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Thermal Conductivity Measurement Methods for SiGe Thermoelectric Materials

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A new technique to measure the thermal conductivity of thermoelectric materials at the microscale has been developed. The structure allows the electrical conductivity, thermal conductivity, and Seebeck coefficient to be measured on a single device. The thermal conductivity is particularly difficult to measure since it requires precise estimation of the heat flux injected into the material. The new technique is based on a differential method where the parasitic contributions of the supporting beams of a Hall bar are removed. The thermal measurements with integrated platinum thermometers on the device are cross-checked using thermal atomic force microscopy and validated by finite-element analysis simulations.

Key words: Silicon germanium, thermal conductivity, thermoelectrics, heterostructure, device fabrication

INTRODUCTION

The efficiency of a thermoelectric material is evaluated by calculating the figure of merit $ZT = \alpha^2\sigma T/\kappa$, where α is the Seebeck coefficient, σ is the electrical conductivity, T is the temperature, and κ is the thermal conductivity. While great progress has been made in the design of engineered materials to enhance the ZT value, very few structures have been proposed to allow accurate characterization of all the parameters in ZT for a single structure. The electrical characterization of the structure is easily done using van der Pauw or Hall bar structures, where the latter is able to guarantee an accuracy in the measurement as good as 1% if the physical dimensions of the structure are chosen properly. For the estimation of the Seebeck coefficient and the thermal conductivity, an accurate temperature distribution across the structure under examination is required. Moreover, for the calculation of the thermal conductivity a precise value of the thermal flux is required.

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One of the most popular techniques for the characterization of the thermal properties of materials is the 3ω technique.[1] In this method, temperature oscillations of a metal line that is used as both the heater and the thermometer are excited at an angular frequency ω and measured at a frequency 3ω. The response is related to the κ of the material under examination, and this technique has found application in both bulk and thin-film sample characterization.[2] The approach for 3ω analysis of multilayer material is more difficult: differential techniques[3] and numerical extraction of the parameters are required to discriminate between the vertical and lateral thermal conductivities.[4,5] A number of possible structures could be used to measure all the required important thermoelectric parameters either individually or all in a single device. A Hall bar structure has been chosen where integrated thermometers, heaters, and Ohmic contacts are integrated onto the surface at both ends of the Hall bar (Fig. 1) so that the thermal transport and Seebeck coefficients can be measured in both directions along the Hall bar to check consistency of the measurements.[6] The proposed structure and measurement procedure have a high degree of