Effect of Zn Additions on Microstructure and Properties of Near Eutectic Sn–3.0Ag Solder Alloy

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ABSTRACT

In this study, the effect of Zn concentration on microstructure refinement, melting behavior, electrical resistivity and mechanical properties of near-eutectic Sn–3.0Ag alloy has been investigated. The addition of 1% Zn is found to contribute to the refinement of mostly eutectic Ag3Sn IMC phase and suppressed the formation of β-Sn dendritic structure. The microstructure analysis also revealed that a new ξ-AgZn and γ–Ag5Zn8 fine particles containing large amount of Zn were generated. ξ-AgZn and γ–Ag5Zn8 phases are observed to enlarge with a high Zn of concentration. Although the pasty range slightly increased, Zn addition can effectively reduce the onset temperature and undercooling. Moreover, it was found that the Sn–3.0Ag–1.0Zn alloy undertakes with the compromise between low electrical resistivity, high tensile strength and ductility. Particle strengthening by Ag3Sn phase, β-Sn grain refinement, and the stress concentration along both types of Zn-rich IMC particles contributed more significantly to the electrical and mechanical properties of the investigated solder systems.

Keywords: Lead-free solder/ Microstructure/ Thermal behavior/ Electrical resistivity/ Mechanical properties

1. INTRODUCTION

The Sn–Ag alloy system is promising lead-free solder systems for electronic packaging processes (1,2). This is especially true for inkjet printing materials and engine control units (ECU) box that contain many electronic chips and devices circuits (3,4). In the ECU box, the melting temperature of the Pb-free solder is a life-threatening point from a view of safety. Thus, a melting temperature of the designed solder alloy higher than 200 °C must be the process requirement to ensure its reliability. The Sn–3.5Ag solder alloy has a fairly high melting temperature of approximately 221 °C (5). In this solder, β-Sn-rich dendritic matrix is formed with eutectic mixture of β-Sn phase and Ag3Sn IMC particles, which are located at the interdendritic regions. According to phase diagram (6), the Ag–Sn system is an important model system for studying the growth kinetics of Ag3Sn intermetallic compound (IMC) prepared by solidification process. This IMC significantly affects the mechanical properties and lifetime of Sn–Ag solders due to the trend of the miniaturization of electronic circuits. Since the solder alloys are typically subjected to harsh environments and are used at high-temperature above half of their melting points in degrees absolute, the thermal aging at high-temperature for up to 1,000 h may promote the void formation and coalescence at IMC interfaces of solder joints. Void formation could result in joint embrittlement and degradation of mechanical properties for more typical use (7). Rapid solidification process from the liquid state is a significant none equilibrium processing technique for enhancing the properties and performance of solder alloys (8,9). Shen et al. (10) found that the greater the cooling rate applied, the greater the volume fraction of primary β-Sn crystals formed in rapidly solidified Sn-3.0Ag solder. On the other hand, addition of alloying elements (such as Cu, Ni, Sb, Zn, Bi, etc) to eutectic Sn-3.0Ag solder is one prime avenue attempting to suppress void formation (11). However, the enhancement of mechanical properties is frequently associated to the type and amount of alloying elements. Therefore, some of alloying elements may improve the properties of solders to a desirable extent and sometimes deteriorate its properties. For instance, the effect of same amount of Zn and Sb (1.5 wt.%) on the creep behavior of
Sn-3.5 wt.% Ag solder alloy was examined by Pourmaward et al. (12). It was found that the Sb-containing ternary alloy exhibited the highest creep resistance due to strong solid solution effect of Sb in β-Sn matrix. In a previous study (13), the mechanism of Sn3.5Ag/Cu solder bump during induction heating were investigated to elucidate the basic characteristics of the induction heating soldering process. Cu6Sn5 grains with a round scallop shape were generated at the interface and transformed to a scallop-shaped grains surrounded by prismatic grains, which affected the hardness and shear strength of solder bumps. In this study, we developed Sn-3.0 wt.% Ag solder alloys for automotive parts that are exposed to temperatures above 200 °C. Zn seems to be a potential alloying element in alloy design for Sn-Ag-Cu solders. We adopted a minimal Zn addition to avoid the reliability and growth kinetics of Ag3Sn IMC problems of Sn-3.0 wt.% Ag solder alloys. Thus, the first step of this work is to experimentally measure the variations of the microstructure, electrical resistivity, thermal and mechanical properties of Sn-3.0 wt.% Ag solder alloys with small amounts of Zn addition. The key factors that affect their mechanical properties under a range of thermal conditions are discussed.

2. EXPERIMENTAL

Master alloys of near-eutectic Sn–3.0 wt.% Ag solder alloy and those with a Zn content of 1:0-3.0 mass% were prepared by melting pure tin, pure silver and pure zinc (4N purity) in a high frequency induction furnace. The chemical compositions of three Sn–3.0 wt.% Ag, Sn–3.0 wt.% Ag–1.0 wt.% Zn and Sn–3.0 wt.% Ag–3.0 wt.% Zn alloys investigated are listed in Table (1).

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Ag</th>
<th>Zn</th>
<th>Sn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sn-3.0Ag</td>
<td>3.0</td>
<td>-</td>
<td>Bal.</td>
</tr>
<tr>
<td>Sn-3.0Ag-1.0Zn</td>
<td>3.0</td>
<td>1.0</td>
<td>Bal.</td>
</tr>
<tr>
<td>Sn-3.0Ag-3.0Zn</td>
<td>3.0</td>
<td>3.0</td>
<td>Bal.</td>
</tr>
</tbody>
</table>

The process of melting was carried out under a KCl + LiCl (1:3:1) atmosphere in a steel crucible, and kept at 600 °C for about 1 h to achieve homogeneous characteristics. Each alloy sample was re-melted several times to produce rod-like specimen with diameter of about 1.0 cm. A cooling rate of 10–15 °C/s was achieved for the produced samples, so as to create fine microstructures typically found in small solder joints in microelectronic packages. The microstructure of solders was examined using field emission scanning electron microscopy (FE-SEM, model: S-4800, HITACHI) in backscattered electron (BSE) mode. Qualitative phase identification was conducted by using energy dispersive spectroscopy (EDS). A solution of 3% HCl, 2% HNO3 and 95% (vol.%) Ethyl alcohol was prepared and used to etch the samples. The crystal structure of prepared solders was determined. X-ray diffraction (XRD, Rigaku D/MAX-III A) with Cu Ka radiation (k =0.15418 nm). The melting characteristics of lead-free solder alloys were measured using differential scanning calorimetry (Shimadzu DSC-50). Heating and cooling the specimens in DSC analysis were carried out at 10 oC/min of heating rate in Ar flow. In addition, the room-temperature resistivity, measurements of the solder was conducted by four-point probe method. A total of 5 measurements were recorded and the average value was calculated. The advantage of using four-point probe method is the possibility to measure the sample’s resistance, without any interference from the contact resistance at the probe contacts. The homogenized cast ingots were mechanically machined into a wire samples with gauge length marked 4 x 10-2 m for each samples and 0.8 mm diameter. Before testing, the specimens were annealed at 120 °C for 45 min to reduce the residual stress induced during sample preparation. The tensile tests were conducted at temperature range of 25–120 °C for both solders, under different strain rates of 10^-5 s^-1–10^-3 s^-1. The axial strain was measured in accordance
with the Active Standard ASTM E8 / E8M, and ASTM E1012 / E466 Practice standard for force verification. Details are described in earlier studies (14). Then, the mechanical properties were obtained by averaging testing data. The temperature variation inside the high temperature furnace is maintained within 1.5 oC.

3. RESULTS AND DISCUSSION

3.1. Thermal Behavior of Sn–3.0Ag Solders

The solidification of IMCs in Sn–3.0Ag solders (i.e. nucleation and growth) plays a vital role in the formation of microstructures, which have a strong influence on the mechanical properties (15). In Fig.(1), the DSC curves for Sn–3.0Ag, Sn–3.0Ag–1.0Zn and Sn–3.0Ag–3.0Zn.solders illustrate only one peak for both heating and cooling regimes. Tables( 2 and 3) list the data obtained from DSC curves such as; the solidus temperature (Tonset), liquidus temperature (Tend), eutectic temperature (Tm), pasty range during heating (Tend-Tonset) and undercooling (difference between Tion during heating and Tion during cooling), respectively.

Table (2): Comparison of solidus temperature (Tonset), liquidus temperature (Tend), eutectic temperature and pasty range for Sn-3.0Ag, Sn-3.0Ag- 1.0Zn and Sn-3.0Ag- 3.0Zn solder alloys from heating curve

<table>
<thead>
<tr>
<th>Alloy</th>
<th>(Tonset) (°C)</th>
<th>Tend (°C)</th>
<th>Pasty range (Tend- Tonset) (°C)</th>
<th>Peak Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sn-3.0Ag</td>
<td>220.4</td>
<td>225.8</td>
<td>5.4</td>
<td>222.9</td>
</tr>
<tr>
<td>Sn-3.0Ag- 1.0Zn</td>
<td>215.9</td>
<td>223.0</td>
<td>7.1</td>
<td>220.5</td>
</tr>
<tr>
<td>Sn-3.0Ag- 3.0Zn</td>
<td>217.7</td>
<td>225.1</td>
<td>7.4</td>
<td>221.6</td>
</tr>
</tbody>
</table>

Table (3): Comparison of solidus temperature (Tonset) during heating, liquidus temperature (Tonset) during cooling and undercooling range for Sn-3.0Ag, Sn-3.0Ag-1.0Zn and Sn-3.0Ag 3.0Zn solder alloys

<table>
<thead>
<tr>
<th>Alloy</th>
<th>(Tonset) heating (°C)</th>
<th>(Tonset) cooling (°C)</th>
<th>Undercooling (Tn – Tc) (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sn-3Ag</td>
<td>220.4</td>
<td>203.8</td>
<td>16.6</td>
</tr>
<tr>
<td>Sn-3Ag- 1Zn</td>
<td>215.9</td>
<td>212.5</td>
<td>3.4</td>
</tr>
<tr>
<td>Sn-3Ag -3Zn</td>
<td>217.7</td>
<td>214.6</td>
<td>3.1</td>
</tr>
</tbody>
</table>

Although the addition of Zn did not affect the tendency of DSC curves, it caused a pronounced shift in the processing parameters. The Tonset of Sn–3.0Ag decreases from 220.4 to 215.9 °C and 217.7 °C with 1% and 3%Zn additions, respectively. The pasty range of Sn–3.0Ag, Sn–3.0Ag–1.0Zn and Sn– 3.0Ag–3.0Zn.solders were 5.4, 7.1 and 7.4 °C respectively, which is
lower than 11.5 °C for Sn–Pb eutectic (16). Moreover, the addition of Zn has a direct effect on nucleation and growth process during solidification, since the crystallization temperature (Ton during cooling) was found to increase from 203.8 to 214.6 °C with increasing Zn content. Accordingly, it can significantly decrease the undercooling of β-Sn phase from 16.6 to 3.1°C, and this may cause substantial impacts on the microstructure of the solidified samples. The higher crystallization temperature during cooling for L→ L + ξ–AgZn + γ–Ag5Zn8 could result in lower solidification time for the growth of these IMCs. Consequently, the microstructures of ξ–AgZn and γ–Ag5Zn8 IMC particles may be refined. When the Zn content raised from 1.0 to 3.0 wt%, the composition of solder melt gradually changes due to further precipitation of Ag–Zn IMCs through the above eutectic reaction (see Fig. 1).

![Diagram](image)

**Fig (1):** DSC results of Sn–3.0Ag, Sn–3.0Ag–1.0Zn and Sn–3.0Ag–3.0Zn solder alloys during heating (endothermal) and cooling (exothermal)

### 3.2. Microstructural Characterization

The microstructures and EDS analysis of Sn–3.0Ag, Sn–3.0Ag–1.0Zn and Sn–3.0Ag–3.0Zn solders are shown in Fig. (2).
Fig. (2): SEM microstructures of (a) Sn–3.0Ag, (b) Sn–3.0Ag–1.0Zn and (c) Sn–3.0Ag–3.0Zn solder alloys and corresponding EDS analysis

The typical eutectic structure of Sn–3.5Ag solder contains dendrites β-Sn phases and interdendritic regions of Ag3Sn IMC, as confirmed by XRD analysis (Fig. 3). Owing to the high degree of undercooling of β-Sn during solidification (nearly 18.2 °C), a huge IMC phase is formed in the eutectic area before solidification of β-Sn. Then, the nucleation of β-Sn occurs to form the dendrites β-Sn phase in the remaining molten solder. According to Ag–Zn phase diagram [6], several kinds of non-stoichiometric intermetallic phases are established. All of these IMCs exhibit a wide range of composition. These IMCs are: ε–AgZn3 (19.2–44.4 wt%), γ–Ag5Zn8 (49.5–53.9 wt%), β', and ξ–AgZn (60.9–74.2 wt%). XRD patterns shown in Fig.(3) only confirm the existence of ξ–AgZn and γ–Ag5Zn8 phases in Zn-containing samples. With the addition of 1.0 Zn element, the formation of Ag3Sn particles was suppressed and the size of dendrites β-Sn phase obviously decreased, which will then leads to formation of a large amount of fine ξ–AgZn and γ–Ag5Zn8 particles. These particles are uniformly distributed in the β-Sn matrix. Moreover, the eutectic microstructure of Sn–3.0Ag–1.0 Zn solder increased and refined. When the content of Zn is 3.0 wt%, the microstructure of Ag–Zn IMC becomes coarser than that of Sn–3.0Ag–1.0Zn solder and the amount of Ag3Sn IMC further decreased in Sn–3.0Ag–3.0 Zn solder. According to
our analysis of microstructure, the eutectic regions, in which the small IMC particles of $\xi$–AgZn, $\gamma$–Ag$_5$Zn$_8$ and Ag$_3$Sn appear finely dispersed within a $\beta$–Sn matrix, may play a vital role in the electrical and mechanical properties of the Sn–3.0Ag–1.0Zn solder.

![XRD pattern of Sn–Ag–Zn](image)

**Fig. (3):** XRD pattern of (a) Sn–3.0Ag, (b) Sn–3.0Ag–1.0Zn and (c) Sn–3.0Ag–3.0Zn alloys

### 3.3. Tensile Tests

The tensile testing has been conducted at 5 different temperatures ($T = 25, 50, 70, 90$ and $120$ °C) and different strain rate range ($\varepsilon^o = 10^{-3}$-$10^{-5}$/s). The representative stress–strain plots of one temperature ($RT$) and different strain rates for the Sn–3.0Ag, Sn–3.0Ag–1.0Zn and Sn–3.0Ag–3.0Zn solders are shown in Fig. (4).

![Comparative tensile curves](image)

**Fig. (4):** Comparative tensile curves for Sn–3.0Ag, (b) Sn–3.0Ag–1.0Zn and (c) Sn–3.0Ag–3.0Zn alloys at $T = 25$ °C and different strain rates
The mechanical properties of three alloys over the wide range of temperatures and strain rates have been extracted from the stress–strain curves and presented in Fig.(5). As can be seen, the mechanical parameters of three solder alloys show sensitivity to both strain rate and temperature. It can be stated that both tensile strength (UTS), yield strength (YS) and ductility rises with increasing Zn content and strain rate, while decreases with increasing temperature, except for the Sn–3.0Ag and Sn–3.0Ag–1.0Zn specimens, in which there is a small decline in elongation at some strain rates compared to the Sn–3.0Ag–3.0Zn specimen. The optimum amount additive of Zn for the most superior characteristic of Sn–3.0Ag solder is 1 wt.% Zn. These results are similar with those found in literatures for SAC (103), SAC(103)-2Zn and SAC(103)-3Zn alloys. Obviously, at a given temperature and /or strain rate, 1 wt.% Zn addition tends to increase both the UTS, 0.2% YS and ductility more than that with Sn–3.0Ag and Sn–3.0Ag–3.0Zn specimens. This can be explained by the fact that, with the addition of 1 wt.% Zn to the Sn–3.0Ag solder alloy, a huge amount of finely dispersed $\xi$–AgZn and $\gamma$–Ag5Zn8 IMC particles within a $\beta$-Sn matrix are emerged. These IMC particles have a considerable strengthening effect when the deformation is controlled by dispersion strengthening mechanism. The dispersed phase could resist the dislocation motion and therefore, enforced the stress required to deform the material, leading to substantial improvement in UTS and 0.2% YS in 1 wt.% Zn-containing solder. Based on the SEM micrographs, it can be concluded that, as a result of increasing Zn content to 3 wt.%, the microstructure of Ag–Zn IMCs becomes coarser than that of Sn–3.0Ag–1.0Zn solder as seen in Fig.(2), which leads to a reduced quantity of UTS, 0.2% YS and ductility.

Fig. (5): Effect of strain rate and temperature on the mechanical properties of (a) Sn–3.0Ag, (b) Sn–3.0Ag–1.0Zn and (c) Sn–3.0Ag–3.0Zn solder alloys
3.4. Kinetic Analysis of Sn–3.0Ag–xZn Solders during Hot Deformation

In this investigation, the deformation mechanism of solder alloys examined is usually realized from stress exponent \( n \) and activation energy \( Q \) values that could offer useful information on the deformation behavior. Hence, the relationship between the tensile strain rate \( \varepsilon' \) and applied stress \( \sigma \) is given by the following constitutive model (18):

\[
\varepsilon' = A \left[ \sinh(\alpha \sigma) \right]^n \exp(-Q/RT)
\]

Where \( R \) is the universal gas constant, \( n \) is the stress sensitive exponent, \( T \) is the absolute temperature and \( A \) is the material constant independent of temperature. \( \alpha \) was calculated by \( \alpha = \beta/n1 \), where \( \beta \) and \( n1 \) are the average slopes of \( \ln (\varepsilon') - \sigma \) and \( \ln (\varepsilon') - \ln(\sigma) \) lines at temperature of 25, 70 and 120 °C, respectively. The values of \( n \) are calculated from the slope of the ln \( \varepsilon' \) against ln [\( \sinh(\alpha \sigma) \)] plot for varying temperature (Fig. 6).

![Fig. (6): Relationship between ln[\( \sinh(\alpha \sigma) \)] and ln (\( \varepsilon' \)) at: (a) \( T = 25 \) °C, (b) \( T = 70 \) °C and (c) \( T = 120 \) °C for: (a) Sn–3.0Ag, (b) Sn–3.0Ag–1.0Zn and (c) Sn–3.0Ag–3.0Zn solder alloys](image-url)

The \( Q \) value can be expressed as the slope of ln [\( \sinh(\alpha \sigma) \)] against \( 1/T \) (Fig. 7). The results are summarized in Table (4). Comparing the obtained results for three solder alloys, it can be seen that the stress exponents \( n \) varied from 1.5 to 6.8, while the activation energy \( Q \) varied from 84.5 kJ /mol to 109.5 kJ/mol in the temperature ranging 25-120°C. The higher \( n \) values at room temperature suggest that the deformation mechanism of solder alloys is generally controlled by the movement of dislocation. Since the fine particles can effectively hinder the dislocation motion, then the fine IMC particles of \( \xi–\text{AgZn} \), \( \gamma–\text{Ag5Zn8} \) and \( \text{Ag3Sn} \) formed in Sn–3.0Ag–1.0Zn could enhance the resistance to dislocation motion and improve the tensile strength and performance. However, such effect slightly reduced when the Zn content increased to 3.0 wt.% in Sn–3.0Ag–3.0Zn solder due to the coarsening of \( \xi–\text{AgZn} \), \( \gamma–\text{Ag5Zn8} \) IMCs. However, Table (4) shows that these higher values of \( n \) and \( Q \) are close to \( n = 6.5–11 \) and \( Q= 127.5 \) kJ mol\(^{-1} \) suggested for dislocation climb controlled by lattice self-diffusion of Sn.
(123 kJ/mol)\(^{(18)}\). Hence, the formation of fine IMC particles of \(\xi-\text{AgZn, } \gamma-\text{Ag5Zn8 and Ag3Sn}\) in the \(\beta\)-Sn matrix leads to an excellent precipitation strengthening effect for Sn–3.0Ag–xZn solders (x=0, 1and 3 wt.%).

![Graph](image)

**Fig. (7):** Relationship between 1000/\(T\) and \(\ln[\sinh(\alpha\tau)]\) of Sn–3.0Ag, (b) Sn–3.0Ag–1.0Zn and (c) Sn–3.0Ag–3.0Zn solder alloys

**Table (4):** Activation energy (\(Q\)) and stress exponent (\(n\)) values for Sn-3.0Ag, Sn-3.0Ag-1.0Zn and Sn-3.0Ag-3.0Zn solder alloys

<table>
<thead>
<tr>
<th>Alloy</th>
<th>( Q ) (kJ/mol)</th>
<th>Temperature ((^{\circ})C)</th>
<th>( n )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sn-3.0Ag</td>
<td>84.5</td>
<td>25</td>
<td>8.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>70</td>
<td>7.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>120</td>
<td>6.8</td>
</tr>
<tr>
<td>Sn-3.0Ag-1.0Zn</td>
<td>109.4</td>
<td>25</td>
<td>11.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>70</td>
<td>7.8</td>
</tr>
<tr>
<td></td>
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<td>120</td>
<td>7.4</td>
</tr>
<tr>
<td>Sn-3.0Ag-3.0Zn</td>
<td>98.4</td>
<td>25</td>
<td>10.6</td>
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<td></td>
<td></td>
<td>70</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>120</td>
<td>7</td>
</tr>
</tbody>
</table>

3.5. Resistivity of Plain Sn–3.0Ag and Zn-Containing Solders

Fig. (8) presents the resistivity of plain Sn–3.0Ag solder and Zn-containing solders measured at room temperature. The resistivity of a standard Pb-60Sn wire was incorporated in Fig. (6) for comparison. From this measurement, the lowest bulk resistivity was observed in Sn–3.0Ag–1.0Zn solder alloy with a value of 12.6 \(\mu\Omega/cm\). Conversely, the 3.0 wt.% Zn-modified Sn–3.0Ag solder was noticed to exhibit the highest electrical resistivity with a value of 13.5\(\mu\Omega/cm\). Comparing the resistivity value of Sn–3.0Ag–xZn solders with that of Pb-60Sn solder (17.0 \(\mu\Omega/cm\))\(^{(19)}\), it is seen that the resistivity value of Sn–3.0Ag–1.0Zn solder is on the order of 35% lower than that of Pb-60Sn solder, and the
resistivity values for the entire lead free solders are in a good agreement with the published value of SAC solders (13.2 $\mu$Ω/cm)\textsuperscript{(20, 21)}. Generally, the total resistivity of alloys depends on many factors such as impurity, thermal and deformation resistivity components as expressed in the Matthiessen’s rule:

\[
\rho_{\text{total}} = \rho_{\text{i}} + \rho_{\text{t}} + \rho_{\text{d}}
\]

Where $\rho_{\text{i}}$, $\rho_{\text{t}}$ and $\rho_{\text{d}}$ are the resistivity’s due to impurity, thermal and deformation process, respectively. The size, shape and volume fraction of IMCs also have impact on the electrical resistivity value. Although the alloys contains large volume fraction of IMCs which could decrease the conductivity, in the present work, the electronic component contributed dominantly to the total thermal conductivity. According to the Norbury-Linde rule\textsuperscript{(22)}, the residual resistivity caused by the lattice- strain scattering is generally proportional to the square of valence electron difference between solute and solvent, $(\Delta Ve)^2$. In case of Zn-containing solders, the magnitude of $(\Delta Ve)^2$ is 4 for Zn and 9 for Ag. Hence, to a first approximation, the high amount of Ag substitution in a $\beta$-Sn solvent would be necessary to significantly responsible for the bulk resistivity of the alloy samples, whereas the amount of Zn would have the slightest effect.

Fig. (8): Comparative electrical resistivity values of Sn–3.0Ag, (b) Sn–3.0Ag–1.0Zn and (c) Sn–3.0Ag–3.0Zn with Pb-60Sn alloys at room temperature

4. CONCLUSIONS

1) From microstructure evaluation, the addition of 1.0wt. %Zn element dramatically alters the dendrite behavior of $\beta$-Sn phase in Sn–3.0Ag solder and produces fine IMC particles of $\xi$–AgZn and $\gamma$–Ag5Zn8 phases. With the increase of Zn content to 3.0 wt.%, the microstructure of these Ag–Zn IMC becomes coarser than that of Sn–3.0Ag–1.0Zn solder and the amount of Ag3Sn IMC further decreases.

2) Zn additions to Sn–3.0Ag solder can significantly decrease the undercooling of $\beta$-Sn phase from 16.6 to 3.1°C. Besides, the Tonset of Sn–3.0Ag decreases from 220.4 to 215.9 °C and 217.7 °C with 1% and 3%Zn additions although the pasty range slightly increased from 5.4 to 7.4 °C.

3) From the electrical resistivity measurements, it was found that the resistivity of plain Sn–3.0Ag solder slightly decreased with addition of 1.0wt.% Zn from 13.5$\mu$Ω/cm to 12.6 $\mu$Ω/cm, and then increased to 15.1 $\mu$Ω/cm with additions of 3.0wt.% Zn. The resistivity values of Sn–3.0Ag–xZn solders substantially decreased as compared to Pb-60Sn solder (17.0 $\mu$Ω/cm).

4) In Sn–3.0Ag solder, the addition of 1.0% Zn can significantly increase both the strength and ductility. Increasing Zn content to 3.0%, the tensile strength slightly increased and the ductility is slightly reduced.
5-REFERENCES


