



Investigating the effect of isothermal aging on the morphology and shear strength of Sn-5Sb solder reinforced with carbon nanotubes



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ABSTRACT

An analysis of the role played by the addition of carbon nanotubes (CNTs) to the solder matrix of conventional Sn-5Sb lead-free solder was performed. In a bid to determine the potential of this new solder system, the powder metallurgy approach was used to synthesise a plain Sn-5Sb solder system and CNTs reinforced composite solder formulations of Sn-5Sb-xCNT; x = 0.01wt.%, 0.05wt.% and 0.1wt.%. Isothermal aging study was conducted on the solder joints, to examine the evolution of the interfacial intermetallic compound (IMC) layer between solder and the adjoining copper (Cu) substrate. Similarly, shear strength analysis was performed on as-reflow and aged solder joints. A considerable improvement in the wetting properties, the microstructural evolution, and the interfacial intermetallic compound (IMC) layer growth was observed in the composite solder joints. Owing to the excellent mechanical properties of CNTs, the shear strength assessment revealed that the composite solder joints gave a superior shear strength property, especially the Sn-5Sb-0.01CNT solder joint sample.

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1. Introduction

The enactment of legislations barring the utilisation of lead in electronic products [1–3] has instigated the sensitivity of researchers towards conformity with the alternative lead-free standards for electronic systems packaging. Although rigorous efforts have been channeled towards the development of these alternative solder candidates, the Sn-5Sb solder system has received less priority despite its great potential in step soldering and high temperature applications [4–7].

However, with the recent trend of miniaturisation and the IC terminal upsurge in electronic hardware, critical evaluation of the lifetime operational capability in interconnection joints should be of utmost concern in order to inspect and curb the reliability issues associated with the evolving lead-free solder candidates. Several attempts to enhance the performance of these solder materials has

moved researchers towards the development of a composite approach in promoting the mechanical properties of interconnection joints, particularly the limitation in grain boundary sliding, creep rate mitigation and thermo-mechanical fatigue resistance [8,9]. Thus, introducing suitable reinforcement particles to the Sn-5Sb solder matrix is pivotal in fabricating a revamped solder system which can thrive well under extreme service conditions and can function decently in densely packed electronic devices.

Thus far, carbon nanotubes (CNTs) an outstanding nanomaterial have aroused great interest for the production of better solder joints when doped with the conventional lead-free solders due to the exceptional mechanical properties demonstrated by this group of materials. Reports from previous studies have revealed a significant enhancement in the wettability results and the microstructural evolution of the CNT reinforced solders [10–13].

Studies have shown that the IMC layer at the solder/Cu interface increased with aging time and the growth was faster for higher aging temperatures [14,15]. Ko et al. found that the IMC thickness formation of the CNT-SnAg solder was slower than the SnAg solder and the IMC growth difference between both solder samples

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further increased as the aging time increased [16]. Furthermore, shear strength of as-reflow and aged composite Sn-Ag-Cu solder joints was improved with CNTs reinforcement [17].

Accordingly, various researchers [18–25] have adopted the single-lap joint system in conducting experimental evaluations of the shear strength property of solder materials. A bid by Han et al. [26] to develop a composite solder via the incorporation of Ni-coated carbon nanotubes proved rewarding. Although, both the monolithic and the composite solder joints experienced a decline in the shear strength values as the thermal cycle increased. Nonetheless, the composite solders emerged better than the monolithic solder counterpart, irrespective of the thermal cycling period.

Nearly all studies on the development of composite solders through the incorporation of carbon nanotubes have centered mainly on the SAC solder candidate. Nevertheless, the influence of CNTs in the Sn-5Sb solder system is yet to be investigated. Pitching this study on the rattling records of CNTs doped solders, it is imperative to investigate the effect of isothermal aging on the shear strength property of composite and plain Sn-5Sb solder joints. In the present study, triad formulations of the Sn-5Sb composite solder systems were synthesised. The wettability, microstructural evolution and shear strength property of the synthesised solder joints were evaluated under different aging times.

2. Experimental procedures

2.1. Material processing and sample preparation

The powder metallurgy approach was used to synthesise four different solder formulations: Sn-5Sb, Sn-5Sb-0.01CNT, Sn-5Sb-0.05CNT and Sn-5Sb-0.1CNT. Pure Sn and Sb micron-sized particles of 30–45 μm and 3–7 μm respectively were used as the host alloy, while multi-walled carbon nanotubes (MWCNTs) with an outer diameter of 15–20 nm was purchased from Cheap Tubes Inc, USA. For the raw materials, carbon and oxide particulates were identified from the EDS analysis as the main impurities. Using a Planetary Mono Mill, the solder formulations were dry milled for 6 h in a container with a ball to powder ratio of 20:1 at 800 rpm. After mixing, 2 g of the powder blends were compacted at 80 MPa to produce a solder pellet with 20 mm diameter and 2 mm thickness. Fig. 1(a) and Fig. 1(b) respectively present the FE-SEM micrographs of the MWCNTs used in this study and the embedded MWCNTs at the interstices between the compositional elements.

2.2. Microstructural characterization

For the microstructural characterisation studies, solder joints were prepared by the reflow soldering process on a copper (Cu)

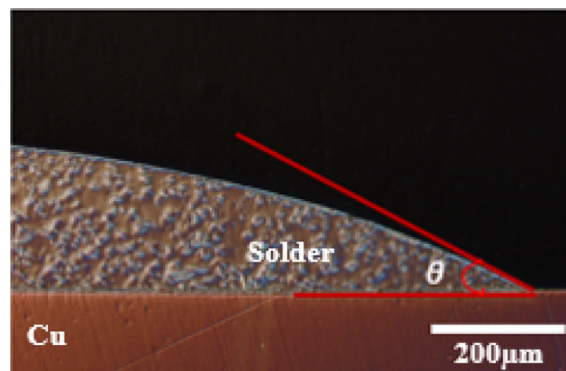


Fig. 2. Optical micrograph of the contact angle between the solder and the Cu substrate.

substrate. Following the reflow process, the solder joint samples were subjected to isothermal aging at 170 °C for 500 h, 1000 h and 1500 h. After the aging process, the samples were cold mounted using the epoxy resin system, cross-sectioned and subjected to standard polishing procedures using a 0.05 μm Master Prep alumina suspension. Prior to the electron microscopy analysis, images of the wetting angle and microstructural morphology were taken using the optical micrograph (OM). Also, the contact angle and the interfacial IMC layer of the respective solder joints were measured using the streams essential software integrated with the OM (see Fig. 2). Finally, the solder samples were observed using the HITACHI SU8000 field emission scanning electron microscope (FE-SEM) equipped with energy dispersive spectroscopy (EDS) to evaluate the microstructural morphology and elemental compositions respectively.

2.3. Shear test

To conduct the shear strength evaluation, single-lap joint samples were utilised. The samples were fabricated in such a way as to mimic actual solder joints by filling the overlap area between the Cu substrates with solder pellets and flux application prior to the reflow process. To ensure the proper alignment of all the components that make up the lap joint setup, the samples were placed in an alumina boat jig and thus subjected to the reflow soldering process. The geometry of the single-lap joint sample is shown in Fig. 3. As pictured, each of the copper substrates has a dimension of $52 \times 11 \times 1 \text{ mm}^3$ and a lap joint area of $10 \times 11 \text{ mm}^2$. After the as-reflow soldering operation, some of the samples were held back for the as-reflow shear strength evaluation, while the other samples were subjected to isothermal aging at a

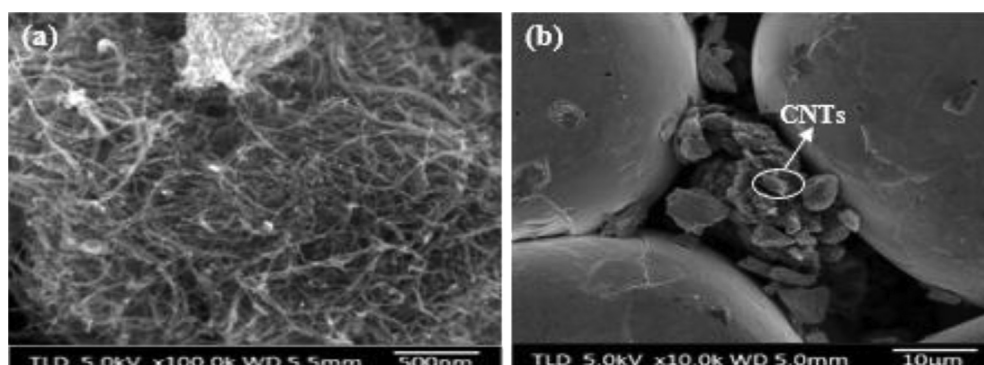


Fig. 1. FE-SEM micrographs of (a) the MWCNTs used in this study and (b) the embedded MWCNTs at the interstices of the compositional elements after ball milling process.

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