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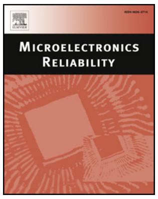

Novel silver die-attach technology on silver pre-sintered DBA substrates for high temperature applications

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ABSTRACT

Currently, Ag die-attach techniques, using nano-silver particles, are of high interest for manufacturing of wide-band-gap (WBG) power module due to their high-temperature operation capability. However, the high cost of silver and complicated processing requirements are the main driving force in the search for simpler and more cost-effective attached technologies. In this study, a new die-attach technique based on silver die-attach, without conventional Ag-paste, for high-temperature applications is developed. Glass containing Ag paste was pre-sintered on the DBA substrates, and later on, semiconductor dies were simply placed on this pre-sintered Ag layer and attached under heat and pressure. The samples were tested under shear and thermal cycling loadings (−45 °C/250 °C) to evaluate the quality and reliability. Destructive and non-destructive analysis methods, such as Scanning Acoustic Tomography and cross-section observation, were used to identify fracture modes. The samples demonstrated sufficient shear strength and high thermal reliability. Furthermore, the effects of Ag recrystallization, grain growth and rearrangement of the voids are considered to be the main fracture factor of conventional Ag die-attach joints based on sample's cross-sections.

1. Introduction

The substitution of conventional silicon semiconductor devices with wide bandgap (WBG) semiconductors enabled miniaturized power devices with higher power and current densities. This results in higher operation temperatures on the device and package. The WBG devices increased the temperature of power devices to more than 250 °C while the other packaging technologies are still limited to traditional temperature limits of silicon devices (175 °C) [1,2]. Die-attach materials are one essential component of power packages which require high melting point and superior mechanical, thermal, and electrical properties. The common high-lead solders used for these purposes are gradually phasing out due to their hazardous effects on human health. The application of Sn-based lead-free solders, as the most widespread substitute for high-lead solders, is limited to 200 °C (melting temperature of Sn). In recent years, Au-Sn solder [3], sintered Ag (submicron and nano-particles) [4–8] or Cu [9,10], and different transient liquid phase sintered (TLPS) joints [11–13] have been developed as the potential high temperature die-attach technologies [14]. Although the new die-attaches require several surface metallization of Au or Ag by spattering or plating technique on the substrates [15], their industrial application requires more reliability and cost-effective qualifications.

Conventionally, direct bonded copper (DBC) and active metal brazed (AMB) substrates are the widely used ceramics substrates in industry. However, the ceramics (i.e. AlN, Al_2O_3) used for DBC and AMB are prone to fracture during high-temperature thermal cycling at temperatures above 200 °C because of work hardening of Cu at the edge of the circuit. Direct bonded aluminum (DBA) substrates have been developed as replacements for DBC and AMB substrates; they have also been used in power modules for hybrid electric vehicles, which require very high reliability under severe thermal stresses. Additionally, AlN provides higher thermal conductivity and better electrical insulation compared to SiN at high temperature. However, it is common that the surface of DBA substrates have displacements and hillocks during thermal cycling. These results in fracture of the die-attach on DBA substrates at high temperature [16–18].

Sintering Ag layer on DBA substrates using Ag paste containing glass frit was reported in our previous study [19]. Bi_2O_3-ZnO-B_2O_3 glass frit (Tg = 355 °C, Ts = 416 °C) was mixed in the silver paste and sintered on DBA substrates. Adhesion tests, thermal cycling and power cycling were performed to evaluate the viability of this technology, and the Ag paste was optimized to ensure good adhesion. Fig. 1 shows the DBA substrate with the sintered Ag layer. This method is very cost effective because the pre-sintered Ag layer was formed by easy process and in

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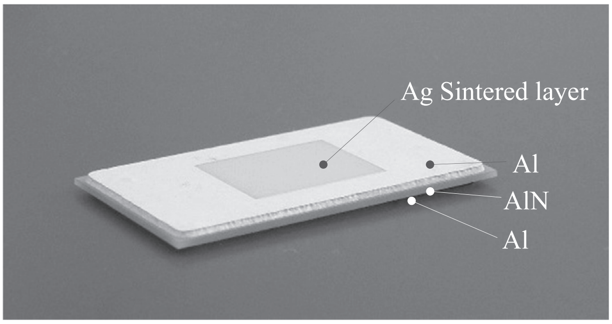

Fig. 1. DBA substrate with Ag pre-sintered layer.

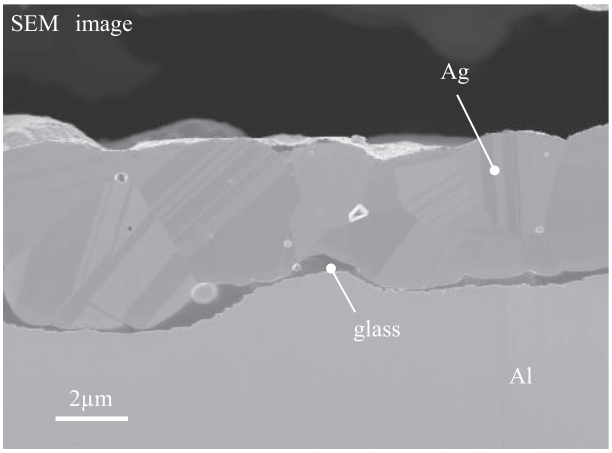

Fig. 2. Cross-section SEM image of Ag pre-sintered layer on DBA substrate.

selected area to reduce material costs. Fig. 2 shows a cross-section SEM image of the interface between the sintered Ag layer and the Al. The pre-sintered Ag layer is precisely bonded to Al and a thin glass layer exists between the sintered Ag layer and Al, indicating that the pre-sintered Ag layer was bonded by a reaction between the glass and Al.

In this study, assembling the silicon dies onto the Ag pre-sintered layer was investigated. Ultrasonic inspection and cross-sectional observations were conducted to evaluate the joint quality. Additionally, shear strength measurement and high-temperature thermal cycling test were performed to demonstrate the advantages and disadvantages of this new technology.

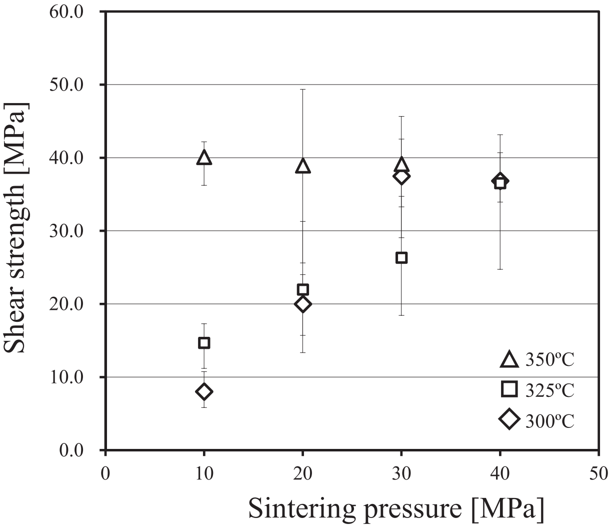

Fig. 4. Shear strength of die-attach at each bonding parameter.

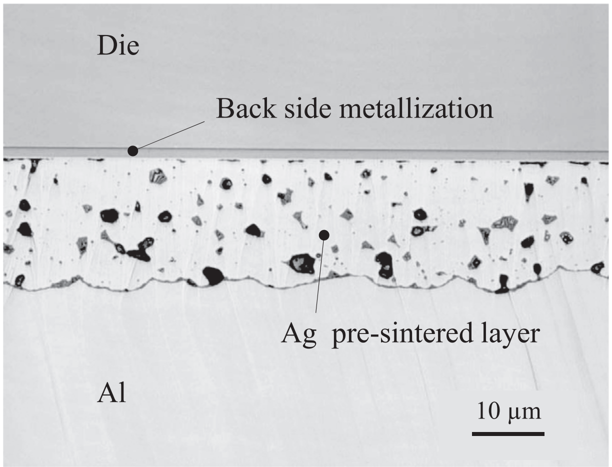

Fig. 5. Cross-section microscope image of the die-attach on Ag pre-sintered DBA substrate.

2. Test process and method

2.1. Sample preparation

Ag paste containing glass frit was screen-printed on the Al layer (thickness = 0.6 mm). Printed Ag paste was sintered at 550 °C for 10 min in air. Then, Si dummy dies were placed on the Ag sintered layer

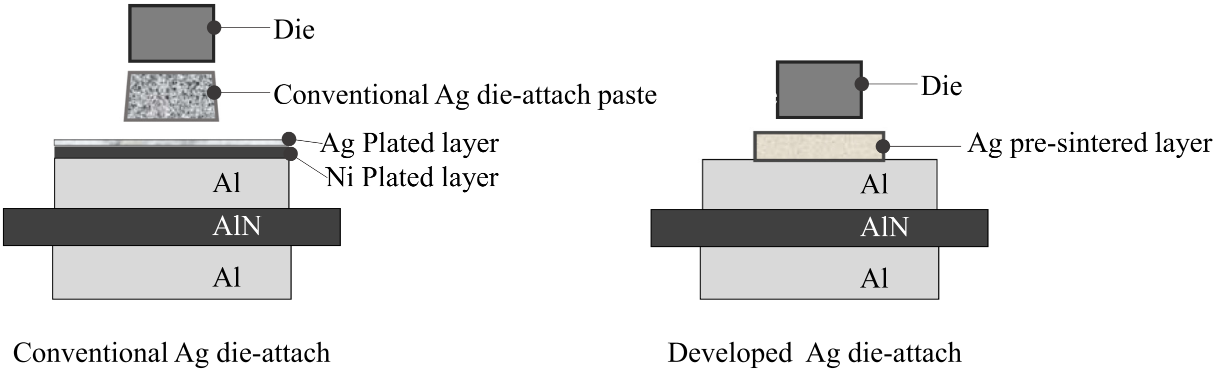

Fig. 3. Schematic view of specimens designed for the experiments. (left); Conventional Ag die-attach, (right); Developed Ag die-attach.