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An influence of substrate thickness on electrical conductivity of dip-soldered copper joints

Tin (Sn) metal is used as a major ingredient in various levels of solders (both lead bearing and lead free) to join electronic components whereas, copper is the most common substrate material to be in direct contact with electronic solders. In this regard, study on the reaction between tin and copper (Cu) is of great practical interest. Copper substrates of two thicknesses (0.3 and 3 mm) were immersed in liquid tin (maintained at 350°C) for the duration of 3mins. An immersion and redrawn speed maintained was 2.5mm/s. An interfacial reaction between substrate metals of different thickness and liquid tin vice versa was investigated. Effect of substrate thickness on electrical resistivity and electrical conductivity was accessed. It was observed that as the thickness of Cu substrate increases both electrical conductivity decreases.

Keywords: Tin, copper, substrate, solder, electrical conductivity

1.0 Introduction

Soldering is a low temperature metallurgical joining method used to hold the parts to be joined together using a filler metal known as solder alloy (Satyanarayan and Prabhu 2011). Pb base and Pb free solders are widely used in microelectronic devices as well as circuits because solders provide good electrical continuity, thermal and mechanical strength to the interfacial joints (Kumar and Narayan Prabhu 2007). The reliability of solder joints is greatly influenced by the interfacial reaction between the solder and substrate because, during reflow when liquid solder react with the substrate, the intermetallic compounds (IMCs) grow at the interface (Satyanarayan and Prabhu 2011, Kumar and Narayan Prabhu 2007). These IMCs provide a strong bond to the solder joints. The formation of a thin IMC layer is vital for good bond ability, while excessive formation weakens the solder joints (Ha, Sang Su, Jin Kyu Jang, Sang Ok Ha, Jeong Won Yoon, Hoo Jeong Lee, Jin Ho Joo, Young Ho Kim, and Seung Boo Jung 2010).

Electrical conductivity or resistivity is considered as one of the important parameters to be evaluated other than mechanical as well as microstructural properties for solder joints in electronic packaging system (Ismail, Norliza, Azman Jalar, Atiqah Afdzaluddin, and Maria Abu Bakar 2021). It is well known that higher electrical conductivity (or lower electrical resistivity) exhibits a better transfer of electrons at the interface of solder joints in electronic devices.

It is reported that (Ismail, Norliza, Azman Jalar, Atiqah Afdzaluddin, and Maria Abu Bakar 2021) awareness on the solder joint in electrical connection is conceded to measure the extend of the reliability in terms of functionality and the flow current to electrical as well as electronic devices. Ismail, Norliza, Azman Jalar, Atiqah Afdzaluddin, and Maria Abu Bakar (2021) stated that, electrical resistivity in solder bulk and solder joint may vary in terms of structure, properties, and performance. Authors also reported that, the role of CNT in solder affected the electrical resistivity of solder joints. Joint reliability in electronic packaging relies on the type of solder alloy (Pb free), substrate (thickness), and soldering method (SMT, BGA, wave soldering) (Sona and Prabhu 2013, Kumar and Narayan 2007).

At present, new lead-free solders such as Sn–Cu, Sn–Ag, Sn–Zn–Bi, Sn–Ag–Bi, Sn–Bi, Sn–Ag–Cu, Sn–Ag–Zn, Sn–Zn, and Sn–In are widely used for electronic applications (Hwang JS. (2005), Appan, Ramani May, Ahmad Badri Ismail, Zainal Arifin Ahmad, Tadashi Ariga, and Luay Bakir Hussain. (2007), Kumar Swamy, Satyanarayan (2019). However, most lead-free solders are Sn rich alloys (or in which Sn is a major element more than 95 wt.%), and the properties of Sn dominate the solders behaviour (Satyanarayan and Prabhu 2011). So, it is important to understand the interfacial reactions and electrical conductivity performance between pure Sn and the substrate metal, especially prepared by using dipping method. Literature review suggests that research attention on effect of substrate thickness on accessing reliability in terms of electrical conductivity or resistivity of solder joint is not much focused (Wang, Jianhao, Songbai

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Xue, Peng Zhang, Peizhuo Zhai, and Yu Tao 2019, Fazal M.A, Liyana N.K, Rubaiee S and Anas A 2019). Hence in the present study, effect of substrate thickness on electrical resistivity and electrical conductivity of Sn/Cu interfacial joint was accessed.

2.0 Materials and methods

In the present study, commercially available base metal copper (Cu, 99% pure) is used as substrate material. The materials were purchased from High Tech Steels, Mangalore. Cu metallic materials were purchased in the form of long strips (0.8m) of two different thicknesses (0.3 and 3mm). All the Cu sample materials were cut into rectangular (L×B×H) shape of sizes 50mm × 30mm × (0.3mm and 3mm). A drill of 3mm diameter was drilled at a distance of 1cm from one end for the suspension (support) through the chain. The substrate surfaces were polished by using emery papers of different grit sizes (number 80, 120, 220, 320, 400, 600, 800, 1200, 1500 and 2000) to obtain scratch free (mirror) finish on surface. The pure tin (Sn, 99.90% pure) was purchased from Azeez Hardware and Metals, Bunder, Mangalore for the preparation of solder bath (liquid Sn). Cu substrates after polishing were cleaned by using acetone.

After applying a Rosin Mildly Activated (RMA) flux (purchased from Tejas Technologies, Chennai) thoroughly, the substrates were dipped (immersed) into the molten solder (liquid tin-maintained temperature was 350°C). Immersion speed maintained was 2.5mm/sec by using a motor and chain set up as shown in Fig.1.

The immersion time chosen was 3 minutes and the immersion depth was 25mm and the samples were drawn out from the bath with the same speed of 2.5mm/sec. Preheated (300°C) graphite crucible was used to hold the liquid Sn. Copper samples after dipping in solder bath were subjected to electrical resistivity test (Keithley 2400 Graphical Series SMU instruments) and their values were measured. Further electrical conductivity was calculated. The samples after cooling were sectioned using precision diamond cutter (Magnum make, Bangalore). After polishing with different grade emery papers and disc polishing machine (Chennai Metco make, Madras) sectioned samples were used for the microstructural study to investigate the diffusion behaviour at the interface between Sn and substrate materials for this Metallurgical Microscope (Leica) was used.

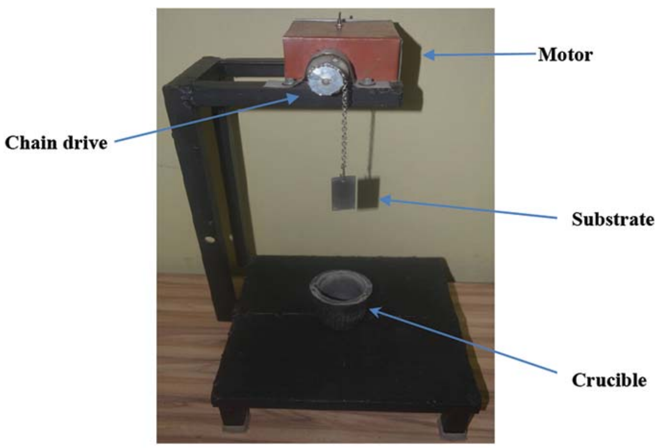

Fig.1: Experimental setup

3.0 Results and discussion

The macroscopic images of surface appearance of the hot dipped substrate samples are shown in Fig.2. Sn/Cu plates can be successfully bonded using dip soldering. There was a poor wetting between tin and copper substrate of thickness 3mm is compared to 0.3mm Cu sample. The wetting of liquid tin decreased with increasing thickness of Cu substrate.

An interfacial microstructures of Sn/Cu joints at lower magnification are shown in Fig.3. The optical microscopic images indicated the extent to which Sn dissolution and IMC development occurred at the interface of all substrates. The wetting of 0.3mm copper exhibited excellent wetting whereas the cross-sectional interfacial microstructure of Cu sample of thickness 3mm exhibited a minimal tin dissolution indicating poor wetting.

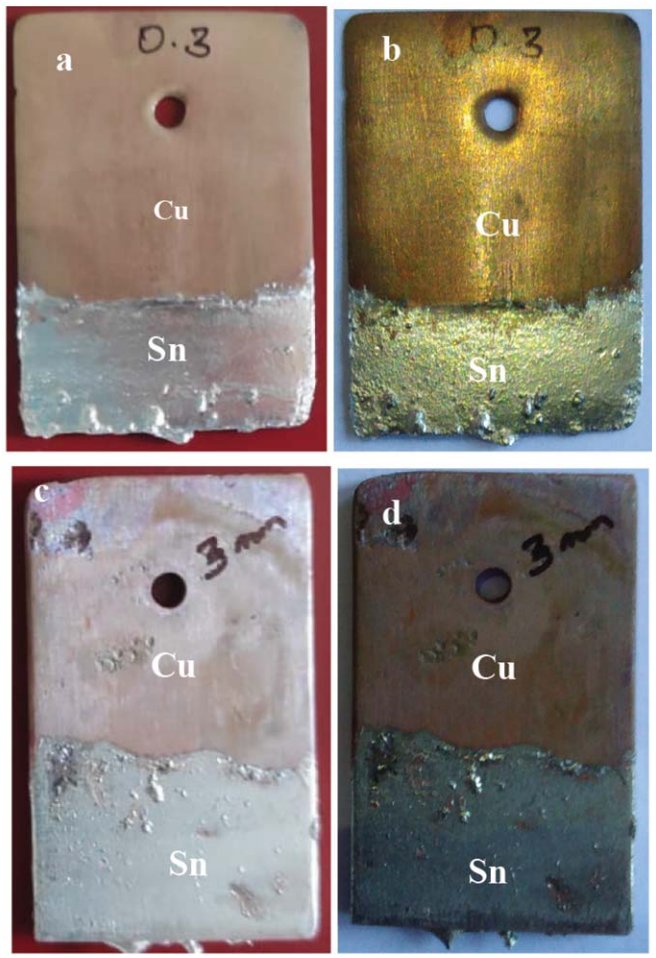

Fig.2: Dipped copper substrates at 3mins. (a, b for trail 1 and 2 for 0.3mm Cu samples) (c, d for trail 1 and 2 for 3mm Cu samples)

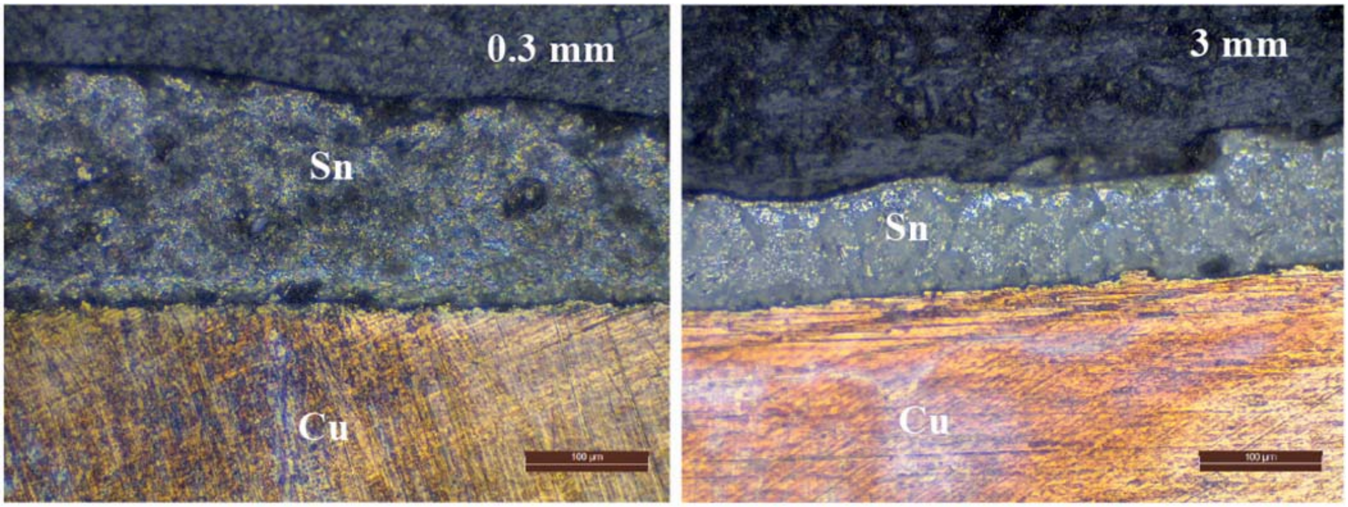

Fig.3: Cross-sectional micrographs of Sn/Cu interfaces for dip soldering at 350°C for (a) 0.3mm (b) 3mm at lower magnification (10x)

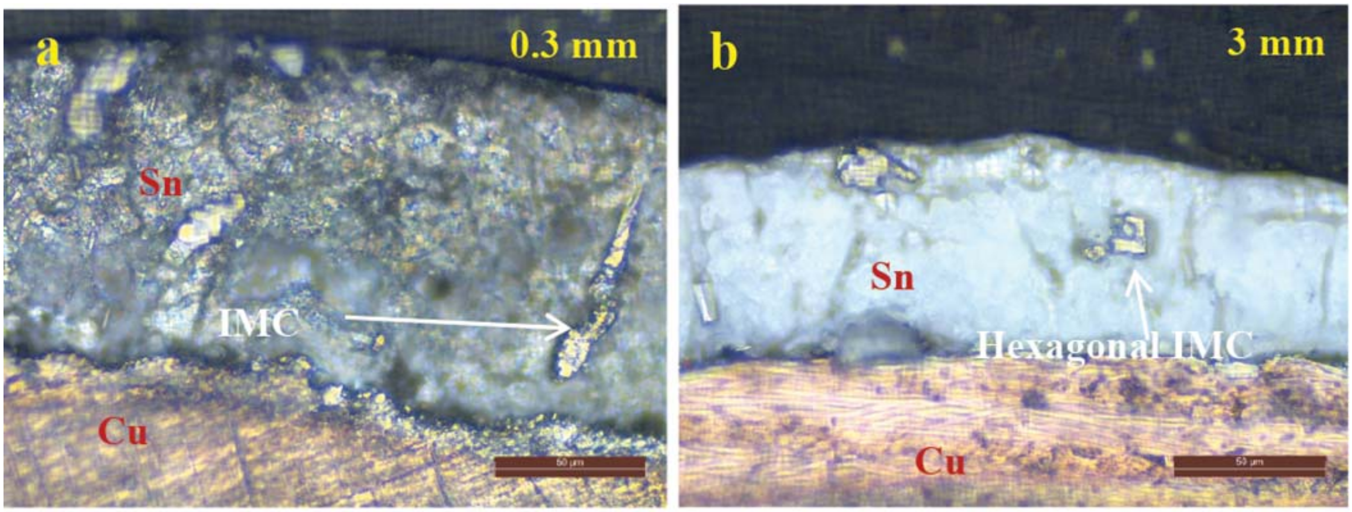

Fig.4: Cross-sectional micrographs of Sn/Cu interfaces for dip soldering at 350°C for (a) 0.3mm (b) 3 mm at higher magnification (50x)

A continued tin wetting layer was dominated at the interfaces of both the substrates. Conversely, for 0.3 Cu sample considerable higher dissolution of liquid Sn into Cu substrates was observed; also, the wetting layer was found to be slightly thicker (150µm). The formation of diffused layer was slightly thin for 3 mm Cu samples (53µm). An increasing thickness of Cu substrate resulted in decreasing thickness of wetting layer as well as growth of intermetallic compounds (IMCs).

An interfacial microstructure of Sn/Cu joints at higher magnification are shown in Fig.4. The morphology of intermetallic compounds was found to be in the form of needle and hexagonal shape. IMCs were found in the matrix of Sn. As per the Sn-Cu phase diagram, intermetallic compound can be identified as Cu_6Sn_5.

Effect of substrate thickness on electrical resistivity and conductivity was assessed. Electrical conductivity measurements were done at room temperature. Figs.5 and 6 indicate the effect of substrate thickness on electrical resistivity (R, Ω) and conductivity (σ, S/m).

Electrical conductivity of Sn/Cu interfacial joint was calculated using the following equation.

$$\sigma = \frac{L}{RA}$$

Where, σ = electrical conductivity in, siemens per meter (S/m, R= resistance in ohms (Ω), L=length in meters (m), A=area in square meters (m^2, A=thickness of the substrate × length of the substrate).

Hot dipped substrate sample of thickness 3mm offered lower electrical conductivity (0.68232×10^3 S/m) and resistivity (0.4898354741, Ω). whereas sample of thickness 0.3mm exhibited higher electrical conductivity (6.6587×10^3 S/m) and resistivity (0.5005407333 Ω). It clearly indicates that, electrical conductivity decreases as thickness of substrate increases. Almost similar trend was observed when the effect of solder

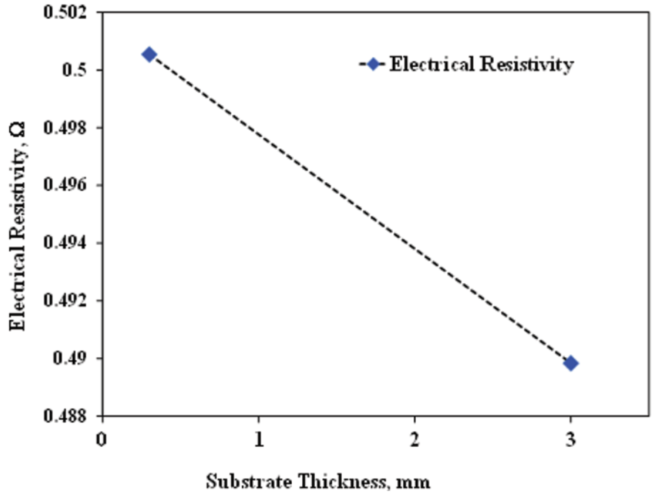

Fig.5: Effect of substrate thickness on electrical resistivity (R, Ω)

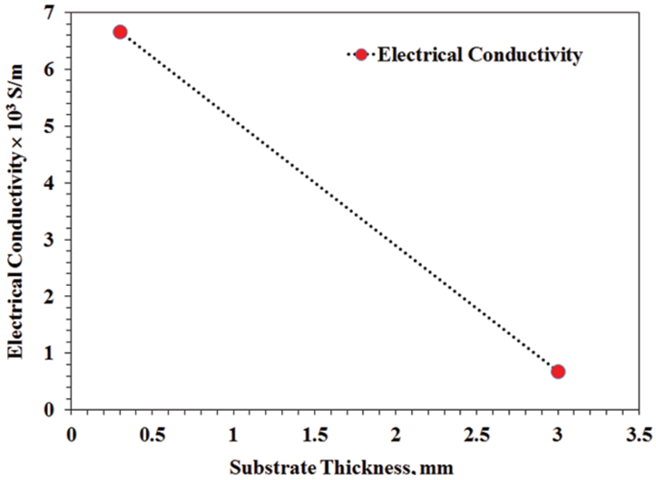

Fig.6: Effect of substrate thickness on electrical conductivity (σ, S/*m*)

composition, solder film thickness and joint overlap on the electrical resistance of soldered copper joints was accessed (Reichenecker, 1981). This is due to higher dissolution of liquid Sn into Cu substrates for the substrate thickness on 0.3mm. The formation of hexagonal shaped IMCs impedes the flow of current, because IMCs are having covalent/ionic bonds.

Based on research it is found that substrate thickness of 0.3mm copper is more suitable than the 3mm copper thickness for soldering purpose because electrical conductivity decreases as the substrate thickness increases.

4.0 Conclusions

Based on results and discussion the following conclusions are drawn

- Sn/Cu plates can be successfully bonded using dip soldering.
- There was less bond formation between tin and copper substrate of thickness 3 mm than 0.3 mm
- Increasing substrate thickness decreases the electrical conductivity
- Copper of thickness 0.3mm offered a slightly lower joint resistance/higher electrical conductivity than copper of thickness of 3mm.

5.0 Acknowledgments

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References

1. Appan et al., (2007): Wetting Properties of Sn-Pb, Sn-Zn and Sn-Zn-Bi Lead Free Solders. *Jurnal Teknologi*, pp. 1-14.
2. Fazal M.A et al., (2019): A critical review on performance, microstructure and corrosion resistance of Pb-free solders. *Measurement*, 134, pp. 897-907.
3. Ha et al., (2010): Effect of multiple reflows on interfacial reaction and shear strength of Sn–Ag electroplated solder bumps for flip chip package. *Microelectronic Engineering*, 87, no. 3, pp. 517-521.
4. Hwang JS, (2005): Implementing lead-free electronics. The McGraw-Hill companies, pp. 10-50.
5. Ismail et al., (2021): Electrical resistivity of Sn–3.0 Ag–0.5 Cu solder joint with the incorporation of carbon nanotubes. *Nanomaterials and Nanotechnology*, 11, pp. 1847980421996539.
6. Venkatesha, B. K. and Saravanan, R. (2020): Effect of Cenosphere Addition on Mechanical Properties of Bamboo and E-Glass Fiber Reinforced Epoxy Hybrid Composites. *International Journal of Vehicle Structures and Systems*, 12(4), 447–451. https://doi.org/10.4273/ijvss.12.4.18
7. Kumar Swamy M. C and Satyanarayan, (2019): A review of the performance and characterization of conventional and promising thermal Interface materials for electronic package applications. *Journal of Electronic Materials*, 48, no.12, pp. 7623-7634.
8. Kumar et al., (2007): Review of non-reactive and reactive wetting of liquids on surfaces. Advances in colloid and interface science, 133, no.2, pp.61-89.
9. Reichenecker W. J, (1981): Effect of Solder Thickness and Joint Overlap on the Electrical Resistance of Soldered Copper Joints. *Welding Journal*, 60, no. 10, pp. 1995-2015.
10. Venkatesha, B. K., Saravanan R. and Anand Babu, K. (2021): Effect of Moisture Absorption on Woven

Bamboo/Glass Fiber Reinforced Epoxy Hybrid Composites, Materials Today Proceedings, 45(part1), 216-221. https://doi.org/10.1016/j.matpr.2020.10.421

11. Satyanarayan and Prabhu K, (2011): Wetting behaviour and evolution of microstructure of Sn-Ag-Zn solders on copper substrates with different surface textures. In Lead-free Solders. ASTM International, pp. 50-73.
12. Satyanarayan and Prabhu K. N, (2011): Reactive wetting, evolution of interfacial and bulk IMCs and their effect on mechanical properties of eutectic Sn–Cu solder alloy. Advances in colloid and interface science, 166, no. 1-2, pp. 87-118.
13. Venkatesha, B. K., Pramod Kumar, S. K., Saravanan, R. and Ishak, A. (2020): Tension Fatigue Behaviour of Woven Bamboo and Glass Fiber Reinforced Epoxy Hybrid Composites. IOP Conference Series: Materials Science and Engineering, 1003 0120187 https://doi.org/10.1088/1757-899x/1003/1/012087
14. Sona, Mrunali, and Prabhu K. N, (2013): Review on microstructure evolution in Sn–Ag–Cu solders and its effect on mechanical integrity of solder joints. *Journal of Materials Science: Materials in Electronics*, 24, no. 9, pp. 3149-3169.
15. Wang et al., (2019): The reliability of lead-free solder joint subjected to special environment: a review. *Journal of Materials Science: Materials in Electronics*, 30, no. 10, pp. 9065-9086.