

§10. Nernst-Seebeck Element in High Magnetic Field

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Thermoelectric generator has the advantage that it exchanges heat energy directly to electric energy. We have proposed the use of the magnetic field effect as a new approach to enhance conversion efficiency of the thermoelectric generator.¹⁾ The following magnetic field effect were observed for the polycrystalline bismuth (Bi): [1] increase of the electric resistivity, [2] increase of the Seebeck coefficient, [3] decrease of the thermal conductivity, and [4] occurrence of the high Nernst coefficient.²⁾ Effect [2]~[4] acts as the positive effect for the thermoelectric element, though effect [1] is negative.

In the Seebeck element, the Peltier heat flux flows to the same direction as the thermal conductive heat flux, and then the Peltier heat flux increases the total heat flux. In the Nernst element, the Ettingshausen heat flux flows to the opposite direction to the thermal conductive heat flux, and then the Ettingshausen heat flux reduces the total heat flux; therefore, the conversion efficiency of the Nernst element can approach to the Carnot efficiency at the lower figure-of-merit ZT than that of the Seebeck element.¹⁾

Unlike the Seebeck element, the heat leakage occurs in the Nernst element along the electrodes which are equipped on the side wall of the element. This heat leakage causes the difficulty in utilizing the Nernst element. On the Nernst-Seebeck element, two electrodes (A and B in Fig. 1) are equipped on the diagonal corners. These electrodes defect the heat leakage on the electrodes and enhances the output voltage of the thermoelectric generator by using the sum of the Seebeck electric field and the Nernst electric field in the magnetic field. Dependence of the conversion efficiency of the Nernst-Seebeck element on ZT is considered to be drawn between that of the Nernst element and that of the Seebeck element, since the Nernst-Seebeck element also uses the Ettingshausen heat flux.

To consider the high field limit of the Nernst-Seebeck element, the thermopower measurement and the electric resistance measurement were carried out in a high magnetic field within ± 8 T. Figure 1 shows the geometry of the Nernst-Seebeck sample. The material was the polycrystalline Bi since the polycrystalline Bi showed good magnetic field effects as the low-temperature Nernst-Seebeck element in the weak magnetic field.²⁾ The Nernst voltage is proportional to (width)/(length) of the sample. The geometry of 5 mm in length and 10 mm in width was chosen to attain the large Nernst effect.

Figure 2 shows the magnetic field dependence of the net thermopower ($V_{N+S}/\Delta T$) of the Nernst-Seebeck element at 100 ~ 287 K. Except at 100 K, the net thermopower increased almost linearly to the magnetic field and reached $-800 \mu\text{V/K}$ at 150 K. The values in the high magnetic field correspond to that of the materials like BiTe used for

commercial thermoelectric device. Compared with the thermopowers at -8 T, the thermopowers in the zero magnetic field were sufficiently small; the Nernst-Seebeck element using polycrystalline Bi corresponded at -8 T with the Nernst element concerning the thermopower.

On the other hand, ZT of the thermoelectric generator is inversely proportional to the electric resistance of the material. The electric resistivity of Bi decreases with decreasing temperature, whereas it increases remarkably in the magnetic field at lower temperature. For example, the electric resistance between A and B in Fig. 1 increased at 150 K from 0.00232Ω at 0 T to 0.151Ω at ± 8 T and at 200 K from 0.00279Ω to 0.0643Ω . However, ZT is proportional to (net thermopower)². As a result, the increase of the thermopower exceeded the increase of the electric resistance; ZT at -8 T increased by 15.9 times at 150 K and by 18.8 times at 200 K, compared with ZT in the zero magnetic field.

Reference

- 1) Yamaguchi, S., *Journal of Plasma and Fusion Research* **78**, (2002) 19 (in Japanese)
- 2) Hamabe, M., et al., *Proc. 22nd Int. Conf. on Thermoelectrics, La Grande Motte, France, 2003* (IEEE, Piscataway, NJ, 2003) 567.

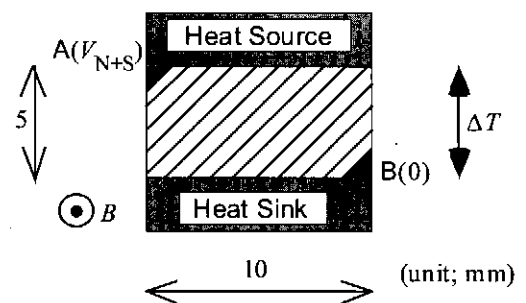


Fig. 1. Schematic diagram of the Nernst-Seebeck element (thickness was 2 mm). Here, ΔT is temperature difference between the heat source and the heat sink.

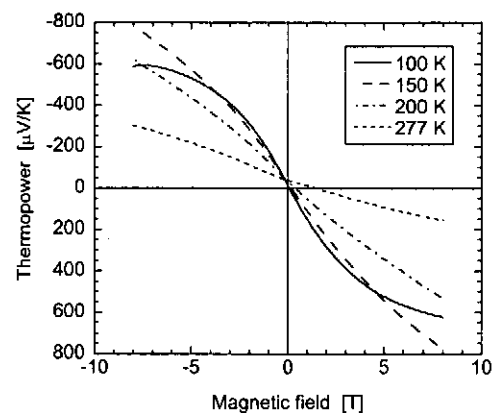


Fig. 2. Magnetic field dependence of the net thermopower of the Nernst-Seebeck element.