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Soft and hard x-ray diffraction studies of $YMnO_3$ thin films

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Introduction

The fabrication of the o-$RMnO_3$ thin films has been especially important for device application of the multiferroic materials. Recently, Nakamura et al. reported the fabrication of o-$YMnO_3$ thin films onto the $YAlO_3$ (010) substrate [1]. Their thin film showed a ferroelectric transition at 40 K with a large saturation polarization of 0.8 $\mu C/cm^2$. The ferroelectric polarization could be controlled by magnetic fields, demonstrating multiferroic behaviors. Therefore it is interesting and important to study the magnetic structures of $YMnO_3$ thin films. In this study we use the technique of resonant soft x-ray diffraction at Mn $2p \rightarrow 3d$ edges to obtain the information of magnetic ordering in $YMnO_3$ thin films. From hard x-ray diffraction, we also observed commensurate lattice-distortion peaks. These results reveal that the ground state of the $YMnO_3$ is the coexisting phase of E-type and cycloidal states.

Experiment

The thin film (40 nm) of $YMnO_3$ was grown on a $YAlO_3$ (010) substrate by pulsed-laser deposition. The details of the sample fabrication were described in Ref. [1]. Resonant soft x-ray diffraction experiments were performed on the RESOXS endstation at the surfaces/interfaces microscopy (SIM) beamline of the Swiss Light Source of the Paul Scherrer Institut, Switzerland. Hard x-ray diffraction experiments were performed on beamlines 3A and 4C at the Photon Factory, KEK, Japan. The photon energy of the incident x-rays was 12 keV.

Results and Discussion

In order to study the lattice distortion, we performed hard x-ray diffraction ($h\nu$ = 12 keV) measurements of the YMnO3 thin film. The commensurate (0, 1, 0) reflection appears below 35 K as shown in Fig. 1. This reflection is a structurally forbidden peak and caused by the lattice distortion accompanying ferroelectricity. No incommensurability of this reflection is observed by hard x-ray diffraction. Fig. 1 (b) shows peak intensities as a function of temperature, demonstrating that the peak appears at 35 K.

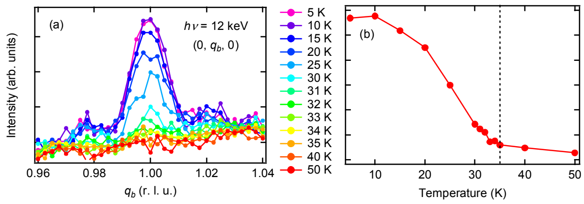

Fig. 1: Temperature dependence of the (0, 1, 0) peak taken at $h\nu$ = 12 keV. Peak intensities are plotted as a function of temperature in panel (b).

We can obtain a full picture of the magnetic states of the epitaxial $YMnO_3$ thin film by combining the above results with the macroscopic measurements of magnetization and electric polarization [1]. From the macroscopic measurements, three transitions were observed: antiferromagnetic transition T_N = 45 K, ferroelectric transition T_C = 40 K, and an increase of electric polarization at 35 K. From resonant soft x-ray scattering, the incommensurate magnetic peak was observed at all temperature below 45 K, and the direction of the observed spin is along the c axis. This means that in the temperature range of 40 - 45 K, a sinusoidal state is realized because such a magnetic ordering has no electric polarization. In the range of 35 - 40 K, ferroelectricity is caused by a cycloidal magnetic structure. Below 35 K, we can observe both the incommensurate magnetic reflection and the commensurate lattice-distortion reflection. This state can be therefore explained by the coexistence of the E-type and the cycloidal states as theoretically predicted in Ref. [2]. In this coexistence region, magnetic reflection is incommensurate as shown in Ref. [2] and lattice peaks are commensurate because the E-type phase has a much larger lattice distortion than the cycloidal phase. The E-type part is the origin of a large electric polarization.

References

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