Journal of Alloys and Compounds 774 (2019) 487–494

Contents lists available at ScienceDirect

Journal of Alloys and Compounds

journal homepage: http://www.elsevier.com/locate/jalcom

Microstructural and mechanical evolution of silver sintering die attach for SiC power devices during high temperature applications

Hongqiang Zhang [a], Wengan Wang [b], Hailin Bai [b], Guisheng Zou [b, *], Lei Liu [b], Peng Peng [a], Wei Guo [a, **]

[a] School of Mechanical Engineering and Automation, Beihang University, Beijing, 100191, PR China
[b] Department of Mechanical Engineering, Tsinghua University, Beijing, 100084, PR China

ARTICLE INFO

Article history:
Received 21 July 2018
Received in revised form
30 September 2018
Accepted 7 October 2018
Available online 9 October 2018

Keywords:
Microstructure
High temperature storage
Reliability
Die attach
Nano-Ag paste

ABSTRACT

Silver sintering is a promising die attach technology to ensure high thermal reliability. The long-term reliability of SiC device sintered by nano-Ag paste has been evaluated by the high temperature storage (HTS) process at 350 °C in air and vacuum, respectively. Although the SiC chip and direct bonding copper (DBC) substrate could be bonded firmly by the nano-Ag paste after sintering at low temperature, the microstructure and shear strength of sintered die attachment experienced the huge evolution during HTS process. The bondline of die attachment became compact, and some pores grow up and pore distribution became nonuniform after HTS in air. While the densification of bondline was significantly delayed because residual organics inhibited the growth and migration of pores during HTS in vacuum. The shear strength of die attachment first increased then decreased slowly with the increasing of storage time. The fracture surface showed that the Ni(P) layer was oxidized, and the formed NiO layer provided the failure location. The results indicated that the electroless nickel/immersion gold (ENIG) surface of DBC substrate was not the ideal metallization when the sintered die attachment applied at the long-term high temperature.

1. Introduction

SiC power devices are shown to have excellent properties at high temperature ranging from 300 to 500 °C, which is extremely attractive for power applications, and have been advanced rapidly in recent decades [1–3]. Such high temperature electronics are widely applied in many industries, like oil & gas, and these high temperature applications require a new way of attaching the die on the chip-carrier [4].

Die attach is a critical technology in power module assembly, impacting thermal, electrical and reliability performances. Traditional solders could not meet the high temperature requirements and different techniques were used to attach the die on direct bonding copper (DBC) substrate [5–8]. Silver (Ag) sintering is a promising die attach technology to provide a high melting-point Ag-based joint. The nano-Ag paste as a die attach bonding material has a high potential to be adopted and used in industry due to the high electrical and thermal conductivity [9–11].

Reliability is one of the important issue for power modules, and the thermal reliability of die attachment has received a great deal of attention. However, most of thermal reliability tests were conducted for Si-based power module at 200 °C, which was lower than the operating temperature of the SiC power module [2,12]. Although SiC devices sintered by nano-Ag paste are able to operate at ambient temperatures exceeding 300 °C, the thermal stability of sintered layer and the metallization structure of SiC chip and DBC substrate is still the challenge to long-term high temperature application [13–15]. Guo-Quan Lu et al. [16,17] measured the die-shear strength of device attached on Ag-coated DBC substrate aged at 300 °C after 400–500 h in air, and considered that the storage at temperatures at least until 300 °C did not lead to reliability problems.

The commercially-available electroless nickel/immersion gold (ENIG) surface was chosen as the metallization of DBC substrate. In this study, the reliability of SiC device sintered by nano-Ag paste was evaluated by high temperature storage (HTS) tests at 350 °C, and the microstructure and shear strength, porosity and pore

* Corresponding author.
** Corresponding author.
E-mail addresses: zougs@tsinghua.edu.cn (G. Zou), gwei@buaa.edu.cn (W. Guo).

https://doi.org/10.1016/j.jallcom.2018.10.067
0925-8388/

distribution in the sintered bondline during HTS in air and vacuum atmospheres were researched, respectively. The failure mechanism of die attachment for high temperature applications was discussed.

2. Experimental details

2.1. Materials

The nano-Ag paste consisted of Ag nanoparticles (average diameter: 80 nm and 800 nm) and organics. Ag nanoparticles were purchased from Haotian Technology Co., Ltd., and the shape was spherical and quasi-spherical, and Ag content in the paste was 84 wt%. Ag nanoparticles were mixed with organics by stirring to form a uniformly nano-Ag paste in the lab, which was suitable for stencil printing. A stencil in 100 μm thickness was used to print nano-Ag paste on the DBC substrate.

650V/8A SiC power schottky diode chip ($1.85 \times 1.85\ mm^2$) was used, and backside metallization was Ni layer (0.7 μm) and sputtered Ag layer (1 μm). The used DBC ceramic substrates were consisted of a ceramic plate (96 wt % Al_2O_3, thickness 635 μm) sandwiched between two Cu layers of 300 μm thickness. Ni(P) (4 μm)/Au (70 nm) metallization was deposited onto DBC substrates, which were labelled as the electroless nickel/immersion gold (ENIG) surface. The actual sintering layer structure was sputtered Ag layer/bondline/Au layer, as shown in Fig. 1.

2.2. Sintering process and HTS test

Die attachment was made by sintering the prepared nano-Ag paste, and the entire sintering process contained following steps, as shown in Fig. 2. The drying step was processed at 150 °C for 5 min to remove solvent in the paste and prevent the chip from being buried and shorted by the squeezed paste [2]. Then the paste continued to be processed at 250 °C for 5 min to further burn out organics and cure the paste. The sintering step was applied at 300 °C for 15 min with a 3 MPa of pressure to allow Ag to diffuse into the backside finish metal of the SiC chip and DBC substrate. The pressure was to avoid the formation of high-porosity bondline [18]. After sintering, a Dage 2400 shear tester with a 100 kg die shear module was used for die shear strength testing.

HTS tests were carried out at 350 °C both in air and vacuum, respectively. The air atmosphere storage tests simulated the situation where the device packaging hermetic seal has failed and oxygen has begun to infiltrate and, presumably, degrade the semiconductor device chip. The vacuum atmosphere storage tests were carried out using a Muffle furnace, and the sintered die attachments were sealed by a vacuum tube machine.

After HTS, die attachments were molded in cured epoxies and then cut and polished with different grade abrasive sandpapers. To obtain a clearer and more accurate cross-sectional microstructure, the mechanical polished die attachments were further polished by an ion milling machine (Leica, EM TIC 3X). The cross-sectional microstructure were observed by using a scanning electron microscope (SEM, Zeiss EVO MA10). The porosity of bondline and pore size were calculated from 3 typical cross section SEM images. The total cross-sectional area of bondline (A) and the pore area (Ai) were measured, as shown in Fig. 3. The porosity (f) was obtained from the equation $f = \sum Ai/A$ [19,20]. The thickness of bondline and sintered Ag dense layer were also measured based on the SEM images. The normalized thickness of bondline could obtain, namely, the thickness of dense layer divided by the thickness of bondline. The chemical composition of fracture surface was investigated using an X-ray photoelectron spectroscopy (XPS, PHI 5000C ESCA system).

3. Results and discussion

3.1. Cross-sectional microstructure after sintering

The microstructure and actual bonding surfaces of the bondline

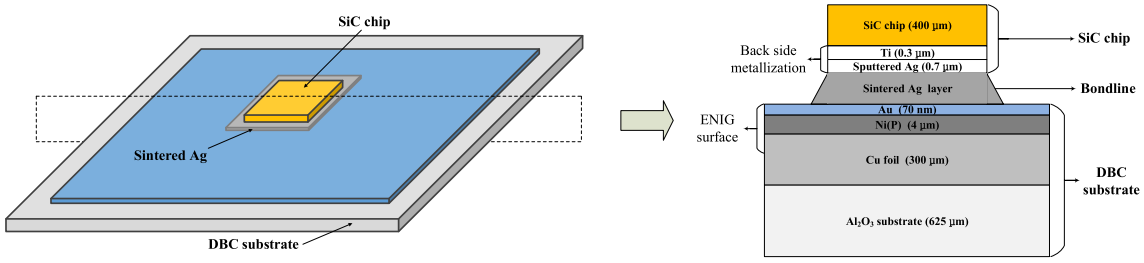

Fig. 1. The structure of die attachment with their metallization systems.

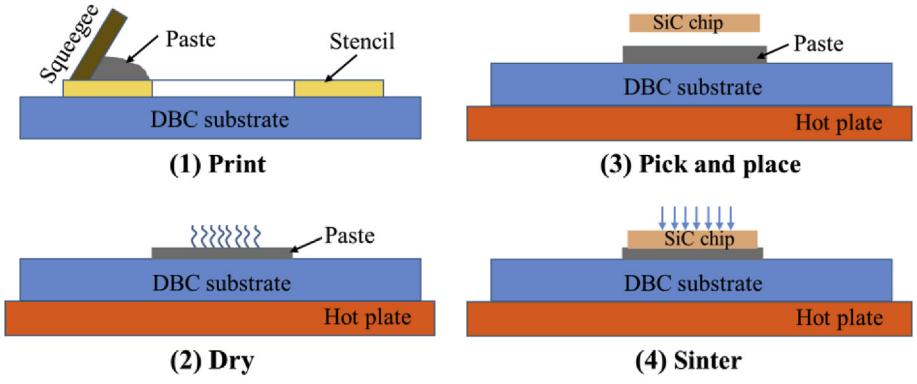

Fig. 2. Schematic diagrams for the sintering process with nano-Ag paste.