# Electromigration induced failure in $SnAg_{3.8}Cu_{0.7}$ Solder Joints for Flip Chip Technology

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**Abstract**

Electromigration of $SnAg_{3.8}Cu_{0.7}$ solder was investigated in flip chip solder bump. An under-bump metallization (UBM) of Cr/Cr-Cu/Cu tri-layer was deposited on the chip side and electroless Cu/Ni/Au pad was deposited on the BT board side. Electromigration damage was observed under the current density of $2 \times 10^4$ A/cm$^2$ at 100 ℃. Voids were found at cathode side and crack was observed at solder/thin film UBM interface after current stressing, and the bump failed after 168-hour stressing. Copper atoms were found to move in the direction of electron flow. Intermetallic compounds of Cu-Sn and Ni-Cu-Sn were also observed to spread into the solder bump due to current stressing.

## Introduction

Flip Chip technology has been used in electronics industry due to the higher packaging density (more I/Os), better performance, smaller device footprints, and lower packaging profile. This technology consist two basic steps, first solder bumps are deposited on the chips and reflowed, then the chips are flipped over, aligned to a substrate, and reflowed again [1][2]. Serious reliability issues like thermal-mechanical fatigue, heat dissipation and electromigration have received tremendous amount of attention in these solder bumps. Concerning electromigration problem, the number of input/output pin counts will increase for the flip chip products in the near future, the bump pitch and the diameter of UBM decrease rapidly due to the small contact area of the solder bumps. For solder bumps in flip chip technology is approaching to 50 $\mu$m in diameter, if a solder bump was carry 0.2A electrical current, the current density will reach to $10^4$A/cm$^2$ and is large enough to cause electromigration damage, so the eletromigration in flip chip solder bumps needs to be investigated. For the recent studies on electromigration were mainly focus on eutectic SnPb solder [3]-[6]. Due to the environmental concern, Pb containing solders will be replaced by Pb-free solder. $SnAg_{3.8}Cu_{0.7}$ solder will be one of the most promising lead-free solders in microelectronic packaging industry. However, only a few researches have been studied on the solder bumps of $SnAg_{3.8}Cu_{0.7}$ [7]-[9].

In this work, the electromigratoin of $SnAg_{3.8}Cu_{0.7}$ flip chip structure has been studied under the current density of $2 \times 10^4$ A/cm$^2$ at 100 ℃. Current crowding and polarity effect were examined in the solder bump. The failure was found to be at solder and thin film Cr/Cr-Cu/Cu tri-layer interface.

## Experiment

The SnAgCu solder bumps structure was stressed at 100℃ of the current density of $2 \times 10^4$ A/cm$^2$ on a hot plate in atmospheric ambient. An under-bump metallization (UBM) of Cr/Cr-Cu/Cu tri-layer was deposited on the chip side and electroless Cu/Ni/Au pad was deposited on the BT board side. The solder bumps were formed by printing solder paste through a metal stencil and reflowed twice in a furnace. Then the package was filled with underfill. In order to observe the electromigration of the solder bumps under high current density, the solder bumps were cross sectioned first, then they were stressed at the current density of $2 \times 10^4$ A/cm$^2$. Schematic diagram of the structure is shown in Fig. 1.

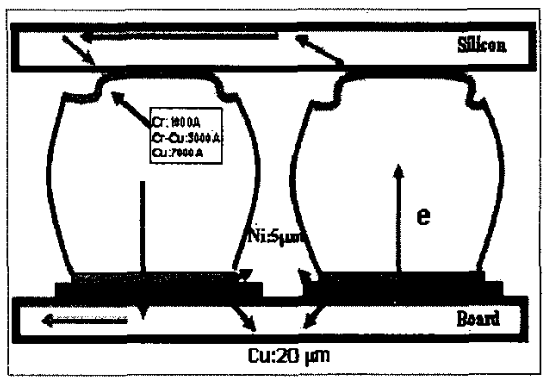



Fig. 1 Schematic diagram of sold bump structure

Electromigration damage was examined by scanning electron microscope (SEM). Composition of intermetallic compound and migration of metal atoms were determined by using energy dispersive spectroscopy(EDS). Due to the Aluminum circuit design in the structure, electron flow is moved upward from the board side to the left corner of the chip side, then downward from the left corner of the chip side to the board side as indicated by the arrows in Fig. 1. This will lead current crowding effect at these corners in the solder bumps.

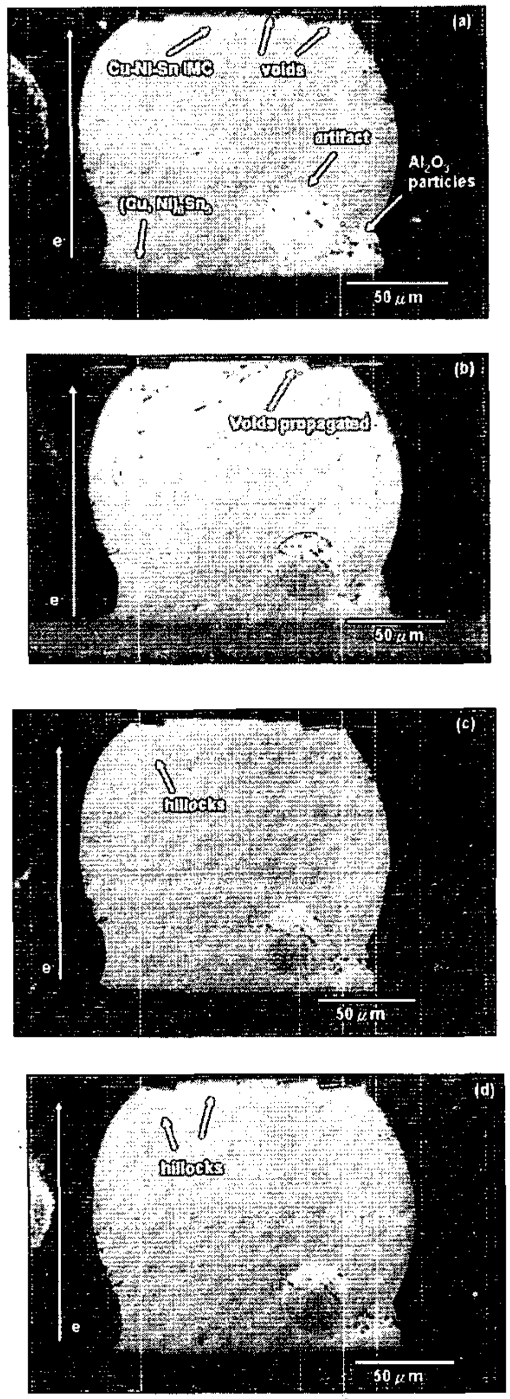
**Results and discussion**

Fig. 2(a) through 2(e) illustrate the electromigration phenomenon in $SnAg_{3.8}Cu_{0.7}$ solder bump before and after stressing for 20, 70, 110, 168 hours, respectively. Intermetallic compounds $(Cu, Ni)_6Sn_5$ was observed at the interface of solder and Ni UBM interface and also in the solder. However it is only a few intermetallic compounds at the interface of solder and Cu UBM. This is attributed to the thickness of Cu at UBM. Cu may almost dissolve into the solder and react with Tin after reflowed.

The direction of the electron flow is from board side Ni UBM toward chip side. The original voids at solder and Cu thin film UBM interface can be observed in Fig. 2(a). Voids propagated as stressing time increased, and hillocks were observed at the left side of the UBM as shown in Fig. 2(b) through 2(d). At Ni thick film and solder interface, voids were only observed at the center of the interface after stressing as shown in Fig. (3). The solder bump was failed after 168 hours stressing, the surface sank and become very rough.

At Cu thin film and solder interface, hillocks and lump were observed. They are due to mass transport by the electron flow. Also the voids can be observed and propagated during current stressing. It is attributed that, in the solder bump, metal atoms were migrated with electron flow from the board side to the left corner of chip side, the more and more metal atoms were accumulated at the left upper corner, and mass transport by metal atoms induced voids concentration gradient at the solder and UBM interface, voids were pushed from the left side to the right side during electromigraton. Consequently voids propagated and became crack. Fig. 4(a) through 4(e) illustrate the electromigration phenomenon with opposite polarity before and after stressing of 20, 70, 110, 168 hours, respectively. The direction of electron flow now is from the chip side to the board side. Voids and hillocks were observed at cathode side and anode side, respectively. The voids were propagated as stressing time increased. The solder bump was failed after 168-hour stressing, the surface sank and become very rough.

Intermetallic compounds of Cu-Sn and Cu-Sn-Ni were observed to spread into the solder bump due to current stressing. Intermetallic compound found in the solder is not uniformly distributed, there were more compound particles on the right-hand. This is due to the current crowding effect, since electron flow is from the left corner of the chip side downward to the board side. Besides intermetallic compounds of Cu-Sn and Cu-Sn-Ni were observed to accumulate at solder and UBM interface as shown in Fig. 4(e). Fig. 5(a) and 5(b) are the enlarged image of Fig. 4(e). The elemental EDS mapping and Cu accumulation were observed at the left side of the UBM clearly due to current stressing. However, in the solder bump which with opposite direction of electron flow, Cu-Sn and Cu-Sn-Ni intermetallic compound were not found to spread into the solder bump. This is due to that the opening of Ni UBM is larger than Cu UBM, which means that the current density of the Ni UBM is much lower than of Cu UBM. Therefore, the electromigration damage at Cu UBM side is more serious than that of Ni UBM.



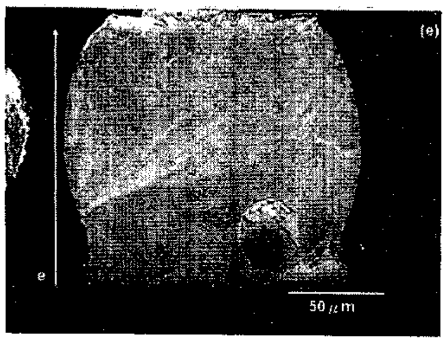



Fig. 2. Cross-sectional SEM images of the solder bump under the current density of $2 \times 10^4$ A/cm$^2$ at 100 ℃ (a) 0hr, (b) 20hrs, (c) 70hrs, (d) 110hrs, and (e) 168hrs

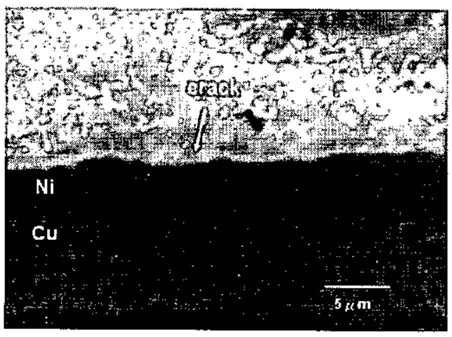
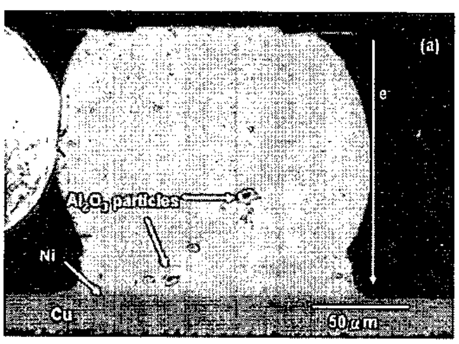



Fig. 3 Cross-sectional SEM image of the solder bump after 168 hrs stressing. Voids were observed at the middle of the interface.



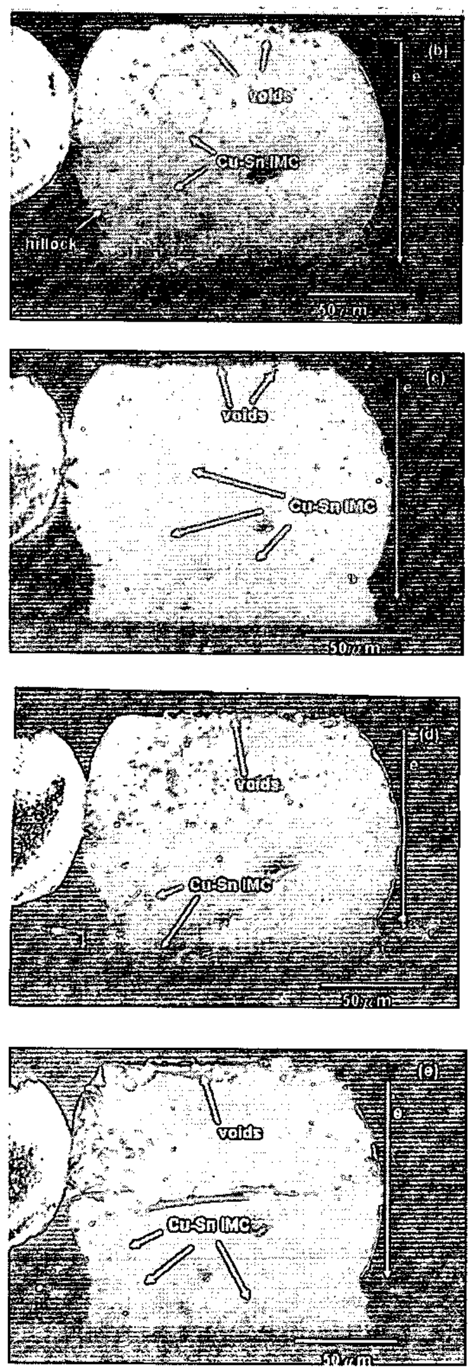
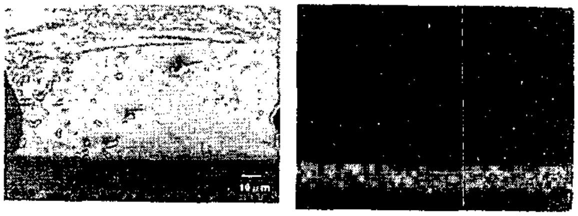




Fig. 4 Cross-sectional SEM images of the solder bump under the current density of $2 \times 10^4$ A/cm$^2$ at 100 ℃ (a) 0hr, (b) 20hrs, (c) 70hrs, (d) 110hrs, and (e) 168hrs.



(a) (b)

Cu

Fig. 5(a) enlarged image of Fig. 4(e), and (b)the elemental EDS mapping, dot mat of Cu element.

## Conclusions

Electromigration induced failure in $SnAg_{3.8}Cu_{0.7}$ solder joints was observed under the current density of $2 \times 10^4$ $A/cm^2$ at 100℃. Voids were found at cathode side and crack was observed at solder/thin film UBM interface after current stressing. Current crowding and polarity effect were examined. Copper atoms were found to move in the direction of the electron flow. Intermetallic compounds of Cu-Sn and Ni-Cu-Sn were also observed to spread into the solder bump due to current stressing. Bump failed after 168-hour stressing. .

## Acknowledgment

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