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Percolation Conduction in Hybrid Thermoelectric Material Consisting of $Bi_{0.88}Sb_{0.12}$ and Barium Ferrite Particles

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A hybrid material consisting of thermoelectric $Bi_{0.88}Sb_{0.12}$ and Ba ferrite $Bi_{0.88}Sb_{0.12}(BaFe_{12}O_{19})_x$ (x = 0, 0.025, 0.04, and 0.08) was synthesized using sintering. Powder x-ray diffraction patterns and scanning electron microscopy images of the hybrid indicate that the $BaFe_{12}O_{19}$ particles were well distributed in the host $Bi_{0.88}Sb_{0.12}$ phase. The temperature dependence of the electrical resistivity ρ of the host Bi-Sb exhibits metallic behavior. By the addition of Ba ferrite particles, the ρ at 300 K increases intensively, and ρ(T) then behaves similarly to a semiconductor. However, it is noted that the thermoelectric power S is unchanged. Inhibition of current and heat flows by a restricted conduction path and the unchanged electromotive force generated by the Seebeck effect in the conduction path can be understood based on a site-percolation model consisting of conducting Bi-Sb and insulating Ba ferrite. The critical volume fraction p_c of this system was estimated experimentally as p_c = 0.68.

Key words: Thermoelectric, bismuth-antimony, magnetic particle, hybrid, percolation

INTRODUCTION

Thermoelectric (TE) technology enables direct conversion between thermal and electric energy based on the Seebeck or Peltier effect.[1,2] Therefore, a TE device can be used as an electric power generator using waste heat from blast furnaces, automobiles, or distributed natural heat. Furthermore, such generators can create electricity from so-called cold heat, such as that from a liquefied natural gas (LNG) vaporizer.[3] Conversion using cold heat requires that the material show, at low temperatures, high TE performance determined by the dimensionless figure of merit

$$ZT = \frac{S^2}{\rho\kappa}T,$$

where S represents the thermoelectric power, ρ denotes the electrical resistivity, κ stands for the thermal conductivity, and T signifies the absolute temperature.

Bismuth-antimony (Bi-Sb) alloys, which are n-type conductors, exhibit good TE performance at low temperatures around 100 K.[4–9] The electrical properties of $Bi_{1-y}Sb_y$ depend on the Sb concentration y. In the Bi-rich range of $y < 0.05$, $Bi_{1-y}Sb_y$ is a semimetal because the conduction bands at L-points overlap the valence bands at T-points. In the range of $0.05 < y < 0.22$, the alloys are semiconductors because of the existence of a band gap. For $y > 0.22$, the H-hole band goes up in energy and overlaps with the L band so that the alloy turns into a semimetal again. The maximum energy gap is approximately 20 meV at y = 0.12.[10–12] It is noteworthy that the ZT of this material is greatly enhanced on application of a magnetic field.[5,13,14] Remarkably, ZT reaches approximately 1.1 under a 0.3 T magnetic field.[5]

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