The order of electron degrees of freedom studied by resonant x-ray scattering

Youichi MURAKAMI*1,2, Hironori NAKAO1, Takeshi MATSUMURA1, Kazuma HIROTA1, Yusuke WAKABAYASHI3, Hiroshi SAWA3, Hiroyuki OHSUMI4, Masato, KUBOTA5, Takahisa ARIMA5,6, Yoshinori TOKURA5,7, Fumitoshi IGA8, Aya TOBO9, and Hideya ONODERA9

1Department of Physics, Tohoku University, Sendai 980-8578, Japan
2Synchrotron Radiation Research Center, JAERI, Sayo, 679-5148, Japan
3KEK-PF, Tsukuba, Ibaraki 305-0801, Japan
4Japan Synchrotron Radiation Research Institute, Sayo 679-5198, Japan
5ERATO, Tsukuba 305-8562, Japan
6Institute of Materials Science, University of Tsukuba, Tsukuba 305-8573, Japan
7Department of Applied Physics, University of Tokyo, Tokyo 113-8656, Japan
8Department of Quantum Matter, ADSM, Hiroshima University, Higashihiroshima 739-8526, Japan
9Institute for Materials Research, Tohoku University, Sendai 980-8577, Japan

Introduction

Our goal is to understand the ordering mechanisms in charge-, spin-, and orbital-ordered systems. To achieve the aim we have developed a technique of the resonant x-ray scattering (RXS). We have not only applied this technique to interesting systems but also studied the microscopic mechanism of the scattering. This year we have searched a new direction of "Orbital Physics". We report four important results in the accomplished works.

Experimental Results

Charge and Orbital Ordering of La2-xSr1+2xMnO7

We have studied charge and orbital states in the bilayered manganite using resonant and non-resonant x-ray scattering. The wave number of the superlattice due to the charge and orbital ordering is shifted when we increase the hole concentration from the half doped state. However, we have found that the wave number shows a constant value in a finite concentration region. Namely, the charge and orbital ordering has a lock-in-structure like the devil's staircase. This structure and its temperature dependence are discussed on the basis of the charge and orbital correlations.

Orbital Ordering in Y1.1Ca0.9MnO3

A perovskite-type transition metal oxide, Y1.1Ca0.9MnO3, has the metal-insulator transition (MIT) governed by the band-filling control. The parent material YTiO3 is a ferromagnetic (FM) insulator. The FM ordering disappears by the small amount of Ca substitution. The FM-paramagnetic (PM) phase boundary is xFM=0.15, while the insulating state is preserved up to xMIT=0.4. At the xMIT the drastic MIT occurs, and above xMIT the PM-metal phase is stabilized. The orbital ordered states have been systematically investigated by the RXS technique near the Ti K-edge. The RXS intensities at 1s ->3d transition energy reflecting the 3d-orbital ordering dramatically decrease with increasing Ca concentration toward xFP. The intensity remaining above xFP decreases gradually and almost disappears at xMI. Consequently, the orbital ordering is strongly suppressed toward xFP, and nearly vanishes at xMI. The hole concentration dependence of Jahn-Teller distortion determined by the x-ray structural analysis is also consistent with that of the orbitally ordered state.

Quadrupolar Ordering in RB2C2 (R = Ho, Tb)

We have been performing RXS experiments to observe various behaviour of the quadrupolar moments of the 4f-electron systems. Following the success of the observation of the antiferro quadrupolar ordering in DyB2C2, we have extended the study to HoB2C2 and TbB2C2 in which the competition between magnetic and quadrupolar interactions is more important for the physical properties. In HoB2C2, temperature dependence of the order parameter shows that magnetic and quadrupolar orderings of long range appear at the same temperature of 5 K, indicating the crucial role of the quadrupolar moment for the unusual magnetic structure.

Magnetic X-ray Scattering in GdAs

We have performed resonant and non-resonant x-ray scattering experiment on GdAs, which exhibits type-II antiferromagnetic order below 19 K. We succeeded in observing both non-resonant and resonant x-ray magnetic scattering. The energy spectra of the superlattice magnetic reflections show characteristic interference structure around the L3 absorption edge of Gd. Analysis of the spectrum would lead us to a more precise understanding of the scattering mechanism of the resonant x-ray scattering.

* murakami@iyo.phys.tohoku.ac.jp