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Thermal cyclic test for Sn-4Ag-0.5Cu solders on high P Ni/Au and Ni/Pd/Au surface finishes

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ABSTRACT

In electronic packaging, the reliability of the interconnection changes with the surface finish and the type of solders being used. Thermal cycling is one method of reliability assessment. In thermal cycling experiments, the strain state is simplified by soldering together regular shaped pieces of materials with different coefficients of thermal expansion and exposing the joint to repeated fluctuations of temperature within a certain range. Thus, this study focuses on the intermetallic evolution of Sn-4Ag-0.5Cu on Ni/Au and Ni/Pd/Au surface finishes with thermal cycling up to 1000 cycles with the range of temperature varying from 10 to 80 °C. Sandwich samples were prepared by placing solder balls of Sn-4Ag-0.5Cu between two substrates of two different surface finishes: Ni/Au and Ni/Pd/Au. Optical microscope and FESEM (Field emission scanning electron microscope) were used to analyze the samples. From the study, it was observed that the intermetallic changes from $(Cu, Ni)_6Sn_5$ to $(Ni, Cu)_3Sn_4$ after 1000 thermal cycles for Ni/Au. These changes promote the formation of cracks at the solder joint because of the different mechanical properties between Ni-Sn based intermetallic and Cu-Sn intermetallics. However, for the Ni/Pd/Au surface finishes, no cracks formed after thermal cycling up to 1000 cycles. This shows that the reliability of the solder joint is higher for Ni/Pd/Au surface finishes in this experiment. Based on these results, it can be concluded that the reliability of the Ni/Pd/Au surface finishes with Sn-4Ag-0.5Cu solders is higher within the given condition of this research.

Keywords: Ni/Au; Ni/Pd/Au; lead free solders, thermal cyclic test; Sn-4Ag-0.5Cu.

INTRODUCTION

The Restriction of Hazardous Substances Directive (RoHS) issued by the European Union (EU) has been applied as a legal restriction since July 2006 [1]. One of the materials being mentioned as hazardous in this legislation is lead. In electronic packaging, lead is one of the core materials in the solders and surface finishes. The move to lead-free soldering has opened up the possibility for other surface finishes and solders options. It is necessary to make sure that the lead-free product is just as reliable as the established product, even in critical applications with very demanding environments [2]. However, assessment of solder joint reliability of electronic packages has become difficult because of the large number of components and materials involved in the package. Thus, identifying the failure mechanisms has become a challenge due to the various interactions of several factors.

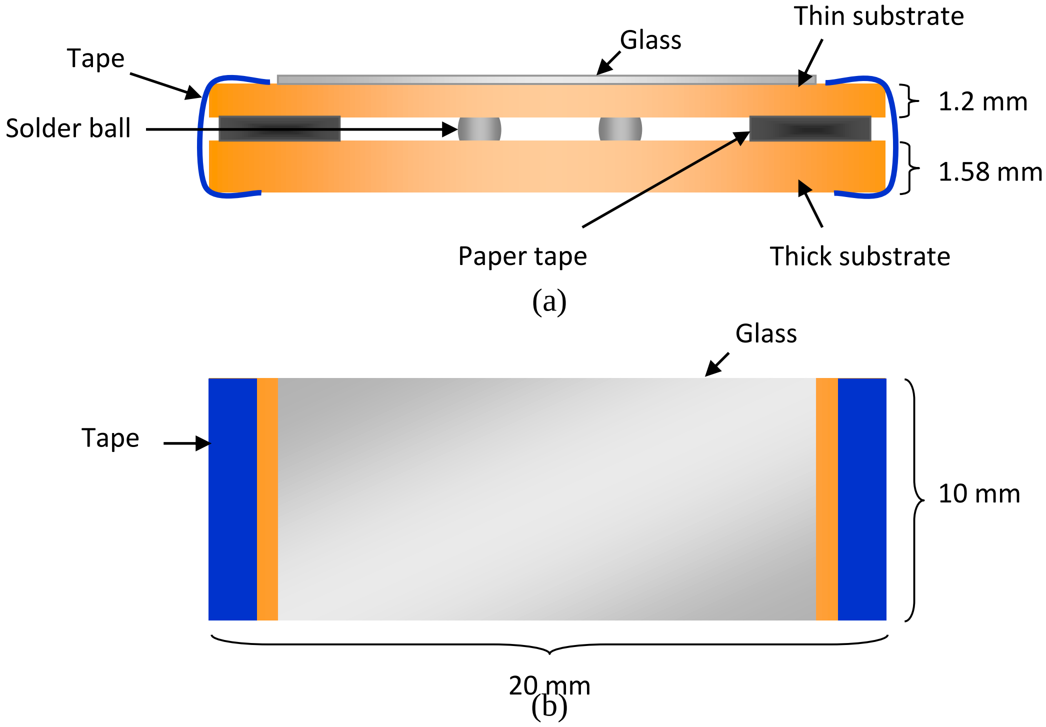
Reliability studies of electronic packages are the assessment of the capability of the solder joint to withstand the service conditions through accelerated testing methods. In thermal cycling experiment, the part is subjected to changes in temperature that is representative of the full range of temperatures encountered in the end use environment. Basically, in thermal cycling, the temperature is cycled from a maximum (T_{max}) to a minimum (T_{min}) value. Temperature is ramped from one temperature extreme to another at a controlled rate (referred to as the ramp rate). Temperature is also held at the maximum and minimum values for a predetermined time known as the dwell time [3]. Since normal operating scenarios may require too long a time to gain sufficient reliability data, the temperature cycling tests are usually designed to accelerate the failure process [4-6]. In this research, the impact of thermal cyclic test was studied to further understand the relationship between intermetallics and thermal cyclic for Sn-4Ag-0.5Cu on high phosphorus electroless nickel and immersion gold (Ni/Au) compared to electroless nickel electroless palladium and immersion gold (Ni/Pd/Au) surface finishes with the parameters given.

EXPERIMENTAL SET UP

In thermal cycle testing, sandwich samples were prepared for cyclic testing to determine the effect of fatigue failure purely by thermal stress. Solder joints were prepared by placing solder balls of Sn-4Ag-0.5Cu between two substrates of two different surface finishes: Ni/Au and Ni/Pd/Au. The bottom substrate has a thicker Cu layer than the top substrate. The purpose is to provide thermal stress in the sandwich sample. A thin slide of glass with a thickness of 0.13-0.17mm was glued on the top surface of the substrate with the thin Cu layer in order to obtain higher difference in thermal coefficients of expansion between the substrates. The schematic of the sandwich sample is shown in Figure 1. The prepared samples were put into the thermal cycling chamber for 200, 500 and 1000 cycles. The period of each thermal cycle was 2 hours, with the temperature varying from 10 to 80 °C. Failure analysis was performed after the thermal cycling through cross section analysis using optical microscopy and the types of intermetallics formed were analyzed using FESEM.

RESULTS AND DISCUSSION

Figure 2 shows crack initiation locations of solder joints on Ni/Au samples. No cracks were observed on either side of the solder joint model sample used up to 500 cycles. However, after 1000 cycles, cracks were observed to initiate in the solder joints at the edges as shown in Figure 2 (c – d) on both the thin and the thick Cu boards. In Figure 2, the Ni/Au surface finish on both sides resulted in the formation of intermetallic layers at both ends of the solder joint. On the thick Cu side of the solder joint, presence of blocky intermetallic particles formed on top of the interface intermetallic, while none of these particles was seen on the thin Cu board side. EDX analysis confirmed that these blocky particles were Ag_3Sn. This is probably expected as the cooling rate on the thick Cu board side is slower than that on the thinner board side, since a slower cooling rate promotes the growth of the blocky-type Ag_3Sn [7, 8].



(a)

(b)

Figure 1. Thermal cycle fatigue sandwiches sample: (a) cross section, (b) top view

Based on previous researchers' comments on the mechanical properties of Cu_6Sn_5-based intermetallic and Ni_3Sn_4-based intermetallic, Ni_3Sn_4 is believed to be mechanically less favorable than Cu_6Sn_5 due to the lower fracture toughness [9]. Therefore, it has a higher risk for brittle failure. Alloying of Cu in Ni_3Sn_4 or Ni in Cu_6Sn_5, however, alters the mechanical properties of the respective intermetallic compounds. The morphology also plays a role in the formation of cracks. Incorporation of Cu into the Ni_3Sn_4 intermetallics changes the morphology to adhere more to the electroless Ni–P layer [10]. The incorporation of Cu may also improve the ductility of the Ni_3Sn_4 compound [10]. Figure 3 shows the SEM cross-sectional views of intermetallic morphology after 200 cycles. The intermetallics that formed on both sides of the solder joint are $(Cu, Ni)_6Sn_5$ with some Ag_3Sn on the thick board side. The intermetallic has the scallop-like morphology and its thickness varies between the centre and edges of the joints, being thicker at the edge and thinner at the centre. This effect is supposed to occur only in smaller solder joints, but in large solder joints, this edge effect is not as evident [11]. Although the solder size that was used here is Ø 700 µm solder size, the effect of different intermetallic thickness between centre and edge was observed. This is probably due to the hour glass shape of the solder joint after reflow as can be seen in Figure 2 (a). The hour glass shape has thin layers of solder at the edges and this promotes faster heating and cooling rates [12]. Since the samples were then heated and cooled several times, the intermetallic at the edges grew faster than the intermetallic in the middle, and since the solder bulk here is thinner, this will be the weakest spot in the solder joint.

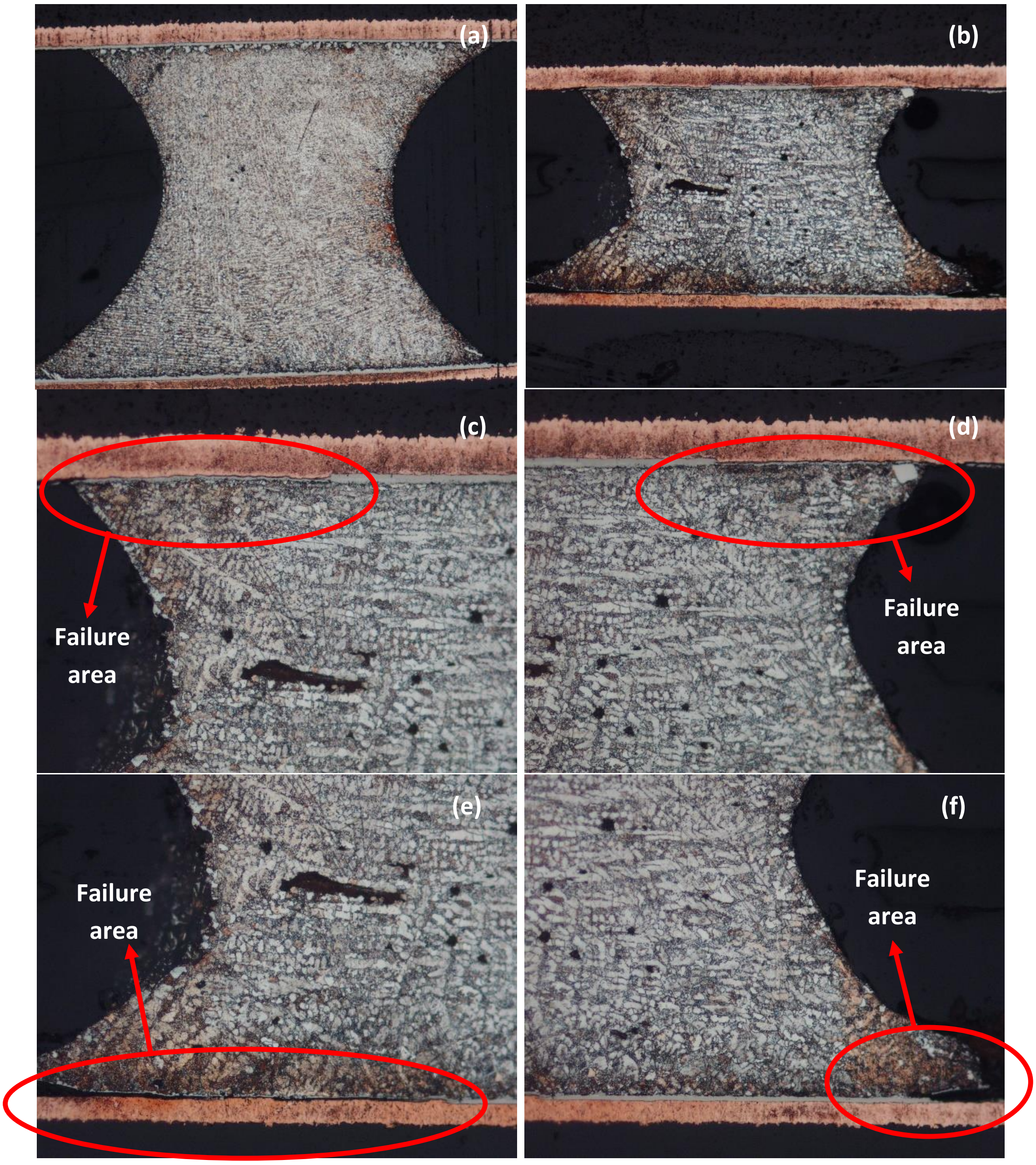


Figure 2. Cross-section pictures for Ni/Au with Sn-4Ag-0.5Cu solder, after thermal cycle testing; (a) 200 cycles mag 100x, (b) 1000 cycles mag 100x, (c) 1000 cycles mag 200x, thick Cu left, (d) 1000 cycles mag 200x, thick Cu right, (e) 1000 cycles mag 200x, thin Cu left, and (f) 1000 cycles mag 200x, thin Cu right.

Figure 4 shows the cross-sectional views of the solder joints after 1000 cycles. With continuous thermal ageing, the $(Cu, Ni)_6Sn_5$ intermetallic which formed after reflow has now transformed into a more planar $(Ni, Cu)_3Sn_4$ intermetallic after 1000 cycles. Since $(Ni, Cu)_3Sn_4$ is more brittle than Cu-rich intermetallic, it explains why cracks initiated and propagated at the corners or edges of the solder joints.

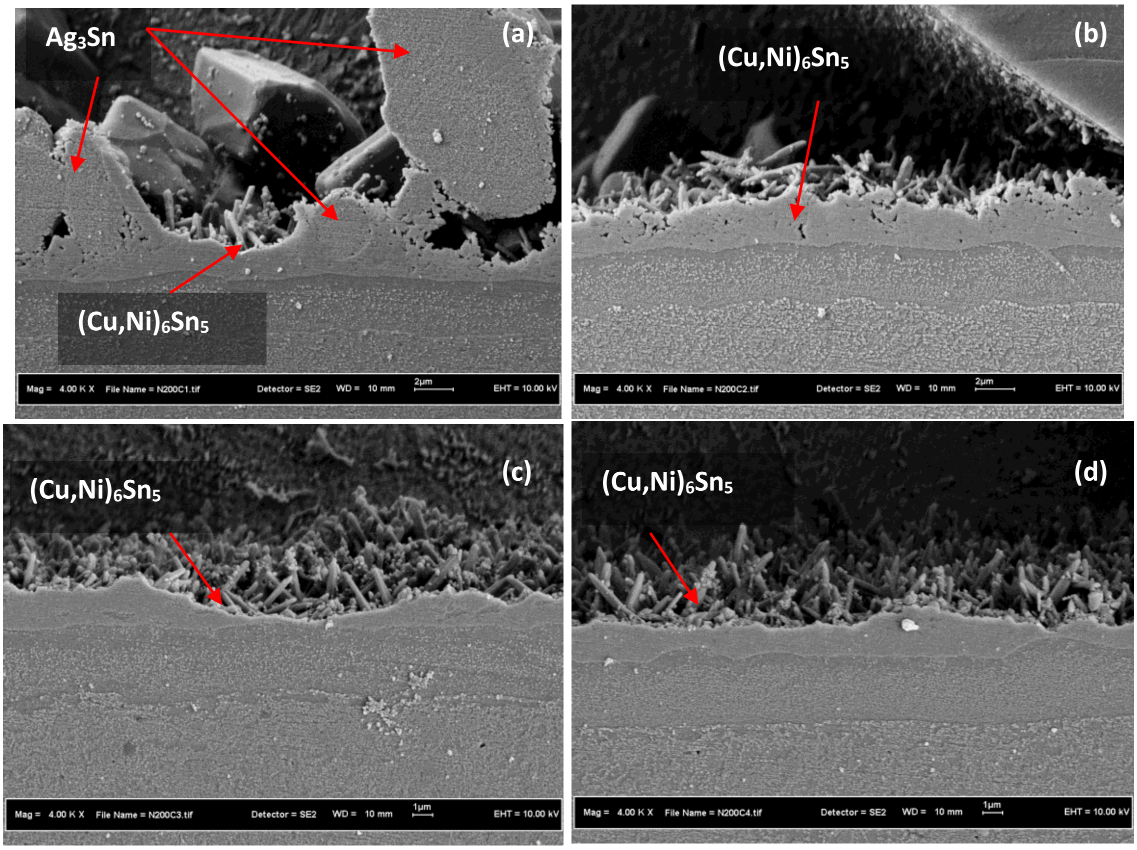


Figure 3. Cross-section pictures for Ni/Au with Sn-4Ag-0.5Cu solder; after 200 cycles, mag 4000x; (a) thick Cu board middle, (b) thick Cu board edge, (c) thin Cu board middle, and (d) thin Cu board edge.

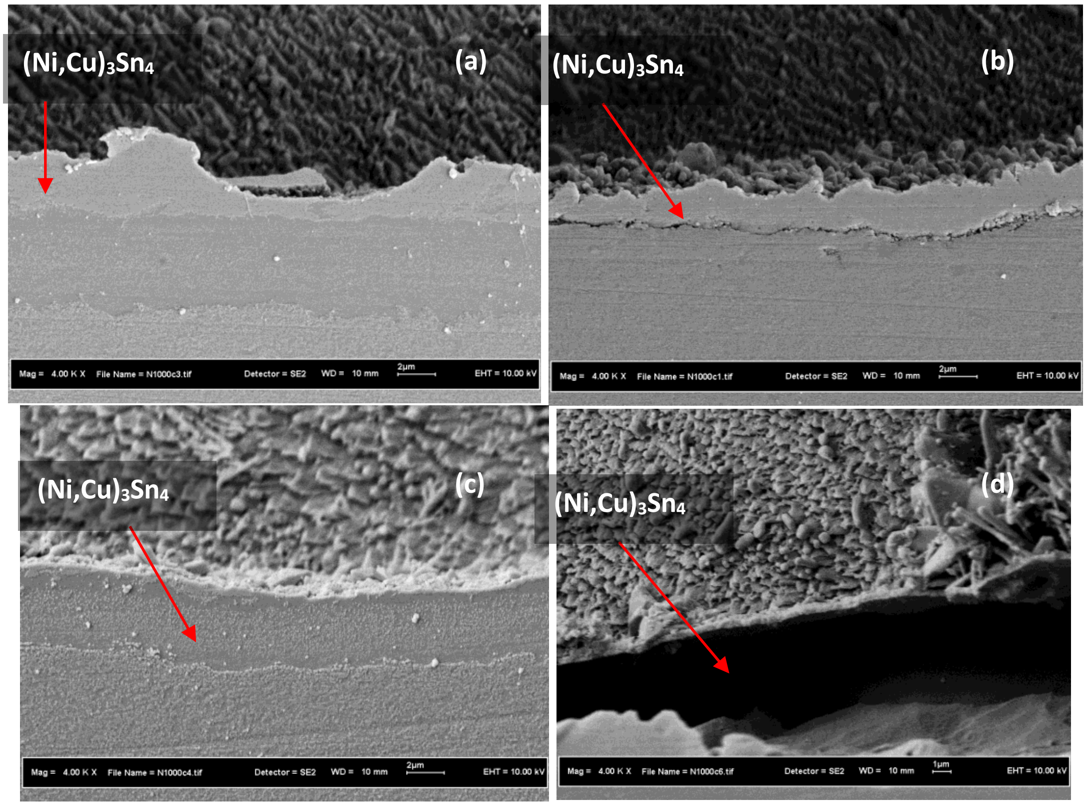
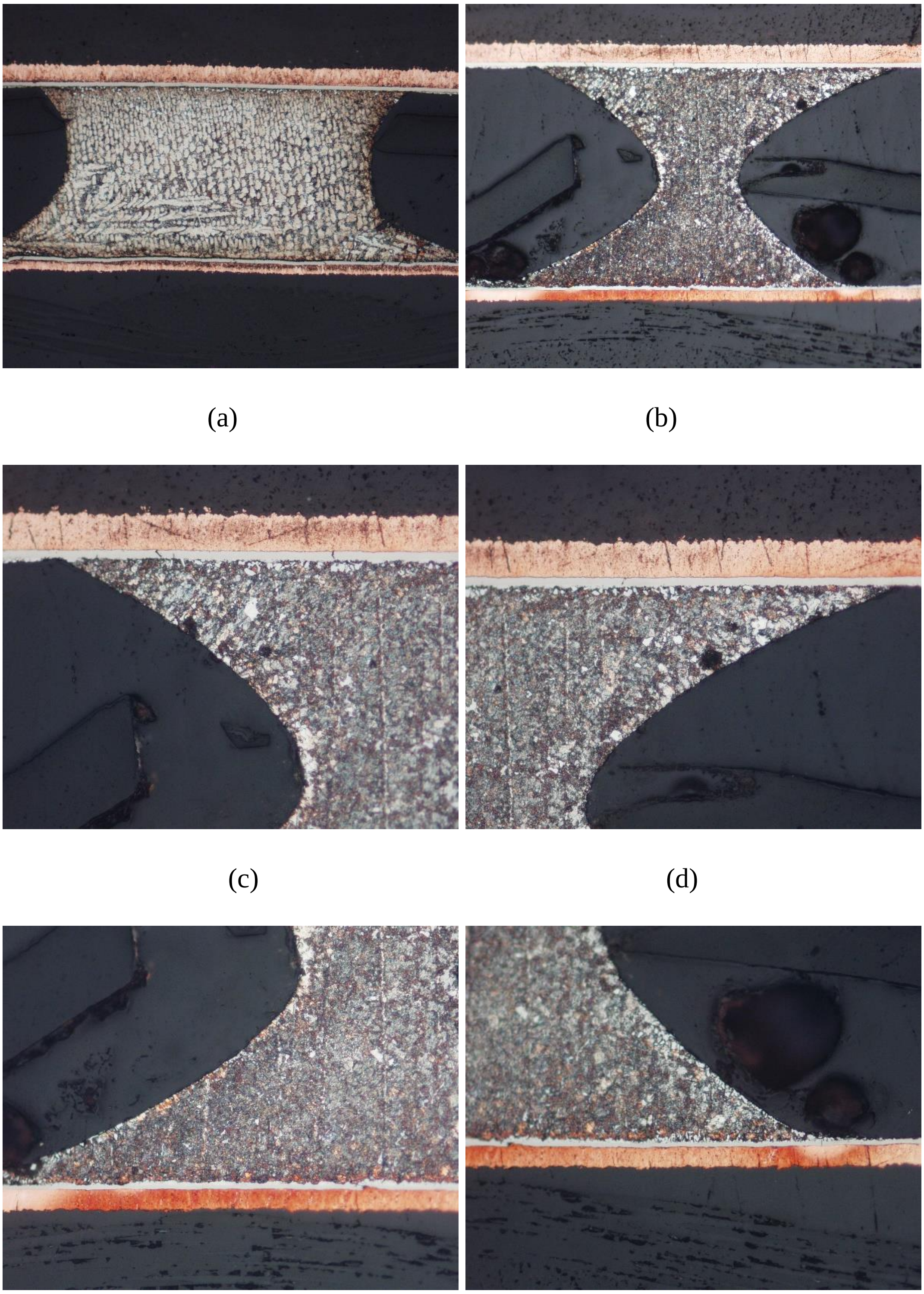


Figure 4. Cross-section pictures for Ni/Au with Sn-4Ag-0.5Cu solder, after 1000 cycles, mag 4000x; (a) thick Cu board middle, (b) thick Cu board edge, (c) thin Cu board middle, and (d) thin Cu board edge.



(a) (b)

(c) (d)

(e) (f)

Figure 5. Cross-section pictures for Ni/Pd/Au with Sn-4Ag-0.5Cu solder, after thermal cycle testing; (a) 200 cycles mag 100x, (b) 1000 cycles mag 100x, (c) 1000 cycles mag 200x, thick Cu left, (d) 1000 cycles mag 200x, thick Cu right, (e) 1000 cycles mag 200x, thin Cu left, and (f) 1000 cycles mag 200x, thin Cu right.

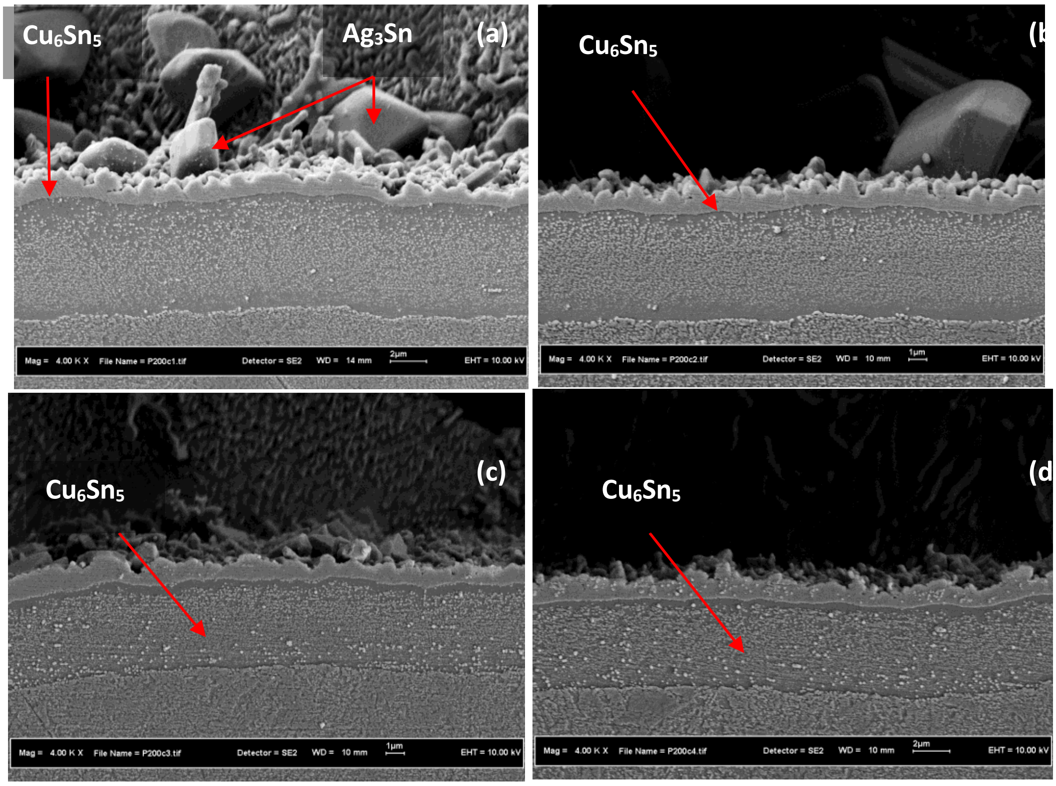


Figure 6. Cross-section pictures for Ni/Pd/Au with Sn-4Ag-0.5Cu solder, solder size Ø 700 µm after 200 cycles, mag 4000x; (a) thick Cu board middle, (b) thick Cu board edge, (c) thin Cu board middle, and (d) thin Cu board edge

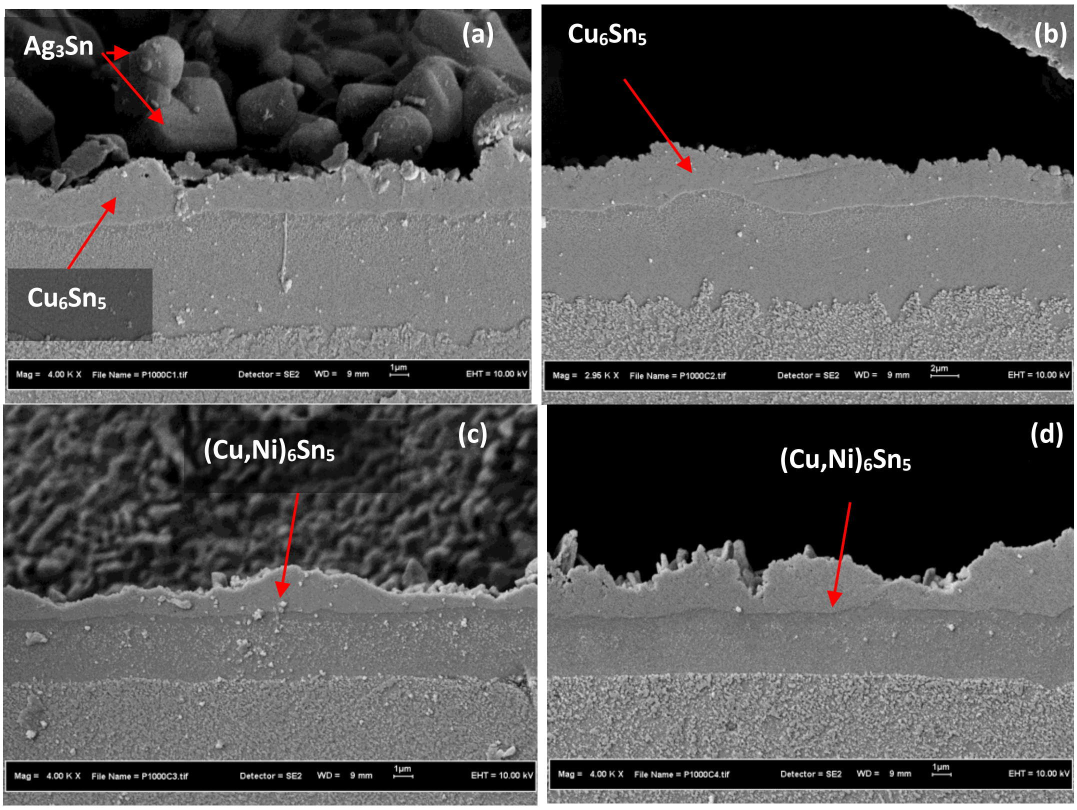


Figure 7. Cross-section pictures for Ni/Pd/Au with Sn-4Ag-0.5Cu solder, solder size Ø 700 µm after 1000 cycles, mag 4000x; (a) thick Cu board middle, (b) thick Cu board edge, (c) thin Cu board middle, and (d) thin Cu board edge.

CONCLUSIONS

In this study, Ni/Au surface finish failure analysis of tested solder joints showed that cracks start to initiate at the solder joint edges between intermetallic interface and the surface finish after 1000 cycles. Furthermore, Ag_3Sn intermetallics were observed to form at the interface on the thick substrate side because of the slower cooling rate. The intermetallic also changes from $(Cu, Ni)_6Sn_5$ to $(Ni, Cu)_3Sn_4$ after 1000 thermal cycles for Ni/Au. This promotes the formation of cracks because the Ni-Sn based intermetallic is more brittle than the Cu-Sn intermetallic and the cracks formed at the edges of the solder ball because it is the weakest spot of the solder joints. There are no crack formation after thermal cycling of 1000 cycles on Ni/Pd/Au surface finish and the intermetallic changes from Cu_6Sn_5 to $(Cu, Ni)_6Sn_5$ at the thin board side of Ni/Pd/Au after 1000 thermal cycles. Based on these results, it can be concluded that the reliability of the Ni/Pd/Au surface finishes with Sn-4Ag-0.5Cu solders is higher within the given condition of this research.

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