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Enhancement in Performance of the Tubular Thermoelectric Generator (TTEG)

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For use in a tubular thermoelectric generator (TTEG), we fabricated tubular $Bi_{0.5}Sb_{1.5}Te_3$/Ni composite using a melt-spinning technique combined with the spark plasma sintering (SPS) process. With this method, powder sintering, joining of two different materials, and tubular shaping can be achieved simultaneously. The tilted laminate structure which is crucial for the transverse thermoelectric effect was successfully achieved in the sample after SPS densification. The sintered samples showed better mechanical stability and thermoelectric properties compared with the previously studied melt-cast sample. We confirmed larger open-circuit voltage of 240 mV and generating power of 2.5 W with a 100-mm-long TTEG under the small temperature difference of 83 K, and the corresponding power density for a unit heat transfer surface area was approximately 800 W m^{-2}.

Key words: Thermoelectric generation, tubular thermoelectric generator, transverse thermoelectric effect, melt-spinning, spark plasma sintering

INTRODUCTION

There is an increasing need for waste heat recovery technologies to reduce the total primary energy consumption in the world. Most waste thermal energy is transferred to fluid media (e.g., hot water, steam, and exhaust gas) and dissipated to atmosphere. Recent research work has included the development of cylindrical-shaped thermoelectric generators aiming at efficient heat exchange with fluids.[1] This generator was constructed by using ring-shaped shunts to nicely fit the heat exchanger tubes. As another approach, using the transverse thermoelectric effect,[2–4] we recently realized tubular thermoelectric generators (TTEGs) in which the tubular structure itself serves as both the thermoelectric generator and the heat exchanger.[5]

Figure 1a shows a schematic illustration of a TTEG. The TTEG has a layered structure made of thermoelectric $Bi_{0.5}Sb_{1.5}Te_3$ and metallic Ni (Fig. 1b), and each of these materials has conical-ring shape. This tubular heterogeneous structure gives rise to artificial anisotropy which can be simply expressed in cylindrical coordinates, and a transverse voltage $\Delta V = (l/2d)(S_{//} - S_{\perp})(T_H - T_C)\sin 2\theta$ is induced in the axial direction due to the transverse thermoelectric effect.[6] Here, l is the length, d is the thickness of the TTEG, $S_{//}$ and $S_{\perp}$ are the Seebeck coefficients along the parallel (//) and perpendicular (⊥) directions, T_H and T_C are the hot-side and cold-side temperatures, and θ is the tilt angle with respect to the layered structure. To develop the transverse voltage of ΔV in the above equation, large material anisotropy $S_{//} - S_{\perp}$ is needed. According to the result by the equivalent circuit model in the laminate structure made of two materials,[4] $S_{\perp}$ and $S_{//}$ are dominated by the properties of the thermoelectric and metal material, respectively. Therefore, we chose the two highly dissimilar materials of thermoelectric $Bi_{0.5}Sb_{1.5}Te_3$ and metallic Ni to obtain higher power generation performance. In our previous study,[5] we prepared these conical rings by casting molten materials into molds because $Bi_{0.5}Sb_{1.5}Te_3$ is too brittle for conventional machining

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