Review on the effect of Gallium in solder alloy

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Abstract. Soldering is a well-known metallurgical joining method that uses a filler metal, the solder, with a melting point below 425°C. The trends toward to miniaturization in microelectronic packaging industries have motivated the development of high performance lead-free solders. However, the properties of the lead free solder cannot match the properties of lead solder. To overcome this problem, a dopant is added to the based lead free solder. In this paper, review on the effect of Gallium as doped was discussed.

1 Lead free solder

Recently, the regulation of certain hazardous substances (RoHS), and waste electrical and electronic equipment (WEEE) has resulted in extensive researches on lead-free solders due to their harmful effects of Pb on the environment and human health [1].

The elimination of Pb-containing components in the microelectronics industry is a worldwide significant target. A number of available Pb-free solder alloys such as Sn–Bi, Sn–Ag, Sn–Au, Sn–In, Sn–Sb, Sn–Pd and Sn–Zn are considered as potential lead-free alternatives to the classical Sn–Pb alloy. These alloys have low melting temperatures and good wettability when compared with the traditional Sn–Pb alloy [2].

2 The effect of dopant in lead free solders

In the last few decades, researchers have been focused on developing lead-free solder for the electronic industry [3][4][5]. In parallel of developed lead-free solder, many researchers have studied the addition of different micro/nanoparticles into the solder matrix to form a solder composite, aiming to improve the microstructure and control the growth rate of IMCs, as well as to enhance the mechanical properties [5][6]. Hence, producing better solder alloy especially for electronic packaging, this is to produce better solder alloy especially for electronic packaging [7]. The effect of dopant can be classified into three which are microstructure, mechanical properties and physical properties.

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2.1 The effect of Gallium as dopant in lead free solders.

The element of Gallium (Ga) has several interesting physical properties. One of the interesting is it has melting point of 29.78°C [8][9][10]. Besides that, its boiling point is 1983°C and it expands 3.4% in volume during solidification [12].

Ga has been used as an additive in lead free solder [11]. It is applied to increase the tensile strength, enhance fatigue life, increase the ductility, increase the wettability and lower the melting temperature of solders [13][14][15]. In addition, its inherent characteristic of wetting most metals and oxides without the use of flux becomes a very attractive feature for microelectronic packaging industry [16][17]. It is founded that Ga may form solid solutions with Sn and Zn [18][19][20].

Mohanty and Lin [18] studied the effect of alloying element gallium in the polarization characteristics of Pb-free Sn-Zn-Ag-Al-xGa solders in NaCl solution. Based on their studies, they concluded that low content of gallium (wt.%) shifts the corrosion potential towards more noble values but contents of gallium more than 0.25 wt.% shifts the corrosion potential towards active values. The passivation behavior of the solder is improved by increasing the Ga content up to 0.25 wt.%. However, the film formed is not completely protective. The maximum corrosion of the solder is observed at 5.0 wt.%. This is reflected in the increase of the maximum passivation current density.

Another study conducted by Zhang et al, reported that with the addition of Ga to the Sn-Zn, the melting properties and wetting abilities of the solder alloy improved. To examine the melting point of the solder alloy, differential scanning calorimetry (DSC) method is used. Sn-Zn-6Ga solder has a melting point of 174.4°C and wetting rate of 48.9% compared with Sn-Zn solder that has melting point of 198.5°C and wetting rate is about 20%. As the conclusion, the addition of Ga can decrease the melting point of Sn-Zn eutectic system. As the content of Ga increases, the melting point will decrease. It also can decrease the wetting angle and increase the wetting rate.

Addition of Ga element on Sn-Ag-Cu solder can obviously decrease the melting point [21]. Each percentage addition of Ga element can decrease the melting point of Sn-Ag-Cu eutectic solder alloy by 4°C. The Ga element forms Cu2Ga phase around the joint interface during the soldering process. This can leads to the decreasing of growth rate of the interfacial IMCs layer and also decrease the ductility of solder. Compared to Sn-Ag-Cu/Cu, less Cu3Sn forms at the Sn-Ag-Cu-Ga/Cu.

Increasing the Ga concentration will effects on microstructures, thermal and mechanical properties of the Sn-9Zn solder alloys, the melting temperatures of the alloys will decrease and the pasty ranges of the alloys are simultaneously enlarged [22-25]. They showed that addition of Ga element causes the Zn-rich phase precipitates to grow and disperse in the β-sn matrix. Moreover, it also decreases the fraction of the Sn/Zn eutectic region, increase the Sn-matrix region and make the needle-like Zn-rich phase becomes coarser and longer. Small additions of 0~0.75wt.% Ga decrease the melting point of the solders alloy but maintain the same strength and ductility as Sn-9Zn solder. The effect Gallium in lead free solder is summarized in the Table 1 based on the properties [25-36].
Table 1. The effect of Gallium as dopant in lead free solders.

| Properties       | Solder alloy | Description of Ga | Effects                                      |
|------------------|--------------|-------------------|----------------------------------------------|
| Polarization     | Sn-Zn-Ag-Al  | Low (<0.25wt.%)   | Corrosion potential towards noble values     |
|                  |              | High (>0.25wt.%)  | Corrosion potential towards active values    |
|                  |              | High (5.0wt.%)    | Maximum corrosion occur                      |
| Passivation      | Sn-Zn-Ag-Al  | Increase          | Improved                                     |
| Melting temperature | Sn-Zn       | Increase (6wt.%)  | Decrease about 24.1°C                        |
|                  | Sn-Ag-Cu     | Increase (1wt.%)  | Decrease about 4°C                           |
| Wetting rate     | Sn-Zn        | Increase (6wt.%)  | Increase about 28.9%                        |
| Wetting angle    |              | Increase          | Decrease                                     |
| Growth rate      | Sn-Ag-Cu     | Increase (0.25wt.%) | Decrease Cu:Ga phase formed rather than Cu:Sn |
|                  | Sn-Bi        | Increase (0.25wt.%) | Various IMCs formed                           |
| Ductility        | Sn-Ag-Cu     | Increase          | Decrease                                     |
| Microstructure   | Sn-Zn        | Increase          | • Phase precipitation grow and disperse      |
|                  |              |                   | • Zn-rich phase becomes coarser and longer    |
|                  |              |                   | • Zn-rich phase becomes blunted, enlarged and |
|                  |              |                   | less densely                                 |
| Tensile strength | Sn-Zn        | Increase          | Increase                                     |
| Fracture         | Sn-Zn        | Increase (0.75wt.%) | Larger cup and cone fracture seen            |
| Oxidation resistance | Sn-Zn     | Increase          | Much better                                  |
| Concentration on | Increase      | 40 times higher in bulk solder                  |
| surface          |              |                   |                                              |

3 Conclusion

Even though the usage of lead solder has been banned, the lead free solder can be developed and match the properties of lead solder. Furthermore, the lead free solder can give better properties than lead solder if adding dopant such as Gallium Ga to solder alloy, but more research need to be develop. In addition, the temperature of the lead free solder is lower than lead solder where the temperature for lead solder is 183°C.
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