Micro-straining tuning for strong and isotropic artificial pinning centers (APCs) in YBCO films

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Epitaxial APC/RE-123 nanocomposites

Controlling parameters:
• Lattice mismatch at the interfaces (three shown)
• Elastic properties of both APCs and RE-123

• Shi and Wu, *Philosophic Magazine* 92, 2911 (2012); 92, 4205 (2012);
• Wu and Shi, in SUST Special Issue on Artificial Pinning Centers (2017), DOI:10.1088/1361-6668/aa8288
Understanding the Interplay of strains is important towards controlling APCs

**Specific questions:**

- **Morphology:** What impurity materials will form aligned nanorods (1D APCs) or nanosheets (2D APCs) and nanoparticles (3D APCs) in YBCO matrix?
- **Dimension:** What determines the dimension of the APCs?
- **Orientation:** What determines APC orientations? Is it possible to obtain mixed orientations from the same dopant?
- **Mixed APCs:** 3D pinning landscape via control of each types of APCs? (by *vicinal* or/and double doping)
Elastic Strain Model + Experiment
Understanding & controlling self-assembly of artificial pinning centers

APC material selection
APC morphology can be pre-screened based on their elastic properties & lattice constants

APC dimension
1D APC diameter is determined by the inverse strain decay length $\lambda_1(2)$

APC orientations
Configurations of APCs can be tuned by both APC concentration and YBCO matrix strain

Shi and Wu, Philosophic Magazine 92, 2911 (2012); 92, 4205 (2012); Wu and Shi, SUST Special Issue on Artificial Pinning Centers (2017) ASAP

Wu and Shi, in SUST Special Issue on Artificial Pinning Centers (2017), DOI:10.1088/1361-6668/aa8288
Switch of 1D APC orientation

1D APC switch from c-aligned to ab-aligned at high APC concentrations

Increasing YBCO matrix ab-plane tensile strain can cause splay around c-axis and switch from c- to ab-aligned of BaZrO$_3$ and BaSnO$_3$ APCs.

Flat STO

(a) Flat 2 vol. %

(b) Flat 4 vol. %

(c) Flat 6 vol. %

5 deg Vicinal STO

(d) 5° 2 vol. %

(e) 5° 4 vol. %

(f) 5° 6 vol. %

1D (c-axis)

1D (c-axis)+2D APC (ab-plane)

2D APC (ab-plane)

Wu et al, SUST 28, 125009(2015)
Mixed orientations of 1D+2D APCs

APCs of mixed morphologies can be generated from the same APC material
Benefits of mixed 1D+2D APCs: enhanced $J_c$

Overall enhanced $J_c$ in all H directions in mixed BZO APC/YBCO possibly due to 1) reduced strain on YBCO; 2) mixed orientations of BZO APCs
1D+2D+3D mixed APCs
Rigidity of 1D APCs – tuning APC morphology using double doping (DD)

1D APCs with higher rigidity:
BSO + Y2O3:
1D + 3D APCs

1D APCs with lower rigidity:
BHO (BZO) + Y2O3:
1D + 2D + 3D APCs

Wu and Shi, in SUST Special Issue on Artificial Pinning Centers (2017), DOI:10.1088/1361-6668/aa8288
4 vol % BZO+3 vol % Y$_2$O$_3$  6 vol % BZO+3 vol % Y$_2$O$_3$

(a)  

(b)  

(c)  

(d)  

(e)  

1D APC  2D APCs  3D APCs

Chen et al, submitted to SUST
Opposite trends in $J_c$ of DD (BZO+Y$_2$O$_3$) and SD (BZO only) with BZO APC concentration

Chen et al, submitted to SUST

Reduced $J_c$ anisotropy in DD samples

6 vol % BZO (open) vs. 6 vol% BZO +3 vol % Y$_2$O$_3$ (solid)
B. Gautam et al, *AIP Advances*, 7 (7), 0753082017; Gautam et al, manuscript in preparation
Low rigidity of BHO 1D APCs allow mixed 1D+2D+3D APCs to be obtained via double doping for reduced $J_c$ anisotropy.

B. Gautam et al, *AIP Advances*, 7 (7), 0753082017;

Gautam et al, manuscript in preparation.
2-6 vol% BHO + 3 vol % $Y_2O_3$ (open-65K, solid-77K)

4% BHO DD shows the best $J_c$, and smallest angular misalignment. More ab-aligned APCs at 6% BHO DD

B. Gautam et al, *AIP Advances*, 7 (7), 0753082017; Gautam et al, manuscript in preparation
Summary

- Understanding the Interfacial strains (local and global) provides means to control APC’s morphology, orientation and dimension.

- Two approaches have been explored to generate mixed APCs:
  - Single-doping APC (BZO, BSO) for 1D+2D APC/YBCO via control of the APC concentration and YBCO in-plane lattice constants (vicinal)
  - Double-doping $\text{Y}_2\text{O}_3 + \text{BZO}$ (or BHO) for 1D+2D+3D APC/YBCO at different concentrations

- The mixed APCs provide benefits of strong and isotropic pinning