Scripta Materialia 146 (2018) 272–275

Contents lists available at ScienceDirect

Scripta Materialia

journal homepage: www.elsevier.com/locate/scriptamat

Regular article

Domain switching behavior in lead zirconate titanate piezoelectric ceramics

Mitsuhiro Okayasu *, Kohei Bamba

Graduate School of Natural Science and Technology, Okayama University, 3-1-1 Tsushimanaka, Kita-ku, Okayama 700-8530, Japan

A R T I C L E I N F O

Article history:
Received 18 October 2017
Accepted 2 December 2017
Available online xxxx

Keywords:
TEM
PZT ceramic
Domain switching
Lattice structure
High temperature

A B S T R A C T

The domain switching behaviors of lead zirconate titanate ceramics were monitored via direct, in-situ lattice observation using transmission electron microscopy. The lattice structures were monitored via video as a sample was heated from room temperature to 300 °C. The lattices vibrated in the [110] direction several times over a short period, e.g., 0.1 s. Moreover, lattice sliding occurred in the [100] direction for about 15 Å. Those lattice motions were detected at around 83–84 °C. Lattice orientations were analyzed using the domain switching model to substantiate whether these movements can be attributed to domain switching.

Piezoelectric ceramics have been used in a number of engineering applications such as ignition systems, sensors, and actuators because they exhibit spontaneous polarization. Lead zirconate titanate (PZT) ceramics have perovskite structures and represent a common class of this type of material. This structure provides the ability to transform electrical energy into mechanical strain energy, and vice versa [1]. In recent years, the generation of electric power from piezoelectric ceramics has garnered significant interest due to applications such as energy harvesting [2]. The extent of electric power generation from PZT ceramics is influenced by material characteristics such as the lattice structure and domain orientation. Crystallization of lead titanate (PT), lead zirconate (PZ), and PZT piezoelectric ceramics has been investigated at temperatures from 380 to 500 °C [3]; however, severe material damage occurs as the applied stress and heating temperature increase, leading to diminished piezoelectric properties [4]. PZT ceramics are subject to several damage mechanisms, including domain switching and crack generation. Domain switching and wall formation reduce the piezoelectric properties of PZT ceramics [5]. Several technical approaches can be used to understand domain switching characteristics, including electron back scatter diffraction (EBSD) [6] and x-ray diffraction (XRD) [7]. The extent of domain switching depends on the loading conditions: strong domain switching occurs when the loading direction is near the *c*-axis of the tetragonal structure [8]. Thus far, several researchers have examined domain switching behaviors. Zhang and Ren have performed in-situ observations of domain structures in aged, Mn-doped $BaTiO_3$ during electric field cycling. Their approach revealed mesoscopic domain switching behavior that affected macroscopic properties [9]. Lee et al. continuously observed ferroelectric 90° domain switching in epitaxial $Pb(Zr,Ti)O_3$ thin films via synchrotron x-ray diffraction [10]. Polarization reversal mechanisms have been investigated via sub-10 nm real space imaging of domain pattern evolution under an applied electric field [11]. Gruverman et al. have reported the first direct studies of ferroelectric capacitor switching on a sub-microsecond time scale, in which polarization reversal is dominated by domain wall motion. That is, switching takes place more quickly in high fields and more slowly with larger capacitors [12]. Although several researchers have systematically investigated domain switching characteristics, there is still insufficient experimental data to convince scientists of domain switching behavior. In-situ observation of domain switching may help. Thus, in the present work, an attempt was made to directly monitor the lattice structures of PZT ceramics via transmission electron microscopy (TEM) as they were heated.

The piezoelectric material used in this study was a commercial bulk PZT ceramic with tetragonal piezoelectric polycrystalline structure. A sample was machined with dimensions of 3 mm × 3 mm × 40 mm. The nominal grain diameter was measured to be about 5 μm. The lattice parameter aspect ratio (*c*/*a* axis in the tetragonal structure) was about 1.014, as determined via XRD with Cu-Kα incident radiation. Thermal energy was used to apply stress to the PZT ceramic in order to observe domain switching behavior. The sample was heated from 25.0 °C to 300.0 °C at 1 °C/s in air. The test ended just above the Curie temperature of the material (295 °C). During heating, the lattice structures were observed via TEM (JEM-2100F) using an acceleration voltage of 200 kV. The TEM image was monitored using a video camera at 160 frames per second (fps), and TEM samples 50–150 nm in thickness were prepared using a focused ion beam technique. To clearly observe the lattice

* Corresponding author.
E-mail address: mitsuhiro.okayasu@utoronto.ca (M. Okayasu).

https://doi.org/10.1016/j.scriptamat.2017.12.003
1359-6462/

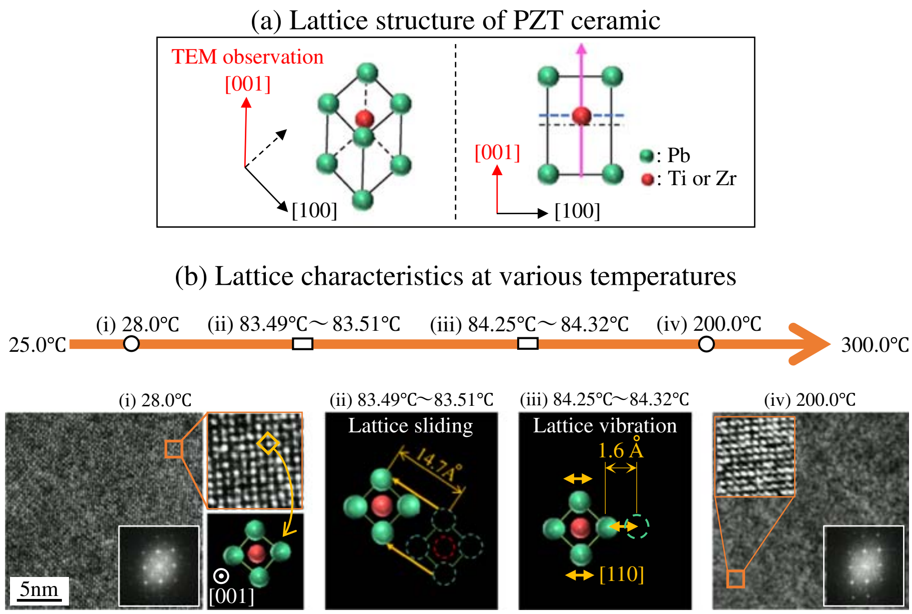

Fig. 1. (a) Lattice structure of the PZT ceramic and (b) lattice characteristics at various temperatures.

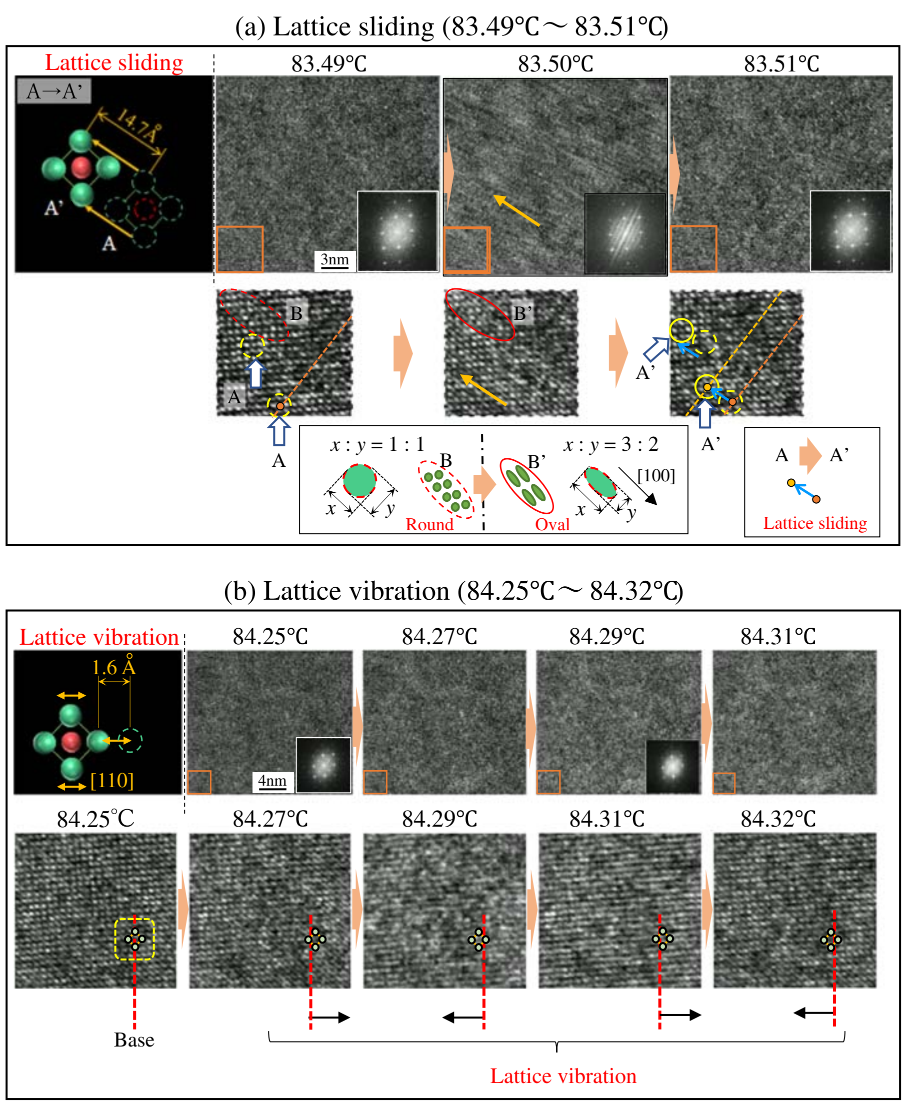

Fig. 2. Lattice motion of the tetragonal structure during heating: (a) sliding and (b) vibration.