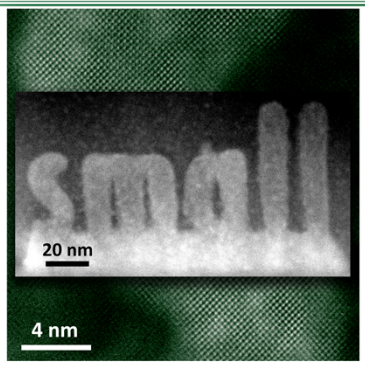
Nanofabrication with Single Atomic Plane Precision: Atomic-Level Sculpting Of Crystalline Oxides



The e-beam of an electron microscope is used to crystallize amorphous $SrTiO_3$ with atomic plane precision. The word "small" is epitaxially patterned onto a 160 X 80 nm area. The background is a zoomed-in, atomic resolution view of the letter "s".

This work was coordinated through ORNL's Institute for Functional Imaging of Materials (IFIM), as collaboration between a MSED-funded project, a strategic LDRD, and CNMS staff research.

Scientific Achievement

Fabrication of epitaxial nanostructures of complex oxide with single atomic plane precision and arbitrary shapes.

Significance and Impact

This bottom-up, atomic-level complement to 3D printing enables the formation of epitaxial structures as small as 1-2 nm.

Research Details

- The e-beam in an aberration-corrected scanning transmission electron microscope crystalizes an amorphous complex oxide (BES-MSED funded research).
- A precise e-beam control system was developed through a CNMS-led LDRD.
- Molecular dynamics simulations (CNMS research) shed light on the mechanism of beam-induced crystallization.

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Narrative Highlight Text:

Researchers developed a unique method[1] to create epitaxial nanostructure of a complex oxide with single atomic plane precision and arbitrary pre-defined shapes. This achievement not only provides another technique for manipulation and control of matter at the nanometer scale, which may advance the fundamental understandings of e-beam matter interaction and epitaxial growth mechanisms of complex oxides, but also suggests a way of larger scale atomic-level fabrication using existing e-beam lithography systems, providing a bottom-up, atomic-level complement to 3D printing.

The paper first describes the local implementation of the e-beam induced crystallization of amorphous-$SrTiO_3$ onto a crystalline-$SrTiO_3$ substrate in an aberration-corrected scanning transmission electron microscope (STEM). Epitaxial growth of $SrTiO_3$ crystalline structures as small as 1-2 nm with atomic plane precision has been achieved. Theoretical investigation suggests that the energy required for phase transition is transferred from e-beam through a knock-on process. A custom developed e-beam control system enabled the creation of arbitrary patterns by precisely controlling the e-beam path and dwell time. As a proof-of-concept, epitaxial growth of $SrTiO_3$ is achieved to pattern text "small" onto a 160-by-80-nm area. We believe that these studies can be extended to creating heterostructures as well as other non-equilibrium systems and materials, enabling fundamental experimental studies of crystallization, segregation, and diffusion processes at the atomic-level. This technique can be migrated into existing e-beam lithography systems to achieve larger scale device fabrication.

Reference

[1]"Atomic-level sculpting of crystalline oxides: towards bulk nanofabrication with single atomic plane precision"
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