



Silver nanoporous sheet for solid-state die attach in power device packaging

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A novel die attach process that utilizes an Ag nanoporous sheet has been investigated for power device packaging. This Ag nanoporous sheet, which has a ligament size of about 110 nm, was fabricated through the dealloying of Al–Ag precursor in hydrochloric acid. When used as a die attach layer, no large voids or gaps were observed in the interfacial area, and a shear strength equivalent to conventional Pb–5Sn solder could be achieved without the need for any organic substances.

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In response to strict environmental regulation, such as the Restriction of Hazardous Substances (RoHS) of the European Union, Sn-based alloys have now replaced traditional Pb–Sn eutectic solder in electronic devices; however, the substitution materials or process have not yet been established in the case of high-temperature Pb–5Sn solder [1]. Given the demand for high-temperature solder, numerous investigations have aimed at finding a suitable Pb-free high-temperature solder alloys, which have included Au-, Bi- and Zn-based alloys. Despite this, there are still inherent problems related to either their high cost (Au-based), low thermal conductivity (Bi-based) or poor corrosion resistance (Zn-based) [1–3].

One approach is the sintering of micro- and nanoparticles of silver, which has already shown great promise as a joining process by virtue of the high melting temperature, superior electrical and thermal conductivity and low-temperature bondability [2,4,5]. In the fabrication of the requisite nanoparticle paste, various organic substances, including solvents, capping molecules and binder, have been adopted to adjust the final properties of the paste [4]. For example, polyvinylpyrrolidone has been used as a capping molecule to provide control over the size of the nanoparticles and to protect them against oxidation [6–8]. After the joining process, however, residual organics after the joining process

or coffee-ring effect can induce unexpectedly large voids or gaps in the joint area [9,10].

To address these problems, this article focuses instead on the nanoporous metals that are fabricated through the dealloying method [11], and proposes that solid-state nanoporous bonding (NPB) can be achieved using an Ag nanoporous sheet without the need for any solvent, organic substance or flux. The use of Au nanoporous bumps for low-temperature flip-chip bonding has previously been reported by Oppermann and Dietrich [12]; however, assessments of the joint strength and interfacial bonding force have been not undertaken. Furthermore, it is rational to apply Au to a fine-pitch interconnection [13] rather than a large area die attach, due to its extremely high cost. With this in mind, we attempted to apply the Ag nanoporous sheet to create a large area joint for power device packaging, and characterized the microstructure and shear strength of the resulting joint.

The Ag nanoporous sheet (thickness = 90–100 μm, ligament size = 110 nm) was fabricated by dealloying a melt-spun Al–Ag precursor alloy in a 2 M HCl solution for 3 h at 348 K, as shown in Figure 1a and b. The phase change from the α-Al(Ag) and γ-Ag₂Al of the precursor to a single Ag phase as a result of dealloying is confirmed in Figure 1c. A more detailed description of this fabrication method and the microstructural change of the Al–Ag precursor has been given in previous research [14]. An electroless nickel/immersion gold (ENIG) finished Cu disk, shown in Figure 1d, was used to evaluate the strength of the NPB joint. The thicknesses of Ni(P) and Au were about 2 μm and 80 nm, respectively. To ascertain this, the ENIG-finished Cu disk

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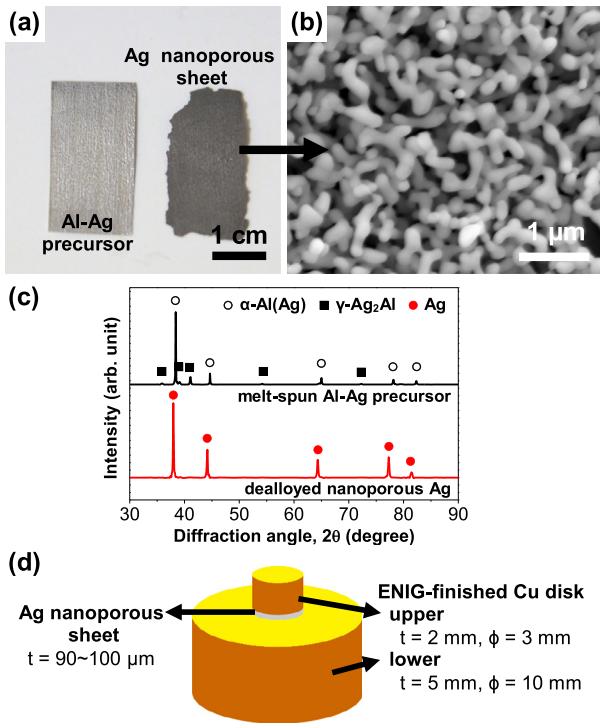


Figure 1. (a) Optical microscopy image of melt-spun Al–Ag precursor and dealloyed Ag nanoporous sheet, (b) secondary electron (SE) image of Ag nanoporous structure, (c) phase constitution of Al–Ag precursor and the dealloyed sample, and (d) schematic diagram of the ENIG-finished Cu disk for the evaluation of shear strength of nanoporous bonding.

was first immersed in acetone and degreased using an ultrasonic cleaner for 5 min. Next, the Ag nanoporous sheet was applied to the ENIG-finished Cu disk, then bonded at 573 K for 30 min under an applied pressure of 20 MPa using a thermo-compression bonding system under both a nitrogen atmosphere and air.

Figure 2 shows cross-sectional scanning electron microscopy (SEM) and transmission electron microscopy (TEM) images of the NPB joint. These images reveal that the Ag layer has a dense/porous sandwich structure, wherein the dense layer provides interfacial bonding between Ag and ENIG, and the porous layer can play role in relaxing stress due to it having a lower elastic modulus than the bulk metal

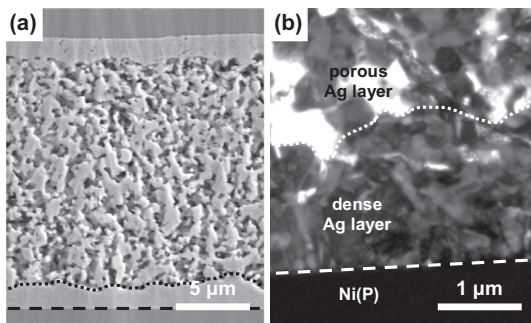


Figure 2. (a) Back-scattered electron image and (b) TEM bright field (BF) image of nanoporous bonding joint. The dotted lines indicate the borderline of the porous Ag/dense Ag layer and the interface of Ag/ENIG.

[12,15]. The origin of this unique structure lies in the partial deformation of the Ag nanoporous sheet by compression. Specifically, the initial nanoporous structure collapses near the surface, thereby creating greater contact. This increased direct contact of Ag can then lead to densification of the collapsed nanoporous structure during the joining process. On the other hand, the internal region of the Ag nanoporous structure is not fully deformed, and therefore does not have direct contact. Thus, it was not a sintering reaction, but rather a thermal coarsening by surface diffusion in order to reduce the surface area of the nanoporous structure [16]. After the joining process, the dense Ag layer exhibits a sub-micron grain structure and good contact with the ENIG surface. Furthermore, no voids or gaps are evident at the interface, which would otherwise have an adverse effect on the reliability of the joint. The pore volume fraction of the porous Ag layer, as evaluated from the SEM images, is about $22 \pm 6\%$. This means that, although the pore volume fraction was reduced, the sizes of individual pores and ligaments were increased compared with the initial Ag nanoporous structure.

The shear strength of the NPB joint was measured by a die shear tester at a strain rate of 1 mm min^{-1} . As shown in Figure 3a, the shear strength of the NPB joint is consistently about 22 MPa, regardless of the atmosphere used during the joining process, and is similar in value to conventional Pb–5Sn solder [17,18]. The observation of fracture morphology and elemental mapping of the fracture surface that was conducted by SEM and electron probe microanalysis is shown in Figure 3b–d. From this, we can see that fracture of the NPB occurred mainly in the Ag layer

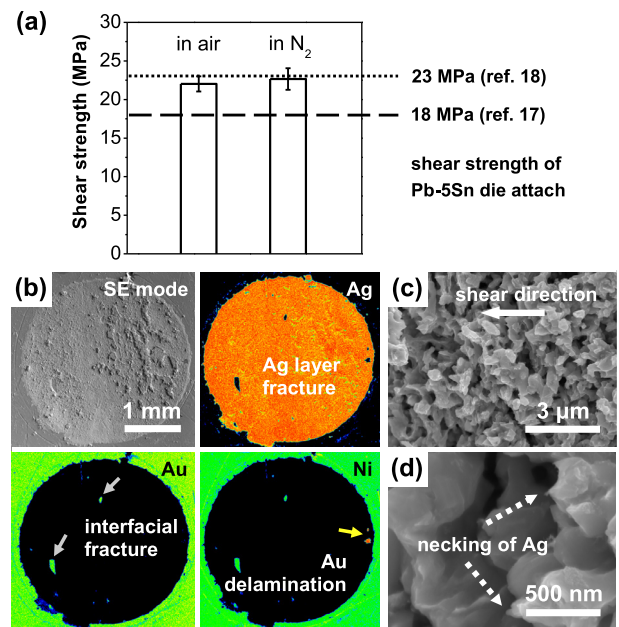


Figure 3. (a) Shear strength of the nanoporous bonding joint in air and under an N₂ atmosphere. The dashed lines indicate the joint strength of the Pb–5Sn solder die attach evaluated according to the Japanese Industrial Standards (JIS Z 3198-5) for comparison [17,18]. (b) SE image and elemental mapping results (Ag, Au and Ni) of the fracture surface after the shear test (the high Au signal regions indicated by grey arrows present the interfacial fracture and the high Ni signal region indicated by a yellow arrow presents the Au delamination). (c, d) SE images of the fracture morphology of the Ag layer.

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