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Study on the microstructure and mechanical properties of a novel SWCNT-reinforced solder alloy for ultra-fine pitch applications

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Abstract

In the present study, the influence of single-walled carbon nanotubes (SWCNTs) of 93% purity on the phase formation, microstructural characteristics and mechanical behaviour of conventional solder alloys (63Sn/37Pb and Sn/3.8Ag/0.7Cu) was studied. The composite solder specimens were prepared by mechanical mixing of SWCNTs with solder powders. The homogenous powder mixture was compacted, sintered and extruded at room temperature. The composite solder alloy was characterized by XRD and SEM to identify the phase formation and morphological features. The mechanical properties such as microhardness, tensile strength and percentage elongation of the nanocomposite solders were evaluated as a function of SWCNT addition. The addition of SWCNTs was observed to influence the grain size and interfacial reaction kinetics of solder alloys. This work describes the physical and microstructural properties of the 63Sn–37Pb and Sn–3.8Ag–0.7Cu solder material alloyed with different weight proportions of SWCNTs. In particular, the melting behaviour and mechanical properties of SWCNT-reinforced composite solders are discussed.

Keywords: Solder alloys; SWCNTs; Microstructure; Tensile strength

1. Introduction

The demand for interconnection density both on integrated circuit (IC) and packages increases tremendously as microsystems move towards higher speed and miniaturized form factor. Reducing interconnect pitch limits the use of conventional solder material for interconnect technology due to the intermetallic diffusion and electromigration issues [1]. Therefore, the requirements of materials with enhanced electrical and mechanical properties are a need at this juncture. Recently, nanosolder composites have been identified as potential material to provide the higher strength when compared to the conventional solders. Especially, the addition of carbon nanotube is expected to provide dispersion strengthening to the resulting composite structures so as to enhance their mechanical properties [2,3].

The effects of foreign particulate reinforcement on the microstructural, mechanical, thermal and electrical properties have been extensively investigated [4–10].

CNTs have attracted the attention of the researchers worldwide due to its excellent mechanical and electrical properties. CNTs possess the highest elastic modulus of the order 1–3 TPa [11], which is 1000 times higher than the high-strength steel alloys [12]. They exhibit superior electrical and thermal properties [13]. Until recently majority of the research focus is being made in the field of polymer-based CNT composites to improve the electrical, mechanical and thermal properties of the polymer composites [14]. There is very limited focus on the CNT-based metal matrix composites.

Efforts have been made to increase the wear resistance and the fracture toughness of the Ni- and Cu-based composites [15,16]. CNT-reinforced Al-based composites were synthesized successfully [17].

S.M.L. Nai et al. [18] have produced the MWCNT-reinforced Sn–Ag–Cu composite solders using the powder metallurgical synthesis approach. The resultant MWCNT-dispersed solder exhibited superior coefficient of thermal

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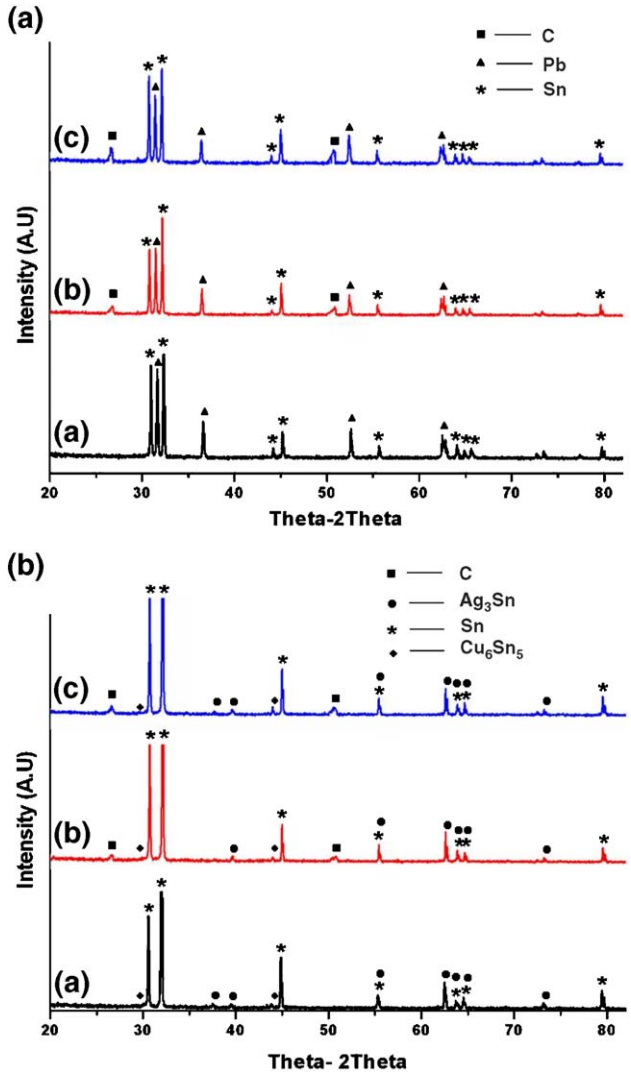

Fig. 1. (a) XRD analysis of (a) 63Sn–37Pb, (b) 63Sn–37Pb+0.05 wt.% CNT, and (c) 63Sn–37Pb+0.5 wt.% CNT solders. (b) XRD analysis of (a) Sn–3.8Ag–0.7Cu, (b) Sn–3.8Ag–0.7Cu+0.05 wt.% CNT, and (c) Sn–3.8Ag–0.7Cu+0.5 wt.% CNT solders.

expansion, lower density and higher hardness and tensile strength than the unreinforced solder matrix.

Although the studies on composite solders are reported in the literature, the influence of single-walled carbon nanotubes (SWCNT) addition on the composite solder has not been subjected to a detailed study so far. Therefore, the present work is focused to study the microstructural morphology and mechanical properties of Sn–Pb and Sn–Ag–Cu composite solder alloys with the various weight proportions of single-walled carbon nanotubes (SWCNT) and recommends the desired weight percent of nanopowders for enhancing the mechanical properties of the Pb-free solders.

2. Experimental

The composite solders of 63Sn–37Pb and Sn–3.8Ag–0.7Cu were prepared by the following procedures. The starting materials were 63Sn–37Pb, Sn–3.8Ag–0.75Cu powders (Type 7: size range 2–11 μm) and single-walled carbon nanotubes (SWCNTs). The diameter of the SWCNT is 20–30 nm. The composite solders with various weight proportions (0.05 and 0.5 wt.%) of SWCNTs were prepared by powder metallurgical route. The solder powder and SWCNTs were pre-weighed and then mechanically mixed together using a blender at 50 rpm for 15 h. The mixed powder was cold compacted at 110 bar and sintered at 150 °C for 2.5 h in the case of Sn–Pb solder. For the Sn–Ag–Cu composite preparation, the mixtures of solder powder and nanopowders were cold compacted at 120 bar and sintered at 180 °C for 3 h. The sintered Sn–Pb and Sn–Ag–Cu composite solders were extruded at room temperature with an extrusion ratio of 20:1.

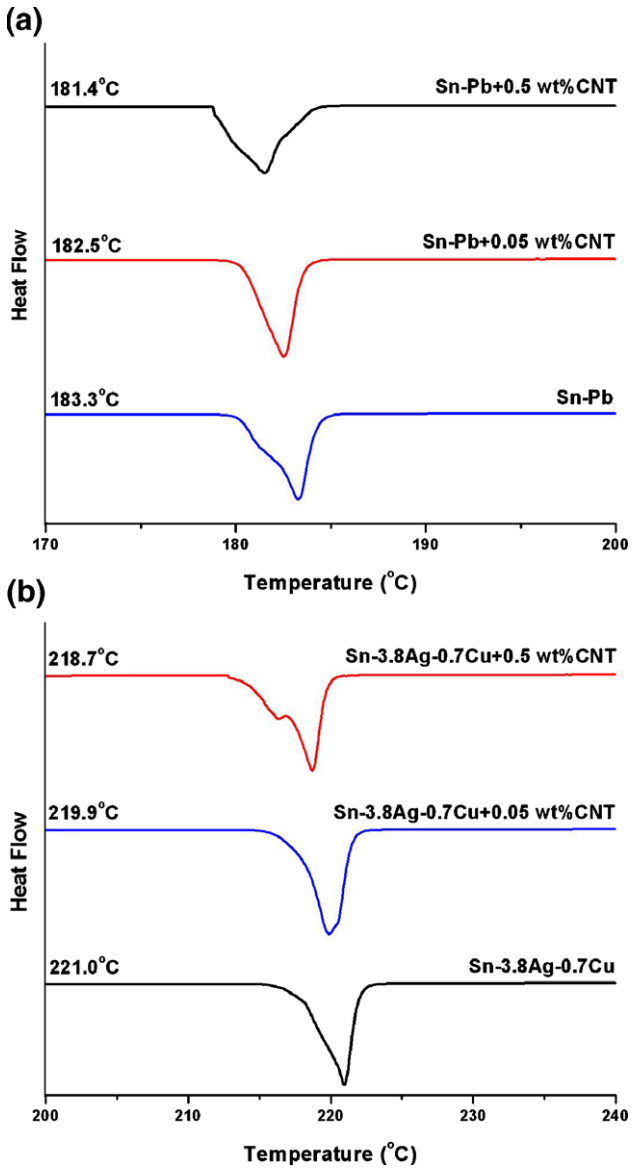

Fig. 2. (a) DSC curves of 63Sn–37Pb, 63Sn–37Pb+0.05 wt.% CNT, and 63Sn–37Pb+0.5 wt.% CNT composite solders. (b) DSC curves of Sn–3.8Ag–0.7Cu, Sn–3.8Ag–0.7Cu+0.05 wt.% CNT, and Sn–3.8Ag–0.7Cu+0.5 wt.% CNT composite solders.