*Solid State Science and Technology, Vol. 26, No 1 (2018) 115-121*
ISSN 0128-7389 | *http://journal.masshp.net*

# INTERMETALLIC AND JOINT STRENGTH STUDY OF Sn-9Zn SOLDER WITH ADDITION OF CARBON NANOTUBE UNDER LIQUID STATE AGING

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## ABSTRACT

In this study, the effect of carbon nanotube (CNTs) on the intermetallic and joint strength study of Sn-9Zn lead free solder under liquid state aging was investigated. The formations of intermetallic were observed under scanning electron microscopy (SEM) and the thicknesses of the intermetallic were measured by using imageJ software. Only $Cu_5Zn_8$layer was found for Sn-9Zn/Cu interface. Meanwhile, there was three type of intermetallic formed for Sn-9Zn-0.1CNT/Cu interface which were $Cu_5Zn_8$, $Cu_3Sn$ and $Cu_6Sn_5$. The thickness of intermetallic increased as the time of aging increases. However, the thickness of intermetallic formed with the addition of CNT was slightly smaller than those solder without the CNT. The joint strength of the Sn-9Zn solder was higher compared to Sn-9Zn-0.1CNT.

Keywords: $Cu_5Zn_8$ Intermetallic; Lead-free Solder; Sn-9Zn Solder; Joint Strength

## INTRODUCTION

Sn-Pb solder is the most widely used solder in the interconnection electronics assembly. Nevertheless, Environmental Protection Agency (EPA) has cited lead and Pb compounds as one of the top 17 chemical posing the greatest threat to human life and the environment [1]. Hereby the advents of lead-free solders were proposed. Although there are many potential lead-free solders, Sn-9Zn solder is one of the most recommended solder due to its low (198°C) melting temperature. The mechanical property of the Sn-9Zn was improved by adding third element into it [2]. During soldering, the solder material will react with the Cu substrate and forming interface termed intermetallic compound (IMC). In the Sn-Zn system, both Sn and Zn interact with Cu to form intermetallic such as $Cu_5Zn_8$, $Cu_6Sn_5$ and $Cu_3Sn$ [3]. The formation of the intermetallic compounds between solder and Cu substrate is desirable for the good formation of the solder joint and play a crucial role in the reliability of solder joints. However, too thick of intermetallic and the brittleness of the intermetallic layer may be detrimental to joint reliability. This study investigated the effect of carbon nanotube (CNTs) on the intermetallic and joint strength study of Sn-9Zn lead free solder under liquid state aging.

## METHODOLOGY

Solder/copper joint were made by reflowing around 0.5g of solder on Cu substrate with some $ZnCl_2$ flux were placed on the hot plate and heated at temperature 250°C. The soldering time were set at 1, 30, 45 and 60 minutes.

After the soldering and left to be cool, the samples were cleaned using soap and were cross- sectioned by using 8" sheet metal shear steel aluminum copper hand cutter. The samples were then mounted using epoxy resin. The mounted samples were mirror polished and etched by 93 vol % $C_2H_5OH$, 5 vol % HNO3 and 2 vol % HCl. The Cu/solder interface was then analyzed under scanning electron Microscope (SEM) and the average thickness of IMC was calculated by using imageJ 1.46r software. For each sample, 3 micrographs were taken. To determine the joint strength of the solder/Cu, the two ends of the Cu was pulled using Instron machine, the stress and strain were then measured. There is no specific standard since we are comparing the joint strength.

## RESULT AND DISCUSSION

*Intermetallic formation*

Figure 1 and 2 shows the intermetallic formation after soldering for 1 and 45 minutes at 250°C. As reported [4-5], by using thermodynamic calculation the $Cu_5Zn_8$ was the first of the intermetallic formed at the Sn-9Zn/Cu interface. The Zn concentrates at the interface close to the Cu substrate and reacts with Cu to form the $Cu_5Zn_8$. In figure 1(a) and (b), the morphology of the $Cu_5Zn_8$intermetallic planar-shape formed with both Sn-9Zn/Cu interface and Sn-9Zn-0.1CNT/Cu interface.

Figure 2(a) shows the formation of $Cu_5Zn_8$ intermetallic after soldering for 45 minute at 250°C. The thickness of intermetallic was increases. The scallop-shaped $Cu_6Sn_5$ and planar-shaped $Cu_3Sn$ intermetallic layers were formed at the Sn-9Zn-0.1CNT/Cu interface after soldering at 250°C for 45 minutes, as shown in figure 2(b). The $Cu_6Sn_5$ colour is light grey meanwhile the $Cu_3Sn$ colour is darker. According to the Chang *et al*. [6], this is due to the fact that the Cu atoms in the $Cu_5Zn_8$ layer diffuse to the solder alloy and then react with Sn. Wang *et al.* [7] reported that the $Cu_6Sn_5$ and $Cu_3Sn$ phases could form at the Sn-9Zn/Cu interface after aging at higher temperature due to phase fracture of $Cu_5Zn_8$. At longer time aging, the CNT may have retarded the diffusion of Zn atoms. These allow the diffusion of Sn atoms towards Cu to form the $Cu_6Sn_5$ and $Cu_3Sn$ intermetallic.

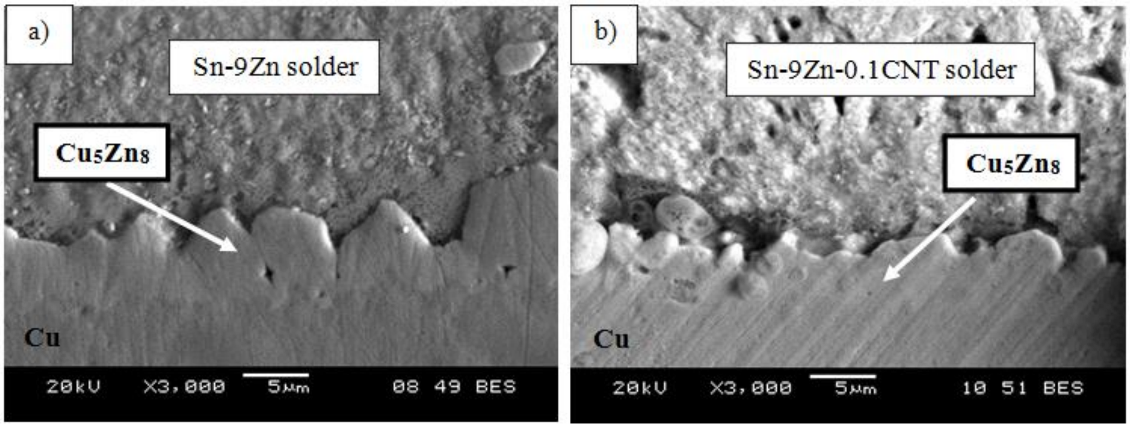


Figure 1: IMC formation of (a) Sn-9Zn, (b) Sn-9Zn-0.1CNT at 1 minute aging time under SEM

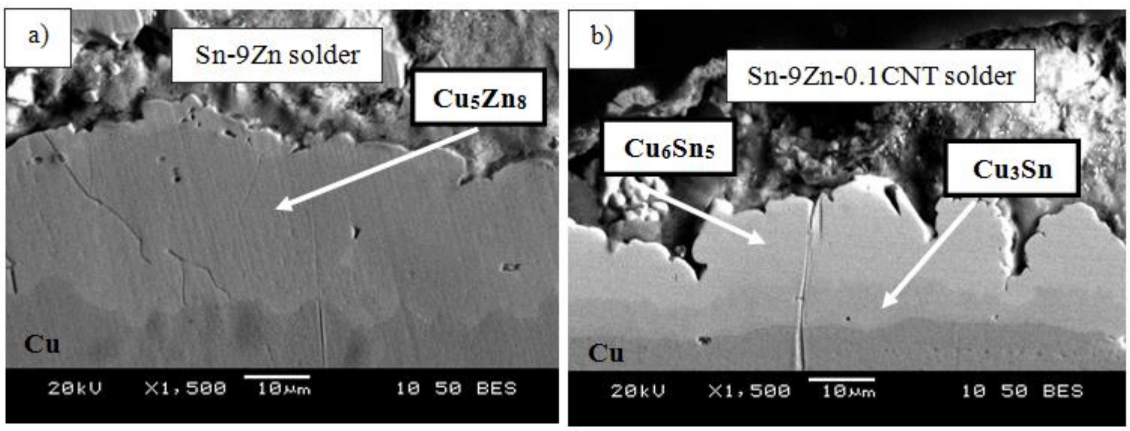


Figure 2: IMC formation of (a) Sn-9Zn, (b) Sn-9Zn-0.1CNT at 45 minute time aging under SEM

*Intermetallic thickness formation*

When soldering was done at 250°C for 1 minute, the $Cu_5Zn_8$ intermetallic for Sn-9Zn/Cu and Sn-9Zn-0.1CNT/Cu have thickness around 7µm and 5µm. This intermetallic thickness increases as the aging time increases as shown in figure 3 and 4. A few studies [8-9] reported that the thickness of $Cu_5Zn_8$ increases as the time of soldering increases for liquid state aging for Sn-9Zn/Cu system. The present results clearly show that the addition of CNT in the Sn-9Zn solder retarded the growth of intermetallic. Figure 5 shows the bar chart intermetallic thickness vs time for both solders.

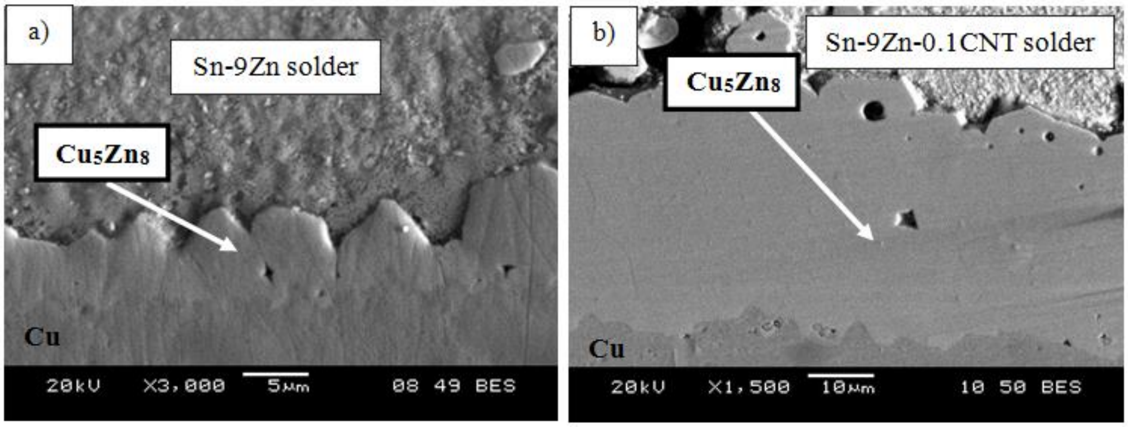


Figure 3: IMC formation soldering at Sn-9Zn/Cu interface for (a) 1 and (b) 60 minutes

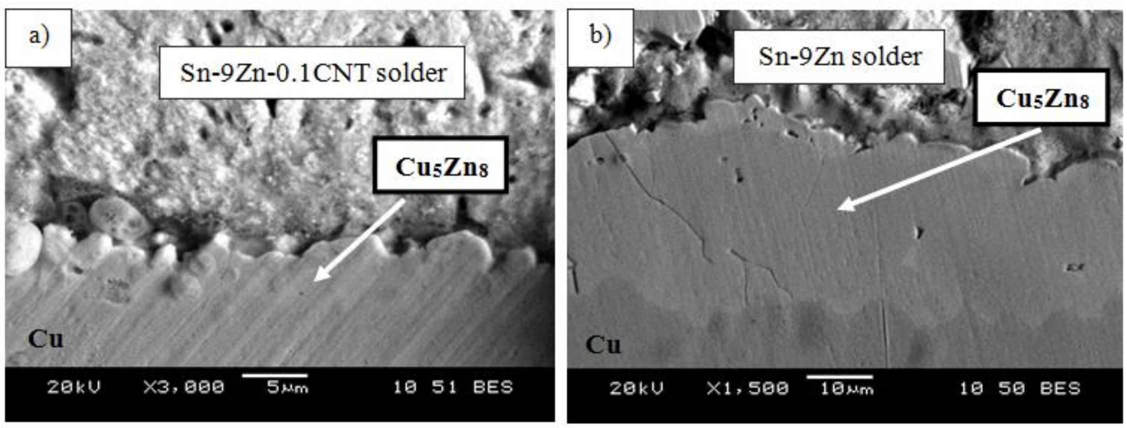


Figure 4: IMC formation soldering at Sn-9Zn-0.1CNT/Cu interface for (a) 1 and (b) 60 minutes

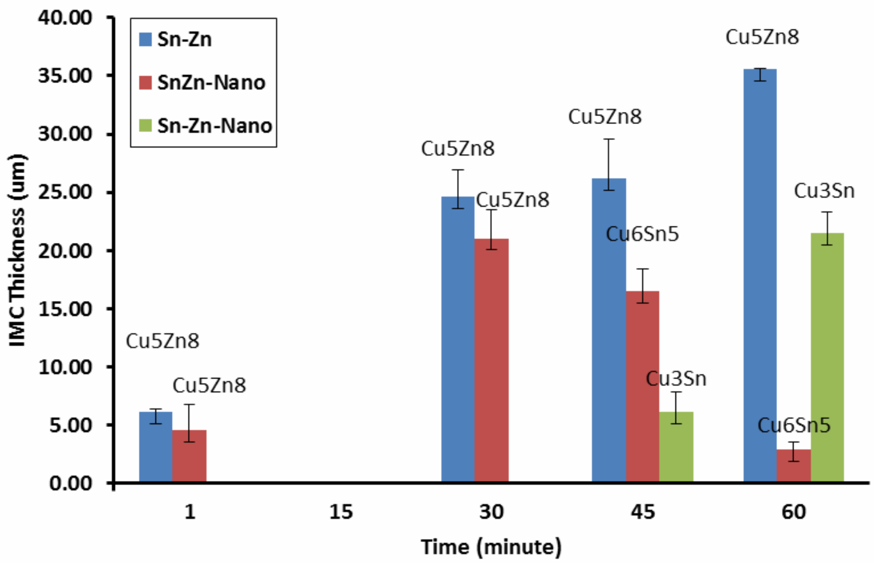


Figure 5: Bar chart IMC thickness vs Time

*Joint strength*

Figure 6 shows stress at maximum of solders which decreases as time of aging increases. According to Ahat et al. [10], as the intermetallic increases it will cause the strength of the solder joint decreases. The strength of Sn-9Zn solder is higher than the Sn-9Zn-0.1CNT. Meanwhile, figure 7 show strain at break of solders which increases as time of aging increases from 1 to 30 minutes. Then the strain reading decreases after aging for 45 minutes and increases when time is raised until 60 minutes. The strain of Sn-9Zn solder is higher than the Sn-9Zn-0.1CNT. The results for both stress at maximum and strain at break of the solders are summarized in tables 1 and 2.

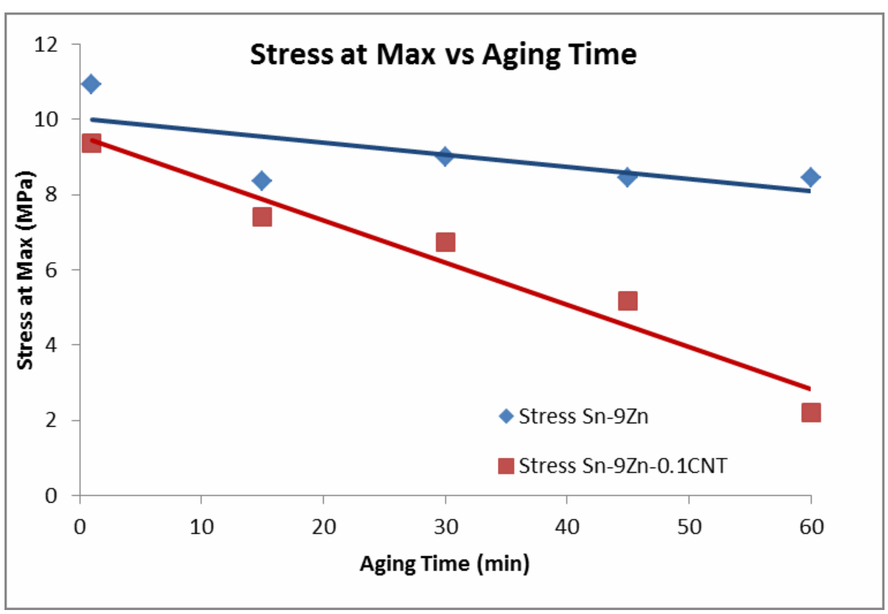


Figure 6: Graph Stress at Max vs Aging Time

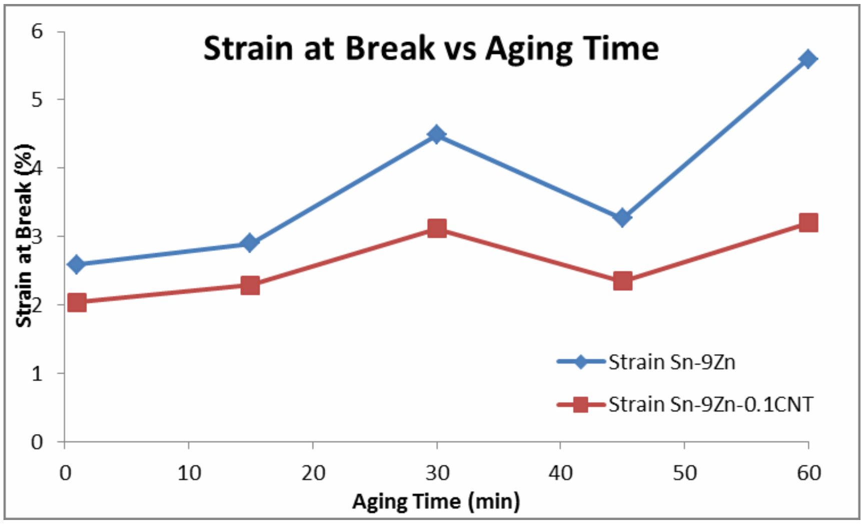


Figure 7: Graph Strain at Break vs Aging Time

Table 1: Stress at maximum for joint strength test

| Aging Time [minute] | Stress at Max [MPa] | |
|---|---|---|
| | Sn-9Zn/Cu | Sn-9Zn-0.1CNT/Cu |
| 1 | 10.93 | 9.37 |
| 15 | 8.37 | 7.4 |
| 30 | 9.00 | 6.75 |
| 45 | 8.47 | 5.17 |
| 60 | 8.47 | 2.20 |

Table 2: Strain at break for joint strength test

| Aging Time (minute) | Strain at Break (%) | |
|---|---|---|
| | Sn-9Zn/Cu | Sn-9Zn-0.1CNT/Cu |
| 1 | 2.59 | 2.04 |
| 15 | 2.90 | 2.29 |
| 30 | 4.49 | 3.11 |
| 45 | 3.27 | 2.35 |
| 60 | 5.60 | 3.20 |

## CONCLUSION

The formation of the thickness of the intermetallic was investigated including the joint strength properties of those solder. The formations of the $Cu_5Zn_8$ were observed at the Sn-9Zn/Cu interface and thickness of IMC was increased as the aging time increased. Meanwhile, the formations of two layers of $Cu_6Sn_5$ and $Cu_3Sn$ demonstrated on the Sn-9Zn-0.1CNT/Cu interface after soldering for 45 and 60 minutes. Based on the results, the thickness of the intermetallic layer of Sn-9Zn- 0.1CNT/Cu interface was smaller compared to thickness of intermetallic layer for Sn-9Zn/Cu interface. This indicated that the presence of the CNT in the Sn-9Zn solder acted as effective retarding agent. However, the joint strength properties were observed to decrease with addition of CNT in the Sn-9Zn solder. The stress strength of the solder decreased with the increased of the aging time.

## ACKNOWLEDGEMENT

This study is financially supported by The Minister of Higher Education (MOHE) for the Grant 600-RMS/FRGS 5/3 (104/2015). Authors also thank Universiti Teknologi MARA for facilities.

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