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Introducing Researchers

Featured in this issue is Associate Professor Yukio Nozaki, whose research focuses on the development of new electronic devices based on magnetic substances.

Dedicated to electronic device innovation through the pursuit of spin electronics

Contributing to the development of nanoelectronic device technology

Electronic spin is the smallest form of magnet. Electronic spin has two directions; the difference in these two directions produces N and S poles of a magnet. Moreover, the two kinds of electronic spin are under the strong influence of magnetic fields and electric currents, which sometimes cause the directions to be switched. Spin electronics takes note of relationships between magnetic fields, electric currents and electronic spin. A relatively new research field, yet spin electronics is a focus of attention among researchers worldwide. We visited Associate Professor Nozaki who addresses spin electronics research for its practical applications.

Electronic spin as the source of magnetism

"Magnets refer to substances that have N and S poles, and the source of their magnetism is a phenomenon known as electronic spin. This spin phenomenon enables electrons themselves to function as a small permanent magnet" says Associate Professor Yukio Nozaki as he explains the basic principle of a magnet.

Then what is electronic spin? While admitting that there are still many unknowns due to its extremely microscopic nature, Dr. Nozaki continues, "Electronic spin is a strange rotational motion that won't return to its original position until it completes two rotations. Since it has the magnetic moment, it performs precession motion within a magnetic field (Fig. 1). You may compare its image to a spinning top wobbling with its rotation axis aslant. However, unlike a top whose rotation will stop with the lapse of time due to friction, electronic spin continues to rotate indefinitely. This is because electrons have properties of a wave. The magnetic field produced by that electronic spin serves as the source of magnetism of a magnetic substance."

Spin electronics is a research area aiming to control the direction of electronic spin as one likes, thus attracting the attention as a technology that can remarkably enhance the performance of electronic devices (Fig. 2).

Electronic spin with these properties, when magnetic field, electric field, heat, and/or microwave are given as stimuli, shows greater precession and eventually reverses the spin direction – in other words, the N pole and S pole of the substance interchange with each other. Also known as magnetization reversal, this phenomenon is applied, for example, to the hard disk drive (HDD: a magnetic data recording device based on binary assignment of 1 or 0 to the direction of magnetization). HDDs currently in use employ magnetization reversal via magnetic field for rewriting digital data. Some specialists, however, point out that the use of this method is reaching its limits in terms of power saving and recording density enhancement for HDDs. In response to this challenge, Dr. Nozaki noticed magnetization reversal via electric current and is moving forward with research on a technology that can control electronic spin reversal with less energy consumption and at high speeds.

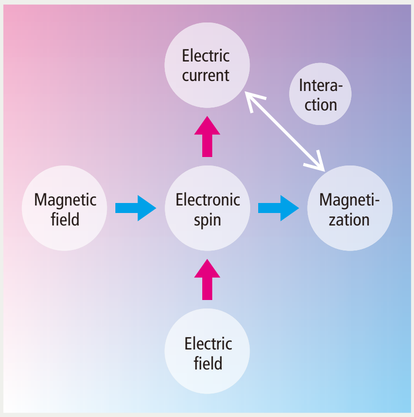

Fig. 2 Concept of spin electronics
Within a given substance, electric current induced by the electric field interacts with magnetization induced by the magnetic field. Using this interaction, it is possible to control magnetization by electric current and vice versa.

Elucidation of 4 types of torque is the key to effective control of electronic spin

Key to effective control of electronic spin is the force (torque) that works on electronic spin. This torque comes in four types: (1) damping torque; (2) precession torque; (3) spin transfer torque; and (4) non-adiabatic torque (Fig. 3). When magnetic field and/or electric current are given as stimuli to electronic spin, these four torques work to reverse electronic spin. This is already theoretically confirmed. Especially when it comes to the relationship between torque's action and magnetization reversal when magnetic field is given as a stimulus,

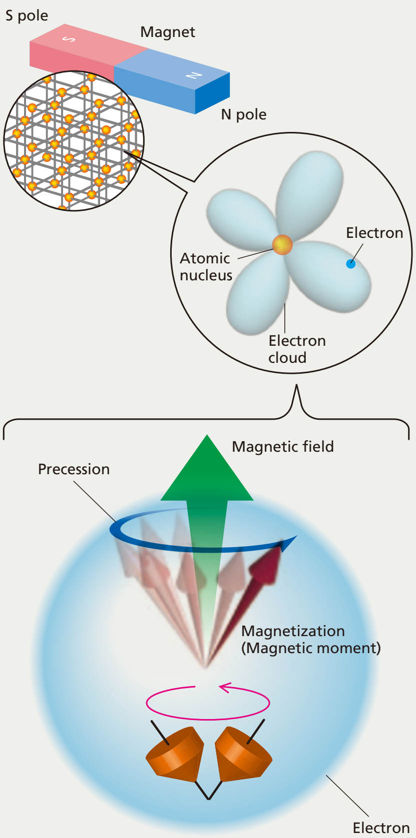

Fig. 1 Electronic spin is a magnet in the microscopic world
As electrons around the atomic nucleus spin, magnetization (magnetic moment) occurs and functions as a permanent magnet. There are two kinds of electronic spin in terms of direction – up spin and down spin – and this direction determines N or S pole.

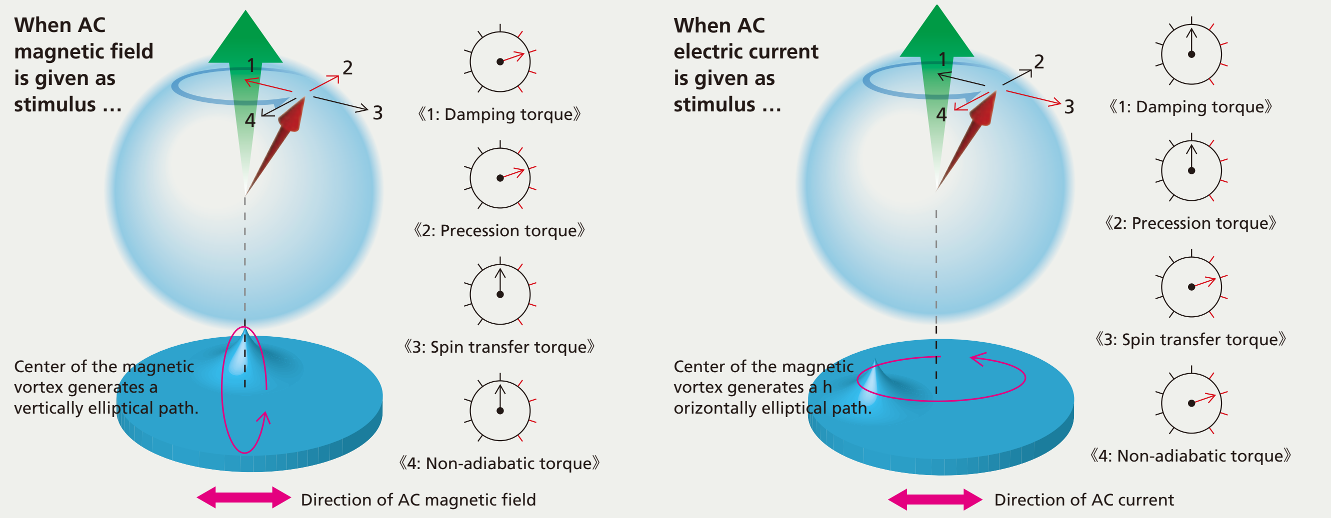

Fig. 3 4 torques that act on electronic spin

Four torques act on electronic spin. These are regarded as factors that determine the direction and motion of the magnetic moment. Since all of these torques directly interact with the magnetic moment, they can alter the direction of the magnetic moment without changing the moment' s magnitude. If frequencies of the magnetic field and electric current given as stimuli are changed, the torques change their respective actions, which will appear as changes in the turning path of the magnetic vortex. This means that by analysis of changes in the stimuli given and changes in the magnetic vortex it is possible to quantify changes in each torque relative to stimuli given.

there are prior research works as seen in the example of HDDs mentioned above. "By contrast, research into magnetization reversal via electric current has just begun, with few research endeavors being made. Unlike magnetic field-based magnetization reversal, magnetization reversal via electric current is highly efficient as it can directly access individual ferromagnetic devices, thus realizing high-speed motion of tens of GHz with limited power consumption," remarks Dr. Nozaki explaining advantages of electric current-based control.

What Dr. Nozaki pursues is research into how to quantify each torque that results when electric current has been used as a stimulus. And his aim is not only to reverse the spin but also to reverse it most efficiently – at even higher speeds and with less stimuli.

So he attempted to shed light on how effectively each of the four torques, when electric current is given as a stimulus, would work on magnetization reversal. However, the subjects are too small to observe changes in individual electronic spins and to analyze actions by each of the four torques. This led Dr. Nozaki to notice a magnetic structure comprised of multiple electronic spins and make the most of its characteristics.

"Between adjoining electronic spins there is interaction to maintain their directions parallel to each other. If you reduce the size of magnetic devices to the nanometric scale, therefore, it becomes possible to analyze the behavior of an individual electronic spin by judging from the collective behavior of the electronic spins as a whole. For example, by reducing the size of a given material to something like 100 nanometers, it is possible to realize electronic spin in which all the individual electronic spins move in unison with each other. Furthermore, by arranging individual electronic spins in the shape of a disk, the electronic spins seek to harmonize with each other and form a magnetic vortex as a result," remarks Dr. Nozaki. These magnetic structures are extremely high in stability and show simple and linear reactions to stimuli given, making it easy to analyze the four torques. However, when the size of the collective electronic spin exceeds 10 micrometers, the spin tends to take a stable structure at several different locations, making the overall structure complex.

Potential applications ranging from magnetic memory to logic devices

"Research into macrospin and magnetic vortex is making rapid progress, shedding light on the behavior of electronic spin," Dr. Nozaki says with a smile.

"For example, if you use AC current as a stimulus to a magnetic vortex, the center of the magnetic vortex resonates with the stimulus and begins to rotate in a concentric manner. It has been well known that at this time, the linewidth of resonance spectrum has much to do with (1) damping torque, and the resonance frequency with (2) precession torque, respectively. However, a discovery was made of late that a significant change in the frequency of electric current given as a stimulus transforms the vortex's path from a concentric shape to an elliptic one. After further detailed calculations, it has also been found that from the shape of the elliptic path it is possible to obtain (3) spin transfer torque and (4) non-adiabatic torque (Fig. 3). I'm now moving forward with verification tests for this theory," he continued.

Elucidation of relationships between the four torques and stimuli will pave the way not only for quantitative determination of magnetization reversal via electric current, but also for development of new applications, such as high-speed magnetic memories and rewritable spin logic devices (Fig. 4).

"As electronic spin control increases in speed, it will come to be used as a micro switch that switches electric current ON and OFF. It will also make a post-semiconductor device technology a reality, which will enable an all-purpose electronic circuit capable of rewriting data into diverse functions, for example."

Indeed, electronic spin is a focus of attention today as a technology that will lead to the development of epoch-making devices.

(Reporter & text writer: Kaoru Watanabe)

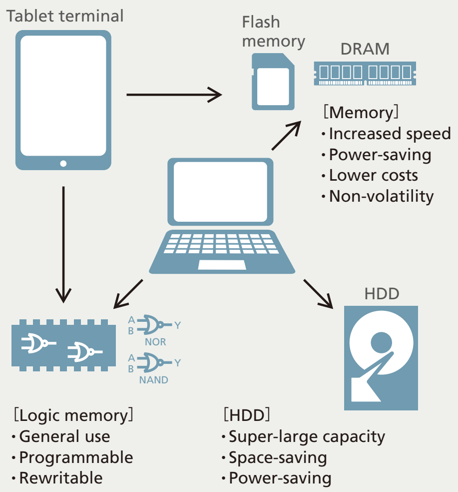

Fig. 4 Application electronic spin to devices

Expectations are high for electric spin for applications to magnetic memories that enable zero consumption of standby electricity, and electronic devices capable of rewriting into various functions.