Creating Nanoionic Devices with Diverse New Functions

— Development of Low Power Consumption Spintronic Devices Enabling High Integration —

Kazuya Terabe
MANA Principal Investigator
Nano-System Field

Importance of next-generation nanodevices

Many electronic devices, the majority of which are semiconductor-based, are used in familiar information and communications equipment. Although semiconductor devices continue to achieve astonishing progress, supported by technical developments in miniaturization and integration, there are fears that this progress may slow in the near future. To ensure sustained progress toward an advanced, next-generation information society, we must actively create devices which operate on principles different from those of conventional semiconductor devices, and thereby realize new functions and higher performance. At MANA, we are focused on the development of nanoionic devices for these new devices.

Nanoarchitectonics utilizing ion transport

One distinctive feature of nanoionic devices, which differentiates them from conventional semiconductor devices, is that they control/utilize the transport of ions, which form crystal lattices, on the atomic to nano scales. Ion transport in crystals reconstructs their crystalline structure, interfacial structure, and other parameters, enabling nano architecture, that is, "nanoarchitectonics," in materials. Use of this nanoarchitectonics gives nanoionic devices plasticity and enables functional and structural changes where necessary.

Development of new spintronic devices

By utilizing nanoarchitectonics, we have created nanoionic devices with diverse new functions. For example, we have succeeded in developing new spintronic devices that are aimed at application to high density, large capacity memory, etc. (Fig. 1) Conventional spintronic devices, which utilize electron charges and spins to store information, have complex structures that make it difficult for them to realize higher integration. Some problems have been pointed out in these devices, such as that they require large write currents. By inserting lithium ions into and removing them from Fe_3O_4 magnetic material, using a solid electrolyte that allows lithium ion transport between electrodes, our new technology changes the electronic carrier density and electronic structure of Fe_3O_4. This enables the control of magnetic properties such as magnetoresistance and magnetization. (Fig.2)

This novel control technology, which utilizes ion transport, allows magnetism to be controlled at lower currents compared to conventional electron transport spintronic devices, and also makes it possible to realize higher integration owing to its simple structure. Moreover, as the spintronic devices are all-solid-state devices, they do not suffer from problems such as liquid leakage. Development of low power consumption/high-performance memory is expected to become possible using conventional semiconductor processes. We plan to develop microfabrication techniques for higher integration, etc., and to conduct demonstration experiments aimed at application of the technology to high-density, large capacity storage devices and other electronics devices.

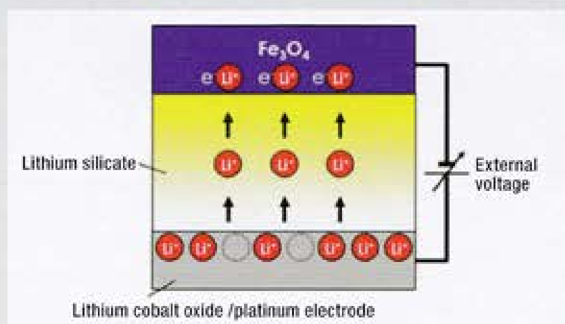

Figure 1: Schematic diagram of novel magnetism control technology utilizing solid-state ion transport. Magnetoresistance and magnetization are controlled by inserting/removing lithium ions into/from a magnetic material (Fe_3O_4) by applying an external voltage.

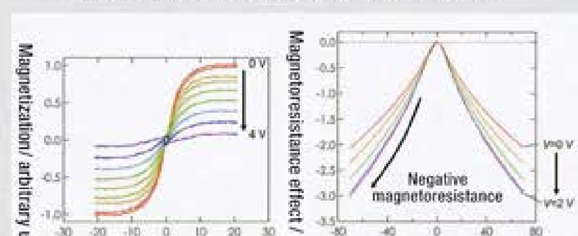

Figure 2: Magnetization-magnetic field loops **(left)** and magnetoresistance-magnetic field curves **(right)** of the device tuned in situ by lithium ion insertion into Fe_3O_4. The amount of lithium ion insertion is controlled by an external voltage (V).

References

1) K. Terabe, M. Aono, "Current progress in solid state ionics: Nanoionic devices with a variety of novel functions. *Oyo Buturi*, Vol. 85, No. 5, p. 364 (2016), *in Japanese*.

2) T. Tsuchiya, K. Terabe, M. Ochi, T. Higuchi, M. Osada, Y. Yamashita, S. Ueda, M. Aono, In Situ Tuning of Magnetization and Magnetoresistance in Fe_3O_4 Thin Film Achieved with All-Solid-State Redox Device, *ACS Nano* 10[1] 1655-1661 (2016).