Interfacial Reactions of Pure Sn and Sn-3.0Ag-0.5Cu Lead-free Solders with the Fe-42Ni Substrate

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Abstract

The interfacial reactions between pure Sn and Sn-3.0Ag-0.5Cu solders with the Fe-42Ni (Alloy 42) substrate at 240, 255 and 270°C were investigated in this study. The experimental results indicated that two intermetallic compounds (IMCs) with different surface morphologies were observed in the Sn/Alloy42 couple. The layer close to the substrate had a flat interface and the layer near the Sn solder side contained needle and mass shaped structure. However, both they were the FeSn₂ phases. Only the (Fe,Ni)Sn₂ phase was found in the Sn-3.0Ag-0.5Cu/Alloy42 couple. The IMC thickness in both couples increased as increasing reaction times and temperatures, and it was proportional to the square root of time. The reaction was diffusion-controlled.

Keywords: Sn-3.0Ag-0.5Cu solder, Alloy 42, intermetallic compound (IMC), diffusion-controlled

I. INTRODUCTION

Sn-Pb solders were widely used in the micro-electronic products such as solder past or plating. Due to the toxicity of Pb and being harmful to the environment and human health, Sn–Pb solders are forbidden in using electronic products now. After July 1, 2006, the European Union passed the waste electrical and electronic equipment (WEEE) and restriction of the use of certain hazardous substances (RoHS) in electrical and electronic equipment laws to ban the sales of lead-containing electronic products. Hence, lead-free solders have replaced lead-containing solders for electronic assemblies.

There are many suitable candidates of lead-free solders, such as Sn-Cu · Sn-Ag · Sn-Ag-Cu and Sn-Bi alloys, can be used to replaced the traditional Sn–Pb solders. Among those Sn-based solders, the Sn-3.0 wt% Ag-0.5 wt% Cu solder (SAC) with an eutectic temperature at 217°C, superior workability characteristic and better mechanical properties becomes the most popular lead-free solders to replace the traditional Sn–Pb solders. The Fe-42wt%Ni alloy is usually called a 42 invar alloy (Alloy 42). It has been used as an excellent electrode substrate or leads because its
coefficient of thermal expansion is much closer to Si devices than those of Cu or Ni. [ref.]
However, the interfacial reaction between solders and Alloy 42 has rarely been studied. [ref]
Hwang and Suganuma found the two IMCs layers with different structures, both of them were the FeSn$_2$ phases. [ref.) This study is to investigate the interfacial reaction between pure Sn, Sn-3.0 wt% Ag-0.5 wt% Cu and alloy42 at 240, 255 and 270°C for 1, 2, 3, 4 and 5 hr.

II. EXPERIMENTAL

The cleaned Fe-42wt%Ni alloy (15.0 mm×5.0 mm), removing the grease stains with alcohol and deionized water and polished with Al$_2$O$_3$ particles was dipped in a rosin mildly activated (RMA) flux. Then the substrate and pure Sn · Sn-3.0 wt% Ag-0.5 wt% Cu solders (with the proportions 1:3) were put together into a quartz tube to prepare a liquid/solid reaction couple. The schematic diagram of the reaction couple is shown in Fig.1. This sample was then placed in a tube-furnace at 240, 255 and 270°C for 1, 2, 3, 4 and 5 h, respectively. After the reaction, the sample tube was then quenched in icy water.

The sample was first examined metallurgically. Optical-microscopy (OM) and scanning electron microscopy (SEM) were used to observe the surface morphology. Those samples were dipped in HCl + CH$_3$OH etching solution and then observed the deep-etched microstructure by SEM, as well. SEM with energy dispersion spectrometer (EDS) and electron probe micro-analyzer (EPMA) were used to determine the compositions of the IMC that were formed on the solder/substrate interface.

III. RESULTS AND DISCUSSION

3.1 Interfacial reaction between Fe–42Ni and

Fig. 2 shows the relationship between IMC thickness and square root reaction time in Sn/Alloy 42 couples at various reaction temperatures. Fig.2 reveals that the reaction layer thickness and the square root of the reaction time are in linearly related. This result shows the IMCs layer thickness increased with the temperature, as well.

![Fig. 2 The relationship between IMC thickness and square root reaction time in Sn/Alloy 42 couples at various reaction temperatures](image-url)
Fig. 3 shows the deep-etched BEI (backscattering electron image) micrographs of Sn/alloy42 couple reacted at 240°C for 3h. Two IMCs layers were formed at the Sn/Alloy 42 interface. The composition of layered IMCs, closed to alloy42 side was Sn-32.5 at.% Fe. An another square pillar and needle shaped IMCs, closed to solder side was Sn-32.1 at.% Fe. Based on the compositional analysis from EPMA, and Sn-Fe, Sn-Ni and Ni-Fe binary phase diagrams [ref], both of them are likely to be the FeSn$_2$ phase. Meanwhile, the square pillar and needle shaped IMCs, closed to solder side maybe formed at the initial reaction stage, and were shift into solders with the increase of time.

Fig. 4 shows the deep-etched BEI micrographs of the solder side in Sn/alloy42 couple reacted at 240 for 3h. The irregularly shaped region with composition of Sn-84.5 at.% Ni- 15.4 at.% were scattered in the solder and it was likely to be the Sn–rich phase with solubility of Ni. Fe reacted with Sn to form FeSn$_2$ at the interface, and Ni tended to react with Sn in the solder. Thus, the Sn–rich phase with solubility of Ni formed in the solder.

Who?? [ref.] found a IMCs layer at the interface and asserted that it was Ni$_3$Sn$_4$ IMCs. Thess results concerning the interfacial reactions were inconsistent with this study.

3.2 Interfacial reaction between Fe–42Ni and SAC solder

Fig. 5 shows the relationship between IMCs thickness and square root reaction time in SAC/alloy42 couple at various reaction temperatures. The reaction layer thickness and the square root of the reaction time are also in linearly related as shown in fig.5. This result reveals that the IMCs layer thickness increased with the temperature.

Fig. 6 and Fig. 7 show the deep-etched BEI micrographs of SAC/Alloy 42 couple reacted at 255 and 270°C for 1 and 2 h, respectively. The IMCs layer found at the interface. From the EPMA analysis, the compositions of the IMCs layer was Sn-- at.% Ni- at.% Fe, and labeled as (Fe,Ni)Sn$_2$. Fig. 6 and Fig. 7 also reveals that the (Fe,Ni)Sn$_2$ IMCs layer thickness increased with the temperature. As the reaction
temperatures increases to 270 °C or is reduced to 240 °C, similar results were obtained for each SAC/Alloy42 reaction couple aged for 1 to 5 h.

Fig. 5 The relationship between IMCs thickness and square root reaction time in SAC /Alloy 42 couples at various reaction temperatures

Fig. 6 Deep-etched BEI micrographs of SAC/Alloy 42 couples reacted at 255 °C for 1 h

Fig. 7 Deep-etched BEI micrographs of SAC/Alloy 42 couples reacted at 270°C for 2 h

IV. CONCLUSIONS

The experimental results indicated that two intermetallic compounds (IMCs) with different surface morphologies were observed in the Sn/Alloy42 couple and the layer close to the substrate had a flat interface and the layer near the Sn solder side contained needle and mass shaped structure. However, both they were the FeSn₂ phases. Only the (Fe,Ni)Sn₂ phase was found in the Sn-3.0Ag-0.5Cu /Alloy42 couple. The IMCs thickness in both couples increased as increasing reaction times and temperatures, and it was proportional to the square root of time. The reaction was diffusion-controlled.

REFERENCES