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Growth behavior of IMCs layer between Sn-3.0Ag-0.5Cu solder and Cu substrate during aging

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Abstract. Growth behavior of intermetallic compounds (IMCs) layer between Sn-3.0Ag-0.5Cu solder and Cu substrate were studied during aging at 150 ℃ for 1 day, 3 days, 6 days, 8 days and 10 days, respectively. Results shows that the IMCs layer is scallop shape at aging stage, and the aspect ratio of scallop shape decreases with time increasing. Moreover, the IMCs layer grows thicker with extended aging time. Furthermore, the IMCs layer grows linearly with square root of aging time, and the growth kinetic equation of Sn-3.0Ag-0.5Cu/Cu solder joints is obtained by linear fit, which is X = 1.94 +1.95t1/2. Finally, the diffusion coefficient D is verified as 3.8025μm2/d.

Key word: Intermetallic compounds, Sn-3.0Ag-0.5Cu solder, Aging, Thickness

INTRODUCTION

Solder joints play a critical role in electronics packaging, serving both as mechanical support for components and as electrical interconnections between the components and the board. Sn-Pb alloy has applied as solder deeply in individuals' mind over a long period of time. However, with the growing concerns about environment and folks' health, Sn-Pb alloy has attracted human's increasing attention due to the toxicity of lead.

However, as European Union Waste of Electrical and Electronic Equipment (UNWEEE) and RoHS (Restriction of Hazardous Substances) legislated strictly to prohibit the use of Pb in most electronic components, scholars have dedicated tremendous efforts on lead-free solders as a replacement of Sn-37Pb eutectic solder[1]. Most of them have focused on Sn-based alloys, they explored binary alloy including Sn-Bi, Sn-Zn, Sn-Cu, Sn-Ag etc. successively. However, in spite of the candidates of Sn-Pb alloy, there are still quite a few shortcomings in binary alloys, for instance, poor wettability, poor mechanical properties, high melting point, high cost, excessive growth of interfacial compounds, easy oxidation as compared to Sn-Pb eutectic alloys. Accordingly, scholars keep on exploiting tin-based alloys, for example, Sn-Cu-Bi, Sn-Ag-Zn, Sn-Ag-Cu alloy etc[2,3].

Among these alloys, Sn-Ag-Cu alloy is considered to be the most promising solder. As silver is noble metal, scholars try to decrease the content of Ag from Sn-3.8Ag-0.7Cu[4] to Sn-1.0Ag-0.5Cu[5] so as to reduce the cost of solder. Nevertheless, it should pay more attention to the performance of solder although it would be better that the solder with low cost. Consequently, we are intending to investigate the growth behavior of Sn-3.0Ag-0.5Cu alloy, the aim of the study is to obtain a moderate solder not only with good properties but also with low cost.

EXPERIMENTAL PROCEDURES

The commercial copper plates with dimensions of 15 mm×15 mm×3 mm were used as the substrates in this study as shown in Fig.1. The copper substrates were ground with silicon carbide paper and polished with 0.25μm diamond paste until a mirror surface was obtained. The prepared substrates were then dipped into 5% (by volume) nitric acid (HNO_3) to remove oxide layer. Sn-3.0 wt.%Ag -0.5 wt.% Cu solder paste was then placed on the substrates with a diameter of 5 mm as shown in Fig.1. Further, solder joints were formed with a F4N infrared reflow furnace. The specimens were reflowed at above liquidus temperature but the peak temperature wasn't beyond 250℃ for 250s for each reflow soldering cycle, and the solder samples were reflowed one, two, three and four times, respectively.

After reflowing, the prepared solder joints were performed isothermal aging experiment in an vacuum drying oven at 150℃ for 1 day, 3 days, 6 days, 8 days and 10days, respectively. In order to investigate the formation and evolution of interfacial IMCs, specimens were sectioned perpendicularly to the solder/copper interface of the solder joint and mounted in Klarmount. They were successively ground down to 400, 800, and 1000 grit using silicon carbide paper cooled with flowing water, and polished with 5μm Al_2O_3 suspension followed by 0.25μm diamond paste. The interfacial morphologies of solder joints were observed by a Scanning Electron Microscope (SEM, ZEISS-EVO18) equipped with an Energy Dispersive X-ray Spectrometer (EDS).

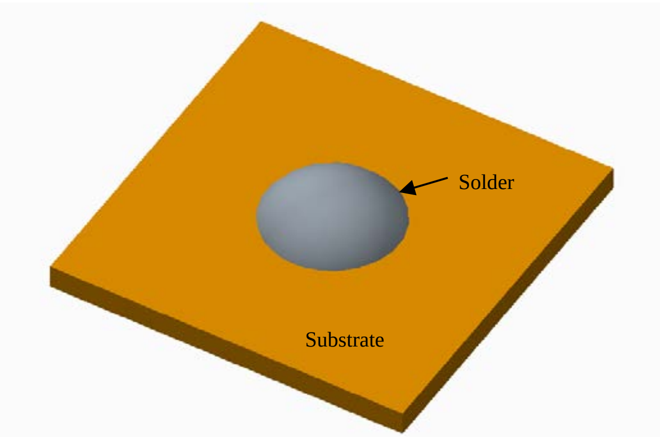


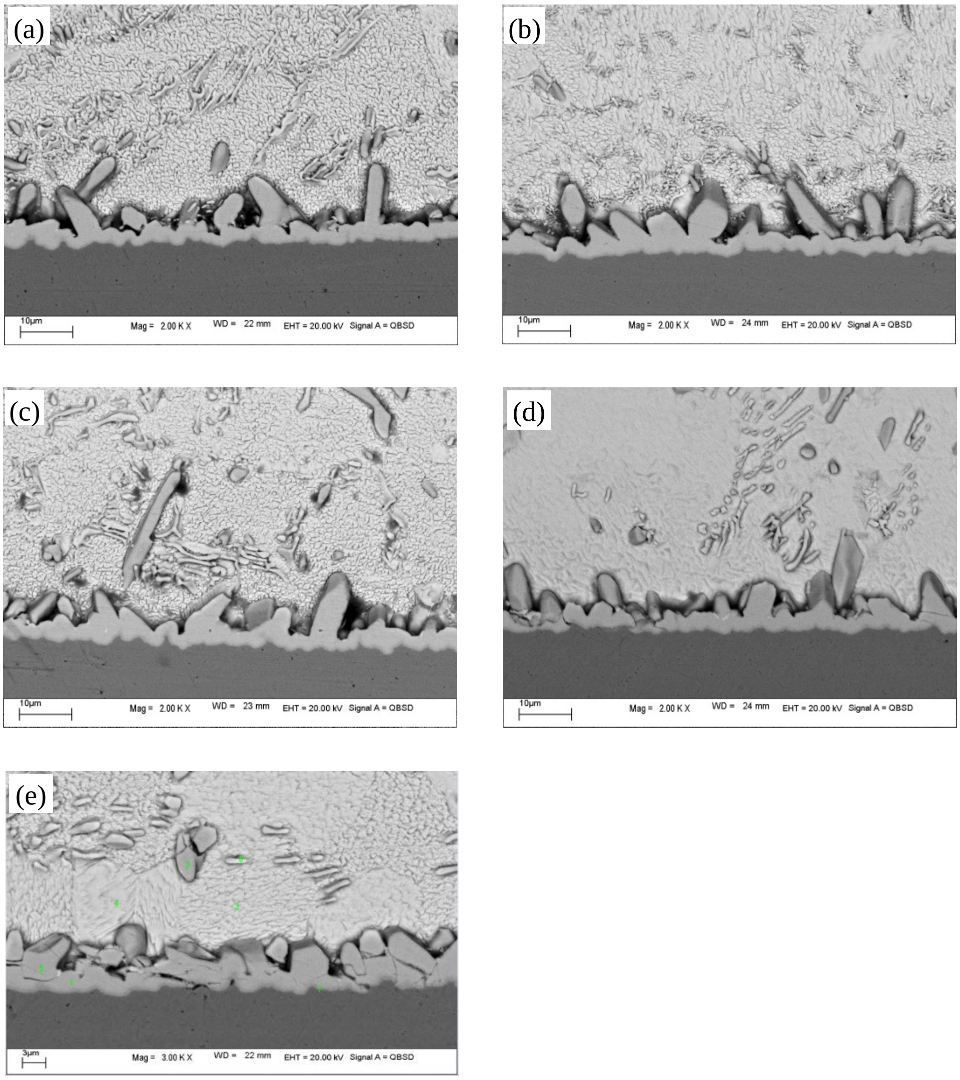
FIGURE. 1 Schematic diagram of solder sample.

Considering the reliable and repeatable data of the mean thickness of IMCs layer, three solder joints samples for each reflow cycle and aging time were used, SEM image analysis software was then employed to digitally measure the areas of each sample's IMCs layers from left side to right side. The thickness of IMCs layer is determined by the area of the IMCs layer dividing its length, and the of IMCs layer is determined by the area of the IMCs layer dividing its length, and the mean thickness of IMCs layers was then calculated by averaging the data.

RESULTS AND DISCUSSION

The SEM micrographs of the Sn-3.0Ag-0.5Cu solder aged at 150℃for various times is shown in

Fig. 2. It is clearly seen that the IMCs layer is scallop shape, in addition, quite a few white needle shape disperse in the Sn matrix. In order to identify the chemical compositions of solder matrix and the IMC phases based on the gray level in BSE micrographs in Fig.2(e), the EDS analysis are used to confirm the phases too. As seen from Fig.2(e), the numbers represent different microstructures, the result is listed in Tab.1. It is confirmed that the light gray part both in IMC layer and Sn matrix is Cu_6Sn_5 phase, a thin layer of dark gray between Cu substrate and Cu_6Sn_5 layer is Cu_3Sn phase. Besides, the needle microstructure in matrix is Ag_3Sn phase. With aging time increasing, the IMCs layer grows thicker, and the aspect ratio of scallop shape is decreased from Fig.2(a) to Fig.2(e). In addition, the IMC layer coarsened with extended aging time. That is probably at the aging stage, Cu is the major diffuse piece and they diffuse to matrix, as Cu_6Sn_5 phase is thermodynamically unstable, the activation energy is lower than Cu_3Sn phase, Cu_6Sn_5 phase forms easily. On the other hand, owing to the unstable Cu_6Sn_5 phase, Cu_6Sn_5 can react with Cu atoms diffused from substrate to keep the system balance and reduce the free energy of the system, it follows $9Cu + Cu_6Sn_5 \rightarrow 5 Cu_3Sn$.



(e)

FIGURE 2. SEM micrographs of microstructure in Sn﹣3.0Ag﹣0.5Cu solder aged at 150℃ for: (a)1 day, (b) 3 days, (c) 6 days, (d) 8 days and (e) 10 days, respectively.

According to the classical diffusion mechanism, generally the growth of the interfacial IMC layer is controlled by bulk diffusion when the growth exponent is equal to 1/2, where the interfacial reaction occurs at the interface between the solid solder and solid substrate, it can be expressed as $X = X_0 + kt^{1/2}$, where k is the growth coefficient. In order to identify the growth behavior of Sn-3.0Ag-0.5Cu/Cu solder joint, the thickness of IMCs layer was plotted with square root of aging time in Fig.3. Fig.3 illustrates the thickness of IMCs layer is linearly growth with square root of aging time, which indicates it follows diffusion controlled mechanism. By linear fit, the growth equation of IMCs layer is obtained, proceeding as

$$X = 1.94 + 1.95t^{1/2}$$

TABLE 1. Phases of different microstructures.

Number	1	2	3	4	5	6	7
Phase	Cu_6Sn_5	Cu_6Sn_5	Sn	Sn	Cu_6Sn_5	Ag_3Sn	Cu_3Sn

In this equation, 1.95 represents the growth coefficient of IMCs layer, from $k=D^{1/2}$, the diffusion coefficient D can be obtained, which is 3.8025$\mu m^2/d$. Accordingly, it is revealed that the diffusion coefficient of Sn-3.0Ag-0.5Cu/Cu solder joints is 3.8025$\mu m^2/d$.

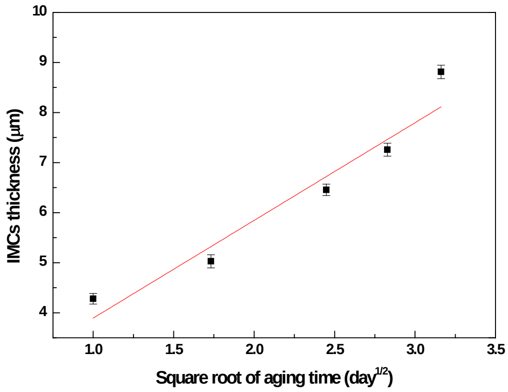


FIGURE 3. Interfacial IMC thickness of Sn-3.0Ag-0.5Cu/Cu joints with different aging time.

CONCLUSION

The growth behavior of Sn-3.0Ag-0.5Cu/Cu solder joints aged at 150℃ for various times was explored in this study. It is found that IMCs layers grow thicker with extended aging time, meanwhile, the aspect ratio of scallop shape decreases during aging for various times. In addition, the thickness of IMCs layer increases linearly with square root of aging time, by linear fit, the growth equation of Sn-3.0Ag-0.5Cu/Cu solder joints was obtained, which is $X = 1.94 + 1.95t^{1/2}$. Further, the diffusion coefficient D is revealed as 3.8025$\mu m^2/d$.

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