Young Scientist

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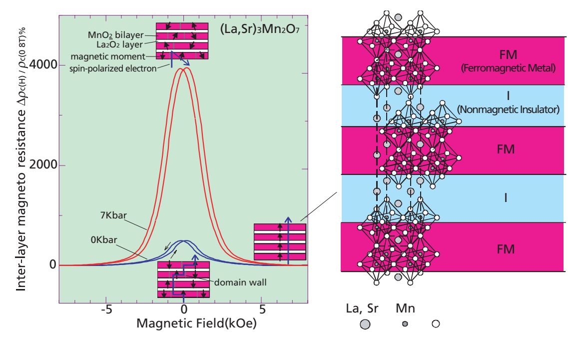

After I finished my Ph.D. course five years ago, I joined a group directed by Prof. Yoshinori Tokura at the Joint Research Center for Atom Technology (JRCAT) in Tsukuba, Japan as a postdoc and started an investigation to explore novel two-dimensional metallic systems with strongly correlated electrons. We believed that such systems to be capable of showing superconductivity similar to high-T_c cuprates. During the research, we unexpectedly discovered the "tunneling" magnetoresistance (TMR) effect in a newly prepared layered perovskite-type manganite crystal.

The TMR is usually investigated in tailor-made trilayer films composed of a ferromagnetic-metal (FM)/insulator/FM junction using transition metals as FM layers. The TMR is also currently of great interest from the viewpoint of its technological applications to the magnetoresistance (MR) head or magnetoresistive random-access memory (MRAM). On the other hand, the perovskite-type manganites show an extremely large MR (so-called CMR) in a bulk (or crystalline) form with application of a relatively large (Tesla-order) magnetic field. The CMR was one of the physical science subjects that were being extensively investigated in those days. Hence, we tried to take the best of both worlds: we demonstrated that a similar but more striking TMR phenomenon can be observed in the interplane transport of the spin-polarized electrons in the layered perovskites of manganite, $(La,Sr)_3Mn_2O_7$.[1] The compound can be viewed as a virtually infinite stacking of ferromagnetic-metal (MnO_2 bilayer) and insulator (La/Sr_2O_2 block layer). A striking TMR phenomenon was found in the ferromagnetic state. In a field of several hundreds of Oe, we have observed a large MR up to several hundreds of percent. Further investigations[2] revealed that the more striking interplane TMR phenomena can be observed by an application of quasi-hydrostatic pressure. The interplane TMR was extremely enhanced up to ~4000% at ~10kbar, perhaps the largest value ever attained for TMR. To tell the truth, we started the high-pressure measurements to lower the magnitude of resistivity and hopefully to achieve superconductivity in the two-dimensional system. The result was contrary to our expectations. The resistivity was drastically increased with the application of pressure. However, the high-resistance state in the absence of magnetic fields consequently gave rise to the colossal interplane TMR effect.

The most important point of the finding is not just the colossal value itself of the low-field TMR, but also the demonstration of the feasibility, or importance, of the use of the highly spin-polarized electron motion across the domain boundary (or the insulating barrier) in the bulk crystal.[3] The manganite showed the nearly 100% spin-polarization due to its strong spin-charge coupling (Hund's-rule coupling) as compared with the case of the transition metal (e.g., ~40% for ferromagnetic Ni). The success in observing the low-field CMR encouraged not only the search for CMR materials in the layer-type compounds, but also the fabrication and characterization of the artificial tunneling junctions, or spin valves, with the use of a material with a high degree of spin polarization.

Nowadays, extensive studies of the correlated-electron systems, such as high-T_c cuprates and magnetoresistive manganites, have shed light on the importance of the "orbital" degree of freedom on the magnetic, electronic, and structural properties.[4, 5] The orbital implies the shape of an electron cloud around an atom with an open shell. In the correlated-electron systems; the anisotropic-shaped *d*-orbital (or *f*-orbital) electrons play a central role in various properties. So far, orbital-ordered states have been found in several compounds. $LaMnO_3$ is among the most typical compounds with orbital-ordered ground states. Recently, we demonstrated the presence of a novel elementary excitation termed "orbital wave" in the orbital-ordered compound $LaMnO_3$.[6] The "orbital wave" can be observed as modulations in the relative shape of orbitals in solids and its quantized object is an "orbiton". (cf. the phonon for a lattice vibration in a crystal; and the magnon for a modulation of the magnetic moment in a magnetically ordered phase). The characters of the excitations play a significant role in determining the response of the system to external stimuli, such as electric and magnetic fields or temperature, that is to say, most of the properties in solids.

When I was an undergraduate student at the University of Tokyo, I started my research experience as a crystal-grower for high-T_c cuprates. At that time, research into the high-T_c cuprates was most active. However, most of the experimental results were obtained by measuring polycrystalline samples in those days, although nowadays most research into the high-T_c cuprates is performed using single-crystal samples. In order to obtain large single crystals, I just kept on working at floating-zone machines day after day. Finally, I obtained a number of large single-crystal high-T_c cuprates. The grown crystals were then distributed overseas for collaborative research: I sometimes hand-delivered them myself. When I was a master's student, my adviser, Prof. Koichi Kitazawa of the University of Tokyo, gave me an opportunity to study with outstanding researchers at AT&T's Bell Laboratories. I was unable to obtain the expected results experimentally at that time, but I was fortunate enough to develop good relationships with some of the researchers there that continue to this day. Moreover, in my doctoral course, I worked mostly in Prof. Hidenori Takagi's laboratory at the Institute for Solid State Physics, in the University of Tokyo. In my present studies, I benefit from those itinerant research experiences.

After my stay at JRCAT, I moved to Prof. Tokura's laboratory at the University of Tokyo,where I struggled to find my "new cheese". The orbital physics of the correlated-electron systems is only a basic science at present. However, if we can obtain materials in which the orbital state can be easily controlled by light-irradiation or electric fields (hopefully at room temperature), a new technology will begin to develop that will be called "orbital electronics". JSAP

References

1) T. Kimura, Y. Tomioka, H. Kuwahara, A. Asamitsu, M. Tamura, and Y. Tokura, *Science 274*, 1698 (1996).
2) T. Kimura, A. Asamitsu, Y. Tomioka, and Y. Tokura, *Phys. Rev. Lett. 79*, 3720 (1997).
3) T. Fukumura, H. Sugawara, T. Hasegawa, K. Tanaka, H. Sakaki, T. Kimura, and Y. Tokura, *Science 284*, 1969 (1999).
4) T. Kimura, Y. Tomioka, A. Asamitsu, and Y. Tokura, *Phys. Rev. Lett. 81*, 5920 (1998).
5) T. Kimura, Y. Tomioka, R. Kumai, Y. Okimoto, and Y. Tokura, *Phys. Rev. Lett. 83*, 3940 (1999).
6) E. Saitoh, S. Okamato, K.T. Takahashi, K. Tobe, K. Yamamoto, T. Kimura, S. Ishihara, S. Maekawa, and Y. Tokura, *Nature 410*, 180 (2001).