High-Efficiency Energy Conversion Materials Based on Correlation Between Heat, Spin, and Electric Field

Collaborative Research Center on Energy Materials

The development of high-efficiency energy conversion materials based on the correlation between heat, spin, and electric field is an interesting and challenging topic. We aim to apply the Nernst effect in magnetic materials to achieve a high-efficiency energy conversion method. Here, we highlight recent advances in fundamental research and the application of the effect; the enhancement of anomalous Nernst effect by the spin-wave generated by a temperature gradient and the control of anomalous Nernst effect by an external electric field.

One of our Center's research activities is directed toward the development of high-efficiency energy conversion materials based on the correlation between heat, spin, and electric field. This research aims to replace existing energy materials and establish the scientific principle on the technology of energy conversion and the solution for the wide-ranging energy problems. We aim to apply the Nernst effect in magnetic materials for a high-efficiency energy conversion method. When a temperature gradient is applied to a material with spontaneous magnetization, an electric field is induced in the direction perpendicular to both the temperature gradient and the magnetization. This phenomenon is termed the anomalous Nernst effect (ANE). Obtaining materials with a large ANE is indispensable to enable its practical application. We have previously reported the dependence of ANE on material type in several perpendicularly magnetized ordered-alloy thin films [1]. In this highlight, the enhancement of ANE in a particular ordered-alloy material "$L1_0$-ordered FePt" was investigated both experimentally and theoretically. In addition, the control of ANE by an external electric field was demonstrated in manganite thin films.

$L1_0$-ordered FePt is known to exhibit a large magnetic anisotropy. The electronic structure of this material was measured by hard X-ray photoemission spectroscopy to investigate the relationship between the electronic structure and magnetic anisotropy [2]. Subsequently, the temperature dependence of ANE in $L1_0$-ordered FePt thin films with different magnetic anisotropies was systematically measured. It was found that the enhancement of ANE over 100 K occurred particularly for FePt with small magnetic anisotropies. It is considered that the spin-wave generated by the temperature difference led to the enhancement of ANE in FePt. The theoretical calculation of the spin–wave successfully depicted the observed enhancement. The effect of the electric field on thermomagnetic properties in a $La_{0.7}Ca_{0.3}MnO_3$ thin film was investigated using a FET structure with an Al_2O_3 dielectric-gate as show in Fig. 1. The anomalous component of the Nernst voltage clearly changed with the gate voltage. This implies that the Nernst effect can be modulated by the electric field, which is advantageous for the control of thermomagnetic properties in various magnetic materials with a high efficiency.

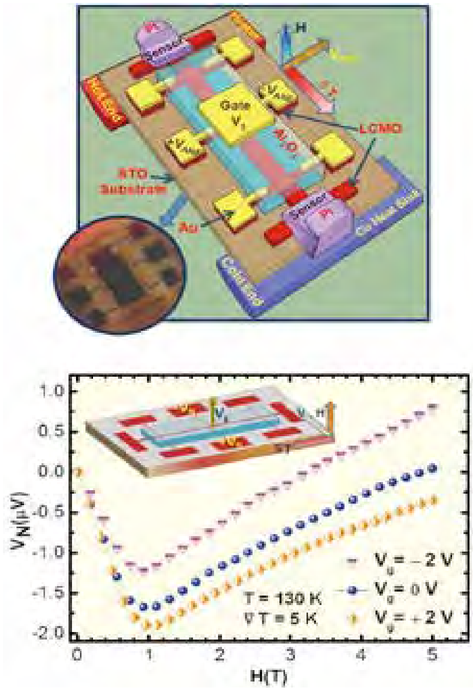

Fig. 1 (Top) Schematic of ANE measurement. (Bottom) Nernst voltage (V_N) as a function of magnetic field with different applied gate voltages measured at 130 K with an in-plane temperature difference of 5 K.

References

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