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Influence of Indium Content on the Wetting Behaviours of $Sn_{3-x}Ag_{0.5}Cu_xIn$ Alloy Systems

A.M. Erer* and O. Uyanik

Karabük University, Science Faculty, Physics Department, 78050 Karabük, Turkey

The purpose of this project is to investigate the wetting behaviors of $Sn_{3-x}Ag_{0.5}Cu_xIn$ (SAC-In) ($x = 0.5$ wt%, 1 wt%, and 2 wt%) alloys at various temperatures (250 °C, 280 °C, and 310 °C) on copper (Cu) substrate in argon (Ar) atmosphere. The contact angles (θ) of alloys were gaged by sessile drop technique. The alloys' microstructures were examined by scanning electron microscopy/energy dispersive spectroscopy. Intermetallic compounds of Cu_3Sn, Cu_6Sn_5, and Ag_3Sn were observed at the interface of SAC-In/Cu. The results of wetting tests represent that the addition of 1 wt% In improves the wetting properties of the Sn–3 wt%Ag–0.5 wt%Cu (SAC305) alloy. The lowest θ was obtained as 35.55° for Sn–2 wt%Ag–0.5 wt%Cu–1 wt%In alloy at 310 °C.

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PACS/topics: wetting, Pb-free solder alloys, IMC's, contact angle, sessile drop method

1. Introduction

Over the last decade, Sn–Ag–Cu (SAC) alloys have been utilized as a widespread solder material in electronics industry with the aim of replacing Pb-based compositions. For this reason, the process and reliability results concerning the compositions have been widely reported recently. However, the quick rise up in the Ag price has placed the solder compositions, which have a low Ag content, in an important position [1]. It has been reported that solder compositions with a low Ag content have improved the impact or drop reliability. For the SAC ternary alloy, Ag helps to lower the melting point of the alloy and increase the mechanical strength [2]. Melting temperatures are important factor for the development of new Pb-free solders. A hopeful solder alloy should have a low melting temperature and a narrow melting range. Generally, adding an alloys element to the solder alloys is a means to reduce the melting temperature. However, the alloying element may have other effects on properties of the alloys, like microstructure and mechanical properties. The suitable amounts of indium (In) added to the SAC305 alloy can change the melting behavior obviously. For this reason, the Ag content throughout with a fourth alloying element to stabilize those impacts must be investigated on account of improving the impact and thermal cycling reliability of the solder joints. Wetting is defined as diffusion tendency of the liquid phase on solid surface and this diffusion capability is determined by the contact angle between the two surfaces [3]. Thus, in this project, the amount of Ag has been reduced and In was selected as a fourth element to be added to SAC305 in the formulation of new quaternary alloys. Suggested Sn–2.5 wt%Ag–0.5 wt%Cu–0.5 wt%In (SAC-0.5In), Sn–2 wt%Ag–0.5 wt%Cu–1 wt%In (SAC-1In) and Sn–1 wt%Ag–0.5 wt%Cu–2 wt%In (SAC-2In) alloys were tested for wetting properties, melting temperatures, microstructures, and intermetallic compounds (IMC's).

*corresponding author; e-mail: mustafaerer@karabuk.edu.tr

2. Experimental procedure

In this project, while different amounts (0.5–2%) indium into the near-eutectic SAC305 alloy were added, new quaternary alloys were produced. The wetting tests were realized for the SAC-0.5In, SAC-1In and SAC-2In alloys by the sessile drop method. The SAC-In solder alloys were dropped on Cu substrate at predetermined temperatures of 250 °C, 280 °C, and 310 °C. Casio M.P. EX-F1, maximum 1200 frame p/s model camera was used to catch views of drop samples at the 0, 5, 10, 15, 30, 60, 90, 120, 150, and 300th seconds, and these views were transferred into Corel-Draw X5 Software to obtain the contact angles of each drop samples from the left and right profiles. As a result of these processes being repeated three times for each temperature and more, mean angle values were calculated and new diagrams were drawn through the Sigma Plot 12.0 Software [4]. In order to determine the melting temperatures of alloys, DSC analysis were carried out. Standard metallographic processes were applied for microstructure examinations. Prepared specimens were characterized by scanning electron microscopy + energy dispersive spectroscopy and X-ray diffraction analyses.

3. Result and discussion

The contact angles loosening graphs at varied experiments are illustrated in Fig. 1a–c at various temperatures. It can be observed that the equilibrium contact angles decrease as the temperature increases, which are 54.17°, 46.70°, and 45.22° for SAC-0.5In, 44.85°, 43.06°, and 35.55° for SAC-1In, 57.09°, 50.35°, and 40.59° for SAC-2In, respectively, while the temperatures are 250 °C, 280 °C, and 310 °C. The valuations of the contact angle

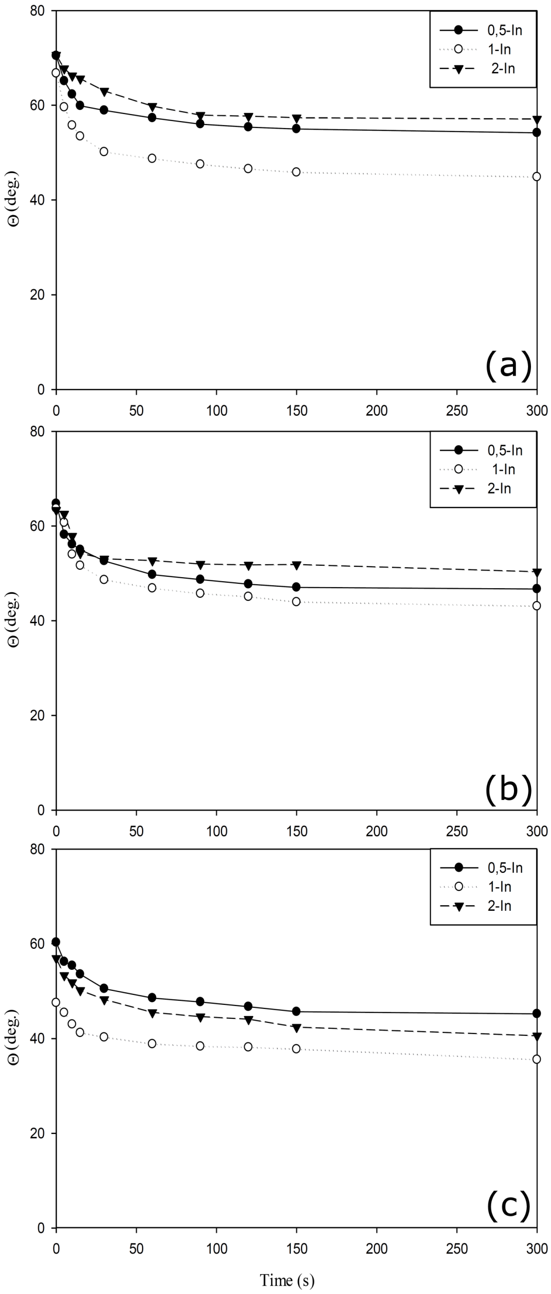

Fig. 1. Time dependence of the contact angle of SAC-0.5In, SAC-1In and SAC-2In alloys on Cu substrate at tests temperatures: (a) 250 °C, (b) 280 °C, and (c) 310 °C.

represent the degree of wettability. Moser et al. [5] proposed that when the contact angle of a solder is between $30° \leq \theta \leq 40°$, it is good and acceptable. Moreover, the degree of wettability for the SAC-1In alloy in the Ar flow is good.

Figure 2a–c shows the SEM images of the SAC-0.5In/Cu, SAC-1In/Cu and SAC-2In/Cu interfaces afterwards of the drop process, respectively. IMC's are formed at the interface Cu_6Sn_5, Cu_3Sn and Ag_3Sn during the soldering process which is a combination of Sn-Ag-Cu-In/Cu matrix [6].

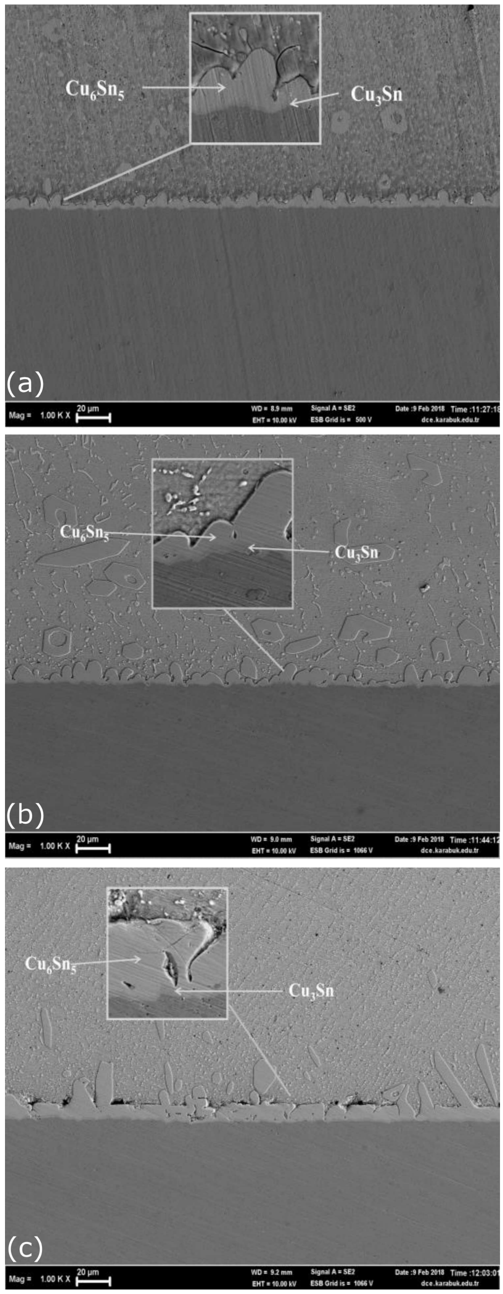

Fig. 2. SEM images of the $Sn_{3-x}AgCu_xIn$/Cu interfaces afterwards of the drop process (a) SAC-0.5In, (b) SAC-1In, and (c) SAC-2In.

According to SEM analysis, the interfacial details are more obviously observed as the growth rate rises. The thickness of the IMC's formed at the interface grows as the contact angle measurement temperatures increases. In addition, where the measurement temperature is high, it is observed that roughness of the IMC's and substrate interface become more uniformed at 310 °C.

On the other hand, thermal morphology and relationship between IMC's are very important. The creation of IMC's in Sn–Ag–Cu–In soldering systems are formed in two steps. Initially, Cu_6Sn_5 is applied on the interface in the soldering process, when at the other stage Cu_3Sn

is formed between Cu_6Sn_5 and Cu substrate [7]. Consequently, the quicker diffusion of Copper atoms related to the Sn atoms occurs and it causes the formation of rich IMC's by the element Cu at the interface. Indium does not significantly affect the chemical composition of intermetallic layers. It is strongly probable that this condition is due to low concentration [8]. Thus, Cu_3Sn layer thickness is thinner compared to Cu_6Sn_5 layer formed at the Sn–Ag–Cu–In/Cu interface.

4. Conclusion

The wetting behaviors of $Sn_{3-x}Ag_{0.5}Cu_xIn$ ($x = 0.5$, 1 and 2 in wt%)was investigated with the use of sessile drop method. Increasing the addition of In (up to 1%) resulted in the lowering of the contact angles. The lowest contact angle, θ was measured as 35.55° for SAC-1In alloy at 310 °C. Also, microstructures, IMC's taking place in the structure of alloys were examined and the results obtained were correlated with the last studies of other researchers and the published references on the properties of Pb-free solders. reactions at interface between the working alloys and Cu substrate lead to IMC's that are Cu_6Sn_5, Cu_3Sn and Ag_3Sn. As a result, if the In and Ag contents are optimized, the SAC-1In solder alloy becomes a potential postulant replacing the commonly used SAC305 alloy.

Acknowledgments

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