Ag/Diamond Composite Shims for HPA Thermal Management

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Keywords: Thermal management, composites, diamond, silver and heat spreader

Abstract

Composite shims consisting of a high volume fraction of diamond (50-75%) serving as both a high-conductivity phase and CTE-modifier distributed in a silver matrix integrate and balance critical RF power amplifier thermal requirements. Some of these components can generate heat fluxes exceeding 8kW/cm^2 at temperatures over 225°C. Consistently dissipating this heat requires CTE-matched, high thermal conductivity, small form-factor shims. Shim microstructures have been designed to have multi-modal diamond particle size and spatial distributions based on a primary diamond monolayer, often with thicknesses as low as 250 µm.

OVERVIEW

A silver-diamond (Ag-Di) composite thermal shim has been developed to meet the thermal management challenges and dimensional constraints of next generation high-power wide-bandgap semiconductor devices [1-3]. Some of these devices can generate heat fluxes exceeding 8kW/cm^2 at temperatures over 225°C, and consistently dissipating this heat requires thermal expansion (CTE) matched, high thermal conductivity, small form factor shims. Composite shims consisting of a high volume fraction of diamond (50-75%) serving as both a high-conductivity phase and CTE-modifier distributed in a silver matrix integrate and tailor these key requirements. Shim microstructures are designed to have multi-modal diamond particle size and spatial distributions based on a primary diamond monolayer. Initial performance has been characterized through thermal expansion and effective thermal resistance measurements up to 250°C as well as quantitative microstructural analyses to evaluate suitability for high power device integration.

FABRICATION

The integrity of the Ag-diamond interface has been one of the greatest challenges in synthesizing metal-diamond composite materials. Typically, interfacial bonding has been achieved using elaborate combinations of shock consolidation, incorporation of reactive compounds, high temperatures and high pressures [4,5]. These techniques can increase the cost and complexity of manufacturing while limiting design flexibility. Diamond particles used in the shims described in this work employ simple surface treatments to facilitate bonding with the Ag matrix.

The desired microstructure of the composite is a homogenous distribution of a bimodal diamond particle size mixture in a silver metal matrix. Bimodal particle sizes are employed to increase the volume fraction of diamonds while minimizing porosity.

The Ag matrix is initially formulated as a metal powder-organic binder system, where the binder promotes microstructural homogeneity and imparts green strength. This Ag-binder mixture is combined with diamond particles and pressed in a die to obtain a composite preform, which is subsequently heat-treated to remove the organic binder and consolidate the remaining structure via sintering. Remaining porosity has been minimized through the optimization of both the diamond volume efficiency and organic binder chemistry.

CHARACTERIZATION

Ag-Di shims with thicknesses ranging from 250µm – 1mm with diamond volume fractions of 0.50 to 0.75 have been produced using this approach (Figure 1). Initial microstructural characterization suggests minimal porosity and uniform distributions for both diamond particle sizes. Thermal expansion measurements, shown in Figure 2, indicate near rule-of-mixtures behavior and, perhaps more importantly, bonding between the diamond particles and their host Ag matrix.

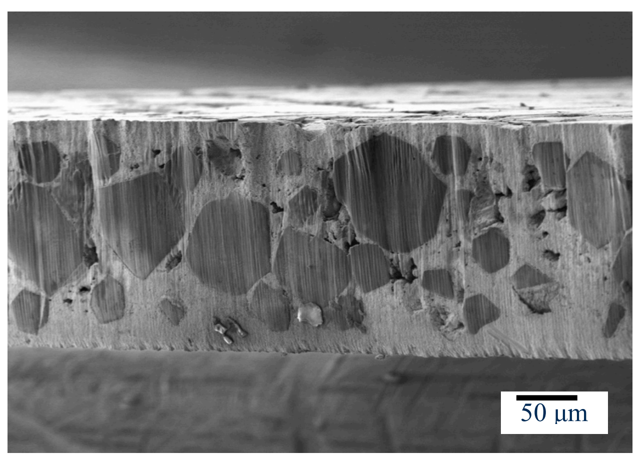

Figure 1. Scanning electron micrograph of Ag-Di shim cross-section.

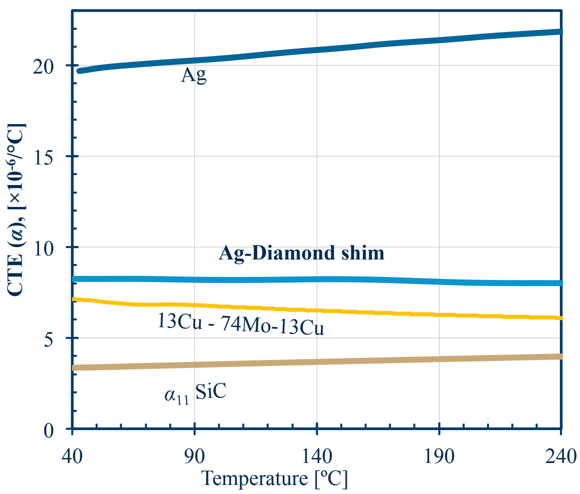

Figure 2. Linear coefficient of thermal expansion for Ag [6], Ag-diamond composite, 13Cu-74Mo-13Cu clad sheet and SiC [7]. Heating schedule for Cu-Mo-Cu and Ag-diamond composite was 1ºC/min → 26ºC, 3ºC /min → 250º C.

Thermal dissipation measurements on these shims included both die-attached HPAs and Ni-Cr heating configurations on shim edges to investigate through-thickness and lateral heat spreading performance.

Acknowledgements

The authors would like to thank Mike Harris, Brent Wagner, Wusheng Tong and Hunter Chan for their suggestions and particularly for their support of the Ag-Di shim thermal dissipation measurements.

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Acronyms

GaN: Gallium Nitride
GaAs: Gallium Arsenide
HPA: High Power Amplifier
RF: Radio Frequency
CTE: Coefficient of Thermal Expansion