SHIMADZU
Excellence in Science

Application News

SPM-Nanoa™ Scanning Probe Microscope (Atomic Force Microscope)

SPM Visualization of Polarized Domains in Ultra-Small Regions of Piezoelectric Materials

K. Kuroda, S. Moriguchi

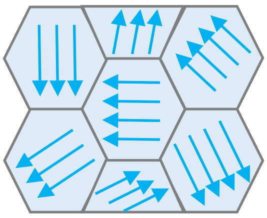
User Benefits

- The distribution of polarized domains in ultra-small regions, an essential factor in determining the properties of piezoelectric materials, can be observed.
- Targets can be evaluated under atmospheres close to the actual use environment (air, inert gas, low vacuum, etc.).
- The high performance optical microscope integrated into the SPM enables precise target location.

■ Introduction

Piezoelectric materials have the piezoelectric property to deform themselves when voltage is applied. Due to this characteristic, piezoelectric materials play an important role in various industrial products such as sensors, buzzers, and filters. Particularly in recent years, as electronic and communication devices have become increasingly miniaturized, piezoelectric materials are required to perform at even higher standards, and vigorous development is underway.

Piezoelectric materials are composed of domains with aligned spontaneous polarization, and these domains are polarized in different directions as shown in Fig. 1. These polarized domains are an essential factor in determining the properties of piezoelectric materials. However, it is not easy to observe the distribution of polarized domains in extremely minute regions. In this article, we introduce an example of capturing polarized domains in an ultra-small region of piezoelectric materials using a scanning probe microscope [SPM (AFM)], which can observe various physical quantities with nanometer-order resolution.



Piezoelectric materials are composed of small domains, each of which is polarized in a different direction.

Fig. 1 Diagram of Polarized Domains

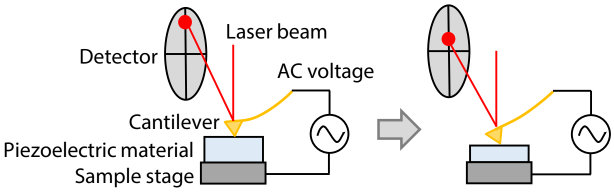
■ Outline of SPM

SPM is a microscope that images the interactive force between a micro probe and the surface of a sample. It is equipped with functions to evaluate the distribution of various physical quantities in an extremely small area, such as observing surface topography by detecting atomic force, observing surface potential distribution by detecting electric force, observing friction characteristics by detecting horizontal force, etc. In this study, we employed the piezoresponse (PFM) mode, which can observe the polarized domain distribution of piezoelectric materials.

Fig. 2 SPM-Nanoa™ Scanning Probe Microscope

■ Principles for Observing Polarized Domains

SPM detects local deformation of piezoelectric materials by using a cantilever with a micro probe molded on it. The detection system is set up so that the laser beam is irradiated on the back of the cantilever and the reflected beam enters the detector. The amount of deflection of the cantilever is detected by utilizing the change in the laser incident position on the detector caused by the cantilever deflection. AC voltage is then applied between the probe and the sample while the cantilever is in contact with the piezoelectric material, and the response of the piezoelectric material to the applied voltage is detected from the change in the amount of deflection of the cantilever.



When the piezoelectric material contracts, the incident position of the laser beam on the detector shifts downward.

Fig. 3 Schematic Diagram of Expansion/Contraction Detection on Piezoelectric Materials

By detecting the response of the piezoelectric material at each location, it is thus possible to obtain the distribution of the direction (expansion/contraction) and magnitude (amplitude) of the response to the applied voltage in ultra-small regions. Fig. 4 illustrates the moment when a negative voltage is applied to the cantilever side and a positive voltage to the sample stage side.

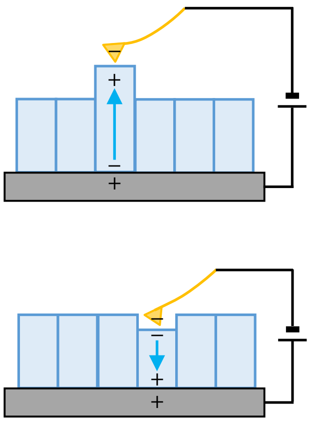


Fig. 4 Diagram of the Moment when Negative Voltage is Applied to Cantilever Side and Positive to Sample Stage Side

■ Observation of Polarized Domains on $BaTiO_3$

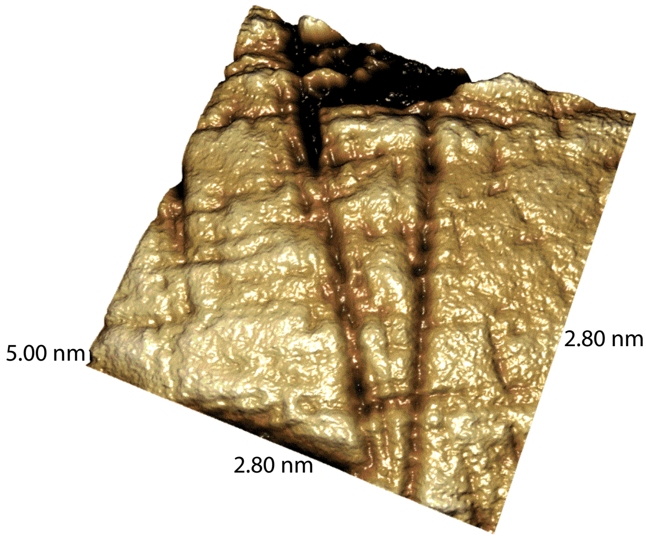
Fig. 5 shows the topographic, phase, and amplitude images of $BaTiO_3$. Table 1 shows the observation conditions.

Table 1 Observation Conditions

Instrument	: SPM-Nanoa Scanning Probe Microscope
Scanner	: Wide-renge scanner (125 µm)
Observation mode	: PFM mode
Observation field	: 2.8 µm × 2.8 µm

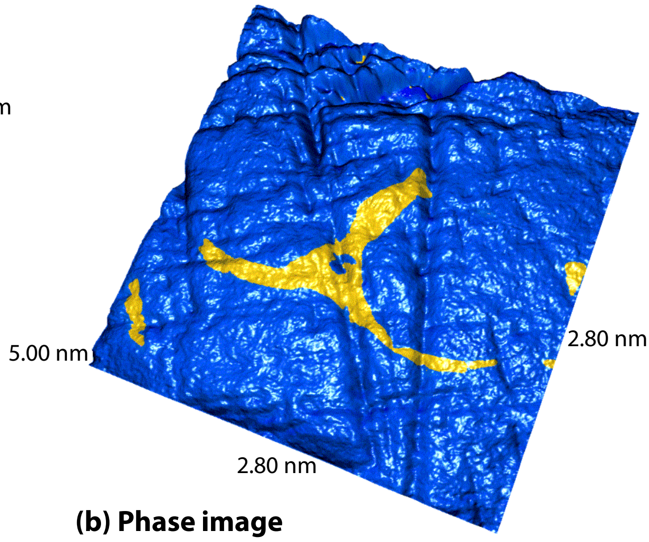
■ Conclusion

Using SPM, we successfully captured the distribution of polarized domains in ultra-small regions of $BaTiO_3$, a piezoelectric material. The polarized domains are one of the key factors in determining the properties of piezoelectric materials, and observation of their distribution will provide useful information for the development of piezoelectric materials according to their applications. Although we introduced here an example of capturing the vertical deformation of piezoelectric materials, the horizontal deformation (torsion) can also be observed in a similar manner.



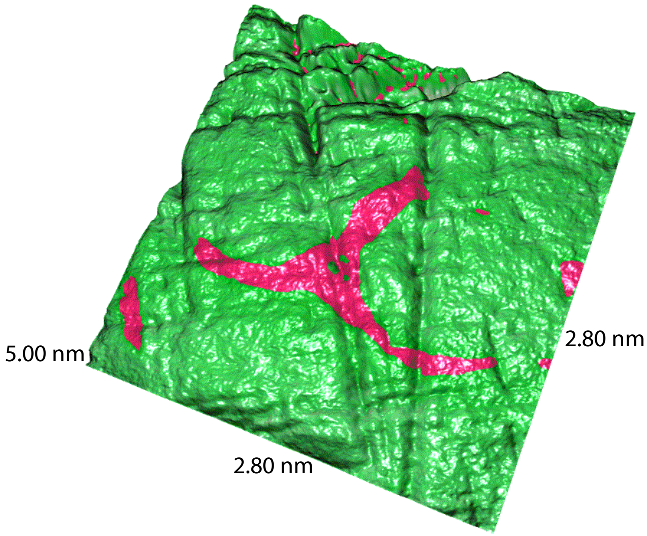
(a) Topographic image (surface topography image)

The topographic roughness on the $BaTiO_3$ surface are observed. The topographic image does not provide any information about the distribution of polarized domains on $BaTiO_3$.



(b) Phase image (overlaid on 3D topographic image)

The responses of $BaTiO_3$ to the applied AC voltage are observed. The area of the yellow pattern in the center of the view indicates that the direction of expansion and contraction in response to the applied voltage is different from that of the surrounding area. The polarized domain structure, which was not visible in the topographic image, is clearly captured.



(c) Amplitude image (overlaid on 3D topographic image)

The magnitude of expansion and contraction of $BaTiO_3$ in response to the applied AC voltage is observed. The area of the pink pattern in the center of the view indicates that the expansion and contraction in the area is smaller than those in the surrounding area. The polarized domain structure, which was not visible in the topographic image, is clearly captured.

Fig. 5 (a) Topographic, (b) Phase, and (c) Amplitude Images of $BaTiO_3$

SHIMADZU

Shimadzu Corporation
Analytical & Measuring Instruments Division
Global Application Development Center

www.shimadzu.com/an/

01-00010-EN First Edition: Sep. 2021