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# Chemical and electronic structure of $BaZrO_3$ nanorods and $RE_2O_3$ particles embedded in superconductive REBCO

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Inclusion of 3D crystalline defects in type-Ⅱ superconductors to improve magnetic flux-pinning, and thus to achieve high current densities, has been widely adopted for development and application of superconducting materials, which is best exemplified by BaZrO3(BZO)-YBa2Cu3O7-δ system1. In particular, self-assembled BZO nanorods in Zr-doped REBa2Cu3O7-δ (Zr:REBCO) superconductors (RE=Y, Gd) have shown promising superconducting properties including high critical temperature and high critical current densities2, 3. In Zr:REBCO films, formation of RE2O3 precipitates in addition to BZO has been also readily observed4. To understand the impact of the embedded nano-scale structures on the materials properties, elemental characterization of them is essential. Here, the chemical and electronic structure of BZO nanorods and RE2O3 nanoparticles in Zr:REBCO matrix is studied at the atomic-resolution utilizing analytical STEM.

Zr:REBCO films were grown by using advanced Metal-Organic Chemical Vapor Deposition (A-MOCVD)3. Plan-view TEM samples were prepared by mechanical dimpling and cross-sectional samples were prepared using focused ion-beam. STEM experiments were carried out using aberration-corrected FEI Titan G2 60-300 (S)TEM equipped with Super-X energy dispersive X-ray spectrometer for EDX and a GatanEnfinium ER EELS. STEM-EELS data was acquired with the monochromated electron beam.

Fig. 1(a) shows ADF-STEM images of the Zr:REBCO film containing BZO nanorods and RE2O3 nanoparticles that was used in this study. Plan-view ADF-STEM images show projected images of BaZrO3 nanorods grown in the c-axis as darker and brighter circular contrasts in HAADF- and LAADF-STEM images, respectively. In cross-sectional ADF-STEM images, bright contrasts spanning along the lateral (in-plane) direction, as well as vertical contrasts from BZO nanorods, are seen, which are likely from RE2O3 particles. Atomic resolution ADF-STEM images and EDX elemental maps of the BZO and RE2O3 precipitates (Fig. 1(b)) reveal unexpected dissolution of Y and Gd in BZO and Zr in RE2O3 nanoparticles, indicating the change of local stoichiometry and, possibly, chemical valence. The local electronic structures of BZO nanorods and RE2O3 in Zr:REBCO are examined by EELS core-loss edges5, where the core-edge fine structures are compared with the density of states of the materials derived from ab initio calculations.6,7

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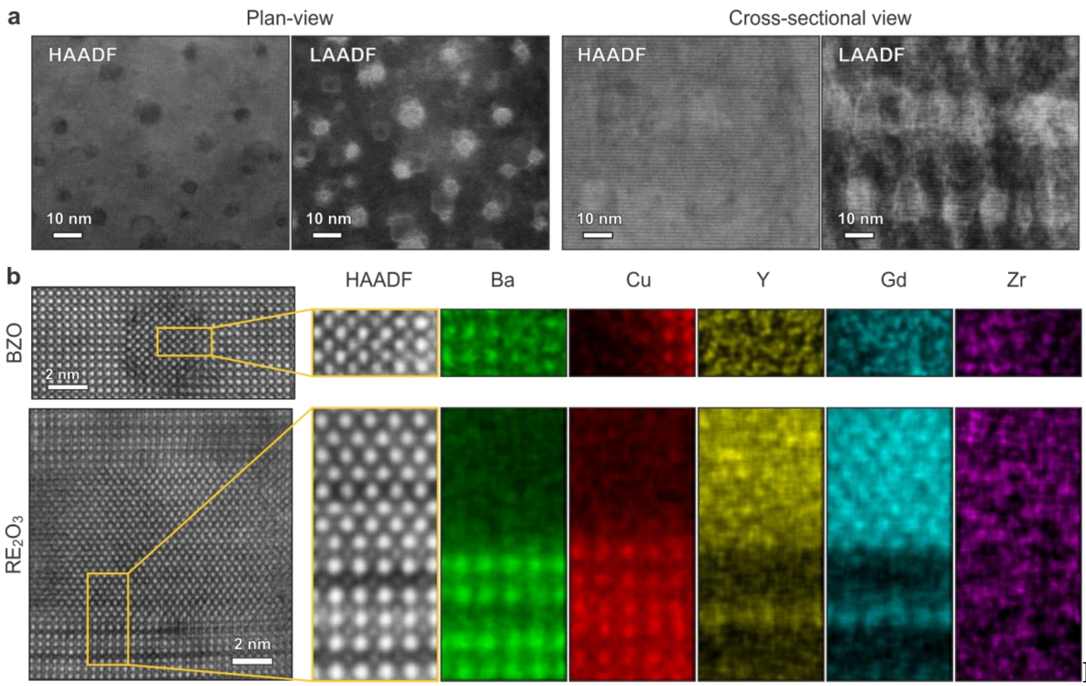


**Figure 1.** Figure 1. (a) HAADF- and LAADF-STEM images of Zr:REBCO films from plan-view and cross-sectional view directions. (b) Atomic-resolution HAADF-STEM images and EDX elemental maps of BZO and RE2O3: (top) BZO nanorods from the plan-view direction, (bottom) RE2O3 particles from the cross-sectional view direction.

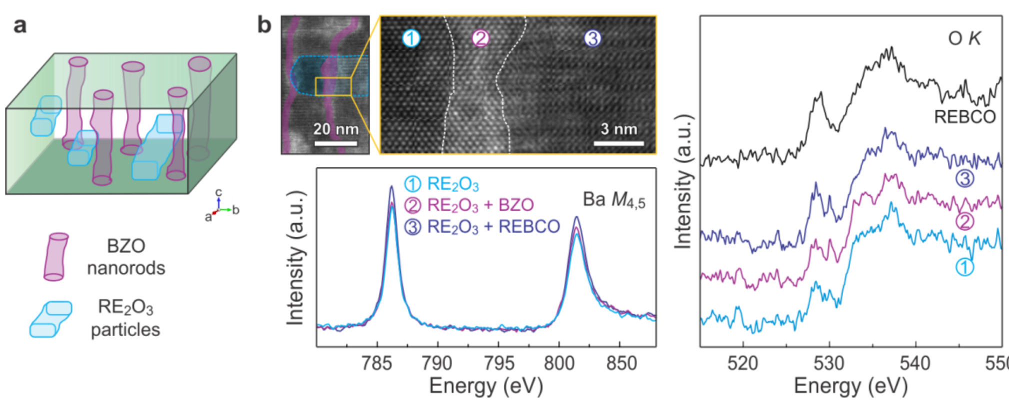


**Figure 2.** Figure 2. (a) Simple schematic of Zr:REBCO + BZO + RE2O3 matrix. (b) EELS core-loss edges (Ba M4,5 and O K) obtained from RE2O3 and BZO in Zr:REBCO.

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