Thermal Transport in ZnO Nanocrystal Networks Synthesized by a Nonthermal Plasma

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Nanocrystal (NC) networks exhibit desirable electronic and optical properties that can be tailored by tuning the nanocrystal compositions and dimensions, which leads to their potential applications such as solar cells, thermoelectric generators, and field-effect transistors. Nanocrystals synthesized with conventional chemical approaches are usually covered with and separated by ligands, which act as electrical insulating barriers between NCs and thus hinder electronic transport in the networks. Alternatively, gas-phase synthesis and deposition can produce ligand-free NC networks with direct contact between NCs, which can significantly enhance the carrier mobility and optoelectronic properties. In parallel with electrical transport, thermal transport in these ligand-free NC networks is also crucial for the high demands of efficient thermal management in device applications which involve NC networks as the building blocks.

In this work, we utilize time-domain thermoreflectance (TDTR) to study the thermal conductivity of zinc oxide (ZnO) NC networks, synthesized in a nonthermal plasma reactor. For such ligand-free ZnO NC networks, their thermal transport properties can be potentially impacted by multiple factors in a complex way, including the NC size, infill materials, porosity, the interfaces between the NCs and the infill material, and the contact radius between adjacent NCs. We conduct systematic experimental studies to reveal the dependence of the thermal conductivity of ZnO NC networks on the NC contact radius (averaged radius of contact area between neighboring NCs), the NC size, the network porosity, and the infill material. We further apply a modified effective medium approximation (EMA) to interpret the experimentally determined thermal conductivities from TDTR. The influence factors of different parameters on the thermal conductivity of ZnO NC networks are elucidated by comparing the TDTR measurements with the EMA prediction. Results from this study can potentially guide the design of ZnO NC-based electronic and thermoelectric devices for optimal thermal management or thermoelectric performance.