Development of Strong and Isotropic BaZrO$_3$ Artificial Pinning Centers in YBCO Films

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Abstract — Artificial pinning centers (APCs) with controlled morphology, dimension, and concentration are key to optimal pinning in superconducting thin films and coated conductors. Strain-mediated self-assembly of APCs is regarded as a viable approach to form APCs in YBa$_2$Cu$_3$O$_{7-x}$ (YBCO) during growth. This makes understanding the growth mechanism essential to controllable formation of desired APCs that provide strong and isotropic pinning. In this work, an integrated study of theoretical modeling and experimental exploiting is presented focusing on the goal to controllably generate 3D pinning landscape by employing several approaches: 1) BaZrO$_3$ and BaSnO$_3$ single doping with variable concentrations by manipulating local and global strains; 2) BaZrO$_3$ and Y$_2$O$_3$ double doping to impede BaZrO$_3$ nanorods formation using Y$_2$O$_3$ and to promote 3D BaZrO$_3$ APCs at high BaZrO$_3$; and 3) low temperature growth of BaZrO$_3$ doped YBCO film to impede BaZrO$_3$ nanorods, followed with fast thermal annealing at higher temperature to promote 3D BaZrO$_3$ APCs. The resulted 3D pinning landscape affects directly the scaling behavior of pinning $J_c$ ($T$, $H$, $\vartheta$). In particular, by fitting the Dew-Hughes equation of the pinning force $F_p$ ($H$) at different temperatures of $T$=30-77K and angles of the applied magnetic field $H$ from parallel ($\vartheta$=0), to $\vartheta$=45 deg. and to perpendicular to ($\vartheta$=90 deg.) the c-axis, we extract the scaling behaviors of the $F_p$ ($H$) to provide insights on the pinning efficiencies of the of APCs interactively as their concentrations are varied to cause strain field overlap.

Keywords, Index Terms—YBCO films, artificial pinning centers, strain-mediated self-assembly, critical currents, pinning force, scaling