Journal of ELECTRONIC MATERIALS, Vol. 42, No. 7, 2013
DOI: 10.1007/s11664-012-2399-5

A Thermoelectric Generator Concept Using a *p–n* Junction: Experimental Proof of Principle

ANDRÉ BECKER,[1,2] RUBEN CHAVEZ,[1] NILS PETERMANN,[1] GABI SCHIERNING,[1] and ROLAND SCHMECHEL[1]

1.—University of Duisburg Essen – CENIDE, Bismarckstraße 81, 47057 Duisburg, Germany.
2.—e-mail: andre.becker@uni-due.de

Conventional thermoelectric generators (TEGs) use single *p*- and *n*-doped legs for thermoelectric energy harvesting. We explore a concept using thermoelectric *p–n* junctions made from densified silicon nanoparticles. The nanoparticle powder was synthesized in a microwave plasma reactor using silane, diborane, and phosphine as precursors. To achieve a bulk sample with a *p–n* junction, a layer of boron-doped nanoparticle powder was stacked on a layer of phosphorus-doped powder and compacted by current-activated pressure-assisted densification. To use the *p–n* structure as a TEG, a temperature gradient was applied along the *p–n* junction. It is expected that this temperature gradient leads to electron–hole pair generation and separation in the junction, and diffusion of the charge carriers. A reference method was used to characterize the open-circuit voltage of the *p–n* junction TEG.

Key words: Seebeck effect, *p–n* junction, ambipolar drift

INTRODUCTION

Thermoelectric power conversion is a promising candidate for reliable and low-maintenance power conversion. For this reason, thermoelectric modules are often used as power generators in deep-space missions as well as for autonomous sensors.[1] Traditionally, in TEGs the thermoelectric materials are connected electrically in series and thermally in parallel. This means that, in the assembly of the TEG, contacts and substrates are necessary at both the hot and cold sides. However, in this traditional configuration, mechanical stress and unavoidable temperature drops across the substrates are typical drawbacks of the TEG.

Span et al.[2,3] suggested a new concept of a thermoelectric generator in which the *p*-type and *n*-type legs are connected directly, forming a *p–n* junction. This eliminates the need for an electric contact at the hot side. In this *p–n* junction device, the temperature gradient is parallel to the *p–n* junction. The bulk of the *p*-type and *n*-type leg generates a thermoelectric voltage, like in a conventional TEG, while the legs are electrically separated by the space-charge region of the *p–n* junction. However, on the hot side, electron–hole pairs are generated in the space-charge region of the junction, making the *p–n* junction more or less ohmic. So far the concept is very close to a conventional TEG. However, Span suggested that electron–hole pairs generated in the space-charge region of the junction diffuse along the temperature gradient parallel to the junction. If these diffusing electron–hole pairs enter a region of lower temperature, the electron–hole concentration will be above the thermal equilibrium concentration at this point and the charge carriers will be separated in the junction, similar to the photovoltaic effect, which leads to an additional thermoelectric contribution. However, the inhomogeneities of the doping concentration, especially close to the *p–n* junction, give rise to current vortices as predicted by Fu et al.[4]

To our knowledge, no experimental proof of principle has been published yet, while the diode characteristics of a thermoelectric *p–n* junction were presented by Kumpeerapun et al.[5] In this paper, we characterize the open-circuit voltage of a thermoelectric *p–n* junction, using different sample geometries.

(Received July 20, 2012; accepted December 26, 2012; published online February 5, 2013)