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# Thermal properties of diamond/SiC/Al composites with high volume fractions

C. Xue, J.K. Yu *, X.M. Zhu

*State Key Laboratory of Solidification Processing, Northwestern Polytechnical University, Xi'an 710072, PR China*

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ABSTRACT

The diamond/SiC/Al composites with high volume fractions and a large ratio of diamond to SiC particle size (7.8:1) were fabricated by gas pressure infiltration. The results show that the fine SiC particles occupy efficiently the interstitial positions around coarse diamond particles; the main fracture mechanism of the composite is matrix ductile fracture, and diamond brittle fracture was observed which confirms a high interfacial bonding strength; the diamond/SiC/Al composites with 80% and 66.7% volume fraction of diamond in the reinforcement have the higher volume fraction in the reinforcement and lower coefficient of thermal expansion compared to the diamond/Al composite. Turner and Kerner models are not in good agreement with the experimental data for the composites based on reinforcement with two phases different in shape and component. When the effect of the coating layer considered, differential effective medium (DEM) model is confirmed a reliable model in designing a composite with a given thermal conductivity based on reinforcement with two phases different in size.

## 1. Introduction

The continuing increase in packaging density and reliability has resulted in a need for new materials with superior properties in current semiconductor industry [1]. Materials with high thermal conductivity (TC) and low coefficient of thermal expansion (CTE) are required for future electronic packaging. However, copper suffers from a high value of the CTE, while Fe–Ni alloy is very poor in TC [2]. The properties of traditional materials such as W/Cu and Mo/Cu are insufficiently high with respect to the predicted exponential growth of power density in electronic packaging [3]. In fact, these traditional materials, despite featuring a low CTE mismatch, are heavy and difficulty to forming. Therefore, some new materials such as SiC/Al [4,5] and diamond/Al composites [6–8] which have higher TC and more suitable CTE have been adopted.

The SiC/Al composite has made a first ingress into the thermal management market. Its heat conduction and heat spreading capacity, however, cannot meet well with the increasing requirement in semiconductor industry. The diamond/Al composite has higher TC and lower CTE compare to the SiC/Al composite, but has so far been limited to niche markets where cost is not of the dominate concern. Therefore, hybrid diamond/SiC/Al composites which combine the thermal properties and cost should meet further market demand.

Gas pressure infiltration is more favorable than squeeze casting with respect to interfacial bonding and thermal properties of diamond/Al composites [6], because the conditions employed during gas pressure infiltration, notably the longer exposure time of diamond to aluminum melt, result in a reaction between diamond and aluminum to produce $Al_4C_3$, which was observed to form with a strong crystallographic preference on the {1 0 0} faces of diamond [7]. The micro-sized diamond particles were observed to be homogeneously dispersed and well bonded in the Al matrix. However, the nano-sized diamond particles principally appear as large agglomerates in the Al-matrix even by squeeze casting [8]. A ratio of diamond to SiC particle size larger than seven is usually needed in order to fabricate composites with sufficiently good thermal properties [9]. This will lead to the highest volume fraction of reinforcement in the composites when the suitable percentage of hybrid particles is selected. Thus, particle selection and infiltration processing are important to improve the thermal properties of the composites.

There have been many models for predicting thermal properties, including Turner and Kerner models for CTE, Hasselman and Johnson (H–J) model [10] for TC. The H–J model is widely used due to the introduction of interfacial thermal conductivity. But just like many other predictive schemes yield quite similar results at low volume fractions and low phase contrast, differences become more important at intermediate to high phase contrast and at high volume fractions of inclusion phase. It has recently been shown that the DEM model for electrical conductivity has a predictive capacity superior to other current models for the case of infinite phase contrast, i.e. non-conductive alumina [11] and silicon [12] inclusions in a conductive aluminum matrix. The DEM model, however, is limited to the cases of composites with a low conductivity ratio of particle to matrix, such as SiC/Al [4]. In addition, Turner and Kurner models are always reported to predict

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* Corresponding author. Tel.: +86 29 8849 4987.
*E-mail address:* jkyu@nwpu.edu.cn (J.K. Yu).

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