Research Group for Spin-Energy Transformation Science

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Research on mutual energy conversion among various forms is a key for improving energy efficiency and further the sustainability of energy. We study the energy conversion using electron spins and their couplings to another type of angular momentum, including mechanical rotation.

Tuneable Nano-scale Inductor Toward Power-spintronics

A coil of a conducting wire induces an electromotive force (EMF) by applying an electric current. This is a classical inductor, being an important element of power electronics for electric voltage transformation and electric noise filtering. The magnitude of the inductance, is proportional to the cross-section of the coil. This feature, however, is a crucial restriction to reduce the size of inductors (Fig.1 left). Recently, researchers in RIKEN have proposed a quantum mechanical version of inductors called "emergent inductor" (EI) using a spiral magnet that exhibits totally opposite system size dependence (Fig. 1 right) and the concept has been experimentally demonstrated [1,2]. Motivated by these findings, we have extended the theory of EI by including the Rashba spin-orbit coupling (RSOC) and the electron spin relaxation [3]. Notably, in the spiral magnet with the RSOC, the EMF of the spin origin, i.e., spinmotive force (SMF) is composed of two parts: One is RSOC-free and depends on the derivatives of magnetization both in time and space. The other one is induced by the RSOC. The latter is missing in the original proposal [1], but it gives rise to a significant impact on the magnitude of EI. In addition, our results indicate that the spin relaxation effect that was also discarded in [1] is crucial in determining the overall sign of the EI. If one can prepare a spiral magnet with 20 nm half-pitch and the RSOC with a magnitude ~10^4 m/s, the RSOC effect results in a large enhancement of the EI about three orders of magnitude. Furthermore, this enhancement factor can be tuned by electrical gating because of the RSOC. Surprisingly, the spin relaxation effect leads to negative EI. These two factors can be tuned independently by electrical gating and appropriate material choice. More importantly, our EI is enhanced in the small size in contrast to the classical inductor made of conducting wire. Our results will contribute to a nano-scale power supply circuit and a noise canceller of electromagnetic noise.

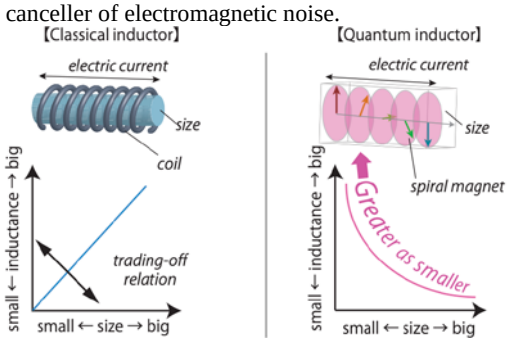

Fig.1 Comparison of classical and quantum inductors. The size (cross-section) dependence is totally different between two systems [3].

Non-reciprocal Pumping of Surface Acoustic Waves

Sound waves in a solid are small deformations and distortions of solid transmitted as vibrations. The Rayleigh wave is a sound wave propagating only along a surface, i.e., surface acoustic wave (SAW), and is widely used as sensors and filters, because it can propagate in any solid with a slower velocity and lower attenuation than ordinary bulk sound waves propagating through the solid volume. In addition, many studies on spintronics focus on the SAW to develop a new information carrier using electron spins. For this purpose, a directional control of SAW is crucial.

We have predicted that the SAWs can be generated preferentially in one direction in a magnetic film by applying a driving magnetic field (Fig. 2) [4]. The non-reciprocity of SAW arises from magneto-elastic coupling and magneto-rotation coupling. Equations of motion of magnetization and lattice-displacement are simultaneously solved under certain assumptions, where only one spin wave mode couples dominatly to the SAW instead of bulk phonons. The magnetic susceptibility resulting from the equations indicates that the hybridization between SAW and spin wave is very different for positive wave numbers, k>0, and negative wave numbers, k<0. The SAWs themselves are reciprocal, because both senses of rotation of the atoms at the surface in SAWs, i.e., clockwise and anticlockwise, are allowed. However, their couplings with the magnetization depend on the handedness formed by the wave vector of SAW, the surface normal of the sample, and the magnetization. This frame is switched from the left-handed to the right-handed and vice versa with chaging sign of *k*. This means that the non-reciprocity is already implemented in the coupling. Although its magnitude is rather small, we have found that the non-reciprocity is enhanced by the magnon-polaron resonance.

Our results will contribute to the development of an acoustic rectifier for information processors using SAWs and effective use of waste heat by controlling SAWs in insulators.

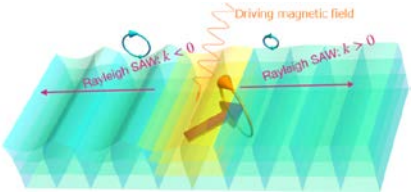

Fig.2 Schematic of the magnetic film [4]. The ring surrounding the thick arrow at the centre indicates the precessing magnetisation and the other rings at the back represent the rotation of surface atoms. In this figure, energy is dominantly channelled into SAWs propagating in the negative direction.

References

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[3] J. Ieda *et al.*, Phys. Rev. B **103**, L100402 (2021).
[4] K. Yamamoto *et al.*, J. Phys. Soc. Jpn. **89**, 113702 (2020).