Seebeck Measurements on $Bi_{1-x}Sb_x$ Nanowire Arrays*

S. Müller[1], M. Cassinelli[1], K.–O. Voss[1], C. Trautmann[1,2], and M. E. Toimil-Molares† [1]
[1]GSI, Darmstadt, Germany; [2]TU Darmstadt, Germany

In thermoelectrics, the efficiency of a material is expressed by the dimensionless figure-of-merit ZT. ZT and the Seebeck coefficient S are defined by

$$Z \cdot T := \frac{\sigma S^2}{\kappa} T \quad \text{and} \quad S(T) := \frac{\mathrm{d}U}{\mathrm{d}T}$$

being T the absolute temperature, σ the electrical conductivity, κ the thermal conductivity, and U the thermovoltage.

One dimensional materials such as nanowires (NWs) are of interest because it was predicted that they exhibit an enhanced value of ZT due to quantum confinement of the charge carriers [1, 2]. Also finite-size effects, e. g., enhanced scattering of phonons at the wire surface [3], could contribute to increase their ZT to values interesting for thermoelectric (TE) commercial applications.

To investigate the influence of size-effects on the TE properties of nanomaterials, it requires the development of new techniques able to measure reliably temperature gradients, thermovoltages, as well as electrical and thermal conductivities along a nanostructure. Here, we present a setup developed and optimized at GSI to measure S of NW arrays fabricated by electrodeposition in etched ion-track membranes. These membranes were produced by irradiation with $\sim$ 2 GeV Au heavy ions at the UNILAC facility. The ion tracks were etched in 6 mol/l NaOH at 50 °C to form channels with diameters between 25 and 200 nm. Nanowires were grown by electrodeposition inside the nanochannels [4, 5].

In Figure 1, the setup for the measurement of S is depicted. The NWs remained in the PC template and were electrically contacted by a Au layer sputtered on top. The array was clamped between two copper plates placed in a stainless steel frame. This frame was mounted on a cooling finger in a cryostat. Contacts are attached from top and bottom as well as Si diodes to measure the temperatures T_1 and T_2 at both sides of the membrane. The polymer matrix has only a small thermal conductivity and, therefore, a temperature difference $\Delta T = T_2 - T_1$ was readily created and varied by heating and cooling the bottom part around a predefined set-point that can be selected from 30 to 300 K. The slopes of the obtained $U - \Delta T$ curves provide S.

Figure 2 shows S as function of temperature T for four different NW arrays: Cu (green), Bi (black), Sb (blue), and $Bi_{0.9}Sb_{0.1}$ (red). The Cu NW array (d $\sim$120 nm) served as a reference sample for NW configuration, since no size effects are expected for Cu NWs of such dimensions. The Cu NW sample exhibited $S = (2.0 \pm 0.5)$ µV/K, which is in excellent agreement with S of bulk Cu, namely

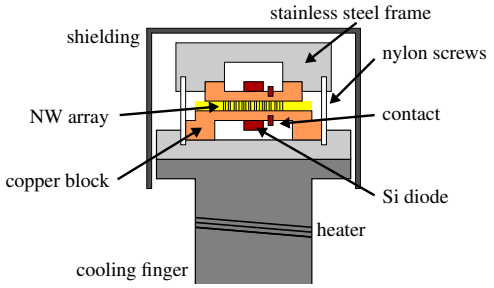

Figure 1: Schematic of the setup for the measurement of the Seebeck coefficient.

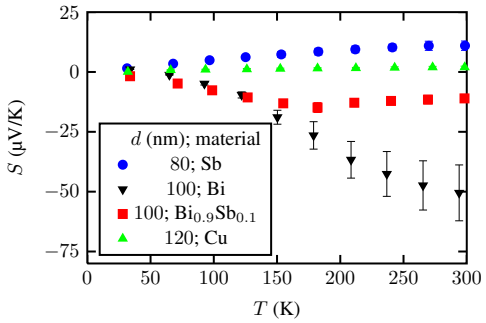

Figure 2: Seebeck coefficients of nanowire arrays of different materials as function of temperature.

S =1.83 µV/K [6]. In the case of Bi compound nanowires, the diameter $\sim$ 100 nm is comparable to the mean free path of charge carriers and thus size effects are expected. At room temperature, S was (-50 ± 12), (11 ± 2), and (-11 ± 2) µV/K for Bi, Sb, and $Bi_{0.9}Sb_{0.1}$, respectively. While the NW arrays were p- and n-type materials as their bulk counterparts, the Seebeck values measured at room temperature were considerably smaller.

Further measurements are underway to study the influence of nanowire diameter, crystallite size, crystallographic orientation, and thermal contacts on the value of S.

References

[1] Hicks, Dresselhaus, Phys. Rev. B 47 (1993) 16631.
[2] Rabin et al., Appl. Phys. Lett. 79 (2001) 81.
[3] Hochbaum et al., Nature 451 (2008) 163.
[4] Müller et al., J. of Crystal Growth 12 (2012) 615.
[5] Müller, PhD thesis, University of Heidelberg (2012).
[6] Cusack and Kendall, Proc. Phys. Soc. 72 (1958) 898.
[7] Issi, Australian J. of Phys. 32 (1979) 585.

* funding within DFG priority program 1386
† M.E.ToimilMolares@gsi.de