Nanostructured Thermal Interface Materials

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The performance of modern semiconductor devices depends largely on thermal interface materials to adequately transfer heat while retaining mechanical integrity. Thermomechanical stresses arise due to the mismatch in thermal expansion in multi-component systems, which can cause brittle bonds to fail in these devices. An ideal thermal interface material (TIM) can accommodate both the high thermal conductance to improve heat transfer across the interface and the mechanical compliance to alleviate these thermomechanical stresses. Nanostructured TIMs have been developed to exhibit this unique combination of high thermal conductivity and mechanical compliance. In the present work, TIMs are constructed of both vertically-aligned films of carbon nanotubes (CNTs) and metal nanowires (NWs). These types of structures capture the high thermal conductivity of the base material (graphene, metals) while adding the mechanical flexibility derived from nanostructuring with a low volume fraction. The result is a TIM that is stable under extreme application conditions, including large temperature and pressure ranges, and can accommodate large temperature gradients and thermal cycling without failing.

Carbon nanotubes have gained significant attention in the last decade owing to the high intrinsic thermal conductivity of individual CNTs and the low elastic modulus due to a high aspect ratio. In this work, we examine the use of a solder bonding layer to attach and transfer CNT films from a silicon growth substrate onto metalized surfaces. Indium foil is considered as a bonding layer for low-temperature (<150°C) applications while a tin-plated aluminum/nickel foil is used for high temperature applications (<1000°C). The intrinsic thermal conductivity of the CNT film and the thermal boundary resistances between the CNT film and the surrounding materials are measured with comparative infrared microscopy before and after solder bonding. The thermal properties are measured over a range of applied compressive stress. In general, compressive stress reduces the thermal boundary resistance and improves the thermal conductivity of the CNT films. Solder bonding of the exposed (non-growth) interface reduces the thermal boundary resistance by up to a factor of 30 over a dry unbonded contact.

Films of metal NWs are grown by electrodeposition in track-etched polycarbonate membranes. These films can be made of a variety of different metals, including traditional thermal conductors such as copper and aluminum and noble metals such as silver and gold. The membrane geometry determines the aspect ratios and film densities and allows for fine-tuning of film properties. After electrodeposition, the membrane is etched away to produce a freestanding film to be bonded and transferred into the target application. Electroplating and other surface treatments are used to prevent oxidation in high temperature environments, which may degrade the NWs and cause mechanical failure. Thermal properties are measured using picosecond thermoreflectance and the 3ω technique. Nanoindentation and laser Doppler velocimetry can be used to measure the out-of-plane and in-plane elastic modulus of these films, respectively.