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Microstructure and Properties of Cu/W85Cu/Cu Composites for Electronic Packaging

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Abstract: The Cu/W85Cu/Cu composite was fabricated by pressureless infiltration and brazing method successfully. The microstructure and physical properties of Cu/W85Cu/Cu composites were investigated. The results show the interfacial region of Cu/W85Cu/Cu composites was consisted of Cu substrate, Cu–BAgCu28 interfacial layer, BAgCu28 layer, BAgCu28-Ni interfacial layer and W85Cu composite. Moreover, the interfacial microstructures investigated by SEM shows that that the electroplated Ni on the surface of W85Cu composites can improve the fillers wettability of the W85Cu composites. Further investigation reveals that the Cu/W85Cu/Cu composites possess relative low density (13.88g/cm^3), excellent thermal management function as a result of high thermal conductivity up to 288.68 W/(m•K) and low coefficient of thermal expansion (7.55×10^{-6} K^{-1}) at room temperature. The above properties of composites successfully meet the requirement of electronic packaging. The shear strength test analysis shows that the Cu, filler (BAg72Cu), and electroplated Ni layer and W85Cu realized metallurgically joining.

Keywords: Cu/W85Cu/Cu Composites, Braze, Electronic Packaging

1. Introduction

In the last several years, thermally conductive and electrically insulating composites have been attracted more and more attention due to their wide applications in electronic devices and electrical facilities [1]. Enhancement of the thermal performances of traditional metal matrix composites (MMC), especially, Cu-W has a great potential to meet the demands of electrical packaging materials[2-4].

It is well known that the density of W85Cu composites (16.3g/cm3) are too large to satisfy the application in microelectronics packaging in the future. But, W85Cu composites have the TC about 210 W/m•K, with a low coefficient of thermal expansion (CTE) of 6.3×10^{-6} K^{-1} at room temperature, essential for particular application. Copper is widely used as thermal management material due to its high thermal conductivity (401 W/m•K). However ,it presents a high coefficient of thermal expansion (CTE) of 17x10^{-6}K^{-1}, which induces thermal stress and degrades reliability as well as lifetime of the electronic components [4, 5]. W85Cu composites combined with a pair of Cu can decrease the density and increase the thermal conductivity (TC) relatively. These desirable combinations of physical properties enable Cu-W85Cu-Cu to be a very promising candidate for electronic packaging. Composite rolling is considered to be an effective method for joining Cu and WCu [6]. But researches on the welding and joining of Cu-W85Cu-Cu have not been found. Therefore, exploiting a method to improve traditional electronic packaging materials has important practical value and theoretical significance.

In order to fabricate Cu/W85Cu/Cu composites, the brazing technology is adopted to join Cu- W85Cu-Cu, which provides a simple and low-cost method for producing Cu/W85Cu/Cu composites. The high adhesion strength and minimum thermal boundary resistance between W85Cu and copper are the most important issues. Eutectic phase BAg72Cu in the form of 50mm thick foil with a composition of Ag72–Cu28 was selected as a solder. For better wetting properties of the Ag-based solder to base materials, W85Cu composites are nickel-plated before they are soldered to Cu. There is no reaction at all between BAg72Cu and Ni, but Ni and Cu atom can dissolve into liquid BAg72Cu. The three-layer sandwich structure of Cu/W85Cu/Cu composites is shown in figure 1 [5, 6].

The objective of this work is to investigate the influence of seam on the properties of the Cu/W85Cu/Cu composites and obtain excellent performance Meanwhile, fabrication technology, microstructure and properties of Cu/W85Cu/Cu composites are also discussed in this article.

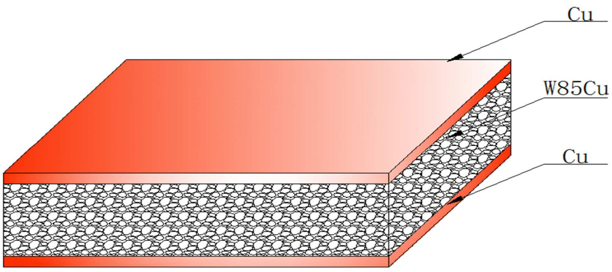


Figure 1. *Schematic structure of Cu/W85Cu/Cu composites.*

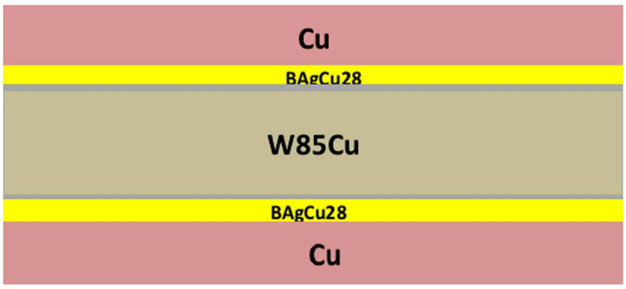


Figure 2. *Assembly of soldered specimen of W85/Cu and Cu.*

2. Experimental

Figure 3 is the flowchart of the experiment procedures in this work

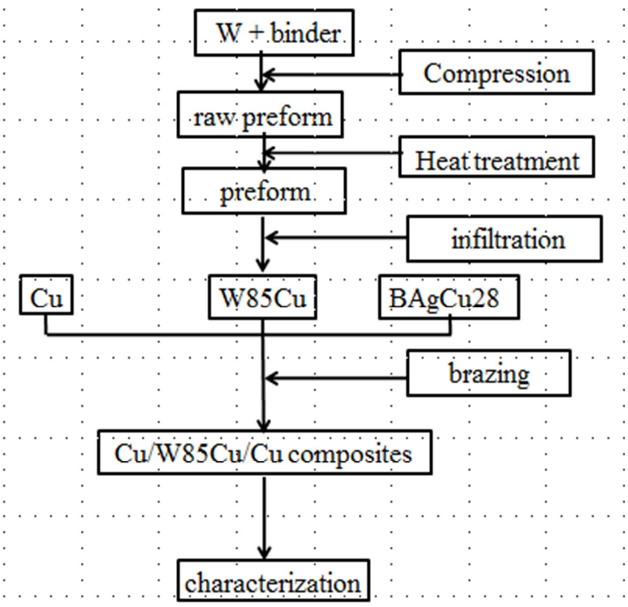


Figure 3. *Flowchart of preparation and characterization of Cu/W85Cu/Cu composite components.*

2.1. Materials and Processing

Tungsten powder ((purity>99.8wt%), oxygen free copper and BAg72Cu were used as starting materials. The Ag-based solder is in the form of the 50mm thick foil with a composition of Ag72–Cu28. The physical properties of the oxygen free copper and tungsten were listed in Table 1.

Table 1. *The physical properties of the starting materials.[7, 8]*

materials	CTE/ ppm/°C	TC/ W/(m·K)	Density/ (g/cm^3)
Cu	17.0	400	8.90
W	4.5	174	19.30

The W85/Cu composites with 85% mass fraction of W particles were fabricated by pressureless infiltration method. The representative micrograph of W85Cu composites are shown in Figure 4. A nickel layer was introduced onto W85Cu by electroplating, with a thickness ranging from1 to 2um. Details of the techniques are described in Ref. [5].

Cu plates with a size of 45×45×0.35mm were purified in a mixed solution of concentrated H_2SO_4/ H_2O_2(volume ratio 3:1) to remove the oxide. Solders (BAg72Cu) with a size of 31.8×31.8×0.05mm was boiled in a solution of concentrated NaOH for 20mins to remove the grease. Subsequently, the degreased-as solders were ultrasonically cleaned in a HCl solution for 5min. Then, the solders were washed with distilled water for several times and dried by a drying chamber.

The Cu/W85Cu/Cu composite with a size of 45mm×45mm×1.6mm was obtained by brazing technology. The composite are characterized by a tungsten volume fraction of 55.9%. The brazing temperature was 815°C and the holding time 5 min. High-purity H_2 was used as protection gas. The assembly of the specimen is shown in Figure 2. Figure 6.(b) illustrates the specimen of shear test.

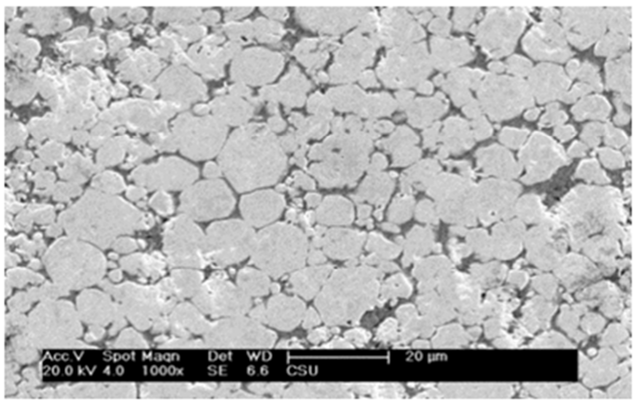


Figure 4. *SEM micrograph of W85Cu composite.*

2.2. Characterization

The density of the Cu/W85Cu/Cu composite specimens were measured by the Archimedes method. The thermal conductivity of the specimen with a size of Φ12.7 mm×3 mm was measured with the thermal physical testing apparatus (LFA 447 Nanoflash, NETZSCH Co. Ltd, Germany). The average CTE, within a temperature range from 20 to 500°C, was measured in a dilatometer with an accuracy of 5%. The microstructures of the composite is observed by scanning electron microscopy (SEM). The open porosity was confirmed visually using scanning acoustic microscope (SAM).

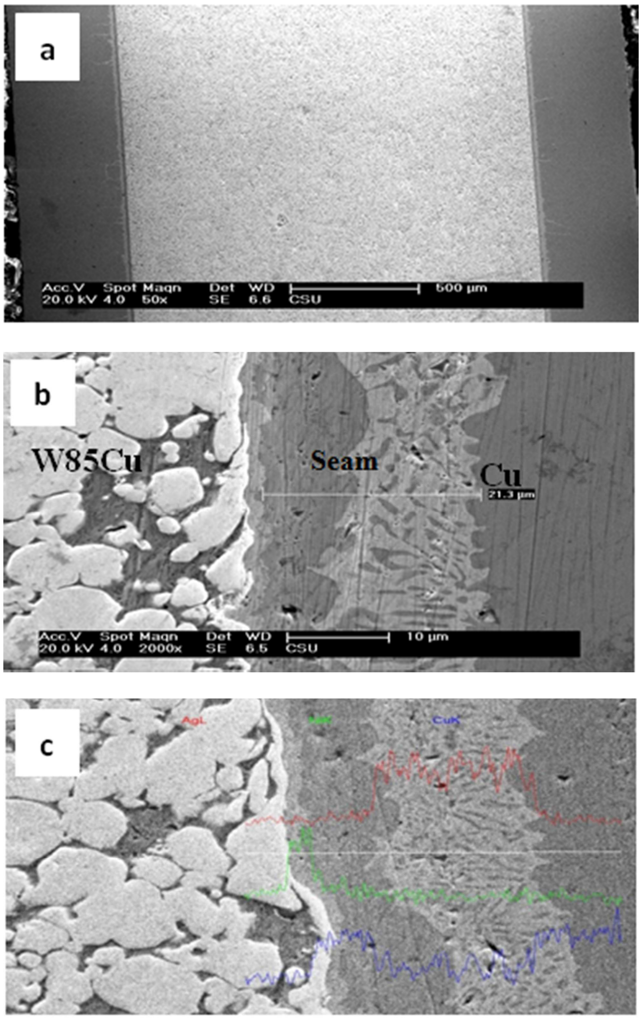
3. Test Results and Discussions

Table 2. lists the typical properties of Cu/W85Cu/Cu composites determined in this study, It can be concluded that Cu/W85Cu/Cu composites has a lower density (2.42 g/cm^3 lower than W85Cu composites). Moreover, the excellent thermal conductivity makes it more appropriate for advanced electronic components [9-10].

Table 2. *Properties of Cu/W85Cu/Cu composites.*

Shear strength/MPa	CTE/ ppm/°C	TC/ W/(m·K)	Density/ (g/cm^3)
≥121	7.55	288.68	13.88

3.1. Microstructure and Shear Strength Tests



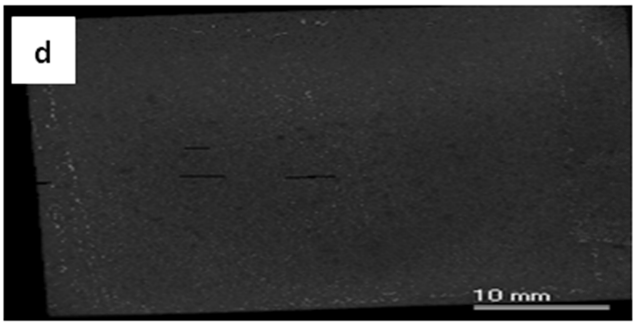


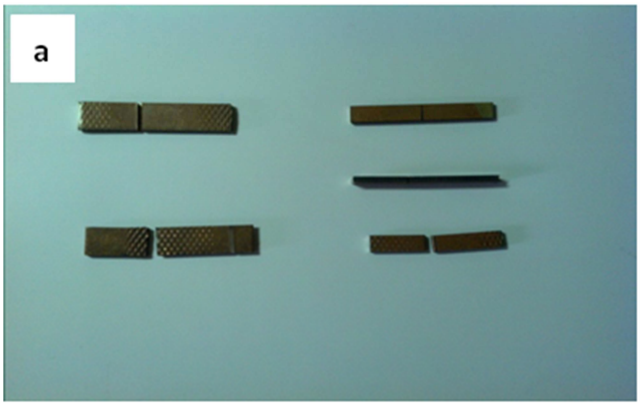
Figure 5. *(a) SEM image of Cu/W85Cu/Cu; (b) The Magnified morphology of Cu/W85Cu/Cu composites;(c)Microstructure and line analysis of chemical composition at Cu/W85Cu/Cu interface(Blue curve represents Cu , light green curve represents Ni and red curve represents Ag);(d)SAM image of Cu/W85Cu/Cu solder joints.*

Figure 5.(a) shows the microstructure of Cu/W85Cu/Cu at brazing temperature was 815°C for holding time of 10 mins. It can been seen the interfacial region between the W85Cu composite and Cu layer was uniform and continuous, due to the filler metal spreading fully and rather great wetting of Cu-BAg72Cu-W85Cu system. Excellent thermal and mechanical properties depend on the high-quality joint.

Figure 5.(b) exhibits the microstructure of welding area, It can be seen that the thickness of the welding area is constantly about 21um. The value of the thickness is measured via average ten figures in different regions and the errors are in the range of 5%−9%. Typical joints pores are also observed in the seam, implying that re-arrangement of gases have taken place during solidification ,which can be testified by Figure 5.(d), but the pore is too small and few to weaken the joint performance [11].

Line analysis of chemical composition at the Cu/W85Cu interface is investigated and is shown in Figure 5.(c). The figure shows four distinct zones: the W85Cu zone, the Ni layer, the BAg72Cu zone, and the Cu zone. When entering the interfacial Ni coating from the W85Cu zone, one can observe a sharp decrease in intensity of the Ni signal, indicating a very low diffusion of Ni atoms into the BAg72Cu. Furthermore, from the Cu to the Ni zone, the element of Ag evenly distributed, and there is no element accumulate, implying that the choice of BAg72Cu very reasonable. Wettability level of the soldering filler metal over composites is greatly improved because of electro-plating.

Figure 6.(a) shows the result of shear strength test. on one hand, the photograph illustrates that Cu and W85Cu composites can be connected by using the BAg72Cu as brazing filler metals. On the other hand, the joint shear strength was tested, but the test was failed. As is shown in Figure 6.(a), the break position appears in Cu foil, implying the value of shear strength of welded joints minimum is 121MPa, exceed that of Cu, which means a metallurgical g at the interface between Cu and filler metal is formed.



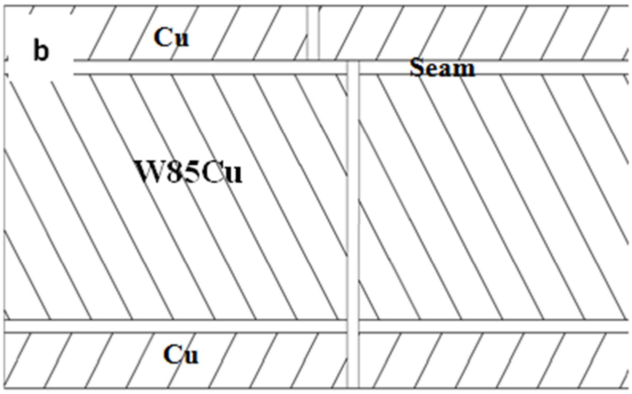


Figure 6. *Shear strength test of Cu/W85Cu/Cu composites:(a)The result of composite specimens for shear strength tests; (b) Schematic of the specimens for shear test.*

3.2. Thermal Conductivity (TC)

The TC of the Cu/W85Cu/Cu composite is 288.68 W/(m•K), which is 78.68 W/(m•K) higher than that of W85Cu composites, an enhancement of 37.46%. This indicates that the effect of the brazing layer is rather evident for the composites with high copper volume fraction. Considering the higher volume fractions of copper and the higher TC values, the composite containing 44.1vol.% copper was introduced. Meanwhile, the TC of the Cu/W85Cu/Cu composite is calculated by the rule of mixture.

The rule of mixture can be represented by:

$$\lambda comp = \Phi w\lambda w + \Phi cu\lambda cu \quad (1)$$

where Φ and λ are the volume fraction, thermal conductivity, respectively. The subscripts $_{comp}$, cu and w refer to composite, matrix and filler, respectively. The influence of the coating and filler metal on the TC was not taken into consideration, because of the low volume fraction in the composite. In the calculation in room temperature, reference data are used: λ_w = 174W/m·K for tungsten and λ_{cu}=400 W/m·K for copper. Substituting the experimental data for a volume fraction of copper (Φcu=0.441) into Eq.1-1. Thus, the thermal conductivity of the composites Cu/W85Cu/Cu we produced is 273.666w/m.k, which is in very good agreement with experimental data(288.68 W/(m•K)) The reasons for those are on the one hand scanty pores and on other hand a good interface between Cu and W85Cu. It is also because the brazing layer can not only improve the combination of the interface but also not induce the additional thermal resistance such that the experimental result of the thermal conductivity is higher than the calculation result. Based on the above analysis, the BAg72Cu intermediate joint plays a positive role in enhancing the thermal conductivity of the Cu/W85Cu/Cu composite, and High thermal conductivity of the composite Cu/W85Cu/Cu means much lower interfacial thermal resistance of the welded joint.

3.3. Coefficient of Thermal Expansion

Figure 7. shows the CTE curve of Cu/W85Cu/Cu composites at different temperatures. It can be divided into three stages. With temperature increasing, CTE firstly increases slowly from room temperature to 150°C at stage I, and increases rapidly at stage II (150−350°C), finally stabilizing at 9.16×10^{-6}/K over 350°C at stage III. This reveals that the CTE of composites matches with the chip Si. CTE of composites increased when temperature reaches 50~350°C, in this temperature range, the average distance of Cu atoms in crystal lattice was enlarged due to intensified lattice vibration [12, 13]. As a result, the metallic bonds and elastic modulus have been harmed and finally resulted in the growth of CTE. However, CTE of composites stabilized when temperature become higher than 350°C because W85Cu with lower CTE (6.3×10^{-6}/K), which limits the thermal expansion of composites itself. The above two aspects account for the abnormal phenomenon.

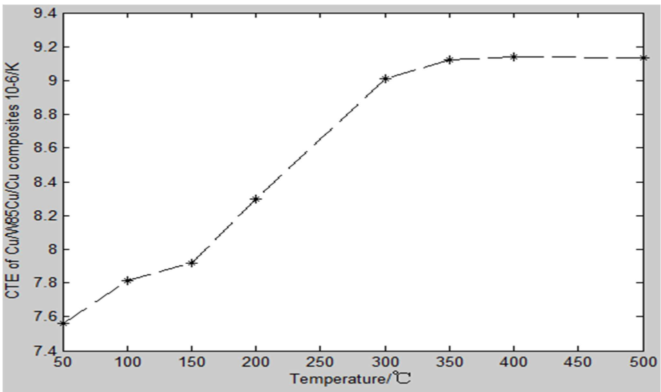


Figure 7. *CTE of Cu/W85Cu/Cu composites.*

4. Conclusion

1. Cu/W85Cu/Cu composites are successfully produced by brazing technology. Interfacial region between W85Cu composites and Cu layer was uniform and continuous without obvious defects.

2. BAg72Cu alloy utilized to solder W85Cu composites substrates electroplated by Ni layers is very reasonable. The electroplated Ni on the surface of W85Cu composites can improve the filler's wettability to W85Cu composites.

3. Cu/W85Cu/Cu composites possess excellent properties, including relative low density (13.88g/cm3), high thermal conductivity (288.68W/(m•K), and low CTE (7.55×10-6/K) at

room temperature. The shear strength of joint is over 121MPa. Meanwhile, the Cu, filler, electroplated Ni layer and W85Cu realized metallurgically joining

4. The BAg72Cu intermediate joint plays a positive role in enhancing the thermal conductivity of the Cu/W85Cu/Cu composite.

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