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Preparation of Copper Lead Frame by Powder Metallurgy Technique

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Abstract

Pure Cu is prepared with the dimension of 17.7 mm in diameter and 10 – 15 mm in height using powder metallurgical method to characterize its electrical and mechanical properties. These samples are compacted at a constant pressure of 280 MPa. Pure Cu pellets are sintered at 600°C and 950°C for 3, 4 and 7 hours. Before sintering, pure Cu pellet is subjected to SEM in order to check the compactness of the pellet, and also the grain structure of the Cu. All the pellets with different temperatures are re-weighed and sintered density are calculated after sintering. Besides that, porosity of the pellets is measured to analyze the closed packed particles stacking in the pellet. SEM and EDX of this pure Cu pellet have been captured to observe the presence of pores and agglomeration of particles in the sample. Pellets are also subjected to electrical conductivity measurement by comparing it to the commercial Cu lead frame in industry.

Keywords: Copper, sintered density, porosity and electrical conductivity

Introduction

Copper (Cu) lead frame has been in use in the semiconductor industries for century. The Cu alloy lead frame had first been used when the Cu price was low in year 2004 against the price now in year 2010 which is 4 times higher[(1)]. Pure Cu is an element with face center cubic crystal structure, excellent conductor, malleable and easily cast and shapes. But this pure Cu has to be alloyed with many other elements to effect minor changes in terms of the properties such as improving the tensile strength, machinability and oxygen free etc[(2)]. Owing to the high strength and conductivity of the Cu alloy, it is highly sought after for high technology usage such as lead frame. Therefore, with the increasing Cu price in the foreseeable future and coupled with the above disadvantages from Cu, it has become very critical to find an alternative material and method for producing Cu lead frame.

Powder metallurgy[(3)] (PM) is a methodology which involves blending and mixing of the powder materials, compacting and sintering. In basic condition, powder pressing and compacting are performed at room temperature and sintering under elevated temperature in a vacuum environment. Liu,*et al*[(4)] had studied the sintering reaction of Cu-Mg-B system through PM method. In their work, it showed that PM method is able to fabricate Cu-10 wt% (Mg + 2B) composite with sintering exhibit higher density and hardness. However, the electrical conductivity of the study is considerably lower than that of the former composite. Furthermore, Upadhyaya, *et al*[(5)] had reported a study of sintering of Cu-Al_2O_3 composites through blending and mechanical alloying PM routes. The study showed that there is an influence of compaction pressure on the mechanical properties of the samples. As the compaction pressure increases, both sintered density and hardness increase too. With the increase of Al_2O_3 powder content, it generally increases the hardness but with an associated loss in electrical conductivity. It shows that PM method is able to give good mechanical properties but low electrical conductivity on the sample produced. However, Feng, *et al*[(6)] had reported the microstructure and electrical conductivity of aluminum alloy foams. Aluminum alloy foams with different densities and cell diameters have been fabricated by using powder metallurgy technique. The result shows that electrical conductivity of foams increases with increase of relative density while cell diameter has a minor influence on the electrical conductivity of foams.

Findik, *et al*[(7)] had investigated the electrical conductivity, hardness and microstructure of Ag-W and Ag-WC refractory contact materials. Ag-W and Ag-WC refractory contact materials had

fabricated by powder metallurgy involving powder compacting and then liquid silver vacuum infiltration. The powder metallurgy fabrication of Ag-W composites have relatively high hardness and electrical conductivity that make it attractive materials for contactors, switch gear, low-voltage regulators and electrodes for electric discharge machining.

This paper mainly describes the powder metallurgy preparation method and evaluation on different temperatures duration in order to find the suitable condition to improve the density, porosity and electrical conductivity.

Materials and Experimental Procedures

To study the effects of different temperatures and duration of sintering with powder metallurgy, and only a 100 wt% of Cu without any alloying effect is used. Firstly, the desired amount of Cu powder is weighed according with the total weight of 5 gm. The 5 gm of Cu powder is poured into the die hole of the pressing jig. Then the powder mixtures are compacted at pressure of 280 MPa using a manual hydraulic press. A pellet with the dimension of 17.7 mm in diameter and 15 mm in height is produced. Finally, the pellets are sintered in a furnace at 3 different temperatures and durations as shown in Table 1.

The pellet is sintered with the rate of 10 °C/min for Samples 1 and 2 while Sample 3 is with the rate of 4°C/min in a vacuum environment without presence of gases. The sintered temperature is let constant for 2 hours before the temperature ramp down with the rate of 10°C/min and 4°C/min respectively for Samples 1, 2 and 3. In additional, only Sample 3 is subjected to pre-sintering at 750°C for 1 hour.

Table 1. The sintering temperature and duration for 3 different samples.

Sample	Sintered Temperature (°C)	Total Time (hours)
1	600	3
2	950	4
3	950	7

Pure Cu and commercial lead frame (EFTEC) are having the same value of density which is 8.94 g/cm^3. The densities and porosities are evaluated using the water displacement method. Water displacement is a method using Archimedean principle[8]. The samples are weighed in air and then re-weighed when suspended in water. The volume of the sample is calculated from the displacement measurement. The sample relative density is defined as the ratio of Cu pellet density to that of pure Cu density in percentage. Besides that, microstructure observations have been carried out using scanning electron microscope (SEM) and electrical conductivity is performed using Ohm's law circuitry setup.

Results and Discussion

The pure Cu sintered density results are to be determined by using Archimedes's principle.[9] Figure 1 shows the density comparison between the commercial lead frame and the sintered density of 3 pellets at different temperatures and duration.

In Figure 1, the result shows sintered densities of the 3 samples towards the lead frame. Sample 2 is with the nearest sintered density to the lead frame (8.94 g/cm^3) with 7.45 g/cm^3. Besides that, Sample 3 is also showing the highest relative density, 83.3 % as compared to Samples 1 and 2. The relative density is 78.5 % (7.02 g/cm^3) for Sample 2 compared to the commercial lead frame. While for Sample 1, it gives the lowest relative density as it is showing the lowest sintered density which is 6.51 g/cm^3.

Small relative densities are achieved at lowest sintering temperature in Figure 1. This can be explained by Eq. (1), showing the dependence of diffusion to sintering temperature[10,11]. Hence, a denser structure is achieved at higher sintering temperature,[3]

$$D = D_0 \exp(-Q/kT) \quad (1)$$

where D is the diffusion coefficient, D_0 is the constant, Q is the activation energy, k is the Boltzman's constant and T is the temperature. This co-relates to the theoretical performance where the sample that sintered at 950°C shows higher density as compared to sintering at 600°C.

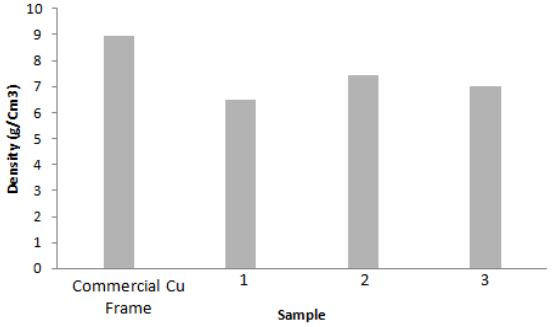


Figure 1. The sintered densities for samples at different temperatures and durations.

There are a few factors that can lead to the low sintered density of a pellet. In some cases, it is caused by insufficient compactness that leads to high porosity. Other factors could be due to insufficient sintering temperature that leads to incomplete grain growth and shrinkage. This is because the mechanism is still occurring in the early stages of the sintering process whereby only inter-particle bridging through surface diffusion. Moreover, sintering mechanism still yet to reach boundary or lattice diffusion stages whereby no neck growth or pore elimination and densification occur. This is mainly because grain boundaries are not successfully formed within each neck and leaving every interstice between particles becoming a pore.

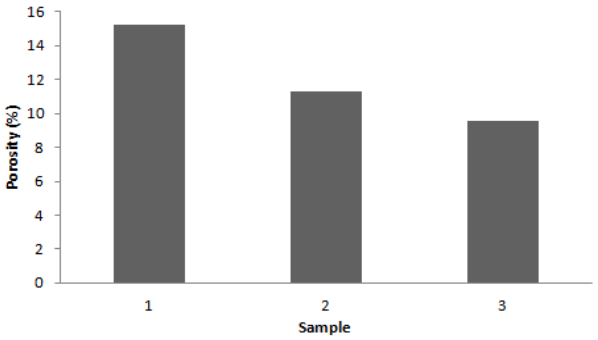


Figure 2. Porosity with different temperatures and durations.

In Figure 2, it is observed that the porosity from Sample 1 is the highest in both open and closed porosity as compared to Samples 2 and 3. The reason for the higher porosity in Sample 1 is mainly due to insufficient sintering temperature and too short duration which is clearly observed in Figure 3.

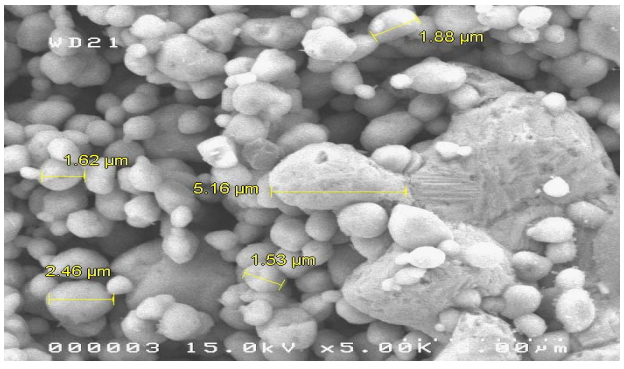


Figure 3. SEM micrograph for Sample 1 which sintered at 600°C and 3 hours.

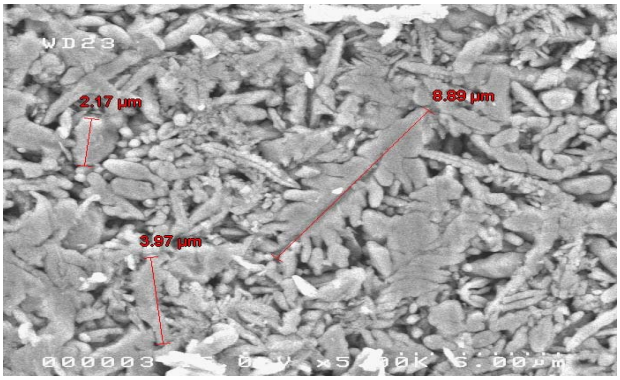


Figure 4. SEM micrograph for green sample before sintering for Sample 1.

In Figure 4, it shows that the powder particles that touch one another after pressing has begun to adhere to the adjacent particles. Unfortunately for Sample 1 of Figure 3 shows that the sintering mechanism is still not complete as it is observed that in average the powder particles have a rounded shape and less of boundary and lattice diffusion from grain boundary to neck that lead to no volume shrinkage internally of the pellet as compared to sample before sintering. Furthermore, the large Cu particles (10 µm) that are observed in micrograph reduce the contact area between Cu particles leading to higher porosity. This has explained the reason of low density and high porosity of Sample 1 as compared to others.

Samples 2 and 3 show low porosity results which are 11.3 % and 9.54 % compare to Sample 1. This means that, sintering at 950°C is sufficient to result in neck growth which subsequent creates grain boundaries within each neck, reduction of pores and densification to occur in the pellet. Although both samples with comparable porosity percentage, but they have a different grain structures.

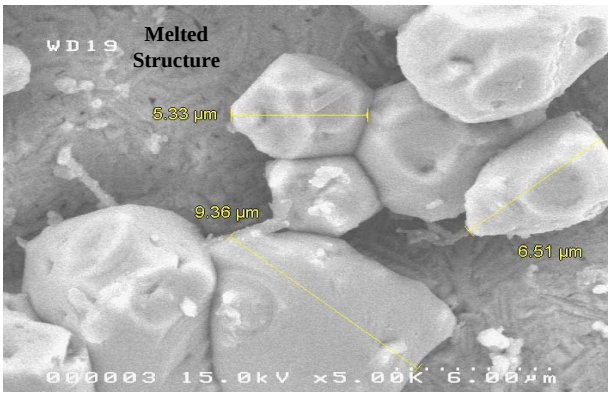


Figure 5. SEM micrograph for Sample 2 which sintered at 950°C for 4 hours.

Figure 5 micrograph shows that the pellet is partially melted and there is presence of grain on top of the melted structure. The structure seems to be not homogeneously sintered. This is because the ramping temperature used is 10°C per min before reaching sintering temperature of 950°C for 2 hours. This short sintering duration led to partial melting of the sample and not homogenized that subsequently cause incomplete inter-diffusion and presence of pores. In addition, grains that are present are more rounded as compared to Figure 6.

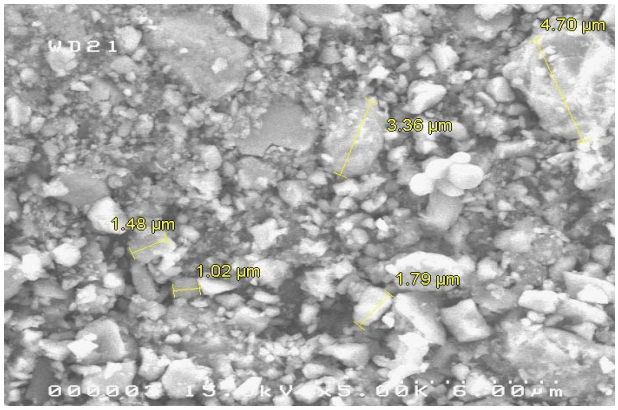
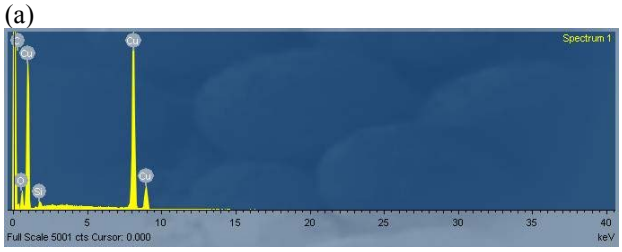


Figure 6. SEM micrograph for Sample 3 which pre-sintered at 750°C for 1 hour and sintered at 950°C for 2 hours.

Sample 3 with longer heating duration shows on average a smaller grain size as compared to Sample 2. Basically the grain size reduces from 9.36 µm to 4.70 µm with the decrease of the heating rate from 10 to 4°C/min which lead to longer sintering duration. This basically shows that, longer sintering duration gives a homogeneous sintering across the sample. But the longer sintering duration shows higher carbon and oxygen content which are approximate of 14.94 wt% each. The high carbon and oxygen content that present in the sample are mainly due to burning and oxidation effects of Cu powder. This gives the remaining of 68.69 wt% of Cu in the pellet as per Figure 7(a). The presence of Si is a contamination from the pressing jigs.

(a)



(b)

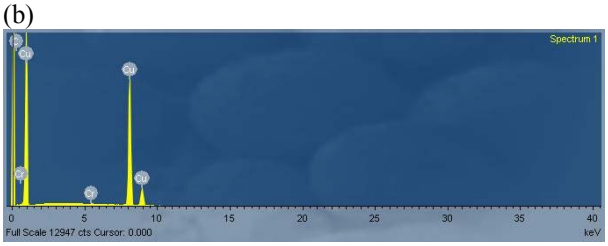


Figure 7. EDX graphs for (a) Sample 3 and (b) Cu lead frame.

As a comparison to the commercial Cu lead frame structure, it shows a totally different structure as compared to the pelletized sample. The Cu lead frame structure shows rolling lines and no pores observed on the surface. This is mainly because Cu lead frame is produced through melting method and subsequent undergoing rolling process to form into sheet form. Besides that, the Cu lead frame shows high Cu content of 89.79 wt%, Cr of 0.42 wt%, C of 9.79 wt% and no O present at all in the sample as per Figure 7(b). The presence of Cr is due to the alloying effect enhancing the hardness and magnetizing the frame. The microstructure for the entire sample of Cu lead frame is shown in Figure 8. It can directly relate to the electrical conductivity performance.

The electrical measurements show a significant difference between the electrical conductivity of Cu lead frame as compared to the pelletized samples. Cu lead frame electrical conductivity is $3.66 \times 10^7\ \Omega^{-1}m^{-1}$ while Samples 1 to 3 are roughly of 1.06×10^6, 6.10×10^5 and $1.53 \times 10^6\ \Omega^{-1}m^{-1}$ respectively. The difference of our electrical measurement for Cu lead frame compared to the technical data sheet is 2.7 %.

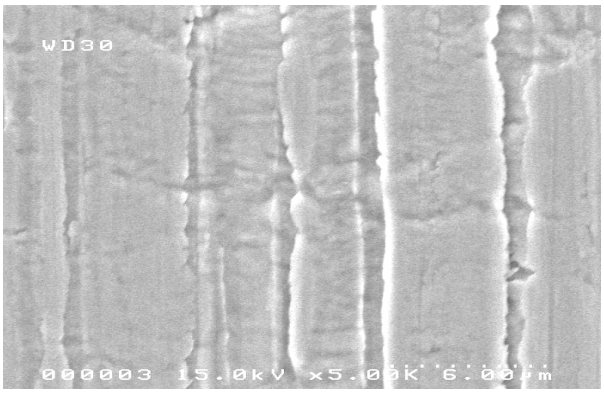


Figure 8. SEM micrograph of commercial Cu lead frame.

This is mainly due to the two different methods used for the Cu lead frame and the prepared samples. Cu lead frame which uses melting method has no pores and gives better metallic bonding. The subsequent rolling had enhanced the mechanical and electrical properties of the frame. Therefore, Cu lead frame shows higher electrical conductivity as electron can move easily. The Samples 1 to 3 are prepared through powder metallurgy method. They show the presence of pores due to uneven shrinkage and inter-diffusion between the grains with high porosity as show in Figure 2. Furthermore, high oxygen present in Samples 1 to 3 which are 7.27 wt% to 14.94 wt% had led to electrical resistance as this Cu oxide would resist the electron from going through the samples. This subsequently lowers down the electrical conductivity of Samples 1 to 3 compared to Cu lead frame which is free from oxide. Hence, the higher the oxygen concentration in a sample, the lower is electrical conductivity or near insulative.

Conclusion

Sample 3 with pre-sintering temperature of 750°C and sintering at 950°C for 2 hours gives the nearest sintered density as compared to commercial Cu lead frame. It also gives relatively low porosity and high electrical conductivity value compared to Samples 1 and 2. This means that powder methodology at 950°C sufficient to sinter the Cu powder to achieve similar mechanical and electrical properties of the Cu lead frame. However, the electrical conductivity of the sample is still low as compared to Cu lead frame. This is because of the presence of high oxygen level and closed porosity that lead to the lower electrical conductivity of the samples. Therefore, the controlling of the copper oxide and closed porosity are critical in order to achieve high electrical conductivity.

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