In-situ and precise atomic-scale transmission electron microscopy for electronic materials

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Intriguing physical properties of materials often originate from their micro and nano-scale structures and their responses to external stimuli. In this context, we explore dielectric materials as a prime example. The emergence of dielectricity, piezoelectricity, and ferroelectricity is closely linked to the intricate details of the crystal unit cell and the structure of domains where the polarization of numerous unit cells is aligned in the same direction. Moreover, the response of these structures to applied external electric fields plays a significant role. (Scanning) Transmission electron microscopy is a powerful method that enables us to elucidate detailed unit-cell and domain structures, along with their responses to an electric field, with high spatial resolution and in real time. In this talk, we will introduce some of our key results.

The atomic arrangement of crystals can be directly observed using atomic-scale STEM (scanning transmission electron microscopy). However, errors in the obtained internal atomic positions within unit cells and lattice parameters are usually not negligible. We have developed a methodology that significantly reduces these errors. Errors in lattice parameters can be reduced from 2−3% to 0.1%, and those in cell angles from approximately 0.6° to around 0.1° [1,2]. This method can be applied to determine or discover new crystal phases in localized regions.

In-situ electrical biasing transmission electron microscopy (TEM) has been utilized to visualize response of ferroelectric domain structure by applying electric fields. For example, it was clarified that lamellar-like nanodomains in a piezoelectric single crystal, PMN-PT ($0.68Pb(Mg_{1/3}Nb_{2/3})O_3-0.32PbTiO_3$) reorients by applying an electric field and revert to an original state when the field is removed. These results can explain a part of piezoelectric coefficient and the low hysteresis in the strain-electric-field loop [3]. Not only direct-current electric field but also alternative-current field can be applied using our system. Furthermore, such in-situ observations can be done at an atomic scale precisely by combining the aforementioned methodology [2,4].

References

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Acknowledgement

A part of this work was supported by JSPS KAKENHI (JP23K26382 and JP23H03804). A part of experiments was conducted at Ultramicorscopy center, Kyushu University and Engineering Research Equipment Center, Kumamoto University.