Research Group for Spin-Energy Transformation Science

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Spin and orbital angular momentum are the origin of magnetism. We quest to extend these degrees of freedoms for energy sustainability. One strategy is to use for transformation between thermal and electric energies via spin, i.e., spin Seebeck effect and its inverse one called spin Peltier effect [1]. This subject is explained in Research Highlights. Another effort is devoted to conversion between magnetism and mechanical motion such as rotation and vibration. Two interesting results are reported below.

Spin Current Generation by Surface Acoustic Wave [2]

In a rotating frame, a mechanical rotation is equivalent to a magnetic field. In fact, a conversion from a magnetic moment of spin to a macroscopic rotation was experimentally demonstrated in a ferromagnet by Einstein and de Haas, and its inverse effect is done by Barnett. We successfully generate an alternating spin current (SC) using a surface acoustic wave (SAW) in a Cu film via spin-rotation coupling (SRC). A SAW generates a gradient of vorticity, i.e., rotational deformation of lattice, in a depth direction. The SRC directly converts the vorticity to electron spin in the metallic film. Hence, we can generate a spin current in a nonmagnetic material by the SAW. Figure 1 (a) shows a basic principle of our experiment to create an alternating SC generated by a SAW. The Cu and NiFe layers shown in Fig. 1(a) act as source and detector of the SC, respectively. An injected SC into NiFe layer is observed by its ferromagnetic resonance (FMR) and the interdigital transducers (IDTs) are used for transmitter and detector (see Fig.1 (b)). When a frequency of SAW matches to that of FMR frequency, the FMR is excited in a NiFe layer. It is confirmed that the resonance is suppressed by inserting a SiO_2 film at the interface of Cu and NiFe layers. This is the clear evidence that the SC is injected by the SAW. The intensity of the resonance depended on the angle between the wave vector of the SAW and the magnetization of the Ni-Fe film. This angular dependence is associated with the presence of spin transfer torque from a SC generated via SRC. We further found that the amplitude of SC increases with the thickness of Cu layer. Our experimental results open pathways to the generation of alternating SC in SAW devices without ferromagnets and/or large spin-orbit interaction.

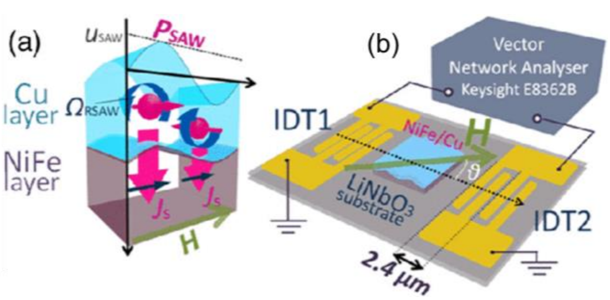

Fig.1 Schematic illustrations of (a) spin-current (Js) generation via spin-rotation coupling in surface acoustic wave (SAW) and (b) experimental setup for measuring microwave absorption caused by the ferromagnetic excitation.

Magnetic Control of Cantilever [3]

A cantilever is a long rigid plate, whose one end is supported tightly and the other end can mount a load. Thanks to its high sensitivity and feasible fabrication in large area, the cantilever is a good tool to study an interplay between magnetism and mechanical motion. We fabricate a cantilever of ferrimagnet, $Y_3Fe_5O_{12}$ (YIG) with $0.8\times0.9\times80$ μm. Vibration spectra are measured by a laser Doppler vibrometer at room temperature as shown in Fig. 1 (a). The obtained minimum detectable force is as small as 10^{-16} N. This is much less than that used commercially in the atomic force microscopy. In a magnetic field, resonance frequencies of both (horizontal and vertical) vibrations are changed as shown in Fig. 1 (b), where a case of non-magnetic cantilever using gadolinium gallium garnet (GGG) is also shown as reference. The resonance frequency of the horizontal mode steeply increases with magnetic field. Also for the vertical mode, the similar strong magnetic field dependence is observed especially at low magnetic fields. However, on the contrary to the horizontal mode, the resonance frequency of the vertical mode decreases with increasing magnetic fields. Hence, the clear difference in the response to magnetic field is observed between the two modes. This difference can be understand by an effective spring constant associated with a magnetic force gradient, which is induced by a stray field of surrounding YIG film (See also Fig. 4 in Ref. [2]). Since YIG has been typically used for various spin current phenomena, the YIG cantilever will be useful for the mechanical detection of spin currents.

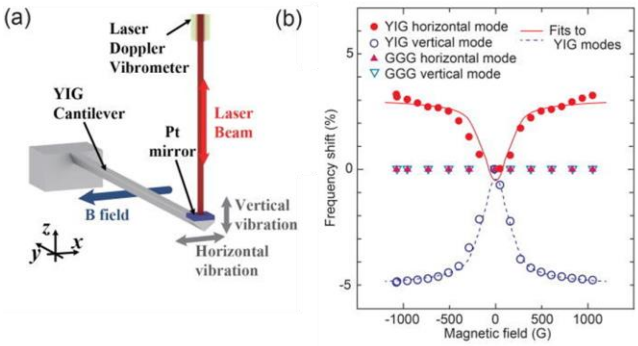

Fig.2 (a) A schematic illustration of cantilever and setup of our measurement. (b) The frequency shifts with magnetic fields are plotted as a function of external magnetic fields for the YIG and GGG cantilevers. The solid and dashed curves are fitting results of the experimental data.

References

[1] Y. Ohnuma et al., Phys. Rev. B **96**, 134412 (2017).

[2] D. Kobayashi et al., Phys. Rev. Lett. **119**, 077202 (2017).

[3] Y. Seo et al., Appl. Phys. Lett. **110**, 132409 (2017).