Development of silver-silicon composite paste sinter joining to achieve high reliability and low material cost for next-generation power semiconductors

SANKEN (The Institute of Scientific and Industrial Research), Flexible 3D Systemintegration Laboratory

Specially Appointed Associate Professor Chuantong Chen Researchmap https://researchmap.jp/chenchuantong?lang=en

Specially Appointed Professor Katsuaki Suganuma Researchmap https://researchmap.jp/ksuganuma?lang=en

Abstract

Owing to its cost-effectiveness and low coefficient of thermal expansion (CTE), micron Si is incorporated into sintered Ag matrix to develop an Ag@Si composite sintering strategy. The Si integration helps reduce cost and alleviate CTE-mismatch of Ag-sintered die attachments. An innovative Ag@Si composite sintering structure is achieved by low-temperature and pressure-less sintering process, where a possibly slight diffusion of native SiO_2 on the Si surface toward Ag is indicated by TEM observation, enabling the integration of Ag and Si into one continuous network. Owing to the robust well-bonded composite sintering, the Ag@Si joining strategy provides mechanical/microstructural reliability far beyond the pure Ag sinter joining, demonstrating significant prospects in high-temperature interconnection applications. During the harsh thermal cycling (— 50–250 ˚C), the mitigating effect of the Si addition on CTE mismatch is manifested through the substantial suppression of microstructure deterioration in Ag@Si joint that occurs in pure-Ag-sintered joint, while the shear strength retention rate is doubled. The incorporation of Si helps modify the CTE, elastic properties, and stress distribution of Ag@Si-sintered material, synergistically contributing to the satisfactory joining reliability.

Background & Results

The use of power converters has considerably increased over the past few decades, with a general trend of progress in the use of renewable energy. Third-generation wide band-gap (WBG) semiconductors, such as SiC, GaN, and Ga_2O_3, have revolutionized the use of power converters because of their high temperature and high power-density capabilities. The Ag-sintering method outperforms various die-attached methods in terms of its high melting point (961 ˚C) and the superior electrical conductivity (63 × 10^6S/m) and thermal (429 W/mK) conductivities of Ag among various metals. The power module using the Ag sinter joining encounters serious CTE mismatch, wherein Ag (18.4 ppm/K) possesses a much higher CTE value than its adjacent SiC chip (4.0 ppm/K) and Si_3N_4 ceramic substrate (3.2 ppm/K), causing the overall device to fail. In this study, Daicel Corporation proposed a silver-silicon alloy sintering material aimed at the social implementation of next-generation power devices, which require higher reliability. Through this joint research, the alloy sintering material was applied to the junctions between SiC power semiconductors and DBC substrates (ceramic substrates). It was found that this application reduces the thermal expansion of the circuit board, making it less likely to experience cracking or structural failure, even in harsh operating environments, thereby achieving excellent bonding reliability.

With an increase in the Si additive amount, a noticeable inhibitory effect was exhibited on the deterioration of Ag sintered joint during the thermal cycling. That is, the average crack width was obviously narrowed, and the substrate cracking and interface delamination were completely suppressed. These microstructural improvements ultimately endow the Ag@Si20% joint with much higher mechanical reliability, exhibiting a shear-strength-retention rate twice that of a pure Ag joint (Figure 1).

In particular, the FEM results showed that Si addition actively adjusted the thermal stress to be uniform or reduced within the module (Figure 2). These factors together contribute to the enhancement of material resistance to thermal cycling stress.

Significance of the research and Future perspective

The well-bonded Ag@Si sinter matrix allows for inherently good material strength, resulting in high mechanical/microstructural reliability of the die-attached structure under harsh thermal cycles. This is essential for applications, such as electronic components and automotive parts, wherein a consistent performance is required. This novel Ag@Si joined material, with its good cost-effectiveness and superior reliability to that of pure sintered Ag joints, holds significant promise for large-scale, high-power module joining applications.

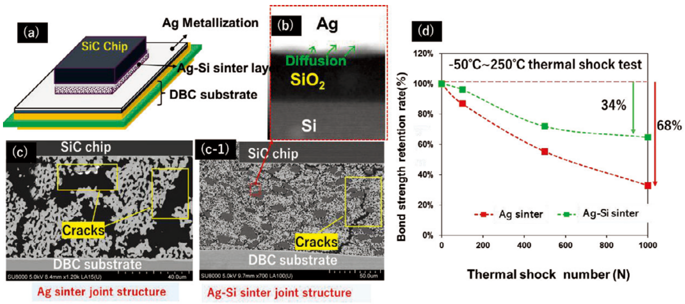

Figure1. (a) The die-attached structure consisting of SiC chip, Ag sinter-based paste and Ag metallized DBC substrate. (b) STEM observation of the interface between Ag and Si, (c) Microstructure in the cross-sections of Ag100% joint structure after thermal cycling test, (c-1) Microstructure in the cross-sections of Ag@Si20% joint structure after thermal cycling test, (d) Shear strength retention rate of Ag sinter joint and Ag@Si20% sinter joint structure during thermal cycling.

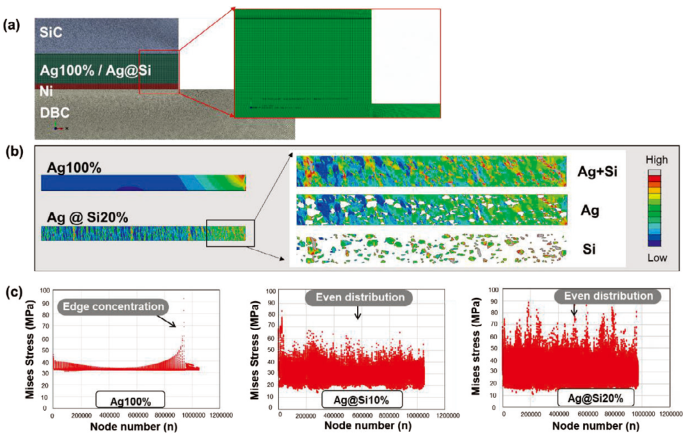

Figure 2. (a) The Finite-element model corresponding to the die-attached structure consisting of SiC chip, Ag sinter-based paste and EN-ELNPA metallized DBC substrate. (b) In the case of Ag@Si treated as a heterogeneous material, Mises stress distribution in Ag100% and Ag@Si20% joined layers after thermal cycling test. (c) The corresponding stress intensity across nodes within the Ag100%, Ag@Si10% and Ag@Si20% joint structures.

Patent WO/2024/219382, PCT/JP2024/031626

Treatise Liu, Yang; Chen, Chuantong et al. Development of Ag@Si composite sinter joining with ultra-high resistance to thermal shock test for SiC power device: Experiment validation and numerical simulation. Composites Part B: Engineering. 2024, 281, 111519. doi: 10.1016/j.compositesb.2024.111519

URL

Keyword power device, Ag sinter joining, EV/HEV car, aerospace, 5G/6G communication