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Mechanical properties of sintered Ag–Cu die-attach nanopaste for application on SiC device

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ABSTRACT

In this work, mechanical properties of Ag–Cu nanopaste that formulated by mixing Ag and Cu nanoparticles with organic compounds have been reported. Various weight percents of Cu nanoparticles (20–80 wt%) had been loaded in the nanopaste, in which an increasing trend for hardness, stiffness and Young's modulus were recorded with the increment of Cu loading. When the nanopaste was used to bond two pieces of Cu substrates, a declining of bonding strength has been recorded with an increasing of Cu loading. For metallization studies, Ag and Au coatings on Cu substrate have displayed the highest (52.6 MPa) and the lowest (34.4 MPa) bonding strength, respectively. The values of bonding strength were found to have a close relationship with the interface microstructure between the nanopaste and metallization layer on the substrate. Finally, the nanopaste was used to attach a SiC die on a substrate with either Ag or Au coating. The entire bonding structure has undergone a thermal aging test, whereby the thermal-aged microstructure was in agreement with the microstructure of metallization studies.

1. Introduction

Over the past decade, tin (Sn) based solder alloys have been widely used for level-one interconnection, namely die-attach material, which serves to attach a semiconductor die on a substrate [1]. The wide used of Sn based solder alloys are mainly due to the low cost and acceptable mechanical properties [2]. However, with the recent development of silicon carbide (SiC) power device that could be operated at temperature exceeding 400 °C [1], Sn based solder alloys that melt at temperature below 300 °C [2] become no longer meet the operating temperature requirement. The challenge is thus driven to seek a die-attach material that is having the capability to operate at temperature beyond that.

Gold (Au) [3–6], bismuth (Bi) [7,8] and zinc (Zn) [9,10] based solder alloys are next being proposed as alternative solutions. But most of these solder alloys are having melting point that below 400 °C [1], which also failed to be considered as a suitable die-attach material for SiC power device. Although Au–nickel (Ni) [11], with its high melting point of 980 °C, is an exceptional solder alloy that meets the operating temperature requirement (>400 °C) of SiC power device, but its high soldering temperature at 980 °C has also become a drawback. Two new die-attachment techniques, namely inter-diffusion bonding of metal film and sintering of metal paste, are subsequently being introduced to overcome the weakness (i.e., high soldering temperature) that associated with Au–Ni solder alloy. For instance, Au–Au [12], Au–indium (In) [13,14], and silver (Ag)–In [14,15] are particular die-attaches that utilized inter-diffusion bonding technique to form a joint between metal films at temperature of 180–300 °C with pressure of 0.28–40 MPa. Meanwhile, Ag [16] and copper (Cu) [17] micropastes (i.e., a mixture of micro-sized metal particles and organic compounds) are particular die-attaches that formed a joint by sintering the micropaste at temperature of 250 °C with pressure of 40 MPa. Overall, the advantage of these die-attachment techniques [12–17] is able to process at a moderate temperature (180–300 °C), yet the forming joint could be operated at temperature exceeds 480 °C. On the other hand, application of pressure during the process is one of the disadvantages of these die-attachment techniques [12–17], which could complicate the manufacturing process and with slight irregularities during application of pressure may lead to cracking of both the die and the substrate.

In recent years, a strategy of reducing the size of metal particle in metal paste, from micron to nano, has been introduced, which it is termed as nanopaste (i.e., a mixture of nano-sized metal particles and organic compounds). The reduction of particle size aims to increase the chemical driving force of metal particle and thus contributes to eliminate the application of pressure during sintering. Ag [18–24] and Cu [25,26] nanopastes are the leading candidates of this strategy, where they could be sintered at

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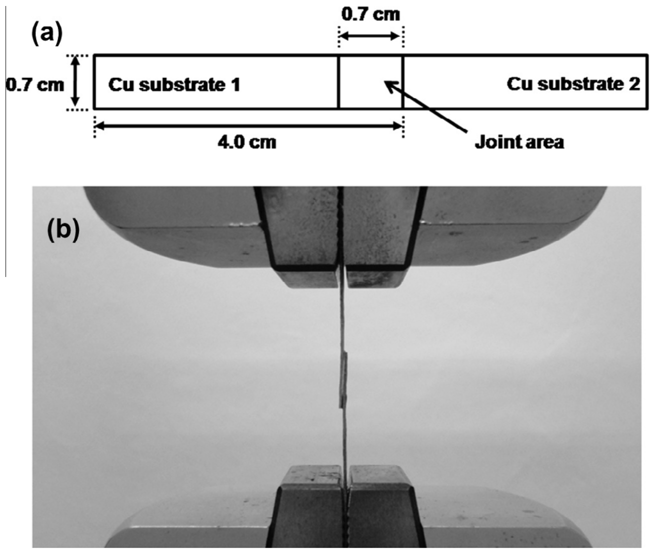

Fig. 1. (a) Schematic top view configuration of a single lap shear joint specimen, and (b) setup of the lap shear test.

temperature of 280–380 °C without the need of applying any pressure during sintering. Positive results were obtained for these sintered nanopastes, namely: (i) no existent of die-shifting issue as the nanopaste does not undergo liquid-state transformation during sintering [20,21,25]; (ii) atomic inter-diffusion between the nanopaste and metallization layer on die or substrate could produce a more reliable joint than solder alloys [20,21,23,25]; (iii) lower Young's modulus was detected for sintered nanopaste as compared to bulk materials and solder alloys; this is important to reduce the build-up of thermal stress among the die, die-attach and substrate in an operating power device [18–20,23]; and (iv) high melting point at 962–1085 °C for sintered nanopaste that may meet the operating temperature requirement of a SiC power device (>400 °C) [20,23,25]. Despite that, both Ag and Cu nanopastes are actually having their own limitations, where Ag nanopaste is limited to its high cost and low electrochemical migration resistance [27,28]; whereas Cu nanopaste is easy to be oxidized. To overcome the oxidation issue, additional time is needed for annealing process (4 h) in a nitrogen environment [25,26]. For these reasons, Ag–aluminum (Al) [29,30] and Ag–Cu nanopastes [31,32] are being introduced and aimed to surpass the preceding limitations of Ag and Cu nanopastes. Indeed, these Ag–Al and Ag–Cu nanopastes not only could tailor the cost to be cheaper than Ag nanopaste, but they also able to sinter at 380 °C in air atmosphere without the need of additional annealing process in a nitrogen environment. Although a minor amount of metal oxides has been detected for both sintered Ag–Al and Ag–Cu nanopastes, yet the presence of a minor amount of metal oxides has no significant adverse effect on the electrical and thermal properties of sintered nanopastes [29,32].

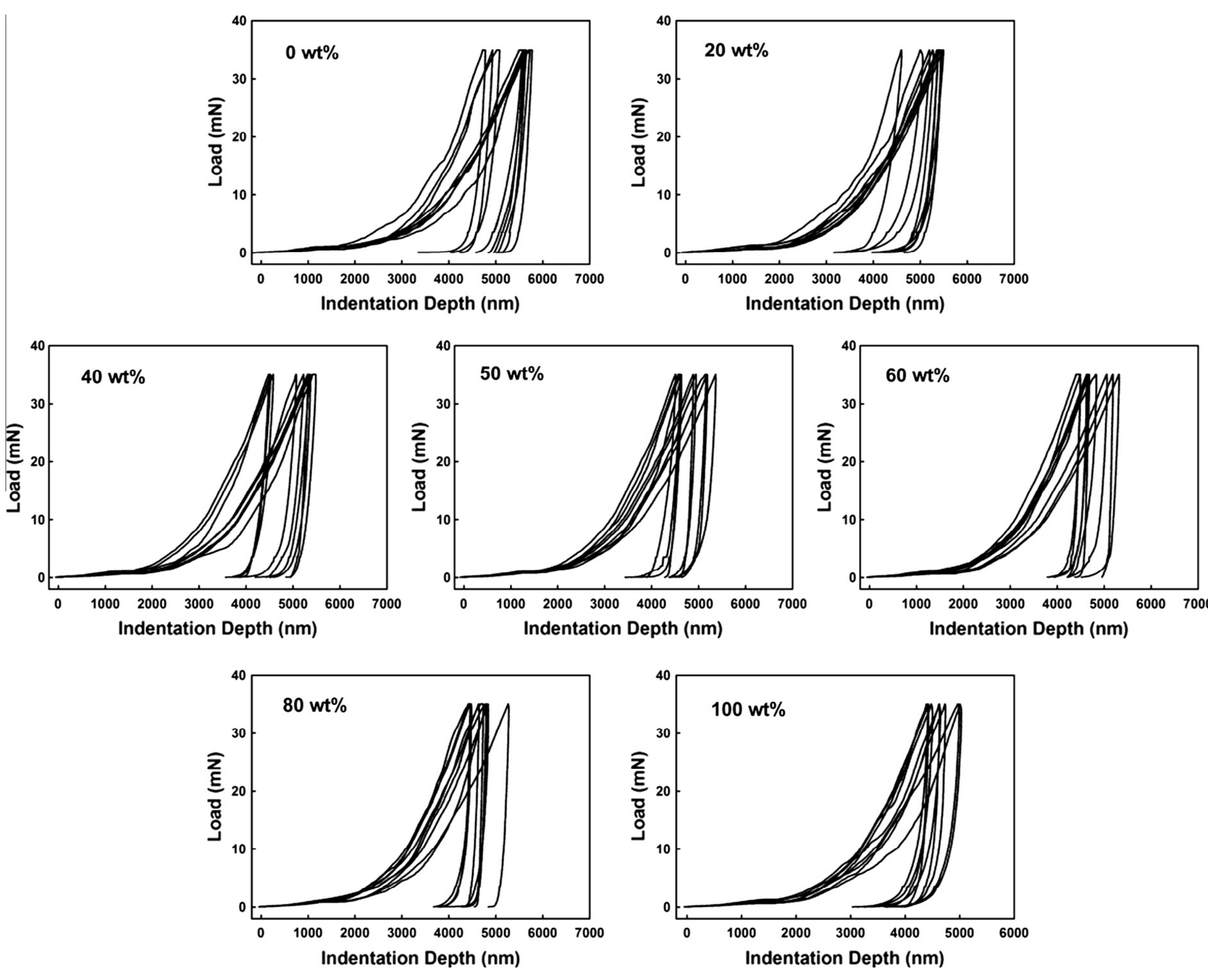

Fig. 2. Indentation hysteresis of sintered pure Ag nanopaste (0 wt% Cu), sintered pure Cu nanopaste (100 wt% Cu) and sintered Ag–Cu nanopaste with various Cu loadings (20–80 wt%).