Articles

Development of Transfer Bonding Sheet Using Copper Nanoparticles

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Power devices are used in power converters such as inverters for electric vehicles and other applications, and recently, SiC power devices capable of high-temperature operation are expected. On the other hand, the solder bonding materials used in conventional Si power devices have poor heat resistance and are unsuitable for SiC power devices, so metal nanoparticle bonding materials with high heat resistance are attracting attention. In this paper, we report on the development of a transfer bonding sheet that enables low-temperature bonding (below 250°C) using copper nanoparticles manufactured by our company. Specifically, by examining the glass transition temperature and concentration of the binder, we were able to create a transfer bonding sheet that can stably obtain a shear strength of 70 MPa or more at a bonding temperature of 250°C.

1. Introduction

In recent years, the demand for power devices has been increasing due to the spread of electric and hybrid vehicles and the reacknowledged importance of photovoltaic and wind power generation. This has led to the development of higher-efficiency inverters and other equipment, which requires downsizing of modules to fit power converters in a limited space. For this purpose, it is necessary to increase the output power density by raising the upper limit of the operating temperature. However, the upper limit of the operating temperature of Si power devices, which are currently the mainstream, is 150°C, and the miniaturization of modules is approaching its limit due to heat resistance issues [1).

On the other hand, power devices using SiC, GaN, or other materials can be operated at temperatures of 200°C or higher and are expected to replace Si power devices. In conjunction with this trend, there is a need to develop highly reliable mounting technologies for bonding devices to substrates and other components. Conventional bonding materials widely used for electronic components of Si power devices are based on solder materials. However, solder materials lack heat resistance and are not suitable for SiC power devices, which are expected to be used in high-temperature environments, and therefore there is a need for a bonding material that can withstand high-temperature operation.

One of the bonding materials expected to be used for SiC power devices is sintered metal nanoparticle bonding materials. The metal nanoparticles can be sintered at low temperatures due to their extremely high surface activity brought by the size effect and do not melt until the bulk melting point after being sintered. This feature makes them promising high heat-resistant bonding materials, and the use of bonding materials using silver nanoparticles has already begun [2)]. However, the silver nanoparticles are costly and have low ion migration resistance, and therefore, the development of bonding materials using copper nanoparticles, which are less costly and more resistant to ion migration than silver materials, is expected [3)].

We have a technology to mass-produce copper nanoparticles having a particle size of about 100 nm and the surface covered with few-nanometer copper suboxide as shown in Fig. 1 using a dry process, utilizing oxygen combustion technology [4)], and have developed a transfer bonding sheet using copper nanoparticles. This paper reports on the development of the transfer bonding sheet using copper nanoparticles manufactured by us.

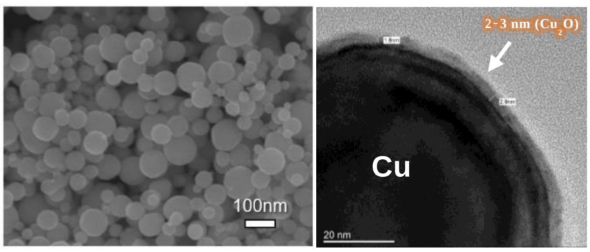

Figure 1 SEM and TEM image of Copper nanoparticles.

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2. Overview of transfer bonding sheet

Fig. 2 shows an overview of the developed transfer bonding sheet. The transfer bonding sheet is a sheet-shaped bonding material consisting of a dried copper nanopaste film formed on a release film base, and can be transferred to the parts to be bonded, such as SiC chips, in the same size as the parts by mounting them on this sheet and applying heat and pressure.

Compared to typical paste bonding materials, this transfer bonding sheet has higher productivity in creating a bonded body because printing and pre-drying are not required, and has excellent handling characteristics due to its sheet form and same-size transferability as the part to be bonded.

In the development of this transfer bonding sheet, there were three technical issues shown below from the viewpoints of user needs, stable bonding performance, and ease of handling by the user.

(1) Formation of a dry film without cracks
(2) Transferring the transfer bonding sheet onto the entire surface of a SiC chip
(3) Providing a bondability at low temperatures of 250°C or lower

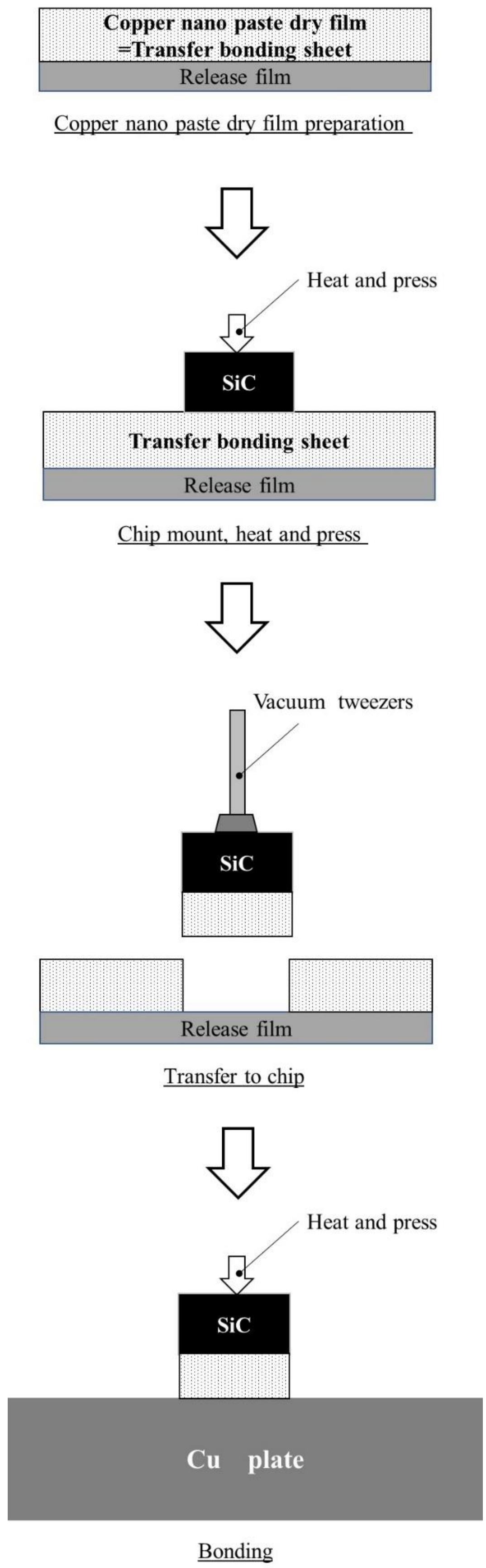


Figure 2 Development overview of transfer bonding sheet

3. Experimental methods

3.1 Studies for crack suppression and transfer to entire surface

We studied the composition of the copper nanopaste to produce an appropriate copper nanopaste dry film. Table 1 shows the composition of the copper nanopates prototyped and studied.

In order to realize the transfer to the entire surface of SiC chips, it was necessary to add an adhesive function to the copper nanopaste dry film. Therefore, we added an acrylic binder, which gives a viscosity to the paste and an adhesive function to the dry film, to the copper nanopaste, and mixed our copper nanoparticles with a reducing agent to reduce copper oxide on the surface and terpineol as a solvent to prepare the copper nanopaste. Since cracking of the dry film is generally correlated with the glass transition temperature of the acrylic binder, we prepared two kinds of acrylic binders with different glass transition temperatures and added each to the pastes made with the same composition to study the effect of glass transition temperature on the formation of the dry film of the copper nanopaste.

Table 1 Paste compsition

Paste	Composition	Binder glass transition temperature
A	Copper nanoparticles Acrylic binder A Reducing agent Terpineol	45℃
B	Copper nanoparticles Acrylic binder B Reducing agent Terpineol	5℃

We made transfer bonding sheets by applying the copper nanopastes shown in Table 1 on release films and using a hot-air oven to dry the solvent in the applied paste films. Next, we mounted a SiC chip (5 mm square, 350 μm in thickness) on the transfer bonding sheets and applied heat and pressure of 150°C and 10 MPa for 30 seconds to verify their transferability to the SiC chip metallized surface (top surface: Au).

3.2 Study for providing low-temperature bondability

In order to provide a bondability at low temperatures of 250°C or lower, we studied the concentration of binder in the copper nanopaste using the acrylic binder B. Table 2 shows the composition of the studied pastes. Two samples with different binder concentrations were compared.

Table 2 Paste compsition

Paste	Composition	Binder concentration
B	Copper nanoparticles Acrylic binder B Reducing agent Terpineol	X
C	Copper nanoparticles Acrylic binder B Reducing agent Terpineol	0.5X

We used the copper nanopastes shown in Table 2 to make transfer bonding sheets and transferred them to SiC chips as in 3.1, and conducted a bonding test. For the bonding test, we mounted a SiC chip to which the bonding sheet was transferred on a C1020 oxygen-free copper plate (20 mm square, 2 mm in thickness), bonded it in a nitrogen atmosphere at a bonding pressure of 10 MPa using a pressure bonding machine with the temperature increase pattern shown in Fig. 3 to make a bonded sample, and fractured it using a fructure tester to evaluate its shear strength. This test also investigated the variation of the shear strength by preparing five bonding-sheet-transferred SiC chip samples from a single A4-size transfer bonding sheet.

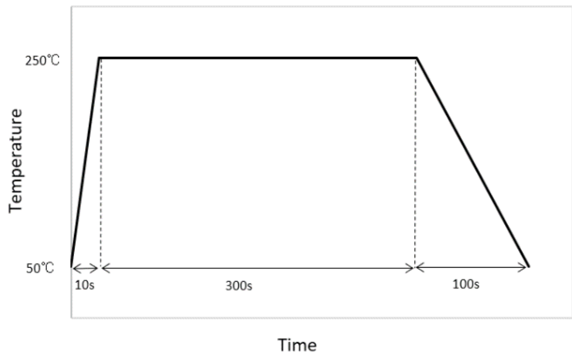


Figure 3 Heating pattern in bonding test

4. Experimental results and discussions

4.1 Studies for crack suppression and transfer to entire surface

Fig. 4 shows a microscopic image of a transfer bonding sheet using the copper nanopaste A. The transfer bonding sheet made with the copper nanopaste A had many cracks in the dried film. On the other hand, a transfer bonding sheet using the copper nanopaste B showed a good dry film without cracks, as shown in Fig. 5.

The cracks observed in the transfer bonding sheet using the copper nanopaste A are considered to be caused by insufficient drying shrinkage stress resistance. On the other hand, the transfer bonding sheet using the copper nanopaste B is considered to have mitigated drying shrinkage stress and suppressed cracking because the acrylic binder used, which has a glass transition temperature below room temperature (5°C), exhibits a plasticizing effect to provide its dried film with flexibility.

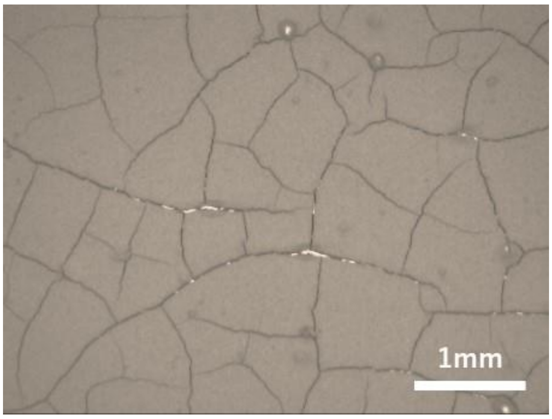


Figure 4 Microscope image of paste A dry film.

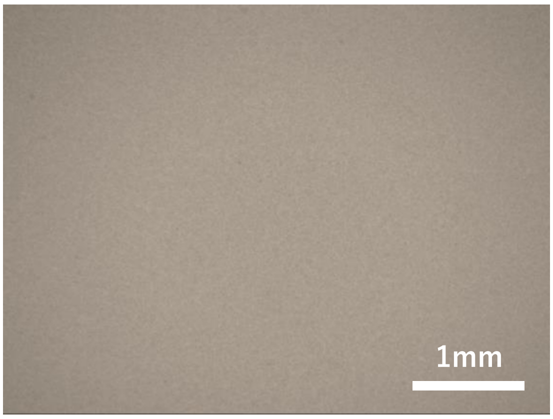


Figure 5 Microscope image of paste B dry film.

Fig. 6 shows a SiC chip metallized surface after transferring the transfer bonding sheet prepared with the copper nanopaste B, which produced a good dried film without cracks, to it, and the PET release film then. There is no residue on the release film, confirming that the transfer bonding sheet was able to be transferred to the SiC chip in the same size as it.

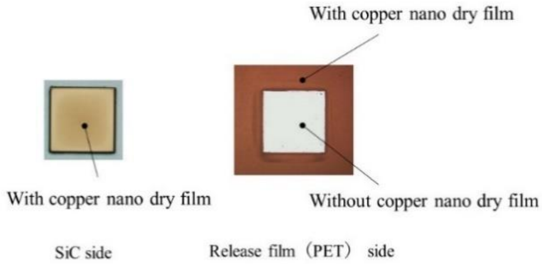


Fig. 6 Microscope image of SiC and release film after transfer

4.2 Study for providing low-temperature bondability

Table 3 shows the results of bonding test of transfer bonding sheets made with the copper nanopastes B and C.

Table 3 Shear strength measurement results of transfer bonding sheet

Paste	Sample	Bonding conditions	Shear strength [MPa]
B	1	250°C 10 MPa 5 min @N_2	>79.3
	2		>79.3
	3		41.9
	4		37.9
	5		58.6
C	1	250°C 10 MPa 5 min @N_2	>79.3
	2		>79.3
	3		>79.3
	4		>79.3
	5		>79.3

Two of the five transfer bonding sheet samples using the copper nanopaste B had a high shear strength (>79.3 MPa) and did not fracture under a 200 kg load, while the remaining three samples had a strength around 40 MPa, indicating variation in shear strength. At this time, all of the samples that fractured exhibited peeling at the interface between the SiC chip and the transfer bonding sheet. On the other hand, all of the transfer bonding sheet samples using the copper nanopaste C, which has a low binder concentration, consistently had a high shear strength (>79.3 MPa) and did not fracture under a load of 200 kg.

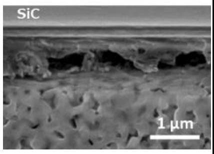
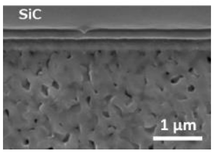
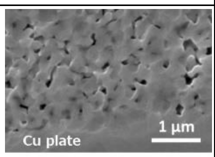
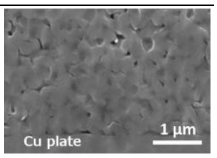
In order to study the variation of shear strength of transfer bonding sheets using the copper nanopaste B, we conducted cross-sectional observation of separately prepared bonded samples. Table 4 shows the observation results.

All of the samples showed that the copper nanoparticles in the transfer bonding sheet were sufficiently sintered and there were no voids at the interface between the copper plate and the transfer bonding sheet, indicating good bonding. On the other hand, some samples had voids at the interface between the SiC chip and the transfer bonding sheet (Pattern 1), while others showed good bonding with no voids (Pattern 2). These voids were assumed to be the cause of the fracture at the interface between the SiC chip and the transfer bonding sheet.

As shown in Fig. 7, there are two types of acrylic binders in the copper nanoparticle paste: adsorption binders adsorbed on the copper nanoparticle surface layer and free binders dispersed in the solvent without adsorbing on the copper nanoparticle surface layer. The free binders, which are lighter in specific gravity than copper, are assumed to move to the surface of the coating film during the drying of the paste solvent and tend to segregate on the top surface of the transfer bonding sheet. Furthermore, variations in binder distribution are expected to occur by uneven drying [5]. Therefore, it is likely that the SiC chip and the transfer bonding sheet were bonded with the binder segregated at the interface between them and then the decomposition of the binder during bonding created voids at the interface, which became the starting point of peeling.

We consider that the binder segregation at the top surface of the transfer bonding sheet and the variation in the distribution of the binder are the factors causing the variation in the shear strength.

Table 4 Cross sectional observation results of bonded sample using paste B.

Pattern	1	2
SiC - bonding sheet interface		
Cu plate- bonding sheet interface		

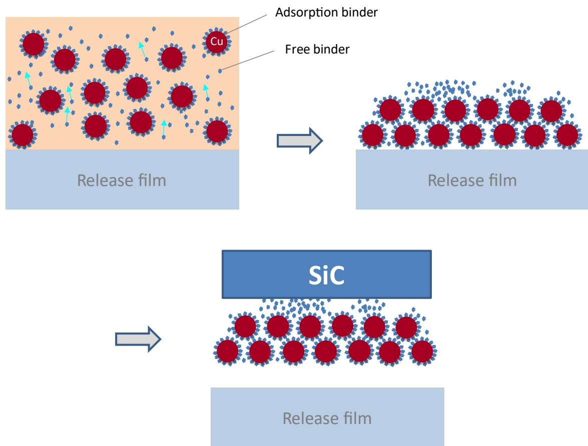


Figure 7 Surface segregation image of free binder

On the other hand, the copper nanopaste C had a lower binder concentration than the nanopaste B, and therefore was assumed to have fewer free binders. Accordingly, it is likely that the binder segregation on the top surface of the transfer bonding sheet was also reduced, resulting in the consistent achievement of high shear strength.

5. Conclusion

In this study, we developed a transfer bonding sheet that consists of a dried copper nanopaste film formed on a release film base and can be transferred to the parts to be bonded, such as SiC chips, in the same size as the parts by mounting them on this sheet and applying heat and pressure and that can be bonded at low temperatures of 250°C or lower. As a result of this study, we made the following findings.

- By using an acrylic binder having a glass transition temperature lower than room temperature, a good copper nanopaste dried film without cracks can be obtained, and a transfer bonding sheet that can be transferred to SiC chips in the same size as them by applying heat and pressure at 150°C and 10 MPa can be made.
- Transfer bonding sheets with reduced binder concentration consistently achieve high strength of 70 MPa or higher under low temperature and pressure bonding conditions at 250°C and 10 MPa.

In the future, we plan to further improve the performance of transfer bonding sheets by optimizing the glass transition temperature of the binder and the amount of the binder added.

Reference

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