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Thin Solid Films 504 (2006) 401 – 404
thin solid films
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Influence of ceramic reinforcements on the wettability and mechanical properties of novel lead-free solder composites

S.M.L. Nai [a], J. Wei [b,*], M. Gupta [a]

[a] Department of Mechanical Engineering, National University of Singapore, 9 Engineering Drive 1, Singapore 117576, Singapore
[b] Singapore Institute of Manufacturing Technology, 71 Nanyang Drive, Singapore 638075, Singapore

Available online 30 September 2005

Abstract

In the present study, two sets of Sn–3.5 Ag–0.7 Cu solder-based composite materials were successfully synthesized using the powder metallurgy route of blending, compaction, sintering and extrusion. Varying amount of titanium diboride particulates and multi-walled carbon nanotubes were introduced respectively as reinforcements to obtain the two sets of composite solders. Following synthesis, the extruded materials were characterized in terms of their wettability and mechanical properties. Wettability property of the composite solder was found to improve with a threshold addition of reinforcements. Moreover, the results of mechanical properties characterization exhibited enhanced overall strength of the composite solders. An attempt is made in the present study to correlate the variation in amount of the reinforcements with the properties of the resultant nanocomposite materials.
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Keywords: Lead-free solder; Composite; Wettability and mechanical properties

1. Introduction

For years, Sn–Pb solders have been used extensively as interconnect materials. However, environmental concerns have created a need to move beyond such solders. Lead-free solders are the proposed candidates to address the environmental concerns [1,2]. With the advancement of micro-/nanosystems technology towards faster speed, increasing service performance and miniaturization, packaging technology is facing its limitations. In accordance to the International Technology Roadmap for Semiconductors (ITRS), it has been projected that the pad pitch may fall below 20 μm by the year 2016 [3]. Conventional solder technology can no longer guarantee device reliability. Thus, to fulfill the ever-stricter service requirements, new interconnection materials have to be developed. These new materials need to be equipped with a combination of good mechanical, electrical and thermal properties.

A viable way to enhance the performance of a solder (in terms of mechanical, electrical and thermal properties) is to introduce second phases to a conventional solder alloy, forming a composite solder. In existing literature, precipitation and dispersion hardening are two approaches utilized to strengthen solders through the introduction of a second phase in the matrix. The former approach is to precipitate particulates from supersaturated solid or liquid solution. This method can be achieved by the desirable selections of alloy composition. On the contrary, particulates formed this way are likely to coarsen undesirably, in particular when service temperature exceeds 0.5 T_m (melting temperature of the alloy). The latter approach is thus preferred, as it externally incorporates non-reacting, non-coarsening, foreign particulates as dispersoids into the solder alloy. These dispersoids have very little solubility in the matrix even at elevated temperatures. They can hinder the coarsening of the solder microstructure and even inhibit grain growth [4,5].

In this study, titanium diboride (TiB_2) particulates and multi-walled carbon nanotubes (MWCNTs) were chosen as the reinforcement materials to synthesize two different composite systems. An attempt was made in the present study to synthesize SnAgCu/TiB_2 and SnAgCu/CNT solder composites via the powder metallurgy route. Characterization study such as wettability tests was conducted to assess the wettability of the composite solders. The mechanical property was also assessed using tensile tests. In addition, particular emphasis was placed on correlating the increasing presence of reinforcement with

* Corresponding author. Tel.: +65 6793 8575; fax: +65 6792 4967.
E-mail address: jwei@simtech.a-star.edu.sg (J. Wei).

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doi:10.1016/j.tsf.2005.09.057

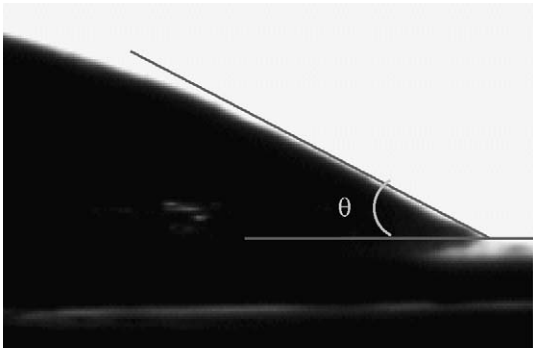

Fig. 1. A representative picture showing the measured contact angle (θ) of the solder sample on copper substrate.

the wettability, microstructural development and mechanical properties of the resultant composites.

2. Experimental details

2.1. Materials

In this study, lead-free (95.8 Sn–3.5 Ag–0.7 Cu) solder powder of size range 25–45 μm, titanium diboride (TiB_2) particulates (3–5 μm) and multi-walled carbon nanotubes (MWCNTs) of outer diameter (3–20 nm) and length (tens of micrometers) were used. Varying volume percentages of TiB_2 particulates and varying weight percentages of MWCNTs were incorporated into the solder matrix to synthesize two different systems of lead-free solder composites. The materials synthesized here are designated as SAC, SAC–1.5TiB_2, SAC–3TiB_2, SAC–5TiB_2, SAC–0.01CNT and SAC–0.04CNT in the forthcoming sections. These designations indicate that they are synthesized with 0 vol.% of reinforcement, 1.5 vol.% TiB_2, 3 vol.% TiB_2, 5 vol.% TiB_2, 0.01 wt.% MWCNTs and 0.04 wt.% MWCNTs addition in the solder matrix.

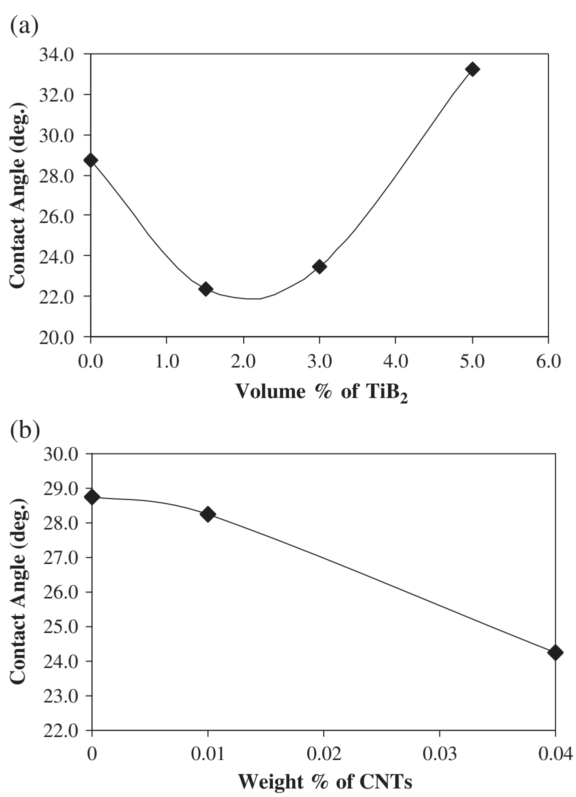

Fig. 2. Graphical relationship between (a) volume percentage of TiB_2 addition in solder matrix and contact angle and (b) weight percentage of CNTs addition in solder matrix and contact angle.

Table 1
Tensile results of monolithic and SnAgCu/TiB_2 composite solders

Material	Reinforcement (vol.%)	0.2% YS (MPa)	UTS (GPa)	Ductility(%)
SAC	–	31±2	35±1	41±8
SAC–1.5TiB_2	1.5	32±1	38±1	30±2
SAC–3TiB_2	3.0	39±4	43±5	29±2
SAC–5TiB_2	5.0	34±4	38±2	24±7

2.2. Synthesis of solder composite

The powder metallurgy route was used to synthesize the materials. For solder composites, the synthesis procedure is as follows: firstly, the solder powder and reinforcements (TiB_2 particulates or MWCNTs) were pre-weighed and mixed homogeneously in a V-blender. Then, the mixture was uniaxially compacted and the compacted billet was sintered in an inert argon atmosphere. Lastly, the billet was extruded at room temperature, into 8-mm-diameter rods. For SAC, the material was fabricated as stated above (starting from the compaction step), omitting the blending process. All the samples required for the various characterization studies were cut into discs from the extruded materials using a diamond cutter.

2.3. Solder wettability test

Solder wettability was determined with respect to the contact angle. Firstly, the extruded solder rods were cut into 5-mm-thick discs. One disc was then placed on a copper substrate with fluxing and heated to 250 °C in a furnace. Flux was introduced to remove the possible oxides resulted from oxidation in both solder and substrate. The contact angle of the solder sample was then measured using the OCA-20 contact angle meter. Fig. 1 shows a representative picture of the measured contact angle (θ) of the solder sample on copper substrate.

2.4. Mechanical behavior

The smooth bar tensile properties of the extruded samples were determined in accordance with ASTM test method E8M-96. The tensile tests were conducted on round tension test

Table 2
Tensile results of monolithic and SnAgCu/CNT composite solders

Material	Reinforcement (wt.%)	0.2% YS (MPa)	UTS (GPa)	Ductility (%)
SAC	–	31±2	35±1	41±8
SAC–0.01CNT	0.01	36±2	47±1	36±2
SAC–0.04CNT	0.04	36±4	46±6	37±5

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