Scripta Materialia 150 (2018) 7–12

Contents lists available at ScienceDirect

Scripta Materialia

journal homepage: www.elsevier.com/locate/scriptamat

Regular article

Characterization of novel high-speed die attachment method at 225 °C using submicrometer Ag-coated Cu particles

Chang Hyun Lee, Eun Byeol Choi, Jong-Hyun Lee *

Department of Materials Science and Engineering, Seoul National University of Science and Technology, 232 Gongneung-ro, Nowon-gu, Seoul 01811, Republic of Korea

ARTICLE INFO

Article history:
Received 2 February 2018
Received in revised form 19 February 2018
Accepted 19 February 2018
Available online 20 March 2018

Keywords:
Sintering
Surface modification
Nanostructured materials
Electronic packaging
Bonding by silver dewetting

ABSTRACT

A novel die-attaching technology, using the in-situ dewetting of Ag shells in submicrometer Ag-coated Cu (Cu@Ag) particles during heating in air, was suggested for power device packaging. The particle size-dependent dewetting of Ag induced the formation of tiny nodules and rapid sinter bonding via fast Ag transfer under external pressure. A die attached by thermal compression for 5 min at 225 °C using 200- or 350-nm Cu@Ag particles showed shear strengths approaching or surpassing that (18.0 MPa) of a die attached using Pb-5Sb.

As hybrid and electronic vehicles gain prevalence, packaging technologies for high-heat power devices, such as insulated-gate bipolar transistors using Pb-free and low-cost bonding materials, have attracted increasing industrial interest [1–7]. In such applications, Si is increasingly replaced with wide-bandgap semiconductor materials, such as SiC and GaN, which operate with higher power densities and efficiencies at higher temperatures [8–11]. Hence, there have been many studies using wide-bandgap semiconductors to increase chip junction temperatures beyond 200 °C with bondlines indicating higher remelting points and thermal conductivities [1,5,6,12–20].

Regarding die-attachment processes and materials, soldering inevitably forms large voids that may cause severe degradation in thermal conductivity and reliability. Studies on the suitability of high-temperature Pb-free solder alloys retain problems inherent to soldering, such as high processing temperatures, low thermal conductivities, high cost, insufficient wettability, and poor corrosion resistance [21–24].

Transient liquid-phase (TLP) bonding and sinter bonding using Ag particles are the best available alternatives to soldering [25–28]. Despite the low material cost and the uniqueness of inducing a remelting point higher than the bonding temperature, TLP bonding possesses serious drawbacks including the brittle nature of the intermetallic compound (IMC) bondline and long bonding times at relatively high temperatures to form full IMC bondlines [25–28]. Therefore, more recent studies on alternative die-attachment technologies have focused on sinter bonding under external pressure >10 MPa, using pastes including Ag particles, which present high remelting point and thermal conductivity [12,15,16,19]. The development of processes with short sintering times, low sintering temperatures, and pressureless attachment is also important [12–14,16,20]. For example, since the Ag particle size significantly influences the sintering speed, much smaller Ag particles are used to increase the sintering speed [12,16]. Nevertheless, industrial sinter bonding using Ag particles is not common because of the inherently high material cost (which increases with decreasing size of Ag particles) and Ag migration.

Cu, which exhibits high electrical and thermal conductivities approaching those of Ag, is considered the best low-cost alternative material. However, the easy surface oxidation of Cu severely impairs its application as a bonding material [29–31]. These disadvantages can be overcome by converting or suppressing surface oxidation. For example, a low-pressure die attachment process using in-situ surface reduction of Cu particles during heating at 300 °C in formic acid vapor has been reported recently [5].

Here, a novel high-speed die attachment technology at 225 °C has been suggested, using the Cu-based particulate material Ag-coated Cu (Cu@Ag). The main parameters considered were the Cu@Ag core-shell structured particle sizes and bonding times.

Cu particles of three different sizes (200, 350, and 900 nm) were synthesized in house using a retained wet reduction method. The Cu particles were coated with 15 wt% Ag shells by electroless plating to yield sufficient coating coverage, though the average size of the core Cu particles was several hundreds of nanometers [32]; the shell thickness was varied from several to several tens of nanometers depending on the average sizes of the core particles.

The initial sizes and morphologies of the prepared Cu@Ag particles and morphological changes after heating in air were examined using

* Corresponding author.
E-mail address: pljh@snut.ac.kr (J.-H. Lee).

https://doi.org/10.1016/j.scriptamat.2018.02.029
1359-6462/

field-emission scanning electron microscopy (FE-SEM, JSM-6700F, JEOL Ltd.). Phase changes after heating in air were analyzed using X-ray diffraction studies (XRD, JP/MAX-3C, Rigaku Denki). To evaluate oxidation behavior, the weight changes of the Cu@Ag particles upon heating in air were measured by thermogravimetric analysis (Q600, TA Instruments, installed in KBSI PH407 Pusan) in both dynamic and isothermal heating modes.

Pastes containing the fabricated Cu@Ag particles were prepared by mixing with α-terpineol (98.5%, Samchun Chemical Co., Ltd.) as a vehicle with a particle-to-vehicle weight ratio of 85:15. Die attachment tests were performed using a dummy Si die of area 3×3 mm^2 and a Si substrate of area 10×10 mm^2 finished with Ag. The Ag finishes were formed by additional sputtering onto a Cu/Ti-metallized Si wafer. The prepared pastes were printed onto the Ag-finished substrates through a stencil mask with a slit volume of $5 \times 5 \times 0.1$ mm^3 using a squeegee. After printing, the die was aligned with the printed pattern and the sandwich-structured sample was heated to 225 °C at 50 °C/s. The die attachment was performed in air by pressing at 10 MPa throughout the bonding time. In some cases, preheating at 150 °C was applied for 5 min to evaporate the vehicle from the paste and the die was aligned after the preheating. The microstructures of the bondlines after pressing and shear fracture were observed using FE-SEM. The bonding strength of the bondline was defined as the maximum stress value measured during shear testing at 200 μm/s. To indirectly evaluate the electrical properties of the bondline containing only Cu@Ag particles, the sheet resistance of a Cu@Ag pellet was measured for different heating times. For pelletization, 0.5 g of Cu@Ag particles was poured into a mold cavity over a 15-mm-diameter bottom punch and pressed at 4900 N using the identical-diameter upper punch for 1 min. The sheet resistance was measured using a four-point probe linked to a source meter (2400, Keithley Instruments Inc.).

Fig. 1a–f shows the initial images of the Cu@Ag particles and the images obtained after heating at specific temperatures. The 900-nm Cu@Ag particles do not show any significant change in the surface until after heating at 200 °C; however, numerous tiny nodules are formed on the surface and the Cu@Ag particles are severely agglomerated upon heating at 250 °C [33]. This agglomeration is attributed to sintering among the Ag nodules formed via in-situ dewetting caused by the interfacial instability induced by the lattice difference of 11.7% between materials [34–36]. The 350-nm Cu@Ag particles (Fig. 1a–c) show many Ag nodules immediately after heating at 200 °C; particle agglomeration occurs at 250 °C. Meanwhile, Ag nodule formation and interparticle agglomeration occur throughout the 200-nm Cu@Ag particles upon heating at 200 °C (Fig. 1e). The agglomeration intensifies as the temperature is increased to 250 °C (Fig. 1f). These results imply that the in-situ Ag dewetting and interparticle agglomeration depend on the particle size after heating at identical temperatures.

In the XRD patterns (Fig. S1) obtained for the different Cu@Ag particles before and after heating at specific temperatures, the 900-nm particles show peaks attributed to only Cu and Ag even after heating at 200 and 225 °C, and a Cu_2O phase is formed by Cu oxidation after heating at 250 °C. Based on the microstructure reported previously [33], oxidation was expected immediately after Ag dewetting. Meanwhile, the 350-nm particles show a small Cu_2O (111) peak after heating at 225 °C, implying that dewetting and oxidation occur more quickly. With the 200-nm particles, a small Cu_2O peak appears after heating at

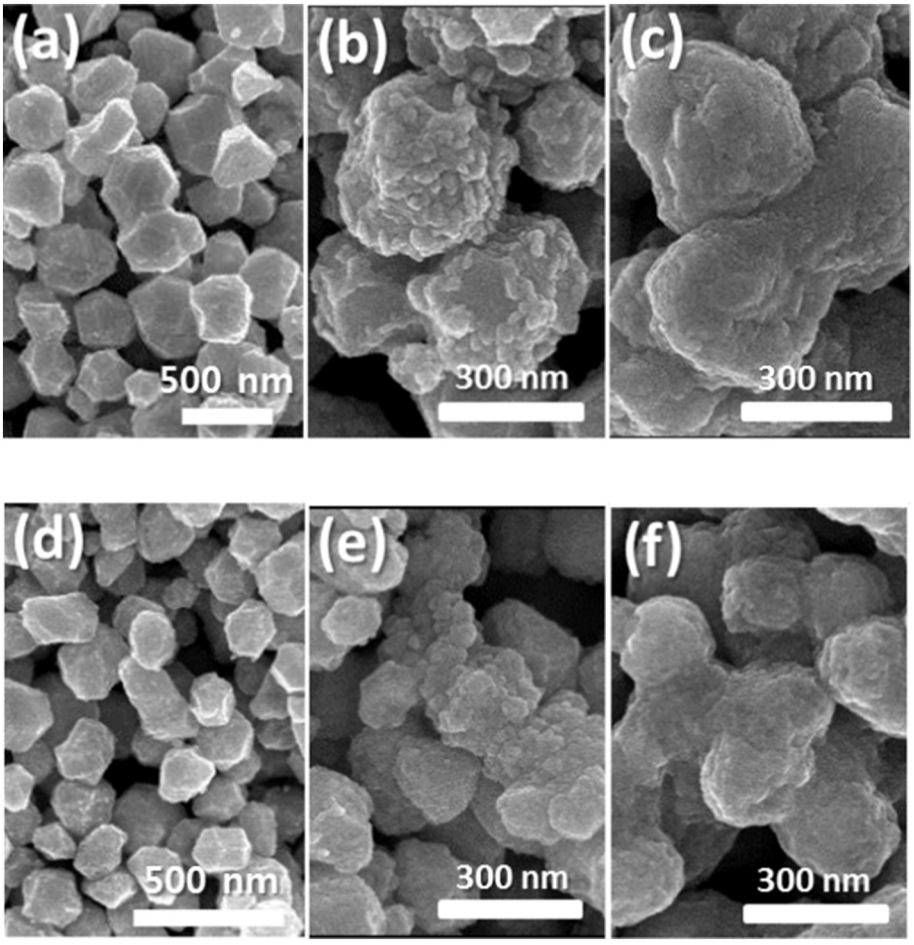

Fig. 1. (a, d) SEM images of initial Cu@Ag particles, and those of particles after heating to (b, e) 200 °C and (c, f) 250 °C. Different average particle sizes of (a, b, c) 350 nm and (d, e, f) 200 nm are shown.