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Thermal Conductivity of Silicon and Germanium from 3°K to the Melting Point*

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The thermal conductivity K of single crystals of silicon has been measured from 3 to 1580°K and of single crystals of germanium from 3 to 1190°K. These measurements have been made using a steady-state, radial heat flow apparatus for $T>300$°K and a steady-state, longitudinal flow apparatus for $T<300$°K to give absolute K values. This radial flow technique eliminates thermal radiation losses at high temperatures. The accuracy of both the low-temperature apparatus and the high-temperature apparatus is approximately ±5%. Some special experimental techniques in using the high-temperature apparatus are briefly considered. At all temperatures the major contribution to K in Si and Ge is produced by phonons. The phonon thermal conductivity has been calculated from a combination of the relaxation times for boundary, isotope, three-phonon, and four-phonon scattering, and was found to agree with the experimental measurements. Above 700°K for Ge and 1000°K for Si an electronic contribution to K occurs, which agrees quite well with the theoretical estimates. At the respective melting points of Si and Ge, electrons and holes are responsible for 40% of the total K and phonons are responsible for 60%. The measured electronic K yields values for the thermal band gap at the melting point of 0.6±0.1 eV for Si and 0.26±0.08 eV for Ge.

INTRODUCTION

IN a semiconductor, various carriers can contribute to the thermal conductivity. These are phonons, photons, electron-hole pairs, and the separate electron and holes. The problem of sorting out the contributions from these processes has been handicapped by the lack of accurate high-temperature measurements. In this paper, we report on measurements of the thermal conductivity K of single crystals of germanium and silicon between 300 and 1580°K taken with an improved cylindrical heat flow apparatus. The measurements of K of silicon below 300°K have been taken with an existing longitudinal heat flow apparatus.[1] Germanium and silicon were measured because they are easily obtained with high purity and known electrical characteristics. As a consequence of this investigation, they could serve as standard materials for K measurements.

The purpose of this investigation was to measure and analyze the K of these materials up to the melting point and, in particular, to unravel the magnitude of the contributions from the various carriers of heat. It was found that the phonon or lattice thermal conductivity is dominant and decreases faster than $1/T$ at high temperatures. The bipolar thermal conductivity, i.e., from electron-hole pairs, is significant at high temperatures and agrees with a simple theory. The polar thermal conductivity, i.e., from the separate electrons and holes, is small, and the photon thermal conductivity is not detectable.

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[1] G. A. Slack, Phys. Rev. 122, 1451 (1961).