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Supriya Ghosh, Fengdeng Liu, Bharat Jalan, K Andre Mkhoyan

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Meeting-report

Control of Extended Defect Growth in Perovskite Oxide Thin Films using Nanoscale Patterning

Supriya Ghosh[1,*], Fengdeng Liu[1,2], Bharat Jalan[1], and K. Andre Mkhoyan[1,*]

[1]*Department of Chemical Engineering and Material Science, University of Minnesota, Minneapolis, MN, USA*
[2]*Department of Electrical and Computer Engineering, University of Minnesota, Minneapolis, MN, USA*

*Corresponding author: ghosh115@umn.edu and mkhoyan@umn.edu

Extended defects are commonly present in thin film perovskite oxides, which can impact their performance in functional devices [1]. Recently, discovery of new unique defects with desirable properties has made it important to understand their origins to control their formation, which is imperative to design functionalities accessing these properties in applications like electrical conductivity, catalytic efficiency and magnetic transport [2–5]. Previous efforts to control defects in perovskite oxide thin films have utilized strain engineering techniques, by varying substrates used for growth [5–6]. In this work, we utilize nanoscale patterning using a Ga ion beam in a focused ion beam scanning electron microscope (FIB-SEM) to create atomically rough surfaces on the substrate with goals to control defect density in perovskite oxide thin films.

To create nanoscale patterns on the substrates, a Ga ion beam was used on an FEI Helios NanoLab G4 dual-beam FIB-SEM. Pattern lines with different milling depths were used to create trenches in the substrate, Nb:$SrTiO_3$ (STO). Thin films of $SrSnO_3$ (SSO) were grown on the patterned substrates using hybrid molecular beam epitaxy (MBE) [7]. Cross-section samples from the patterned areas were then prepared using the FIB-cut method to study thin film growth using a combination of scanning transmission electron microscopy (STEM) imaging and energy dispersive X-ray spectroscopy (EDX).

First, the impact of ion-beam modification of the STO substrate was investigated. Depending on the beam parameters, patterns of different sizes are created on the substrate surface (Fig. 1(a)). When looked in cross-section, ion-beam impacted areas showed formation of trenches with removal of STO as well as amorphization of neighboring regions (Fig. 1(b)). The patterned substrates were then used for growth of SSO films. SEM imaging after film growth showed uniform surface texture in non-patterned regions. In patterned areas, some surface texturing was visible, where the underlying patterns can be observed as seen in Fig. 1(c). This, as well as X-ray diffraction, confirmed the growth of epitaxial SSO thin film on the modified substrate. Next, impact of the substrate modification on the atomic structure of the film is studied using STEM. Fig. 2 (a) and (b) show a cross-section from a patterned area, where, the SSO film is epitaxially grown in both the trench as well as the flat substrate regions. A closer look into the SSO within the trenches reveals a network of horizontal and vertical Ruddlesden-Popper (RP) defects, as seen in Fig. 2 (c) and (d). This concentration of RP defect in trenches is much higher is the non-patterned areas, providing a method to control them in the trenched channel [8].

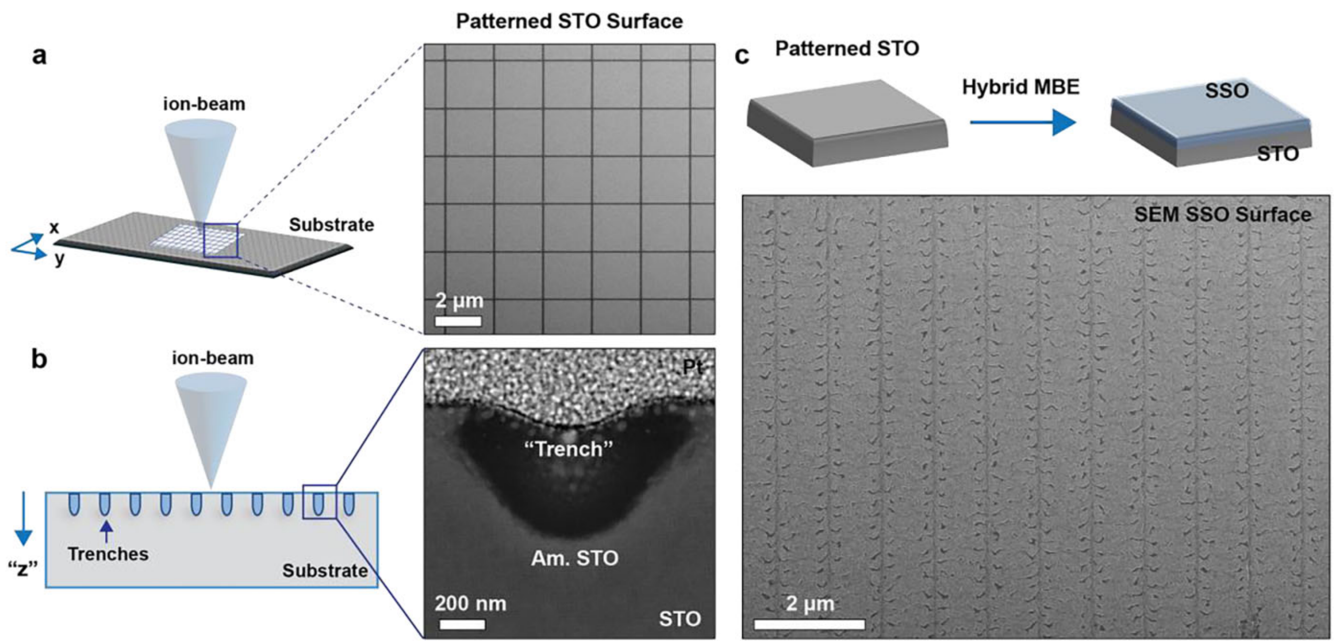

Fig. 1. (a) FIB patterning of a STO substrate surface, seen in an SEM image. (b) Ion-beam induced modification of the substrate surface when viewed in cross-section, showing a trench formed in STO, with surrounding amorphous region. (c) SEM image from the surface of a 13nm-thick SSO grown on top of patterned STO by hybrid MBE.

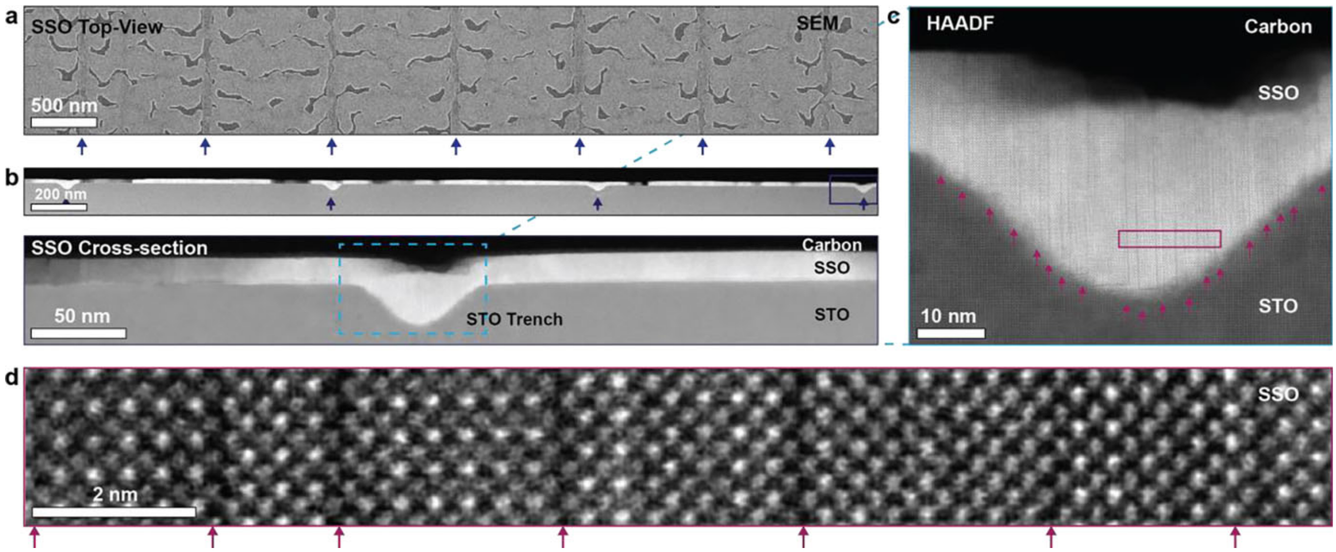

Fig. 2. (a) SEM image of SSO surface showing film growth on the patterned substrate, marked by the blue arrows. (b) Cross-section HAADF-STEM image from the same region as (a) showing multiple trenches and SSO film growth within. (c) SSO film structure inside one trench highlighted in (b) showing high density of vertical and horizontal Ruddlesden Popper (RP) defects. (d) Atomic-resolution HAADF showing one such arrangement of the RP faults within a trench.

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