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Soft and hard x-ray diffraction studies of $DyMnO_3$ thin films

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Introduction

Recently, there has been a lot of interest in multiferroic materials displaying both ferroelectric and magnetic orders. Orthorhombic (*o*) $RMnO_3$ (*R* denotes rare earth metal) with perovskite structure belongs to this category and can be viewed as prototypical multiferroic materials. The fabrication of the *o*-$RMnO_3$ thin films has been especially important for device application of the multiferroic materials. Nakamura *et al*. reported the fabrication of *o*-$YMnO_3$ thin films onto the $YAlO_3$ (010) substrate [1]. By combining soft and hard x-ray diffraction, it was revealed that the magnetic structure of the $YMnO_3$ thin film is the coexistence of the E-type and the cycloidal states [2]. They also succeeded in fabricating *o*-$DyMnO_3$ thin films onto the $YAlO_3$ (010) substrate. In this study we performed soft x-ray diffraction at Mn $2p \rightarrow 3d$ edges to obtain the information of magnetic ordering and hard x-ray diffraction to investigate lattice distortions in the $DyMnO_3$ thin film. Our results reveal that the ground state of the $DyMnO_3$ thin film is very similar to that of the $YMnO_3$ thin film, that is, the coexistence of the E-type and the cycloidal states.

Experiment

The thin film (40 nm) of $DyMnO_3$ was grown on a $YAlO_3$ (010) substrate by pulsed-laser deposition. Hard x-ray diffraction experiments were performed on beamlines 3A at the Photon Factory, KEK, Japan. The photon energy of the incident x-rays was 12 keV.

Results and Discussion

In order to investigate the lattice distortions associated with magnetic order and electric polarization, we performed hard x-ray diffraction measurements of the $DyMnO_3$ thin film. The commensurate (0 3 0) reflection appears below 35 K as shown in Fig. 1. This reflection is structurally forbidden in the chemical high-temperature structure (Pbnm) and caused by the lattice distortion accompanying ferroelectricity. Interestingly, no incommensurability of this reflection is observed by hard x-ray diffraction, in clear contrast to the observed magnetic reflection. This reflection does appear below 35 K as can be seen from the temperature-dependent integrated intensity shown in Fig. 1(b). This temperature is lower than the onset of the magnetic reflection of 40 K.

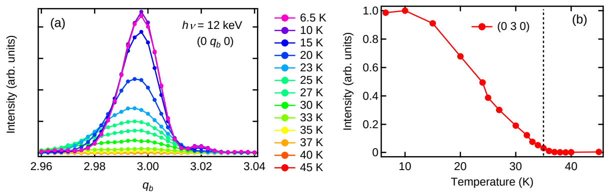

Fig. 1: Temperature dependence of the (0 3 0) peak taken at $h\nu = 12$ keV. Peak intensities are plotted as a function of temperature in panel (b).

Our results indicate that the magnetic states of the epitaxial $DyMnO_3$ thin film is similar to those of the $YMnO_3$ thin film [2], that is, the coexistence of the E-type and the cycloidal states. In this coexistence region, magnetic reflection is incommensurate and lattice peaks are commensurate because the E-type phase has a much larger lattice distortion than the cycloidal phase. Further studies such as the measurements of electric polarization will be necessary for supporting this scenario.

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