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Structural and elastic properties of eutectic Sn–Cu lead-free solder alloy containing small amount of Ag and In

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ABSTRACT

Sn–Cu alloys have been considered as a candidate for high temperature lead-free microelectronic solders. In the present study, the change in microstructure, attenuation and elastic behavior associated with alloying of Ag and/or In into the eutectic Sn–Cu solder alloy system have been evaluated. The study involved measurements of longitudinal and shear wave velocities, attenuation, hardness, bulk and shear moduli, Young's and Poisson's ratio. The results of attenuation show that a clear attenuating effect in the ternary Sn–Cu–Ag and Sn–Cu–In alloys is realized, whereas the quaternary Sn–Cu–Ag–In solder displays an obscure attenuating effect. The obscure effect is mainly attributed to the competition for In between Sn and Ag, which results in weak interface formed between intermetallic compounds (IMCs) and β-Sn matrix. Likewise, Poisson's ratio results indicate that its value decreases with increasing the elastic moduli and ultrasonic velocities of Ag and In-containing alloys. The analyzed enhanced ductility of Sn–0.7Cu and Sn–0.7Cu–2In alloys and brittleness of Sn–0.7Cu–2Ag and Sn–0.7Cu–2Ag–2In alloys were rationalized on the basis of Poisson's ratio and the quotient of shear modulus to bulk modulus (Pugh's ratio). Microstructural analysis revealed that the origin of change in the elastic properties of the ternary and quaternary alloys is ascribed to smaller β-Sn dendrite grain dimensions and formation of new IMCs in the ternary and quaternary alloys.

1. Introduction

Following the miniaturization of contemporary solder joints, the fraction of IMCs to the total volume of solder is increasing, and hence the elastic properties of IMCs formed during soldering reaction become crucial to the reliability of solder joints [1]. For Sn-based soldering system, it has been shown that Sn–0.7Cu alloy is considered as the most promising candidate lead-free solder materials to replace eutectic Sn–Pb solder for wave, dip, and iron soldering processes. It is environmentally benign, inexpensive and has good electrical conductivity. Sn–0.7Cu solder has a melting point equal to 227 °C. Meanwhile, the primary interest is the lower cost compared with the other candidate lead-free solder alloys [2,3]. The presence of Cu in Sn-based materials leads to an improvement in resistance to thermal cycle fatigue and wetting properties due to the formation of Cu_3Sn and Cu_6Sn_5 IMCs. It also plays an important role in decreasing the rate of dissolution of Cu from the board [2,4]. However, its main disadvantage of high melting temperature, insufficient oxidation resistance characteristic and tin whiskers caused by the formation of Sn-rich phase prevents its wide practical application in microelectronic packaging industry, especially in the wave soldering applications, which are considerably forced nowadays [5–7].

Because of the technological interest, investigations of new Sn–Cu-based solder materials for electronic packaging products have never been stopped. Great achievement has been focused on developing the overall wetting and soldering properties of Sn–Cu solder and progress has been made by adding different alloying elements, such as Ag, In, Zn, and Ni [3,8–10]. The presence of the second phase has been shown to trigger the microstructural mechanism that enhances the reliability of the solder joints. Recently, Wang and Shen [9] revealed that a small amount of Ni addition to the Sn–Cu solder could effectively improve the solder properties, such as the mechanical strength and wettability. The Ni

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