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Thermoelectric Properties of High-Doped Silicon from Room Temperature to 900 K

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Silicon is investigated as a low-cost, Earth-abundant thermoelectric material for high-temperature applications up to 900 K. For the calculation of module design the Seebeck coefficient and the electrical as well as thermal properties of silicon in the high-temperature range are of great importance. In this study, we evaluate the thermoelectric properties of low-, medium-, and high-doped silicon from room temperature to 900 K. In so doing, the Seebeck coefficient, the electrical and thermal conductivities, as well as the resulting figure of merit *ZT* of silicon are determined.

Key words: Silicon, thermoelectric, material properties, Seebeck coefficient

INTRODUCTION

Most of the energy consumed in the world is produced by combustion of fossil fuels.[1] These processes produce waste heat, which should be minimized not only to conserve primary energy sources but also to reduce the environmental impact of CO_2 emissions. Thermoelectric (TE) modules convert thermal energy into electrical energy and vice versa. However, today's commercially available thermoelectric modules based on bismuth telluride are limited in conversion efficiency and temperature stability.[2] Thus, a major challenge in thermoelectrics is the search for alternative materials.

Earth-abundant silicon can be an attractive, low-cost thermoelectric material for high-temperature applications up to 900 K. Recently, nanostructured silicon has been proposed as a promising material for high-temperature thermoelectric applications.[3–5] Whereas use of bulk silicon for thermoelectric energy conversion is limited by its high thermal conductivity, a strong reduction in thermal conductivity has been found related to an increased surface influence on phonon scattering in silicon nanowires.

Nevertheless, for the design of TE modules, the specific material properties of commercially available bulk silicon over a large temperature range have to be known. So, for the calculation of module design, especially the Seebeck coefficient, the electrical conductivity, as well as electrical contacts for the high-temperature range are of great importance. However, a comprehensive compilation of TE data for silicon is lacking, especially for high doping concentrations in the temperature range up to 900 K.

In this paper we describe the characterization of low-, medium-, and high-doped silicon in the high-temperature range related to thermoelectric applications regarding Seebeck coefficient, electrical and thermal properties, and figure of merit *ZT*.

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THERMOELECTRIC PROPERTIES OF SILICON UP TO 900 K

Seebeck Coefficient and Thermal Conductivity

Measurements of thermoelectric properties of bulk silicon were performed using a self-developed measurement setup. The studies took place in a rough vacuum chamber at pressure <1 mbar. To achieve temperatures up to 900 K, electric igniter elements (glow igniter type HH; Bach Resistor Ceramics GmbH, Germany) were installed in this chamber as high-temperature heaters. The temperature measurements were performed using type K thermocouples (NiCr-NiAl) with wire diameter of 0.08 mm. Commercial *n*-doped and *p*-doped