Fabrication and Microstructure Characterization of Diamond/Aluminum Composites by Gas Pressure Infiltration Technology

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Abstract
The necessity to remove the local heat accumulation of electronic devices has brought great challenges to the thermal management aluminum matrix composites designed to effectively dissipate heat in electronic applications. In this work, diamond/aluminum composites have been produced by gas pressure infiltration of the continuous aluminum matrix into the diamond particles preforms at 800℃. The interfacial product of Al_4C_3 was found mostly on diamond (100) surfaces. Nanoscale W coating was produced on diamond particles by magnetron sputtering method. Then the formation of hydrophilic Al_4C_3 was supressed, with reduced content and size of Al_4C_3 and newly formed Al_5W in the composite. The effect of these interfacial phases on the phonon scattering and consequent thermal conductivity of diamond/aluminum composites was also discussed. This research helps to understand the microstructure features in diamond/aluminum composites.

Keywords: Diamond, Aluminum matrix composites, Interfacial microstructure

1 Introduction

The miniaturization, high-performance and multifunction of electronic devices have caused huge local heat accumulation which needs to be removed to avoid functional failure of devices. The traditional thermal management materials, such as Cu, Mo-Cu or W-Cu composites, cannot satisfy the current requirements of high thermal conductivity and low quality [1].

Diamond, with an ultra-high thermal conductivity (~2200 W/(m·K)), is a prominent filler material to produce aluminum matrix composites for thermal management applications [2]. Diamond has poor wettability with most metals because of its inert feature. Therefore, it is a major challenge to tailor the interfacial microstructure and corresponding properties. In this work, pristine and W-coated diamond particles were added into the continuous aluminum matrix by the gas pressure infiltration process. The interfacial microstructure was characterized and the corresponding effect on the thermal conductivity was discussed.

2 Experimental procedure

The diamond particles were deposited with 50 nm tungsten coating by the magnetron sputtering method. The pure aluminum was chosen as the matrix. Then the diamond/aluminum composites were fabricated by the gas pressure infiltration process.
The composite surfaces were polished by IB-09020CP cross-section ion polishing instrument. The interfacial microstructure was observed by Quanta 200FEG field emission environmental scanning electron microscope (SEM).

3 Result and discussion

Fabrication and distribution of diamond particles

The fabrication process of diamond/aluminum composites is illustrated in Fig.1. Firstly, the pristine or W-coated diamond particles were filled into a graphite mold to produce the preform according to the given volume fraction. Then the mold, with the aluminum ingot on top of the diamond preform, was put into the vacuum furnace. When the mold was heated to 800 °C and maintained for 10 min, a gas pressure of 15MPa was applied to force the molten aluminum to infiltrate into the diamond preform completely. When the furnace was cooled down to the room temperature, the diamond/aluminum composites were obtained.

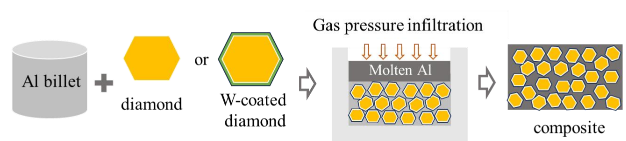

Fig.1 Fabrication route of diamond/aluminum composites

Fig.2 shows the optical microstructure of as-fabricated diamond/aluminum composite. The diamond particles distributed uniformly in the composite. The composite was dense and macroscopically homogeneous, and seldom particles cluster was observed. A dense microstructure was beneficial to thermal management applications because of improvement in heat conduction.

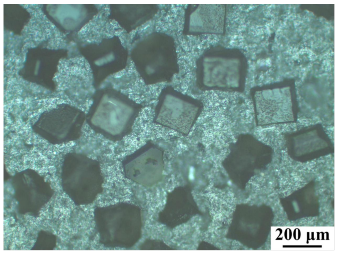

Fig.2 Optical micrograph of diamond/aluminum composite

4 Interfacial microstructure

Fig. 3 is the SEM morphology showing the interfacial microstructure of uncoated diamond/aluminum composite after cross-section ion polishing. The interfacial reaction product of Al_4C_3, was found at the interface of uncoated diamond/aluminum composite, mostly on diamond (100) surfaces.

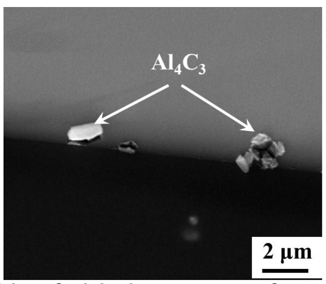

Fig.3 Interfacial microstructure of uncoated diamond/aluminum composite

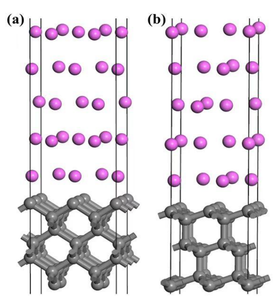

Fig.4 Model of diamond (100)/aluminum (111) (a) and diamond (111)/aluminum (111) (b)

The first-principles calculation was used to study the interfacial properties and reaction of diamond/aluminum composites. Fig. 4 is the model for calculation. The calculated interfacial adhesion work of diamond (111)/aluminum (111) was 4.14 J/m^2, while that of diamond (100)/aluminum (111) was 5.85 J/m^2. It was 41% higher than that of diamond (111)/aluminum (111), suggesting a stronger interfacial bonding of diamond(100)/aluminum(111). More charge transfer was also found at the diamond(100)/aluminum (111) interface during the differential charge density analysis. As a result, the diamond (100) was prone to react with aluminum, as was found in Fig.3.

For the W-coated diamond/aluminum composite, the interfacial microstructure is shown in Fig.5. The Al_4C_3 and Al_5W were both found, with a decrease in the content and size of Al_4C_3. The Al_4C_3 had an acoustic impedance between diamond and aluminum, which was beneficial to the thermal conductivity of composites, while the Al_5W would lead to additional phonon scattering. But the hydrophilic feature of Al_4C_3 would deteriorate the long-term reliability in humid environment. Therefore, it is important balance the interfacial microstructure and the final properties.

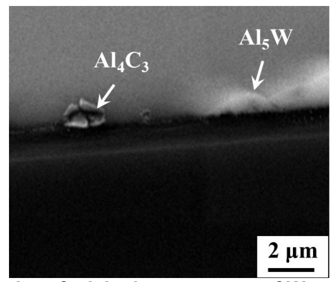

Fig.5 Interfacial microstructure of W-coated diamond/aluminum composite

5 Conclusion

The interfacial microstructure of diamond/aluminum composites were modified using nanoscale W coating on diamond particles. The Al_4C_3 was found on the diamond (100) of diamond/aluminum composite. The first-principles calculations suggested higher interfacial adhesion work and more charge transfer at the diamond (100)/aluminum (111) interface. The nanoscale W coating on diamond particles suppressed the formation of Al_4C_3, then to tailor the final properties of composites.

6 Acknowledgments

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