Research Group for Spin-Energy Transformation Science

Group Leader: Eiji Saitoh

Members: Michiyasu Mori, Hiroaki Onishi, Jun'ichi Ieda, Koki Nakata, Kei Yamamoto, Yasufumi Araki, Satoru Okayasu, Masao Ono, Hiroyuki Chudo, Kazuya Harii, Masaki Imai

We are searching for new pathways to transform various forms of energy such as heat, magnetic and mechanical ones into electricity by means of spintronics. The conversion from heat to a magnetically polarized current (spin current) is applied to find a spin on-off switch as reported below in the first subject. To generate a spin current, detailed information on magnetic excitation in various materials is necessary. For a new candidate of a spin current generator, the magnetic phase diagram of a frustrated spin ladder is introduced. In addition, some interesting results observed by a mechanical rotation are reported in the research highlight of our group [1].

Spin Colossal Magnetoresistance in an Antiferromagnetic insulator [2]

One of the important components in electronics is a transistor based on an on-off switch of charge current. A spin current is a flow of angular momentum. By using thespin current as an alternative to the charge current, the Joule heating can be reduced particularly in an insulator. However, it is not easy to realize an on-off switch of spin current. Colossal magnetoresistance (CMR) is a large change in electrical conductivity induced by a magnetic field in the vicinity of a metal–insulator transition. We demonstrated an analogous spin effect near the Néel temperature, $T_N = 296$ K, of the antiferromagnetic insulator Cr_2O_3. By applying a temperature gradient in $Y_3Fe_5O_{12}$(YIG)/Cr_2O_3/Pt tri-layer (see the inset of Fig. 1 (a)), a spin current is injected from YIG to Pt through Cr_2O_3 and converted to a charge current, which is observed as a voltage, V_{SSE}. This phenomenon is called the spin Seebeck effect (SSE). As shown in Fig. 1 (a), V_{SSE} suddenly drops to zero at T_N. If Cr_2O_3 layer was absent, i.e., in YIG /Pt bi-layer, V_{SSE} is almost constant around T_N as shown in Fig. 1 (b). The transmittance of spin current is defined by the ratio of V_{SSE} in YIG/Cr_2O_3/Pt tri-layer to that in YIG/Pt. Therefore, our result means that the spin-current transmission can be modulated by up to about 500%. Above T_N, the spin current is carried by correlations of the paramagnetic moments in Cr_2O_3, while below T_N, the spin current cannot propagate, since the magnetization in Cr_2O_3 is perpendicular to the polarization of the injected spin current. In fact, this spin version of CMR can be controlled by changing the direction of a magnetic field. Our results have the potential to simplify the design of fundamental spintronics components, such as enabling the realization of spin-current switches or spin-current-based memories.

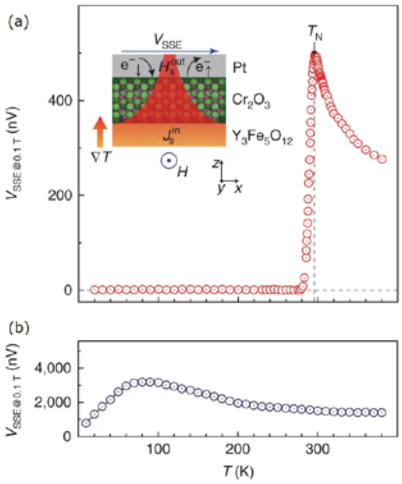

Fig.1 The temperature dependence of V_{SSE} (a) in the YIG/Cr_2O_3/Pt tri-layer and (b) in a YIG/Pt bi-layer. The inset is a schematic picture of our device. The temperature gradient, ∇T, is along the *z* direction, and the external magnetic field (*H*) is along the *y* direction. The magnetic insulator, YIG, is used as a spin source to inject aspin current J_s^{in} into the Cr_2O_3. TA transmitted spin current J_s^{out} through the Cr_2O_3 is detected as V_{SSE} in the Pt layer. The symbols, $e_\downarrow^-$ and $e_\uparrow^-$, indicate a flow of electrons.

Magnetic Phase diagram of a Frustrated Spin Ladder [3]

In the first subject of this report, the spin current is carried by magnons generated in YIG. A magnetic field generally leads to a gap in a dispersion relation of magnons and suppresses a spin current at low temperatures. On the other hand, another type of quasi-particle called triplon is generated in the frustrated spin ladder of $BiCu_2PO_6$. A triplon is a triplet excitation and is stabilized in amagnetic field. Since it has a well-defined dispersion relation, there is a possibility to be used in the SSE instead of YIG. To utilize the triplons, we studied the magnetic phase diagram of a frustrated spin ladder shown in Fig. 2 (right). The phase diagram has not been determined so far since a frustrated spin system is essentially a many-body problem and is difficult to be solved analytically. Then, we have numerically solved a Hamiltonian composed of three types of anti-ferromagnetic Heisenberg interactions as assigned in Fig. 2 (right). As a result, it is found that the triplon has a gap in energy when the magnetization is set to 0, 1/3, 1/2, and 2/3. Those appear in the shaded areas of the phase diagram in Fig. 2 (left). The three types of interactions, J_1, J_2, and $J_\perp$, can be changed by substituting elements, e.g., partial substitution of P by As, and/or applying pressure. It is expected that such a gap-engineering will provide a new source for the progress of spin current generators.

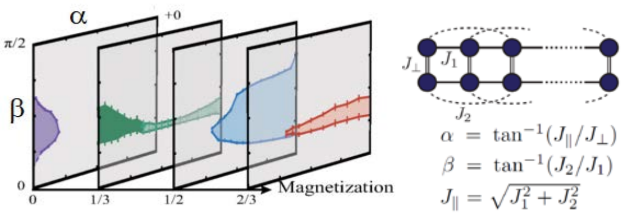

Fig. 2 The magnetic phase diagrams of a frustrated spin ladder at the magnetization 0, 1/3, 1/2, and 2/3. In the shaded areas, the magnetization curve shows a magnetic plateau, where the magnetic excitation has a gap.

References

[1] M. Imai et al., Appl. Phys. Lett. 113, 052402 (2018).
[2] Z. Qiu et al., Nature Materials 17, 577-580 (2018).
[3] T. Sugimoto et al., Phys. Rev. B 97, 144424 (2018).