Thermal and thermoelectric transport in nanostructured materials from pnictogen chalcogenide nanoplate crystals

by

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ABSTRACT

Thermoelectric materials are excellent candidates for solid-state refrigeration, waste heat recovery and power generation due to many attractive characteristics, such as no moving parts and environmental benign. In this thesis, thermal and thermoelectric transport in a novel class of nanostructured materials is investigated thoroughly through novel characterization techniques combined with theoretical modeling. The objective is to establish quantitative understanding of the phonon and charge carrier (electrons or holes) transport properties, which is the key to achieve high figure-of-merit thermoelectric materials.

Efficient and high resolution characterization methods are crucial to the development of nanostructured thermoelectric material. A novel scanning thermal probe microscopy is developed to measure local thermal conductivity κ and Seebeck coefficient α with microscale spatial resolution. The scanning thermal microprobe was applied to map local κ and α of the nanoporous thin films and nanostructured bulk materials with microscale inhomogeneous thermoelectric properties. In addition, we demonstrated for the first time that ballistic air conduction in a nanoscale air gap between probe tip and sample is capable of local heating, temperature sensing and non-contact probing of local κ, which addressed a longstanding challenge due to the complicated tip-sample heat transfer mechanisms at contact mode.

In order to study phonon thermal transport mechanisms, we experimentally determined the temperature-dependent lattice thermal conductivity κ_L of the nanostructured bulk materials. We also investigated the phonon thermal transport by modeling and quantitatively determined the contributions of different nanostructures to the lattice thermal conductivity reduction. To assess the effect of nanostructuring on charge carrier transport, we determined the carrier concentration and mobility via Hall effect measurement and found the underlying mechanisms that affect the thermoelectric power factor of nanostructured bulk materials. The results reported in this dissertation greatly enhanced our understanding of thermal and thermoelectric transport mechanisms and provided promising pathways to design favorable material structures towards high-efficiency thermoelectric energy conversion.