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Modification Structure and their Effects on Physical Properties of Tin Based Lead Free Solder Alloys for Industrial Applications

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ABSTRACT

Soldering properties such as melting temperature and wettability of tin-zinc alloy improved after adding different alloying elements such as indium, aluminum, cadmium and bismuth. Decreasing zinc content ($Sn_{91}Zn_9$) up to 4% ($Sn_{96}Zn_4$ alloy) increased corrosion resistance from -0.847 to -0.530 and decreased corrosion rate from 51.84 to 7.705 mpy. Microstructure of tin-zinc alloy changed with increasing hardness value of it after adding alloying elements. Tin-zinc alloys have lower melting temperature compared to $Sn_{95}Sb_5$, $Sn_{96.5}Ag_{3.5}$ and $Sn_{99.3}Cu_{0.7}$ alloys. The $Sn_{90}Zn_4Bi_6$ alloy has beast solder properties for electronic industrial applications.

Keywords: Tin-Zinc Alloy, Wettability, Melting Temperature, Hardness

I. INTRODUCTION

Soldering is a low temperature metallurgical joining process. In electronics applications low temperature and reversibility are especially important because of the materials involved and the necessity for reworking and making engineering changes. Tin- zinc eutectic alloy is a lead free solder which used in different industrial applications. The aim of this research was to improve physical and soldering properties of tin- zinc eutectic alloy by adding different alloying elements (Al or In or Al-In or In-Bi). Many studies have been made on various alloy system solders based on Sn such as $SnZn_9$, $SnAg_{3.5}$, $SnAg_3Cu_{0.5}$, etc. as possible replacements [1, 2]. Tin- zinc eutectic alloy has been considered as a candidate for lead free solder materials because of its low melting point, excellent mechanical properties and low cost [3- 5]. Microstructure, corrosion behavior and soldering properties of tin based or tin-zinc or tin based with adding alloying element or effect of adding titanium oxide on all properties have been studied [6-10]. The results show, correction behavior, soldering properties and microstructure of tin based alloy changed after adding alloying elements and titanium oxide.

II. EXPERIMENTAL WORK

The alloys $Sn_{91}Zn_9$, $Sn_{96}Zn_4$, $SnZn_9In_{1.5}$, $SnZn_9Al_{1.5}$, $Sn_{90}Zn_4Bi_6$, $Sn_{95}Sb_5$, $Sn_{96.5}Ag_{3.5}$ and $Sn_{99.3}Cu_{0.7}$ which used tin, zinc, indium, copper, aluminum, antimony, cadmium and bismuth elements with a high purity, more than 99.95%, were molten in the muffle furnace. The resulting ingots were turned and re-melted several times to increase the homogeneity of the ingots. From these ingots, long ribbons of about 3-5 mm width and ~ 100 μm thickness were prepared as the test samples by directing a stream of molten alloy onto the outer surface of rapidly revolving copper roller with surface velocity 31 m/s giving a cooling rate of 3.7×10^5 k/s. The samples then cut into convenient shape for the measurements using double knife cuter. Structure of used alloys was performed using an Shimadzu x–ray diffractometer (Dx–30, Japan) of Cu–Kα radiation with λ=1.54056 Å at 45 kV and 35 mA and Ni–filter in the angular range 2θ ranging from 20 to 100° in continuous mode with a scan speed 5 deg/min. **Scanning electron microscope JEOL JSM-6510LV, Japan was used to study microstructure of used samples.** The melting endotherms of used alloys were obtained using a SDT Q600 V20.9 Build 20 instrument. A digital Vickers micro-hardness tester, (Model-FM-7- Japan), was used to measure Vickers hardness values of used alloys.

III. RESULTS AND DISCUSSION

3.1 Microstructure

X-ray diffraction patterns, Figure (1), for $Sn_{91-x}Zn_9X_x$(X=0 or In or Al, x=0 or 1.5 wt. %) rapidly solidified alloys show sharp lines of body centered tetragonal Sn and hexagonal Zn phase. From x-ray analysis, it obvious that adding In or Al content to $SnZn_9$ alloy caused a change in its matrix microstructure (as lattice parameters, unit cell volume and crystal size) and the shape of formed phases (such as peak intensity, peak broadness and peak position). That is because indium or aluminum atoms dissolved in $SnZn_9$ matrix formed a solid solution\or and some In or Al atoms formed a traces of undetected phases (In or Al or In or intermetallic phases).

Scanning electron micrographs, SEM, of $Sn_{91}Zn_9$, $Sn_{96}Zn_4$, $SnZn_9In_{1.5}$, $SnZn_9Al_{1.5}$, $Sn_{95}Sb_5$, $Sn_{96.5}Ag_{3.5}$ and $Sn_{99.3}Cu_{0.7}$ alloys show heterogeneous structure (different features) as seen in Figure (2) which agreed with x-ray analysis.

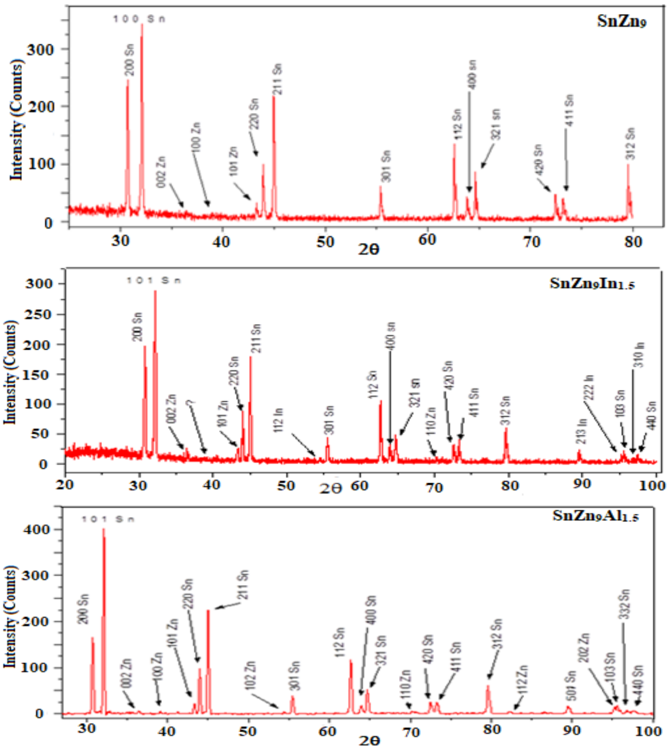

Figure 1: x-ray diffraction patterns of $Sn_{91-x}Zn_9X_x$(X=0 or In or Al, x=0 or 1.5 wt. %) alloys

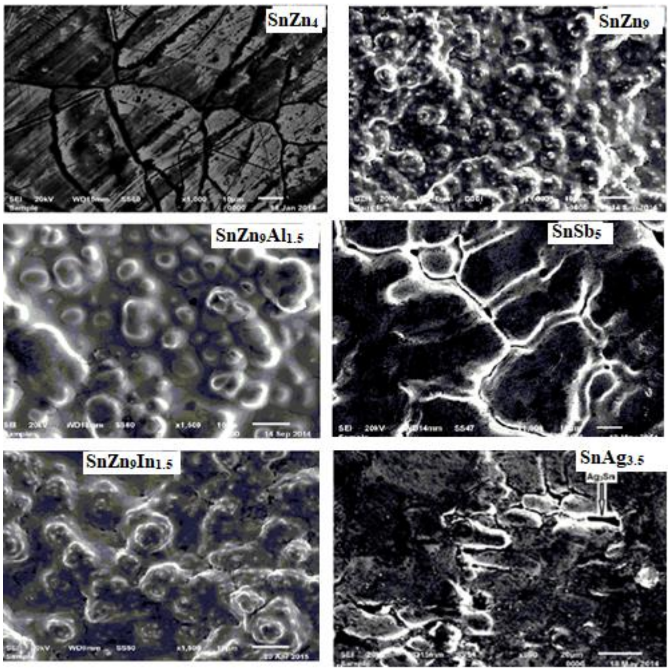

Figure 2: scanning electron micrographs of tin based alloys

3.2 Soldering properties

Wettability

Wettability is quantitatively evaluated by the contact angle formed at the solder substrate's flux triple point.

The contact angles of $Sn_{91}Zn_9$, $Sn_{96}Zn_4$, $SnZn_9In_{1.5}$, $SnZn_9Al_{1.5}$, $SnZn_9Cd_{1.5}$, $Sn_{90}Zn_4Bi_6$, $Sn_{95}Sb_5$, $Sn_{96.5}Ag_{3.5}$ and $Sn_{99.3}Cu_{0.7}$ alloys on Cu substrate in air presented in Table (1) show that the contact angle for $Sn_{91}Zn_9$ alloy decreased after adding alloying elements.

Thermal parameters

The amounts of thermal properties depend on the nature of solid phase and on its temperature. The melting point for $Sn_{91}Zn_9$, $Sn_{96}Zn_4$, $SnZn_9In_{1.5}$, $SnZn_9Al_{1.5}$, $SnZn_9Cd_{1.5}$, $Sn_{90}Zn_4Bi_6$, $Sn_{95}Sb_5$, $Sn_{96.5}Ag_{3.5}$ and $Sn_{99.3}Cu_{0.7}$ alloys listed in Table (1), show that the melting temperature of $Sn_{91}Zn_9$ alloy decreased after adding alloying elements.

Table 1: contact angle and melting temperature of tin based alloys

Alloys	Contact angle°	M. P °C
$SnZn_9$	36±75.15	198.28
$Sn_{96}Zn_4$	24.5±1.2	216.42
$SnZn_9In_{1.5}$	21.25±1.3	194.98
$SnZn_9Al_{1.5}$	20.25±1.2	196.68
$SnZn_9Cd_{1.5}$	28.25±1.23	195.38
$Sn_{90}Zn_4Bi_6$	27.5±2	190.75

Alloys	Contact angle°	M. P °C
$Sn_{95}Sb_5$	27±2	242.06
$Sn_{96.5}Ag_{3.5}$	26±2	223.81
$Sn_{99.3}Cu_{0.7}$	37.5±3.15	231.55

3.3 Vickers microhardness

The greater of material hardness is the greatest of the resistance to deformation. Table (2) shows Vickers hardness value for $Sn_{91}Zn_9$, $Sn_{96}Zn_4$, $SnZn_9In_{1.5}$, $SnZn_9Al_{1.5}$, $SnZn_9Cd_{1.5}$, $Sn_{90}Zn_4Bi_6$, $Sn_{95}Sb_5$, $Sn_{96.5}Ag_{3.5}$ and $Sn_{99.3}Cu_{0.7}$ alloys at 10 gram force for 5 sec. Vickers hardness value of $Sn_{91}Zn_9$ alloy increased by adding alloying elements.

Table 2: Vickers hardness value of tin based alloys

Alloys	H_v kg/mm^2
$SnZn_9$	22.75±1.1
$Sn_{96}Zn_4$	30.75±0.4
$SnZn_9In_{1.5}$	23.53±1
$SnZn_9Al_{1.5}$	32.2±2.1
$Sn_{90}Zn_4Bi_6$	27.53±1.54

Alloys	H_v kg/mm^2
$Sn_{95}Sb_5$	20.05±1.8
$Sn_{96.5}Ag_{3.5}$	23.067
$Sn_{99.3}Cu_{0.7}$	12.025

IV.CONCLUSION

Adding alloying elements improved soldering properties of $SnZn_9$ alloy with increasing its hardness value. Tin-zinc based solder alloys have the beast properties compared other tin based alloys.

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