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Pd-doped Sn–Ag–Cu–In solder material for high drop/shock reliability

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ABSTRACT

Pd was chosen as a minor alloying element in a new Sn–1.2Ag–0.7Cu–0.4In solder alloy to improve the drop/shock reliability. The tensile properties and drop/shock reliability of the new Sn–1.2Ag–0.7Cu–0.4In–0.03Pd solder alloy was compared with those of the Sn–1.0Ag–0.5Cu and Sn–3.0Ag–0.5Cu alloys. The UTS, yield strength and elongation of Sn–1.2Ag–0.7Cu–0.4In–0.03Pd were superior to those of the other alloys tested. Sn–1.2Ag–0.7Cu–0.4In–0.03Pd showed outstanding drop/shock reliability compared to the representative Pb-free solder, Sn–3.0Ag–0.5Cu. Therefore, the Sn–1.2Ag–0.7Cu–0.4In–0.03Pd composition is assessed to be an alternative Pb-free solder composition that may replace Sn–3.0Ag–0.5Cu.

1. Introduction

Sn–Pb solders are used in the electronic packaging industry on account of their unique electrical, chemical, physical, thermal and mechanical properties [1]. However, legal restrictions in the use of Pb have recently led to the spread of the Pb-free solders [2–3]. Among the various Pb-free solder alloys, the Sn–3.0 (wt.%)Ag–0.5Cu composition appears to have become the industrial standard [4–8]. Its wetting property is acceptable and its mechanical properties and ATC (accelerated temperature cycling) reliability is among the best of Pb-free solders. However, the solder joints of Sn–3.0Ag–0.5Cu composition were reported to experience externally stress-induced brittle crack propagation more often than the Sn–Pb composition. This behavior tends to be more severe when an external stress is applied rapidly, such as drop/shock conditions [9].

In previous studies, the authors suggested that Sn–1.2Ag–0.7Cu–0.4In quaternary Pb-free solder composition is a promising candidate for replacing the Sn–3.0Ag–0.5Cu composition [10]. The raw material cost could be decreased by 20% due to the lower Ag content. Its wettability was comparable to that of the Sn–3.0Ag–0.5Cu composition, and the reaction and mechanical properties of solder joint were found to be competitive. In addition, the drop/shock reliability of the Sn–1.2Ag–0.7Cu–0.4In composition was improved to more than double compared to that of the Sn–3.0Ag–0.5Cu composition, which was regarded as a representative Pb-free solder. However, the drop/shock reliability of the Sn–1.2Ag–0.7Cu–0.4In composition was slightly lower than that of the Sn–1.0Ag–0.5Cu composition, which was regarded as an excellent drop/shock reliability solder.

In this study, Pd was chosen as a minor alloying element in the new formulation of the Sn–1.2Ag–0.7Cu–0.4In solder alloy to improve its drop/shock reliability. The newly suggested Sn–1.2Ag–0.7Cu–0.4In–0.03Pd solder alloy was tested for its tensile properties and drop/shock reliability and compared with those of Sn–1.0Ag–0.5Cu, Sn–3.0Ag–0.5Cu and Sn–1.2Ag-0.7Cu–0.4In alloys.

2. Experimental procedure

Four solder compositions, i.e., Sn–1.0Ag–0.5Cu, Sn–3.0Ag–0.5Cu, Sn–1.2Ag–0.7Cu–0.4In and Sn–1.2Ag–0.7Cu–0.4In–0.03Pd, were prepared. Bar solder was firstly made for the tensile test, and solder balls were made for the rod drop impact test. Table 1 lists the melting temperatures of the solders used in this study.

The mechanical properties of each solder alloy were assessed by performing tensile tests using an Instron-type mechanical tester (Model: Instron 4481, Instron). The tensile sample was prepared in the form of a dog bone type, with a gauge section size, 2.0 mm thick × 3 mm wide × 13 mm long, according to the KS B 0801-standard metal material tensile testing method. Tensile testing was performed at room temperature at various strain rates from 10^{-4} to 10^{-2} s^{-1}.

Solder balls with a 450 μm diameter were manually attached to a chip scale package (CSP) and reflowed. The bumped CSP was then surface-mounted on the printed wiring board (PWB) using a chip mounter (model: cp-45fv, Samsung Techwin). The surface finish of the CSP and board were Au/Ni and organic solderability preservative (OSP)/Cu, respectively. A water-soluble type flux

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Table 1
Melting temperatures of solder alloys used.

Alloy	Melting temperature (°C)	
	Solidus	Liquidus
Sn–1.0Ag–0.5Cu	218	226
Sn–3.0Ag–0.5Cu	217	220
Sn–1.2Ag–0.7Cu–0.4In	217	224
Sn–1.2Ag–0.7Cu–0.4In–0.03Pd	216	219

(model: WF6063M5, Senju Metal) was used for the solder bumping process. Solder pastes with the same composition of the solder balls were used for the surface mounting of the CSP with a screen printer (Model: MK-878MX, Minami). The peak temperature of the reflow process (model: 1809UL, Heller) was set to 242 °C for the bumping and surface mounting.

The drop/shock reliability of the solder joints was assessed by dropping a rod onto the backside of PWB using a self-made rod drop impact tester (Fig. 1). A rod was dropped repeatedly from a certain height onto the backside of a fixed CSP mounted board to generate a sudden shock. The rod weight was 30 g and the drop height was 100 mm. The failure criterion was established as 100 Ω. The first event among intermittent electrical discontinuity was selected when the event followed by 3 additional such events during 5 subsequent drops.

3. Results and discussion

Fig. 2 shows the effect of the strain rate on the ultimate tensile strength (UTS), yield strength (YS: 0.2% proof stress) and elongation. The UTS and YS of all solder alloys increased with increasing strain rate. The UTS and YS of Sn–1.2Ag–0.7Cu–0.4In–0.03Pd were higher than those of the other alloys over the entire strain rate region. The UTS and YS of Sn–3.0Ag–0.5Cu were lower than those of Sn–1.2Ag–0.7Cu–0.4In–0.03Pd alloys, although higher than those of the other two alloys, i.e., Sn–1.0Ag–0.5Cu and Sn–1.2Ag–0.7Cu–0.4In, over the entire strain rate range. The elongation decreased with increasing strain rate for the Sn–1.2Ag–0.7Cu–0.4In–0.03Pd and Sn–1.0Ag–0.5Cu alloys. In contrast, the elongation of the Sn–3.0Ag–0.5Cu alloy was increased with increasing strain rate. The Sn–1.2Ag–0.7Cu–0.4In alloy showed nearly constant elongation value irrespective of strain rate. Interestingly, the elongation of Sn–1.2Ag–0.7Cu–0.4In–0.03Pd alloy was higher than that of the other alloys over the entire strain rate region. The elongation of Sn–1.0Ag–0.5Cu alloy was lower than that of the Sn–1.2Ag–0.7Cu–0.4In–0.03Pd alloy, although higher than that of the other two alloys, i.e., Sn-3.0Ag–0.5Cu and Sn–1.2Ag–0.7Cu–0.4In, over the entire strain rate range.

As explained above, the Sn–3.0Ag–0.5Cu alloy exhibited relatively high tensile strength, but the elongation was insufficient. In contrast, the Sn–1.0Ag–0.5Cu alloy exhibited opposite results with regard to the tensile strength and elongation properties. As a solder joint material, Sn–3.0Ag–0.5Cu alloy has been reported to have excellent accelerated temperature cycling reliability compared to the Sn–1.0Ag–0.5Cu alloy [11]. Meanwhile, as a solder joint material, the Sn–1.0Ag–0.5Cu alloy has been reported to have outstanding drop/shock reliability compared to the Sn–3.0Ag–0.5Cu alloy [12]. In the comparison with ternary alloys, the Sn–1.2Ag–0.7Cu–0.4In–0.03Pd alloy indicated the best tensile strength and the highest elongation. In conclusion, the fracture energy, i.e., the integrated area in the stress–strain curve, was highest for the Sn–1.2Ag–0.7Cu–0.4In–0.03Pd alloy. Such excellent mechanical properties for the Sn–1.2Ag–0.7Cu–0.4In–0.03Pd alloy were expected to be effective in the applications to mobile electronics that require excellent drop/shock resistance as well as accelerated temperature cycling reliability.

Fig. 3 shows the results of rod drop impact tests for the different solder joint compositions. The Sn–3.0Ag–0.5Cu composition indicated lower drop/shock reliability than the other solders. The drop/shock reliability of the Sn–1.2Ag–0.7Cu–0.4In composition was more than double compared to that of the Sn–3.0Ag–0.5Cu composition. However, the drop/shock reliability of the Sn–1.2Ag–0.7Cu–0.4In composition was slightly lower than that of the Sn–1.0Ag–0.5Cu composition, which was regarded as an excellent drop/shock reliability alloy. On the other hand, the drop/shock reliability of the Sn–1.2Ag–0.7Cu–0.4In–0.03Pd composition was surprisingly observed to be higher than that of the other compositions. The drop/shock reliability of the Sn–1.2Ag–0.7Cu–0.4In–0.03Pd composition was almost three times compared to that of the Sn–3.0Ag–0.5Cu composition. These results might be attributed to the superior plastic deformation susceptibility, namely, the excellent fracture energy of the Sn–1.2Ag–0.7Cu–0.4In–0.03Pd alloy.

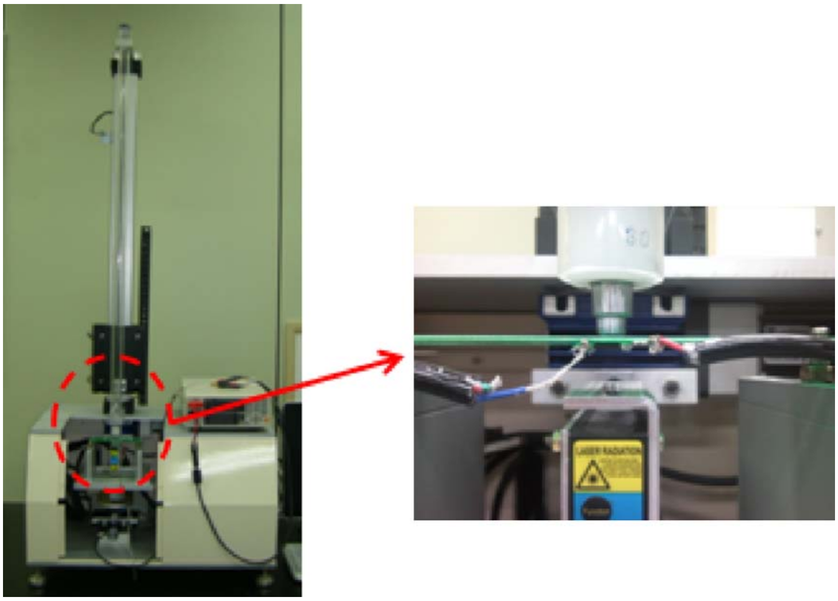

Fig. 1. The rod drop (impact) tester used in this study.

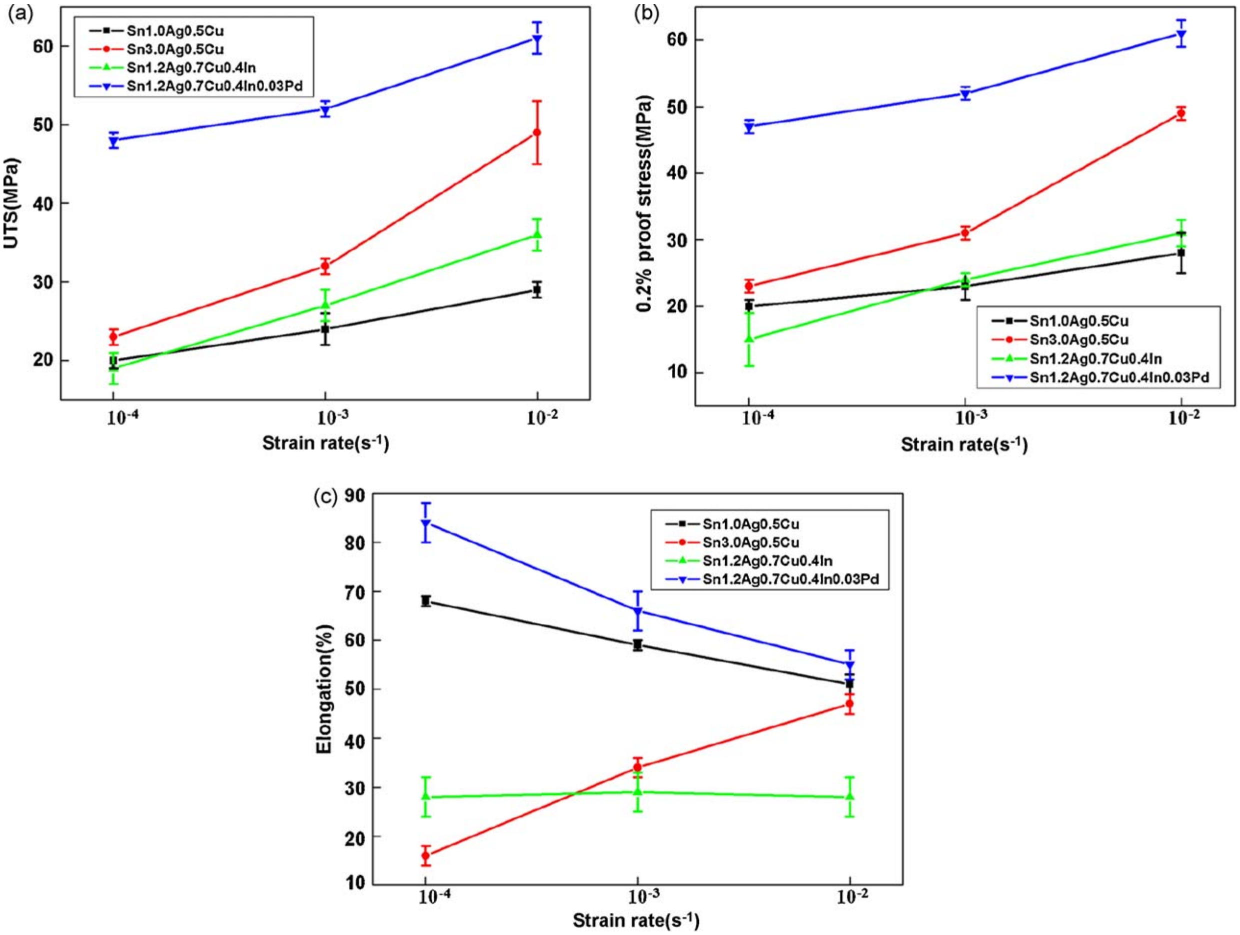

Fig. 2. Tensile properties of the solder alloys as a function of strain rate. (a) UTS, (b) 0.2% proof stress and (c) elongation.

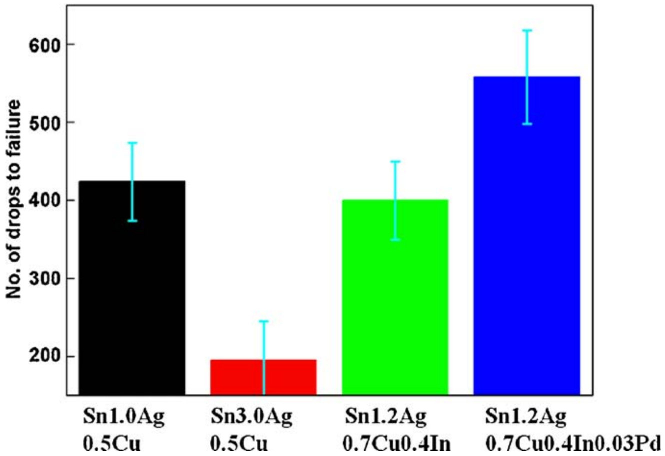

Fig. 3. Number of drops to failure obtained from the rod drop (impact) test as a function of solder composition.

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References

[1] P.T. Vianco, D.R. Frear, J. Met. 45 (1993) 14.
[2] D.P. Napp, SAMPEJ 32 (1996) 59.
[3] Y. Kariya, M. Otsuka, J. Electron. Mater. 27 (1998) 1229.
[4] K.W. Moon, W.J. Boettinger, U.R. Kattner, F.S. Biancaniello, C.A. Handwerker, J. Electron. Mater. 29 (2000) 1122.
[5] K. Suganuma, Curr. Opin. Solid State Mater. Sci. 5 (2001) 55.
[6] K.S. Kim, S.H. Huh, K. Suganuma, Mater. Sci. Eng. A 333 (2002) 106.
[7] E. Bradley, C. Handwerker, J.E. Sohn, Surf. Mount Technol. (SMT) 1 (2003) 24.
[8] C.M.L. Wu, D.Q. Yu, C.M.T. Law, L. Wang, Mater. Sci. Eng. R 44 (2004) 1.
[9] W. Liu, N.-C. Lee, JOM 59 (2007) 26.
[10] A.M. Yu, M.-S. Kim, J.-H. Lee, in: Proceedings of 9th EMAP, 2007.
[11] S. Terashima, Y. Kariya, T. Hosoi, M. Tanaka, J. Electron. Mater. 32 (2003) 12.
[12] M. Amagai, Y. Toyata, T. Tajima, Electronic Components and Technology Conference 2003 Proceedings, 53rd, 2003, p. 317.