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Effect of alumina nanoparticles on the microstructure and mechanical durability of meltspun lead-free solders based on tin alloys

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ABSTRACT

As one of the key technologies for high performance electronic devices, composite solders have been recently developed to improve thermal and mechanical properties of solder joints. In this research, melt spinning was employed to fabricate a lead-free based nanocomposite solder for electronic application materials via introducing Ni-coated Al_2O_3 nanoparticles (0.1 wt%) into a Sn-Ag-Cu ternary eutectic alloy during rapid solidification. These surface-modified nanoparticles were synthesized by an *in situ* chemical reduction method. The effect of rapid solidification on the distribution of reinforcing nanoparticles, microstructural evolution, and solderability of the tin alloy were studied. Microstructural studies determined that rapid solidification refined brittle and elongated intermetallic compounds (IMCs) into small particles with an average diameter of a few hundred nanometers. The particles were uniformly dispersed into an amorphous/recrystallized fine-grained eutectic morphology of the solder matrix. It was also found that the addition of Ni-coated Al_2O_3 nanoparticles could effectively suppress the growth of IMC layers, which enhanced the reliability of solder joints. Effects of solid-state ageing phenomenon on the tensile and shear properties of the soldered joints were also evaluated. Higher strength and ductility was measured for joints prepared from the nanocomposite solder as compared with the unreinforced solder. A maximum enhancement of ~20% in the shear strength was obtained.

1. Introduction

In the last few decades, the development of modern electronic industry has put forward higher requirements of electronic products [1]. Although lead alloys are widely used in electronic packaging industry, environmental issues possess a great motivation for development of alternative solders [1,2]. Currently, lead-free solders have gained a rapid development opportunity, particularly those based on tin eutectic alloys [3–7]. Demands for high-performance electronics and the recent miniaturization trend have emerged new materials with high robustness and stability [8–11]. As a result, enhancement of mechanical and physical properties of thin-based solder alloys has been the subject of many recent studies [1,8,12–14]. Sn–Ag–Cu (SAC) ternary eutectic alloys have particularly been attracted significant attention among other lead-free solders [3–7]. Meanwhile, high demands for quality electronic devices and recent miniaturization trend require novel interconnecting materials with high robustness and stability [8–11]. As the soldered joints are probably experienced temperatures close to the traditional solders melting temperature during service, physical and mechanical properties of SAC solders should be improved [1,8,12–14].

To promote the performance of lead-free solders, distributing reinforcing particles into the matrix alloy aiming to prepare composite materials is suggestible [15]. Many studies have been performed to investigate the influence of intermetallics and reinforcing particles (e.g., metallic powders, carbon-based materials, and fine oxide or carbide ceramic particles) on the microstructural development and physico-mechanical properties of solders [6,7,9,11,13,15–43]. Preparation of composite solders via reinforcing particles including intermetallics [7,10,11,17,20,31,33], carbon nanotubes [19,21,26,32,41], graphene [9,18,25,29,30,44], fine oxides and carbides (ZrO_2 [12], TiO_2 [28,39], SnO_2 [12] and CeO_2 [35,36,45]) and silicon carbide [14,46–49]) have been investigated. Results of these studies have determined the effect of the

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secondary particles on the hardness, tensile strength and creep resistance of soldered joints.

The common manufacturing processes for the fabrication of composite solders such as casting [50,51] and conventional powder metallurgy routes [18,25] usually do not provide defect-free and homogeneous microstructure due to agglomeration, segregation, gas trapping, and coarsening of the particles. Therefore, these methods are not appropriate for small size solders and micro/nano-joining, where the homogeneity and defects are crucial. More recent advances are dealing with severe plastic deformation of solder alloys in order to remove the casting defects and to distribute ultrafine particles more homogeneously into the metal matrix. For instance, Roshanghias et al. [45,52] have shown that by employing accumulative roll bonding (ARB), more uniform distribution of nanometric CeO_2 inclusions into the Sn–Ag–Cu solder alloy can be attained. Another approach, which has recently gained significant attention for the processing of solder alloys, is planar flow melt spinning [2,38]. As schematically shown in Fig. 1a, in this method, a molten metal is ejected onto a rotating water cooled copper wheel maintaining a pre-determined nozzle-wheel gap, which controlling the geometry (length or width) of the ribbons can be formed [53]. As a result of rapid solidification, high mechanical properties are attained due to potential formation of metastable crystalline and amorphous phases, extension of solid-state solubility, grain refinement, and modification of the segregation pattern [38]. Because of these advantages, preparation of solder alloys by melt spinning have received many attention in recent years [34,54–58]; however, to the best knowledge of the authors, no reports on the processing of nanocomposite solders by melt spinning are available. This lack of studies is possibly attributed to the technical challenges of processing of nanocomposites by the melt spinning process, such as macro- and micro-aggregation and segregation of nanoparticles stimulated by weak wettability of lead-free solders and considerable differences in their physical properties such as density and surface free energy [16,18,27,40,42,46,52].

It is known that liquid-solid interfacial chemical reactions lead to the formation and growth of an intermetallic compound (IMC) layer between the solder alloy and substrate at the interface [11,33,59]. The formation of this interfacial IMC layer can provide a great

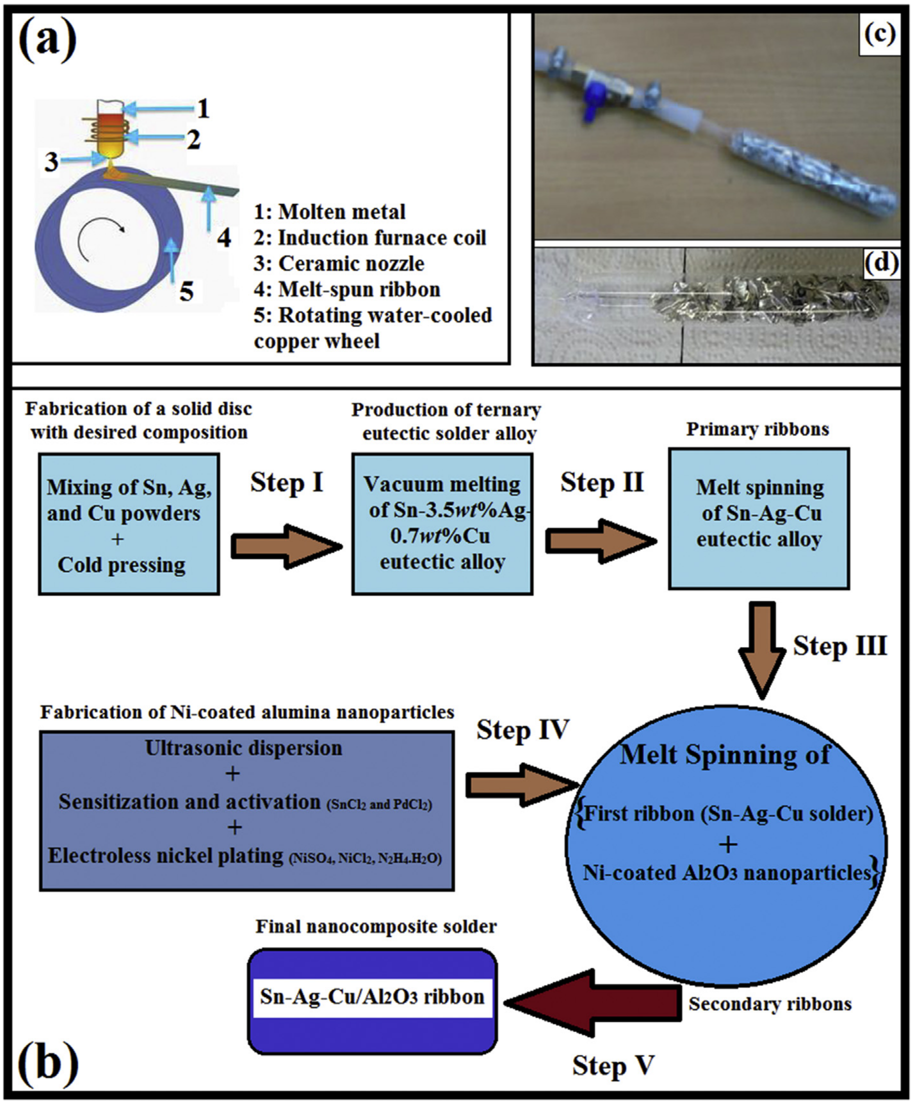

Fig. 1. Schematic representations of (a) melt spinning process and (b) preparation of the unreinforced and reinforced solders. (c) The utilized quartz set-up for vacuum melting of solder alloys or nanocomposites. (d) An image from the prepared nanocomposite ribbon by the explained procedure.