Statistical Modeling of Thermal Conductivity in Thin-Film and Deformed Bulk Superconducting Niobium

Peng Xu
Mechanical Engineering, Michigan State University, East Lansing, MI, U.S.A.

Thomas Bieler
Chemical Engineering and Material Science, Michigan State University, East Lansing, MI, U.S.A.

Neil Wright [C,S]
Mechanical Engineering, Michigan State University, East Lansing, MI, U.S.A.
ntwright@msu.edu

Phonons determine the thermal conductivity of niobium (Nb) at the working temperatures (~2 K) of superconducting radio frequency (SRF) cavities. This results from electrons condensing into Cooper pairs. Understanding the individual scattering mechanisms (i.e., phonon-electron, phonon-boundary, phonon-dislocation) is critical for modeling the lattice thermal conductivity of thin-film or deformed bulk Nb. These models may improve understanding of the interaction between deformation (i.e., increased dislocations, altered surface roughness) and conductivity and provide guidance for design of the next generation of SRF particle accelerators. Here, a Monte Carlo simulation is developed to predict the lattice thermal conductivity of bulk superconducting Nb, as well as thin film Nb, and compared with the Bardeen-Rickayzen-Tewordt model for phonon-boundary scattering and phonon-electron scattering. The statistical model was first verified by comparing predicted values of the thermal conductivity of bulk Si and Si nanowires with experimental results. When applied to Nb, predictions of the temperature dependent thermal conductivity due to boundary scattering of phonons agree well with a kinetic theory model and experimental data. The relaxation time of the phonon-electron scattering is obtained using the model of Callaway. Results show that boundary scattering dominates for temperatures less than 2 K where the phonon mean free path is comparable to the size of the sample, and that phonon-electron scattering is important for temperature greater than 2 K. Phonon-dislocation scattering is also considered in the model for samples after deformation. Distinction is made between screw and edge dislocations and the dynamic dislocations. A local maximum in thermal conductivity (i.e., a phonon peak) appears at temperatures of approximately 2 K for undeformed samples. The temperature of the phonon peak shifts to warmer temperatures due to deformation or the size effect.