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Enhanced pressureless bonding by Tin Doped Silver Paste at low sintering temperature

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ABSTRACT

The nanosilver sintering die-attach technique has been a promising alternative for wide band gap semiconductors. However, it is less preferable in industry because of its high sintering temperature. Recently research has been initiated to develop transient liquid phase sintering (TLPS) solder paste for use in electronics packaging. In this article, in order to lower the sintering temperature of nanosilver paste, we develop a novel tin (up to 10 wt%) doped silver paste (TDSP) and a sintering profile with the highest processing temperature of 235 °C based on TLPS. Sintered TDSP is Ag/Ag_3Sn/Ag–Sn solid solution composites. The composites have a microstructure of Ag matrix grains reinforced by Ag_3Sn and Ag–Sn solid solution within the matrix grains. And this microstructure endows the sintered Ag+4%Sn with a pressureless bonding strength of 23 MPa. The improved mechanical properties of sintered TDSP are attributed to second-phase strengthening and solid solution strengthening mechanisms. However, the overmuch formation of brittle Ag_3Sn phase is the main reason resulting in sharp decrease of bonding strength when the Sn content over 5 wt%. The new TDSP technology is expected to be applicable to a wide range of power semiconductors devices, such as organic devices and printed circuit boards. Furthermore, it provides new strategies for low-temperature sintering.

1. Introduction

Emerging novel-generation wide band gap semiconductors such as SiC and GaN have attracted more and more attention due to their excellent ability to achieve higher power density [1]. Moreover, the SiC-based power devices can withstand higher operating temperature than conventional silicon devices [2]. However, when these power devices are working after packaging, they generate more heat that is negative for the operation of devices. Thus, it's important to dissipate the heat approaching effective thermal management [3].

Currently, two of the most commonly used die-attach materials are Sn-based solder alloys and Ag-based conductive adhesives. Regardless of the excellent thermal and electrical conductivity properties of Sn-based solder alloys, the low melting temperature of the materials is considered to be a serious issue [4]. And as the processing temperature increases, interconnection generates mismatch because of intermetallic compounds [5]. That is the resource of failure. Most Ag-based conductive adhesives are thermoset-based materials which can be used above their attachment temperatures. However, when the operating temperature is higher, Ag-based conductive adhesives lose their stiffness [6]. Due to improper connections between Ag particles, Ag-based conductive adhesives may not create sufficient pathways for thermal and electrical conductivity [7,8]. Both of two kinds of materials are not suitable for high-temperature applications [9].

As the development of nanotechnique, the nanosilver-sintering die-attach technique has been a promising alternative for interconnecting power semiconductor devices [5]. However, it is less preferable as a die attach material in industry because of its sintering temperature that is as high as 280 °C [10–12]. Furthermore, many organic devices and printed circuit boards cannot withstand a higher processing temperature at which they are generally unstable [13]. So it's very urgent to develop new technique to lower the processing temperature.

For the nanosilver paste whose particle diameter is 100 nm, if sintered at a low temperature, the bonding strength of the joint is low because the organism cannot be effectively decomposed. So it is urgent to make efforts improving the bonding strength of nanosilver joints at a low sintering temperature. In general, metal matrix composites containing homogeneously refined grains (SiC and so on) in a matrix result in enhanced mechanical properties [14]. But the joints face many challenges due to poor wettability between metal and SiC [15]. Further, there are two other strategies

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to improve the bonding strength of nanosilver joints at a low sintering temperature, one is inducing pseudo-hydrostatic pressure [16], but the use of external pressure tends to complicate the manufacturing process [17]. Another is reducing silver particle size into the quite small range (20 nm or even less) and sintering without applying any pressure [18], but thus bringing external cost.

Recently research has been initiated to develop transient liquid phase sintering (TLPS) solder pastes for use in microelectronics packaging [19]. Some advantages of TLPS include a reduction in the processing temperature, enhanced densification and reduced cost [20]. Among the doping in particular, tin is considered one of the best dopant due to its low melting point and similar ionic radius with silver. Here, at the melting point as low as 235 °C, a transient liquid Sn phase will diffuse into a higher melting point Ag matrix that remains in the solid state. After the process of isothermal solidification, it will lead to the formation of Ag_3Sn with a melting point (as high as 470 °C) higher than Sn reactant. At the same time, the liquid phase wets the contacting Ag matrix, which produces capillary action resulting in particle re-arrangement and densification. After the process of isothermal solidification, we will prepare Ag–Sn solid solution/Ag_3Sn composites. Further, the solid solution will strengthen the matrix. And, the certain amount of Ag_3Sn as second phase will reinforce mechanical strength of the Ag matrix to some extent. The Ag–Sn solid solution/Ag_3Sn composites play an astonishing role in improving the bonding strength based on solid solution strengthening and second phase strengthening mechanisms [21,22].

It is therefore expected that adding a few Sn particles to the Ag particles bonding layer would improve the pressureless bonding strength. Therefore, we examined the mixture of tin (up to 10 wt%) doped silver paste (TDSP) for pressureless bonding. In this article, we report on the pressureless bonding properties of TDSP joints. Then we analysis the properties based on different strengthening mechanisms.

2. Experimental procedure

2.1. Preparation of Tin Doped Silver Paste

In this article, we prepared a novel bonding material which is Tin Doped Silver Paste (TDSP).

In order to prevent agglomeration of nanoparticles, the silver nanoparticles used as a base material are fabricated by mixing 100 nm average diameter silver powders with selected organic

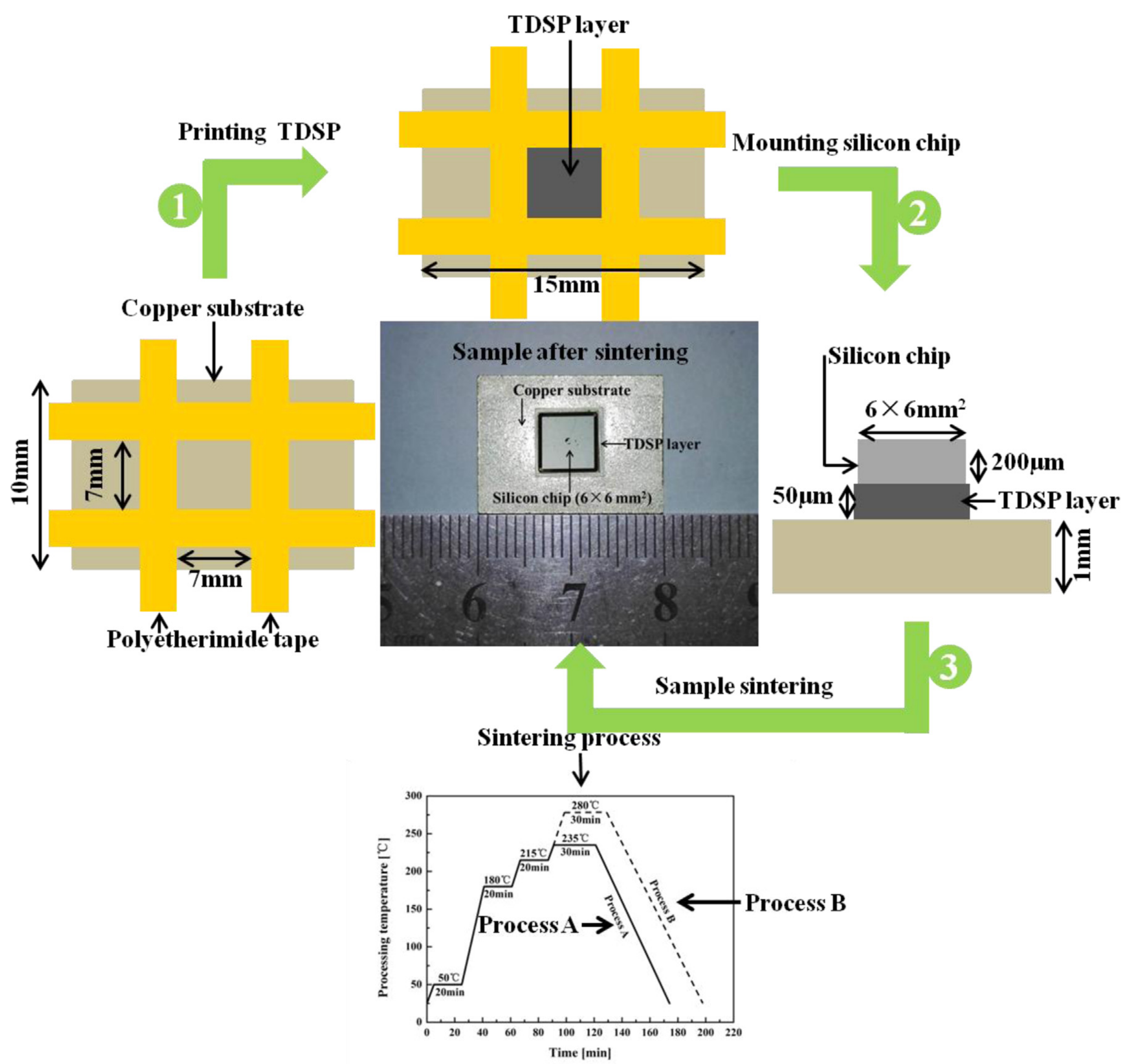

Fig. 1. Preparation process of bonding samples.