

Aberration-corrected STEM Observations on the Interfacial Structure and Strain Fields of Patterned SrRuO₃ Artificial Atoms

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Artificial atoms (AAs), also known as quantum dots or zero-dimensional electron systems, describe the shell structure of the electron states and their coherency across the material, which mimic the electron states of natural atoms by a coherent many-body wave function with one macroscopic phase [1]. The exotic electronic structure thus leads to fascinating optical, electrical and magnetic properties [2] that have been applied in the fabrication of novel catalytic, electronic, and photonic devices [3]. In addition, their novel strongly correlated electromagnetic properties are very susceptible to the size, geometry, strain and interfacial states [4]. For understanding the underlying physical properties of AAs, nanoscale structural explorations are indispensable.

In our work [5], SrRuO₃ (SRO) thin films were epitaxially grown on SrTiO₃ (STO) substrates by pulsed laser deposition and afterwards patterned to SRO AAs using ion milling and e-beam lithography. Aberration-corrected scanning transmission electron microscopy (STEM) investigations were carried out to unravel the interfacial atomic structure and strain distributions of the SRO AAs, which play a crucial role in the in-depth understanding of their intriguing properties. Simultaneously acquired atomically resolved high-angle annular dark-field (HAADF) and annular bright-field (ABF) images were used to evaluate the lattice structure of SRO AAs and the interfacial structure between STO and SRO. Figure 1(a) shows an HAADF-STEM image of a single SRO AA with a diameter of about 30 nm. The superimposed HAADF and ABF images in Figure 1(b) display the atomic structure at the interface. Given that the contrast of the HAADF image is proportional to $\sim Z^2$ with the atomic number Z , the atomically sharp interface between STO and SRO can be easily distinguished.

Geometric phase analysis was applied to experimental high-resolution HAADF images for evaluating strain fields in the SRO AAs. The spatial distributions of the out-of-plane and the in-plane strain are shown for a single 30 nm sized AA in Figure 2(a) and Figure 2(b), respectively. In the out-of-plane strain (ϵ_{xx}) map (Fig. 2(a)), color differences between STO and SRO indicate their intrinsic lattice mismatch. Large out-of-plane lattice expansion appears at the interface. A gradual color change is visible for the in-plane strain (ϵ_{yy}) map (Fig. 2(b)) due to the progressively relaxation of the epitaxial strain while approaching the surface of the SRO AA (Fig. 2(c)). Patterning of thin films is proven to greatly affect the strain environment, which provides one pathway for tuning material's functional properties [6].

References:

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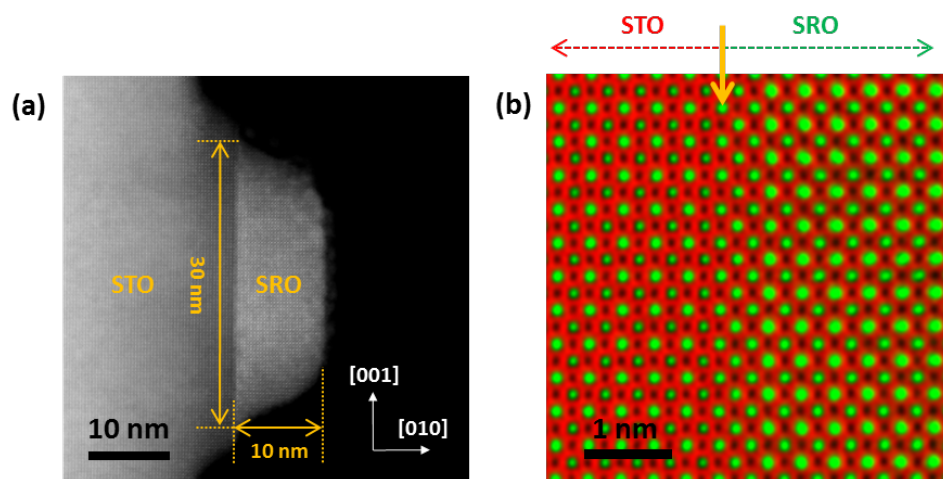


Figure 1. HAADF-STEM image of an individual SRO AA grown on an STO substrate. (b) Overlay of simultaneously acquired HAADF (green) and ABF (red) images of the interface area between STO and SRO. The yellow arrow indicates the nominal interface.

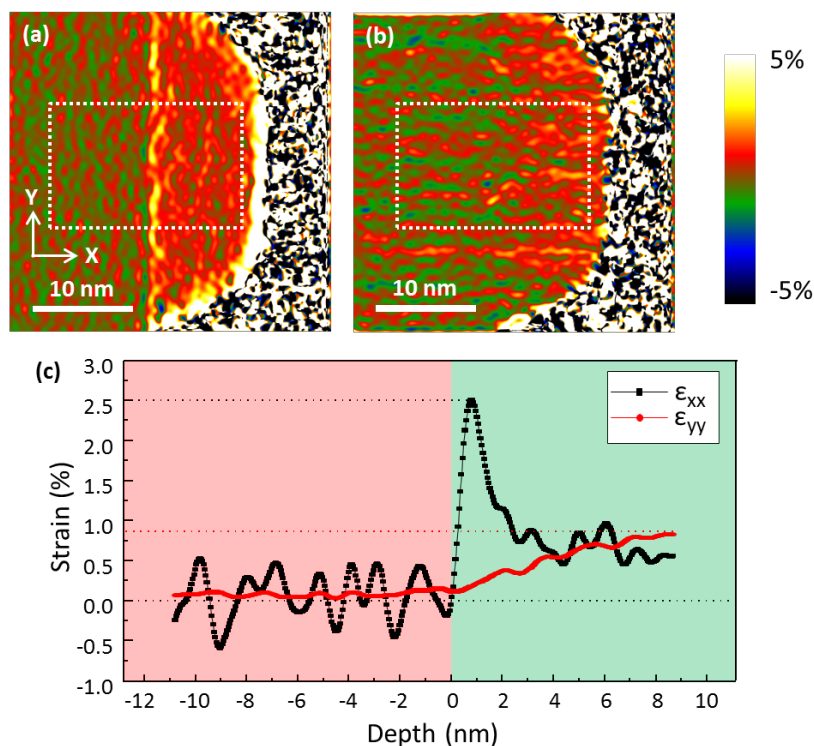


Figure 2. Out-of-plane (ϵ_{xx}) (a) and in-plane (ϵ_{yy}) (b) strain map for a 30 nm sized SRO AA. The color bar represents a strain range from -5% to 5%. (c) Vertical-averaged intensity profiles of the box region marked in (a) and (b). Red and black plots correspond to the in-plane and out-of-plane strain profiles, respectively.