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Wettability of SnCuNi-xEu solders and mechanical properties of solder joints

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Abstract: Wettability balance method was used to investigate the wetting performance of SnCuNi-xEu on Cu substrate, and the mechanical properties and the fracture morphology were studied. The results indicated that the addition of Eu could enhance the properties of solder and solder joints, with the increase of Eu content, tendency of first increase and then decrease could be found in the wetting time, wetting force and the mechanical properties of SnCuNi-xEu, and the optimal content was 0.039%. For SnCuNi-0.039Eu solder joints, the optimum mechanical properties could be found, and the amplitude increased was 20%, with the observation of the fracture morphology, it was found that small dimples could be seen, the toughness fracture for SnCuNi and mixture fracture for SnCuNi-0.039Eu could be demonstrated. And thermal fatigue behavior of SnCuNi solder joints could be enhanced obviously with the 0.039%Eu addition.

Keywords: lead-free solders; wetting; mechanical property; fracture morphology; rare earths

Due to the low cost and low melting point of SnPb solders, these alloys play an important role in joining electronic devices to metallic substrates. However, Pb is toxic and hazardous to human health and environment. Since July 1, 2006, European Union has promulgated directives, such as the Waste Electrical and Electronic Equipment Directive and Restriction of Hazardous Substances Directive^[1]. The evolution of an ultimate leadfree solder solution has become an important issue for electronic interconnection materials because of the health and environmental safety concerning Pb usage^[2,3]. Among the new lead-free solders, SnCuNi is cheap and considered to be equally attractive as SnPb for wave, dip and iron soldering process^[4,5]. But some drawbacks can be found for the SnCuNi solders, for example, the lower wettability and thermal fatigue resistance of solders^[6].

Rare earth (RE) elements have been called the "vitamin" of metals, which means that a small amount of RE elements can greatly enhance the properties of metals^[7]. Trace amount of rare earth Yb can improve the wettability, mechanical properties and the thermal fatigue behavior of SnAgCu solders^[8]. With 0.03% Ce addition, the fatigue life of SnAgCu solder joints in WLCSP device can be enhanced significantly, is 30.2% higher than that of SnAgCu solder joints^[9]. Wang et al.^[10] demonstrated that the addition of Ce can improve the wettability and mechanical properties of SnCuNi solders, and depress the growth of intermetallic compound layers. Rare earth Pr can refine the matrix microstructure and depress the IMC growth of solder joints, the wettability and me-

chanical property can be improved obviously^[11]. Hu et al.^[12] also found the enhancement effect of rare earth Nd on SnZn lead-free solders. Wang et al.^[13] tested the wetting property of SnAg solder with the addition of rare earth elements (La, Ce), it was found that the wetting property, ultimate strength and ductility were improved by 0.25%–0.5% addition of La and Ce.

In this paper, the rare earth Eu was selected as additive into SnCuNi lead-free solders. The wettability of SnCuNi solders and the mechanical properties of solder joints were studied, and the fracture morphology and thermal fatigue behavior of solder joints was analyzed systematically.

1 Experimental

The SnCuNi-xEu (x=0, 0.024, 0.039, 0.061, 0.105) solders were prepared from the pure Sn, Sn-Cu alloy, Sn-Ni alloy, and Sn-Eu alloys. Atomic emission spectroscopy was used to verify the compositions of solders. All the raw materials for SnCuNi-xEu solders were melted in a ceramic crucible, and melted at 550±1 °C for 40 min with mechanical stirring. In order to protect the solder for oxidation during the melting, CeO₂ nano-particles were used over the surface of liquid solder. Then the molten alloys were chilled and cast ingots in a mold and solidified by nominally air-cooling. In order to stabilize the microstructure of SnCuNi-xEu solders, all solder specimens were heated and treated at 125 °C for an hour.

According to IPC/EIA J-STD-003B 2004 specification, the wetting balance test can be utilized to determine the

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dynamic process of wetting by measuring the wetting time and wetting force that act between the immersing samples and molten solder. A typical wetting curve is shown in Fig. 1, in which the wetting time, t_0 , is the time at which the solder contact angle to the coupon is 90°, as shown in point D. Short wetting times and wetting force can demonstrate the good wettability of solders. The immersion depth was 2 mm, the immersion time was 10 s, and the immersion speed was 4 mm/s. And the wetting tests were carried out in air and in N_2 atmosphere, respectively. The effects of soldering temperature (240, 250 and 260 °C), atmosphere and the amount of rare earth Eu on the solderability of solders were investigated simultaneously.

QFP32 device soldered with SnCuNi-xEu solders and no-clean fluxes were carried out for mechanical properties. The package meets the EIAJ (Electronic Industry Association of Japan) package specification. And the samples were fixed on the testing bench of STR-1000 micro-joints strength tester, the testing showed a angle between the hook and the PCB was 45°, which is shown in Fig. 2. And the fracture morphology of the solder joints was examined by scanning electron microscopy (SEM). Moreover, differential scanning calorimetry (DSC) was used to determine the melting temperature of SnAgCu-xEu solders.

Thermal fatigue behavior of SnCuNi-xEu solder joints in QFP32 devices were tested using a TL-100 thermal cycle equipment. According to MIL-STD-883 specification^[14], accelerated thermal cycle tests was selected to be imposed on the QFP32 assembly. It was performed at temperatures ranging from 218 to 398 K, dwell time at all peak temperature is 15 min, the rates of descend and ascend temperature were 12 K/min.

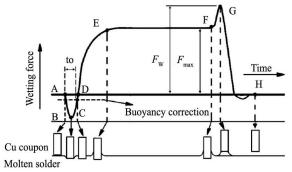


Fig. 1 Wetting curve of lead-free solders

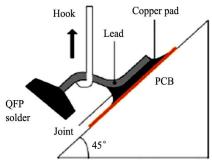


Fig. 2 Tensile testing of QFP devices

2 Results and discussion

The onset point of the DSC heating curve is related to the solidus temperature while the peak point is recognized as liquidus temperature of solders. Fig. 3 shows the solidus temperature and liquidus temperature of SnCuNi solders bearing different Eu contents. It is found that the addition of rare earth Eu has a trifling effect on the melting temperature of SnCuNi solders, with the increase of Eu contents, the liquidus temperature and solidus temperature show a small increase, the liquidus temperature range is 227.5–228.1 °C, for solidus temperature, it is 229.1–229.9 °C. Therefore, the reflow soldering curve of SnCuNi-xEu in electronic packaging can be designed with the same parameters of SnCuNi solder.

Wetting is very important for solder alloys because a reliable solder interconnection requires a good wetting property^[15]. The wettability of SnCuNi-xEu solder is assessed based on the wetting balance testing. Fig. 4 shows the wetting time of SnCuNi solders with the addition of rare earth Eu with air and N₂ atmospheres under different temperatures. With the addition of Eu, the wetting time can be reduced obviously, and the smallest wetting time can be demonstrated with the optimal Eu content (0.039%). However, with the further increase of Eu addition, the wetting time increases significantly.

From the N_2 atmosphere, similar phenomena can be observed. Moreover, the wetting time can be reduced in N_2 atmosphere. The wetting behavior of SnCuNi-xEu solders is clearly good in comparison with the air samples, because the oxidation of SnCuNi and SnCuNi-0.039Eu solders was more severe in air than in N_2 atmosphere. The similar superiority of N_2 atmosphere also demonstrated by Baated et al. [16].

Fig. 5 shows the effect of Eu on the wetting force of SnCuNi solders. As the oxidation of molten solder and Cu substrate is depressed, the wetting force of SnCuNi solders is increased in N_2 atmosphere. And the rare earth Eu can effectively increase the wetting force of alloys in air and N_2 atmospheres. From Fig. 5(a) and (b), the optimal content of rare earth Eu is demonstrated to be 0.039%, with 0.039% Eu addition, the wetting force reaches the largest value among these bars.

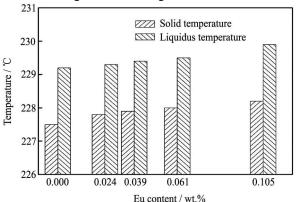


Fig. 3 Solidus-liquidus temperature

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