IOP Conference Series: Materials Science and Engineering

PAPER • **OPEN ACCESS**

Influence of kaolin geopolymer ceramic additions to the wettability and electrical properties of Sn-3.0Ag-0.5Cu (SAC305) lead free solder

To cite this article: Nur Syahirah Mohamad Zaimi *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **701** 012033

IOP Conf. Series: Materials Science and Engineering **701** (2019) 012033 doi:10.1088/1757-899X/701/1/012033

Influence of kaolin geopolymer ceramic additions to the wettability and electrical properties of Sn-3.0Ag-0.5Cu (SAC305) lead free solder

Nur Syahirah Mohamad Zaimi [1] , *Mohd Arif Anuar* Mohd Salleh [1,*], *Mohd Mustafa Al Bakri* Abdullah[1], *Marliza* Mostapha[1] and *Romisuhani* Ahmad[2]

[1]Centre of Excellence Geopolymer and Green Technology, School of Materials Engineering, Universiti Malaysia Perlis (UniMAP), Taman Muhibbah 02600, Jejawi, Arau, Perlis, Malaysia
[2]Faculty of Engineering Technology, Uniciti Alam Campus, Universiti Malaysia Perlis (UniMAP), Perlis, Malaysia

Abstract. The effect of kaolin geopolymer ceramic addition to the wettability and electrical resistivity of Sn-3.0Ag-0.5Cu (SAC305) lead free solder was successfully explored. Powder metallurgy with microwave sintering method was used to fabricate SAC305 composite solder. Five different weight percentage (wt.%) of kaolin geopolymer ceramic (0, 0.5, 1.0, 1.5 and 2.0 wt.%) were used in this study. The wettability of composite solder revealed the optimum contact angle was achieved at 1.0 wt.% with 20.8 °. Then, the electrical resistivity of composite solder showed significant change in the resistivity value.

1 Introduction

The world nowadays is facing on a fast-track in technology transformation. The fundamental factors for this was the ever developing and advancing in electronic packaging industry. The emergence of advance electronic devices that are getting smaller and thinner [1] with more complicated functions demand a very reliable and high-performance solder interconnections. In solder interconnections, solder which employed as interconnections materials play a vital role in producing the ever-reliable solder joints that determine the overall functionality [2].

Tin-Lead (Sn-Pb) solder alloys are widely used in the electronic packaging industry as an interconnection material since more than 50 years ago due to its outstanding reliability and solderability. However, as the health and environment matters had been taken seriously, the usage of lead in any electric and electrical equipment had been prohibited. Therefore, a new lead free solder system with excellent properties need to be introduced [3-10]. There are numerous of studies had been done by previous researchers in order to improve the performance and properties of lead-free solders such as microalloying, composite and transient liquid phase (TLP) bonding [11]. Among all those methods, the

* Corresponding author: arifanuar@unimap.edu.my

IOP Conf. Series: Materials Science and Engineering **701** (2019) 012033 doi:10.1088/1757-899X/701/1/012033

most attractive, promising and viable way to enhance the performance and properties of solder is by introduce a second phase or reinforcement to an existing lead-free solder, forming a lead-free composite solder. In general, a composite solder is form when the solder alloy was intentionally corporate or reinforced with metals or non-metals materials [12]. Ceramics is one type of reinforcement which can be incorporated in lead free solder forming composite solders. An extensive studies on the ceramic particles incorporating with solder matrix had been carried out by many researchers [13-18]. According to Wang et.al., [19], the addition of Silicon Oxide (SiO_2) into SAC solder give positive effects to the performance of solder. The addition of SiO_2 results in refining the microstructures, improve wettability, shear force and suppress the growth of IMC [19]. Besides that Tsao [20] discussed possibility of adding Titanium Oxide (TiO_2) into SAC solder systems in terms of the performance of solder during isothermal ageing.

Therefore, with the improvements shown in the lead-free solder as it was reinforced with various reinforcements, it is very interesting to study on how the other type of ceramic reinforcement could affect the performance of solder in terms of the microstructure, solderability, thermal properties and electrical properties. In this research, an attempt was made by incorporating Sn-3.0Ag-0.5Cu (SAC305) lead free solder with kaolin geopolymer ceramics. There are no research reporting on the effects of kaolin geopolymer ceramics to SAC305 lead free solder to date.

2 Methodology

In this research, the base material, Sn-3.0Ag-0.5Cu (SAC305) lead free solder powders with an average size of 25-45 µm was supplied by Sigma Aldrich. Kaolin geopolymer ceramic (KGC) with particle size less than 38 µm was used as the reinforcement material. Powder metallurgy with microwave sintering method was performed to fabricate composite solders with the addition of KGC particles. Five different wt. %. of KGC (0, 0.5, 1.0, 1.5 and 2.0 wt.% KGC) were homogeneously mixed with SAC305 powder by using planetary mill machine at 200 rpm for one hour. Subsequently, the solder mixtures for each composition were uniaxially compacted at 4.5 tonnes by using a Specac 15-ton Manual Hydraulic Press. Then, each of compacted pellets were sintered by a microwave sintering method at a temperature of 185 ˚C under ambient conditions in an 800 W, 50 Hz Panasonic microwave oven.

Then, the samples were reflowed in a F4N reflow oven with the aid of rosin mildly activated flux (RMA). The samples were mounted with epoxy resin, grinded and polished. For the solder, about 10 samples for each of compositions were measured in order to ensure the accuracy of the results. The wettability of solders can be determined respected to the contact angle to the Cu substrates. The contact angle was measured by using J- Image software.

The electrical resistivity of composite solders was measured by using 4-point probe as shown in Fig. 1. The samples used for these testing was compacted into a cylindrical shape with approximately 12 mm diameter and 5 mm thick. A set of 5 samples for each monolithic and composite solders system were prepared. A probe spacing (s) of 3 mm was used in this measurement. The current applied in this measurement was fixed to 1 A and the corresponding voltage (V) drop across the samples were measured. As the sample thickness (t) was greater than the probe spacing, the following formula equation (1) was used to measure the electrical resistivity (ρ) of SAC 305 composite solder system.

$$\rho = 2\pi s \left(\frac{V}{I}\right) \quad (1)$$

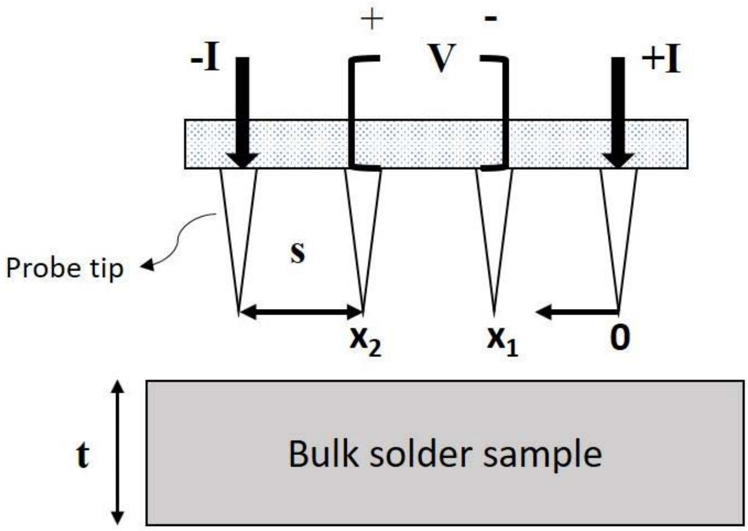

Fig. 1. Four-point probe schematic diagram.

3 Results and Discussions

3.1 Wettability

Wettability is one of crucial parts in the soldering which determine the solderability classification. Forming a reliable solder bonding with substrate was very important in order to produce electrical and electronic device with an excellent performance. The wettability of the composite solder can be measured with respect to the contact angle (ϴ°) of the solder materials and Cu substrate [21]. To create a reliable solder bonding, the contact angle (ϴ°) formation must be smaller and it was acceptable if the contact angle measured was less than 45° [17].

The influence of various weight percentage (wt. %) kaolin geopolymer ceramic (KGC) reinforcement on the wettability of SAC305 lead free solder was shown in Fig. 2. The error bars on the graph represent the standard deviations. Results shows that the average contact angles of solder is firstly decreased and then starts to increase with the increasing content of KGC reinforcement. Specifically, the average contact angle firstly decreased from 24.0 µm for SAC305 without the addition of KGC to 22.3 µm and 20.8 µm at 0.5 wt.% and 1.0 wt.% KGC addition, respectively. Then, the increasing trend of contact angle was shown as the value of contact angle increased to 22.0 µm and 23.1 µm for SAC305/1.5 wt.% and SAC305/2.0 wt.% KGC, respectively. Although the contact angle of SAC305 solder with the addition of 1.5 wt.% and 2.0 wt.% KGC particles shown an increasing trend, the value was still lower than the contact angle of SAC305 without the addition of KGC. These results indicate that the appropriate amount of KGC reinforcement added on the SAC305 lead free solder influenced the wettability performance.

The improvement in the wettability of SAC305 composite solder as compared to SAC305 without the addition of KGC may be attributed to the facts that the KGC particles added accumulated at the interface between the molten solder and the flux during soldering process. The accumulation of KGC particles causes the surface tension between molten solder and flux to be lowered whereas the surface tension between substrate and solder will be high. Therefore, the contact angle formed for SAC305 composite solder at 0.5 wt.% and 1.0 wt.% KGC were smaller than SAC305 without addition of KGC. However, an excess addition of KGC particles beyond than 1.0 wt.%, increased the contact angle of composite solder. The possible reason for this was that the higher fraction of KGC particles may inhibited the flow of molten solder by increase the viscosity of the solder and 'pins' the leading edge of the molten solder from further spreading [22].

This result was in consistent with the previous finding by Wang et.al., [19] whereby the wettability of SAC 305 was improved with the addition of SiO_2 up to 0.1 wt.%. However, as 0.5 wt.% and 1.0 wt.% SiO_2 were added into SAC305 solder, the wettability declined with the contact angle value lower than the pure solder.

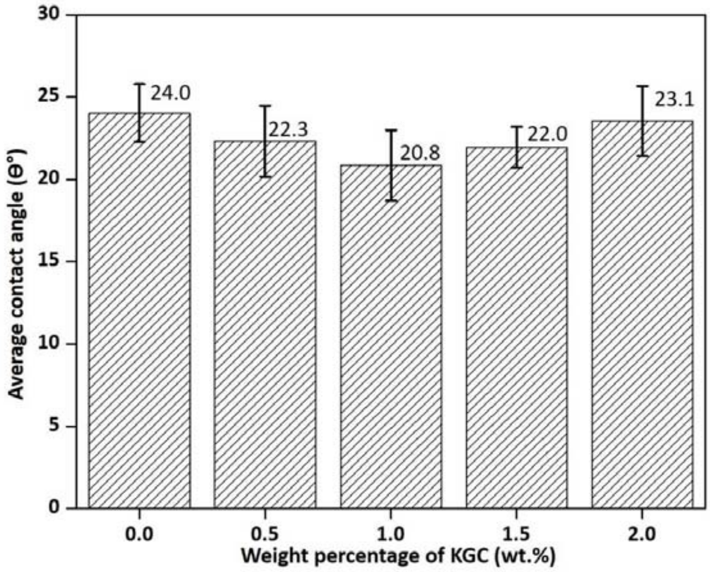

Fig. 2. Bar graph showing the influence of geopolymer ceramics addition to the wetting angle of SAC 305 lead free composite solder.

3.2 Electrical properties

Solder plays an important role in the electronic industry such that it acts as an electrical interconnection in the electronic devices. Thus, it was necessary for the composite solders to provide good electrical properties. In this research, an electrical resistivity of the composite solders was measured. Fig. 3 depicts the average electrical resistivity of SAC305 lead free solder with addition of various weight percentage (wt.%) of kaolin geopolymer ceramic (KGC) particles. The result on the electrical resistivity of SAC305 lead free solder at various wt.% of KGC particles shows an showing an insignificant change in electrical resistivity values. The electrical resistivity of SAC305 lead free solder at 0 wt.% KGC was 4.190 μΩ.cm. With the addition of KGC particles, the electrical resistivity value shows slightly increased. The electrical resistivity of 0.5 wt.%, 1.0 wt.%, 1.5 wt.% and 2.0 wt.% KGC were 4.219, 4.220, 4.222 and 4.229 μΩ.cm, respectively.

According to Chen et.al., [23], the electrical resistivity value was determined by type, size, shape and volume fraction of reinforcements added. Based on Marthiessen's rule, the total electrical resistivity of materials consists of three parts which are impurity resistivity, thermal resistivity and deformation resistivity. The existence of these three types of resistivity will disturb the normal electron motions in which it affects the impurity scattering and lattice scattering. In the case of composite solder, the electrical resistivity value was strongly depending on the impurity resistivity. The reinforcement particles added serves as electron scattering centres. Therefore, high amount of reinforcement particles can greatly affect the electrical resistivity of composite solder system. However, in this research, the changes in the electrical resistivity was not significant between monolithic SAC 305 solder and composite SAC 305 solder which corresponds to the small addition of KGC particles. Therefore, the addition of KGC particles would not disturb the ability of the solder to perform as electrical interconnect with lower electrical resistivity value. The results obtained was in good agreement with the research done by Babaghorbani et.al., [24] where the addition of ZrO_2 insignificantly influence the electrical resistivity of Sn-3.5Ag and Sn-3.5Ag-0.7Cu.

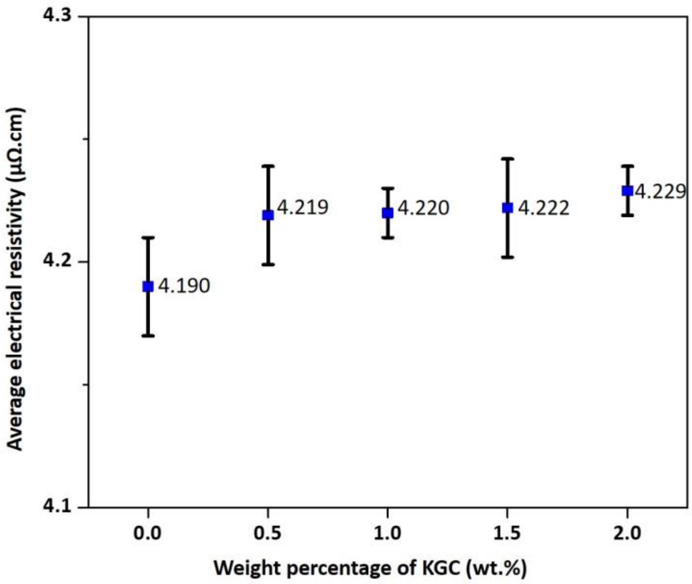

Fig. 3. Average electrical resistivity of SAC305 lead free solder at various weight percentage (wt.%) kaolin geopolymer ceramic.

4 Summary

A new lead-free composite solder system with the addition of various wt.% KGC to the wettability and electrical properties of SAC305 composite solder were investigated. The addition of KGC improved the wettability of the solder. The optimum value of contact angle was achieved at 1.0 wt.% with contact angle value of 20.8 °. Then, in terms of electrical resistivity, the addition of various wt.% KGC do not significantly change the resistivity value as compared to SAC305 without the addition of KGC. Based on the results obtained, it is interestingly to explore and investigate more on the influence of the KGC to the microstructure, thermal properties and mechanical properties.

The authors acknowledge the financial support through the Ministry of Higher Education, Malaysia, under the Fundamental Research Grant Scheme (FRGS/1/2017/TK10/UNIMAP/03/2) (9003-00612).

This work was also supported by an Institutional Links grant, ID 332397914, under the Newton-Ungku Omar Fund partnership. The grant is funded by the UK Department of Business, Energy and Industrial Strategy (BEIS) and Malaysia and delivered by the British Council.,. The authors also acknowledge Center of Excellence Geopolymer & Green Technology (CEGeoGTech) and School of Materials Engineering, Universiti Malaysia Perlis.

References

1. 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)
2. Che, F.X. and J.H.L. Pang,. J Alloy Compd, **541**, 6-13 (2012)
3. R.M. Said, M.A.A.M. Salleh, M.I.I. Ramli, and N. Saud, Solid State Phenomena. **280** (2018
4. M.A.A.M. Salleh, S.D. McDonald, and K. Nogita, Journal of Materials Processing Technology. **242** (2017)
5. F. Somidin, H. Maeno, M.M. Salleh, X.Q. Tran, S.D. McDonald, S. Matsumura, and K. Nogita, Materials Characterization. **138**
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**
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. (2013)
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**(7) (2013)
11. Guo, Q., et al., Microelectron Reliab, **80**, 144-148 (2018)
12. Mohd Salleh, M.A.A., et al., Mater. Des, **82**, 136-147 (2015)
13. Mohamad Zaimi, N.S., et al., Solid State Phenomena, **280**, 169-174 (2018)
14. Wattanakornphaiboon, A., R. Canyook, and K. Fakpan, Mater Today-Proc, **5**, 9213-9219 (2018)
15. Gain, A.K. and L. Zhang,. Materialia, **3**, 64-73 (2018)
16. Mohd Salleh, M.A.A., S.D. McDonald, and K. Nogita,. J. Mater. Process. Technol, **242**, 235-245 (2017)
17. Ramli, M.I.I., et al., Microelectron Reliab., **65**, 255-264 (2016)
18. Chellvarajoo, S., M.Z. Abdullah, and Z. Samsudin,. Mater. Des,**67**, 197-208 (2015)
19. Wang, Y., et al., J. Mater. Sci.: Mater. Electron., **26**(12), 9387-9395 (2015)
20. Tsao, L.C., J Alloy Compd, **509**(33),8441-8448 (2011)
21. Zaimi, N., et al.,. IOP Conf Ser Mater Sci Eng, **551**, 012081 (2019)
22. Zhang, L. and K.N. Tu, Mat Sci Eng R **82**,1-32 (2014)
23. Chen, G., et al.,.Mater. Sci. Eng. A, **636**(Supplement C), 484-492 (2015)
24. Babaghorbani, P., S.M.L. Nai, and M. Gupta, J Alloy Compd, **478**(1), 458-461 (2009)