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Brazing copper and alumina metallized with Ti-containing Sn0.3Ag0.7Cu metal powder

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ABSTRACT

A Sn-based metallization layer was successfully prepared on the surface of alumina at 900 °C by using Ti-containing Sn0.3Ag0.7Cu (SAC, wt.%) metal powder. Reliable alumina/copper joints were obtained by brazing pre-metallized alumina and copper using SAC filler at 580–660 °C for 5 min. The typical interfacial microstructure of brazed joint was copper/Cu_3Sn layer/Cu_6Sn_5 layer/β-Sn layer containing Ti_6Sn_5 phase and Al_2O_3 particles/alumina. As brazing temperature increased, the Cu–Sn intermetallic layers thickened rapidly and the amount of β-Sn phase reduced. When brazing temperature exceeded 640 °C, Kirkendall voids and microcracks formed at copper/Cu_3Sn interface. The joints brazed at 580–620 °C possessed high shear strength and the highest average shear strength of 32 MPa was achieved when brazed at 620 °C. Fracture analyses indicated that the joints mainly fractured inside of the Cu_6Sn_5 layer and β-Sn layer. The joints brazed above 620 °C demonstrated low shear strength due to the formation of Kirkendall voids which caused the joints fractured along the Cu/Cu_3Sn interface.

1. Introduction

Alumina–copper composite components have a significant potential for many structural, electrical and electronical applications, especially for high-performance microelectronic packaging. Hence, alumina–copper joining is becoming an important technique to widen their applications [1–6]. Brazing, as the most feasible and economical method, has received special attention in joining of alumina and copper. In the conventional brazing of alumina, the nickel-plated alumina is brazed after it has been metallized by the molybdenum–manganese method that metallizes the ceramic surfaces by coating it with a mixture of molybdenum and manganese powders, followed by a sintering treatment at high temperature more than 1300 °C [7]. Furthermore, the active brazing method has been also applied in brazing alumina [8–10]. The addition of active elements (Ti, Zr, etc.) in filler metals can effectively improve their wettability on the surface of alumina by reducing the liquid/solid surface free energy and formation of the subsequent chemical reactions [11–14]. However, both the molybdenum–manganese method and the active brazing method to achieve the brazing of alumina and metals require a high-temperature heating process. It inevitably deteriorates the microstructures and performances of base materials, especially reduces the strength and toughness of metal parts. Therefore, brazing of alumina and copper at relative low temperature is in demand in engineering field, especially in electrical and electronic engineering field.

In the present study, active Ti was introduced into commercial Sn0.3Ag0.7Cu (SAC) metal powder for metalizing alumina. A desirable metallization layer was prepared on the surface of alumina at 900 °C that was much lower than the operation temperature of the molybdenum–manganese method. Then the reliable brazing of pre-metallized alumina to copper was achieved using SAC filler at medium temperatures (580–660 °C) for 5 min. The microstructures both of metallization layer/alumina interface and alumina/copper brazed joint were characterized, and the brazing mechanism and microstructure evolution were analyzed. Furthermore, the effect of brazing temperature on interfacial microstructure, joint properties and fracture mode of alumina/copper joints were investigated in detail.

2. Experimental

The Sn0.3Ag0.7Cu (SAC) metal powder was supplied by Zhejiang Metallurgical Research Institute, Hangzhou, China, with an average diameter of 37 μm. A new metal powder for metalizing alumina was prepared by adding 6 wt.% active Ti particles (~40 μm) into SAC powder, followed by ball-milling for 10 h using a QM-SB planetary ball mill. The morphologies of original SAC powder and as-prepared SAC-6%Ti powder are illustrated in Fig. 1(a) and (b) respectively. It can be seen clearly that the SAC powder contained a large number of metal balls with smooth surfaces. However, the spherical SAC powder became irregular after ball-milling. X-ray diffraction analyses were carried out on SAC powder and SAC-6%Ti powder to verify metallurgical reactions

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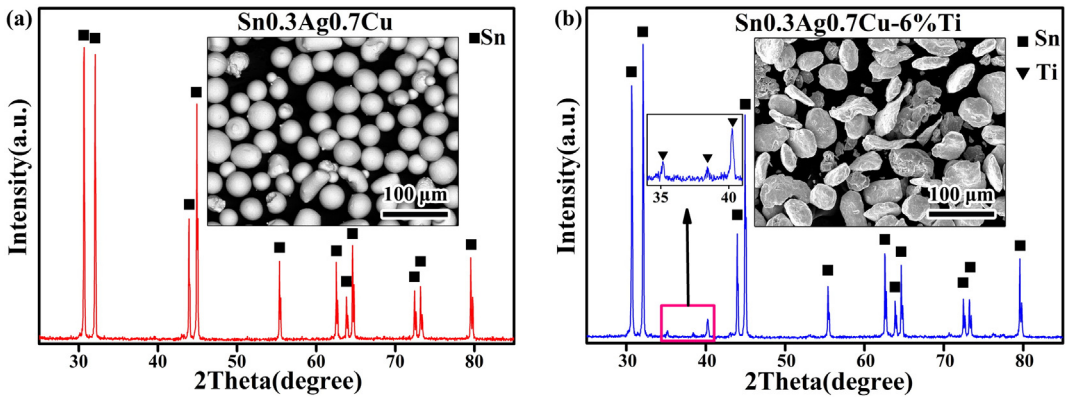

Fig. 1. XRD patterns and secondary electron SE images of metal powders: (a) Sn0.3Ag0.7Cu powder and (b) Sn0.3Ag0.7Cu-6%Ti powder.

during the ball-milling process. By comparing the two XRD patterns shown in Fig. 1, it is concluded that both SAC powder and SAC-6%Ti powder mainly consisted of Sn. There was no new peaks appeared in the XRD pattern of SAC-6%Ti powder besides some tiny peaks of Ti, indicating that no metallurgical reaction occurred during ball-milling process. It is noted that both Ag and Cu could hardly be detected by XRD due to their low contents in SAC powder. Moreover, both SAC powder and SAC-6%Ti powder melted in the temperature range 219–231 °C, which was determined by using a differential thermal analyzer.

The SAC-6%Ti powder was spread on the surface of alumina substrate by the method shown in Fig. 2(a) that could ensure the thickness of covered powder layer was about 50 μm. Subsequently, the alumina covered by SAC-6%Ti powder was metalized at 900 °C for 30 min in a furnace under the vacuum of 1.33×10^{-3} Pa. The high operating temperature was essential for activation of titanium metallization process. The metallized alumina was cut into blocks with a dimension of 5 mm × 5 mm × 5 mm, and the metallization layer was ground on SiC grit paper until its thickness was down to about 20 μm. The metallized alumina block, copper sheet (20 mm × 10 mm × 3 mm) and the SAC filler (100 μm in thickness) were assembled into a sandwich type as shown in Fig. 2(b), and then placed into a resistance furnace carefully. At the beginning of brazing process, the furnace was heated to brazing temperatures (580–660 °C) at a rate of 10 °C/min. Subsequently, the brazing assemblies were held for 5 min at brazing temperature, then cooled down to room temperature at a rate of 10 °C/min. During brazing process, the vacuum was kept at $1.3–2.0 \times 10^{-3}$ Pa and a pressure of 15 KPa was applied on each brazing assembly to ensure proper contact.

The microstructure both of metallization layer and alumina/copper brazed joints were characterized employing scanning electron microscope (SEM, Quanta 200FEG). Componential analysis of reaction phases in metallization layer and brazed joints was performed using EDS (EDS, Genesis Apollo X/XL) with the operation voltage of 20 KV and minimum spot size of 1 μm. The shear tests were conducted at a constant speed of 1 mm/min by using a universal testing machine (Instron 1186) at room temperature, and a schematic of the shear test can be seen in Ref. [15]. For each set of experimental data, at least five samples were used to average the joints strength. After shear test, the fractures of brazed joints were also inspected by SEM and XRD to identify the fracture locations.

3. Results and discussion

3.1. Microstructure of metallization layer on the surface of alumina

A desirable metallization layer was successfully obtained on the surface of alumina after heating at 900 °C for 30 min. It is clear seen from the morphology of metallization layer illustrated in Fig. 3(a) that alumina substrate was covered evenly by a Sn-based metallization layer, indicating a good wettability of molten SAC-6%Ti on the surface of alumina. The XRD analysis of the surface of metallization layer shown in Fig. 3(a) suggested that two phases including β-Sn and Ti_6Sn_5 were detected. Fig. 3(b) shows the microstructure of metallization layer/alumina interface in backscatter electron (BSE) mode. It is found that a good bonding interface without any voids and defects formed between alumina substrate and metallization layer. Moreover, the metallization layer mainly contained three different phases: white matrix, gray irregularly shaped phases and several black particles. The major elements of each phase detected by EDS are listed in Table 1. According to the EDS analysis results, the three phases in metallization layer shown in Fig. 3(b) were: white β-Sn matrix (marked as A), gray Ti_6Sn_5 intermetallic (IMC) phase (marked as B) and black Al_2O_3 phase (marked as C).

Fig. 3(c)–(f) display the distributions of main elements including Sn, Ti, Al and O in metallization layer/alumina interface. It is seen in Fig. 3(c) that the element Sn dominated in the metallization layer. Fig. 3(d) shows that element Ti was mainly distributed in Ti_6Sn_5 IMC phases. Moreover, elements Al and O were mainly existed in alumina substrate and in black Al_2O_3 particles distributed in Sn matrix, as shown in Fig. 3(e) and (f). It is worth to note that a slight enrichment of element Ti along the metallization layer/alumina interface (Fig. 3(d)), which can be inferred that active Ti in molten SAC-6%Ti diffused toward alumina substrate and enriched on its surface.

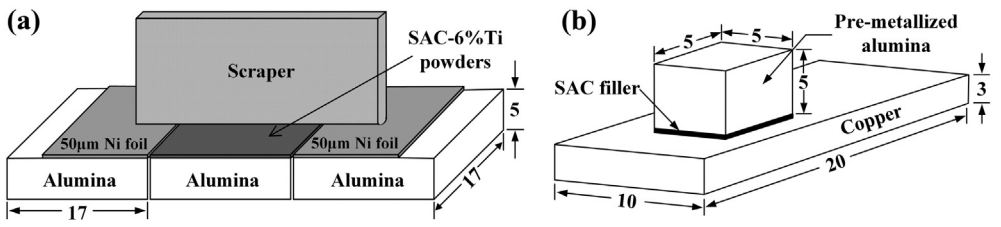

Fig. 2. Schematics of spreading metal powder on alumina surface and brazing joint assembly: (a) spreading metal powder on alumina surface and (b) pre-metallized alumina/copper joint assembly (mm).