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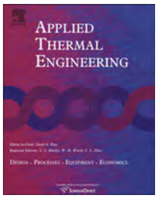

High thermal conductivity composite of diamond particles with tungsten coating in a copper matrix for heat sink application

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HIGHLIGHTS

- ► We obtained new material for heat sinks with thermal conductivity of 500–900 W m^{-1} K^{-1}).
- ► Diamond–copper metal matrix composite with a tungsten coating on the diamond filler.
- ► Structure, thermal and mechanical properties, electroconductivity.
- ► Experimental investigations, modelling.

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ABSTRACT

A composite material from particles of synthetic or natural diamond in a copper matrix, having a thermal conductivity (TC) of 500–900 W m^{-1} K^{-1}, is obtained by capillary infiltration. A tungsten coating of 100–500 nm thickness is first applied to the diamond powder. The carbidization of the coating during annealing and melt infiltration is studied by X-ray diffraction. Measurements of TC λ, using the stationary heat flux method, and of thermal diffusivity a, using the flash method, agree. A longitudinal speed of sound of 8–9 km/s, an ultimate tensile strength of 150 MPa and a coefficient of thermal expansion (CTE) of ~6 ppm/K at 25 °C are also measured for the composite. Model calculations of the composite's CTE are carried out using the rule of mixtures and the Kerner and Turner equations. The composite's specific electric resistance is 5–8 μΩ cm, according to calculations by the rule of mixtures, the Maxwell equation and the differential effective medium model. In comparison with other diamond–metal composites and materials with high TC intended for heat sinks, the composite developed is characterized by a combination of good thermal and mechanical properties, manufacturability and a relatively low cost.

1. Introduction

Developments in electronics are stimulating investigations in the field of materials with high thermal conductivity, which are necessary for manufacturing heat sinks to operate with high heat fluxes (power transistors, integrated microcircuits, synchrotron sources of radiation, etc.). Besides high TC, a number of additional features are required of these heat-conducting materials [1], such as

- a CTE value close to those characteristic for semiconductors (3–7 ppm/K at a room temperature);
- stability under thermal cycling in an operating temperature range from −50 to 150 °C;
- low specific weight;
- manufacturability, low cost, etc.

Universal materials do not exist, and a gain in certain parameters therefore entails a loss in others. Available metals with a high TC are copper, which is relatively heavy ($\lambda = 390$ W m^{-1} K^{-1} and density $\rho = 8.9$ g/cm^3) and aluminium, which is lightweight but does not conduct heat as well ($\lambda = 230$ W m^{-1} K^{-1} and $\rho = 2.7$ g/cm^3), both of which have a high CTE ($\alpha = 17$ ppm/K and 23 ppm/K respectively) [2]. Hereinafter, TC, CTE and other properties are indicated at room temperature, if not otherwise specified. Composites of Cu–W ($\lambda \sim 200$ W m^{-1} K^{-1}, $\alpha \sim 7$ ppm/K) have been developed to overcome this drawback; however, they have high specific weight (~16 g/cm^3). More recently, light composites with a filler of silicon carbide particles and an aluminium binder have appeared ($\lambda \sim 200$ W m^{-1} K^{-1}, $\alpha = 6$–7 ppm/K, $\rho = 3$ g/cm^3). Although fairly inexpensive, the TC of these Cu–W and Al–SiC

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