

TEM Study of Oxide Nanopillars in Superconducting BaFe₂As₂ Films for Vortex Pinning

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In recent years major efforts have been invested in optimizing high-temperature superconductors by increasing their critical current density J_c and reducing their anisotropy. This requires pinning the magnetic flux vortices whose motion under the Lorentz force results in energy loss. In general, optimum vortex pinning is achieved by a high density of nanoscale defects whose size is comparable to twice the superconducting coherence length ξ , especially when elongated along the applied magnetic field direction [1].

Recently, we have observed correlated line defects in thin films of the Co-doped superconductor BaFe₂As₂ (Ba-122) grown on SrTiO₃ (STO) surfaces which exhibit strong and anisotropic vortex pinning [2]. In this work we report on the structure, composition and growth mechanisms of these nanopillars using sub-Å resolution transmission electron microscopy (TEM) and electron energy-loss spectroscopy (EELS). The TEM shows how a high density of nanopillars can be incorporated in the Ba-122 films while producing very strong vortex pinning and very high J_c without degrading the structural properties of the superconducting matrix [3].

The microstructure of a Co-doped Ba-122 film grown on 100 u.c. STO buffered LSAT is shown in the cross-sectional TEM image of Fig. 1(a). The corresponding selected-area electron diffraction (SAED) pattern (Fig. 1(b)) shows the film is single crystal and epitaxial to the substrate. A moderate density of vertical nanosized pillars nucleate at the Ba-122/STO interface and grow parallel to the c-axis as shown in the insert of Fig. 1(a). A planar view STEM image (Fig. 2(a)) shows the uniformly distributed nanopillars with a uniform size of 4-5 nm. Z-contrast images (Fig. 2(b)) show the nanopillars have a rectangular cross section and a perovskite structure. EELS analysis across such a nanopillar (Fig. 3(a)) indicates a compositional variation from the surrounding film (Fig. 3(b)). It shows that the nanopillar is a Ba-Fe-O phase that does not contain As. Quantitative analysis suggests that the elemental ratio of Ba:Fe:O varies from 1:1:2 to 1.4:1:2.8 suggesting they are nonstoichiometric BaFeO₂. The BaFeO₂ nanopillars nucleate as nanosized oxide islands on the STO template as shown in Fig. 4(a). The nanopillar shape and size is due to the low-energy (100) planes of the perovskite structure and the misfit with Ba-122 and the LSAT substrate which puts the nanopillars in compression from both the substrate and the surrounding Ba-122 matrix as schematically shown in Fig. 4(b).

In conclusion, the oxide nanopillars exist in Ba-122 films grown on STO templated LSAT substrates with reduced oxygen content. The nanopillars form an epitaxial BaFeO₂ phase that nucleates on the surface of the STO template. The in-plane compressive misfit strain restricts the lateral size of the nanopillars to ~10 u.c. The high density of these self-assembled nonsuperconducting nanopillars provides very effective flux pinning centers in the Ba-122 film.

References

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- [4] The authors gratefully acknowledge the financial support through DOE grant DoE/BES DE-FG02-07ER46416 and NSF DMR-0907191.

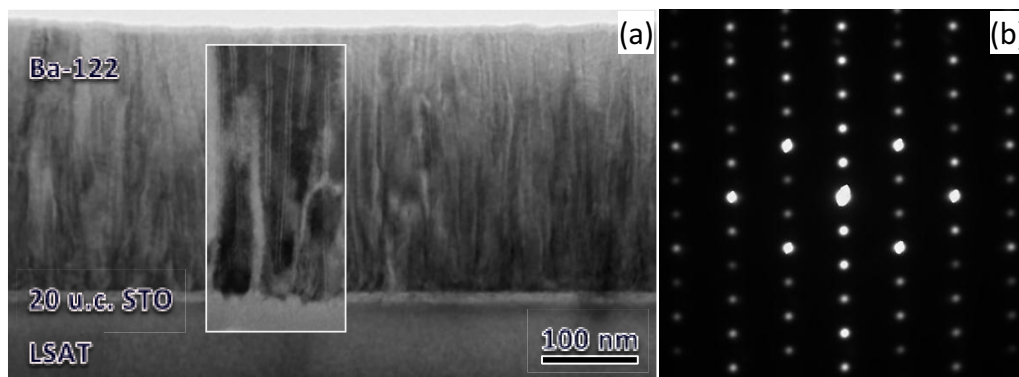


Figure 1 – (a) Cross-sectional TEM image of Ba-122 / 20u.c. STO / LSAT. Insert shows nanopyllars near the interface. (b) Corresponding electron diffraction pattern.

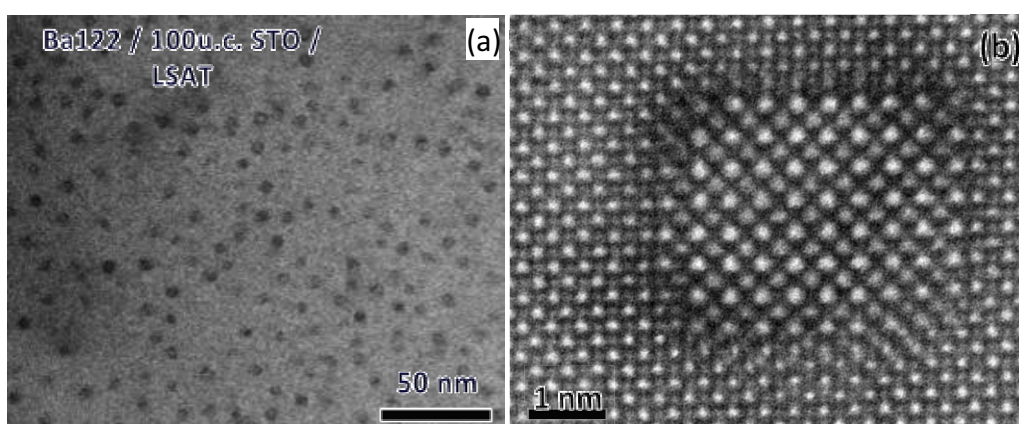


Figure 2 – (a) Planar-view STEM image of Ba-122 grown on STO / LSAT. (b) Z-contrast image of an nanopyllar.

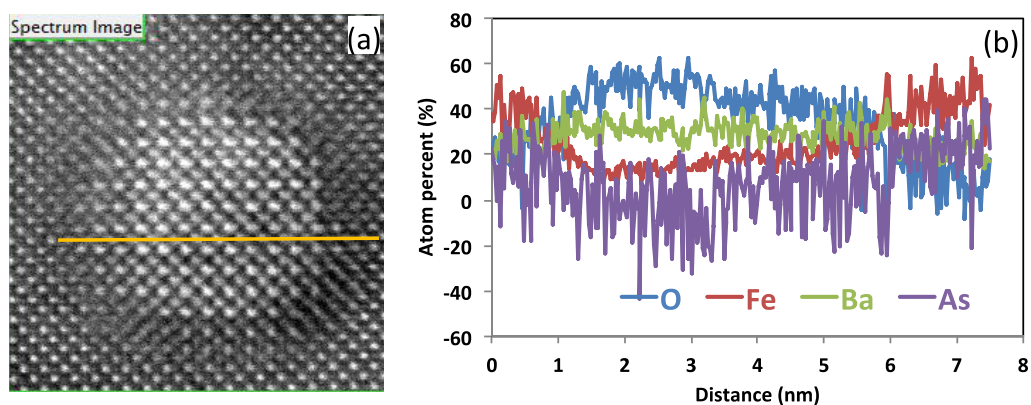


Figure 3 – (a) HAADF image of the analyzed region. (b) The change of the atomic ratio of Ba, Fe, As and O measured by EELS.

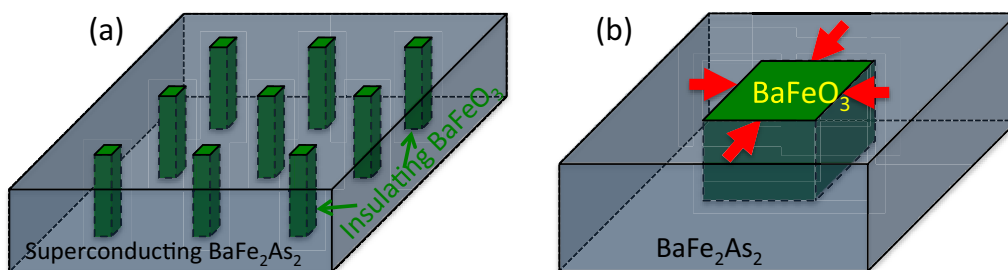


Figure 4 – Schematic models showing the growth of the oxide nanopyllars in Ba-122 matrix.