3 Condensed Matter Research Center

3-1 Overview

The Condensed Matter Research Center (CMRC) was established on April 1, 2009, in the Institute of Materials Structure Science (IMSS), KEK. The objective of the CMRC is to pursue cutting-edge research on condensed matter science through the comprehensive use of multi-probes supplied by the IMSS, such as synchrotron light, neutrons, muons, and slow positrons. The CMRC has four research groups: the correlated electron matter group, the surface/interface group, the matter under extreme conditions group, and the soft matter group. The members of these groups work closely with researchers at various universities and institutes around the world.

Through collaboration among these groups we are conducting nine bottom-up projects: 1. Hybridized Orbital Ordering, 2. Geometrical Correlation, 3. Molecular Crystals, 4. Oxide Hetero-structures, 5. Surface/interface Magnetism, 6. Extreme Conditions, 7. Soft Matter, 8. Hydrogen, and 9. Surface Structure and Electronic States. In addition, the CMRC is conducting two types of MEXT project: the Element Strategy Initiative to Form a Core Research Center, and the Photon and Quantum Basic Research Coordinated Development Program. In these national projects, the CMRC members are focusing on the Element Strategy Initiative for Electronic and Magnetic Materials, and Tribology with Muons and Neutrons.

(URL of CMRC: http://cmrc.kek.jp)

3-2 CMRC Projects

Hybridized Orbital Ordering Project [1-3]

Strong correlation among orbital, charge, and spin degrees of freedom often plays important roles in strongly correlated electron systems. The study of these electronic ordering states is essential to microscopically understand the phenomena in the systems. Resonant X-ray scattering (RXS) at the *K*-edge is a powerful tool for observing the spatial ordering of charge and orbital degrees of freedom in *3d* transition metal oxides. The RXS signal at the *K*-edge (*1s* -> *4p* transition energy) reflects the *4p* electronic state. On the other hand, the RXS signal at the $L_{2,3}$-edge (*2p* -> *3d* transition energy) can probe the *3d* electronic state directly. Moreover, signals at the *K*-edges of O, S, and P ions, which play a key role for the itinerancy through the orbital hybridization with the metal ion, are observable by using soft X-ray. In this project we have developed new diffractometers for resonant soft X-ray scattering depending on the experimental conditions.

Geometrical Correlation Project [4]

Geometrical frustration in the electronic degrees of freedom such as spin, charge, and orbital, which is often realized with highly symmetric crystals, has been one of the major topics in the field of condensed matter physics. The objective of this project is to determine a characteristic correlation time for fluctuations in itinerant

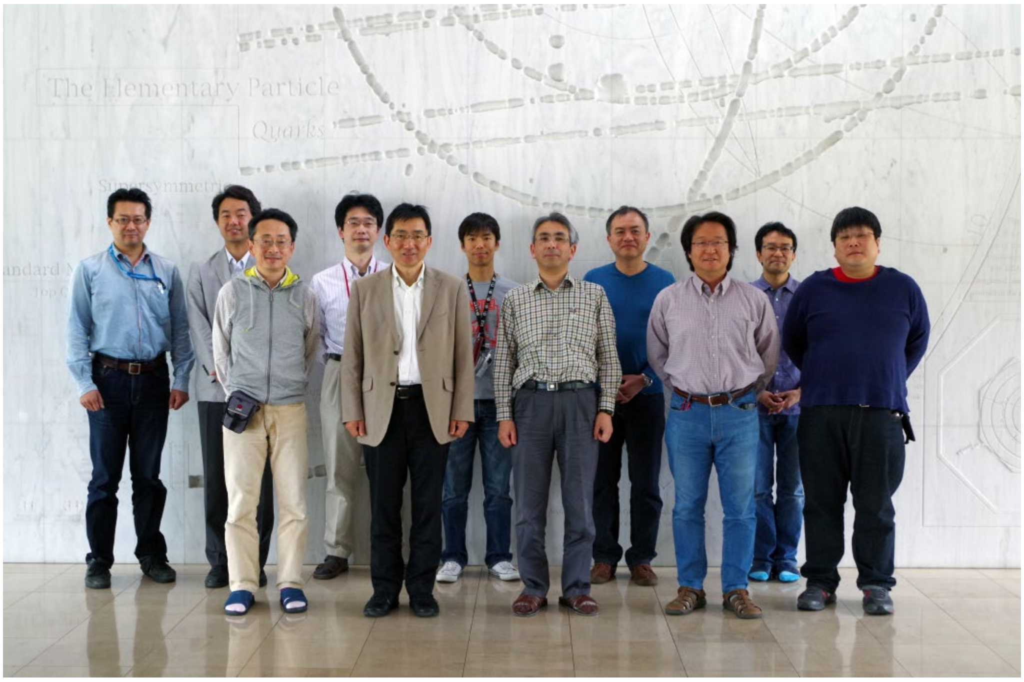

Figure 1: Project leaders of the Condensed Matter Research Center (CMRC).

systems with strong electron correlation under the influence of geometrical frustration using muons, neutrons, and synchrotron X-rays, which have different probing-time scales.

Molecular Crystals Project [5]

The electronic correlation in molecular crystal systems is being investigated to elucidate novel phenomena such as superconductivity and charge ordering. One topic in this project is the observation of a charge-cluster glass state in an organic conductor with triangular lattice. A combination of time-resolved transport measurements and X-ray diffraction revealed that the charge-liquid phase has two-dimensional charge clusters that fluctuate extremely slowly and heterogeneously.

Oxide Hetero-structures Project

The goal of this project is to design novel physical properties appearing at the heterointerface of strongly correlated oxides. The physical properties arise from strong mutual coupling among the spin, charge, and orbital degrees of freedom in the interface region between two different oxides. In order to control such properties, it is necessary to clarify the interfacial electronic, magnetic, and orbital structures. We are therefore using synchrotron radiation spectroscopic techniques having elemental selectivity to probe these structures in the nm-scale at the oxide heterointerface. For example, the electronic structure at the interface is determined by photoemission spectroscopy and X-ray absorption spectroscopy, the magnetic structure by magnetic circular dichroism of XAS, and the orbital structure by linear dichroism of XAS. We aim to design and create novel quantum materials by optimally combining sophisticated oxide growth techniques using laser molecular beam epitaxy and advanced analysis techniques using quantum beams.

Surface/Interface Magnetism Project [6]

The surface and interface of magnetic thin films play essential roles in the appearance of extraordinary magnetic properties such as perpendicular magnetic anisotropy and the giant magnetoresistance effect. We are investigating the crystalline, magnetic and electronic structures at the surface and interface of magnetic thin films and multilayers, in order to reveal the origin of fascinating magnetic properties that cannot be realized in bulk materials. For example, we have studied magnetic anisotropy of Fe/Ni multilayers, magnetic structures at the interface between antiferromagnetic FeMn and ferromagnetic Ni, effects of ion irradiation on ultrathin films, and a voltage-induced change in magnetic anisotropy of FeCo thin films grown on a ferroelectric substrate, by means of X-ray magnetic circular dichroism, extended X-ray absorption fine structure, and polarized neutron reflectivity techniques. We also plan to perform muon spin rotation experiments using an ultra-slow muon source.

Extreme Conditions Project

Materials under pressure and temperature show many interesting behaviors unlike those under ambient conditions. In this project, we are developing a new in-situ technique to investigate physical and chemical properties of the Earth and planetary materials including iron and hydrogen under extreme conditions.

Soft Matter Project [7]

Soft matter is a subfield of condensed matter comprising a variety of physical states that are easily deformed by thermal stresses or thermal fluctuations. They include liquids, colloids, polymers, liquid crystals, amphiphilic molecules, and a number of biological materials. These materials often self-organize into mesoscopic physical structures that are much larger than the microscopic scale (the arrangement of atoms and molecules), and yet are much smaller than the macroscopic scale of the material. The properties and interactions of these mesoscopic structures may determine the macroscopic behavior of the material. In spite of the various forms of these materials, many of their properties have common physicochemical origins, such as a large number of internal degrees of freedom, weak interactions between structural elements, and a delicate balance between entropic and enthalpic contributions to the free energy. These properties lead to large thermal fluctuations, a wide variety of forms, sensitivity of equilibrium structures to external conditions, macroscopic softness, and metastable states. From the above viewpoint, we are investigating the structural properties of soft matter such as liquids and amphiphilic molecules.

Hydrogen Project

Hydrogen plays important roles in material and life sciences and bridges fundamental science and engineering. There are many unsolved issues related to hydrogen: hydrogen bonding, hydrogen induced properties such as magnetism, superconductivity, embrittlement, thermal conductivity, hydrogen absorption/desorption mechanisms on material surfaces, activation of hydrogen near the surface of photo catalysts, and so on. Isotope effects and/or quantum effects are dominant for these properties, such as the effects of inverse isotopes on the superconductivity of palladium. This project involves neutron, synchrotron and muon beam specialists for observing hydrogen and aims to make observations to establish the quantum nature of hydrogen in materials.

Surface Structure and Electronic States Project [8]

Surface and near-surface structures have large effects on the properties of industrial materials especially those used for nanoelectronics devices and as catalysts. To develop those materials efficiently, definitive knowledge of the material surface and near-surface structures is essential. Recently, it has been revealed that reflection high-energy positron diffraction (RHEPD), a positron counterpart of reflection high-energy electron diffraction (RHEED), is an ideal method for solid surface and near surface structure analysis. Emphasizing the advantage of using total reflection, we propose to rename the RHEPD method as total-reflection high-energy positron diffraction (TRHEPD). We have started a project "Surface structure and electronic state", which makes use of TRHEPD for surface structure analysis and other complementary methods for determining surface electronic states, e.g. angle-resolved photoemission spectroscopy (ARPES), to obtain complete information at and near the surface.

The Element Strategy Initiative Electronic Materials [9]

We are aiming to develop entirely new materials that do not use rare elements. In the Tokyo Institute of Technology for Element Strategy, we are developing materials based on successful experience far away from development policy, and are pioneering electronic materials to create new guidelines for material design using harmless elements to open up new fields of material science. We are researching the crystal, electronic, and magnetic structures of light elements such as hydrogen and oxygen in materials synthesized by the Material Creation Group by using synchrotron radiation, muon and neutron sources.

Magnetic Materials

The Elements Strategy Initiative Center for Magnetic Materials (ESICMM) at the National Institute of Material Science (NIMS) has set the goals of (1) laboratory-scale synthesis of mass-producible high-performance next-generation permanent magnets that do not use critical scarce elements and (2) framework-building and the provision of basic science and technology that are needed in industrial R&D activities. In the CMRC, the "In situ analysis using neutrons and X-rays" project has been started as an analysis group member of ESICMM. The complementary use of neutrons at J-PARC/MLF and synchrotron X-rays at the Photon Factory is very useful for characterizing magnetic materials from the atomic scale to micrometer scale.

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