Malaysian Journal of Microscopy Vol.8 (2012) pg. 102-106

MICROSTRUCTURE AND MECHANICAL PROPERTIES OF Sn-3Ag-0.5Cu ALLOY CONTAINING Fe, Ce AND Sb ON Cu SUBSTRATE

A. S. Anasyida*, N. M. Sharif and C. L. Teh

School of Materials and Mineral Resources Engineering, Engineering Campus, Universiti Sains Malaysia, Nibong Tebal 14300 Pulau Pinang.

Sn-Ag-Cu solder is the mostly likely candidate for replacement of SnPb solder compared with other solder alloys. In order to further enhance the microstructure and properties of the SnAgCu solder alloy, this study was carried out to investigate the effect of adding alloying element Fe, Ce and Sb into the SnAgCu solder. The results showed that the addition of Ce and Sb results in reduction of grain size and IMC thickness. Sample 3 which contains alloying element Fe and Ce was found to have the highest tensile strength.

Keywords : Lead free solder, microstructure, tensile strength, alloying element

INTRODUCTION

Solder plays a crucial role for the interconnection and packaging of all electronic devices and circuits. It provides electrical, thermal and mechanical functions. Due to the toxicity of the lead, the electronic industries are moving towards using a lead-free solder. The most widely used lead-free solder is SnAgCu near-eutectic alloys. This is due to its relatively low melting point as compared with SnAg binary alloy and its superior mechanical properties as well as good solderability. However many problems of Sn-Ag-Cu still exist, such as large brittle intermetallic phases and high cost [1]. The formation of intermetallic compound (IMC) is crucial in forming reliable solder joints. However, the growth of interfacial IMC while the solder is in the solid state is of great concern because of the brittleness of IMC [2]. If it becomes a significant fraction of the solder joint, it can act as a site for crack initiation and propagation when the joint is deformed [3].

The challenge is even greater as the electronic devices such as notebook computer and cellular phones are required to be thin and small with complicated function. Thus, the electronic industry has to copy with these changes, providing the necessary miniaturization of these electronics devices and ability to meet the required reliability. To support the changes, the interconnections provided by solder joints have become finer and finer in pitch size, and yet the reliability is maintained. In order to meet the present and future strength requirement, thus it is imperative to design and develop solders with higher mechanical properties. A viable way to enhance the performance of SnAgCu solder alloys is by incorporating the alloying elements such as rare earth, Bi, Sb, Fe, Ce, In, Co, Ga, Ni and Ge. The addition of Ce was significantly improved the wetting force as reported by Yu et al. [4]. This study was focus on development of SnAgCu solder alloy with addition of Sb, Ce and Fe and their effects on wetting behaviour, microstructure and mechanical properties of SnAgCu alloy with Cu coated substrate.

MATERIALS AND METHODS

Solder alloys were prepared from pure metals, tin (99.99%), silver (99.99%) and copper (99.99%). The alloys were melted in the furnace at 500 °C for 1 hours to produce solder alloys of Sn-3Ag-0.5Cu (wt.%). Then the alloying element of Fe, Ce and Sb were added in the following nominal composition (wt.%) as shown in Table 1. Although Fe, Ag, Cu, Sb and Ce have higher melting point, they dissolved readily in the molten Sn bath. The solder alloys were then cast into the ceramic mould with diameter of 6 mm. After that, the solder ball samples were attached on bare Cu through reflow process. The evaluation will include microstructure, wetting behaviour and elemental profiling analysis. The wetting of solder on the substrate was consequently measured using Vis PLUS Digital Imaging and Measurement system.Reliability of the solder joints will be evaluated using pull tests.

Table 1. Composition of the solder alloys

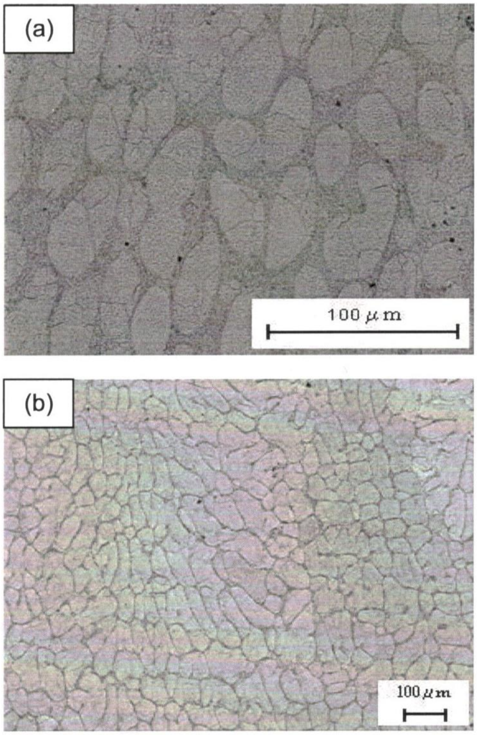
Samples	Solder Composition
1	Sn3.0Ag0.5Cu
2	Sn3.0Ag0.5Cu0.2Fe0.5Sb
3	Sn3.0Ag0.5Cu0.2Fe0.5Ce
4	Sn3.0Ag0.5Cu0.2Fe0.5Sb0.5Ce

**Corresponding author: Tel. + 6(04)5995216; Fax. + 6(04)5941011
E-mail.anasyida@eng.usm.my (Anasyida Abu Seman)*

RESULTS AND DISCUSSION

Bulk Solder Microstructure

Fig. 1 shows the microstructure of bulk solder alloys with addition of Fe, Ce and Sb. Fig. 1(a) shows typical microstructure of Sn-3Ag-0.5Cu alloy consisting of primary-Sn grains, eutectic structure particles and intermetallic compound. With addition of Fe and Ce to the Sn-3Ag-0.5Cu alloy, the microstructure of the bulk solder does not change significantly. According to Kang *et al.* [5], when alloying elements such as Fe and Co are added to the SAC solder system, more eutectic phases such as Ag_3Sn and Cu_6Sn_5 are produced due to the modification of the matrix structure. These additions also inhibit solder joint interfacial reactions to occur. As reported by Chen and Li [6], the properties of SAC305 solder were improved significantly as Sb is added into the solder. This is due to the dissolution of some Sb powders in the β-Sn matrix and some form $Ag_3(Sn,Sb)$. The remaining powders are said to dissolve in the IMC layer which consists of mainly Cu_6Sn_5 compound. Besides that, addition of Sb in the SAC305 solder also proved to have reduced the thickness and grain size of the IMC according to their findings.



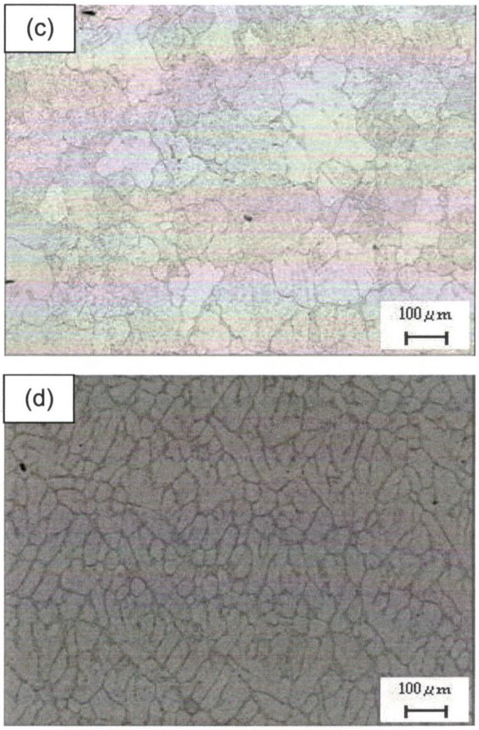


Fig.1. Microstructure of bulk solder alloys (a) Sample 1 , (b) Sample 2, (c) Sample 3 and (d) Sample 4

IMC Formation

Fig. 2 shows IMC formation between the SAC305 solder and the bare Cu substrate consists mainly of Cu_6Sn_5. The IMC shown have irregular metallic shapes unlike the solder which were added with alloying elements. The IMC thickness of solder alloys are shown in Table 2. Sample 1 showed the highest IMC thickness as compared to the other solders reflowed on the same substrate which indicated that the solder joint strength is the lowest. The scallop-like IMC can be observed at the solder/substrate interface consisting of Cu_6Sn_5 dendrites and Ag_3Sn eutectic compounds. When compared to the IMC thickness of Sample 1 in Table 2, the thickness of the IMC in Sample 3 is less than that of Sample 1. This is because the addition of Ce in SAC305 solder causes the microstructure to be refined and thus reducing the amount of Ag_3Sn phase. Finer IMC thickness contributes to better solder joint strength during the reliability testing. The addition of Ce in solder system containing Fe and Sb shows tremendous reduction of the IMC thickness at the solder/substrate interface from 4.094 µm to 3.890 µm. This means that addition of Ce can retard the effect of Sb by reducing the IMC thickness, making it less brittle and stronger.

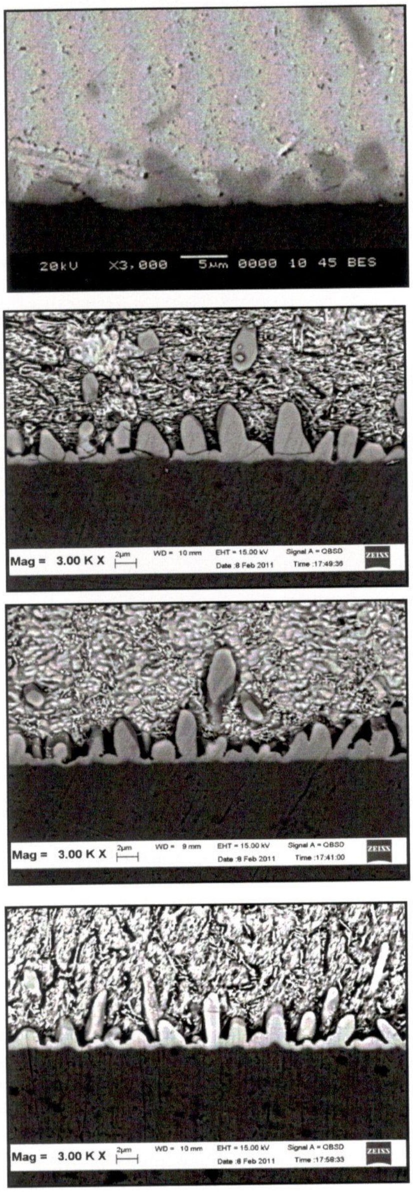


Fig. 2 SEM micrograph of IMC formation (a) Sample 1, (b) Sample 2, (c) Sample 3 and (d) Sample 4

Table 2.Thickness of IMCs formed for each solder alloys

Samples	Average thickness of IMCs (µm)
1	4.593
2	4.094
3	3.239
4	3.890

Wetting Angle

The formation of solder-to-base metal contact depends largely on the wetting process. This process does not differ a lot from the wetting of any solid by a liquid but the results of the wetting leads to solidification of the molten solder which forms a permanent bond at the solder/substrate interface. To measure the wetting capability of the solder, spreading test is applied whereby it is a type of quantitative test that involves the spreading of solder when melted on the surface of the substrate.

Fig. 3 shows the wetting angles results of the solder pellets reflowed on bare Cu substrates. Based on the Fig. 3, Sample 3 has the highest wetting angle (28.60°) followed by Sample 4 at (25.60°) and Sample 3 (25.00°). The lowest wetting angle is recorded by Sample 1 which is the SAC305 solder at 23.00°.

Based on Manko [7], total wetting occurs when θ is 0° while partial wetting is when θ is less than 180° and more than 0°. However, due to the short soldering time and the freezing of the system before reaching equilibrium, additional range of wetting information has been attained whereby a good wetting is obtained at $\theta < M$, with $M \leq 75°$. This proves that all samples reflowed on substrates exhibited good wetting as their wetting angles are between the ranges allowed.

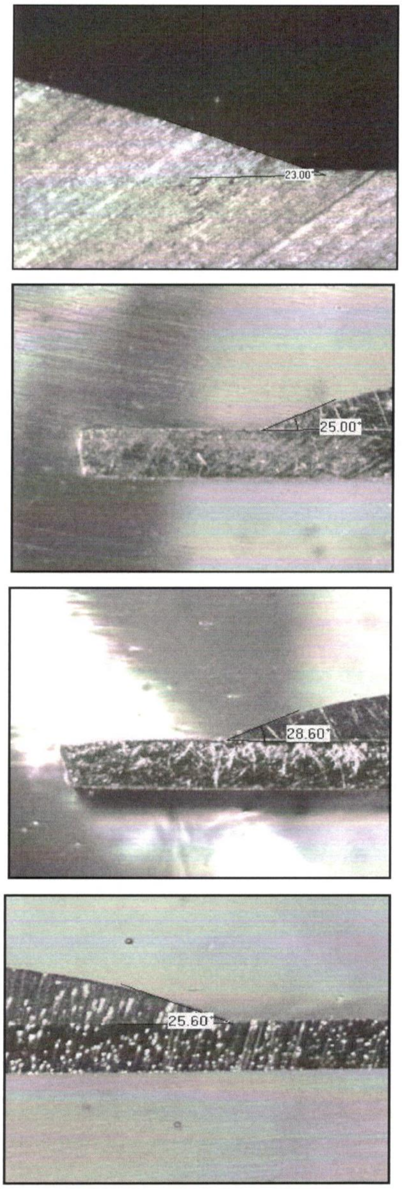


Fig.3. Wetting angles of solder alloy reflowed on Cu substrates (a) Sample 1, (b) Sample 2, (c) Sample 3 and (d) Sample 4

Ball Pull Test

For this reliability test, the solders reflowed on Cu substrates was subjected to the pull test in order to analyze the tensile strength behaviour of the different solder compositions. The strain rate for this testing was 10 mm/min with 5 kN load in room temperature. Table 2 shows the results of the tensile test on the solder alloys. Sample 3 showed the highest tensile strength at 47.959 MPa followed by Sample 4 with 29.655 MPa and Sample 2 with 29.325 MPa. The lowest tensile strength was shown by Sample 1 (25.575 MPa). The results showed that additions of 0.2Fe and 0.5Ce in SAC305 solder system (Sample 3) are able to improve the tensile strength of the solder joints as compared to 0.2Fe and 0.5Sb as alloying elements. Studies conducted by Gao *et al.* [8] have shown that addition of rare earth elements (Ce) will also improve the mechanical properties of soldered joints. Hence, with the addition of rare earth element such Ce in the SAC solder, the microstructure of the solder was refined which led to improved tensile properties as compared to the SAC305. Furthermore, addition of Fe and Ce into SAC alloys have been proven to reduce the possibility of brittle failure of the solder joint by allowing slow diffusion of Cu from the substrate. Hence, formation of brittle Cu_3Sn can be minimized and the possibility for void formation is also reduced [9].

Table 3. Tensile strength of the solder alloys on bare Cu substrates

Samples	Diameter (mm)	Area (mm^2)	Pull Stress (MPa
1	4.895	16.553	25.575
2	4.620	16.879	29.325
3	5.680	25.432	47.959
4	5.120	20.592	29.655

CONCLUSION

The bulk microstructure of SAC305 with additional alloying elements have smaller β-Sn grain size which contributed to better mechanical properties as compared to the SAC305 solder. The microstructure also consisted of Ag_3Sn and Cu_6Sn_5 in the Sn matrix which deteriorated the mechanical behavior of the solder. SAC305 solder with Fe and Ce as additional alloying elements has the highest tensile strength (48.911Mpa) when reflowed on NiP-coated substrate while the same composition but with bare Cu substrate has the highest shear strength (44.099Mpa).

ACKNOWLEDGEMENTS

This work is supported under Ministry of Higher Education Malaysia, through FRGS grant. The authors gratefully acknowledge the support provided by USM.

REFERENCES

[1] Xiao, W.M., Shi, Y.W., Lei, Y.P., Xia, Z.D. & Guo, F. (2006).*Journal of Electronic Materials* 35 (5), 1095-1103.

[2] Rizvi, M.J., Chan, Y.C., Bailey, C., Lu, H. & Islam, M.N. (2006). *Journal of Alloys and Compounds* 407, 208-214.

[3] Frear, D.R., Jang, J.W., Lin, J.K. and Zhang, C. (2001). *Journal JOM* 53(6), 28 – 32.

[4] Yu, D.Q, Zhao, J., Wang, L. (2004). *Journal of Alloys and Compounds*, 376(1-2), 170-175.

[5] Kang, S. K., Lauro, P. A., Shih, D. Y., Henderson, D. W. & Puttlitz, K. J. (2005). *IBM J. Res.& Dev,* 49, 607 – 620.

[6] Chen, B. L. & Li, G. Y. (2004). *Thin Solid Films,* 462-463, 395-401.

[7] Manko, H. H. (2001) *Solders and Soldering*, McGraw-Hill.

[8] Gao, L., Xue, S., Zhang, L., Sheng, Z., Ji, F., Dai, W., Yu, S.-L. & Zeng, G. (2010. *Microelectronic Engineering,* 87, 2025-2034.

[9] Andersson, C., Lai, Z., Liu, J., Jiang, H. & Yu, Y. (2005). *Materials Science and Engineering A,* 394, 20-27.