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Effect of ageing time on the tensile behavior of Sn–3.5 wt% Ag–0.5 wt% Cu (SAC355) solder alloy with and without adding ZnO nanoparticles

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ABSTRACT

In this work, lead-free composite solder was produced by mixing ZnO-nano-sized particles with Sn–3.5% Ag–0.5% Cu solder. The effects of nano-particle addition on the melting behavior, microstructure and tensile properties of the as-solidified composite solder are systematically investigated. In comparison with solder without the addition of ZnO nanoparticles metallographic observations revealed that the grain size of β-Sn, the intermetallic compounds (IMCs) average grain size and distance decreased significantly in the composite solder matrix. This was possibly ascribed to the strong absorption effect and high surface free energy of ZnO nanoparticles. Our results show that 0.5 wt% addition of ZnO nanoparticles led to an improvement in microstructure, proof stress ($\sigma_{y0.2}$), ultimate tensile stress (σ_{UTS}) and fracture stress (σ_f) compared with non-composite solder. Differential scanning calorimetry (DSC) revealed that the melting temperature of SAC355 composite solder is slightly higher by about 1.1 K than that of the conventional SAC355 solder. The observed increase of mechanical properties was rendered to refined IMCs, acting as a strengthening phase in the solder matrix. Ageing the specimens of both solders for different aging times at all different testing temperatures, resulted in the decrease of tensile properties investigated. This was attributed to ripening of IMC particles leading to decrease of their pinning action of dislocation movements which was emphasized by SEM examinations. This interpretation is in consistence with the theoretical prediction from dispersion strengthening theory.

1. Introduction

Recently, much attention has been paid to the development of lead-free solder alloys which avoid the environmental problem of lead [1,2]. Many investigators consider that the Sn–Ag–X–Y (X, Y: other elements) is a promising system for the high mechanical strength lead-free solder alloy [1]. The main reason behind this is the toxicity of lead and the need to replace it with more environmentally friendly production and products. Lead-free production can also grant other benefits such as increased reliability of electronics products in some cases if it is properly carried out.

The lead-free solder Sn–Ag–Cu (SAC) alloys have been recognized as the most promising candidate for substituting the Pb-containing solder in microelectronic packaging and they interconnect due to their slightly lower melting temperature compared with the Sn–Ag binary eutectic alloy and their generally superior mechanical properties as well as relatively good solderability [3]. This lead-free solder began to come into use in the packaging of some microelectronic components and devices.

Electronic devices such as computers, cellular phones and portable products have become lighter and thinner while the functions are becoming more complicated. The miniaturization of these electronic devices demands better solder-joint reliability. An attractive and potentially available method of enhancing solder joints is by adding reinforcements to solder alloys [4]. The reinforcing particles should have small size (nano-particles) and serve to suppress grain-boundary sliding, formation of large intermetallic compound and grain growth, thereby causing uniform distribution of the stress in the solder joints. Consequently, the solder joint could provide better reliability with improved thermal stability of the microstructure [5] and a high stress resistance.

There are various types of nanoparticles such as metal nanoparticles, metal oxide nanoparticles and polymer nanoparticles. Among all these, metal oxide nanoparticles stand out as one of the most versatile materials, due to their diverse properties and functionalities. Most preferentially, among different metal oxide nanoparticles, zinc oxide (ZnO) nanoparticles have their own importance due to their vast area of applications, e.g., gas sensor, chemical sensor, bio-sensor, storage, optical and electrical devices,

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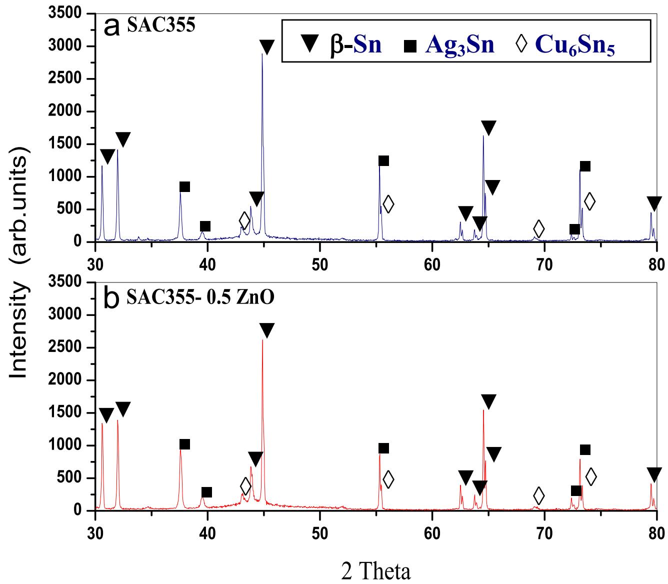

Fig. 1. XRD patterns showing the existence of three types of phases for (a) SAC355 plain solder and (b) SAC355 composite solder alloys.

window materials for displays, light-emitting diodes and solar cells [6–10].

Due to the toxicity of Pb in traditional solders, solder material has to become lead-free. So far, the Sn–Ag–Cu solder is regarded as the promising replacement for Sn–Pb eutectic solder. The ZnO reinforced lead-free solder has been recently reported in our laboratory [11–13].

2. Experimental procedures

Nominal composition of the selected Sn–3.5 wt% Ag–0.5 wt% Cu (SAC335) is prepared from high purity metals. ZnO nanoparticles reinforced composite solder was prepared through mechanically incorporating 0.5 wt% of about 66 nm ZnO particles into a portion of the prepared conventional SAC335 lead free solder. To ensure homogeneous distribution of ZnO nanoparticles inside the solder matrix an over etched SAC355 composite solder was examined by SEM and EDS analysis.This investigation was done by the authors in a previous work [12]. High purity metals (99.99%) were melted in a vacuum furnace at 603 K for 2 h followed by casting into a stainless steel mold and cooled down to room temperature in air. Ingots from both alloys were cold drawn into 0.8 mm diameter wire. A part of each alloy was rolled into sheet of 0.4 mm for microstructure investigations. Specimens with a gauge length of 50 mm were prepared for tensile testing. Prior to the tensile testing, all specimens were heat-treated for 0.5 h at 393 K to produce relatively stable and homogeneous microstructures

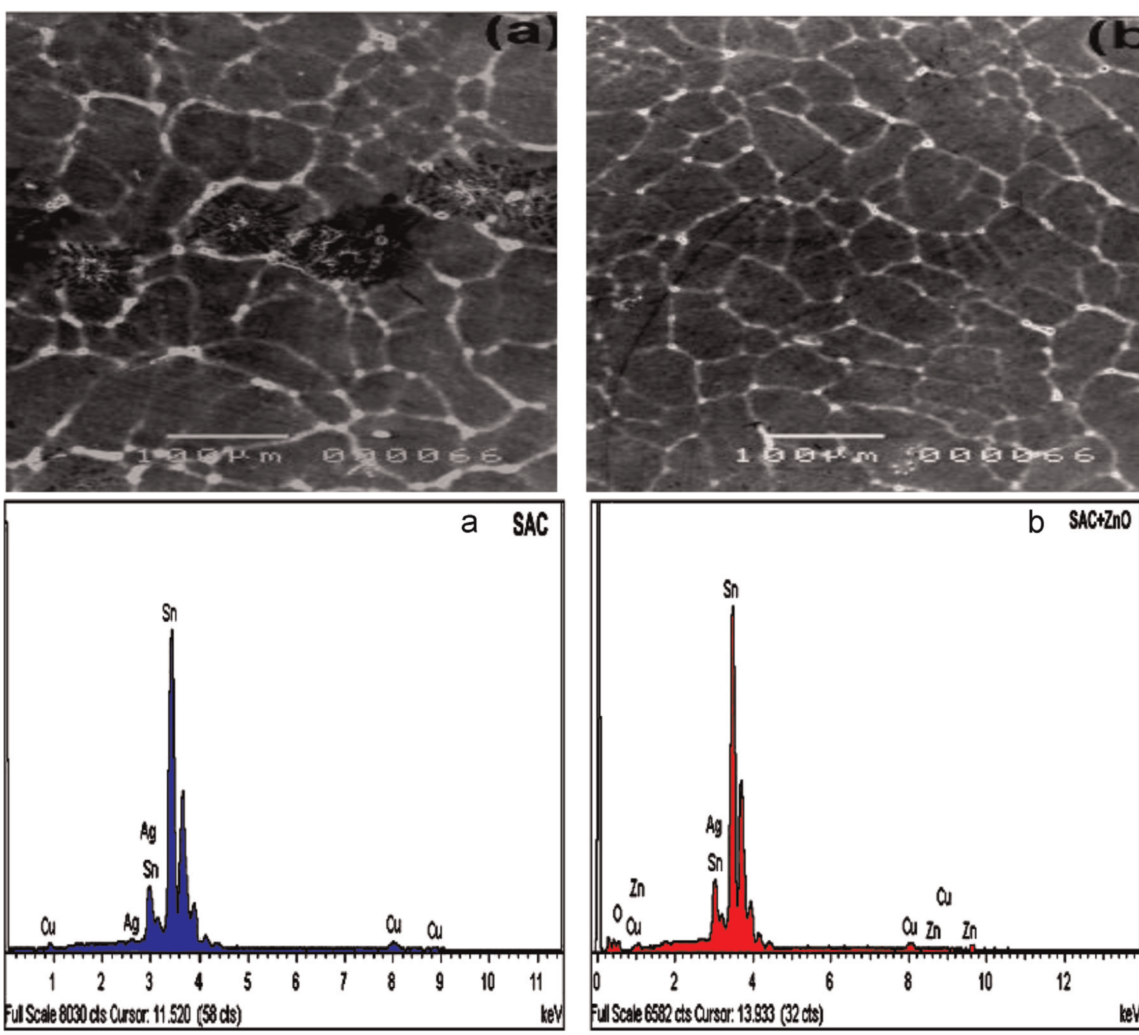

Fig. 2. SEM micrographs showing the grains and the corresponding EDS curves of (a) SAC355 solder and (b) SAC355 composite solder alloys.