Wettability and thermal properties of Sn-0.7Cu-0.05Ni-xZn solder alloy

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Abstract. This study investigate the effect of Zn additions on wettability and thermal properties of Sn-0.7Cu-0.05Ni lead-free solder alloy. The additional of alloying element have been developed by using casting technique with different percentage of Zn which is 0.5, 1.0 and 1.5 wt.%. The Sn-0.7Cu-0.05Ni-xZn solder alloy samples were then analyzed by using the optical microscope (OM) to observerse the wettability performance by contact angle. From this study, it was found that different composition of Zn affected the wettability and thermal properties of Sn-0.7Cu-0.05Ni solder alloys. The addition of 0.5 wt.% has slightly increase the melting point while the addition of higher than 1.0 wt.% Zn can decrease the melting temperature. The addition of 0.5 wt.% of Zn also can reduce the undercooling of solder alloy. Thus, the minor addition of Zn for Sn-0.7Cu-0.05Ni can influence the wettability and thermal properties of solder alloy.

1 Introduction

Soldering is a process in which two or more metal items is joined by melting and flowing a filler metal (solder) into the joint. As a joining interaction, solder plays a critical role and has been extensively used in the electronic packaging industry. For years, Tin-Lead (Sn-Pb) solder has been widely used as interconnect materials. However, application of Pb in electronic product is being discontinued due to environmental and health concerns [1-4].

With the advancement of micro/nano systems technology towards faster speed, increasing service performance and miniaturization, packaging technology is facing its limitations. Therefore, it is an imperative issue for the electronic business to improve a viable alternative solder for electronic assemblies. Thus, to fulfil the ever-stricter service requirements, new interconnection materials have to be developed. Eutectic alloy of Sn-Cu that has recently gained researchers attention due to its availability and low production cost. However, Sn-0.7Cu has been reported to have poorer mechanical properties and wettability compared to lead free solder alloys containing silver [1, 5-7]. With a small amount of nickel (Ni) were added into Sn-Cu solder, it can and improve the fluidity of Sn-0.7Cu. So, Sn-0.7Cu-0.05Ni is most commonly used as lead free solders alloy that eco-friendly with the
The properties of Sn-0.7Cu-0.05Ni solder alloy are good on fluidity and give uniformity to the thickness in copper substrate. The addition of Zn can reduce the low melting temperature of the solders [11] and also good in improvement the wettability which is giving the ability to molten solder spread over the copper pad [11].

In this study, the development of new solder alloys which is Sn-0.7Cu-0.05Ni-xZn has been investigated. The result discusses the understanding of Zn addition on wettability and thermal properties of the solder alloys.

2 Experimental Procedure

The Sn-0.7Cu-0.05Ni based alloy was supplied by Nihon Superior Co Ltd., Japan. The solder alloy was mixed with different composition (wt.%) of Zn by using casting technique. The solder alloys were mixed with three different composition which is 0.5, 1.0 and 1.5 wt.% of Zn. The Sn-0.7Cu-0.05Ni solder alloy and Zn element was carefully weighing and put into graphite crucible. The graphite crucible was then put into the furnace at 600 °C. The liquid alloy was held at 600 °C for 1 h and was stirred sufficiently each 10 min, and then the liquid alloy was casted in the atmospheric environment and then was cooled to the ambient temperature.

For wettability analysis, the samples were then reflowed onto Cu-substrates in a F4N reflow oven. Some activated rosin flux was applied during reflow soldering to act as a cleaning agent to remove and prevent the formation of oxides. The reflowed sample were mounted with epoxy resin, grinded, polished. The wettability was carried out by optical microscope (OM). This analysis was investigated by measured the contact angle formed in the copper substrate solder as shown in Fig.1. For thermal analysis sample, the sample are in solder ball shaped. To making a solder ball shaped, the bulk sample must through a rolling process which making solder alloys thickness become 0.2 mm. Therefore, the piece of sheet solder alloy was cutting into 0.002 gram and reflow it. The solder ball is prepared on the Al pan with piece of sheet of Cu and some flux as shown in Fig. 2. In this study, differential scanning calorimetry (DSC) is used to determine the melting point of the material. The solder alloys were heated at temperature of 250 °C by using a heating rate of 10 °C/min under the nitrogen atmosphere.

![Fig. 1. Contact angle of the solder alloy.](image-url)
3 Results and Discussion

3.1 Wettability Analysis

Wettability is described as the capability of the molten solder to spread over on a substrate during the reflow process and was determined with respect to the contact angle. Wettability depends on several factors such as surface properties and also solder alloys compositions [4, 12, 13]. By minimize the value of the contact angle, the wettability can be optimized that corresponds to lower surface-interfacial energy. Based on the graph in Fig. 3, the contact angle for pure Sn-0.7Cu-0.05Ni solder alloy sample is 23.61° which is higher than 0.5 wt.% Zn but lower than 1.0 and 1.5 wt.% addition of Zn. Shen et al. [14] also discovered that the addition of 0.01 and 0.03 wt.% Ni can decrease the wetting force and the wetting time of Sn-Cu solder. Based on the review, the minor addition of Ni can reduce the contact angle of Sn-0.7Cu-0.05Ni solder alloy. The similar observation can be seen in this study, with the addition of minor 0.5 wt.% Zn in the solder system make the contact angle decrease to 17.32°.

However, when 1.0 and 1.5 wt.% Zn was added into the solder alloys, the contact angle slightly increases to 26.78° and 28.48° respectively. L. Zang et al. [15] reported that improvement of the wettability on the Cu substrate with molten solder alloy are related with the formation of intermetallic. By the formation of intermetallic that have been investigate for the addition of 1.0 and 1.5 wt.% of Zn, the higher thickness has been occurred and formed a higher wetting angle. This was reported by Ramli et al. [16] when they added in range 1.0-1.5 wt.% of Zn into Sn-0.7Cu solder alloy. In addition, alloying of Zn element into the Sn-based solder is concerned because Zn is very active and may deteriorate wetting performance of lead-free solder at molten state [17]. This is show that the Ni and Zn have exactly same properties to lowered the wetting angle by addition of small amount of element. However, with the higher amount of Zn can increase the contact angle value due to the oxidation and high activity of Zn in Sn alloy [18].
3.2 Thermal Properties

Thermal properties such as melting temperature is important factors in soldering industry where it can determines the operating system temperature. Fig. 4 shows the melting point of Sn-0.7Cu-0.05Ni solder alloy with addition of 0.5, 1.0 and 1.5 wt.% Zn. The Sn-0.7Cu-0.05Ni solder alloy with the addition of 0.5 wt.% has slightly increase the melting point with 230.93 °C while the addition of 1.0 wt.% Zn can decrease the melting temperature with 227.63 °C. This process is known as endothermic process because the process towards to heating process. Bao et al. [19] found interesting behavior in the phase diagram by using simple regular model which is claims when the positive interaction of solid and negative liquid occur, all the solidus and liquidous with the eutectic point move at the lower melting point component. Liu et al. [20] also report that the addition of Ni increase the melting temperature of the low-Ag solder.

For thermal analysis, it can be concluded that the low melting point achieved when 1.5 wt.% Zn are added. The range of the melting point also have low value when 1.5 wt.% Zn are added into Sn-0.7Cu-0.05Ni solder alloy than others because the composition just need a short time to fully melt. Solder alloys must have low melting temperature with narrow melting range [11]. However, there are no slightly different value of melting point temperature and melting range temperature for all samples. The melting point temperature are still around with eutectic or near-eutectic composition. For undercooling temperature, it shows that the addition of 0.5 wt.% of Zn has a short time to transfer from liquid to solid. According to Fig. 5, the onset and endset heating point was calculated the range melting point of solder alloys. The addition of 0.5 wt.% Zn give the higher value of melting range with 9.27 °C than others because the composition totally melting at high temperature which is 238.42 °C. In addition, Liu et al. [20] explain that the higher addition of Bi in the solder alloys could increase the melting range and can lead to the initiation of solidification crack of the solder joints.

Fig. 6 show the undercooling of Sn-0.7Cu-0.05Ni-xZn solder alloy. Undercooling range temperature refer to solder alloys transfer from liquid to solid. The undercooling value can be calculated by minus the onset heating point with onset cooling point. The graph shows the higher undercooling of Sn-0.7Cu-0.05Ni solder alloy is 63.84 °C.
compared to addition of 0.5 wt.% of Zn which have lower undercooling temperature. This is show that the optimum value for undercooling temperature is 0.5 wt.% addition of Zn because have low undercooling compare with addition different up to 1.0 and 1.5 wt.% Zn.

Fig. 4. Melting point of Sn-0.7Cu-0.05Ni solder alloy with addition of 0.5, 1.0 and 1.5 wt.% Zn.

Fig. 5. Melting range of Sn-0.7Cu-0.05Ni solder alloy with addition of 0.5, 1.0 and 1.5 wt.% Zn.
4 Conclusion

This study investigated the effect of Zn addition on intermetallic compound, wettability and morphology of Sn-0.7Cu lead free solder alloy. The conclusion was summarized as follows:

i. The addition of with 0.5 wt.% Zn in Sn-0.7Cu-0.05Ni could improve the wettability.

ii. The thermal properties including melting temperature, undercooling and melting range has been investigated. The addition of 0.5 wt.% has slightly increase the melting point with 230.93°C while the addition of 1.0 wt.% Zn can decrease the melting temperature with 227.63°C.

iii. The addition of 0.5 wt.% of Zn has a short time to transfer from liquid to solid thus reduce the undercooling.

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