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Electric field response of strain-induced polarization in $SrTiO_3$ thin film

Yuki Nekomoto[1*], Kai Kamijo[1], Nobuo Nakajima[1], Shintaro Yasui[2], Jun-ichi Adachi[3], Yasuhiro Niwa[3], and Hiroaki Nitani[3]
[1]Graduate School of Advanced Science and Engineering, Hiroshima University, 1-3-1, Kagamiyama, Higashi-Hiroshima 739-8526, Japan
[2]Laboratory for Zero-Carbon Energy, Tokyo Institute of Technology, 2-12-1, Ookayama, Meguro 152-8550, Japan
[3]Photon Factory, Institute of Materials Structure Science, High Energy Accelerator Research Organization, 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan

1 Introduction

Strontium titanate ($SrTiO_3$) is a quantum paraelectric material and exhibits paraelectricity in all temperature ranges at ambient pressure. It is reported that the ferroelectricity appears by several methods such as UV irradiation [1], oxygen isotope substitution [2], and uniaxial pressure [3]. However, the appearance of the ferroelectric phase is at low temperatures of several tens of K.

Recently, room-temperature ferroelectricity was reported by Haeni *et al* [4] through the application of biaxial strain in thin films. In the present study, the existence of electric polarization in a $SrTiO_3$ thin film at room temperature was examined in the first place. Then, its response to the ap-plied electric field was observed by time-resolved X-ray absorption spectroscopy (TR-XAS).

2 Experiment

A thin film with a structure of Pt (50 nm) /$SrTiO_3$ (35 nm) /$SrRuO_3$ (20 nm) /LSAT was fabricated using the pulsed laser deposition method. In the $SrTiO_3$ layer, an in-plane compressive strain of ca. 1% due to the lattice mismatch with the LSAT substrate was confirmed by X-ray reciprocal mapping.

Ti-K edge X-ray absorption spectra (XAS) were measured on the beamline BL-15A1 under ambient conditions using the fluorescence mode. TR-XAS measurements were done by the same method reported previously [5]. A single triangular pulse at a frequency of 1 kHz followed by a null voltage was applied to the $SrTiO_3$ layer through Pt and $SrRuO_3$ electrodes. The X-ray fluorescence signals were recorded by a digital signal processor together with time information to obtain TR-XAS.

3 Results and Discussion

Ti pre-K edge spectra with and without the electric field (***E***) is compared in Fig. 1. The e_g-peak intensity changes upon application of the electric field as shown in the inset. It is reported that the e_g peak intensity (I_{eg}) is proportional to the square of the Ti off-center displacement, (δ_{Ti}) [6], i.e., $I_{eg} \propto \delta_{Ti}^2$, therefore the electric field response is direct evidence of existence of spontaneous polarization in the $SrTiO_3$ thin film at room temperature.

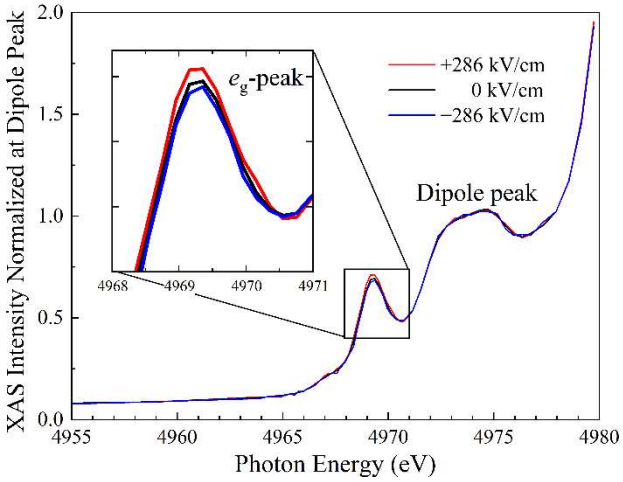

Figure 1: Ti pre-K edge XAS of $SrTiO_3$ with (red/blue) and without (black) the apply electric field. Inset: Enlarged view of the e_g peaks.

The dynamic response of the polarization to the applied field was investigated by TR-XAS. Figure 2(b) shows the time variation of the relative e_g-peak intensity in response to the applied field (Fig. 2(a)), in which average voltage during zero voltage (1.0-2.9 ms) is set to unity. As a comparison, the similar response of the ferroelectric $BaTiO_3$ is displayed in Fig. 2(c). When the positive field is applied during 0.0-0.5 ms, both $SrTiO_3$ and $BaTiO_3$ present the enhancement of the e_g peak intensity, i.e., the increase of the electric polarization (***P***). On the contrary, when the negative field is applied during 0.5-1.0 ms, their responses differ from each other.

Based on the Landau phenomenological theory, a double-peak feature observed in $BaTiO_3$ is reasonable because of the quadratic nature of the free-energy in ***P***. Intuitively speaking, in the case of ferroelectric perovskite titanates, the amount of δ_{Ti} is irrespective of the sign of the electric field. On the other hand, in the case of $SrTiO_3$, the e_g-peak intensity decreases when the negative electric field is applied. From this unusual behavior, reduction of δ_{Ti} can be concluded instead of polarization reversal. It should be also noted that the decrease in the negative field is smaller than the increase in the positive field.

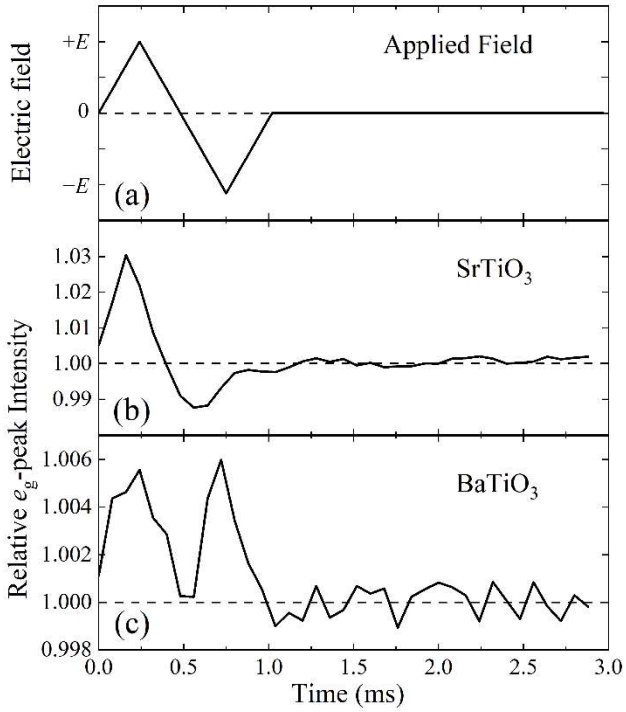

Figure 2: Temporal variation of (a) the applied electric field and the e_g-peak intensities of (b) $SrTiO_3$ and (c) $BaTiO_3$.

This asymmetric response to the electric field, along with the lack of polarization reversal, naturally reminds us of the flexoelectricity where a strain gradient induces polarization in the lattice even in an originally centrosymmetric $SrTiO_3$. In general, the flexoelectric polarization is very small. However, the relative intensity enhancement in $SrTiO_3$ is 5 times larger than that of $BaTiO_3$. Oxygen defects introduced during the film deposition process would be a plausible cause of the enhancement of the electric field response in the $SrTiO_3$ thin film [7].

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* nekomoto-yuuki@hiroshima-u.ac.jp