Characterizing SAC305 Inter-metallic Layer and Inter-metallic Compounds Growth Model Fitting

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Abstract

Lead-free solders have got extensive attention in Electronic industry, after restrictions imposed by Waste from Electrical and Electronic Equipment (WEEE). Tin-Silver-Copper (Sn-Ag-Cu, or simply 'SAC') solders hold a strong position in replacing conventional lead solders, with improved mechanical, electrical and thermal properties. This paper focuses on study of micro-structure of Sn-3.0%Ag-0.5%Cu (SAC305) solder joint Inter-metallic Layer (IML). SAC305 solder samples are prepared using standard metallographic techniques and images are obtained using Scanning Electron Microscope. The cross-sections of the samples are examined and their Inter-Metallic-Layer (IML) growth is calculated by thermally aging the samples at elevated temperature. The IML growth is then compared to the established theoretical model. The results show the increasing thickness of IML on elevated temperature of 200^{o}C with increasing aging time.

Keywords

Solder joint, SAC alloy, Inter-metallic compounds, Inter-metallic layer, micro-structure analysis.

1. Introduction

The emerging new technologies provide ever more challenges to assure the reliability of electronic products. The ever increasing demands in electronic products for higher performance, lower cost, less space (weight) is leading to ever denser interconnection needs. This makes solder joint reliability an even more important issue (Engelmaier, 2011)**Error! Reference source not found.**.

Solder joint reliability is of great concern for electronic packaging under thermal and mechanical loading. The material properties of the small solder joints used in electronics assembly are different from those of bulk solder bars, because they have significantly different microstructures and different inter-metallic compound layers. To account for the effects of microstructures and inter-metallic compound distribution, it is necessary to perform characterization on actual solder joints (Nguyen et.al., 2011).

Inter-metallic Compounds (IMCs) are formed during diffusion of elements of the solder, during soldering. In thermal aging of solder joint, IMCs grow and agglomerate together forming a layer called Inter-metallic Layer (IML). The growth rate of IMCs depends upon the temperature during the thermal aging and the time duration of thermal aging itself. The size, shape, spacing and volume fraction of IMCs play vital role in determining the properties of solder joint (Sadiq et al., 2013).

Inter-metallic layer that appears at the interface of solder and substrate is of great concern as it grows continuously with time and affect solder joint performance. Thickness and morphology of this can affect

the joint. In development of an alloy this interfacial inter-metallic feature should be focused, as it can significantly affect the solder joint strength and reliability (Swearman et al., 2011). Studying inter-metallic growth formation in solder joint is important because the coarsened IMC of Cu-Sn cause brittle fracture and it's the IML that is accountable for this fracture (Grusd, 1999). Temperature and time are the two factors affecting the IML thickness as thickness increase with rise in temperature.
Reported by (Evans, 2007), IML thickness calculations can be found using parabolic growth curve. Equation 1 expresses the IML thickness

$$X = K\sqrt{t} \quad \textbf{(1)}$$

Where X is layer thickness, K is growth constant at specific temperature and t is time in hours. Growth constant K can be calculated through

$$K = K_0 . e^{-\left(\frac{Q}{R.T}\right)} \quad \textbf{(2)}$$

where K_o is proportionality constant expressed in units of μm/hour$^{1/2}$, Q is the activation energy for IMCs growth, R is ideal gas constant and T is the temperature in absolute scale.

2. Experimentation

Solder joints on PCB were made using lead-free alloy- SAC305. Hand soldering technique was followed using soldering iron with pre-heating temperature of 350^{o}C. Four normal sections were cut from PCB and each of them was placed in heating oven for three different time durations: 50 hours, 100 hours and 150 hours at 200^{o}C. After aging time was over, those samples were passed through metallographic techniques of grinding on different grit size papers, and then carefully polished on soft cotton cloth using diamond paste. Before having SEM micrograph, etching was done using etchant, 5% HCl and 95% ethanol.
Normal section's microstructure analysis was then carried out on JEOL, JSM 5901 Scanning Electron Microscope (SEM). SEM micrographs were helpful in capturing micro level scans. Three different magnification images were taken. All images were analysed in image analyser for quantitative measurements. These measurements were further used in measuring IML thickness.

3. Results

3.1 IML Thickness

Figure 1 shows SEM scans of three different duration aged samples and one un-aged sample. IMC changing size is clearly depicted by micrographs. IMCs Thickness reaches its maximum in 150 hours aged micrograph.

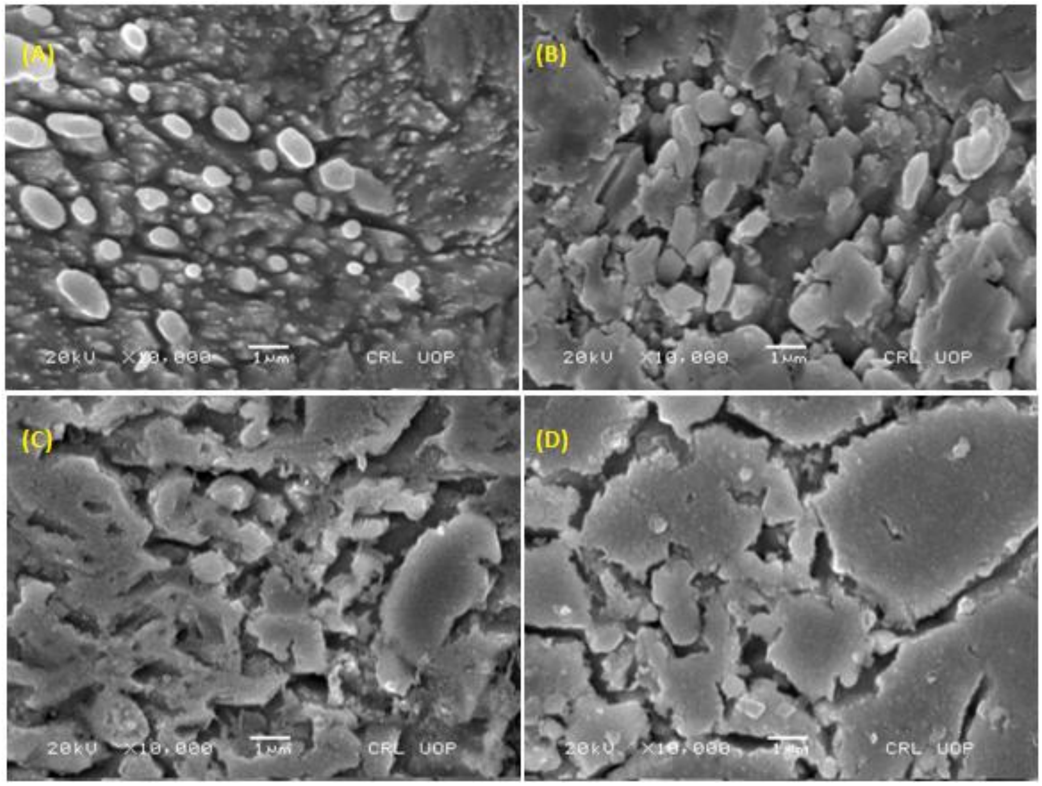

Figure 1: (A) As-soldered normal section of SAC305 solder joint, (B) 50 hours aged at 200°C normal section of SAC305 solder joint, (C) 150 hours aged at 200°C normal section of SAC305 solder joint, (D) 150 hours aged at 200°C normal section of SAC305 solder joint

Many thickness calculation methods are reported by researchers. Reported by (Swearman et al., 2011), IML thickness can be calculated by dividing area occupied by IMC in layer to the length of section in which layer is distributed. ImageJ software measures the total area of IMC and length from selected image dimension. All the observed calculations for three different magnifications were tabulated, as shown in Table 1.

Table 1: Average thickness for 1,500x, 3,000x and 10,000x magnifications

IML Thickness (μm)				
Sample aged (Hours)	**Magnification**			**Average IML Thickness**
	x10000	**x3000**	**x1500**	
Room Temp	0.44	2.50	9.47	4.14
50	1.02	3.38	10.24	4.88
100	1.18	5.51	13.66	6.78
150	1.68	5.84	15.83	7.78

Figure 2 also depicts the IML thickness at different magnifications. Figure 3 depicts average calculation of IML thickness from three different magnification images of as-soldered and isothermally aged sample shows the expected trend line in graph which is increasing with increase in thickness with aging time.

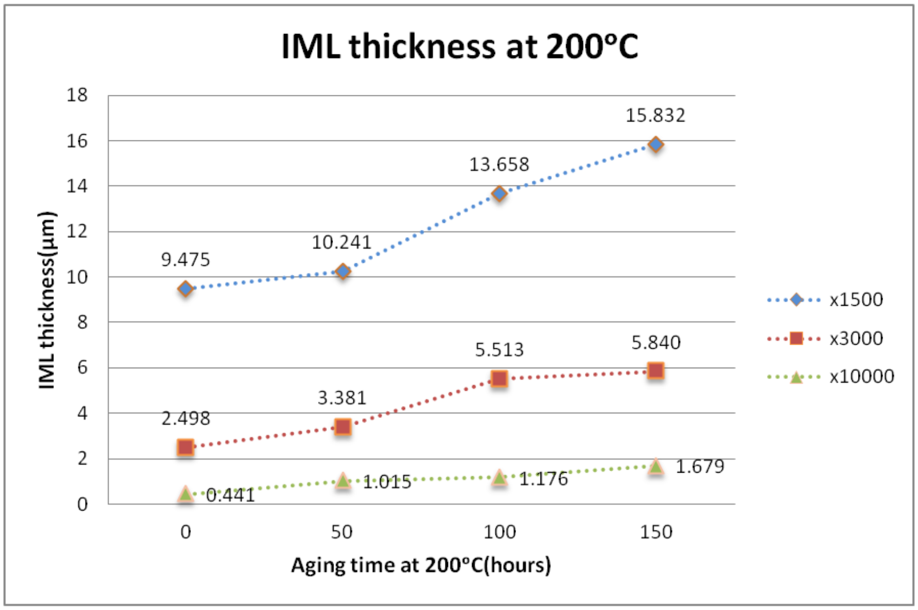

Figure 2: IML thickness vs. aging time at magnifications (x1500, x3000, x10000)

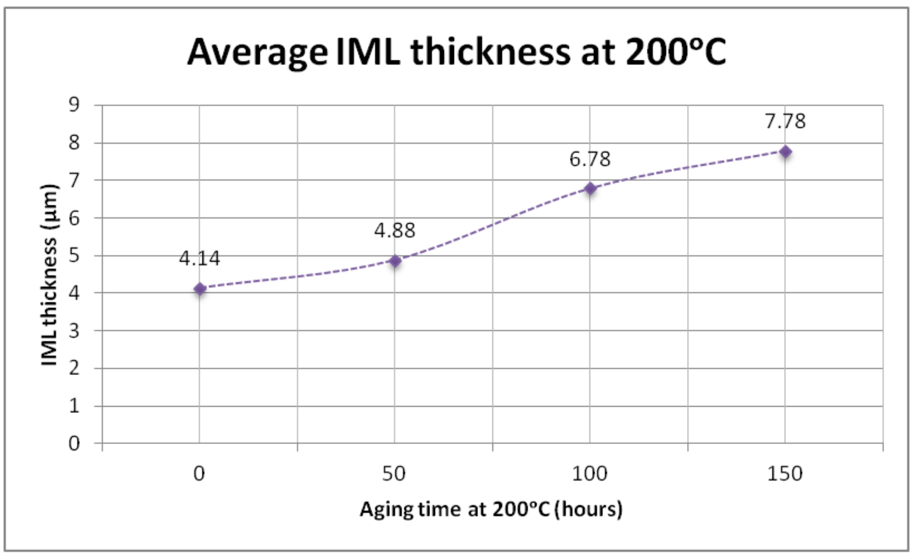

Figure 3: Average IML thickness vs. Aging time at x1,500, x3,000 and x10000

3.2 Model background

IML formed in SAC alloy is significant but continuously increasing thickness of IML from fine thin layer to thick one directly switches to brittle behaviour .Study on Sn-Ag-Cu was done by Hwang (2001) in which he explained this IMC agglomeration behaviour and predicted IMC growth model (Pan et al., 2009)**Error! Reference source not found.**. Equation form of the model is

$$X = X_0 + \left(1.78 * 10^{-2} * t^{0.52} * e^{-\frac{57700}{R.T}}\right) \tag{3}$$

Where $\boldsymbol{X_0}$ and $\boldsymbol{X}$ is IMCs thickness before after thermal aging in meter,$\boldsymbol{t}$ is aging time in seconds,$\boldsymbol{R}$ is universal gas constant equal to 8.314 J/molK and $\boldsymbol{T}$ is aging temperature in Kelvin.

3.3. Model Fitting for IMC growth

Based on the model, thickness increase was found. Results for three different aging durations at 200°C was then graphically plotted. Difference in the plotted values of model and experimental was not deviating much.

$$\Delta X = X - X_0 \tag{4}$$

$$\Delta X = 1.78 * 10^{-2} * t^{0.52} * e^{-\frac{57700}{R.T}} \tag{5}$$

For all experimental values

- t_1= 50 hours(18,000sec)
- t_2=100 hours (360,000sec)
- t_3 =150 hours (540,000sec)
- T= 200°C = 473K

Calculated values of **ΔX** was tabulated, as shown in Table 2.

Table 2: Thickness increase ΔX in μm

Samples Aging Time (Hours)	ΔX Growth Model (μm)	ΔX experimental (μm)
50	1.22	0.77
100	5.86	4.18
150	7.2	6.36

4. Conclusion

The following conclusions about IML thickness were deducted from this research:

- IML thickness increase proportionally with aging time
- Change in thickness between as-soldered and aged samples compared with growth model predict a good fit.

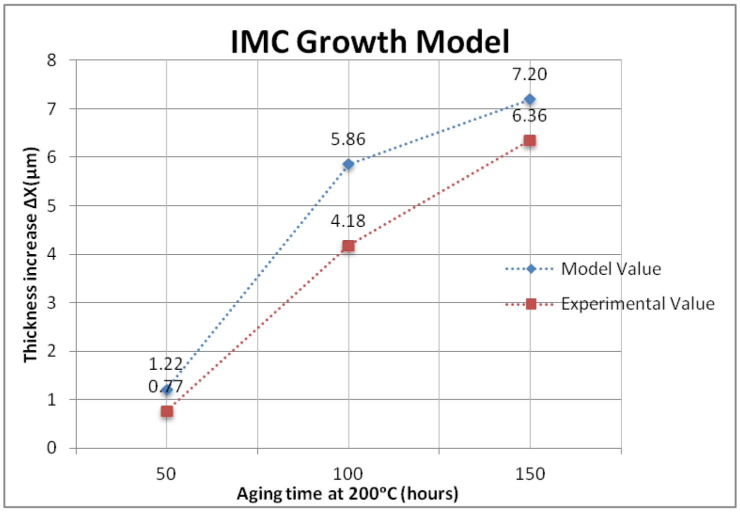

Figure 4:IMCs thickness increase ΔX growth model and experimental values after thermal aging at 200°C for 50,100 and 150 hours

5. References

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