

Time-Resolved X-ray Absorption Spectroscopy of BaTiO₃ Under Pulsed Electric Field

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1 Introduction

The external electric field induces lattice strain in ferroelectric BaTiO₃ by the inverse piezoelectric effect. Recently, there are several papers discussing the response of the BaTiO₃ lattice to the electric field based on X-ray diffraction (XRD) data [1, 2]. A pulsed field seems to induce nonlinear elastic strains in contrast to a static field. The dynamic response of the lattice strain is an essential property of dielectric materials, and it is important to understand the response from an electronic point of view.

In this report, the results of the time-resolved X-ray absorption experiments of a dielectric material are briefly shown. We discuss the dynamical behavior of the ferroelectric moment to explore hidden dielectric properties. This work leads to the development of new dielectrics with high dielectric constant.

2 Experiment

A BaTiO₃(001) single crystal with the size of 5×5×0.5t mm was clamped by copper electrodes. Rectangular pulsed high-voltage (HV) was applied along the thickness direction with a repetition rate of 10 kHz. The pulse width (t_w) was tuned to 5 μ s or 20 μ s, and voltage amplitude was changed up to 1.0 kV (2.0 kV/mm).

Ti *K*-edge X-ray absorption spectra (XAS) were measured on the beamline BL-9A. The linearly polarized X-ray beam was incident on a (100) side surface of the sample. The polarization vector of the X-ray was parallel to the electric field, and therefore to the direction of spontaneous polarization of sample. Ti *K* α fluorescence was detected by a high-speed silicon drift detector (Amptek XR-100SDD). Digitized pulse signals from a multichannel analyzer (Amptek PX4) were gated by 300 ns logic pulses with several delay times (t_d) from the rise of the HV pulse, and were recorded by a counter. In this method, total counts of the signals are limited by the width of the gate signals, so that it is necessary to sum several spectra in order to increase statistical accuracy. A sub-microsecond response is detectable by this technique.

3 Results and Discussion

Figure 1 shows comparison of spectra at different delay times ($t_d = 0 \mu$ s, 15 μ s) under HV pulse with $t_w = 20 \mu$ s. The delay time origin ($t_d = 0 \mu$ s) was set to the rising edge of the trigger pulse which was applied to a HV power supply. Each spectrum was obtained by adding 30 spectra. The pre-edge features between 4965 and 4975 eV as well as a shoulder peak at 4980 eV are insensitive to the HV pulse and remain unchanged. On the other hand, the main

peak at 4985 eV shows a slight energy shift of about 0.2 eV. The main peak is due to the 1s-4p dipole transition. Since the electronic response to the electric field is faster than the our present time-window, this energy-shift is not simply due to a change of the electron orbital.

One possible explanation is the charging effect whose time-scale is governed by the capacitance of the BaTiO₃ sample. Indeed, slight energy shift was observed with $t_w = 5 \mu$ s. The depletion of the electrons may changes the valence of Ti ions. This is a first experimental result that confirm the influence of the HV pulse on the electronic states. Much larger changes can be expected in thin films, since the larger effective electric field may induces additional piezoelectric effect to increase electron depletion.

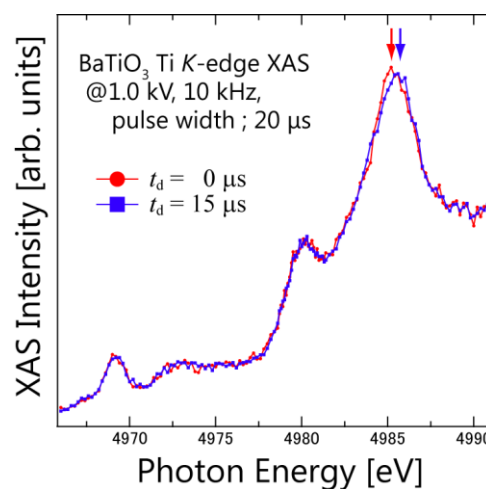


Figure 1. Ti *K*-edge time-resolved X-ray absorption spectra of a BaTiO₃ single crystal under HV pulse. The red (blue) line represents a spectrum with a delay time of $t_d = 0 \mu$ s ($t_d = 15 \mu$ s). The main peak shows an energy shift of about 0.2 eV as indicated by arrows.

References

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