Mechanical Engineering Doctoral Defense

Compression-Activated Thermally Enhanced Liquid Metal Composites with Tunable Functional Properties

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Abstract

Thermal management of electronics is critical to meet the increasing demand for high power and performance. Thermal interface materials (TIMs) play a key role in dissipating heat away from the microelectronic chip and hence are a crucial component in electronics cooling. Challenges persist with overcoming the interfacial boundary resistance and filler particle connectivity in TIMs to achieve thermal percolation while maintaining mechanical compliance. Gallium-based liquid metal (LM) capsules offer a unique set of thermal-mechanical characteristics that make them suitable candidates for high-performance TIM fillers. This dissertation research focuses on resolving the fundamental challenges posed by integration of LM fillers in polymer matrix. First, the rupture mechanics of LM capsules under pressure is identified as a key factor that dictates the thermal connectivity between LM-based fillers. This mechanism of oxide "popping" in LM particle beds independent of the matrix material provides insights in overcoming the particle-particle connectivity challenges. Second, the physical barrier introduced due to the polymer matrix needs to be overcome to achieve thermal percolation. Matrix fluid viscosity impacts thermal transport, with high viscosity uncured matrix inhibiting the thermal bridging of fillers. In addition, incorporation of solid metal co-fillers that react with LM fillers is adopted to facilitate popping of LM oxide in uncured polymer to overcome this matrix barrier. Solid silver metal additives are used to rupture the LM oxide, form inter-metallic alloy (IMC), and act as thermal anchors within the matrix. This results in the formation of numerous thermal percolation paths and hence enhances heat transport within the composite. Further, preserving this microstructure of interconnected multiphase filler system with thermally conductive percolation pathways in a cured polymer matrix is critical to designing high-performing TIM pads. Viscosity of the precursor polymer solution prior to curing plays a major role in the resulting thermal conductivity. A multipronged strategy is developed that synergistically combines reactive solid and liquid fillers, a polymer matrix with low pre-cure viscosity, and mechanical compression during thermal curing. The results of this dissertation aim to provide fundamental insights into the integration of LMs in polymer composites and give design knobs to develop high thermally conducting soft composites.

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