

Imperial Prize and Japan Academy Prize to:

Yoshinori TOKURA
 Director, RIKEN Center for Emergent Matter
 Science
 Professor, Graduate School of Engineering,
 The University of Tokyo



for “Study of Strongly Correlated Electron
 Materials with Emergent Electromagnetic
 Functions”

Outline of the work:

Prof. Yoshinori Tokura has innovated and led a new field of science on strongly correlated electronic materials, which can show gigantic and ultrafast responses of electronic properties with minimal energy dissipation.

Strongly correlated electronic state indicates the state where the mutual Coulomb repulsion suppresses the itinerant motion of each electron in solids. In this system, there emerge novel and gigantic responses/properties/functions which can never be expected from the simple assemble of individual elements (electron, spin, and atom etc.). This phenomenon is termed “emergence”. Strongly correlated electronic system is a representative arena of “emergence”, where the dramatic changes of states, i.e., the phase transitions, occur between the competing phases. Near these phase transitions, marvelous and intriguing electronic functions, such as high temperature superconductivity, colossal magneto-resistance, and colossal magneto-electric effect appear as the gigantic responses to external stimuli. These systems showing the emergent phenomena are the subject of intensive researches in materials science, and also begin to be used in applications as new innovative electronic materials. On the other hand, the obtained knowledge on the physics will be the foundation for new functional operations of electrons. Prof. Tokura has accomplished many achievements and been leading the forefront of the researches in the world by exploring the new correlated materials and electronic functions.

First, Prof. Tokura proposed the generic rule (called Tokura rule) for the high-temperature superconductors, and discovered by himself the electron doped high-temperature superconductors following this rule. This discovery, showing the electron-hole symmetry, is still one of the most important milestones in the researches of high-temperature superconductors. This achievement prompted Prof. Tokura to explore a vast range of correlated-electron materials, especially transition-metal oxides, and their new electronic properties/functions. This idea originates from the insight that anomalous metallic states near the Mott transition are the abundant mine of astonishing physical phenomena such as the high-temperature superconductivity and colossal magneto-resistance (the phenomenon where the resistivity changed orders of magnitude by an external magnetic field). As an example, Prof. Tokura has explored the colossal magneto-resistive materials such as manganese oxides, and unveiled their electronic functions. Namely, the correlated electrons ordering in nano-scale are instantly melted by a magnetic field to result in a metallic state (electron liquid). Since this work by Prof. Tokura, the principle of gigantic responses by competing electronic phases has become widely understood, and the developments of new materials/functions based on it have been started targeting other materials also. Prof. Tokura has established that this transition from insulator to metal and/or ferromagnet can be induced by not only a magnetic field but also the photo-excitation, X-ray irradiation, and electric field

within the time-scale of femtosecond in the systems such as manganese-, copper-, and vanadium oxides. Especially, the researches on the electric-field induced meta-insulator transition has lead to the recent development of the high speed, high density, and non-volatile memory devices, and are now regarded as the pioneering work of the ReRAM close to practical use (Resistive Random Access Memory, a memory device utilizing the resistance change due to the electric field).

Furthermore, Prof. Tokura's group accomplished a breakthrough in the research of correlated transition metal oxides, that is, the discovery of the multiferroics – the coexistence of ferroelectric and magnetic orders. According to Maxwell's electromagnetism, the time-dependent electric and magnetic fields are not independent of each other. However, the control of magnetism (electric polarization) by electric (magnetic) field is difficult and only tiny responses have been observed thus far. Prof. Tokura has realized the gigantic response also in this magneto-electric effect in solids by using the ordering of spins and orbitals of electrons. This phenomenon is now shown to be due to the relativistic spin-orbit interaction, and has grown to be a new principle – enhancement of responses using the electronic orderings in solids – for the novel electronics and materials design, which will enable the remarkable functions such as ultra-low energy consumption information technology and electric control of magnetization. In fact, Prof. Tokura, collaborating with a theory group, has revealed clearly that the gigantic Hall effect (anomalous Hall effect) by the magnetization in ferromagnets is due to the dissipation-less spin currents, and also recently discovered “Hall effect of magnetic excitations in insulating magnets” and “nano-scale spin vortex producing the fictitious magnetic field of hundreds of Tesla (skyrmion)”. By these works, Prof. Tokura continues to produce new and innovative concepts with a wide vision ranging from spintronics to materials design and developments.

As described above, Prof. Tokura has founded the new and rich materials science and technology crucial to the energy functions based on the paradigm of strongly correlated electrons, which is far beyond the simple discovery of a new useful functional material.

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