

# Division of Materials Chemistry

## – Nanospintronics –

<http://www.scl.kyoto-u.ac.jp/~onoweb/>



Prof  
ONO, Teruo  
(D Sc)



Assoc Prof  
MORIYAMA, Takahiro  
(Ph D)



Assist Prof  
SHIOTA, Yoichi  
(D Eng)



PD  
KIM, Duck-Ho  
(Ph D)



PD  
FUJIMOTO, Junji  
(D Sc)

### Students

HAM, Wooseung (D3)  
MIZUNO, Hayato (D3)  
ANDO, Fuyuki (D2)  
OKUNO, Takaya (D2)  
ODA, Kento (D2)

NISHIMURA, Tomoe (D2)  
ISHIBASHI, Mio (D1)  
HIRATA, Yushou (D1)  
LI, Tian (D1)  
IINO, Tatsuya (M2)

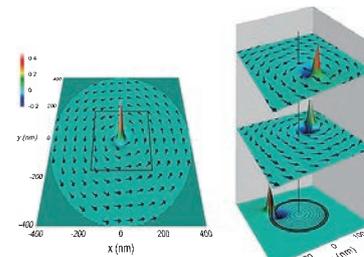
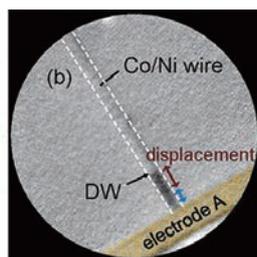
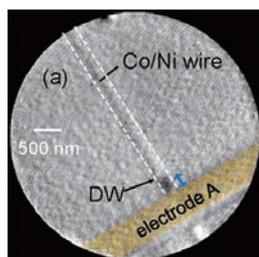
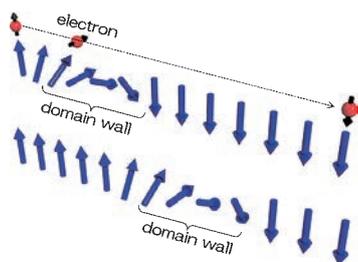
IKEBUCHI, Tetsuya (M2)  
KASUKAWA, Shuhei (M2)  
IWAKI, Hiroyuki (M1)  
FUNADA, Shinsaku (M1)

### 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

Moriyama, T.; Zhou, W.; Seki, T.; Takanashi, K.; Ono, T., Spin-Orbit-Torque Memory Operation of Synthetic Antiferromagnets, *Phys. Rev. Lett.*, **121**, 167202 (2018).

Moriyama, T.; Oda, K.; Ohkochi, T.; Kimata, M.; Ono, T., Spin Torque Control of Antiferromagnetic Moments in NiO, *Sci. Rep.*, **8**, 14167 (2018).

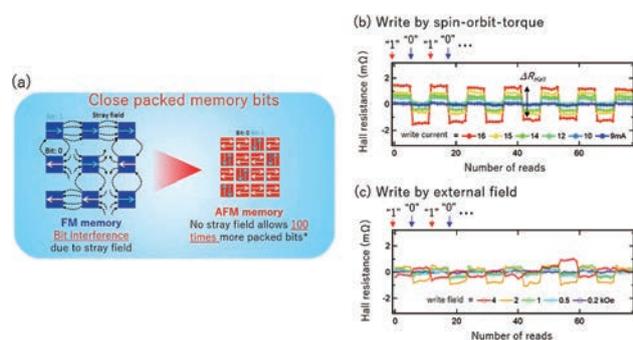
Kim, S.; Ueda, K.; Go, G.; Jang, P.; Lee, K.; Belabbes, A.; Manchon, A.; Suzuki, M.; Kotani, Y.; Nakamura, T.; Nakamura, K.; Koyama, T.; Chiba, D.; Yamada, T. K.; Kim, D.; Moriyama, T.; Kim, K.; Ono, T., Correlation of the Dzyaloshinskii-Moriya Interaction with Heisenberg Exchange and Orbital Asphericity, *Nat. Commun.*, **9**, 1648 (2018).

Yamada, T. K.; Suzuki, M.; Pradipto, A.; Koyama, T.; Kim, S.; Kim, K.; Ono, S.; Taniguchi, T.; Mizuno, H.; Ando, F.; Oda, K.; Kakizakai, H.; Moriyama, T.; Nakamura, K.; Chiba, D.; Ono, T., Microscopic Investigation into the Electric Field Effect on Proximity-Induced Magnetism in Pt, *Phys. Rev. Lett.*, **120**, 157203 (2018).

Baltz, V.; Manchon, A.; Tsui, M.; Moriyama, T.; Ono, T., Antiferromagnetic Spintronics, *Rev. of Mod. Phys.*, **90**, 015005 (2018).

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

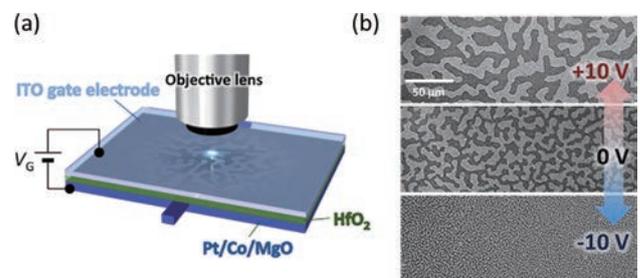
Conventional magnetic data storages, such as Hard disk drives (HDDs) and Magnetic random access memory (MRAM), traditionally use ferromagnets to record the information by flipping the macroscopic magnetic moments. However, as shown in Figure 1(a), a dipole field (or stray field) from the ferromagnets 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 1.** (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.

## Modulation of the Magnetic Domain Size Induced by an Electric Field

The electric field (EF) control of magnetism has intensively investigated because of its potential importance for the reduction of power consumption in magnetic storage devices. In the past few years, we have been focusing on the electric field modulation of the magnetic anisotropy and the Curie temperature in magnetic thin films. However, the microscopic mechanism of why those magnetic properties change with an electric field was not clear in spite of several theoretical suggestions. In this work, we particularly focused on the configuration of the magnetic domains upon the application of the electric field (see Figure 2(a) for the detail measurement setup). With the electric field of  $\pm 10$  V, we observed the significant change in the domain size (Figure 2(b)). Detail analyses on the modification of the magnetic domain size revealed that it is the exchange interaction that is modulated with the electric field and is changing about 50% with  $\pm 10$  V. Our results suggest that the EF control of the magnetism is mainly driven by the modification of the exchange interaction which is a fundamental measure determining the magnetic interaction between microscopic spins.



**Figure 2.** (a) Schematic illustration of the experimental setup (b) Modulation of the magnetic domain size with the electric field of  $\pm 10$  V.