Next-generation device based on magnetism

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A shortage of energy and resources will threaten the future of humankind. In our society, energy and resources are essential to make and use consumer products, such as a car and a computer. In other words, the shortage of energy and resources would give rise to the loss of opportunities to use consumer products. How will the loss of the opportunities affect our lives? If cars are not available, this will result in a shortage of goods that are transported, such as food and books. Furthermore, if the computer is not available, it will not be difficult to use the information. To avoid such inconveniences, we need to solve the problems arising from the shortage of energy and resources. In particular, the inconvenient society without access to information should be avoided, since information is as essential to our lives as money and food.

How can we avoid a society without access to information due to the shortage of energy and resources? The simplest but difficult way is solving the shortage of energy and resources or finding alternatives to them. Another way is to develop more efficient and smaller devices, which allow us to use more information with the same energy and resource costs compared to current devices. As a key ingredient to developing devices, magnetism in a solid has been attracted.

Devices work by manipulating electrons in a solid by external stimuli, such as the electronic current, the electric field, and the magnetic field. So, the performance of the device depends on electronic states in a solid, such as conductivity and magnetism. For example, in order to use devices at low power, metals should be used instead of insulators. Devices using conductivity, such as semiconductors, are called electronics devices. In addition to the conductivity, magnetism can be also used in devices, and such devices are called spintronics devices. In order to utilize both conductivity and magnetism, the spintronics devices are expected to have higher performance compared to the electronics devices.

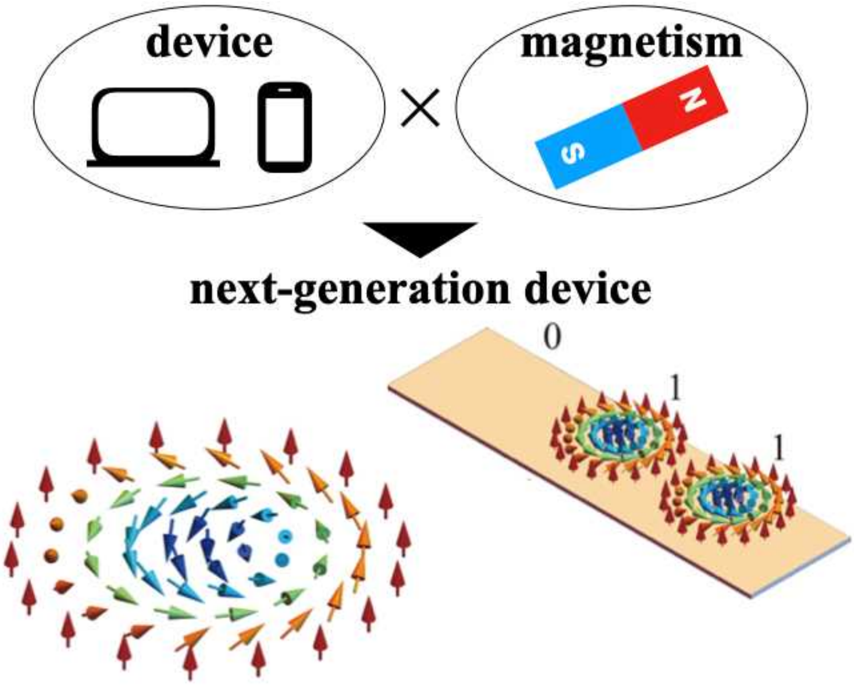
A famous example of spintronics devices is the application of the giant magnetoresistance effect to a hard disk drive. The giant magnetoresistance, the discovery of which was awarded for the Nobel Prize 2007 in physics, is a giant dependence of the electrical resistance on magnetism. With the advent of magnetic heads based on the giant magnetoresistance effect, the capacity of hard disk drives has increased dramatically. Stimulated by such success of spintronics devices, useful magnetism and phenomena related to magnetism are still being explored.

The Discovery of a magnetic skyrmion opens a way to develop next-generation spintronics devices. A concept of the skyrmion was proposed in terms of nuclear physics. After that, the concept was introduced into the field of solid physics and it was theoretically predicted that the skyrmion is stabilized in a solid as a magnetic state, dubbed the magnetic skyrmion. The magnetic skyrmion was first observed in MnSi by Mühlbauer and coworkers [1], which triggers the recent intensive study of the magnetic skyrmion.

The magnetic skyrmion has a vortex-like structure in Figure, where arrows represent the spin of the electron. It is noted that the spin is the origin of magnetism. Although the magnetic skyrmion consists of many spins (electrons) [see Figure], it behaves as a single nanometric particle in a solid. As a result, the magnetic skyrmion can be used as an information carrier in magnetic media. The simplest magnetic media using the magnetic skyrmions is based on the creation and annihilation of the magnetic skyrmion; that is, the presence or absence of the magnetic skyrmion represents the binary information 1 or 0, respectively (Figure).

Although such a magnetic media can be designed by using other magnetic states, one based on the magnetic skyrmion has three advantages. For example, magnetic media based on the magnetic skyrmion and one based on a magnetic domain wall are compared. First, owing to the particle nature, the magnetic skyrmion is more stable against external stimuli and thermal effects than the magnetic domain wall. The information is usually encoded by external stimuli such as current accompanied by Joule heat, so a stable magnetic structure is necessary to avoid unintended changing of information. Second, the threshold current to drive the magnetic skyrmion is 4–5 orders smaller than that to drive the magnetic domain wall, which results in a low energy cost device. Third, the size of the magnetic skyrmion is much small (5~100 nm), which enables us to make compact magnetic media. Thus, the magnetic media based on the magnetic skyrmion performs better than electronics and conventional spintronic devices.

The population continues to grow, and the technology in developing countries is advancing. This means that the demand for devices will increase. But energy and resources are limited, which implies the possibility that life in the future may be inconvenient, with no access to information. The development of highly efficient and compact devices is essential for people all over the world to live equally in a convenient society using information with limited energy and resources. I believe that the magnetic skyrmion is the key to realize such an ideal society.



[1] S. Mühlbauer, B. Binz, F. Jonietz *et al*., Science **323**, 915 (2009).