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Wettability of Lead-Free Solders on Gold-Plated Copper Substrates

Ngoc Binh Duong[2], Tadashi Ariga[1], Luay Bakir Hussain[2] and Amad Badri Ismail[2]

[1]*Department of Materials Science, School of Engineering, Tokai University, Hiratsuka 250-1292 Japan*
[2]*School of Materials and Minerals Resources Engineering, University Sains Malaysia, Malaysia*

Wettability of lead-free solders (Sn-3Ag-0.5Cu, Sn-8Zn-3Bi, and Sn-9Zn) on Au-plated copper substrate was investigated with three different thicknesses of Au layer (0.1 µm, 0.3 µm, and 0.5 µm). The contact angles of solder alloys did not show a dependence on Au thickness. The contact angles of Sn-3Ag-0.5Cu and Sn-9Zn decreased, whereas the contact angle of Sn-8Zn-3Bi remained constant with an increase in temperature. Wetting balance test results indicated that thickness of Au plating affects wetting force, with thinner plating showing stronger wetting force and therefore, lower wetting time. Effects of different fluxes on wettability were also studied.
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1. Introduction

Solder is used to connect devices to printed circuit boards (PCB) in microelectronics.[1)] In the soldering process, a metallurgical bond is formed between the molten solder and a metal surface. Thus, the ability of the molten solders to flow or spread on the metal is important for the formation of a strong metallurgical bond. The phenomenon of a fluid spreading on a surface is also referred to as wetting.

When solder joints are used to connect a electrical device and a substrate, the areas of the substrate surface that are in direct contact with the solder are required to be coated with a surface finish.[2)] Various types of surface finishes have been developed. These surface finishes are composed of a wetting layer to enhance wetting with the solder and a diffusion barrier layer to avoid excessive reaction between the substrate and the solder.

In recent years, Ni/Au coatings have been extensively used as a surface finish on PCB due to its good wettability and slow reaction rate with solder alloys.[3)] The surface Au layer, with a thickness of 0.2–1.0 µm, provides protection from oxidation and is usually deposited by electroplating. The Ni layer, with a thickness of 5–10 µm, is also deposited by electroplating. The function of the Ni layer is to prevent rapid reaction between the solder and the Cu layer[3)] of the PCB.

Ni coating provides flat and uniform surfaces, especially on uneven substrate surfaces. Applied together with Au, it maintains good wettability even after multiple reflows and provides high via strength due to higher mechanical strength and fatigue resistance compared to Cu. Furthermore, the Ni layer serves as a barrier layer between solder and Cu to prevent the dissolution of Cu, and thereby retards the excess growth of Cu–Sn intermetallic compounds (IMCs).

In this study, the wetting behavior of lead-free solders on Au-plated copper substrate was examined. The experiments included wetting balance tests and contact angle measurements of three lead-free solders (Sn-3Ag-0.5Cu, Sn-8Zn-3Bi, and Sn-9Zn) on oxygen free high conductivity (OFHC) copper substrates with Ni/Au surface finish.

2. Experimental Procedures

The wetting balance tests were performed using a SAT5100 (Rhesca Co., LTD. Japan) equipped with data acquisition software. Before testing, Au-plated substrates with the dimensions of $10 \times 30 \times 0.3$ mm were washed with acetone in an ultrasonic bath for 2 min.

Contact angles were measured via a spreading method. Solder paste was placed on the Au-plated substrates using a steel mask to mount the paste. The specimens were then maintained at the testing temperature for 30 s. Next, the specimens were allowed to cool down in air (typical specimen is shown in Fig. 1(a)) and a cross-section (Fig. 1(b)) was obtained for the contact angle measurement.

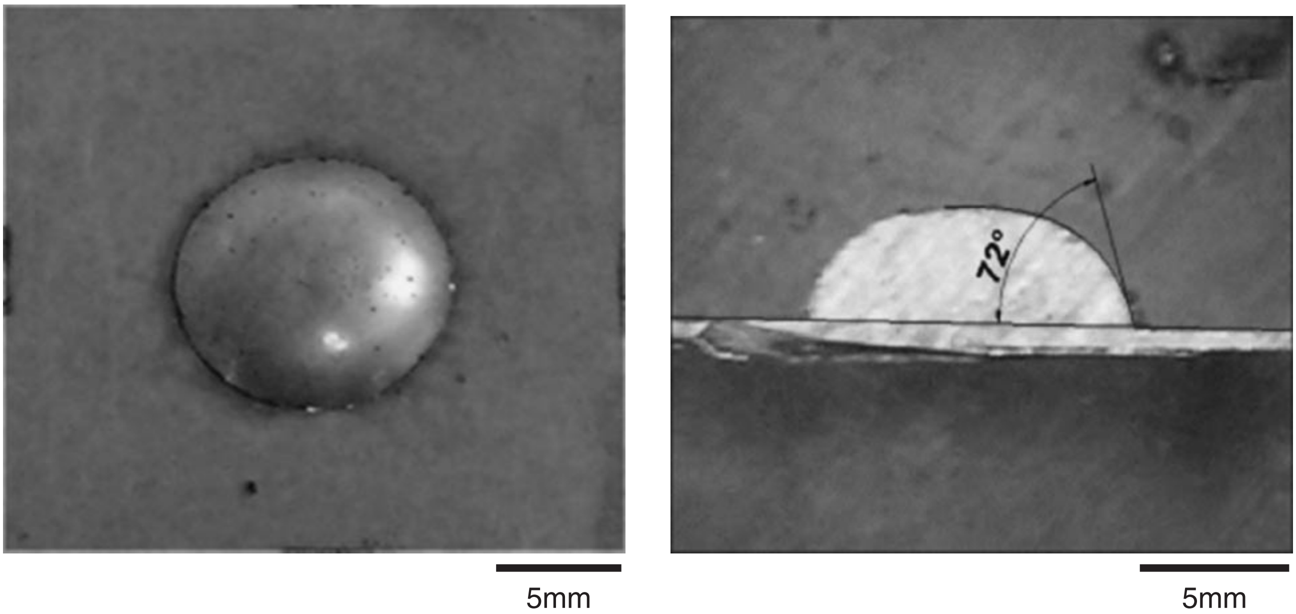
The solder pastes were purchased from Nihon Almit Co., LTD. Japan and contained 12% of RMA-2 (Rosin Mild Activate, Type2) flux. Au-plated substrates with the dimension of $30 \times 30 \times 0.3$ mm were used in these measurements. In present experiment, 2 kinds of flux of RMA-1 and RMA-2 was used. The activity of the flux RMA-1 is higher than RMA-2. Three types of substrates with different Au layer thicknesses (0.1, 0.3, and 0.5 µm) were used in both experiments. Hereafter they are referred to as Au0.1, Au0.3, and Au0.5 substrates.

3. Results and Discussion

3.1 Wetting balance

Figure 2 shows a typical wetting force curve obtained from the wetting balance test. In this curve, two important parameters are used as wettability indices: wetting time (t_1) and maximum wetting force (F_{max}). Wetting time is defined as the time for the meniscus to pass through a contact angle ($\theta = 90°$) or for the measured wetting force to decrease to zero. The maximum wetting force is obtained when the meniscus is stabilized after immersion and the measured force remained constant.

Wetting balance test results of Sn-3Ag-0.5Cu with the RMA-2 flux are shown in Fig. 3. All three substrates showed an increase in F_{max} and decrease in t_1 as the temperature is increased. F_{max} increased from 4.53 to 7.61 mN and t_1



(a) (b)

Fig. 1 Contact angle measurement. a) Solder on copper substrate, b) Cross-section.

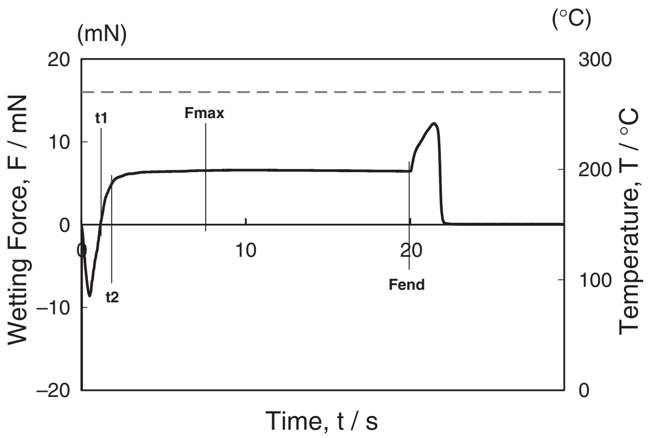
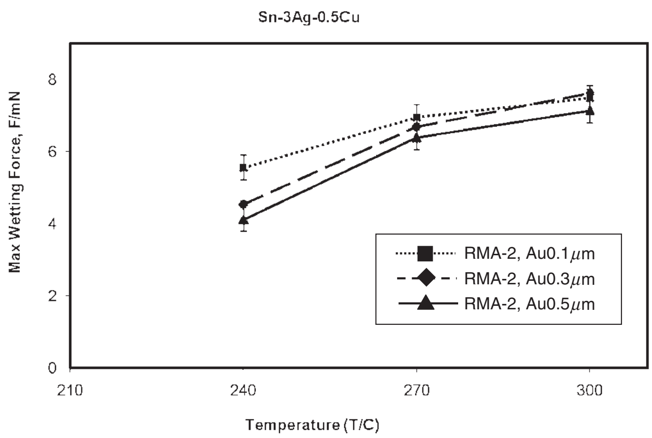
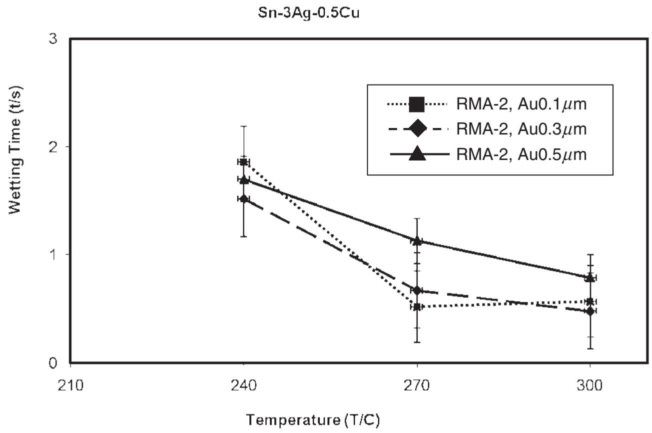


Fig. 2 Wetting force curve of Sn-8Zn-3Bi at 280°C with Au0.1 substrate.



(a)



(b)

Fig. 3 (a) Maximum wetting force of Sn-3Ag-0.5Cu. (b) Wetting time of Sn-3Ag-0.5Cu.

decreased from 1.52 to 0.48 s as the temperature increased from 240 to 300°C (Au0.3). The variation of Au-layer thickness showed a small effect on wettability of the alloy. Under identical testing conditions, wettability of the alloy was better with the Au0.1 substrates than with the Au0.5 substrates. As indicated in Fig. 3, F_{max} obtained with the Au0.1 substrate was higher than that with the Au0.5 substrate. The difference reduced as the temperature increased; at 240°C the difference between F_{max} of Au0.1 and Au0.5 was 1.44 mN, and it reduced to 0.35 mN at 300°C.

The F_{max} and t_1 of Sn-9Zn are shown in Fig. 4. F_{max} of Sn-9Zn increased greatly as the temperature increased from 220 to 280°C. F_{max} obtained with Au0.1 substrate at 280°C (about T_m (Melting Temperature) + 80°C) was more than four times of that at 220°C (about T_m + 20°C). However, further increase in temperature did not lead to a further

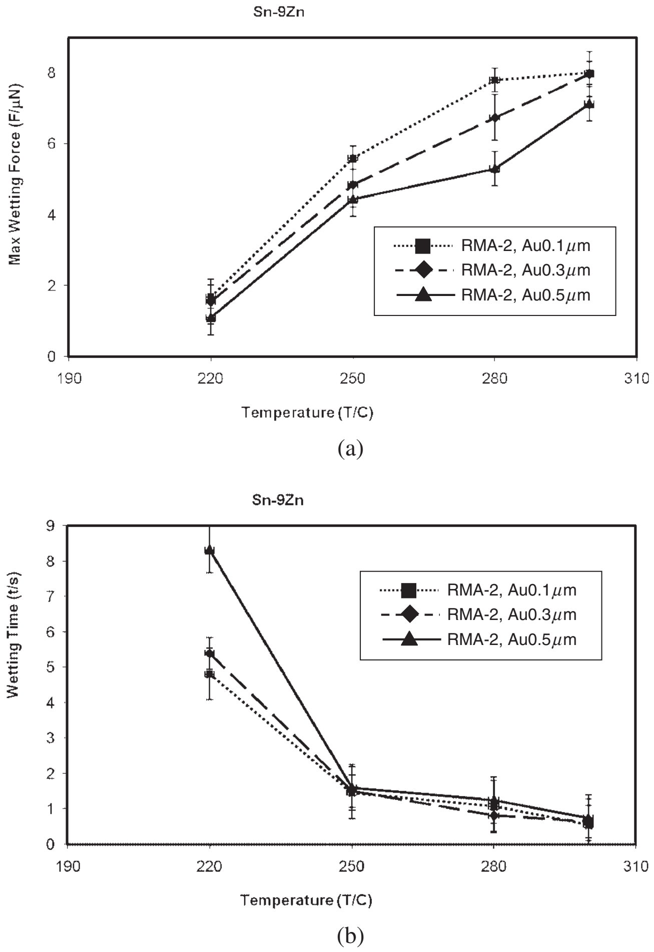


Fig. 4 (a) Maximum wetting force of Sn-9Zn. (b) Wetting time of Sn-9Zn.

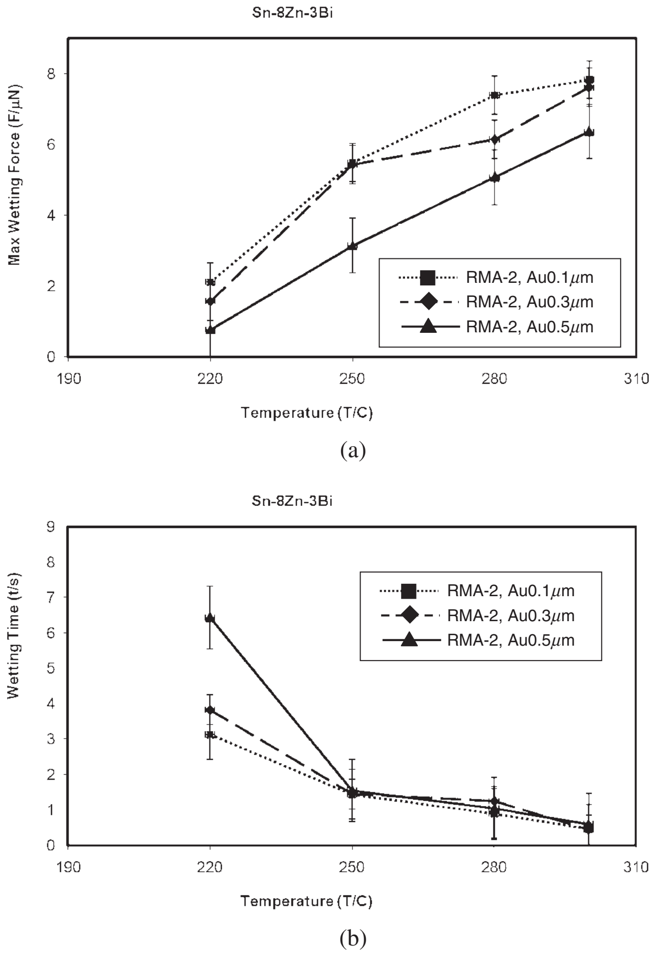


Fig. 5 (a) Maximum wetting force of Sn-8Zn-3Bi. (b) Wetting time of Sn-8Zn-3Bi.

increase in F_{max} as there was almost no difference between F_{max} at 280°C and at 300°C. Similar type of behavior was observed for t_1; it sharply decreased and reached a minimum of 0.6 s at 280°C.

Au-layer thickness also showed a small effect on wettability of Sn-9Zn. Similar to the Sn-3Ag-0.5Cu alloy, Sn-9Zn showed better wettability with thinner Au plating. Results obtained with Sn-8Zn-3Bi were similar to those of Sn-9Zn. F_{max} of Sn-8Zn-3Bi on Au-plated substrates clearly increased as the temperature increased (Fig. 5). F_{max} increased sharply up to 280°C and remained constant at higher temperatures. Highest F_{max} obtained was 7.83 mN at 300°C (Au0.1 substrate) and lowest t_1 was 0.46 s (also with Au0.1 substrate). Thus, Au-thickness showed a small effect on wettability of Sn-8Zn-3Bi.

In order to study the effect of fluxes, wetting balance test was also conducted with RMA-1 (Rosin Mild Activate, Type-1) flux. The results obtained with the RMA-1 flux are shown in Figs. 6 and 7.

Different fluxed showed different effects on solders. The RMA-1 flux resulted in slightly better wettability on Sn-3Ag-0.5Cu at low temperature (Fig. 6(a)). F_{max} of Sn-3Ag-0.5Cu recorded at 240°C with the RMA-1 flux (6.86 mN, Au0.1) were higher than those with the RMA-2 flux (5.55 mN, Au0.1). However, at higher temperatures, those values had a smaller difference between them (RMA-1, 7.28 mN, Au0.1; RMA-2, 7.48 mN, Au0.1). Variation of Au-layer thickness showed an effect similar to the RMA-2 flux case; thinner Au-layers had better wettability. The difference between F_{max} was 1.5 mN at 240°C (Au0.1 and Au0.5) and this difference reduced to 0.1 mN as the temperature increased to 300°C. In case of Sn-8Zn-3Bi, however, the RMA-1 flux resulted in a decrease in wettability compared to the case when the RMA-2 flux was used. Wetting was not observed at 220°C with Au0.3 and Au0.5 substrates (Fig. 6(b)). The use of the RMA-1 flux also caused the wettability to vary significantly with Au-layer thickness. F_{max} increased when Au-layer thickness decreased. At 220°C, while wetting was not observed with Au0.3 and Au0.5 substrates, wetting was observed with Au0.1 substrate. When temperature was increased to 250°C, F_{max} still showed significant differences; F_{max} recorded with Au0.1 substrate (6.56 mN) is almost thrice of F_{max} recorded with Au0.5 substrate (2.27 mN).

Results obtained with Sn-9Zn were similar to those with Sn-8Zn-3Bi. Wetting was not observed at 220°C for all the three substrates. F_{max} measured with Au0.1 substrate was also significantly higher than those with Au0.5 substrate. The difference remained significant even at higher temperatures; at 300°C, F_{max} recorded with Au0.1 substrate (7.96 mN) was nearly twice of that recorded with Au0.5 substrate (4.93 mN).

The different thicknesses of Au-plated layers result in a

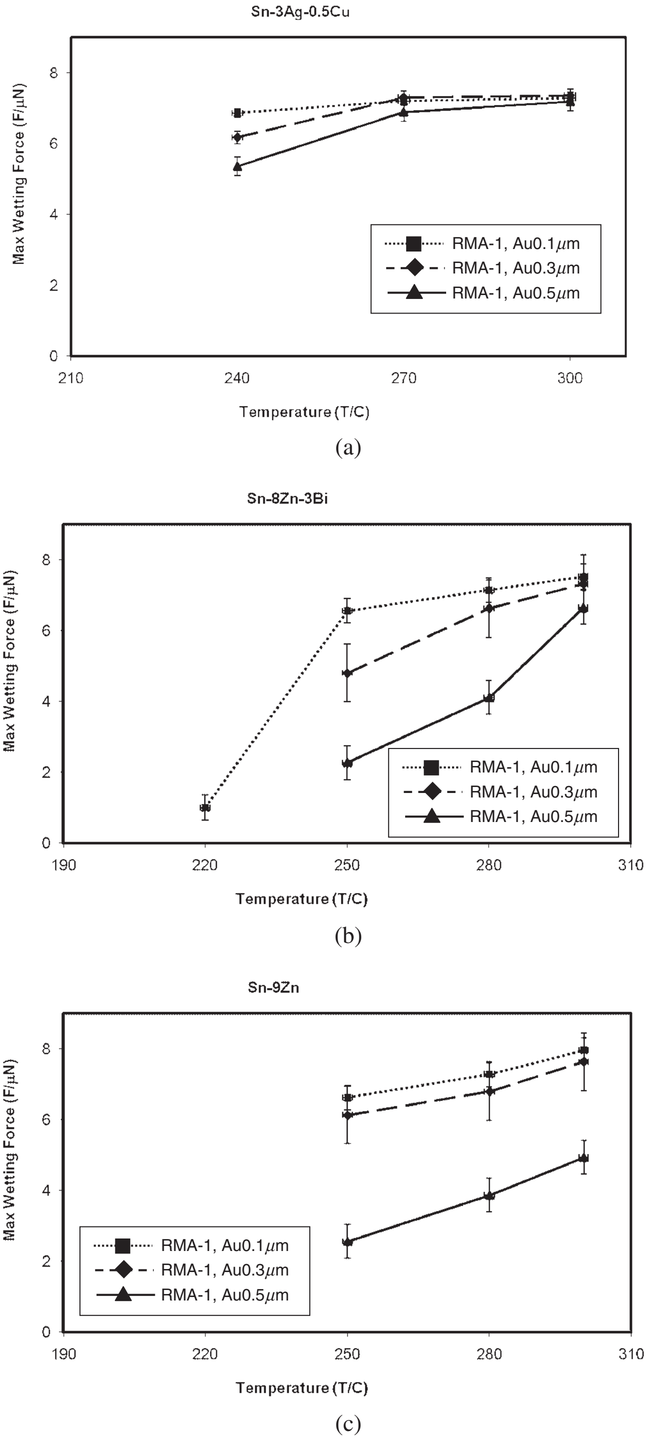


Fig. 6 Maximum wetting force of lead-free solders with RMA-1 flux.

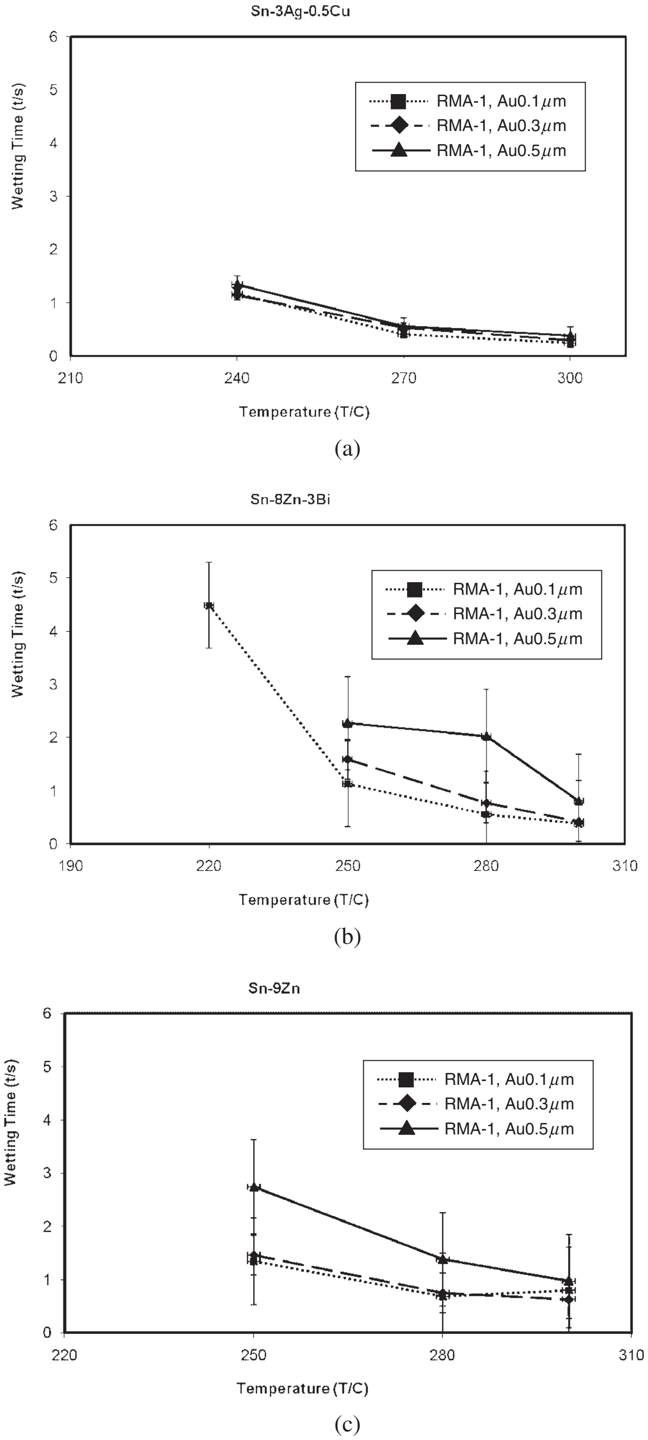


Fig. 7 Wetting time of lead-free solders with RMA-1 flux.

small difference in the interfacial energy between the liquid solder and the substrate, and this resulted in variation of F_{max}. This effect could be explained by the dissolution of Au into molten solder. When the substrate is in contact with the molten solder, the Au layer may partially dissolve. This causes the surface area in contact with solder to be a combination of Au and Ni, and therefore, interfacial energy between the solder and the substrate changes. This effect is prominent for thinner Au layers because in those films it is easier for Ni to be present at the interface, causing a stronger effect on the interfacial energy.

3.2 Contact angle measurement

Contact angles measurement was performed at three temperatures for each solder. The results obtained are shown in Fig. 8.

Figure 8(a) shows the contact angles measured for Sn-3Ag-0.5Cu. The contact angle decreased from 22° at 240°C to 8° at 300°C as the temperature increased. The thickness of Au-plated layer had no effect on contact angle, as indicated in Fig. 8. Figure 8(b) shows the contact angles measured for Sn-8Zn-3Bi from 220 to 280°C. The increasing of temperature had no effect on the contact angle as it remained

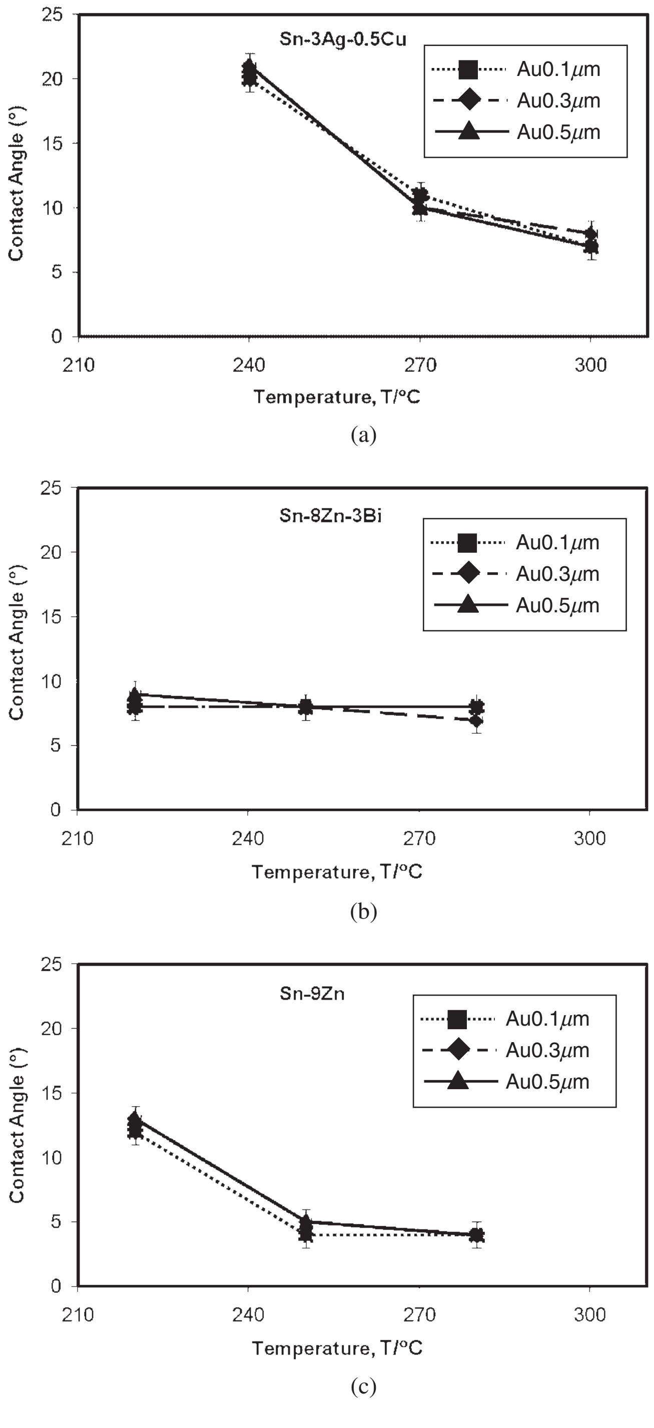


Fig. 8 Contact angle of lead-free solders.

constant at around 8°. The contact angle did not show a variation with Au-layer thickness as well. The contact angles measured for Sn-9Zn solder are shown in Fig. 8(c). The angles decreased from 13° at 220°C to 4° at 280°C as the temperature increased. The contact angle did not show a variation with Au-layer thickness.

As can be seen in Fig. 8, temperature had different effects on contact angles of lead-free solders. Increase in temperature resulted in a decrease of contact angles in case of Sn-3Ag-0.5Cu and Sn-9Zn, but it had no effect on the contact angle of Sn-8Zn-3Bi.

Under similar testing conditions, for the Au–Ni plated substrate, increase in temperature resulted in a decrease of contact angles; however, for the OFHC copper substrate, contact angles were relatively insensitive to the test temperature. It was also reported that fluxes also influence the effect of temperature.[4)]

4. Conclusions

Wetting behaviors of lead-free solders (Sn-3Ag-0.5Cu, Sn-8Zn-3Bi, and Sn-9Zn) on Au-plated copper substrates were investigated for two different fluxes.

The thickness of Au-plated layer showed an effect on the wetting force and wetting time of solder alloys; however, it did not show any effect on the contact angles of solder alloys.

Temperature had no effect on the contact angle of Sn-8Zn-3Bi; however, it showed an effect on the contact angles of Sn-3Ag-0.5Cu and Sn-9Zn. The contact angle of Sn-3Ag-0.5Cu and Sn-9Zn decreased as the temperature increased.

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REFERENCES

1) M. Abtew and G. Selvaduray: Materials Science and Engineering Reports, **R27** (2000) 95–141.
2) Y. L. Lin, W. C. Luo, Y. H. Lin, C. E. Ho and C. R. Kao: J. El. Mater. **33** (2004) 1092–1097.
3) C. E. Ho, R. Zheng, G. L. Luo, A. H. Lin and C. R. Kao: J. El. Mater. **29** (2000) 1175–1181.
4) M. F. Arenas, M. He and V. L. Acoff: J. El. Mater. **35** (2006) 1530–1536.