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The effect of high magnetic field on the growth behavior of Sn–3Ag–0.5Cu/Cu IMC layer

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Abstract

In this paper, the effects of high magnetic field intensity and its direction on the growth behavior of an Sn–3Ag–0.5Cu/Cu intermetallic compound (IMC) layer have been investigated. It is found that both the kinetics and crystal orientation of the IMC layer changed under high magnetic field.

Keywords: High magnetic field; Intermetallic compounds; Solder; Aging; Kinetics

1. Introduction

Research on homogeneous high magnetic fields in materials science is in its early stages [1–3]. A lot of pioneering theoretical and experimental studies have been done and many important experimental phenomena have been found though [2].

High magnetic field can apply heavy intensity magnetization energy to mass on an atomic or molecular scale, and change its thermodynamic state [3]. When the magnetic property of a new phase is significantly different from the parent phase, high magnetic field can markedly change the materials thermodynamic conditions of the phase transformation process or chemical reaction process [3,4].

When two different materials are soldered with each other, diffusion fluxes occur at the interface because of the chemical potential difference. In some cases, an intermetallic compound (IMC) forms at the joint. The growth rates of IMC layers are dependent upon the balance of their in-and-out atoms [5]. The interfacial reactions of lots of soldered couples have been investigated because of the requirement for lead-free solders and the development of electronic packaging [6]. The growth of IMC layers are affected by many facts, such as the effects of alloying elements, soldering time, times of reflow and electric current, etc. [7,8]. As Sn–Ag–Cu solder is considered the best candidate to replace Sn–Pb alloy, there has been abundant research carried out on this alloy, including its IMC growth behavior. Therefore, in this paper, a Sn–3Ag–0.5Cu/Cu reaction couple was selected to investigate the effect of high magnetic field upon the solid-state IMC growth behavior; the influence of both intensity and direction of magnetic field has been addressed based on experimental results.

2. Experiment

2.1. The preparation of materials

High purity Sn (99.95 wt.%), Ag (99.9 wt.%), and Cu (99.9 wt.%) were weighed and mixed in the weight ratio of 96.5:3:0.5 to make a Sn–3Ag–0.5Cu solder. The solder was re-melted in a furnace at 400 °C and then cast into a stainless steel mold with diameter of 8 mm. The solder was cut into slices of thickness of 2 mm and weight of

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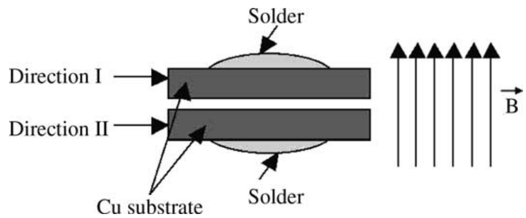

Fig. 1. Schematic diagram of the diffusion couples in the high magnetic fields.

about 100 mg. The substrate used in this study was Cu sheet with a purity of 99.9 wt.%. The diffusion couple samples were reflowed at 260 °C for 60 s. Before reflowing, both the solder slices and Cu substrates were polished, deoxidized and degreased in 5 vol.% HCl solutions to make clean surfaces.

2.2. Experimental methods

Thermal aging treatments with or without the passage of high magnetic field through the diffusion couples were performed to compare the effect of magnetic field. After the reflow process, the Sn–3Ag–0.5Cu/Cu solder joints were put into a quartz tube and placed in 3 T and 8 T magnetic fields at 170 °C for 3, 8, 13, 19 and 25 h. Fig. 1 shows the direction of magnetic field, where Direction I means that the magnetic direction (**B**) is from the Cu substrate to the solder side, and Direction II denotes that the magnetic direction (**B**) is from the solder to the Cu substrate. The aging time for specimens without the passage of high magnetic field was up to 1000 h. After aging, the samples were cooled in the air. The diffusion couples were first mounted by epoxide resin, ground and polished carefully, and at last slightly etched by using a solution of 5%HNO_3–2%HCl–93%CH_3OH. The microstructures were examined by scanning electron microscopy (SEM, JSM 5600LV). The average thickness of the IMC layer was measured by using a Q500IW image analysis meter.

In order to determine the crystal structure and orientation of the IMC layers, the solder material on the reaction couples was removed by using 3%HNO_3 solution in an ultrasonic cleaner, which only left IMC layer on the Cu substrates. The phase structure and orientation of the IMC layer were identified on the top-view of the solder interface with an X-ray diffractometer (X-ray diffraction analysis XRD-6000) with a wavelength of CuKα ($\lambda = 1.5460$ Å). The composition of the layers was measured by using energy dispersive X-ray spectroscopy (EDS).

3. Results and discussion

3.1. Section morphology

Fig. 2 shows the section morphology of the diffusion couples. According to the EDS and XRD results, the IMC layer was mainly composed of Cu_6Sn_5. Fig. 2(a) and (b) shows that formed without the passage of high magnetic field. After aging, the shape of IMC gradually changed from small scallop type to wave type. With the prolonging of aging time, the IMC interface became smoother and the thickness increased. Fig. 2(c) shows the diffusion couples aged at 170 °C for 25 h under 3 T magnetic field with magnetic direction along Direction I, and Fig. 2(d) was the diffusion couple aged at 170 °C for 25 h at 3 T magnetic field with magnetic direction along Direction II as indicated in Fig. 1. Fig. 2(e) and (f) displays the microstructure of the Sn–3Ag–0.5Cu/Cu reaction couples aged at 170 °C for 25 h at 8 T magnetic field with magnetic direction along Direction I and Direction II, respectively. From the pictures it can be seen that the shape of the IMC had also changed from small scallop type to wave type after the aging treatment, while the thickness of IMC layer increased rapidly with increasing intensity of magnetic field. In the case of the solder couple under 8 T high magnetic field, the IMC thickness aged at 170 °C for 25 h is almost the same as that aged for 1000 h without magnetic field as shown in Fig. 2(b). Obviously the growth of the IMC was promoted under a high magnetic field. Considering the influence of the direction of magnetic field by comparing Fig. 2(c), (d) and (e), (f), it is observed that the IMC thickness in the sample aged with the magnetic field along Direction II is thicker than that with the magnetic field along Direction I.

3.2. Growth kinetics

Fig. 3 shows the kinetics of IMC growth behavior of Sn–3Ag–0.5Cu/Cu solder joint aged at 170 °C for various magnetic fields, where the average thickness of IMC layer was calculated by at least 10 measurements. The growth rate of the IMC was markedly accelerated in a high magnetic field, and the growth rate along Direction II was higher than that along Direction I under both high magnetic field cases. A diffusion-controlled solid-state IMC growth behavior was observed in the entire situation as expressed as the following empirical equation [9]:

$$X(t) - X(0) = \sqrt{Dt}, \qquad (1)$$

where $X(t)$ is the IMC thickness at aging time t, $X(0)$ is the initial thickness of the as-soldered joint and D is the diffusion coefficient. Fig. 4 shows the relationship between the diffusion coefficient D and the intensity of high magnetic field. It is clear that the high magnetic field enhances the value of the diffusion coefficient D, and the enhancement is larger when the magnetic field is along Direction II rather than along Direction I. It is generally known that the diffusion coefficient D can be described as per the following description based on atomic model [10]:

$$D = \alpha^2 P \Gamma, \qquad (2)$$

where α is the jump distance of atoms, Γ is mean jump frequency, and P is the probability of jump in the direction.