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The effect of 0.5 wt.% Ce additions on the electromigration of Sn9Zn BGA solder packages with Au/Ni(P)/Cu and Ag/Cu pads

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ABSTRACT

It has previously been established that Sn-9Zn-0.5Ce alloy possesses mechanical properties superior to those of undoped Sn-9Zn alloy, and is free of the problem of rapid whisker growth. However, no detailed studies have been conducted on the electromigration behavior of Sn-9Zn-0.5Ce alloy. In this research, Sn-9Zn and Sn-9Zn-0.5Ce solder joints with Au/Ni(P)/Cu and Ag/Cu pads were stressed under a current density of 3.1×10^4 A/cm^2 at room temperature for various periods of time. Due to finer grain sizes, the electromigration effects were more severe in Sn-9Zn-0.5Ce solder joints than in Sn-9Zn solder joints when joint temperature was around 80 °C. In addition, both solder joints (Sn-9Zn and Sn-9Zn-0.5Ce) with Au/Ni(P)/Cu pads possess longer current-stressing lifetimes than those with Ag/Cu pads because Ni is more resistant than Cu to migration driven by electron flow.

1. Introduction

Eutectic Sn-9Zn solder has a melting point quite like that of traditional Sn-37Pb solder, demonstrating that it has qualities fit for Pb-free solders. Sn-9Zn alloy also has the merits of high strength, longer fatigue life, and low cost [1]. However, certain problems, such as the poor wettability and oxidation resistance, have impeded its applicability in electronic packaging. Efforts on further improvement of its physical and mechanical properties have been made by adding rare-earth (RE) elements into the binary Sn-Zn solder. Wu et al. added 0.05 and 0.1 wt.% mixed metal (Ce, La) into a Sn-9Zn solder and observed that its wettability was better than that of undoped alloy due to the decrease of surface tension [2]. Further work by Wu et al. indicated that the tensile strength and yield strength of Sn-9Zn were improved by alloying with 0.05 to 0.5 wt.% (Ce, La) mixed metal [3]. Although solder alloys doped with rare-earth elements have been reported to show many beneficial effects [4–6], amazingly rapid growth of tin whiskers has been observed in a Sn–Ag–Cu–XCe solder joint after room temperature storage in air for just a few days [7–10]. Such a phenomenon of tin whiskers on solder joints can cause short circuits and the failure of electronic devices. However, the phenomenon of rapid tin whiskers growth is not observed in all rare-earth doped solder alloys. Lin and Chuang found that both fiber- and hillock-shaped tin whiskers were inhibited in Sn-9Zn-0.5Ce solder [11].

With higher I/O density, better performance, and smaller feature size, electromigration has become a crucial reliability issue [12–15]. Although the beneficial effects of 0.5 wt.% Ce addition on the physical and mechanical properties of Sn-9Zn solder joints have been reported [11], the electromigration effects in Sn-9Zn-0.5Ce solder joints are still unclear. This paper reports the effects of 0.5 wt.% Ce addition on electromigration behavior of Sn-9Zn solder joints with Ag/Cu pads and Au/Ni(P)/Cu pads at room temperature.

2. Experimental

For the experiments, Ce was added to Sn-9Zn solder, and electromigration was evaluated in comparison to undoped Sn-9Zn alloy. Sn-9Zn-0.5Ce solder alloy was prepared by melting Sn-6.6 wt.% Ce master alloys, respectively, at 1000 °C in 10^{-5} Torr vacuum and then remelting them under the same conditions while adding the Sn and Zn. The ingots were further punched into disks of 0.45 mm in diameter. The solder disks were dipped in rosin mildly activated (RMA) flux, placed on Electroless Ni(2.54 µm-thick)/Immersion Au(75 nm-thick) and Immersion Ag(75 nm-thick) surface finished Cu pads, and then reflowed in a hot-air furnace. After the first reflow, the other substrate, with corresponding Au/Ni(P)/Cu or Ag/Cu pads, was flipped down to cover the solder balls. Following that, the whole assembly was reflowed again to form a sandwiched sample. Electromigration testing was performed at room temperature, and the average current density at the 300 µm diameter contact opening was 3.1×10^4 A/cm^2. To study the change in solder composition and microstructure induced by electromigration, the solder joints were slightly re-polished with 0.3 µm Al_2O_3 powder after current stressing. After slight re-polishing, the solder joints were examined by SEM combined with EDX. The observed region was the track/solder interface, which is the most favorable region in which to find void or hillock formation due to the current crowding effect [14]. In

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order to perform observations, the current stressing was stopped, and the same site on the specimen was examined by SEM. After the observation, electromigration testing was resumed, using the same specimen with the same current density.

3. Results and discussion

Due to the Joule heating effect, the joint temperature, measured by thermal couple, reached a stable temperature of 80 °C after stressing of 2 h. Fig. 1 shows the microstructure of Sn-9Zn solder joints with Ag/Cu pads after current stressing of 0–150 h, with Fig. 1a, c, and e showing the cathode side and Fig. 1b, d, and f showing the anode side. After reflow, a thin layer of scallop-shaped intermetallic compounds formed at the pad/solder interface, as shown in Fig. 1a and b. EDX analysis indicated that the composition (at.%) of these interfacial intermetallics was Ag: Zn = 18.4:81.6, which corresponds to the $AgZn_6$ phase. Voids and hillocks formed near the cathode side and anode side, respectively, after stressing for 50 h, as shown in Fig. 1c and d. When stressing time increased to 150 h, the void near the cathode side penetrated the interface, thus causing failure of the solder joint, as shown in Fig. 1e. Meanwhile, the Cu_5Zn_8 intermetallics and Cu pad on the cathode side were severely consumed, and the Cu_5Zn_8 intermetallics accumulated near the anode side (Fig. 1f). Since the atomic flux in electromigration is proportional to the diffusivity [13], and Cu possesses higher diffusivity in the solder matrix than Sn and Zn at 80 °C, one might expect Cu to be the dominant electromigration-diffused specie in Sn-9Zn solder joints with Ag/Cu pads. The Cu atoms decomposed from the Cu_5Zn_8 intermetallics and a pad near the cathode interface moved with electron flow and formed Cu_5Zn_8 intermetallics at the anode side during current stressing. With continued migration of the Cu atoms, the Cu pad on the cathode side was continuously consumed, until the voids grew to the point at which they penetrated the entire cathode interface. Fig. 2 shows interfacial microstructures of Sn-9Zn-0.5Ce solder joints with Ag/Cu pads after current stressing for 0–50 h. Compared with Sn-9Zn solder joints with Ag/Cu pads, the electromigration effects in Sn-9Zn-0.5Ce solder joints with Ag/Cu pads were more obvious, and the lifetime was decreased from 150 h to 100 h. Since 80 °C is equivalent to $0.74T_m$ (where T_m is the melting temperature of Sn-9Zn), grain boundary

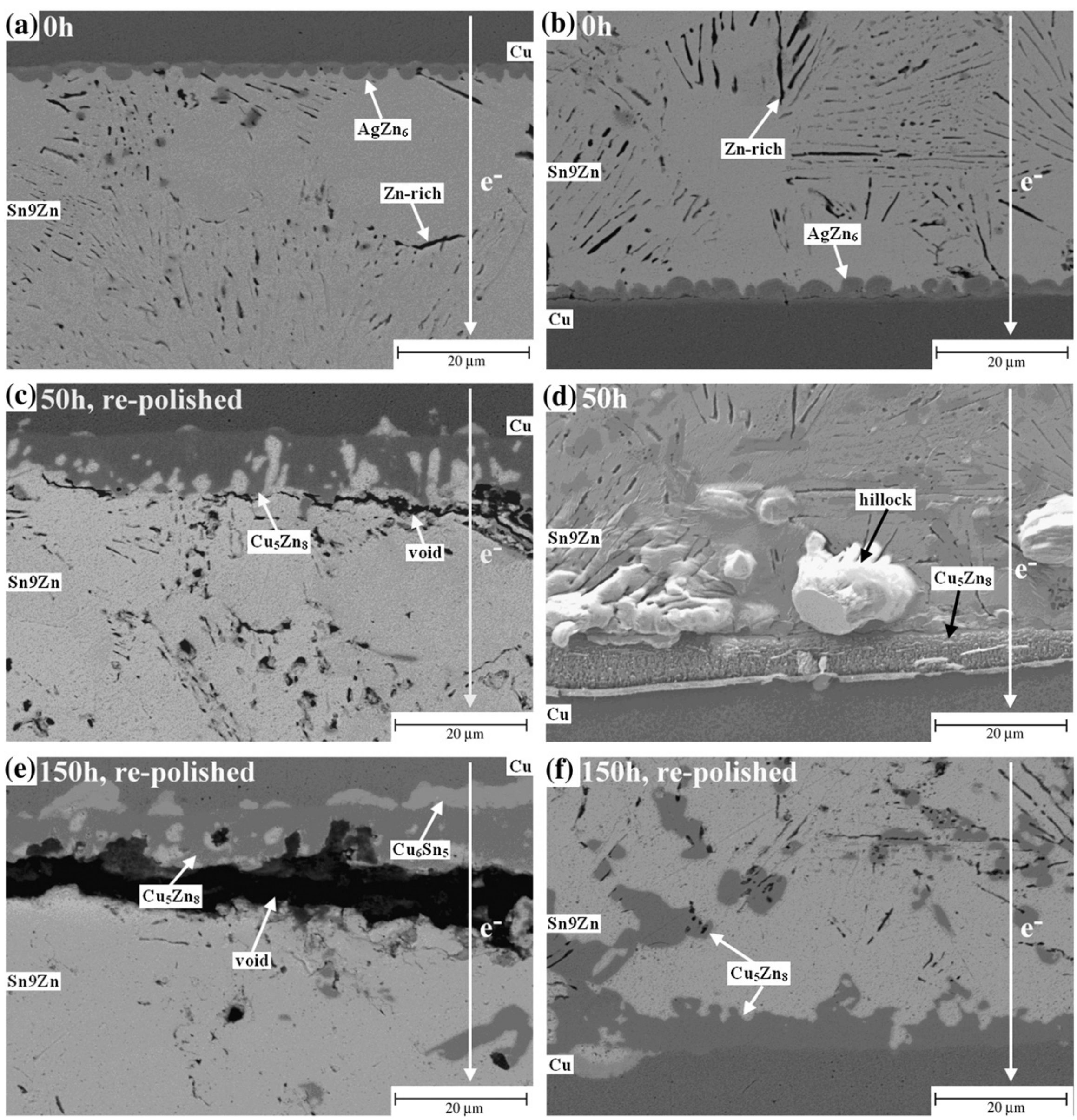

Fig. 1. SEM images of the cross-sectioned Sn-9Zn solder joints with Ag/Cu pads after current stressing with current density of 3.1×10^4 A/cm^2 at room temperature: (a, c, and e) on the cathode side; and (b, d, and f) on the anode side.