Title: Next-Generation Memory Devices: The Application of New Magnets

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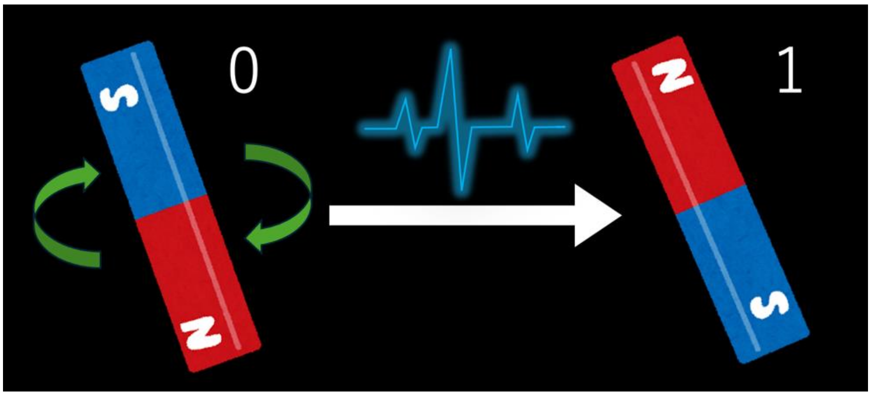

Recent information technology serves as a secure foundation of society. Without these technologies, you couldn’t use your smartphone. An automatic door wouldn’t work since it usually has many sensors. Information technology also has a great role in industry. For example, in agriculture, computers detect the growth of crops and automatically decide the necessary amount of water or temperature. We enjoy a lot of benefits from information technology.

One of the most important gadgets that enables this information society is a memory device. In computer, all information is written in 0 and 1. A typical example is color. 0 means black and 1 means white. If you use more digits, you can represent different colors such as red, blue, green, and so on. If there aren’t memory devices, computers couldn’t store such 0 and 1 information and consequently couldn’t work.

Recent memory devices connect this 0 and 1 information with a very familiar material: magnets. As you know, magnets consist of the N pole and the S pole. Namely, N up corresponds to 1, and N down to 0. This type of memory device is called magneto-memory. Good examples will be a Hard Disk Drive (HDD) or a magnetic card.

The mechanism of a typical magneto-memory device is as follows. We first induce an electrical pulse current to the device. Then, the direction of the magnet is reversed. The information changes from 0 to 1. This reverse process is also called “switching”.

Finally, we use the other electrical current and read out the direction of the magnet.

At present, magneto-memory devices are widely used and have become an indispensable tool. In the near future, AI and IoT will be rapidly introduced, and memory devices will have to process more and more information to deal with such advanced information technology. However, present magneto-memory devices cannot deal with such much information. Besides, the energy consumption at data centers will reach 10% of the total energy of the globe in a few years. A revolution in memory devices is an urgent task.

When I was a junior high school student, a researcher of NTT (one of the most famous Japanese information and communication technology companies) came to my school. He told us that recently new material was found and this material could drastically improve memory devices. I couldn't understand his talk in detail. What is the "new material"? How can they improve memory devices? I thought. But to me, it was really fascinating.

When I grew up to become a university student, I finally got the answer to those questions. One professor in my department made a great contribution to finding the "new material". It is now called an antiferromagnet.

Each material consists of many atoms and you can think that there is one magnet in every atom. Materials are categorized into two types due to the arrangement of the magnets: Ferromagnets (FMs) and Antiferromagnets (AFMs). What you usually consider a magnet (a bar magnet or a compass) is similar to the former one. In a conventional FM, all the magnets face in the same direction. In contrast, in an AFM, 0 magnet and 1 magnet lines alternately, and total magnetization is equal to zero.

I was very interested in the research of the professor, so I made an appointment with him to discuss the research of his laboratory. He enthusiastically taught me how great AFMs are.

"There are several good points to substituting FMs for AFMs. First, since the total magnetism is zero, we can achieve high density. As you know, when you bring two magnets closer, they repel each other. This means that we cannot make high-density FM devices. Second, when current pulses are induced, AFMs respond 1000 times faster than FMs. This leads to faster switching and larger capacity of memory devices. “

He continued.

“In 2015, I found that a special AFM can show anomalously large signal[1]. Besides, this material showed the signal at room temperature and was demonstrated to be robust against thermal fluctuation. This discovery influenced many scientists all over the world. As of 2015, researchers around the world all together are trying to identify the switching mechanism or improve the device for commercial application. Up to now, it is predicted that using this promising material, we can write and read out information 100 times faster than now. “

His talk was very striking and here, I remembered what the NTT researcher had said before. I decided to join his laboratory and make a study about AFMs.

In the next 10-20 years, thanks to the improvement of magneto-memory devices, we will enjoy more benefits from information society. Communication with smartphones will be faster. Self-driving cars will be a common means of transportation. AI in your smartphone will be able to choose the best clothes for you. In addition, the energy consumption will get less. We can achieve an eco-friendly and sustainable society.

However, there are a lot of problems to be solved. The switching mechanism of AFMs remains unclear. Different scientists have different ideas. In addition, the necessary current density is the order of MA/cm^2, which is extremely higher than that of our daily life (cf. normal light: several tens of A/cm^2).

I expect some of the readers to grow up to give an impressive solution to these problems in the future. You shouldn’t forget that the phenomena underlying this advanced society are the combination of magnetism, current, and mathematics: what you learn at school! You might think that the science you are learning, and the one used in the frontier are very different. But that’s not the case. Your learning must lead to the advancement of the cutting edge of science and consequently, it must be the power to change the world.

Acknowledgments

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References

[1] Nakatsuji, S., Kiyohara, N. & Higo, T. Large anomalous Hall effect in a non-collinear antiferromagnet at room temperature. *Nature* **527**, 212–215 (2015).