faster with the presence of electric current. The compound dissolved into layer-type at the cathode while it grew into layer-type at the anode. Chao et al. [8] reported a kinetic analysis for current enhanced growth of Cu_3Sn and Cu_6Sn_5 layers. Simulation showed that when current was absent, intermetallic growth followed a parabolic law, suggesting a diffusion controlled mechanism for thermal aging. However, under significant stressing (4×10^4 A/cm^2), the growth of Cu_6Sn_5 clearly followed a linear law, suggesting a reaction controlled mechanism for electromigration. Lee et al. [9] studied the electromigration damage in flip chip solder bumps of SnPb and Sn3.8Ag0.7Cu. The effect of electromigration in Sn3.8Ag0.7Cu was much smaller than that in eutectic SnPb, and hillocks of IMC at the anode were observed in the former. Mohanasundaram et al. [10] reported a new application of electromigration as tool for engineering the microstructure of thin metal films. By controlling the level of disorder in the microelectromechanical system, electromigration enables us to modify the electrical and electromechanical properties of the films.

The studies mentioned above focused on the effect of high current density (more than 10^4 A/cm^2) on the growth of IMC layers. However, the current density through flip chip solder joints in industry is not as high as 10^4 A/cm^2. The diameters of the solder bumps in 2-level package are usually more than 300 μm. So many components are working at low-density current. The study on the effect of relative low density current (10^3 A/cm^2) on the electromigration is more effective to solve practical issues in packaging industry. Hence, the influences of isothermal aging and low current density (10^3 A/cm^2) on the electromigration of SnAgCu (SAC)/Cu solder joints in BGA package was investigated in this paper.

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2. Experiments

2.1. Materials

Fig. 1 shows a typical BGA package specimen with a chip on a substrate used in this study. Sn3.0Ag0.5Cu solder balls with 600 μm diameter were used in the tests. Dimensions of the Cu pads in the substrate are 48.26 μm in thickness and 533.4 μm in diameter. The pitch is 1 mm. Each copper pad was covered with a thin (about 5.08–7.62 μm) layer of organic solderability preservatives (OSP) coating. The daisy chains on the chip side were copper trace with a thickness of 29.76 μm.

2.2. Sample preparation

The substrates were put into reflow oven with twelve temperature stages (HELLER 1900EXL) to solder with chips. Fig. 2 shows the reflow temperature curve. The reflow peak temperature was 533 K. The heating rate and cooling rate were 1.8 K/s and 1.68 K/s, respectively. The duration above 490 K was about 56 s. After reflowing, the samples were put into a thermal humidity chamber (EBS-SDJ63). The solder bumps in chips were constructed as an array of 33 lines × 3 rows along each side of the chip, and from left the bump was marked as A1, A2, A3–A33. The bumps were divided into two groups. One set of samples was isothermally aged at 398 K, and the aging time was 0 h, 250 h, 500 h, 750 h, 1000 h, 1250 h, 1500 h and 1750 h. Another group of samples was subjected to a 5 A constant current (from the chip side to the substrate side) and aged at 398 K (see Fig. 1). The average current density was calculated to be about 1.77×10^3 A/cm^2 in the solder joints.

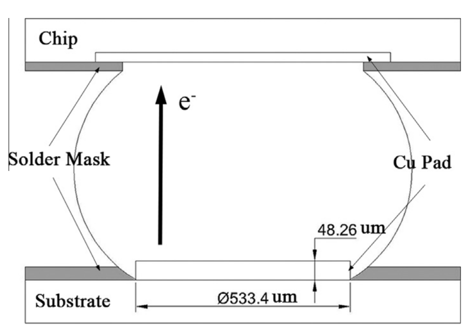

Fig. 1. A cross-sectional area of one solder bump.

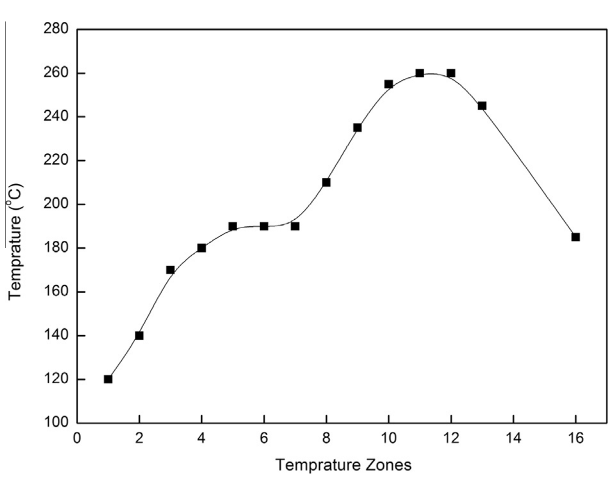

Fig. 2. Reflow temperature curve.

After aging, all the samples were prepared by standard metallographic procedures (grinding, polishing and etching with a solution of 5 vol.% HNO_3 + 92 vol.% C_2H_5OH + 3 vol.% HCl). Scanning electron microscopy (TESCAN VEGAII LMV SEM) and energy dispersive X-ray spectroscopy (OXFORD, Inc., ISIS300 EDS) were employed to characterize the microstructures and phase composition of both the prepared solder matrices and interfacial reaction IMC layers.

3. Results and discussion

3.1. The effect of aging on the growth of the IMC

Fig. 3(a–h) shows cross-sectioned SEM images of solder joints after reflowing and after aging at 398 K for 250 h, 500 h, 750 h,

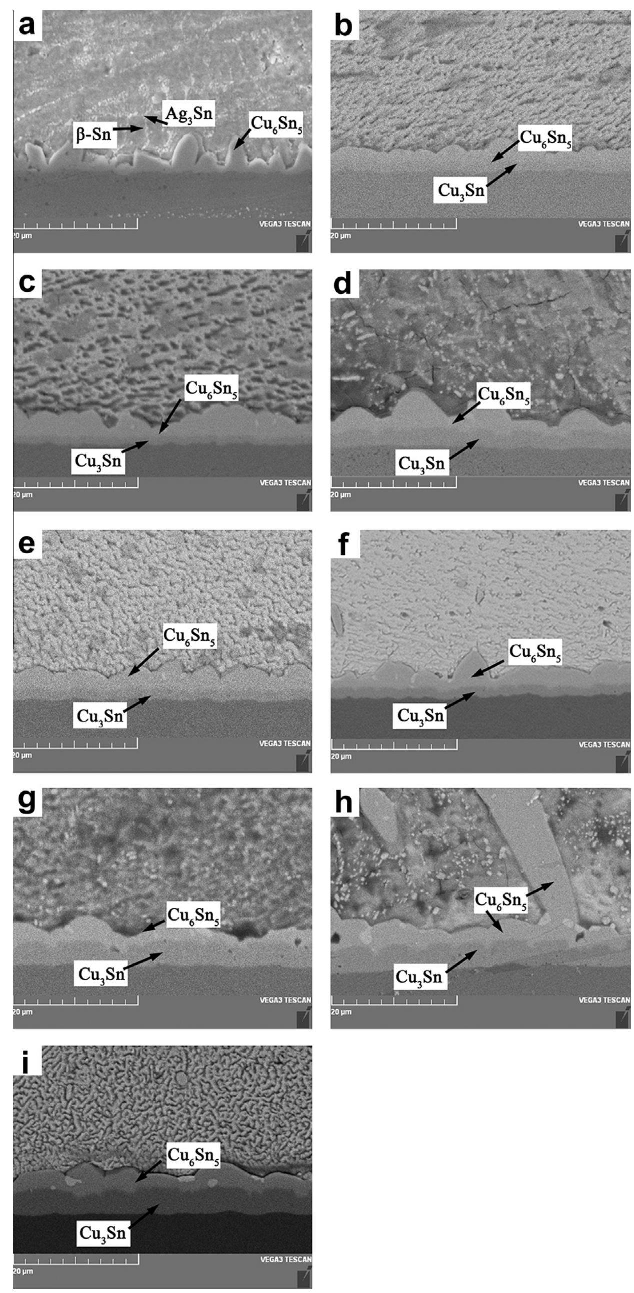

Fig. 3. SEM images of the thickness change of IMC at 398 K (a) after reflowing, (b) after aging for 250 h, (c) 500 h, (d) 750 h, (e) 1000 h, (f) 1250 h, (g) 1500 h, (h) 1750 h, (i) 2000 h.