

Improvement of bonding strength and thermal shock reliability for Ag sinter joining direct on Al substrate

Chuantong Chen*
SANKEN

Osaka University
Osaka, Japan

chenchuantong@sanken.osaka-u.ac.jp

Ran Liu
SANKEN

Osaka University
Osaka, Japan

liu.ran@sanken.osaka-u.ac.jp

Koji Kobayashi
DOWA POWER DEVICE Co., Ltd

Nagano, Japan
kobayak2@dowa.co.jp

Hideyo Osanai
DOWA POWER DEVICE Co., Ltd

Nagano, Japan
osanaih@dowa.co.jp

Zheng Zhang
SANKEN

Osaka University
Osaka, Japan

zhangzheng@sanken.osaka-u.ac.jp

Katsuaki Suganuma
SANKEN

Osaka University
Osaka, Japan
suganuma@sanken.osaka-u.ac.jp

Abstract— Ag sinter paste joining as a proven die bonding technology have been used in the electric vehicle. However, for the Ag sinter paste joining, metallization layers on substrate are usually necessary such as Ni-P/Au or Ni-P/Ag to get a good bonding quality. The direct bonding on DBC (direct bonded copper) or DBA (Direct Bonded Aluminum) substrates without metallization layers are very attractive. In this study, we investigated the direct bonding on an aluminum (Al) substrate by Ag sinter paste and propose an abrasive blasting processes to treat the Al surface to increase the initial bonding quality. The result show that the shear strength of SiC/Al joint structure by Ag sinter paste can be improved by treating the Al surface. The shear strength of joint structure without surface treatment increased from 26.9 MPa to 32.2 MPa for a strong blasting treatment on Al surface. In addition, the results of thermal shock test (-40 °C~150°C) also show that the blasting treatment on Al surface can improve the shear strength and reliability of SiC/Al joint structure.

Keywords—Direct bonding on Al, Ag sinter paste, thermal shock, blasting processes, SiC power modules

I. INTRODUCTION

With the development of wide bandgap semiconductors, such as silicon carbide (SiC) which present more potential properties for delivering improved power densities and frequencies, power module using SiC power chips attract more attention especially in the electric vehicle applications [1-4]. In power module structure, the SiC power chip was attached on a DBC (direct bonded copper) or DBA (Direct Bonded Aluminum) substrates by a die attached material, and finally connect to an aluminum (Al) heatsink for heat dispersal. The bonding quality and reliability of the power chips to substrates is one of the most important factors for the power module structure. Ag sinter paste joining as a proven bonding technology is one of the good selections because which possesses good thermal conductivity and can be sintered in low temperature low pressure air condition [5-8]. In addition, for the DBA and DBC substrate bonding to the Al heatsink, currently, some studies also focus on the Ag sinter paste to replace the traditional solder or TIM materials [9, 10]. The technology of bonding sintered Ag directly on Al substrate is very attractive, because it does not require a metallization layer on Al such as Ni/Au or Ni/Ag, which can save a lot of cost and time.

Recently, direct bonding of a SiC die to a bare DBA substrate via Ag sinter paste joining was achieved under a low-temperature, pressure-less condition [11]. However, a

large deformation occurred on DBA for the direct bonding during a harsh thermal shock test due to the Al was soft. The deformation of Al surface lead to the cracks generation at the sintered Ag layer and thus lead to the possibility of reliability issue for the direct bonding case.

In this work, in order to improve the bonding strength and thermal shock reliability for Ag sinter joining on bare Al substrate, the Al substrate was treated by an abrasive blasting processes before bonding with Ag sinter paste. The abrasive blasting processes treatment was expected to increase the hardness of Al surface and decrease the grain size of Al, and thus to prevent the deformation during the thermal shock test after bonded with SiC chip by Ag sinter paste joining.

II. EXPERIMENTAL

A. Ag paste and Al substrate

In this study, micron-sized Ag flake particles were selected as the Ag precursor. The average size of the Ag particles is 2.5 μm , and cross section of the Ag flake particles was shown in Fig. 1(a). The CELTOL-IA, a kind of solvent was used to mix the Ag flake particles to fabricate the Ag paste with the wight ration of 1:13.

The Al substrate (Al 1050) with the dimension of 35x35x2 mm³ was used in this study. Two kinds of blasting processes treated on the Al surface called as weak treatment and strong treatment, respectively, that were implemented before joint by Ag sinter paste with SiC chip. Fig. 1(c) shows the printing process by Ag sinter paste. Firstly, the paste was printed on the Al substrate by a metal mask with the thickness of 100 μm , the size is 3x3 mm² (Fig. 1(d)). After printed the Ag sinter paste on the Al substrate, SiC with the sputtered Ti (100 nm) and Ag (1 μm) metallization on the bonding surface was attached to the paste and sintering at 300 °C with 2 MPa pressure (Fig. 1(e)).

B. Characterization

The shear strength SiC/Al joint structure was measured via a die shear tester (DAGE, XD-7500). In addition, to investigate the reliability on Al substrate with different surface treatment, SiC/Al joint structure was implemented with a thermal shock test from -40 °C to 150 °C for 500 cycles. The microstructure of SiC/ Al joint by Ag sinter paste was observed by field-emission scanning electron microscopy (FE-SEM, Hitachi SU8020, Hitachi), which equipped with energy dispersive spectroscopy (EDS). The of cross section of joint sample was mechanically polished and then fine polished

by an ion milling process (IM 4000, HITACHI) before observation.

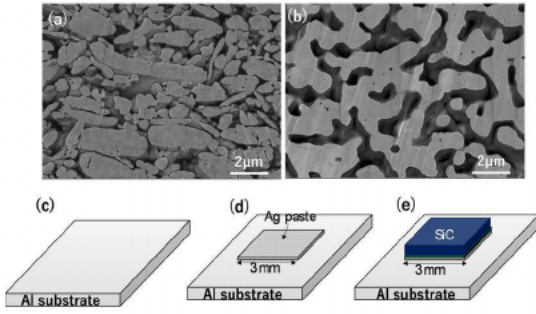


Fig.1 (a) the cross section of Ag flake particles, (b) the Ag porous structure sintering at 250°C for 5 min. (c), the Al substrate, (d) Ag paste printing and (e) SiC mounting process

III. RESULTS AND DISCUSSION

A. Cross section of SiC/Al joint

Fig. 2(a) shows the cross section of SiC/Al joint by Ag sinter paste, where Al substrate did not surface treatment. Sintered Ag layer shows a micron-porous structure without any large voids and interface cracks generation. The sintered Ag paste bonded well with the SiC and Al substrate via a strong interface necking growth as shown in Fig. 2 (b) and Fig. 2(c). By the EDS element analysis, the bonded interface just contains only Ag and Al metal element, not clear diffusion between the Ag and Al layers (Fig. 1(d-f)). The interface bonding mechanism of Ag and Al at low temperature have been discussed in our previous study [11], where the bonding interface between Ag and Al is mainly attributed to the Ag–O–Al bond, beginning from the self-generation of the Ag nanoparticles [12,13].

Fig.3(a) and Fig.3(c) show the cross section of SiC/Al joint structure with a weak and strong blasting processes treated Al, respectively. Sintered Ag layer also shows a micron-porous structure for the both case without any large voids and interface cracks generation. The magnified view of SiC/Al joint structure were shown in Fig.2(b) and Fig.2(d), respectively. It can be found that the sintered Ag paste bonded well with the Al even the Al have a rough surface after treatment.

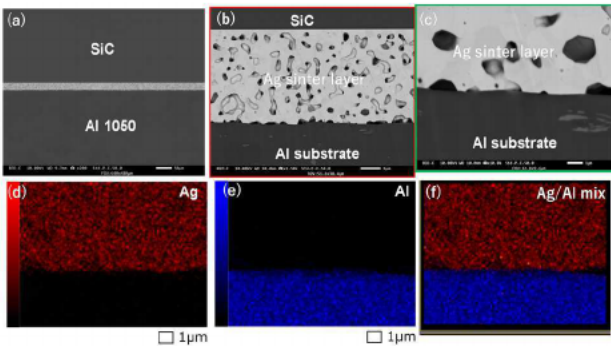


Fig.2 (a) The cross section of SiC/Al joint structure by Ag sinter paste, (b) the micron-sized sintered Ag direct on Al substrate, (c) the magnified view of the bonded interface between sintered Ag and Al substrate, (d-e) the EDS element mapping of Ag and Al, respectively, (f) the mix element mapping of Ag and Al.

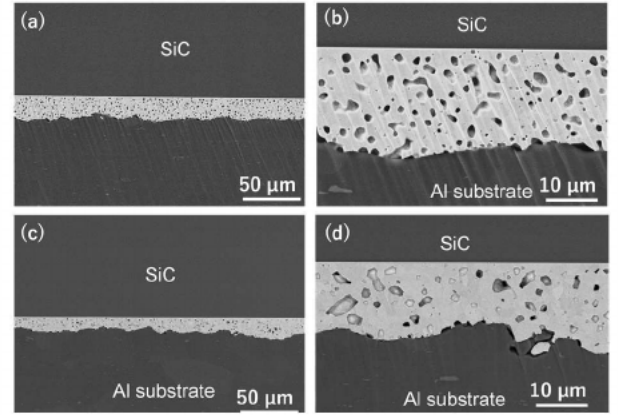


Fig.3 (a) the cross section of SiC/Al joint structure with weak blasting processes treated Al, (b) the magnified view of the bonded interface between sintered Ag and Al, (c) the SiC/Al joint structure with strong blasting processes treated Al and (d) the magnified view of interface between sintered Ag and Al substrate.

B. Fracture surface of SiC/Al joint structure

Fig. 4 (a) shows the fracture surface of SiC/Al joint structure by Ag sinter paste for the Al substrate without surface treatment after shear test. The fracture surface was observed on the Al substrate side, and the result suggested that the fracture occurred on sintered Ag necking interface nearly to the Al substrate as shown in Fig. 4 (b). The sintered Ag remains on the Al substrate with a ductile deformation. Fig. 4 (c) shows the fracture surface of SiC/Al joint structure by Ag sinter paste for the Al substrate with the weak blasting processes surface treatment. Similar with the Al substrate without surface treatment, the SiC/Al joint also fractured at the sintered Ag interface nearly to the Al substrate. The sintered Ag also remains on the Al substrate with a ductile deformation after shear test as shown in Fig. 4 (d). Fig. 4 (e) shows the fracture surface with the strong blasting processes treatment on Al surface. It was also found that some locations of Al substrate was broken with the strong blasting processes, that may be attributed to the large deformation of Al surface during the blasting processes. The sintered Ag still remains on the Al substrate with a ductile deformation even at the location where the Al surface was largely deformed as shown in Fig. 4 (f). These results imply that sintered Ag paste does not have much limitation on the surface roughness of the Al substrate for the direct bonding process with the Al.

C. Shear strength

Fig. 5 (a) shows the shear strength of SiC/Al joint structure by Ag sinter paste for the Al substrate with different surface treatment during shear test. The shear strength was achieved to 26.9 MPa for the directly bonding on Al substrate without any Al surface treatment. The shear strength was larger than that of the solder materials joint and also was able to compare to the Ag nano-paste bonding on an Ag metallized substrate [14, 15]. The shear strength was improved by the blasting surface treatment processes on Al substrate. The shear strength of SiC/Al joint structure separately increased to 29.1 MPa and 32.3 MPa in the case of the weak blasting surface treatment and the strong blasting surface treatment on Al substrates. Comparing with the Al substrate without surface treatment, the shear strength increased by 8.1% and 20.1%, respectively, for the weak and strong blasting surface

treatment. The arithmetic mean roughness R_a and the maximum value of roughness R_z of the Al substrate without surface treatment are $0.49\text{ }\mu\text{m}$ and $1.98\text{ }\mu\text{m}$, respectively. The values of R_a and R_z for the Al substrate with strong blasting surface treatment are $1.98\text{ }\mu\text{m}$ and $8.74\text{ }\mu\text{m}$, respectively. The increased surface roughness may lead to an anchor effect for the interface bonding between sintered Ag and Al substrate [16].

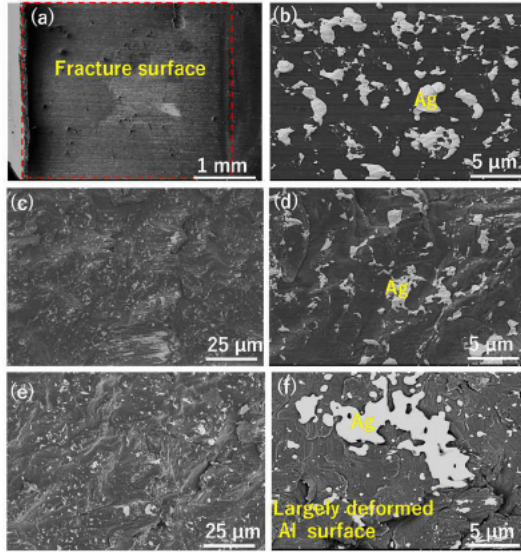


Fig. 4(a) The fracture surface of SiC/Al joint structure for the Al substrate without surface treatment, (b) the magnified view of fracture surface, (c) (e) the fracture surface of SiC/Al joint structure for the Al substrate with weak blasting treatment and strong blasting treatment, respectively, (d) (f) the magnified view of the fracture surface corresponding to the (c) and (e), respectively.

D. Thermal shock test

Fig.5 (b) shows the shear strength of SiC/Al joint structure by Ag sinter paste for the Al substrate with different surface treatment after thermal shock test for 500 cycles. Comparing with the initial shear strength, the shear strength after thermals shock test decreased a lot for the both Al surface treatment and without surface treatment. The decrease in shear strength may be due to delamination at the interface between sintered Ag and Al substrate, and due to the appearance of cracks in the sintered Ag layer. On the other hand, it is found that the shear strength for the Al substrate with strong blasting treatment was higher than that Al substrate without surface treatment. The result indicated that the thermal shock reliability of SiC /Al joint structure could be improved by the blasting surface treatment process. We evaluated the Vickers hardness of the Al surface without blasting treatment and after the strong blasting treatment as 37.2 HV and 43.1 HV , respectively. The Vickers hardness increase after strong blasting treatment may be attribute to the decrease of grain size of Al. The Vickers hardness increase may prohibit the Al surface deformation, and thus influence and improve the structure reliability of SiC/Al direct bonding during thermal shock test.

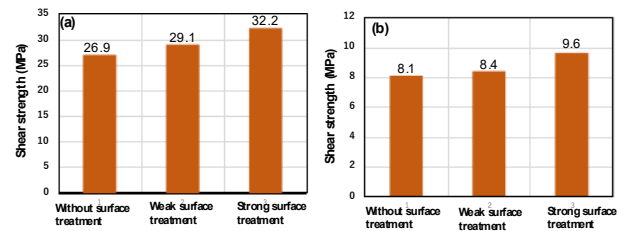


Fig.5 (a) the shear strength of SiC/Al joint structure by Ag sinter paste for the Al substrate with different surface treatment during shear test, (b) the shear strength after thermal shock test for 500 cycles.

IV. CONCLUSIONS

In this study, we investigated the direct bonding on an aluminum (Al) substrate by Ag sinter paste and propose an abrasive blasting processes to treat the Al surface to increase the initial bonding quality. The result show that the shear strength of SiC/Al joint structure by Ag sinter paste can be improved by treating the Al surface. The shear strength of joint structure without surface treatment increased from 26.9 MPa to 32.2 MPa for a strong blasting treatment on Al surface. The increased surface roughness may lead to an anchor effect for the interface bonding between sintered Ag and Al substrate. In addition, the results of thermal shock test also show that the blasting treatment on Al surface can improve the shear strength and reliability of SiC/Al joint structure. This study provides a new method to increase bonding strength and structure reliability of Ag sinter paste direct on Al substrate.

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