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– Nanospintronics –

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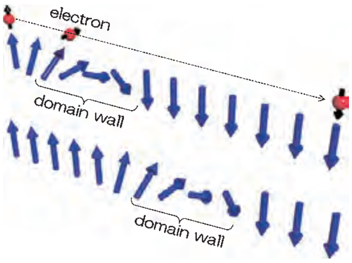
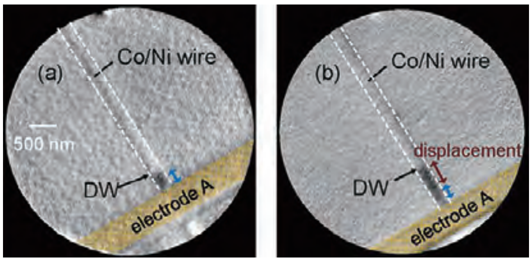
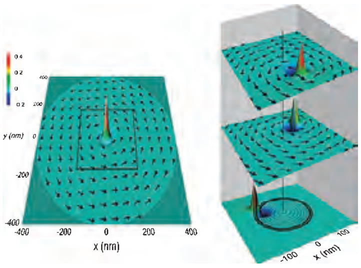
Scope of Research

Conventional electronics uses only the charge of electrons, while traditional magnetic devices use only the spin degree of freedom of electrons. Aiming at complete control of both charge and spin in single solid-state devices, an emerging field called spintronics is rapidly developing and having an impact on information technologies. By combining the atomic-layer deposition with nanofabrication, we focus on the development of spin properties of various materials and the control of quantum effects in mesoscopic systems for novel spintronics devices.

KEYWORDS
Spintronics
Magnetism
Magnetic Materials







Selected Publications

Okuno, T.; Kim, D.-H.; Oh, S.-H.; Kim, S. K.; Hirata, Y.; Nishimura, T.; Ham, W. S.; Futakawa, Y.; Yoshikawa, H.; Tsukamoto, A.; Tserkovnyak, Y.; Shiota, Y.; Moriyama, T.; Kim, K.-J.; Lee, K.-J.; Ono, T., Spin-transfer Torques for Domain Wall Motion in Antiferromagnetically Coupled Ferrimagnets, *Nat. Electron.*, **2,** 389-393 (2019).

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Moriyama, T.; Hayashi, K.; Yamada, K.; Shima, M.; Ohya, Y.; Ono, T., Intrinsic and Extrinsic Antiferromagnetic Damping in NiO, *Phys. Rev. Materials*, **3,** 051402 (2019).

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Iino, T.; Moriyama, T.; Iwaki, H.; Aono, H.; Shiratsuchi, Y.; Ono, T., Resistive Detection of the Neel Temperature of Cr_2O_3 Thin Films, *Appl. Phys. Lett.*, **114,** 022402 (2019).

Spin-transfer-torque-driven Magnetic Domain Wall Motion in Antiferromagnetically Coupled Ferrimagnets

Magnetic domain wall (DW) racetrack memory is a next-generation, non-volatile and high-density magnetic memory, where the magnetic domain walls work as information bits and they are controlled by electric current via the effect of spin transfer torque (STT). Antiferromagnets are considered one of the material candidates for the racetrack memory. However, experimental explorations of STT in antiferromagnets remain elusive because of experimental difficulty accessing some of the magnetic properties. In this work, we instead examined the effects of STT in a ferrimagnetic material (a GdFeCo alloy), a more experimentally accessible material, which mimics an antiferromagnetic property at a certain temperature, the so-called angular momentum compensation temperature T_A. We measured the DW velocity under the application of electric current at various temperatures (see Figure 1 (a) for the experimental setup). We found that, as shown in Figure 1 (b), the DW velocity changes its sign in the vicinity of T_A. By fitting the experimental data with the theoretical model, we quantitatively determined the two components of STT, *i.e.* the adiabatic and non-adiabatic torques. Our result show that the non-adiabatic STT in antiferromagnets is indeed quite large, suggesting that an energy-efficient DW racetrack memory may be possible with antiferromagnets.

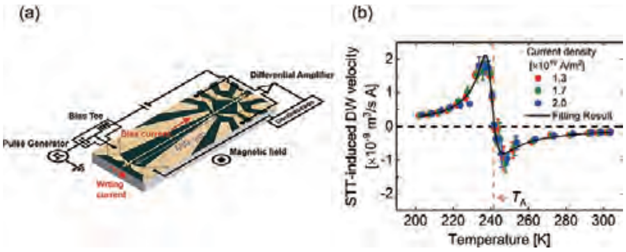

Figure 1. (a) Schematic illustration of the experimental setup. (b) The STT-induced DW velocity as a function of temperature. The dotted orange line represents the angular momentum compensation temperature T_A.

Antiferromagnetic Memory That Cannot Be Written by a Magnetic Field but by a Flow of Electron Spins

Conventional magnetic data storages, such as Hard disk drives (HDDs) and Magnetic random access memory (MRAM), traditionally use ferromagnets to record the information by flipping the macroscopic magnetic moments. However, as shown in Figure 2(a), a dipole field (or stray field) from the ferromagnets ultimately invokes the bit interference and prevents the information bit from packing closely. Antiferromagnets are another class of magnetic materials which have microscopic magnetic moments but they are coupled in opposite directions. Therefore, antiferromagnets have no net magnetic moment and do not produce any stray field or respond to an external magnetic field. By making use of these properties of antiferromagnets, one could make an extremely dense magnetic memory, which can be an important breakthrough for information storages. In this work, we showed the demonstration of a sequential antiferromagnetic memory operation with a spin-orbit-torque write, by the spin Hall effect, and a resistive read in the CoGd synthetic antiferromagnetic bits, in which we reveal the distinct differences in the spin-orbit-torque- and field-induced switching mechanisms of the antiferromagnetic moment. As shown in Figures (b)(c), the memory states (the Hall resistances) are altered by spin-orbit-torque but are not influenced by the external field. We, therefore, succeeded in demonstrating the antiferromagnetic memory that cannot be written by a magnetic field but by a flow of electron spins.

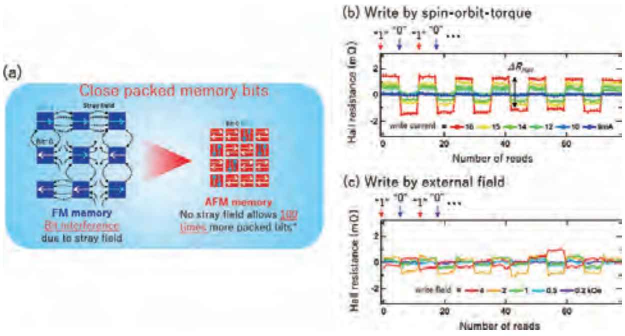

Figure 2. (a) Comparison between ferromagnetic bits and antiferromagnetic bits in terms of memory bit density. (b) After each write ("0", "1") by a spin-orbit-torque, the memory states were read by the Hall resistance. (c) After each write ("0", "1") by an external field, the memory states were read by the Hall resistance.