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Tensile Properties and Thermal Shock Reliability of Sn–Ag–Cu Solder Joint with Indium Addition

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The thermal shock reliability and tensile properties of a newly developed quaternary Sn–1.2Ag–0.5Cu–0.4In (wt%) solder alloy were investigated and compared to those of ternary Sn–Ag–Cu based Pb-free solder alloys. It was revealed that the Sn–1.2Ag–0.5Cu–0.4In solder alloy shows better thermal shock reliability compared to the Sn–1.0Ag–0.5Cu and Sn–3.0Ag–0.5Cu solder alloys. The quaternary alloy has higher strength than Sn–1.0Ag–0.5Cu alloy, and higher elongation than Sn–3.0Ag–0.5Cu alloy. It was also revealed that the addition of indium promotes the formation of $Ag_3(Sn, In)$ phase in the solder joint during reflow process.

Keywords: Pb-Free Solder, Sn–Ag–Cu Alloy, Indium Addition, Thermal Shock Reliability.

1. INTRODUCTION

The demand for portability in electronic appliances requires high reliability of solder joints, especially drop/shock reliability. However, Sn–3.0Ag–0.5Cu alloy (wt%), a representative Pb-free solder material,[1–4] exhibits limited drop/shock reliability compared to Pb-containing Sn-based solder alloys.[5]

Concerning Sn–Ag–Cu-based ternary solder alloys, it has been known that decrease in silver content leads to higher drop/shock reliability, but at the same time, lower thermal shock reliability.[5] Therefore, the addition of a fourth alloy material with the optimization of the silver content is a key factor to satisfy the need for both drop/shock and thermal shock reliability.

In our previous work, the silver content was optimized as 1.2 wt%, and indium was chosen as the fourth alloying element to develop a new quaternary Sn–1.2Ag–0.5Cu–0.4In solder alloy.[6] The previous work revealed that the newly developed quaternary alloy shows better drop/shock reliability than the Sn–3.0Ag–0.5Cu alloy.[6] In this study, tensile properties and thermal shock reliability of the quaternary Sn-1.2Ag–0.5Cu–0.4In solder alloy were investigated and compared to those of conventional ternary Pb-free solder alloys.

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2. EXPERIMENTAL PROCEDURE

Four kinds of solder alloys, namely, Sn–1.0Ag–0.5Cu, Sn–1.2Ag–0.5Cu, Sn–3.0Ag–0.5Cu and Sn–1.2Ag–0.5Cu–0.4In, were prepared in the forms of bars, balls and paste.

Tensile testing was carried out by an Instron type testing machine (Instron 4481) at room temperature with a strain rate of 10^{-2} s^{-1} using specimens with a gauge section of 2 mm × 3 mm × 13 mm.

A surface mount technology (SMT) process was performed as follows; each solder balls (450 μm in diameter) was attached manually to a chip scale package (CSP) and reflowed. The CSP with a solder ball attached was surface-mounted on a solder paste printed PCB (printed circuit board) using a chip mounter (cp-45fv, Samsung Techwin). The pad surface finishes were Au/Ni for the chip side and organic solderability preservative (OSP)/Cu for the board side, respectively. The peak temperature of the reflow (1809UL, Heller) was set to 242 °C.

After the SMT process, the cross section of the solder joint including the solder/pad interface was observed and analyzed using a field emission scanning electron microscope (FE-SEM) (S-4300SE, Hitachi) equipped with an energy dispersive spectroscope (EDS) (EMAX 132-10, Horiba). Phase identification was also done by X-ray diffractometer (XRD) (X'Pert PRO, PANalytical) at 30 kV and 15 mA using Cu Kα radiation with a diffraction angle (2θ) from 20 to 100 and a constant scanning speed of 1 °/min.

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Thermal shock reliability was investigated by a thermal shock tester (VT 7012 S2, Votsch). The test conditions may be summarized as follows. Up to thermal 4,000 cycles (1 cycle period = 30 minutes) were applied at a temperature range between −40 °C and 125 °C. The total resistance change was measured in daisy-chained interconnections including 5 CSPs and a board. A resistance value of 1,000 Ω was set as the failure criterion of the solder joint.

3. RESULTS AND DISCUSSION

Figure 1 shows the ultimate tensile strength (UTS) and elongation of four kinds of solder alloy, obtained from the tensile stress–strain curves. Concerning the ternary alloys, namely, Sn-1.0Ag–0.5Cu, Sn–1.2Ag–0.5Cu, and Sn–3.0Ag–0.5Cu, the UTS increases with increasing silver content. Noticeably lower elongation is observed for the Sn–3.0Ag–0.5Cu alloy compared to the other solder alloys. In contrast, the quaternary Sn–1.2Ag–0.5Cu–0.4In alloy possesses the highest value of elongation together with a relatively high value of UTS.

It was reported that the higher thermal shock reliability of the Sn–3.0Ag–0.5Cu alloy results from high strength and good fatigue resistance.[7–9] It was also reported that the enhanced drop/shock reliability of the Sn–1.0Ag–0.5Cu alloy is due to high elongation[5,7,9] since a ductile solder joint can help to absorb more dynamic energy to reduce the dynamic stress transformed from PCB to the solder layer.[7] From these points of view, the quaternary Sn–1.2Ag–0.5Cu–0.4In alloy is expected to have enhanced thermal shock reliability in addition to improving drop/shock reliability[6] because of proper mechanical properties, that is, higher strength than the Sn–1.0Ag–0.5Cu alloy and higher elongation than the Sn–3.0Ag–0.5Cu alloy.

Figure 2 shows cross-sectional images of the Sn–1.2Ag–0.5Cu–0.4In solder joint after the SMT process. The interfacial layer of the board side and that of the chip side are identified as Cu_6Sn_5 and $(Cu_{1-x}Ni_x)_6Sn_5$, respectively, from the EDS analysis. No trace of indium was detected in either interfacial layer. Instead, indium was detected in the Ag_3Sn phases in the solder matrix. Therefore, it is believed that most of the indium exists in the form of Ag_3(Sn, In) in the solder matrix.[10,11]

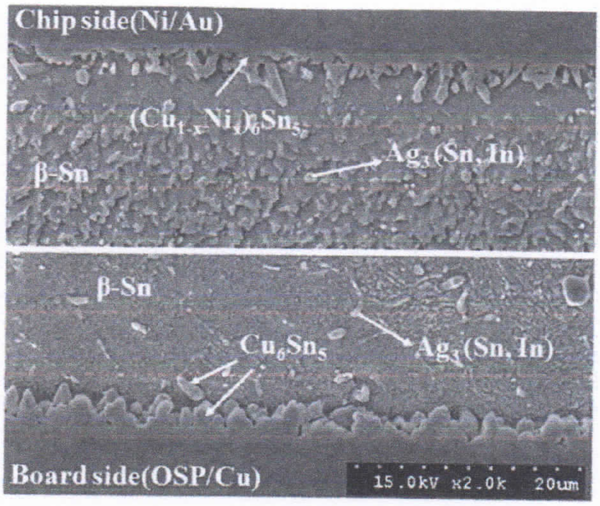

Fig. 2. Cross-sectional images of the Sn–1.2Ag–0.5Cu–0.4In solder joint.

Figure 3 shows XRD profiles taken from the solder joints formed by the Sn–1.2Ag–0.5Cu and Sn–1.2Ag–0.5Cu–0.4In alloys. It can be seen that β-Sn, Ag_3Sn/Ag_3(Sn, In) and Cu_6Sn_5 phases exist in both alloys. Interestingly, the peaks of the Cu_6Sn_5 phase appear to be lower in the Sn–1.2Ag–0.5Cu–0.4In alloy (In-containing alloy) than in the Sn–1.2Ag–0.5Cu alloy (In-free alloy). This fact may reveal that the addition of indium promotes the formation of Ag_3(Sn, In) phase with the suppression of the Cu_6Sn_5 phase.

Figure 4 shows a Weibull plot indicating the distribution of solder joint failure according to thermal shock testing. It can be shown that the solder joint of the

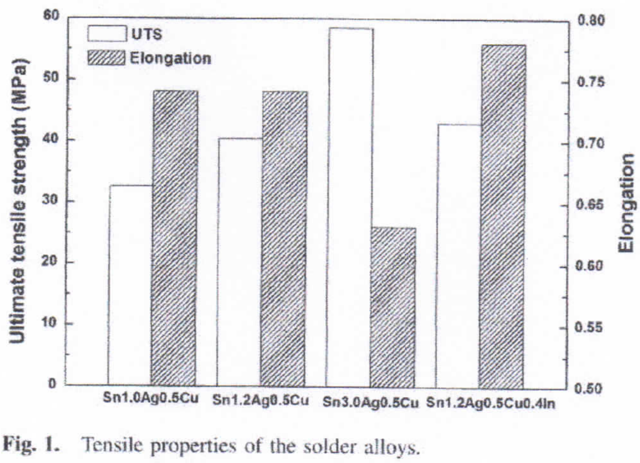

Fig. 1. Tensile properties of the solder alloys.

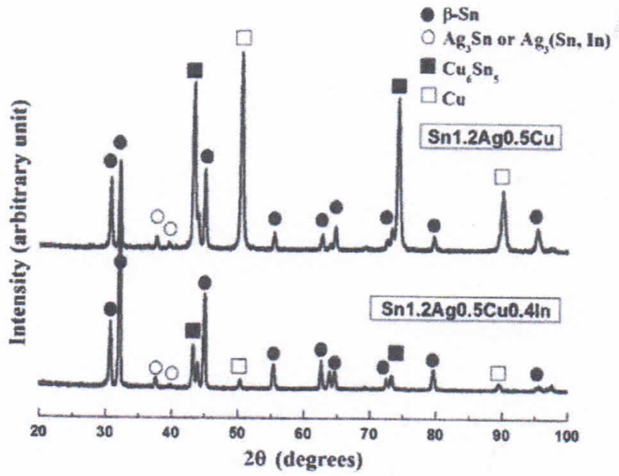

Fig. 3. XRD profiles of the solder joints formed by Sn–1.2Ag–0.5Cu and Sn–1.2Ag–0.5Cu–0.4In alloys.

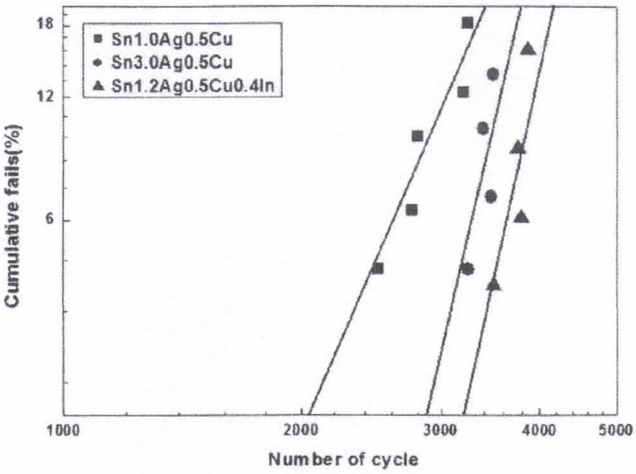

Fig. 4. Comparison of solder joint failure distribution.

Sn–1.2Ag–0.5Cu–0.4In alloy exhibits a delayed thermal cycle failure compared to the Sn–1.0Ag–0.5Cu and Sn–3.0Ag–0.5Cu alloys. Therefore, it can be concluded that the quaternary Sn–1.2Ag–0.5Cu–0.4In alloy is a promising high-performance Pb-free solder material satisfying the need for both thermal shock and drop/shock reliability.

4. CONCLUSION

The tensile properties and thermal shock reliability of a newly developed quaternary Sn–1.2Ag–0.5Cu–0.4In solder alloy were investigated and compared to those of conventional ternary Pb-free solder alloys. It was revealed that the quaternary alloy has superior thermal shock reliability to Sn–1.0Ag–0.5Cu and Sn–3.0Ag–0.5Cu alloys. It was also revealed that the quaternary alloy has higher strength than Sn–1.0Ag–0.5Cu alloy, and higher elongation than Sn–3.0Ag–0.5Cu alloy. The addition of indium promoted the formation of $Ag_3(Sn, In)$ phase in the solder joint.

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