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Observation of Dislocation-Assisted 2-Dimensional Conductive Channels Embedded in Perovskite Thin Films

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Fabrication of 1-Dimentional (1D) or 2-Dimentional (2D) nanochannels into a material matrix opens a path to controllable fabrication of complex nanostructures with refined patterns and allows the design strategy for novel and flexible nanodevices. During the growth of crystalline structures, various defects can form, which in turn may affect the growth dynamics and result in unique microstructures in nanoscale. Recently, it was found that dislocations, one of the most common types of defects, can cause the formation of arrays of metallic Ti nanowires into sapphires[1], or induce the growth of superlattices of WS_2 or MoS_2 nanoribbons into WSe_2 monolayers[2, 3], which represents the self-assembling of patterned quasi-1D channels into 2D or 3D matrices. However, the capability of producing ordered patterns of 2D channels into 3D materials have yet to be explored. In this work, we report the observation of the dislocation-assisted ~ 1 nm-thick 2D $BiMnO_3$ nanochannels in bulk perovskite thin films, the structure and composition are studied using cross-sectional scanning transmission electron microscopy (STEM), atomic energy dispersive X-ray spectroscopy (EDS), and conductive atomic force microscopy (c-AFM).

The thin film was synthesized by growing 25 u.c. thick SrTiO3 on 50 u.c. $La_{0.7}Sr_{0.3}MnO_3$ on $TbScO_3$ substrate. Then the Bi flux was kept on for 100 nm Bi equivalent growth time to deposit a Bi layer on top of $SrTiO_3$ thin film. The cross-sectional STEM image (Fig.1 a) of the as-grown heterostructure revealed 2D nanochannels with ~1 nm in thickness, penetrating through the $SrTiO_3/La_{0.7}Sr_{0.3}MnO_3$ heterostructure. Edge dislocations were found in the $La_{0.7}Sr_{0.3}MnO_3/TbScO_3$ interface. Bi atoms diffused from the top Bi layer through $SrTiO_3$ and $La_{0.7}Sr_{0.3}MnO_3$ layers and toward $La_{0.7}Sr_{0.3}MnO_3/TbScO_3$ interface, and Mn atoms diffused upward from $La_{0.7}Sr_{0.3}MnO_3$ layer. It was found that the diffusion of Bi occurs along channels which are coincidence with the extra lattice plans of the edge dislocations located at the $SrTiO_3$ and $La_{0.7}Sr_{0.3}MnO_3$ interface. The atomic resolution EDS mapping (Fig. 1c) shows the existence of Mn and Bi atoms in the channels. In Fig. 2a, the in-plane conductive atomic force microscopy (c-AFM) indicates the nanochannels grow through the entire film. The conductivity mapping (Fig. 2b) and corresponding I-V curves (Fig. 2d) indicate that the nanochannels are conductive with diode-like behavior.

In conclusion, we report the observation of dislocation-inducced conductive 2D nanochannels in a 3D insulating oxide thin film. Further analysis on the structure and composition shows the existence of $BiMnO_3$, which will be discussed together with more studies on transport magnetism and phase field simulations. This work opens up a way to create 2D conductive path in 3D insulator, giving raise to novel and flexible multidimensional manipulations for nanodevices [4].

References:

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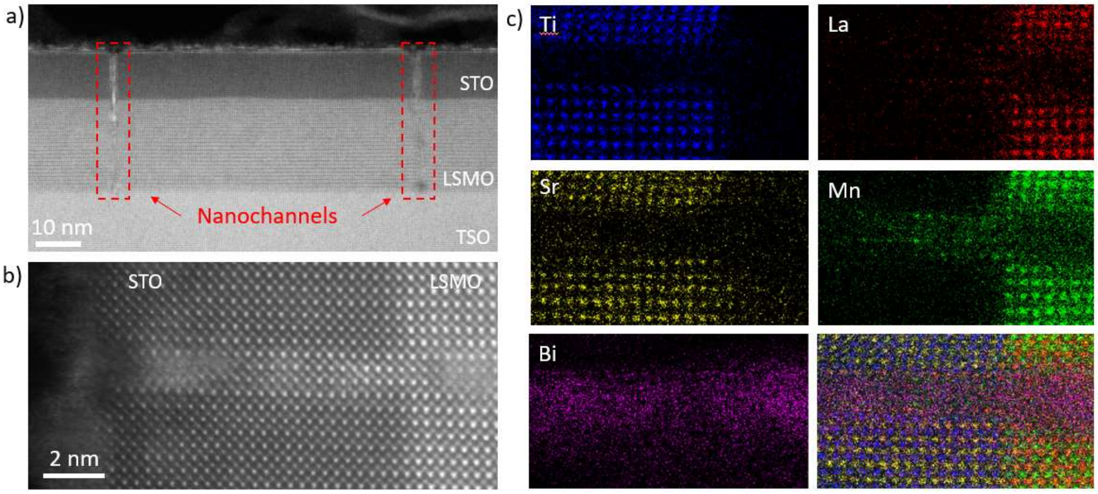

Figure 1. 2D nanochannels and corresponding atomic EDS. (a) Cross-sectional HAADF STEM image and (b) nanochannel atomic structures. (c) is the corresponding atomic EDS mapping on the nanochannel shown in (b).

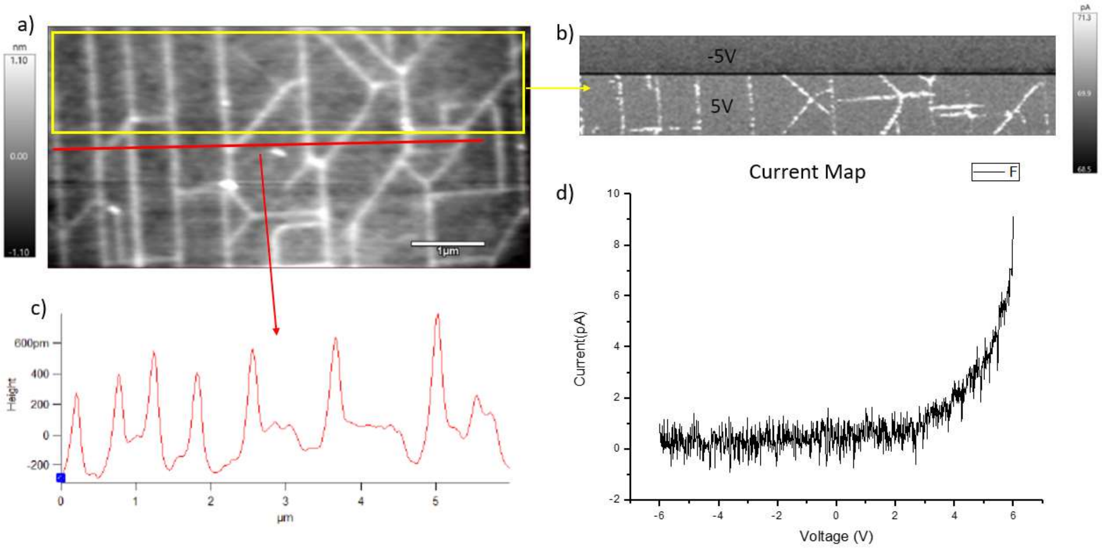

Figure 2. Height and conductivity measurements of 2D nanochannels. (a) Planner view c-AFM phase image of 2D nanochannels with (b) conductivity measurements and (d) corresponding I-V curve, and (c) height measurements.