Experiment Brief

eaSI 4D STEM

Title

Nanobeam strain analysis using STEMx system and your existing Gatan *in-situ* camera

Gatan instrument used

The STEMx® system leverages eaSI™ technology to synchronize the STEM probe with the Gatan *in-situ* camera's fast frame rate to acquire high-quality 4D STEM datasets at high speed.

Background

Strain and its spatial distribution are closely related to the mechanical and electrical properties of materials. Strain analysis at high-spatial resolution (nanometer range), requires electron microscopy. While scanning electron microscopy-based techniques, such as electron backscattered diffraction (EBSD) or transmission-EBSD, can provide strain distribution information from large fields of view (hundreds of microns or larger), their spatial resolution is often limited to >10 nm. Two common STEM methods for high-resolution (~1 nm) strain analysis are the geometric phase analysis (GPA) method, which uses atomic column positions from HR STEM images, and the 4D STEM method, which uses nanobeam diffraction patterns. 4D STEM is the collection of diffraction images at each pixel position as the electron probe scans the specimen. The STEMx system leverages eaSI technology to synchronize the scanning probe with Gatan cameras and provides workflows for 4D STEM data collection and processing (e.g.,strain mapping, orientation mapping, virtual imaging, DPC imaging).

Materials and methods

A cross-sectional TEM specimen was lifted out from a $PbTiO_3$-$SrTiO_3$ (PTO-STO) multilayers synthesized from pulsed laser deposition. 4D STEM data was collected using a OneView® IS camera installed on a JEOL JEM-ARM300F2, operated at 300 kV in a special low convergency mode. The camera was set to bin x8 mode, giving a frame rate of 300 fps with 512 x 512-pixel frame size. A spectrum image of 100 x 150 pixels was collected at a step interval of 0.2 nm in 75 s.

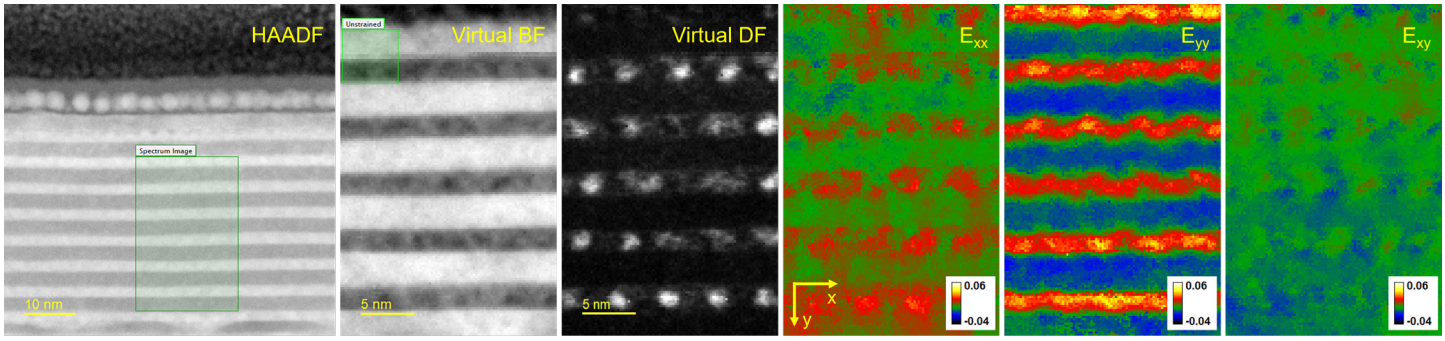

Figure 1. 4D STEM strain mapping results from the PTO-STO multilayer specimen. STEM-HAADF, Virtual BF/DF images and the three strain components E_{xx}, E_{yy}, E_{xy}.

4D STEM data was analyzed using the strain mapping module integrated in DigitalMicrograph® software. A rectangular region containing both layers closer to the free surface was set as the unstrained reference region. The in plane, out-of-plane, and shear strain components were calculated. Due to the slightly larger crystal lattice of PTO than STO, the PTO layers exhibit positive strain while STO, negative. However, because of the lattice constraint existed between the multilayers and from the substrate (further below, not shown here), the in-plane (E_{xx}) strain is smaller than the out-of-plane (E_{yy}) strain and decreases gradually from bottom to top. In contrast, E_{yy} almost remains constant both for PTO and STO layers due to the lack of lattice constraint along vertical direction.

Summary

The STEMx system was used to collect 4D STEM data and perform strain analysis on this PTO-STO multi-layer specimen at sub-nanometer spatial resolution. STEMx leverages eaSI technology to hardware synchronize the Gatan camera (OneView IS in this case) with the scanning probe and provides workflows for data collection and analysis in a single easy-to-use software interface, without requiring additional software, data conversion, or data transfer.

Credit(s)

A special thanks to Dr. Wanrong Geng, Prof. Yinlian Zhu and Prof. Xiuliang Ma, Bay Area Center for Electron Microscopy (BACEM), for sharing the data.

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