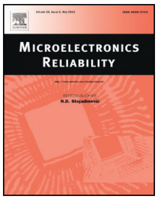
Microelectronics Reliability xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Microelectronics Reliability

journal homepage: www.elsevier.com/locate/mr



Study on high temperature bonding reliability of sintered nano-silver joint on bare copper plate

Su-Yan Zhao [a], Xin Li [a,*], Yun-Hui Mei [a], Guo-Quan Lu [a,b]

[a] School of Materials Science and Engineering, Tianjin Key Laboratory of Advanced Joining Technology, Tianjin University, Tianjin, PR China
[b] Department of Materials Science and Engineering, Virginia Tech, Blacksburg, VA, USA

ARTICLE INFO

Article history:
Received 24 May 2015
Received in revised form 11 October 2015
Accepted 15 October 2015
Available online xxxx

Keywords:
Nano-silver paste
Bare copper plate
Interface reaction
Bonding strength
Thermal aging

ABSTRACT

Nano-silver paste has become an alternative lead-free (Pb-free) die attach material for microelectronic packaging, compared to traditional solders and adhesive films, due to its higher thermal and electrical conductivity, higher temperature operation and higher heat dissipation. In this study, the reliable joints of sintered nano-silver paste on bare copper plate with large-area dummy chips were introduced and thermally aged at 150 °C, 180 °C, or even higher than 250 °C in air or in a coarse vacuum environment. The bonding strength and interfacial reaction were investigated. The results showed, after aging specimens at 150 °C for 960 h in air or at 250 °C for 960 h in a coarse vacuum, the interfaces between the sintered nano-silver and bare copper still consisted of simple inter-diffusion bands and with almost no change in bonding strength. However, the bonding strength sharply decreased to 50% after aging at 180 °C for 72 h in air and it decreased to 20% after aging at 250 °C for 72 h in air. The decrease in bonding strength was mainly attributed to the oxidation of copper at relative elevated temperature in this work.

1. Introduction

In electronic packaging, the die-attach materials play a very important role in providing the packaging interconnection, physical protection, and mechanical support to ensure that the entire system works functionally [1–3]. Nowadays, both solder alloys (leaded or lead-free) and conductive adhesives are commonly used as die-attach materials for use at operating temperatures below 220 °C [4]. However, these solder alloys and conductive adhesives could not meet the stringent requirements for higher temperature applications due to their low melting and operating temperatures, such as in the automotive, aviation, space, and nuclear industries. Nano-silver paste has been reported as a promising die-attach material due to its high melting temperature (960 °C), low sintering temperature (275 °C), high electrical/thermal conductivity (4.1×10^7 $S \cdot m^{-1}$ and 240 $W \cdot m^{-1} \cdot K^{-1}$, respectively), and high reliability [5]. Simultaneously, the properties of nano-silver joints have been extensively studied [2,6,7]. Mei et al. [6] studied the effect of sintering condition on the bonding quality of sintered nano-silver on Cu metallization under different temperatures and holding times, showing that the bonding strength mostly increased with increasing applied pressure, pressing temperature, pressing time, sintering temperature, and sintering time. Wang et al. [2] analyzed the bonding strength of sintered nano-silver joints and the microstructure evolution of the nano-silver paste during sintering. They found that the excellent bonding strength was in accordance with the densification behavior of the nanoparticles. In addition, the adhesion strength of the Ag nanoparticles on the bonding substrate surface is important for this bonding strength [7].

Copper as the material of die-attach substrate is commonly metalized by electroplating, physical or chemical vapor deposition or sputtering to prevent oxidation [8]. Consequently, the metallization increases the cost of manufacturing of the substrate, and cracks are likely initiated between the metalized film and bare copper, leading to poor bonding reliability. Nano-silver paste was introduced to bare copper connections without surface metallization to obtain reliable joints [9–14]. Strong joints were obtained by controlling the surface preparation methods that removed copper oxides from the substrate with diluted nitric acid [9] or hydrochloric acid [10,11] prior to application of nano-silver paste. Some researchers demonstrated that sintering the nano-silver paste in air produced lower bonding strength than sintering the nano-silver paste in nitrogen [12,13].

Currently, most studies on nano-silver paste have focused on its feasibility as interconnected materials, as opposed to its long-term behaviors in the field. However, electronic devices are subjected to long-term high-temperature operations due to the increasing demands for miniaturization, integration, and harsh environment applications [15]. Some researchers studied interfacial microstructure development to determine the reliability of solder joints under high-temperature operations. The formation and change of various intermetallic compounds (such as

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* Corresponding author.
E-mail address: xinli@tju.edu.cn (X. Li).

http://dx.doi.org/10.1016/j.microrel.2015.10.017
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Please cite this article as: S.-Y. Zhao, et al., Study on high temperature bonding reliability of sintered nano-silver joint on bare copper plate, Microelectronics Reliability (2015), http://dx.doi.org/10.1016/j.microrel.2015.10.017

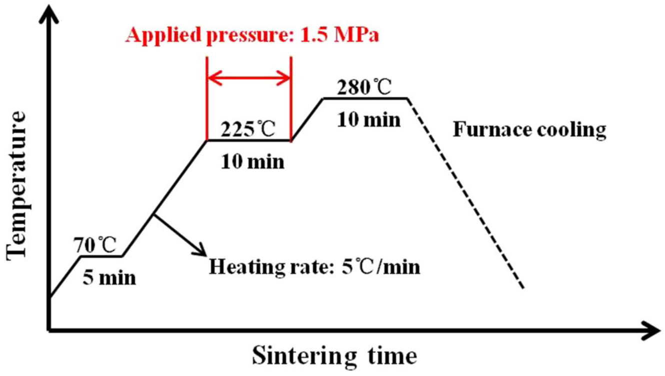

Fig. 1. Temperature profile for nano-silver paste sintering.

Cu_6Sn_5 and Cu_3Sn in a SnAgCu/Cu joint) in the joints guide the joint reliability evaluation [16–19]. The microstructure evaluations of nano-silver joints at high temperatures are urgently needed. In this study, a reliable sandwich joint of sintered nano-silver paste on bare copper with dummy chips was introduced. The bonding strength evolutions were investigated with specimens aged at 150 °C, 180 °C, and even higher than 250 °C in air or in a coarse vacuum. The interfacial reaction of the joints as microstructure evaluation was used to probe the bonding strength evolution.

2. Experiment

To better simulate the actual nano-silver sintered joints in the electronics industry, we designed a sandwich structure of dummy chip (silver coated Si wafer)/nano-silver/bare Cu plate. The nano-silver paste for interconnection with 82 wt.% of spherical nanoparticles smaller than 50 nm was provided by NBE Technologies LLC (www.nbetech.com). Bare copper plates with dimensions of 15 × 22 × 1.5 mm^3 (width × length × thickness) were 99.99% purity. Large area dummy Si chips were 13.5 × 13.5 × 0.2 mm^3 (width × length × thickness). For chip connection, first we polished and cleaned the surface of the bare Cu plate. Then a layer of nano-silver paste with a thickness of 50 μm was stencil printed onto the plate and dried at 70 °C for 5 min. Finally, the chip was placed on the dried paste and pressure aided sintering was done on a hot plate inside a tank according to the temperature profile shown in Fig. 1. A pressure of 1.5 MPa was held for 10 min during sintering at 225 °C. During the sintering process, the sintering tank was filled with protective gas (4% H_2/96% N_2) as shown in Fig. 2 to prevent the oxidation of bare copper. The final structure of a sintered sandwich specimen is shown in Fig. 3(a) and the bond-line thickness is about 28 μm, as shown in Fig. 3(b).

Thermal aging tests were conducted at constant temperatures of 150 °C, 180 °C and 250 °C in air and in a coarse vacuum. To simulate practical coarse vacuum working condition, the specimens were enclosed into the quartz tube, whose vacuum degree achieves to ~0.05 Pa. Samples to be cross sectioned were embedded in an epoxy resin. They were ground with 320, 600, 1200, 1500, 2000 and 3000 grade abrasive sandpapers, and then polished with 2.5 μm, 1 μm, and 0.25 μm diamond suspensions. To reveal details of the interfacial structure, the polished cross-section of a sample was corroded in an etching solution (25% NH_4:distilled water:100% H_2O_2 = 11:10:16). The etching time was 2–3 s. The interfacial microstructure and reaction between the sintered nano-silver and copper were analyzed by scanning electron microscopy (SEM, Hitachi S4800, Japan), energy dispersive spectroscopy (EDS, EDAX Genesis XM2, USA) and electron probe microanalysis (EPMA, Shimadzu EPMA-1600, Japan). The bonding strength of a sintered nano-silver joint was measured by using a bond tester (XTZTEC Condor 150) at a velocity of 100 μm/s. A schematic of the die-shear test is shown in Fig. 4.

3. Results and discussion

3.1. Bonding strength evolution after aging

3.1.1. Bonding strength and fracture surface after aging in air

Fig. 5 shows the bonding strengths and corresponding fracture surfaces of sandwich specimens before and after aging at 150 °C, 180 °C and 250 °C in air. At least three specimens are made for each aging level to obtain an average bonding strength. The average bonding strength was found to be 27.7 MPa for 13.5 × 13.5 mm^2 chips before aging and did not obviously change after aging at 150 °C for 72 h. With increasing the aging temperature to 180 °C and aging this temperature for 72 h, the bonding strengths are reduced to 50% of the initial bonding strength value. Further increasing the aging temperature to 250 °C, the bonding strengths are reduced to 20%. The variation of bonding strengths with aging temperature is closely related to the fracture morphologies (in the inset Fig. 5). The fractures occur in the sintered silver layer rather than at the Ag/Cu or Ag/chip interface before and after aging at 150 °C for 72 h. Moreover, the sheared-off surfaces of silver die attachment before (Fig. 6(a)) and after (Fig. 6(b)) thermal aging show significant plastic flow, indicating that the bonding strength in this case is high. However, the fractures begin to occur at the Ag/Cu

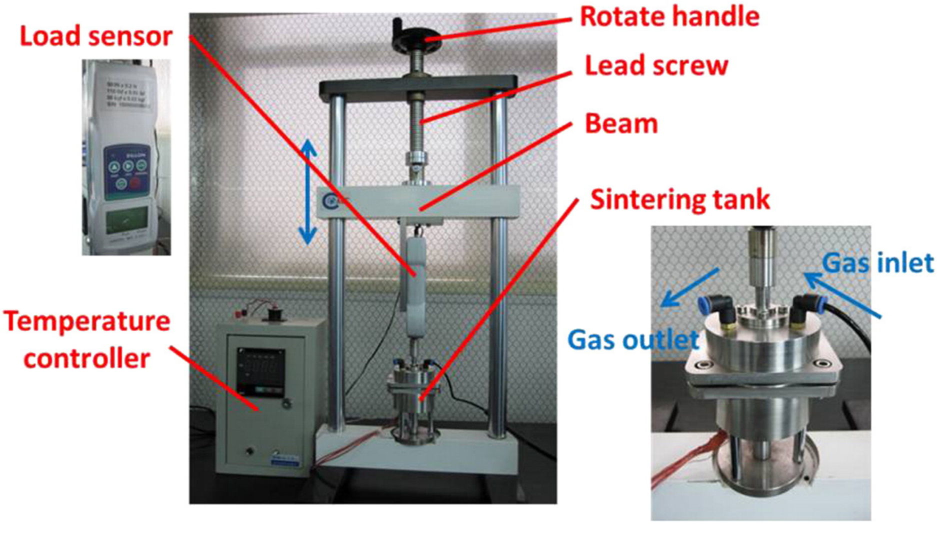

Fig. 2. Apparatus for pressure-assisted sintering with protective gas surrounding.

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