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Effect of Different Amount of Silicon Carbide on SAC Solder-Cu Joint Performance by Using Microwave Hybrid Heating Method

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Abstract. Microwave hybrid heating (MHH) has been recognized for the soldering process especially with lead-free solder alloy. This study seeks to investigate the effect of the different amount of susceptor on the Sn-3.0Ag-0.5Cu-Copper (SAC305-Cu) joint performance by using the MHH method. The susceptor material that was used to facilitate microwave heating in this study was Silicon Carbide (SiC). Different amount of SiC was used to compare its effect on the intermetallic compound (IMC) formed and shear strength at the solder joint. Domestic microwave with operating frequency 2.45GHz and 800W was used to join the solder and Cu substrate for 5, 6 and 7 minutes. Characterization of the samples was carried out using an optical microscope, image analyzer, and lap shear test. The microstructural study showed that scallop type structure of Cu_6Sn_5 was found at the SAC305/Cu interface after soldering with MHH technique. Thinnest Cu_6Sn_5 IMC (14.909 μm) were obtained by soldering with 6 g of SiC for 6 minutes while highest shear strength was observed when 4 g of SiC was used for soldering for 7 minutes (26.71 MPa).

1. Introduction

Increasing environmental concern in microelectronics soldering industry has developed a lead-free solder material due to the toxic nature of lead. Among other lead-free solder alloy candidates, Sn-Ag-Cu alloy has been recognized as the most relevant due to its relatively promising performance [1]. It has a low melting temperature [2], superior mechanical properties [3] and good compatibility with other components [4]. Soldering technology is one of the most important joining methods in the electronics industry as it is capable of filling joints of irregular dimensions and minimal post processing [5]. They were used for the joining of the first-level packages such as modules and for printed circuit boards (PCBs) [6]. According to Wu, Yu, Law and Wang, the International Printed Circuit Association has proposed that the most widely used alloy composition will be 96.5Sn-3.0Ag-0.5Cu (SAC305) and Sn-3.9Ag-0.6Cu [7].

As stated by Lee and Ahmad Azmin in their study, the crucial factors in the fabrication of electronic products are the interfacial reaction at the solder joints [1]. A reliable solder joint depends on the type of solder materials [8], mechanical properties, intermetallic compound (IMC) formation [9] and heating mechanism [10]. The presence of IMC that are thin, continuous and uniform between the solder and base



metal indicates that good metallurgical bonding has formed. Thus, excessive growth of IMC will affect the reliability of the solder joint. Moon, Li, Xu, and Wong suggested that, with faster heating time and shorter holding time, thick IMC layer can be avoided [11]. Those requirements can be achieved by introducing microwave energy.

Microwave energy has been used as an alternative to the process that consumed high energy that is being used in the industries [12]. The reason behind this is that, microwave energy provides faster, cleaner, low cost and versatile process [10][12-14]. Microwave heating is fundamentally contrasting from conventional heating [15]. In microwave heating, energy is directly transferred to the material through electromagnetic waves with molecules and converted into thermal energy [16]. To simplify, the heat is generated internally within the material itself and gets transmitted outward, which is why it is called volumetric heating. On the other hand, conventional heating involves resistant heating.

It is a known fact that metals will reflect microwave energy which means that no bonding will form between solder and the substrate. It is possible that due to this issue, there are only a few studies reported regarding joining of metallic materials using microwave energy [16]. Moon et al., Lutfi et al. and M. Faisal et al. have reported successful soldering of lead-free solder alloy using variable frequency microwave (VFM) and MHH respectively.

Microwave hybrid heating (MHH) can be divided into two classes; a combination of conventional heating and microwave heating or by using microwave susceptors [13]. Figure 1 displays the classes of MHH. The susceptor functions as an absorber of microwave energy which is useful for initial heating and is heated quickly to provide radiant heat to the sample externally [17]. Silicone Carbide (SiC), graphite (C) and magnetite (Fe_3O_4) are some of the material that is commonly used as susceptor [14]. These materials were used as susceptor due to their high dielectric loss factor and excellent refractory properties [19]. When the susceptor is arranged around the sample, it provides thermal radiation to the samples thus aids in increasing the temperature in the microwave in a shorter time.

This study is carried out to investigate the effect of different amount of susceptor on the intermetallic compound formation and the shear strength on Sn-3.0Ag-0.5Cu solder paste and Cu substrate using microwave hybrid heating method with different heating times.

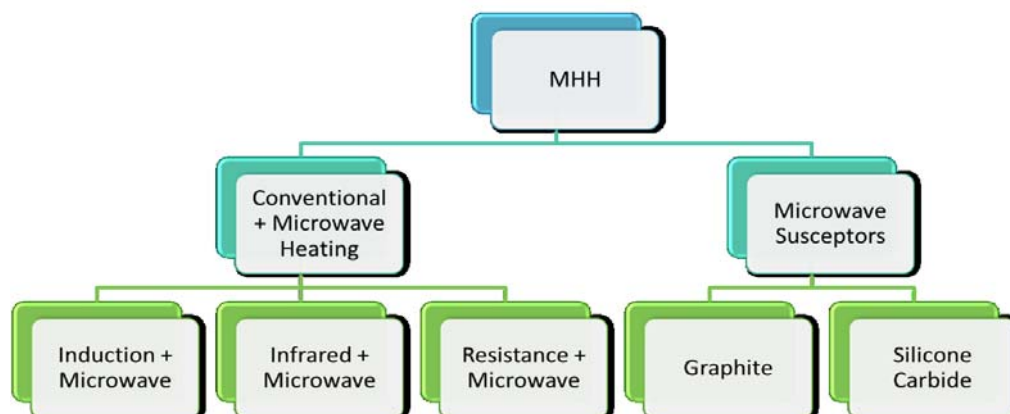


Figure 1. Classes of Microwave Hybrid Heating method [13].

2. Experimental Procedures

2.1. Fabrication of Solder Joint Samples

The solder joint specimen consists of an Sn-3.0Ag-0.5Cu (SAC305) solder paste or solder wire, soldered between the copper plate and copper rod. The copper plate has a dimension of 40 mm X 20 mm while the copper rod has a diameter of 10 mm. A no clean flux was applied to both copper plate and copper rod. A thin layer of SAC305 solder paste (approximately 0.5 mm) was applied onto the copper rod and placed on top of the copper plate. The assembled samples were then placed in the center of the alumina boat. Silicone Carbide (SiC) powder was placed at the sides of the boat which acts as a susceptor. Two different weight of SiC powder were used in this experiment; 4 g and 6 g. Lastly, the samples were reflowed in the domestic microwave using an MHH method at three different heating times; 5, 6, and 7 minutes. Figure 2 illustrates the experimental setup of the MHH method and Table 1 displays the parameters of the experiment.

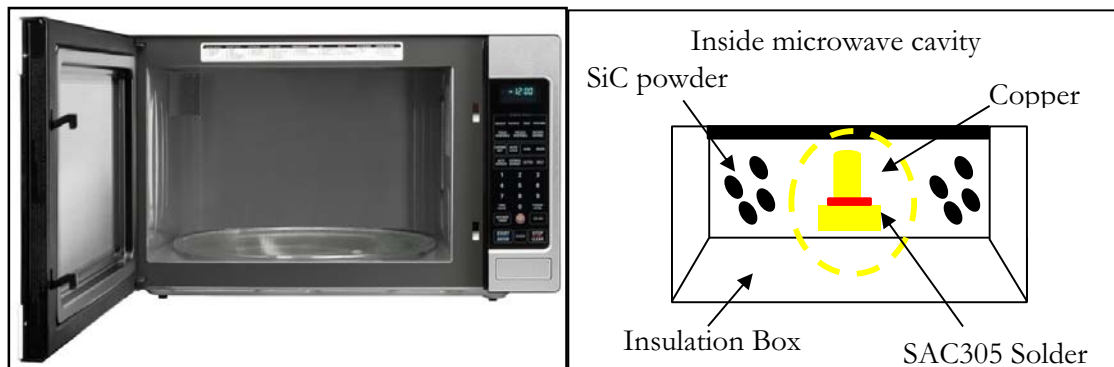


Figure 2. Experimental setup for MHH method

Table 1. The parameters of the experiment

PARAMETERS	
Microwave Frequency	2.45GHz
Exposure Power	800W
Heating Time	5, 6, & 7 minutes
Susceptor Materials	Silicone Carbide (SiC): 4g & 6g
Solder Alloy	SAC305 Paste
Solder alloy Melting Temperature	217°C – 220°C

2.2. Characterization

After reflow soldering, the samples were mounted, ground and polished for optical microscope investigation. Then, they were etched with 5% Hydrochloric Acid (HCl) and 95% Ethanol. The samples were then observed using an optical microscope to study the microstructure. Digital imaging technique was applied in order to measure the average intermetallic compound (IMC) growth thickness. A shear test was also carried out to identify the shear strength of soldered samples at a speed of 1 mm/min. Figure 3 displays the schematic illustration of the shear specimen.

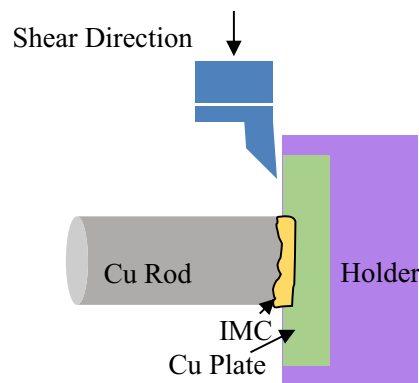


Figure 3. Schematic illustration of the shear specimen

3. Results and Discussion

3.1. Observation of SAC305/Cu Interface

Figure 4 and 5 show the micrograph of the interface between SAC305 solder and Cu substrate reflowed with MHH technique at a different heating time and different amount of susceptor.

Based on Figure 4 (a), a scallop-like structure of Cu_6Sn_5 was formed at the interface after 5 minutes of heating time with 4 g of SiC. As heating time increase to 6 and 7 minutes, the IMC structure of Cu_6Sn_5 changed from discontinuous to continuous thin IMC as can be seen in Figure 4 (b) and (c). Similar Cu_6Sn_5 IMC with scallop-like structure was formed with MHH technique with the use of graphite as the susceptors were reported by Lutfi et. al [12]. On the other hand, Moon et.al mentioned that a larger scallop-like structure of Cu_6Sn_5 IMC formed by VFM compared to conventional soldering process [11].

The incomplete Cu_6Sn_5 IMC at the interface may be due to insufficient heating time to fully melt the solder alloy. Nonetheless, different behavior of Cu_6Sn_5 IMC was recorded after heating with 6 g SiC powder as displayed in Figure 5. It can be observed as the heating time increase, the IMC formed evolve from a uniform structure to a scallop-like structure. In Figure 5 (a), almost no scallop-like structure was observed. The IMC changed to continuous scallop structure and a combination of an angular trapezoid and scallop structure at 6 and 7 minutes, respectively as shown in Figure 5 (b) and (c) respectively.

According to Lee and Mohamad, Cu_6Sn_5 IMC are formed based on the chemical reaction between Cu and Sn atom [1]. When sufficient heat is applied, the solid SAC305 solder starts to melts and the contacted Cu substrate starts to dissolve to the molten SAC305 solder. At the solder/substrate interface, the layer of molten SAC305 solder becomes supersaturated with the dissolved Cu, which is where the solid Cu_6Sn_5 IMC begins to form.

The amount of susceptor used in this experiment also influence the formation of Cu_6Sn_5 IMC at the interface. With the use of 6 g of SiC powder, the IMCs formed are more uniform and thin compared to 4 g of SiC. A thin, continuous and uniform IMC layer is a crucial factor needed to ensure that a good bonding

is formed. It is hypothesized that with 4 g of SiC, insufficient heat was absorbed thus, the solder alloy has not completely melted.

The average thickness of Cu_6Sn_5 has been measured and plotted into a bar graph as displayed in Figure 6. The average Cu_6Sn_5 IMC thickness continues to decrease with increasing heating time with the value of $30.569 \mu\text{m}$, $26.176 \mu\text{m}$ and $22.587 \mu\text{m}$ respectively after heating in 4 g of SiC powder. The high value of IMC Cu_6Sn_5 thickness may be due to the insufficient heat absorbed in the alumina boat thus, hindering the solder alloy to fully melt. The decrease in the IMC thickness signifies that the solder alloy has been melted and formed a more uniform IMC structure.

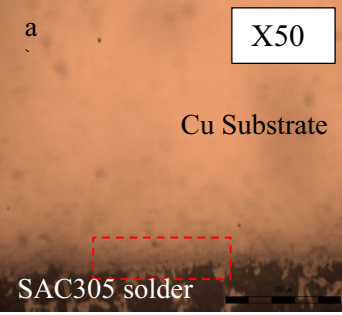

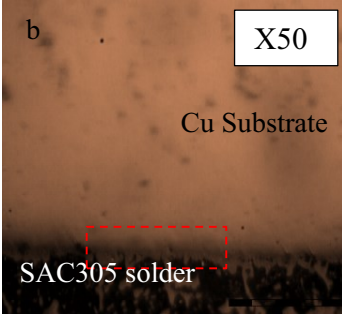

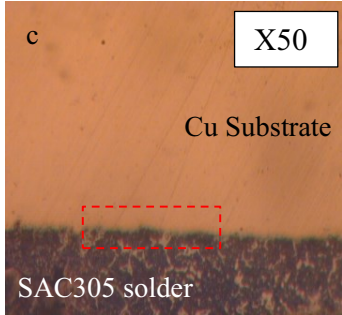

Amount of SiC (g)	Time (min)	Micrograph of IMC	Enlarged View
4g	5min		
	6min		
	7min		

Figure 4. Micrograph of interface between SAC305 solder and Cu substrate reflowed with MHH method with 4 g of SiC at 5, 6 and 7 minutes.

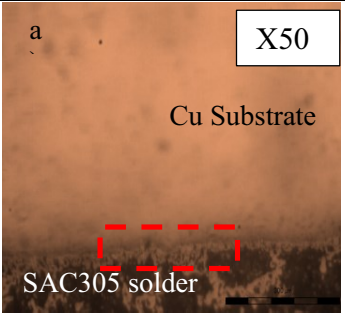

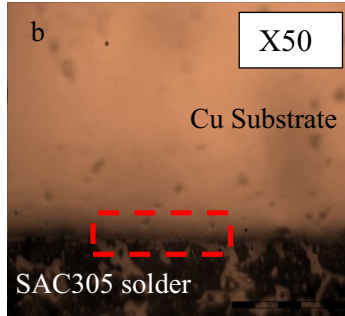

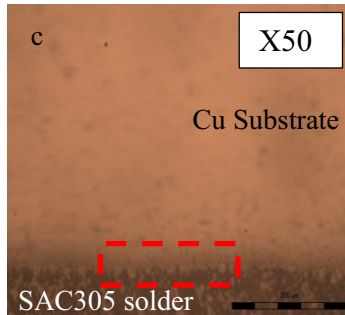

Amount of SiC (g)	Time (min)	Micrograph of IMC	Enlarged View
6g	5min		
	6min		
	7min		

Figure 5. Micrograph of interface between SAC305 solder and Cu substrate reflowed with MHH method with 6g of SiC at 5, 6 and 7 minutes.

The average thickness of Cu_6Sn_5 have been measured and plotted into a bar graph as displayed in Figure 6. The average Cu_6Sn_5 IMC thickness continues to decrease with increasing heating time with the value of $30.569 \mu\text{m}$, $26.176 \mu\text{m}$ and $22.587 \mu\text{m}$ respectively after heating in 4 g of SiC powder. High value of IMC Cu_6Sn_5 thickness may be due to the insufficient heat absorbed in the alumina boat thus, hindering the solder alloy to fully melt. The decrease in the IMC thickness signifies that the solder alloy has been melted and formed a more uniform IMC structure.

While with 6 g of SiC powder, the average Cu_6Sn_5 IMC thickness is significantly lower than 4 g of SiC and does not show a big difference in their value. At 5 minutes, the average Cu_6Sn_5 IMC thickness is $15.411 \mu\text{m}$, followed by $14.909 \mu\text{m}$ and $15.630 \mu\text{m}$ at 6 and 7 minutes respectively. According to Lee and Mohamad, the scallop structure will grow bigger or wider but fewer in relation with time which is due to

the nonconservative ripening among the scallop grains [1]. The ripening process may suggest as to why the Cu_6Sn_5 IMC thickness does not fluctuate much.

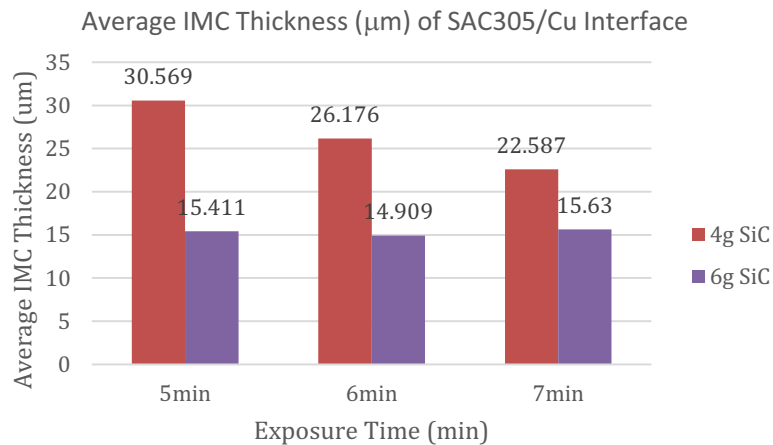


Figure 6. Average IMC thickness (m) of SAC305/Cu interface

3.2. Shear Strength Evaluation of SAC305/Cu Interface

Figure 7 presents the shear strength of SAC305-Cu solder joint after reflowed with MHH technique for 5, 6 and 7 minutes. From Figure 7, it can be concluded that heating with 4 g of SiC for 7 minutes showed the highest shear strength value (26.71MPa). As the heating time decreased, the shear strength value also decreased (16.34 MPa and 13.06MPa for 6 minutes and 5 minutes). However, a different trend was observed when 6 g of SiC was used. The shear strength does not differ much and stays at almost the same range of values. At 5minutes, the shear strength is 16.22 MPa, followed by 15.85 MPa and 16.93 MPa at 6 minutes and 7 minutes, respectively. This result explains that with 6 g of SiC, the Cu_6Sn_5 IMC growth is more uniform and consistent compared to 4 g of SiC. It may be related to the uniformity of Cu_6Sn_5 IMC scallop-

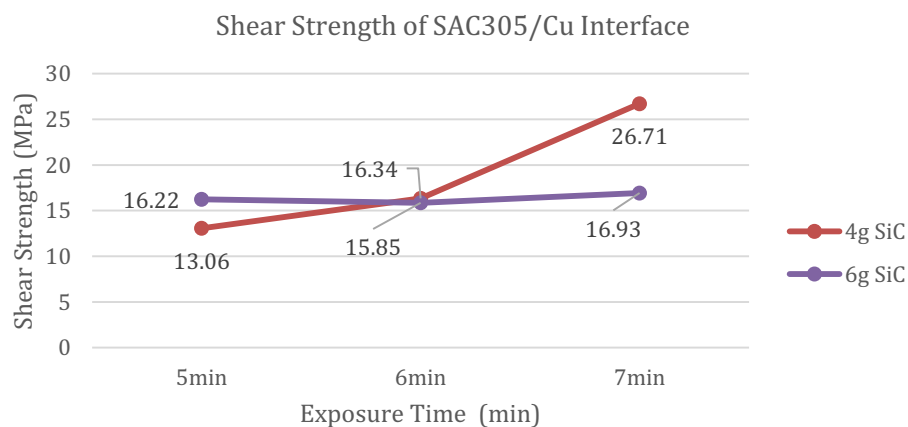


Figure 7. The shear strength of SAC305/Cu interface

like structure at the interface as shown in Figure 7. Larger and thicker Cu_6Sn_5 IMC may impair the reliability of the solder joint due to their brittle nature and by mismatches of the physical properties which may generate structural defects [19].

4. Conclusion

In the present work, the effect of different amount of susceptor on the Sn-3.0Ag-0.5Cu-Copper (SAC305-Cu) joint performance by using MHH method. The interfacial reaction and shear strength were studied. Some concluding observations from the investigation are given below:

- a) Cu_6Sn_5 was found at the SAC305/Cu interface after soldering with MHH technique.
- b) Scallop-like IMCs of Cu_6Sn_5 were observed at the SAC305 solder and Cu substrate for cross-sectional examination.
- c) Soldering with 6 g of SiC for 6 minutes produced 14.909 μm IMC thickness.
- d) The highest shear strength value was obtained by soldering with 4 g of SiC for 7 minutes with the value of 26.71 MPa.

Acknowledgement

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