Effect of surface finish on the wettability and electrical resistivity of Sn-3.0Ag-0.5Cu solder

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Abstract. The effect of different surface finish with Sn-3.0Ag-0.5Cu (SAC305) solder was successfully investigated. The SAC305 solder was fabricated by using casting method and solder was placed on copper substrate that coated with different surface finish. The soldering process was carried out by using F4N reflow oven followed up with the mounted and metallographic steps. Wettability of SAC305 solder was observed through contact angle formed between solder and four different surface finish located on the copper substrate. Subsequently, the electrical resistivity of solder was studied by conducted the four-point probes. The results of wettability test was found to be in the accepted range which is below 45° for all different surface finish. In terms of electrical resistivity, the results showed that the ImAg surface finish had enhanced the electrical conductivity of SAC305 lead-free solder.

1 Introduction

In the past, tin-lead (Sn-Pb) solder have been widely used in electronic packaging due to numerous merits including their low melting point (183 °C), excellent wettability and also good mechanical properties. However, starting on July 1st 2006, the usage of electronic products with Pb content had been banned due to increasing awareness of Pb that can be harmful to human health and environment [1-5]. Consequently, the development to find the suitable replacement for Sn-Pb solder become an important in the electronic field [6-10]. Among the numerous of lead-free solder proposed, the Sn-Ag-Cu (SAC) solder has been the most promising solder for replace Sn-Pb solder owing to its modest melting temperature and [11]. However, there are still problems needs to be resolved for these SAC solder, such as the poor wettability and electrical resistivity [12].

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Generally, there are numerous methods to enhance the solderability and electrical conductivity of the solder and one of a method is by using a surface finish [13]. In surface mount technology (SMT), surface finish that covered the printed circuit board (PCB) plays a significant role. There are several functions of surface finish which are to preserve the solderability layer [14], to act as a barrier to prevent the excessive dissolution of the element from substrate towards the solder [15] and also protect form the oxidation. Example of surface finish that had been used by previous researchers is Hot Air Solder Levelling (HASL) due to the a lower cost and low thermal shock resistance [16]. Furthermore, Arra et al. study the effect of nickel/gold (Ni/Au), ImAg, OSP and ImSn finishes was effect the wetting property [17]. Thus, it is believed that the surface finish has the potential to improve the properties of solder in terms of wettability, conductivity and so forth.

Since the excellent of a solder joint required good wettability and excellent conductivity, this has been motivation for this research to investigated the effects of SAC 305 solder with various surface finish including Immersion Tin (ImSn), Immersion Silver (ImAg), Electroless Nickel Immersion Gold (ENIG) and copper Organic Solderability Preservative (Cu-OSP). In addition, there is no single study reported that comparing the effects of four different surface finish on SAC305 solder.

2 Experimental Procedure

In this study, the material used was 96.5%Sn-3.0%Ag-0.5%Cu (SAC305) solder alloy and four different types of surface finish coated on the copper substrate including copper Organic Solderability Preservative (Cu-OSP), Electroless Nickel Immersion Gold (ENIG), Immersion Tin (ImSn) and Immersion Silver (ImAg). The fabrication of solder alloy was carried via casting method by melting the SAC305 solder in a clean graphite crucible and heated up to 350 °C using a furnace. Subsequently, the ingots performed cold roll to produce thin sheet of solder. Both wetting and electrical resistivity test, the samples were prepared by reflowed the SAC305 solder on different substrate with the of small amount rosin mildly activated (RMA) flux in a F4N reflow oven. The reflowed samples were mounted, grinded and polished to form a flat surface.

The wettability of solder was evaluated through wetting angle of solder on different substrate as shown in Fig.1. A 10 cross sectional samples of each substrate were prepared to measure the contact angle and measured by using Optical Microscope (ECLIPSE L300N) and Image-J software. Moreover, the electrical properties of SAC305 in different surface finish were evaluated by measuring the contact resistance of a sample by using multi-height four-point probe/2400 Source Meter, Keithley four-point probes. This electrical resistivity technique uses separate pairs of probes, the outer probes were used to supply current (I) and other pairs were used to measure a voltage (V) across the samples as illustrate in Fig.2. The resistivity of the solder sample was expressed as equation (1).

$$\rho = k \left( \frac{V}{I} \right)^2$$ (1)
3 Results and Discussion

3.1 Wettability Analysis

The wettability of solder was measured by the contact angle of solder form on substrate [18]. Wetting behaviour is crucial for solder alloys in ensuring an excellent metallic bonding in electronic packaging [11]. In soldering, the smaller the contact angle of solder, the better the wettability of the interconnections [19]. As in Fig. 3, the result showed different surface finish had different value of contact angle. The contact angle of SAC305 solder on Cu-OSP obtained as the largest with 28.64° followed by ENIG and ImAg with values 20.88° and 14.06° respectively. Similar result was found in studies by Siewiorek et al., that investigated the contact angle of the Sn-3.1Ag-0.8Cu solder in contact with Cu-OSP and ENIG surface finish [16].

Meanwhile, it was observed that the optimal contact angle achieved when used the ImSn as a surface finish with the smallest value 11.54°. According to the result attained, the decreasing of contact angle could be attributed with the surface tension of substrate. Studied by M. Arra et al. reported that the ImSn has better wetting property compare on the ImAg
and Cu-OSP surface finish. Therefore, it can conclude that the different surface finish will influence the wetting angle. Overall, smaller contact angle represents excellent wettability.

![Graph showing average contact angle for SAC305 solder alloys with different surface finishes.]

Fig. 3: Average contact angle of SAC305 solder alloys with different surface finish.

### 3.2 Electrical Resistivity Properties

Resistivity is the ability of a material to resist the flow of current. When the value of resistivity is lower, it means the specimens has higher conductivity and can easily allow an electric to flow through it. The electrical resistivity measurements of SAC305 on different surface finish were shown in Fig. 4. The result reveals that with the ImAg surface finish, electrical resistivity was reduced with 11.82 μΩ·cm due to the excess formation of Ag₃Sn intermetallic compound increase after the soldering process. Previous researcher reported that the presence of silver element will reduce the electrical resistivity of solder [20-21]. Moreover, resistivity value for Cu-OSP, ENIG and ImSn was 28.9, 19.5 and 13.92 μΩ·cm. Hence, as the electrical resistivity decreased when used ImAg as surface finish, it will enhance and formed a good electrical conductivity of solder.
Fig. 4: Electrical resistivity of SAC305 solder alloy with different surface finish.

4 Conclusion

The study on difference surface finish underlying on copper substrate is found to influence on the wettability and electrical resistivity of SAC305 solder. The following conclusion can be made:

i. The solderability of SAC305 solder was successfully improved with the presence of ImSn surface finish.
ii. Immersion silver layer on copper substrate decreased the electrical resistivity of SAC305 due to the numerous of Ag3Sn particles formed.

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References

1. R.M. Said, M.A.A.M. Salleh, M.N. Derman, M.I.I. Ramli, N.M. Nasir, and N. Saud, Key Engineering Materials. 700 (2016)
2. M.I.I. Ramli, N. Saud, M.A.A.M. Salleh, M.N. Derman, R.M. Said, and N. Nasir, Materials Science Forum. 803 (2015)
3. M.I.I. Ramli, M.S.S. Yusof, M.A.A.M. Salleh, R.M. Said, and K. Nogita, Solid State Phenomena. 273 (2018)
4. F. Somidin, H. Maeno, M.M. Salleh, X.Q. Tran, S.D. McDonald, S. Matsumura, and K. Nogita, Materials Characterization. 138 (2018)
5. D. H. Jung, A. Sharma, D. U. Lim, and J. H. Yun., Metal Mater Trans A, 48: p. 4372 (2017)
6. M.A.A.M. Salleh, M.H. Hazizi, M.A.B.M. Abdullah, N. Noriman, R. Mayapan, and Z.A. Ahmad, Advanced Materials Research. 626 (2012)
7. K. Nogita, M.A.A.M. Salleh, S. Smith, Y. Q Wu, S.D. McDonald, A.G.A. Razak, T. Akaiwa, and T. Nishimura, 2017 International Conference on Electronics Packaging (ICEP).
8. K. Nogita, M.A.A.M. Salleh, E. Tanaka, G. Zeng, S.D. McDonald, and S. Matsumura, JOM. 68(11) (2016)
9. M.A.A.M. Salleh, A.M.M.A. Bakri, F. Somidin, and H. Kamarudin, International Review of Mechanical Engineering.
10. M.A.A.M. Salleh, M.M.A.B. Abdullah, F. Somidin, A.V. Sandu, N. Saud, K. Hussin, S.D. McDonald, and K. Nogita, Revista de Chimie 64
11. D. H. Jung and J. Jung., Solid State 44: p. 324 (2018)
12. L. Sun and L. Zhang., Adv Mater Sci Eng, (2015)
13. Milad. G., Circuit World, 34(4): p. 4 (2008)
14. R. Berni, et al., IEEE T Reliab, 65(1): p. 274 (2016)
15. R. A. M. Anuar and S.A. Osman., Materialwiss Werkst, 48: p. 235-240 (2017)
16. A. Siewiorek, A. Kudyba, N. Sobczak, M. Homa, Z. Huber, Z. Adamek, and J. W. Budka., J Mater Eng Perform, 22 (8): p. 2247 (2013)
17. M. Arra, D. Shangguan, D. Xie, J. Sundelin, T. Lepisto, and E. Ristolainen., J Electron Mater. 33(9): p. 990 (2004)
18. N. Rodrigues, A. C. Ferreira, and S.F. Teixeira., J Mater Sci-Mater El, 27: p. 8942 (2016)
19. E. E. Mhd Noor, N. F. Mhd Nasir, and S. R. A. Idris., Solder Surf MT Tech, 28: p. 127 (2016)
20. M. A. A. Mohd Salleh, M. H. Zan@Hazizi, Z. A. Ahmad, K. Hussin and K. R. Ahamd., Adv. Mater. Res, 277: p. 109 (2011)
21. N. A. A. Mohd Amin, D. A. Shnawah, S. Mohd Said, M. F. Mohd Sabri and H. Arof., J. Alloys Compd, 599: p. 116 (2014)