Investigation on the Superconducting Properties of YGBCO/STO/YGBCO Tri-layer

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4MP5-10

Introduction

For applications in electrical equipment and mass production, high critical current density (J_C) is required. Unfortunately, J_C decreases with increasing YBCO layer thickness in many cases. Some groups tried slowing down the decrease tendency, but when the thickness of the superconducting layer is over 2 μm, the decrease is still obvious.

Superconductor/insulator/superconductor tri-layer structure can effectively inhibit thickness effect. In former studies, STO, $LaAlO_3$, CeO_2 and $NdAlO_3$ were used as inter-layer materials. Among these materials, STO films represent a promising candidate due to their good chemical stability and small lattice mismatch between YBCO and STO.

Usually, the inter-layer is very thin to match the short coherent length of YBCO along the c-axis direction. And the tri-layer structure is usually prepared symmetrically, which means the thicknesses of the bottom-layer and upper-layer are the same. Former work often focus on the influence of inter-layer on the whole structure.

Motivation

$Y_{0.5}Gd_{0.5}Ba_2Cu_3O_{7-\delta}$ as superconducting layer	←←	T_C>77 K
CeO_2 buffered substrate	←←	High quality template for subsequent deposition of YGBCO films, lattice mismatch -0.52%
Tri-layer structure	←←	To inhibit thickness effect
80 nm STO inter-layer	←←	Former experiment
Asymmetrically	←←	Bottom-layer may have influence on the whole sample's superconducting property
Pulsed Laser Deposition (PLD)	←←	High deposition rate and capability of stoichiometric transfer materials from target to substrate

Method

- **Structure of samples**

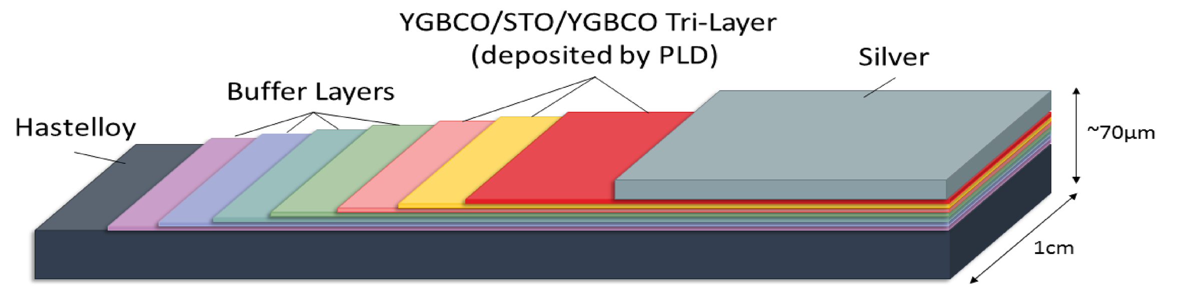


Fig. Basic structure of YGBCO coated conductor.

- **Pulsed Laser Deposition (PLD) system**

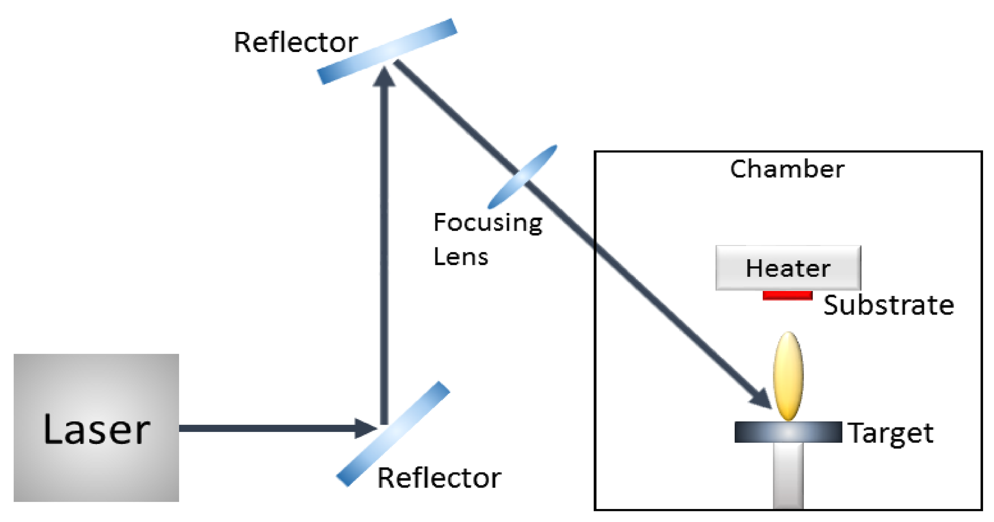


Fig.2 Sketch of the pulsed laser deposition system.

Experimental parameters:

- ✓ KrF excimer laser wavelength of 248 nm
- ✓ Laser power density P_L=1.0 J/cm^2
- ✓ Incident angle between the laser beam and the target surface of 45 °
- ✓ Distance between the substrate and the target of 4 cm.
- ✓ Laser repetition frequency of 160 Hz
- ✓ Oxygen partial pressure P_O=200 mTorr

- **Detail information of samples**

TABLE I
THE DETAILS OF THICKNESS IN DIFFERENT SAMPLES

Label	Total thickness of YGBCO (nm)	Bottom YGBCO layer (nm)	Upper YGBCO layer (nm)
S1	720	240	480
S2	720	480	240

When depositing the tri-layer structure, a multi-step deposition process was used, in which the thickness of the superconducting layer was increased by additional deposition cycles. In each standard cycle, the thickness of the deposited YGBCO layer was approximately 240 nm.

Hence, the deposition of the tri-layer structure in S1 consisted of one standard cycle as the bottom-layer, and two standard cycles as the upper-layer, while S2 had an opposite deposition process.

The thicknesses of the whole YGBCO superconducting layer of the two samples were both 720 nm. The thickness of the STO inter-layer was 80 nm, based on former experiment results.

Results and Discussion

- **Microstructure analysis**

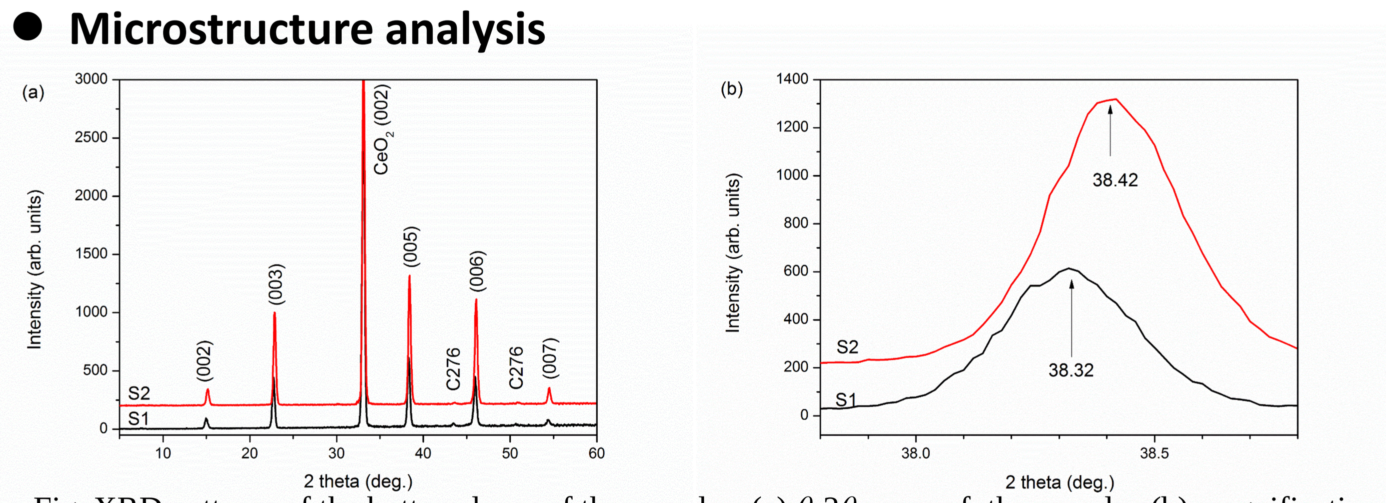


Fig. XRD patterns of the bottom-layer of the samples. (a) θ-2θ scans of the samples;(b) magnification of YGBCO (005) peak.

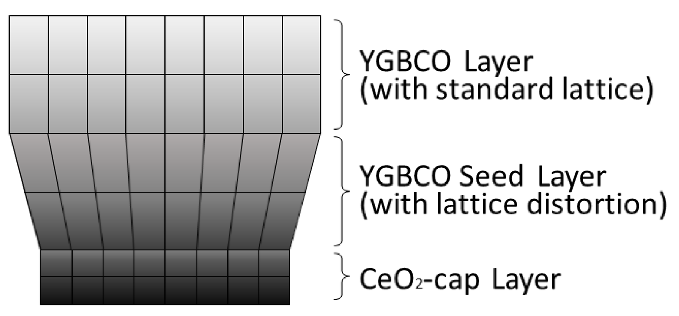


Fig. Schematic diagram of possible growth model for bottom layers in different thickness.

$C-axis$ orientation → Peak shift → Internal residual stress → **Possible growth model**

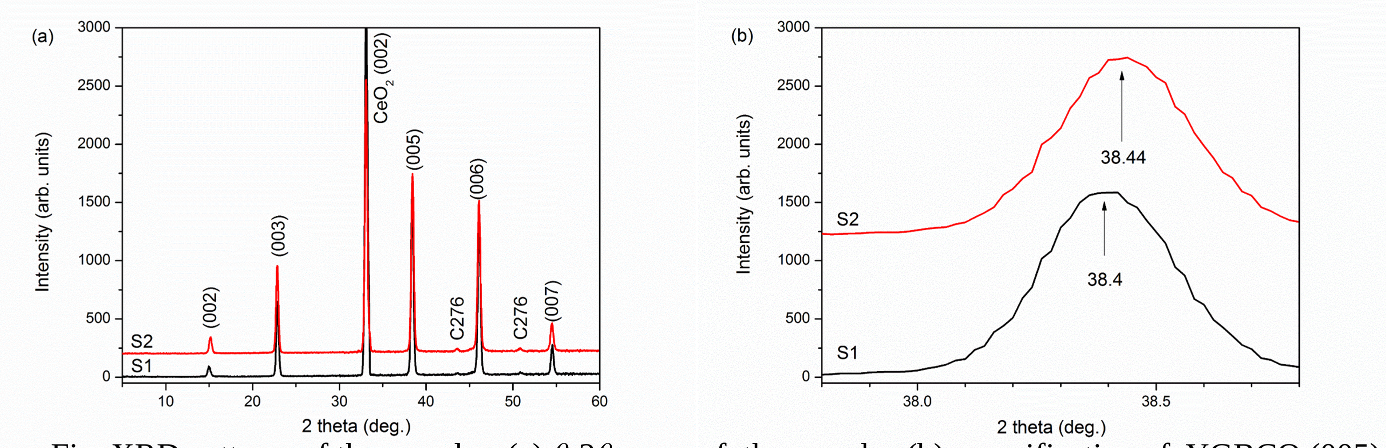


Fig. XRD patterns of the samples. (a) θ-2θ scans of the samples;(b) magnification of YGBCO (005) peak.

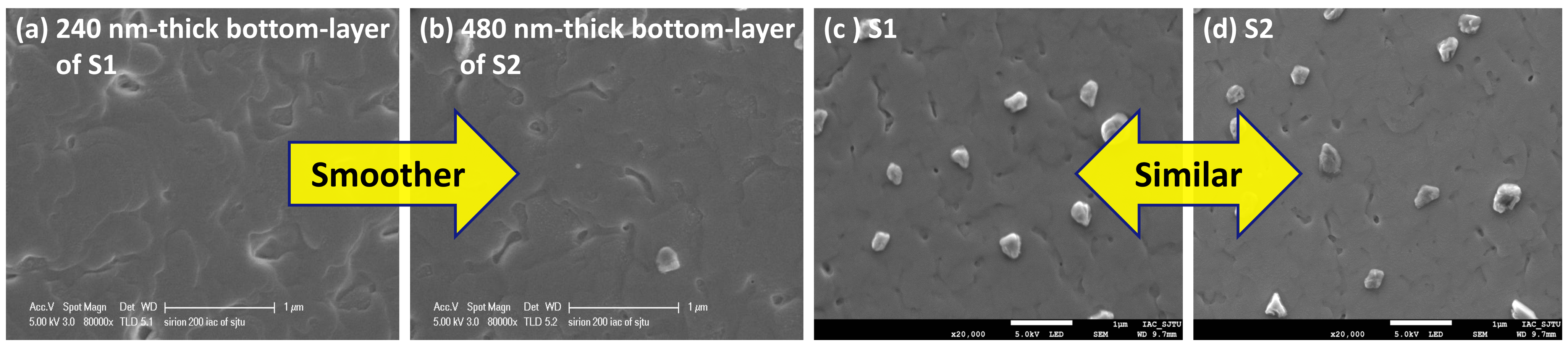
TABLE II
SUBTLE OBSERVATION OF THE XRD SCANNING OF THE SAMPLES

Label	Δω (°)	Δφ (°)	Total intensity of YGBCO (00l) peaks (arb. Unit.)
S1	1.36	2.23	3786
S2	1.06	2.12	4004

$C-axis$ orientation → Almost no peak shift → No internal residual stress

Lattice mismatch:
CeO_2 (-0.52%)
STO (1.53%)
Compensate each other

- **Surface morphology (SEM)**



- **Superconducting properties**

S2 has better microstructure and better surface morphology → Higher T_C

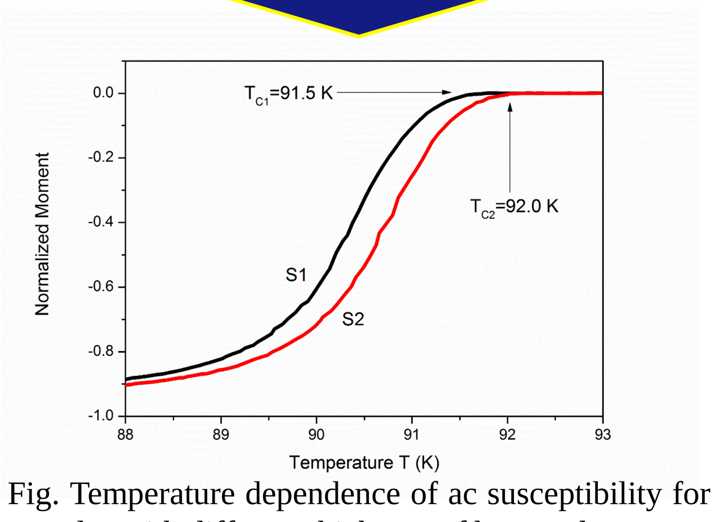


Fig. Temperature dependence of ac susceptibility for samples with different thickness of bottom-layer.

TABLE III
SELF-FIELD I_c AND J_c OF THE SAMPLES AT 77 K

Label	I_C(A)	YGBCO(nm)	J_c(MA/cm^2)
S1	200	720	2.78
S2	260	720	3.61

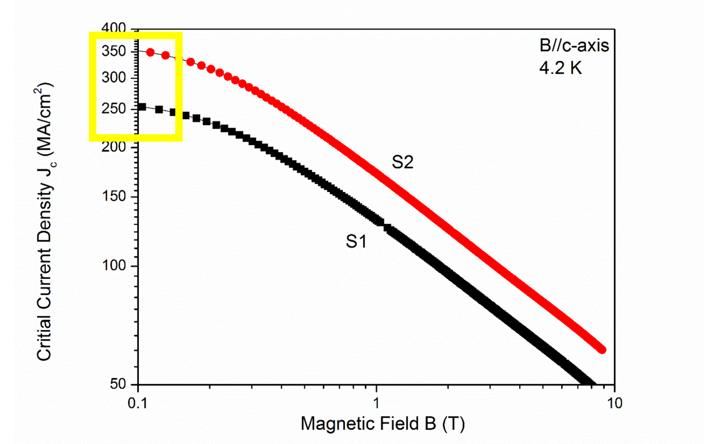


Fig. In-field J_C plotted as a function of applied field (0-9 T) for samples with different bottom layer thickness at 4.2 K (B//c).

At 77 K, J_{C2}= J_{C1} times 1.3

At 4.2 K, J_{C2}=J_{C1} times 1.4

- Lower temperature
- Longer coherence length
- More small-scale (~100 nm) defects act as pinning centers in S2

Conclusion

- YGBCO/STO/YGBCO tri-layer structures with over J_c 3.5 MA/cm^2 (self-field, 77 K) have been successfully fabricated asymmetrically on a CeO_2 buffered C276 tapes by using a multi-step PLD process.
- XRD observation showed that thicker bottom layer had almost no internal stress.
- Better structure and surface morphology contributed to better superconducting properties of the whole samples both under self-field and magnetic field.
- The phenomenon was explained by the growth model, and the results were confirmed with each other.
- Further study on increasing the number of STO inter-layers is in progress.

13th European Conference on Applied Superconductivity
Geneva, 17-21 September 2017
EUCAS 2017