Research Group for Spin-Energy Transformation Science

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Our research objective is to mutually transform various types of energy, e.g., heat, mechanical vibration, and electricity by using spin. The spin Seebeck effect is a kind of thermoelectric generation using a bilayer of metal and ferromagnet. We found that this effect can induce a mechanical vibration as well [1]. Reciprocity is one of important characteristics of spin, which can be seen in our Research Highlight. Some ferrimagnets will be useful for magnetic memory since a magnetic domain-wall moves very fast around an angular momentum compensation temperature, which is observed by the Barnet effect and is controlled to room temperature by substitution of ions [2].

Spin Seebeck Mechanical Force [1]

Magnetic properties of materials originate from a spin of electron. As with an orbital angular momentum, roughly speaking, a spin is also regarded as microscopic rotation. Then, a question arises: Is it possible to induce mechanical rotation by spin? Spin injection can be done by a spin current, which is a flow of magnetism. In the spin Seebeck effect, the spin current is generated by a temperature gradient. The spin Seebeck effect is a kind of thermoelectric generation using a bilayer of metal and magnet. By applying a temperature gradient perpendicular to the bilayer, for example, the spin current is generated in the magnet and is injected into the metal, where the spin current is converted into a charge current. We fabricated a cantilever of yttrium iron garnet (YIG) by using ion focus beam (Fig.1). In order to inject a spin current into this cantilever, a heater made of platinum (Pt) thin wire was formed near the base of the cantilever as a heat source. A heat flow is generated by an alternating current through this heater, and the spin current generated by the spin Seebeck effect propagates toward the cantilever. When a spin current was not injected, only small vibrations due to environmental noise were observed. When a spin current was injected, a clear signal appeared in the vibration of the cantilever. By measuring a current and directional dependence of the magnetic field, it was confirmed that the signal is consistent with the force generated by the spin current injection.

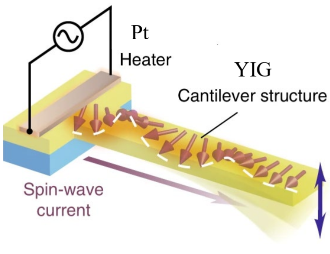

Fig.1 Schematic illustration of spin Seebeck mechanical force. When a part of a magnetic insulator is heated, a spin wave is excited and flows out of the part. A spin wave carries angular momentum. Relaxation of spin waves generates macroscopic mechanical torque and force due to the angular momentum transfer

Angular momentum compensation of ferrimagnet observed by Barnett effect [2]

Ferrimagnet is a kind of ferroganet theoretically predicted by Neel. Among several types of ferrimagnets, one called N-type shows a magnetization compensation, at which a total magnetization becomes zero below Curie temperature. Since a magnetization corresponds to a sum of total angular momentum and spin angular mometum, a angular momentum compensation (AMC) is also possible and becomes a key characteristic of spintronics. In fact, the high-speed magnetic response at the AMC temperature is reported. We reported the direct observation of AMC by using the Barnet effect. On a rotating frame, the rotational frequency couples to an angular momentum itself instead of magnetization. This is the reason why we could successfully observed AMC and we must use the Barnet effect. Figure 2 (left) shows our apparatus. The rotor system was placed in magnetic shields to exclude the geomagnetic field. The sample was rotated using compressed air with angular velocity Ω and magnetized to M_Ω by the rotation. We measured the stray field from M_Ω using a fluxgate magnetic sensor. By applying this method, we observed AMC in the insulating rare earth iron garnet (RIG) $Ho_{3-x}Dy_xFe_5O_{12}$ as shown in Fig. 2 (right), where the temperature dependences of M_Ω are plotted. The AMC can be controlled by Dy substitution, and it found that AMC coincides with room temperature at x~1.5 The advantage of the Barnett effect is that microfabrication of the sample is not necessary regardless of metal or insulator. The Barnett effect enables us to explore candidate materials for high-speed magnetic devices by exploiting fast-magnetization reversal at AMC.

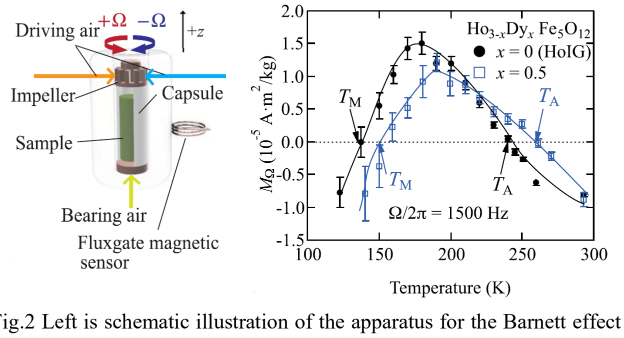

Fig.2 Left is schematic illustration of the apparatus for the Barnett effect measurement using an air-driven rotor system. The rotor system was placed in magnetic shields to exclude the geomagnetic field. The sample was rotated using compressed air with angular velocity Ω and magnetized to $M_\Omega$by the rotation. We measured the stray field from M_Ω using a fluxgate magnetic sensor. Right is Temperature dependence of M_Ω of $Ho_{3-x}Dy_xFe_5O_{12}$ (x=0 and 0.5). The solid lines are guides to the eye. The magnetization and the angular momentum compensation temperatures are denoted by T_M and T_A, respectively.

References

[1] K. Harii *et al.*, Nat. Commun. **10**, 2616 (2019).
[2] M. Imai *et al.*, Appl. Phys. Lett. **114**, 162402 (2019).