Research Group for Condensed Matter Theory

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We study new functional materials emerging from the electrons' internal degrees of freedom (spin, charge and orbital) and the electron correlation. New principles and new functions of devices are also our important targets. In this fiscal year, we found a new principle of magnetic power inverter by magnetic domain wall motion [1]. This makes it possible to generate AC voltages from DC magnetic fields. Furthermore, we proposed that domain wall motion in a perpendicularly magnetized nanowire could lead to a high stability of spinmotive force under strong magnetic fields [2]. Details of these two results are summarized in Research Highlights. Progresses on a ferromagnetic Josephson junction with magnetic domain wall and spin Seebeck effect in ferrimagnets are reported below.

Towards precise measurement of oscillatory domain wall by ferromagnetic Josephson junction

Nano-scale magnetic materials are extensively studied for spintronics devices due to many advantages such as enhanced operation speed, low power consumption, and high integration of memory cell. Non-volatile memory using a magnetic domain wall (DW) is one example of such devices, and many studies are devoted to control the DW. Hence, it is worth developing a method for precise measurement of DW motion.

One example of precise measurements is the Josephson effect. Under irradiation of microwaves to the Josephson junction, in which two superconductors (SCs) are separated by an insulator, the current-voltage (*I*-*V*) curve shows step structures at $V = n(\hbar/2e)\nu$ with microwave frequency ν, integer *n*, and the ratio of the Plank constant and the elementary charge $\hbar/e$. This structure, which is called Shapiro step, is adopted to the voltage standard around the world, since the voltage can be determined in the order of 10^{-9} accuracy by the precise values of ν and $\hbar/e$. Hence, one can say that the Josephson junction has potential for precise measurement in principle.

We considered the ferromagnetic Josephson junction (FJJ) as shown in Fig. 1, in which a ferromagnet with a magnetic domain wall is inserted between two SCs [3]. The *I*-*V* curve is theoretically derived and is found to show stepwise structures only when the DW oscillates in the FW. The voltage step appears at $V = n(\hbar/2e)\omega_{DW}$ with the DW frequency ω_{DW}. Since the voltage is determined in the order of 10^{-9} accuracy, our result provides a method to measure the oscillatory DW more precisely than the present accuracy. This result can be applied to not only the oscillation but also more general dynamics of the DW. Those possibilities will be examined in a forthcoming work.

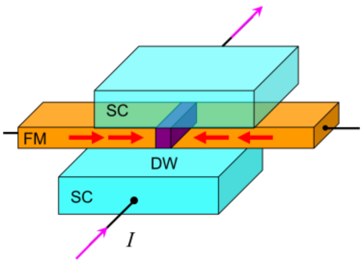

Fig.1 Schematic of the ferromagnetic Josephson junction, which is composed of two superconductors (SCs) separated by a ferromagnet (FM) with a magnetic domain wall (DW). The current (*I*) goes through the junction as denoted by arrows. The red arrows in the FM indicate the magnetic moment.

Spin Seebeck effect in antiferromagnets and compensated ferrimagnets

Electric power generation by a temperature gradient (Seebeck effect) is one of important issues in condensed matter physics, since such a thermoelectric device possesses fascinating properties necessary for future energy resources. The spin Seebeck effect (SSE) can also generate electricity, more importantly, by a simple setup of device such as a metal on top of a ferromagnet with a temperature gradient (See Fig. 2). In general understanding, the spin polarized current (spin current) is injected from the ferromagnet to the metal by the temperature gradient, and then, the inverse spin Hall effect converts the spin current into the usual charge current. In this way, one can obtain electricity from thermal energy in ferromagnets by the SSE.

Here, one question arises: Does the SSE occur in an antiferromagnet and a ferrimagnet? A certain class of ferrimagnets has a compensation temperature, at which the magnetization disappears even below a ferromagnetic transition temperature.

We theoretically showed that the SSE vanishes in antiferromagnets, whereas it always survives in ferrimagnets even at the compensation temperature, despite the absence of its saturation magnetization or total spin [4]. It is found that non-degeneracy of magnetic excitations (magnons) in low energy is the origin for the persistence of the SSE in the ferrimagnets. The compensation temperature is useful for constructing a spin current device, since the leakage magnetic-flux is suppressed and does not disturb the spin and charge currents. Such a situation will be realized in $Er_3Fe_5O_{12}$ as an example.

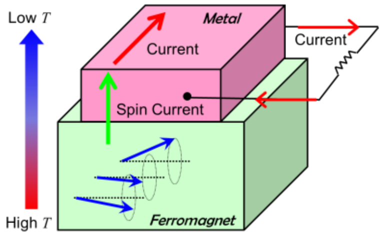

Fig.2 Schematic of the device setup for the spin Seebeck effect (SSE). The spin polarized current (spin current) is injected from the ferromagnet to the metal, where the spin current is converted to the charge current by the inverse spin Hall effect. The blue arrows in the ferromagnet indicate the precessing magnetic moment.

References

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[4] Y. Ohnuma *et al.*, Phys. Rev. B **87**, 014423 (2013).