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Electric control of the orbital zigzag-chain direction in a single-layer manganese oxide $La_{1/2}Sr_{3/2}MnO_4$

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Introduction

Electric-field effect on the charge-orbital ordered (COO) state of perovskite-related manganese oxide compounds has been intensively studied since the large nonlinear conductivity in $Pr_{0.7}Ca_{0.3}MnO_3$ was reported [1]. An interesting feature of COO state is the in-plane anisotropy in optical, electrical, and magnetic properties [2-4], arising from the anisotropic arrangement of occupied orbital. In fact, there are some reports on the control of the anisotropy with respect to the orbital degree of freedom in manganese oxide compounds by the application of an electric field such as an electrical switching between two orbital-ordered phases in $Nd_{1-x}Sr_{1+x}MnO_4$ [5] and a re-arrangement of the more conductive *c*-axis to the current direction in $Bi_{0.53}Sr_{0.47}MnO_3$ [6]. Recently, we have succeeded in an electrical control of direction of orbital stripes and consequent optical anisotropy in a half-doped layered manganite $La_{1/2}Sr_{3/2}MnO_4$ [7]. With using an optical polarizing microscopy, one can distinguish the COO domains with two different directions of orbital zigzag chains as illustrated in two panels of Fig. 1. However, the optical polarizing microscopy images do not provide clear information about the relation between the direction of the electric field and the orbital zigzag chains. In this study, we investigate the electric field effect on the COO state by means of synchrotron x-ray diffraction [7].

Experimental

A boule of single crystal of a typical tetragonal single-layered manganite $La_{1/2}Sr_{3/2}MnO_4$ was grown by using a floating-zone method [8]. A sample was cut from the boule with the dimensions of approximately $1.5\times1.0\times0.1mm^3$. Four electrodes were made on a crystal with silver paint on a cleaved (001) surface, in order that electric fields in the *x* and *y* directions could be alternately applied. Synchrotron x-ray diffraction measurements with an imaging plate system were performed on beamline-1A at Photon Factory, KEK. The incident x-ray beam was collimated to 0.15mmϕ. Electrical voltage V_x or V_y was applied to a sample and a load resistor (R_L = 30Ω) connected in series. The applied voltage was gradually swept with a rate of 100mV/s.

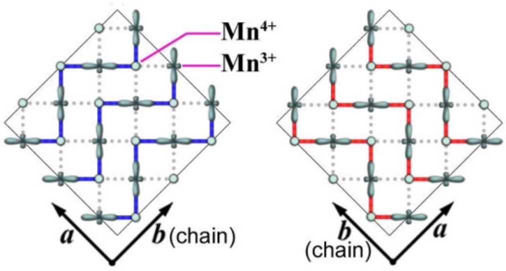

Figure 1 Schematic illustrations of charge-orbital ordering patterns within an MnO_2 plane for two types of domains. The degree of freedom of the direction of the orbital zigzag chains generally gives rise to a twin state. Excerpt from Ref. [7]

Results and discussions

Figures 2(a) and (b) show x-ray oscillation photographs before and after an electric-current annealing with a bias voltage of 14.0V at 120K, respectively. Bright large spots are fundamental Bragg reflections at (0, 3, 19), (0, 4, 20) and (0, 5, 19) indexed in the body-center tetragonal (*I4/mmm*) setting. Green arrows indicate superlattice satellite spots stemming from orbital ordering, and indexed as (h+1/4, k+1/4, l) and (h-1/4, k-1/4, l), while the spots indicated by red arrows are indexed as (h+1/4, k-1/4, l) and (h-1/4, k+1/4, l). In other words, the superlattice spots indicated by red and green arrows correspond to the COO domains with different directions of orbital zigzag chains. After an electric-current annealing with a bias voltage V_y = 15.0V (12.2kV/m), all the superlattice spots indicated by red arrows disappear and spots indicated by green arrows become brighter. This proves that the orbital zigzag chains are aligned perpendicular to the current direction. Another x-ray measurement on a different sample also showed a similar result.

According to previous reports, the zigzag chain axis (b-axis) is more conductive than the direction perpendicular to the chain axis for single- and double-layered manganites [3,4]. The present study suggests that the low-resistivity zigzag chain tends to align perpendicular to the current direction after an electric-current annealing. This phenomenon is contrary to the naïve expectation that the COO domain rearrangement by electric-field should be ascribed to the realignment of the more conductive axis to the current direction [6]. Some theoretical approaches are necessary for elucidating the observed phenomenon.

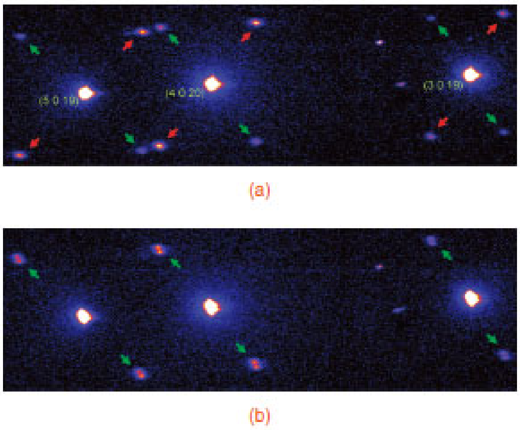

Figure 2 Synchrotron X-ray oscillation photographs of a single crystal at 120K recorded (a) before and (b) after applying an electr.nystaer588.4 (y)4(f)8(1r588.5f)8(V)@7v. Ga (n)-39df

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