Controlling Thermal Conductivity in the Solid-State: New Tricks with Ferroelectrics

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Conduction of thermal energy is a property that exists in all forms of matter. In the solid state, there are two primary thermal conduction mechanisms: 1) electronic carriers (*i.e.* electrons), which dominate in electronically conducting materials and 2) phonons (*i.e.* lattice vibrations), which dominate in insulating materials. In spite of decades (perhaps even centuries) of research into thermal energy, there exists very few means to actively control thermal energy in solid materials. Mechanisms that have been investigated include altering material composition, straining the material, and undergoing phase transformations from insulating to conducting states. Limitations in these mechanisms include rates, magnitudes of change, and operation temperatures over which they can be achieved.

In this talk we will discuss means to deterministically engineer phonon thermal conduction properties by changing configurations of phonon scattering crystallographic twin boundaries. This can be achieved with an electric field in certain ferroelectric materials where electrical fields can affect ferroelastic (twin) boundary populations. It will be shown that crystallographically coherent 71° domain walls in epitaxial $BiFeO_3$ and 90° domain walls in polycrystalline $Pb(Zr,Ti)O_3$ thin films can scatter heat-carrying phonons at room temperature. Utilizing bilayer PZT films, where the ferroelastic domain walls are labile under applied fields, we will show how modifying the domain structure can be used to alter thermal conductivity. For $Pb(Zr_{0.3}Ti_{0.7})O_3$ films a repeatable 11% change in thermal conductivity at room temperature can be achieved with the application and removal of an electric field. Utilizing piezoresponse force and *in operando* channeling contrast scanning electron microscopies, we can identify the domain wall reconfiguration responsible for the observed thermal property tuning. The rapid and reversible response and this demonstration of a voltage tunable thermal conductivity at room temperature without passing through phase transitions, physically separating components, or altering chemical composition opens a pathway to develop phononic devices and may also be exploited for low input energy nanoscale temperature control.

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Jon Ihlefeld is a Principal Member of the Technical Staff in the Electronic, Optical, and Nano Materials Department at Sandia National Laboratories, where he has worked for the last 8 years. He received his B.S. degree in Materials Engineering from Iowa State University in 2002, and M.M.S.E. and Ph.D. degrees in Materials Science and Engineering from North Carolina State University in 2005 and 2006, respectively. After a two-year joint post-doctoral scholar appointment at The Pennsylvania State University, and University of California-Berkeley, he joined the technical staff at Sandia. His research interests and activities include ferroelectric thin films, thermal transport, dielectrics, solid ion conductors, and oxide semiconductors. He has published over 80 peer-reviewed articles, 1 book chapter, has 8 U.S. patents, has 7 patent applications under review, and has given 28 invited presentations including 6 at international conferences and 1 plenary address.