4 Dynamical Cross-correlated Physics Project

– Quantum-beam studies on dynamical cross-correlated physics in strongly-correlated-electron systems –

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Due to strong electron-electron interaction, electrons tend to localize in strongly correlated electron systems. Consequently, spin, orbital occupancy, orbital angular momentum, charge, and lattice serve as degrees of freedom and dominate physical phenomena. When more than one of them order at the same time (multiferroicity), cross-correlation allows the expression of a non-conjugated external field response such as a change in magnetization by applying an electric field and a change in electric polarization by applying a magnetic field, producing advanced features in a monolithic device. The electric field and magnetic field responses of lattice distortion have already been put into practical use as piezoelectric and magnetostrictive devices, respectively. In contrast, it has been considered difficult to use the correlation between magnetism and ferroelectricity in practical devices because of its weakness. However, since 2003 when a large magnetic field response in ferroelectricity in the spin-driven ferroelectric material $TbMnO_3$ was reported by Kimura et al., such magnetoelectric response has been intensively investigated [1], and a number of new materials showing dramatically large electromagnetic response have been discovered and developed [2]. Studies on electromagnetic phenomena were initially limited to static or quasi-static operation, but were extended to the dynamic region thanks to technological advances in spectroscopic measurements in the time-scale region of THz – GHz. Since the very beginning of research, it has been predicted that the coexistence of magnetism and ferroelectricity could induce an unprecedented response to electromagnetic waves or light which can be controlled by applying a magnetic field and an electric field [3]. In practice, dynamical cross-correlation

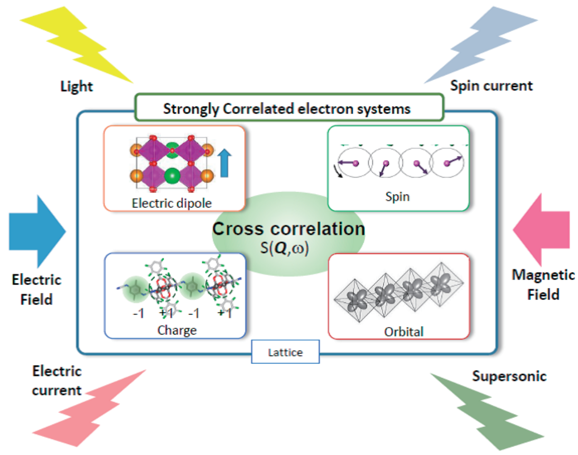

Fig. 1: Schematic view of the cross-crrelation among multiple degrees of freedom of spin, electric polarization, charge, orbital, and lattice in strongly correlated electron systems.

properties such as huge non-reciprocal directional dichroism of light (see Fig. 2) [4] and light-induced phase transition have been discovered in multiferroic materials [5].

For microscopic elucidation of the mechanism of expression of magnetoelectric effects in multiferroic materials, magnetic and lattice structural researches using synchrotron radiation X-ray and neutron diffraction techniques have played a central role. By conducting crystal-structural researches using synchrotron radiation X-rays and magnetic-structural researches using neutrons in a complementary manner, the static and quasi-static processes of magnetoelectric effects have been understood in terms of symmetry. However, the understanding remains qualitative because the electronic state has not yet been sufficiently elucidated; discussions have been based on only simple cluster models, which are too simple for actual systems. Furthermore, there have not yet

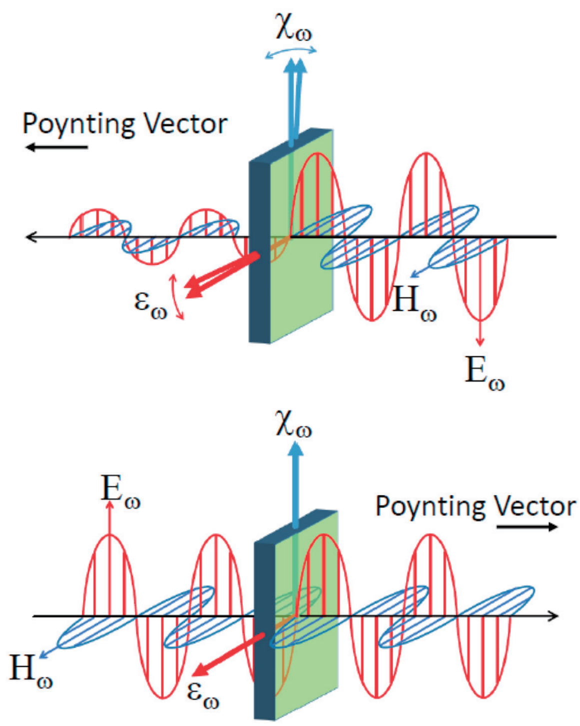

Fig. 2: Schematic view of the absorption difference of counter-propagating light beams (so-called non-reciprocal directional dichroism) in spin-driven ferroelectrics, where the magnetization is orthogonal to the electric polarization.

been enough experiments to elucidate the dynamical magnetoelectric properties. In order to elucidate the microscopic mechanism of the dynamical properties, structural researches of the ordered state and the fluctuation of multiple degrees of freedom should be conducted over wide ranges of space and time.

The objective of this project is to clarify the mechanism of the huge cross-correlation properties in multiferroic materials. By using plural quantum beam scattering techniques in a parallel manner, we intend to investigate the static ordered state and its dynamic behavior. Then, we will try to understand the cross-correlation on a microscopic view by revealing the electronic state. In this project, we are working toward several targets simultaneously, including the following:

- Elucidation of the dynamic giant magnetoelectric effect, the so-called huge non-reciprocal directional dichroism of light, in spin-spiral driven ferroelectric materials
- Microscopic understanding of the cross-correlation interaction mediated by fluctuation of orbital degrees of freedom in a spinel-type vanadate
- Precise structural analysis of the room-temperature multiferroic material $BiFeO_3$
- Microscopic elucidation of the mechanism of expression of magnetic induced ferroelectric polarization by direct observation of *d*-*p* orbital hybridization

For understanding these cross-correlation properties, we need to investigate a number of degrees of freedom which change simultaneously by using a suitable probe, and to comprehensively discuss the experimental results. In particular, crystal structure analysis using synchrotron radiation X-rays and neutrons, magnetic structure analysis with neutrons, inelastic neutron scattering experiments, soft X-ray resonant scattering experiments, and μSR experiments will be performed. Each technique has advantages for each time-space window.

Since new materials and measurement methods for strongly correlated materials are actively being developed, we will add new research subjects and techniques as appropriate, and collaborate with other researchers.

References

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