Seebeck-driven Colossal Transverse Thermoelectric Generation

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The transverse electric field generated by anomalous Nernst effect (ANE) in a magnetic material is perpendicular to both the temperature gradient (∇T) and its magnetization (**M**), different from Seebeck effect (SE) where the generated electric field is parallel to ∇T. This allows different design principles for creating a simple and flexible thermoelectric power generation or heat flux sensing device. However, the practical application of transverse thermoelectric generation is hampered by the small thermopower compared to that of SE, and there has been increasing studies aiming to find magnetic materials with large anomalous Nernst coefficient (S_{ANE}). S_{ANE} can be separated into two components as $S_{\mathrm{ANE}} = \rho_{xx}\alpha_{xy} - \rho_{\mathrm{AHE}}\alpha_{xx}$, where ρ_{xx} is the longitudinal resistivity, ρ_{AHE} is the anomalous Hall resistivity, and α_{xx} and α_{xy} are the diagonal and off-diagonal components of the Peltier tensor, respectively. The first term on the right hand side is considered the intrinsic term of ANE, as α_{xy} directly converts ∇T into a transverse electrical current. The second term on the right hand side can be rewritten as $-S_{\mathrm{SE}} \times \rho_{\mathrm{AHE}} / \rho_{xx}$, indicating it originates from the anomalous Hall effect (AHE) of the longitudinal carrier flow induced by SE, and S_{SE} is the Seebeck coefficient. Here, inspired by the second term, we propose a different approach for transverse thermoelectric generation. We consider a system that consists of a thermoelectric material and a magnetic material electrically connected at both ends along the ∇T direction to form a closed circuit (Fig. 1(a)). The large electric field generated by SE of the thermoelectric material was converted to transverse thermoelectric generation by AHE of the magnetic material, which showed a similar symmetry to ANE, but surprisingly, more than one order of magnitude enhancement in the thermopower. This is referred to as the Seebeck-driven transverse thermoelectric generation (STTG).[1] For the proof-of-concept demonstration of STTG, we deposited a 50-nm-thick Co_2MnGa thin film on an MgO (100) substrate and used it as the magnetic material. The MgO substrate was then cut into a rectangular shape and bonded onto a rectangular-shaped Si substrate, which was used as the thermoelectric material. The Co_2MnGa film and Si substrate were electrically connected to each other through Ohmic contacts and bonding wires near the ends to form the closed circuit. The transverse electric field (E_{M}^{y}) in the Co_2MnGa layer was measured while the magnetic field (H) was swept in the direction perpendicular to the sample plane. The same measurement was also carried out without the Co_2MnGa-Si connection. Figure 1(b) shows the H dependence of E_{M}^{y} divided by ∇T for the samples using an n-type Si as the thermoelectric material. With the Co_2MnGa-Si connection, the total transverse thermopower S_{tot}^{y} = 82.3 μV K^{-1}, more than one order of magnitude larger than S_{ANE} = 6.2 μV K^{-1} measured without the Co_2MnGa-Si connection.

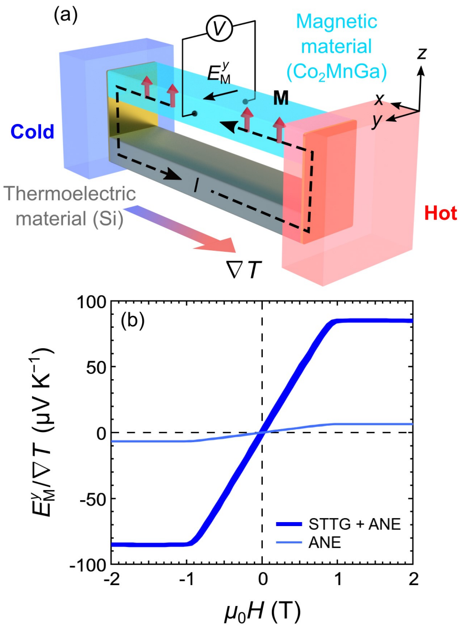

Fig. 1 (a) Schematic of the model system for STTG, which consists of thermoelectric and magnetic materials electrically connected at both ends to form a closed circuit. (b) H dependence of E_{M}^{y} divided by ∇T with (STTG + ANE) or without (ANE) the Co_2MnGa-Si connection.

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