Research Group for Spin-energy Science
Group Leader: SAITOH Eiji
Members: IEDA Jun'ichi, MORI Michiyasu, ONISHI Hiroaki, CHUDO Hiroyuki, NAKATA Koki, YAMAMOTO Kei, ARAKI Yasufumi, IMAI Masaki, SATO Nana, UMEDA Maki

We investigate solid-state physics stemming from "spin", a quantum of angular momentum, i.e., spintronics, magnonics, gyromagnetics, strongly correlated systems, and topological physics. Exploiting the rectification nature of spin, we theoretically and experimentally pursue the potential of spin toward quantum science innovation that will be the basis of next-generation energy-saving and energy-creating technologies.

New development in power control research with the quantum relativistic effect of electron spins

Inductors are basic electric-circuit components for transformers, noise filtering, switching, etc. The mechanism relies on classical electromagnetism: a conducting coil stores the magnetic field energy when an ac electric current flows through it, leading to the induction of an electromotive force that opposes the current change. An inductance, L, of a solenoid coil is proportional to the cross-sectional area, A, of the solenoid [Fig. 1(a)]. This size dependence limits miniaturizing inductors, and thus, to overcome the fundamental difficulty, a new principle beyond the classical electromagnetic induction is requisite.

Recently, the spin-extension of inductor operation in magnetic nanostructures, the so-called "emergent inductor," was invented by using a spiral magnet [Fig. 1(b)]. When an electric current flows in a spiral magnet, it stores the energy in the spiral magnetization texture via its exchange coupling with conduction electron spins. Contrary to the coil inductance, the emergent inductance, L, is inversely proportional to the area, A, that the current passes through ($L \propto A^{-1}$). The concept of the emergent inductor is not limited to spiral magnetization dynamics. In fact, we have unveiled that a novel inductance of a spin-orbit coupling (SOC) origin is possible [1], where a SOC mediates the energy conversion with the prominent size dependence [Fig. 1(c)]. The spin-orbit inductance with spatially uniform magnetization is of particular interest; it provides nearly frequency-independent inductance, except in the vicinity of the ferromagnetic resonance frequency (typically a few GHz). This finding clarifies that the inductor function can be realized by standard magnetic materials without "twists" like conventional coils and magnetic spiral structures.

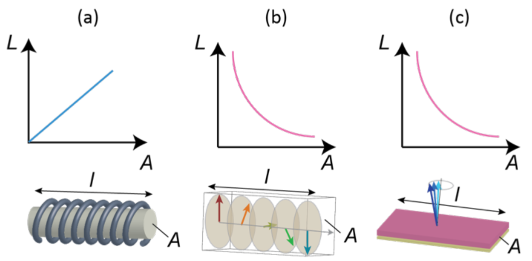

Fig. 1 Schematics of the inductance, L, vs cross-sectional area, A, (upper panels) for the (a) conventional coil inductor, (b) emergent inductor based on a spiral magnet, and (c) spin-orbit emergent inductor based on a collinear magnet showing SOC (lower panels) where I represents the applied ac current. Arrows in the lower panels of (b) and (c) illustrate magnetization direction.

Modification of magnetic properties in a magnetic insulator

Insulating materials have garnered attention toward future information and communication technologies because of the low dissipation of energy, diversity of material choices, and a variety of couplings among elementary excitations in solids. By using the angular momentum transport of spin waves (magnons) in magnetic insulators, spin information can be transferred to solids despite the electrons being immobile. For this purpose, ferrimagnetic rare-earth garnets are particularly suitable because they have extremely stable crystals and long-lived well-characterized magnetic excitations. To further enrich the potential of this material series, we have demonstrated a magnetic property modification in a magnetic insulator caused by the accumulation of nanocolumnar defects based on numerical simulations and heavy-ion beam irradiation [2].

With an increase in the ion irradiation dose, Φ, modifications in the saturation magnetization, M_s, and magnetic coercivity, H_c, were observed [Fig. 2(a)]; the decrease in saturation magnetization caused by ion-beam damage was monotonic with increasing beam fluence [Fig. 2(b)], whereas the enhancement of magnetic coercivity exhibited a fluence threshold [Fig. 2(c)]. These behaviors qualitatively agree with the numerical simulations and models based on the continuum percolation theory. The present method can be used for magnetic property modification, opening a new pathway to a microstructuring technique for magnetic insulators.

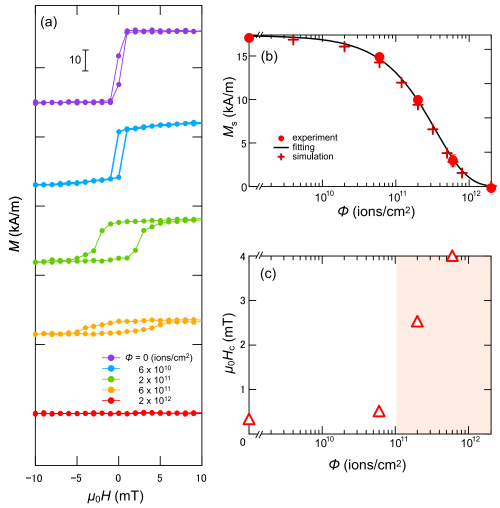

Fig. 2 Results of the ion-beam irradiation experiments. (a) Magnetization hysteresis of the irradiated samples with ion dose of Φ = 0-2×10^{12} ions/cm^2 (data offset for clarity). Beam fluence dependence of (b) the saturation magnetization, M_s, and of (c) the magnetic coercivity, H_c, where the shaded area indicates over the percolation threshold.

References

[1] Y. Yamane, S. Fukami and J. Ieda, *Phys. Rev. Lett.* **128**, 147201 (2022).

[2] K. Harii, M. Umeda, H. Arisawa, T. Hioki, N. Sato, S. Okayasu, and J. Ieda, *J. Phys. Soc. Jpn.* **92**, 073701 (2023).