The Outcome of Sintering Parameters Study toward the Thermal Properties of CuSiC Composite

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Abstract. Miniaturisation of electronic chips which have increasing functionality within the same package size has induced significant increases in requirements for extraction of heat from the integrated circuit (IC). Packaging materials therefore have to be capable to conduct heat efficiently and at the same time have low coefficient of thermal expansion (CTE) to minimize the thermal stress and warping. In the present study, copper silicon carbide was selected with an aim to solve thermal management problem presented by current IC systems. Powder metallurgy routes were chosen to fabricate the MMC based on this materials system. Copper and silicon carbide powders were mixed together in a planetary ball mill, and the green articles were then compacted and sintered to produce the final product of CuSiC. The sintering parameters were investigated for their effects towards the thermal conductivity of the composite. Sintering parameters investigated included temperature, heating duration and the gaseous environment. Upon sintering, the CuSiC particle bond to one another giving a higher strength and a possibility in attaining desirable density. Thus to achieve good thermal conductivity, the recommended sintering parameter suggests that the CuSiC composite should be sintered at 950^{o}C for 7 hours in nitrogen gas.

Introduction

In the past decade, Metal Matrix Composites (MMC's) are rapidly becoming prime candidates as structural material in engineering application due to their excellent thermo-physical properties such as low coefficient of thermal expansion (CTE), high thermal conductivity, and improved mechanical properties such as higher specific strength, better wear resistance, and specific modulus [1]. Thus, it is considered worthwhile to fabricate the copper-based ceramic-reinforced composites and to study their thermal conductivity characteristics. Copper silicon carbide (CuSiC) metal matrix composites were prepared by powder metallurgy routes which sintering was the dominant process [2, 4]. Sintering is faster at higher temperature with longer sintering time because of the increased number of activated atoms and available sites. Thus, proven by the results, sintering temperature and time are dominant parameters in defining a sintering cycle of CuSiC composite. Besides, the sintering atmosphere influences sinter bonding and compact composition of CuSiC composite [3]. Many materials including CuSiC prove unstable with high vapour pressure during sintering, so a protective atmosphere is selected to inhibit volatilization and loss of composition. During heating, the first task of sintering atmosphere is to assist in extracting surface contaminants and processing organics [3]. The use of nitrogen and argon gases is keys to ensure proper sintered properties of CuSiC composite. Nitrogen is neutral in many situations. It is a very active agent in the sintering, because of its role in preserving the compound stoichiometry. Nitrogen is the major constituent of air and leads to nitrogen absorption at high temperatures. Argon, on the other hand, is an inert gas which is useful in sintering since it reduces evaporation and can be purified to high levels and results in some oxide reduction [4].

Materials and Methods

Overview. The sintering parameters investigated included temperature, heating duration and the gaseous environment towards the thermal properties of the composite, in which the main goal is to produce composite with good thermal conductivity.

Procedures. In this study, the CuSiC composite is produced solely by powder metallurgy method. The sequence of steps utilised in the powder metallurgy process of CuSiC metal matrix composite (MMC) production is shown in shown in Fig. 1.

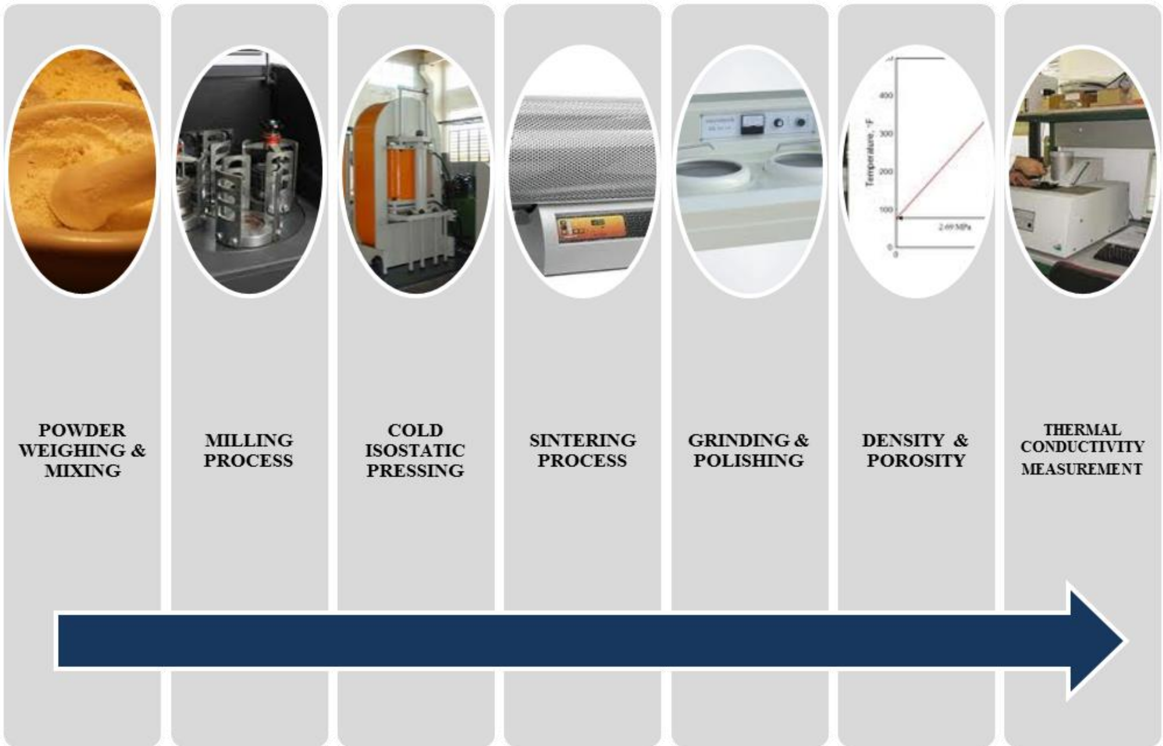

Figure 1: The sequence of steps utilised in the powder metallurgy process of CuSiC metal matrix composite (MMC) production [2,4]

Sintering Process. Sintering has been noted as the most prominent part of the powder metallurgy routes, since the main goal is to study the effects of sintering parameters to the thermal conductivity of CuSiC composite. The sintering was conducted in a tube furnace in which the flow of nitrogen or argon gas can be provided. The sintering processes were performed 8 times, with different sintering parameters. The ramp-up and ramp-down rates were set at 5ºC/minute. Nitrogen or argon gas flow rate was set at approximately 1 litre/minute. Based on the verification and suggestion of the sintering parameters and their conditions by Randall M German [3], the sintering parameters chosen are shown in Table 1.

Table 1: Sintering parameters for CuSiC composite [4]

Sample ID	Temperature [^oC]	Soaking Hour [hrs.]	Gas Type	Ramp Up [^oC/min]	Ramp Down [^oC/min]
1A	850	3	Nitrogen	5	5
1B					
1C					
2A	850	7			
2B					
2C					
3A	950	3			
3B					
3C					
4A	950	7			
4B					
4C					
5A	850	3	Argon		
5B					
5C					
6A	850	7			
6B					
6C					
7A	950	3			
7B					
7C					
8A	950	7			
8B					
8C					

Thermal Conductivity Measurement. Lee Disk's method was used in determine the thermal conductivity of the CuSiC composite (for non-metal). Fig. 2 illustrates the set-up of the thermal conductivity for CuSiC composite [4, 5].

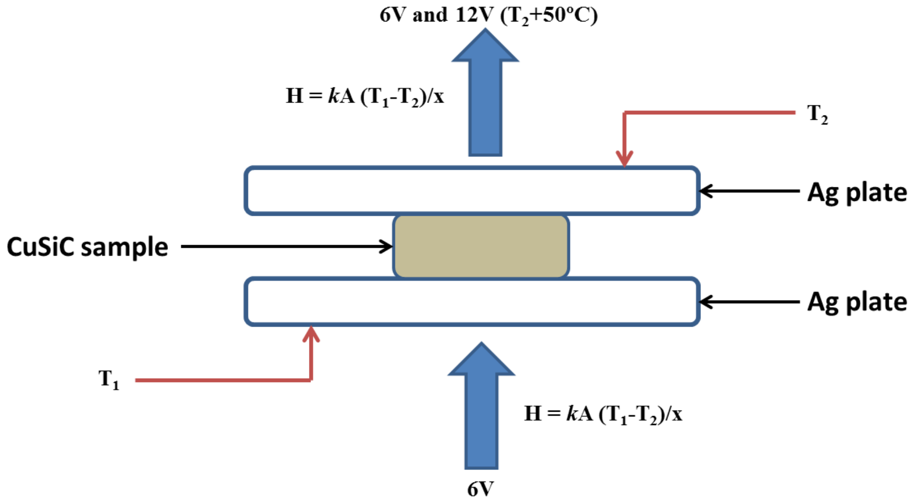

Figure 2: Illustrates the set-up of the thermal conductivity measurement for CuSiC composite [4, 5]

Results and Conclusion

Thermal Conductivity. Theoretically, CuSiC should have high thermal conductivity and been used as a heat spreader or heat sink in power electronics, would achieve high transfer of heat to extend the die or chip life of an integrated circuit (IC) system. The summary of thermal conductivity (in W/mK) readings for all CuSiC composite samples are shown in Table 2 below.

Table 2: Thermal conductivity value for all the tested CuSiC composites [4]

Sample	**Temperature [^{o}C]**	**Soaking Hour [hrs.]**	**Gas Type**	**Thermal Conductivity (W/mK)**
1	850	3	Nitrogen	108
2	850	7	Nitrogen	120
3	950	3	Nitrogen	138
4	950	7	Nitrogen	167
5	850	3	Argon	102
6	850	7	Argon	111
7	950	3	Argon	133
8	950	7	Argon	149

In this study, the thermal conductivity value (in W/mK) of all samples were shown in Table 2. It can be seen that sample number 4 has the highest thermal conductivity value of 167 W/mK, followed by sample number 8 which both samples had been sintered at 950^{o}C for 7 hours. Whilst sample number 5 recorded the lowest thermal conductivity value of 102 W/mK, followed by sample number 1 which both samples had been sintered at 850^{o}C for 3 hours. It can then be concluded that CuSiC composites that were sintered at 950^{o}C for 7 hours either in nitrogen or argon gaseous environment exhibited better thermal conductivity value compare to those composites sintered at 850^{o}C for 3 hours heating duration.

Summary

The consumer's demands of electronic devices that have features like shrinking in size plus increasing in functionality actually had created serious thermal management problems to all electronics manufacturers. The millennium discovery of a new highly potential thermal management material like CuSiC metal MMCs, to be used as heat sink or heat spreader in electronic packages, would be very promising since it has good thermal conductivity, light weight and easy-to-process characteristics. In a nutshell, in order to boost the thermal conductivity of the composite, the recommended sintering parameter suggests that the CuSiC should be sintered at 950^{o}C for 7 hours in nitrogen gas.

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