Microelectronic Engineering 120 (2014) 77–84

Contents lists available at ScienceDirect

Microelectronic Engineering

journal homepage: www.elsevier.com/locate/mee

Effect of surface finishes on electromigration reliability in eutectic Sn–58Bi solder joints

Jae-Ha Kim [a], Young-Chul Lee [a], Sang-Min Lee [b], Seung-Boo Jung [a,*]

[a] School of Advanced Materials Science & Engineering, Sungkyunkwan University, 300 Cheoncheon-dong, Jangan-gu, Suwon-si, Gyeonggi-do 440-746, South Korea
[b] SKKU Advanced Institute of Nano Technology (SAINT), Sungkyunkwan University, 300 Cheoncheon-dong, Jangan-gu, Suwon-si, Gyeonggi-do 440-746, South Korea

ARTICLE INFO

Article history:
Available online 10 December 2013

Keywords:
Electromigration
Sn-58Bi
Solder
Surface finishes
Reliabilty

ABSTRACT

This study focuses on the microstructural evolution and failure behavior induced by electromigration in a eutectic Sn–58Bi solder joint. In order to study their effects, surface finishes were prepared with OSP, ENIG, and ENEPIG. The test sample was a flip chip-type reaction module, and the diameter and height of the solder bump were 180 and 100 μm, respectively. A current was passed through the two solder joints, producing a current density of 1.3×10^4 A/cm^2 at 100 °C. The time to fail test were carried out sequentially using a test kit under a current density of 1.3×10^4 A/cm^2 at 100 °C. The Bi-rich layer was observed at the anode side of the solder joint during the electro migration test. The IMC growth at the interface of the solder joints with current applied was faster than with no-current applied because of a polarity effect. The different surface finished materials affected the behavior of electromigration in the eutectic Sn–58Bi solder joints with current stress. The time to fail (TTF) differed greatly with the surface finishes.

1. Introduction

The trend of electronic packaging changes to be multi-functional and miniaturized due to requirement by consumers for high performance. Flip chip packaging meets the trend, and it was widely used in electronic packaging. In order to improve performance, increased packing density of the I/O and the reduction of the pitch and size of the bump in flip chips have been accomplished [1–2]. As the bump scale decreases, the current density passing through the solder interconnection increases. High current density induces a potential risk of electrical failure in the solder joints due to electromigration. Electromigration describes the atomic motion in a metal under the influence of an applied electric field. It is basically a diffusion phenomenon under a driving force [3].

For two decades, environmentally friendly solder alloys have been researched because of the toxicity of lead in solder alloys. Many different solder alloys have been suggested to replace Sn–Pb solder such as the family of Sn–Cu, Sn–Bi, Sn–Zn and Sn–Ag–Cu [4,5]. The melting point of the SAC (Sn–Ag–Cu) solder alloys widely used in industry is increased by about 40 °C compared to lead containing Sn solder alloys (Sn–Pb), which have a melting point of about 180 °C. The energy consumption for electronics manufacturing is increased with the melting point of SAC solder alloys. Additionally multiple reflows are essential for fabricating high-performance devices. The SAC solder alloy induces thermal damage to electronic components during processing. Therefore, the electronics industry requires low melting point solder alloy to save on energy consumption when manufacturing electronics, even though the reliability of such solders has not been sufficient. Among the various low melting point solder alloys, the Sn–Bi based solder alloys are widely used in the electronics industry [5–8]. Many studies on SAC solder alloys have indicated that electromigration can induce significant microstructural changes at the interface of solder joints, including void nucleation and propagation, hillock formation, and phase segregation [3,8–15]. However, studies of the electromigration reliability and interface behavior of the reaction layer in solder joints of Sn–Bi solder alloy have been insufficient. Therefore, this study focuses on the microstructural evolution and failure behavior induced by electromigration in a eutectic Sn–58Bi solder joint. Specifically, the effect of surface finishes on failure induced by electromigration is investigated.

2. Experimental procedure

A PCB was prepared for electromigration test as shown in Fig. 1. The test sample for electromigration was designed with 10 pairs of I/O electrodes, with 2 solder bumps interconnecting each input and output electrode, as shown in Fig. 1. Only two solder joints in the electromigration test sample have solder bumps with diameter and height of are about 180 μm and 100 μm, respectively. The

* Corresponding author. Tel.: +82 31 290 7359; fax: +82 31 290 7371.
E-mail address: sbjung@skku.edu (S.-B. Jung).

0167-9317/$ - see front matter
http://dx.doi.org/10.1016/j.mee.2013.12.006

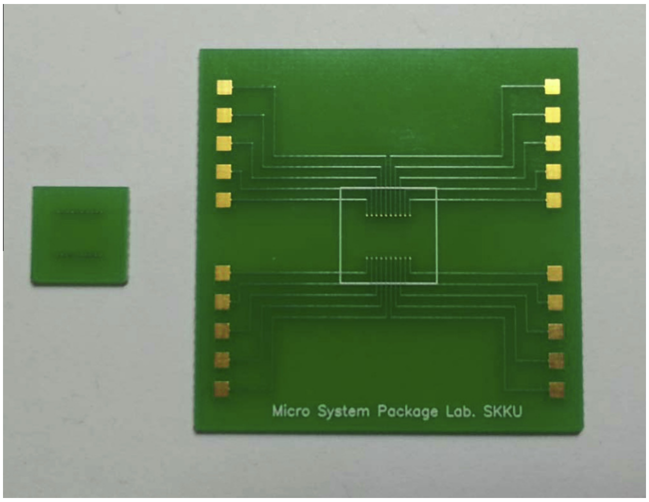

Fig. 1. Design of the substrate and chip.

pitch in the test sample for the electro migration package is 500 μm. The solder was eutectic Sn–58Bi paste (LFSOLDER TLF-401-11, Tamura Co. Ltd.), and the solder bump was fabricated by a stencil printing process. The test sample was reflowed in reflow machine (RF-430-N2, Japan Pulse Laboratory Co. Ltd.) with a peak temperature of 190 °C for 8 min. The solder resist opening size was 120 μm, and the substrate material was FR4. Under bump metallization (UBM) was located under the solder bumps, which were plated with three kinds of surface finishes; organic solderability preservatives (OSP), electroless nickel immersion gold (ENIG), and electroless nickel electroless palladium immersion gold (ENEPIG). The thickness of organic layer was 0.3 μm, and the thicknesses of the Au, Pd, and Ni in ENIG and ENEPIG were 0.08, 0.1, and 5 μm, respectively. A schematic of the test equipment and solder joints is illustrated in Fig. 2. The solder joints were applied under the current density of 1.3×10^4 A/cm^2 at 100 °C for 12, 24, 36, and 48 h. The voltage was sequentially measured until complete failure occurred, as illustrated Fig. 2(b). The cross sections of the solder joints after the electromigration test were polished with 0.3 μm Al_2O_3 particles, and then the microstructures were analyzed by scanning electron microscope (SEM) and energy dispersive X-ray spectroscope (EDX).

Table 1
Measured the mean failure time in the solder joints with a current density 1.3×10^4 A/cm^2 at 100 °C.

Surface finish	OSP	ENIG	ENEPIG
Mean failure time (min)	6372	4568	5284

3. Result and discussion

Fig. 3(a) and (b) show the thickness of the total IMC in solder joints at 100 °C with a current density of 1.3×10^4 A/cm^2. The IMC thickness in all conditions increased with increases in the applied current times. The IMC thickness on the anode side of the solder joints with current density was thicker than in the no-current case. These results, suggest that the IMC growth was enhanced by the electromigration at the anode side, while the IMC growth was inhibited by the electromigration at the cathode side. According to Chen et al. and Lu et al., the electric current enhanced the IMC growth on the anode side and retarded it on the cathode side because of the polarity effect. The IMC layer in ENIG and ENEPIG solder joints was increased with of the applied current, and the behavior at the solder joints in this works was in good agreement with previous results [8,9]. However, the IMC growth on the cathode side of the OSP solder joints was faster than on the anode side after 24 h, as shown in Fig. 3(a). In addition, the IMC thickness on the anode side of the OSP solder joints was thinner than those of ENIG and ENEPIG solder joints, as shown in Fig. 3(b) and (c).

Fig. 4 shows the cross sectional microstructure in the OSP solder joints with current applied for 12, 24, 36, and 48 h. The arrows in Fig. 4 indicate the direction of electron flow. The Bi-rich phase and Sn-rich phase were clearly observable in the solder joints with increasing applied current. The bright region and dark region analyzed by EDX and represent the Bi-rich phase and Sn-rich phase, respectively. According to Yang et al. and Chens et al., the Bi atoms were segregated at the anode side. The Sn, Bi atoms and IMC migrated in response to the electron flow, and then the Sn was transformed into the IMC. Bi was segregated the anode side because the Bi was not transformed into the IMC. The result of this study well matched with reference results [10,11]. The IMC layer at the anode side of the 1st solder joints was thicker than that of the cathode side under the current. However, the IMC thickness at the cathode side in the 2nd solder joints was a few orders of magnitude thicker than that at the anode. The Bi-rich layer grew thick enough to block

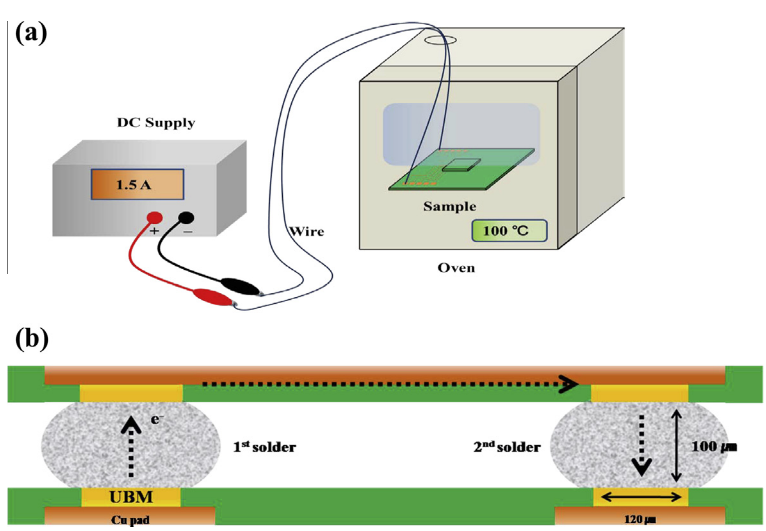

Fig. 2. (a) Illustration of experiment, (b) schematic diagram of the cross-sectional electromigration test sample.