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Effect of humidity on domain switching behaviors of $BaTiO_3$ single crystal under sustained load

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ABSTRACT

Domain switching behaviors of $BaTiO_3$ single crystal in humidity conditions were studied by polarized light microscopy (PLM) and atomic force microscopy (AFM). The results showed that the low humidity has no effect on both *a*–*b* domain configuration and *a*–*c* domain configuration under sustained load. However, the high humidity can promote *a* domain switching to *c* domain under sustained load. The difference of energy reduction induced by H_2O molecules between *c* domains and *a*(*b*) domains leads to this phenomenon.

1. Introduction

In ferroelectrics, domain switching will occur under appropriate mechanical or electric load. Previously, much effort has been dedicated to the ferroelectric domain switching behaviors under electric or mechanical field. The domain configurations have been observed by atomic force microscopy (AFM), Nomarski interference contrast, polarized light microscopy (PLM) and transmission electron microscopy (TEM) [1–7]. However, most of these studies were carried out in normal ambient conditions. In practice, ferroelectric devices are used frequently in some special environments such as humid air conditions. However, the effects of environments on domain switching behaviors have not been well studied.

Previously, the delayed fracture of Pb(Zr,Ti)O_3 and $BaTiO_3$ ceramics in different ambient conditions were observed [8–10]. The results showed that the low humidity has no effect on cracks whereas high humidity could result in delayed crack propagation. Domain configuration changed simultaneously with crack propagation, which was observed around the indentation in $BaTiO_3$ single crystal in humid ambient conditions [11]. However, the internal effect of humid conditions on domain switching during crack propagation is not clear yet. Therefore, we became interested in the effects of humidity on domain switching behaviors under sustained load in non-cracked ferroelectrics. In the present study, domain switching behaviors of $BaTiO_3$ single crystal in the conditions with low humidity and high humidity under sustained load were investigated.

2. Experimental details

In-plane poled and out-of-plane poled $BaTiO_3$ single crystals with dimensions of 5 mm × 5 mm × 1 mm were used. The crystals were poled along the [0 1 0] and the [0 0 1] directions, respectively. The (0 0 1) surfaces were polished carefully by diamond abrasive for observation. The single crystal was pasted on an I-shaped carbon steel slice, as shown in Fig. 1(a). Then the I-shaped slice was put into a matched groove on top of a wedge opening loaded (WOL) specimen, as illustrated in Fig. 1(b). While the WOL specimen was loaded by tightening the screw, a tensile load was applied gradually to the single crystal along the [1 0 0] direction. The value of tensile load was not calculated as qualitative analyses of domain switching behaviors were enough for present study.

The load application was stopped when some new domain stripes appeared. The sample under sustained load was put into a desiccator of constant humidity. The relative humidity (RH) was controlled at 2% and 80% by silicon gel drier and water, respectively. The domain switching behaviors in different

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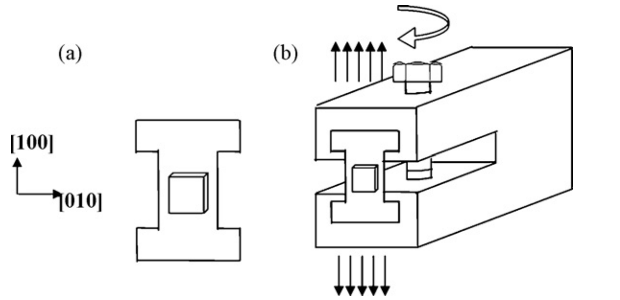

Fig. 1. Illustration of barium titanate single crystal with a sustained load. (a) I-shaped slice with $BaTiO_3$ single crystal and (b) the single crystal was loaded along [1 0 0] direction through WOL specimen.

humidity conditions were observed using an Olympus polarized light microscopy (Olympus, Inc.) and a Digital Instruments Nanoscope III atomic force microscopy (Dimension 3100, Veeco, Inc.).

3. Results and discussions

The domains with polarization vectors along the [1 0 0], the [0 1 0] and the [0 0 1] directions are defined as *a* domains, *b* domains and *c* domains, respectively. In Fig. 2(a), there are entire *b* domains in the surface after the sample poled along the [0 1 0] direction (in-plane polarization). According to criterion of domain switching, *a* domains should be initiated from *b* domain matrix when a tensile load is applied to the sample along the [1 0 0] direction. Therefore, the dark stripes of A–D in Fig. 2(b) are *a* domains induced by the tensile load. The polarization vectors of *a* domain and *b* domain are perpendicular to each other, as illustrated in Fig. 2(e). This type *a*–*b* domain configuration can be observed easily by PLM because of the reflection of light at the domain walls [12,13]. However, *a* domains and *b* domains cannot be distinguished by AFM because they have no morphological contrast. The single crystal sample was put into the air with low humidity of 2% RH. After kept in dry air with 2% RH for 168 h, no changes of the *a*–*b* domain configuration were found, as shown in Fig. 2(c). Then the single crystal sample was moved into the air with high humidity of 80% RH. After kept in humid air with 80% RH for 300 h, there was still no change to the domain stripes, as shown in Fig. 2(d). Fig. 2 indicates that both low humidity and high humidity have no effects on *a*–*b* domain configuration under the sustained load.

In tetragonal barium titanate, *c* domains are higher than *a* domains on the same surface. Therefore, the *a*–*c* domain wall can be distinguished by differential interference contrast (DIC) mode of PLM. Fig. 3 shows the changes of *a*–*c* domain configuration in low humidity and high humidity conditions by DIC mode of PLM. There are *c* domains in the (0 0 1) surface after the sample was poled along the [0 0 1] direction (out-of-plane polarization). According to criterion of domain switching, *a* domain should be initiated from *c* domain matrix when a tensile load is applied to the sample along the [1 0 0] direction. In Fig. 3(b and c), many *a* domain stripes were initiated from *c* domain matrix when increasing tensile load was applied. The dark stripes are *a* domains while the bright zones are

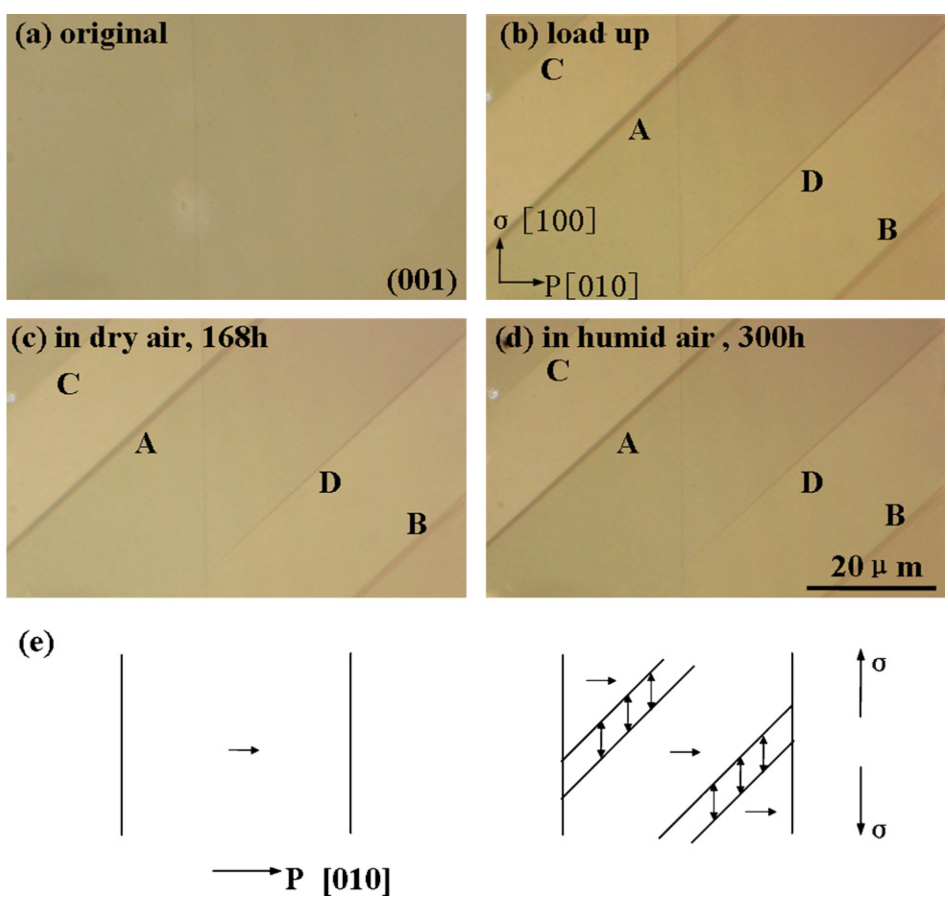

Fig. 2. Effects of the humidity on *a*–*b* domain configuration under sustained load. (a) Original *b* domains; (b) new *a* domain stripes initiated under the tensile load; (c) in dry air with 2% RH for 168 h; (d) in humid air with 80% RH for 300 h; (e) schematic arrangements of domains after a tensile load was applied to the sample.