Abstract

The scaling down of device sizes and increasing in power dissipation make heat transport and removal a major technological impediment to the future development for electronic applications. The limiting heat conduction issues cause serious localized self-heating problems. To solve these issues, the development of highly effective heat transfer material, such as heat sink and thermal interface material, has attracted extensive attention.

Carbons based materials, such as graphite, carbon nanotube (CNT), diamond, as well as graphene, have been found to possess high thermal conductivities, and are attractive for thermal management applications. In this dissertation, the thermal properties of two kinds of carbon-based materials: polycrystalline diamond and carbon nanotube, are investigated in details. Diamond and CNT are proposed to be promising candidates for heat spreader and thermal interface material respectively. For thermal characterization, 3ω method and thermal imaging analysis have been developed for the determination of in-plane and cross-plane thermal conductivities. The theoretical thermal models and the experimental studies have been investigated in this dissertation.

Diamond has been proposed as an advanced heat spreader for high power devices. In this study, the influence of optically active defects on thermal conductivity of polycrystalline diamond has been investigated. Polycrystalline diamond with different crystalline quality and impurity concentration were grown by microwave plasma assisted chemical vapor deposition (MPCVD). The thermal conductivities of

PCDs on the top (growth) and bottom (nucleation) surfaces were characterized with 3ω technique. For top surfaces, the heat transport is limited by the presence of Ns^0 defect. For the bottom surface, non-diamond carbon phase, Si vacancy, C-H stretch and Ns^0 defects all lead to an obvious reduction in the thermal conductivity. The correlation between thermal conductivity and optical transmission was studied, making a fast estimation of thermal conductivity available.

For the study of CNT based thermal interface material (TIM), a novel three dimensional carbon nanotube (3D CNT) network structure has been proposed to improve the thermal performance of currently used TIMs. The 3D CNT network is composed of vertically aligned CNT array (primary CNT) that is bridged with randomly oriented secondary CNTs. The thermal characterization of CNT is always a challenge. In this dissertation, two novel thermal characterization techniques, free-standing sensor-based 3ω technique and thermal imaging technique, have been well developed for the characterization of cross-plane and in-plane thermal conductivities of CNT. The cross-plane thermal conductivity of 3D CNT network has been measured to be 55.9% higher than that of the primary CNT array with a density of 5.6×10^8 /cm^2. The in-plane thermal conductivity of 3D CNT network has been measured to be 5.4W/mK, which is more than 50 times higher than the bare CNT array.