Comparison Study of the Flux Pinning Enhancement of YBCO Superconductor with $BaHfO_3$ and Y_2O_3 Single and Mixed Phase Additions

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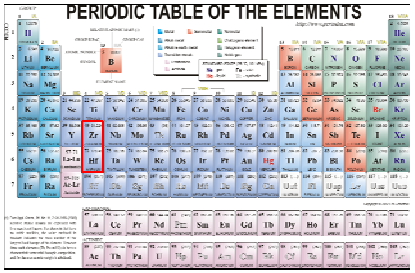
Introduction

Abstract: Adding nanophase defects to $YBa_2Cu_3O_{7-\delta}$ (YBCO) superconductor thin films is well-known to enhance flux pinning, resulting in an increase in current density (J_c). While many previous studies focused on single phase additions, the addition of several phases simultaneously shows promise in improving current density by combining different pinning mechanisms. This paper compares the effect of the addition of two insulating, nonreactive phases of barium hafnium oxide (BHO) and yttrium oxide Y_2O_3, both as a single addition of BHO and as a double addition in conjunction with Y_2O_3. Processing parameters vary the target composition volume percent of BHO from 2-6 vol. % for the single doped YBCO targets and while maintaining 3 vol. % Y_2O_3 for the double doped YBCO targets. Pulsed laser deposition produced thin films on $LaAlO_3$ (LAO) and $SrTiO_3$ (STO) substrates at various deposition temperatures. Comparison of strong and weak flux pinning mechanisms, current densities, critical temperatures, and microstructures of the resulting films will be presented.

	Lattice Parameter (Å)	Lattice mismatch to YBCO wrt ab-avg	Lattice mismatch to YBCO wrt c-axis	Overall Avg. Mismatch
YBCO	a = 3.825 b = 3.886 c = 11.66			
Y_2O_3	10.604	-2.8%	-9.1%	-5.6%
$BaZrO_3$	4.193	8.8%	7.9%	8.3%
$BaHfO_3$	4.161	7.94%	7.06%	7.5%
$LaAlO_3$	3.7903	-1.65%		-1.65%
$SrTiO_3$	3.903	1.24%		1.24%

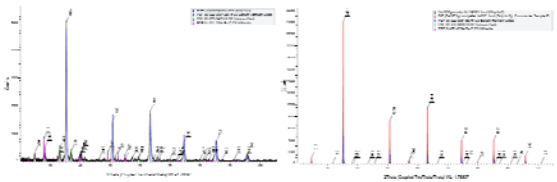


Synthesis of $BaHfO_3$

$BaCO_3(s) + HfO_2(s) \longrightarrow BaHfO_3(s) + CO_2(g)$

- Box Furnace: Ramp rate 150 °C / hr, 1000 °C for 2 hours
  $BaCO_3(s) \longrightarrow BaO(s) + CO_2(g)$
- Ramp rate 150 °C / hr, 1400 °C for 8 hours
  $BaO(s) + HfO_2(s) \qquad BaHfO_3(s)$

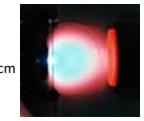
XRD Confirmation



Experimental

PLD Process Parameters

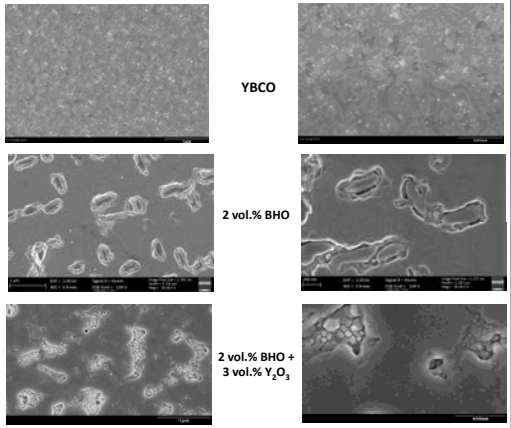
- Laser = KrF, 248 nm
- Fluence ~ 1.6J/cm²
- Rep. Rate 8 hz
- Target-to-Heater Distance = 5.5 cm
- Atmosphere = 300 mTorr O_2
- Laser Energy = 450 mJ



Deposition Parameters							
Target	YBCO (vol.%)	BHO (vol.%)	Y_2O_3 (vol.%)	Temperature (°C)			
				790	810	825	840
TS204	95.0	2.0	3		X		
TS205	93.0	4.0	3	X	X	X	X
TS206	91.0	6.0	3		X		
TS208	98.0	2.0			X		

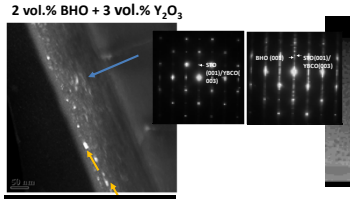
SEM

20 kX | 50 kX

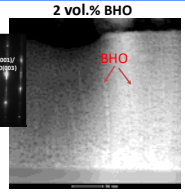


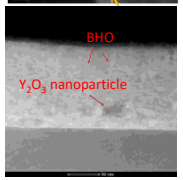
TEM

2 vol.% BHO + 3 vol.% Y_2O_3

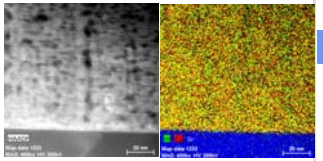


2 vol.% BHO





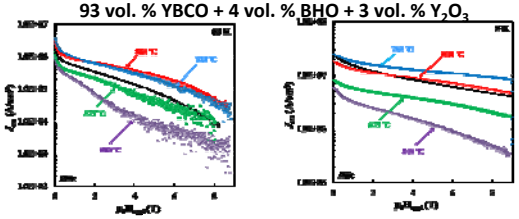
EDX Mapping 2 vol. % BHO



Results

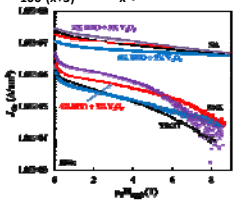
J_{cm} vs. H_{appl}

93 vol. % YBCO + 4 vol. % BHO + 3 vol. % Y_2O_3

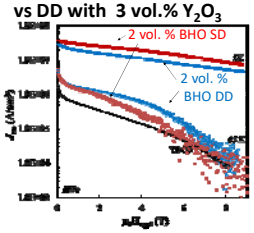


J_{cm} vs. H_{appl} 810 °C

$YBCO_{100-(x+3)}BHO_x$ (x = 2,4,6 vol.%) Y_2O_3 = 3 vol.%

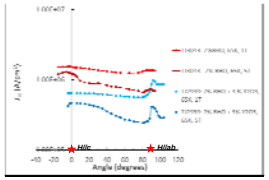


J_{cm} 2 vol. % BHO SD vs DD with 3 vol.% Y_2O_3



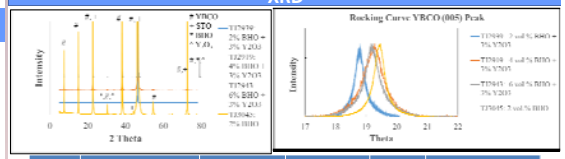
Angular J_{ct}

2 vol. % BHO + 3 vol.% Y_2O_3



	YBCO STO substrate	2 vol. % BHO + 3 vol. % Y_2O_3 + 93 vol. % YBCO STO substrate	4 vol. % BHO + 3 vol. % Y_2O_3 + 93 vol. % YBCO STO substrate	6 vol. % BHO + 3 vol. % Y_2O_3 + 93 vol. % YBCO STO substrate	2 vol. % BHO + 98 vol. % YBCO STO Substrate
T_c K	89.2	88.4	87.1	85.8	88.9

XRD



Film #	Composition	Deposition Temp °C	FWHM (005)YBCO	β	c-lattice parameter (005) YBCO peak (Å)
TJ2939	2 vol.% BHO + 3% Y_2O_3	810 °C	0.353	0.457	11.7779
TJ2919	4 vol.% BHO + 3% Y_2O_3	810 °C	0.759	1.003	11.7571
TJ2943	6 vol.% BHO + 3% Y_2O_3	810 °C	0.567	0.853	11.7336
TJ3045	2 vol.% BHO	810 °C	0.418	0.596	11.7779

YBCO c-lattice parameter = 11.707 Å thin film, 11.66 Å single crystal

Conclusions

- Optimization of J_{cm} occurs at a deposition temperature of 810°C for a concentration of 2 vol.% BHO + 3 vol.% Y_2O_3.
- Epitaxial thin films containing BHO nanorods and Y_2O_3 nanoparticles confirmed with SEM, TEM, and XRD
- Combining BHO with Y_2O_3 improves pinning and J_c at higher temperatures for all fields up to 8T.
- Doping with BHO only at 5K is preferred for all fields up to 8T.
- Combining BHO with Y_2O_3 decreases the difference between J_{ct} with *H//ab* and *H//c* direction.