Research Group for Condensed Matter Theory

Group Leader : Michiyasu Mori
Members : Hiroaki Onishi, Katsunori Kubo, Jun'ichi Ieda, Hiroto Adachi, Bo Gu, Mari Matsuo, Mamoru Matsuo, Yuta Yamane, Yuichi Ohnuma

We study new functional materials emerging from the electrons internal degrees of freedom (spin, charge and orbital) and the electrons correlation. New principle and new function of devices are also our important targets. So far, we have found (1) a new method of spin injection into all types of materials and (2) a spin current generation by a mechanical vibration (phonon). Details of these two results are summarized in Research Highlights. Studies on spin Seebeck effect, spin current generation by mechanical rotation, ferromagnetic Josephson junction with magnetic domain wall, and enhanced spin Hall effect are also progressing soundly.

Theory of spinmotive force and its continuous generation by highly asymmetric geometry

A spin-originated motive force, i.e., "spinmotive force", is the conversion of the magnetic energy in a ferromagnet into the electrical energy of conduction electrons via the magnetic exchange interaction. The spinmotive force is given by the spin electric field,

$$E_s = -\frac{P\hbar}{2e} m \cdot (\partial_t m \times \nabla m),$$

where m is the local magnetization, P is the spin polarization of conduction electrons. The Planck constant and the elementary charge are denoted by $\hbar$ and e, respectively. Note that both the time and the spatial variations of m are necessary to obtain the spinmotive force. So far, a motion of magnetization or ferromagnetic nano-particles has been used to generate the spinmotive force. Hence, the obtained results are limited to a pulse or ac-type generations.

We proposed a new method to generate a dc spinmotive force [1]. By exciting a ferromagnetic resonance in a comb-shaped ferromagnetic thin film as shown in Fig. 1, it is found that the continuous spinmotive force can be obtained. The spin electric field in the comb-shaped ferromagnet is calculated by supposing that the local magnetization dynamics is determined by the Landau-Lifshitz-Gilbert equation. Experimental results are quantitatively well reproduced by our theoretical calculations. Our theory can provide a microscopic understanding of the spinmotive force.

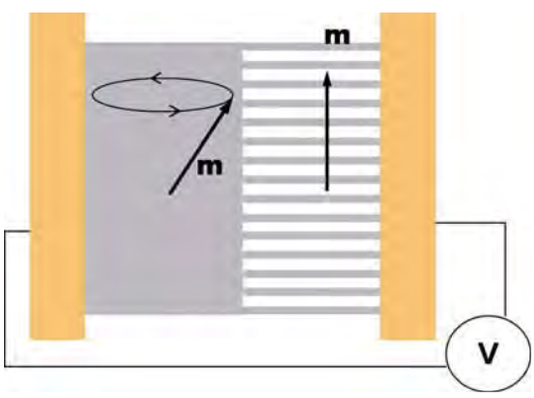

Fig. 1 Schematic of the comb-shaped ferromagnetic thin film. The ferromagnetic resonance frequency in the pad region (left) is different from that in the wire region (right).

Non-monotonic temperature dependence of thermopower in correlated electron systems

Since the discovery of unusually large thermopower in Na_xCoO_2, transition-metal oxides with strong electron correlation have attracted much attention as promising candidates for high-performance thermoelectric materials. Thermopower is none other than the amount of entropy flow along with the electric current. The consideration on the entropy in thermodynamics tells us the low and high temperature (T) limits of the thermopower: In the metallic systems, the thermopower goes to zero as T goes to 0 K. On the other hand, the high-temperature limit of thermopower is given by the entropy consideration in the atomic limit. In the strongly correlated systems, the spin and orbital degrees of freedom can enhance the high-temperature thermopower in principle.

We studied the role of strong Coulomb interaction on thermopower, whose temperature dependence is particularly examined in detail. For this purpose, the single- and multi-band Hubbard models are adopted as a minimum model and the strong Coulomb interaction is treated in the dynamical mean field theory (DMFT), which can capture the coherent-to-incoherent crossover due to the strong Coulomb interaction, U. This method based on the local picture is useful to understand the overall behavior of thermopower as a function of temperature. It is found that the Coulomb interaction gives rise to a non-monotonic temperature-dependence, which is well described by the entropy consideration at high temperatures. In the light of our theoretical results, the thermoelectric response in the transition metal oxides, $La_{1-x}Sr_xVO_3$ is well explained.

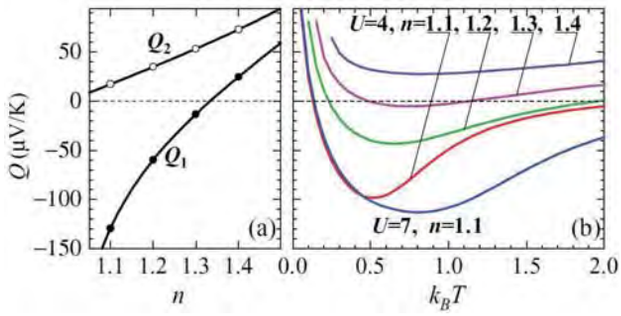

Fig. 2 (a) Thermopower in the high temperature limit, Q_1 ($T \to \infty$ with $k_BT<U$) and Q_2 ($T \to \infty$ with $U<k_BT$), vs. electron density, n in the single band Hubbard model. (b) Temperature dependence of the thermopower calculated by DMFT with the non-crossing approximation as impurity solver, for various parameter sets of U and n.

References

[1] Y. Yamane *et al.*, Phys. Rev. Lett. **107**, 236602 (2011).
[2] M. Uchida *et al.*, Phys. Rev. B **83**, 165127 (2011).
[3] M. Matsuo *et al.*, Phys. Rev. B **84**, 153107 (2011).