



Progress of REBCO Coated Conductor Program at SJTU and SSTC

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EUCAS 2017, Geneva, 17-21 September 2017

- ① **Introduction to REBCO CC program
at SJTU & SSTC**
- ② **Research activities at SJTU**
- ③ **Scale-up processes for fabrication at
SSTC**
- ④ **Summary**

CC Project Background at SJTU & SSTC

- Key National Project from Ministry of Science and Technology of China (2009-2012) (PLD+RABiTS, 3.5 million US\$, SJTU+Northwest Institute for Non-ferrous Metal Research)
- China's domestic ITER (International Thermonuclear Experimental Reactor) matched project (2012-2014, 1 million US\$, SJTU)
- Major industrialization project from Shanghai Municipal Science and Technology Commission (2012-2016) (PLD+IBAD; 8 million US\$, SJTU+Shanghai Superconductor Tech. Co.)

**Lab Research Goal: 3 m μ thick REBCO layer,
J_c>3.5 MA/cm², I_c>1000A/cm**

Pilot-line Goal: L>1000m, I_c=300-500A/cm J_c>3.0 MA/cm²

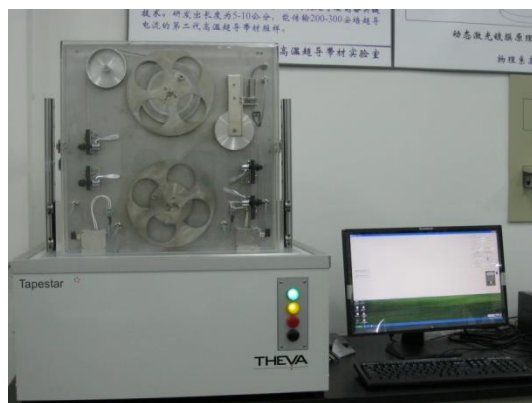
Lab Research Activities @ SJTU

High Jc REBCO CC Process Development



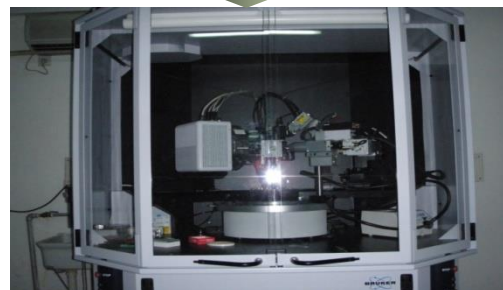
**Proto-PLD
System**

**Sputter
System**



**TapeStar Hall
Probe System**

**Bruker Area-
Detector XRD**



**1000A Four-
Probe I-V
Measurement
System**



AFM



**Ion Beam Assisted
Deposition System**



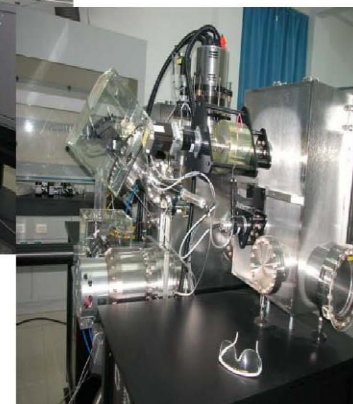
**Reel-to-Reel
Electropolishing
System**



系统侧面

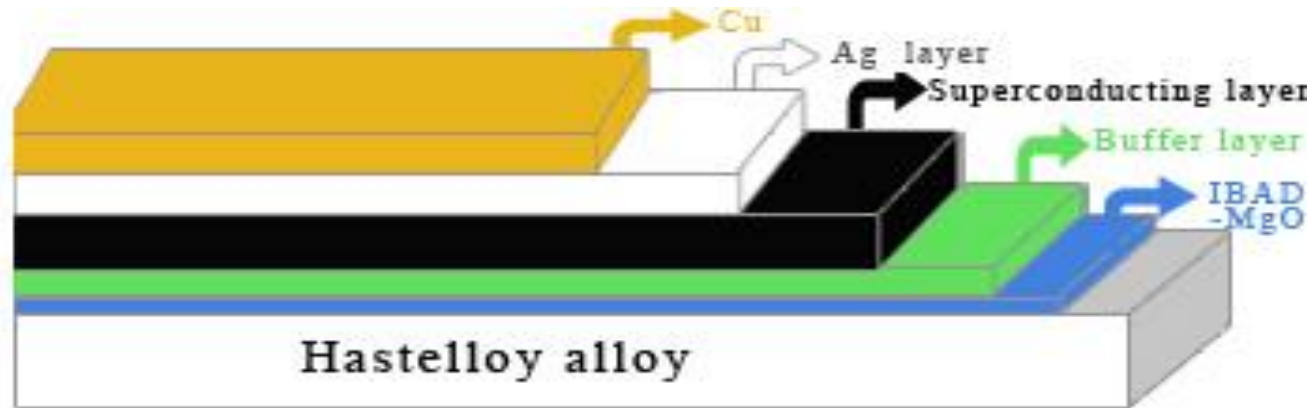


系统侧面

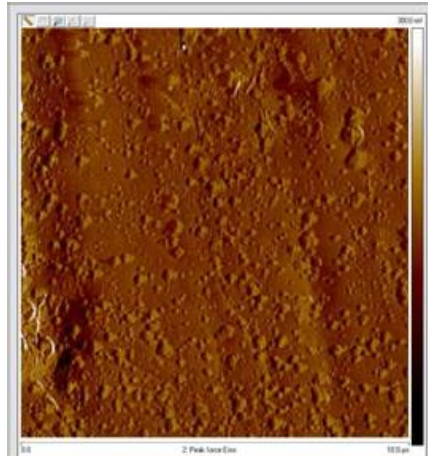
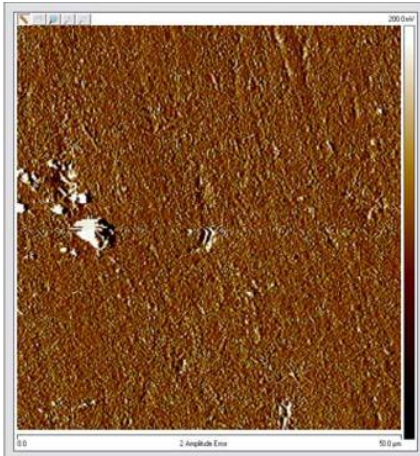


光路

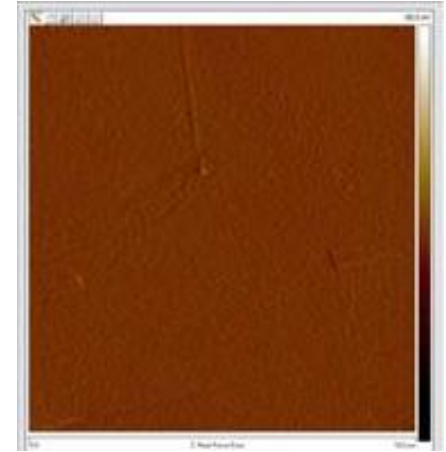
**Maximum Tape Length: 200m,
LPX Pro 220 Laser: 90W, 200Hz, 248nm**



- ❖ Hastelloy C276 substrate
- ❖ IBAD-MgO
 - IBAD-MgO with $\text{Y}_2\text{O}_3/\text{Al}_2\text{O}_3$ barrier layer
- ❖ Buffer layer
 - Sputtering – single CeO_2 layer
- ❖ Superconducting layer
 - PLD-REBCO layer
- ❖ Ag and Cu stabilization
 - Sputtering Ag layer



As-processed metal tapes
 $R_q > 50\text{nm}$ ($10 \times 10 \mu\text{m}^2$)

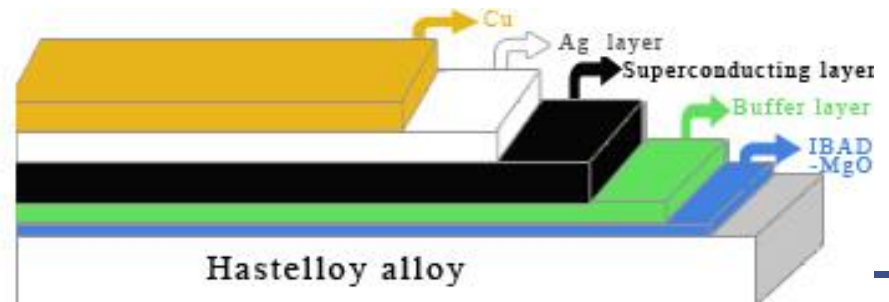


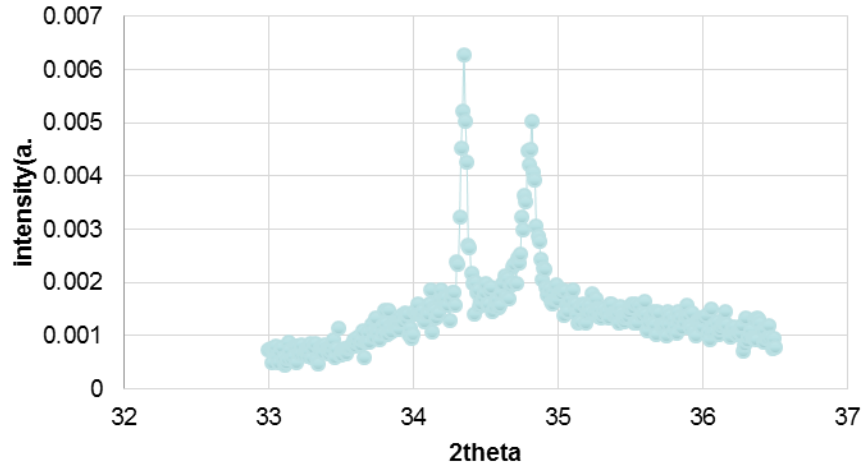
After electropolishing
 $R_q < 2\text{nm}$ ($10 \times 10 \mu\text{m}^2$)



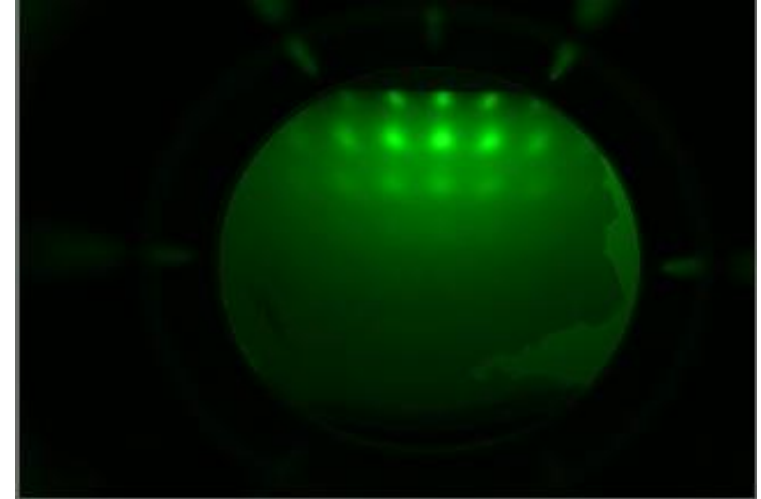
**First Home-made Reel-to-Reel
Electropolishing System in China**

**PLD-IBAD processed YBCO
superconducting tape architecture**

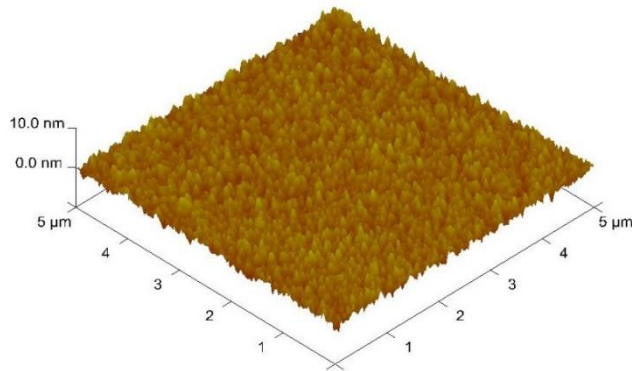




GIXRD profile by Shanghai Synchrotron Radiation Facility

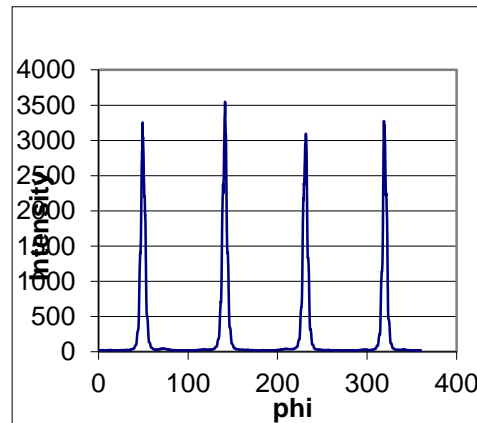
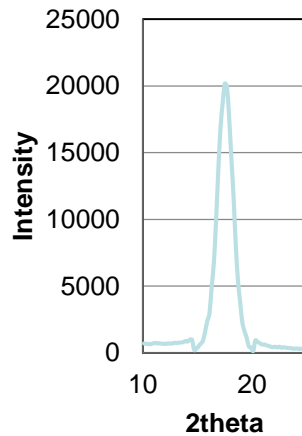
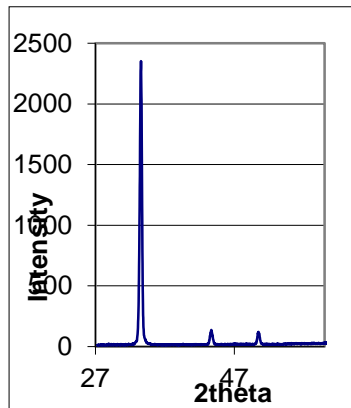
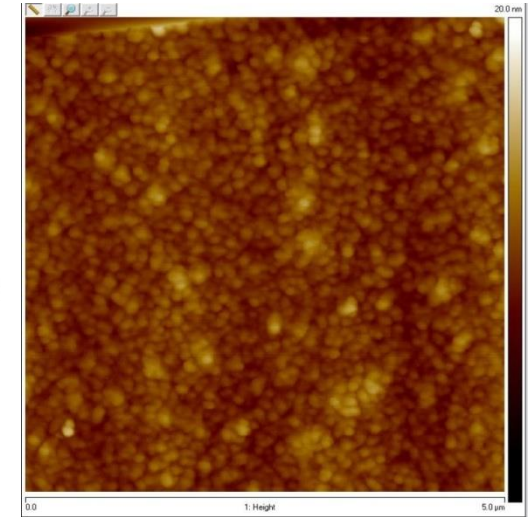
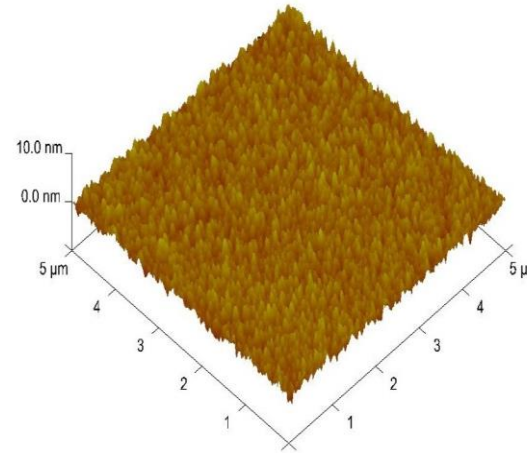
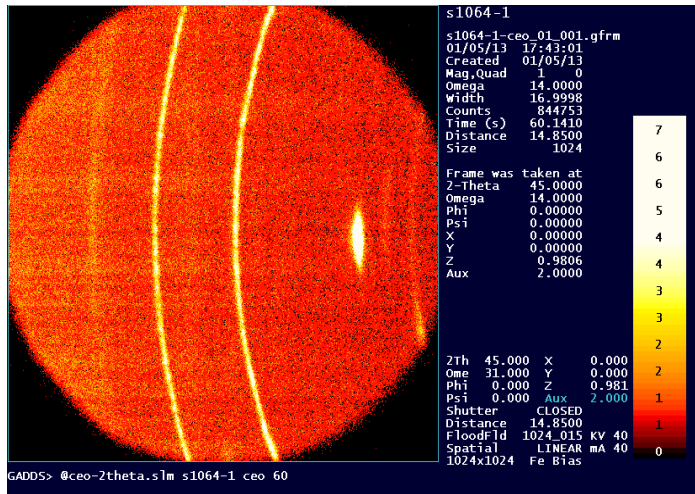


RHEED image of IBAD MgO film



AFM image of IBAD MgO film

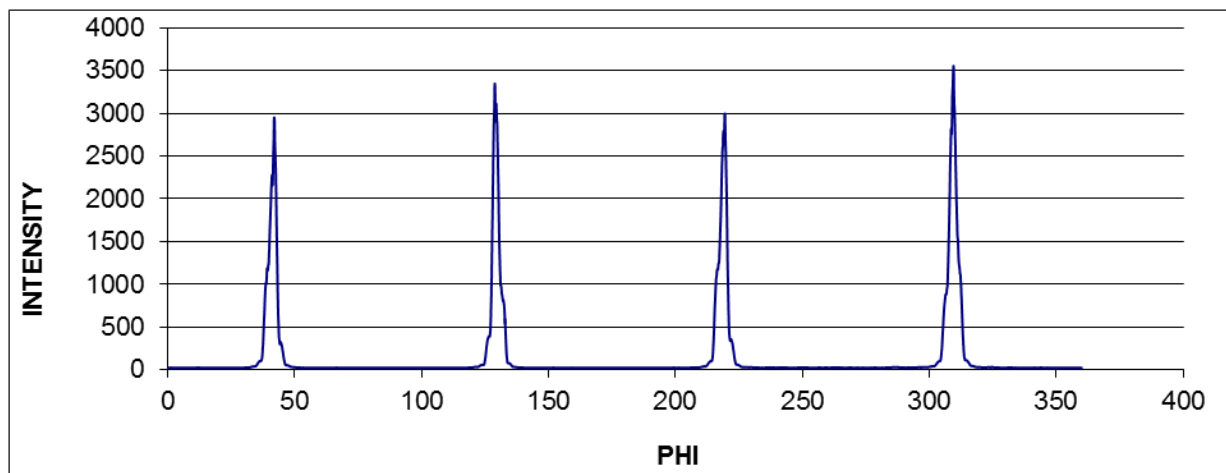
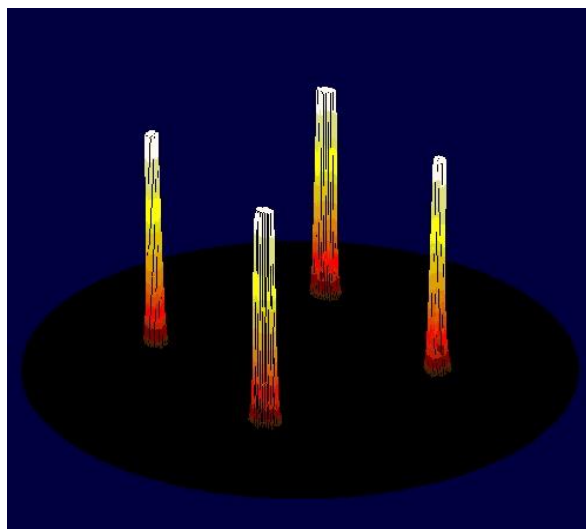
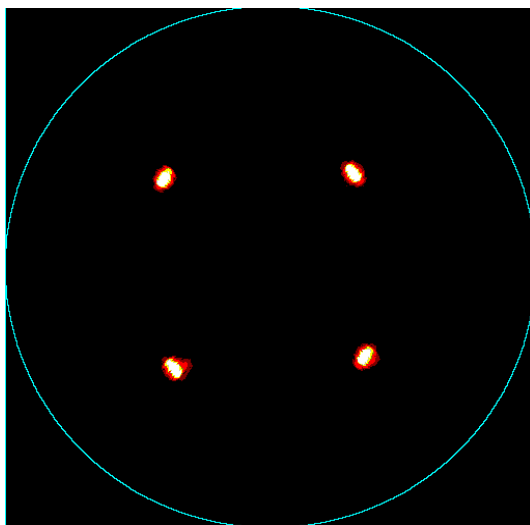
- ❖ IBAD-MgO film had pure c-axis orientation.
- ❖ IBAD-MgO film had smooth surface.
 - $\text{RMS} < 1\text{nm}(5\mu\text{m} \times 5\mu\text{m})$

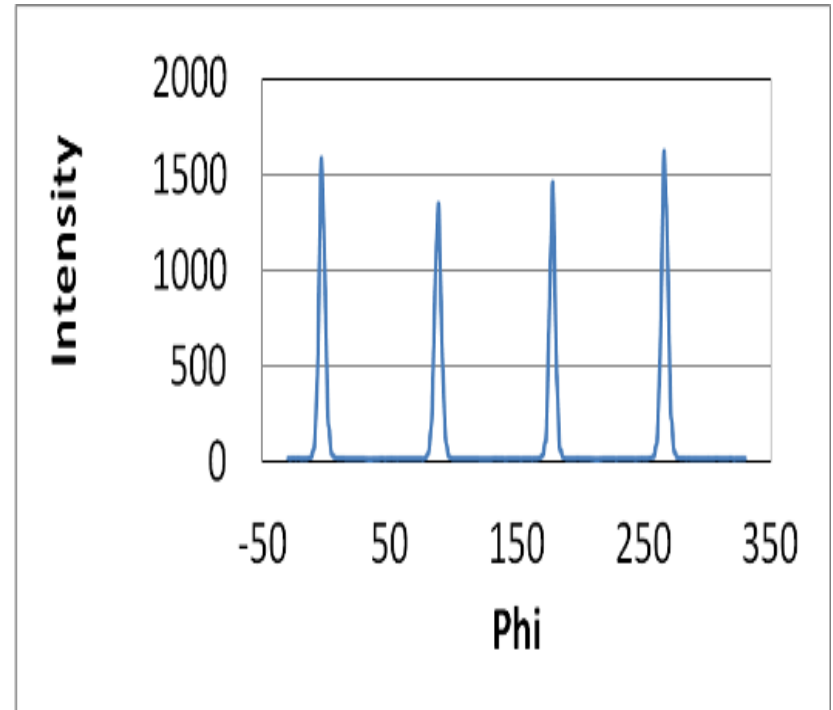
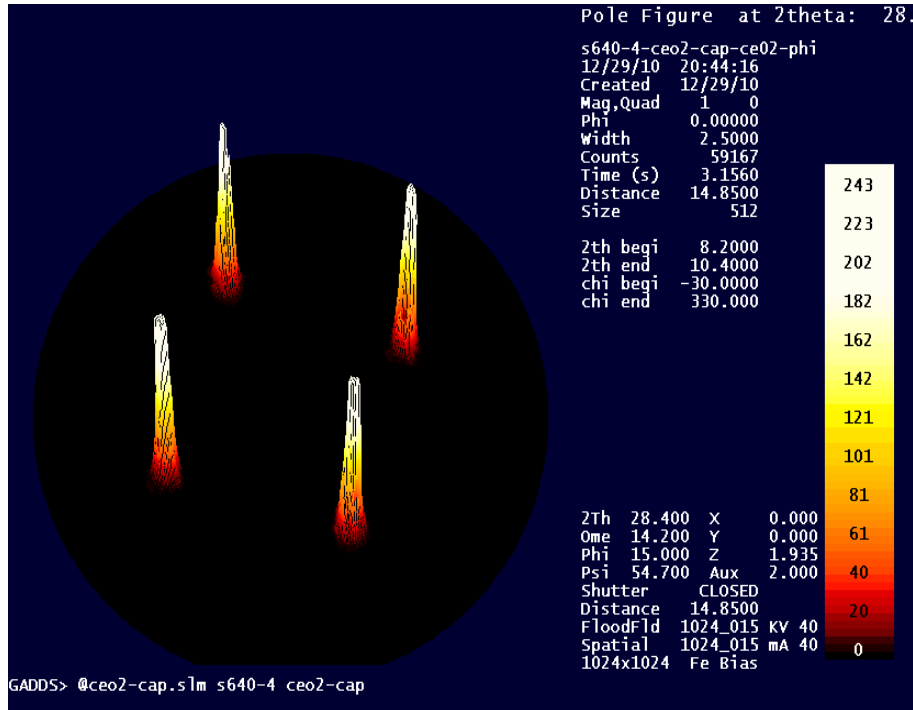


**Sputter-deposited
CeO₂ layers on
IBAD-MgO have
smooth surface and
high texture**

**RMS < 1 nm,
(5 μm × 5 μm);
Δφ < 4.0° Δω < 1.5°**

Optimized CeO_2 layer texture: $\Delta\Phi=2.91^\circ$





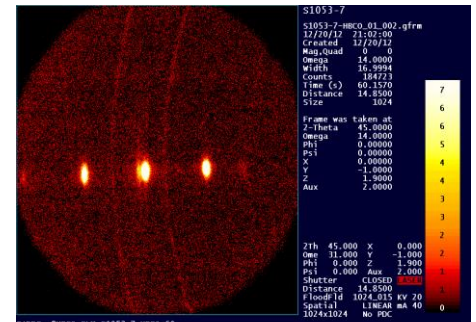
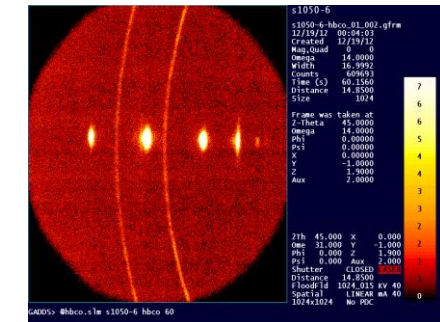
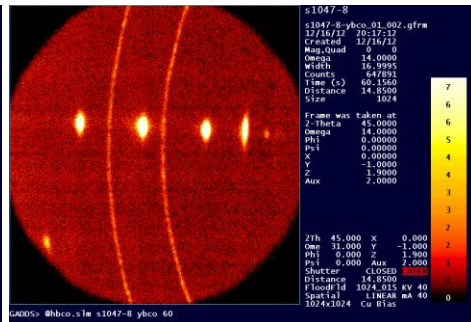
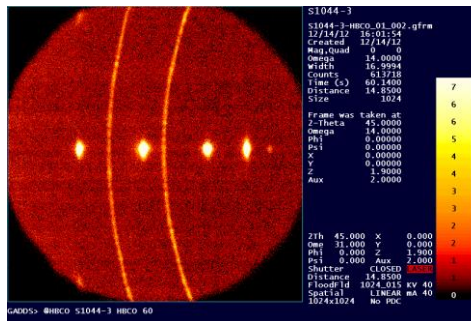
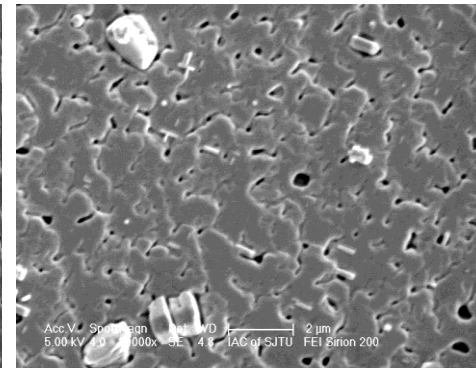
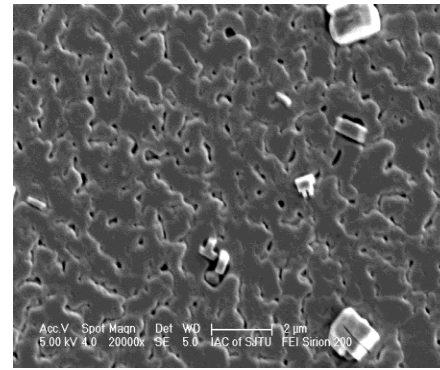
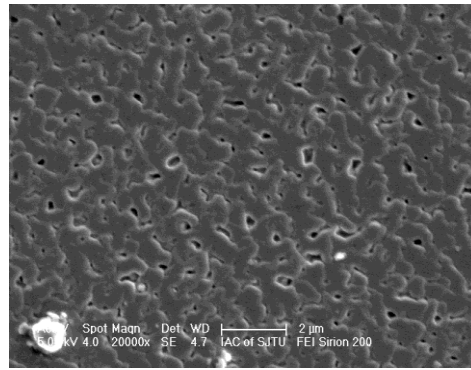
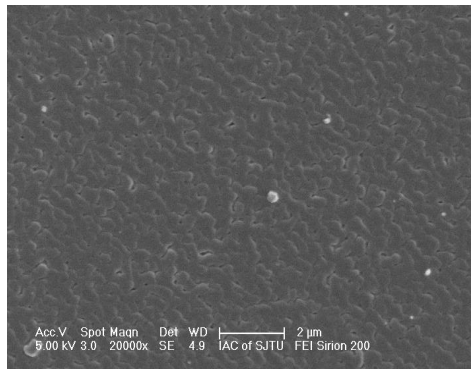
XRD from YBCO layer; in-plane texture is smaller than 2 degree

0.4 μm

0.8 μm

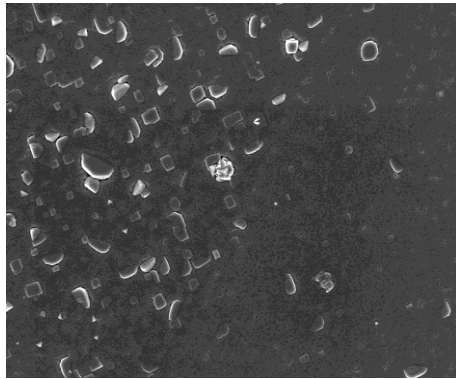
1.2 μm

2.0 μm

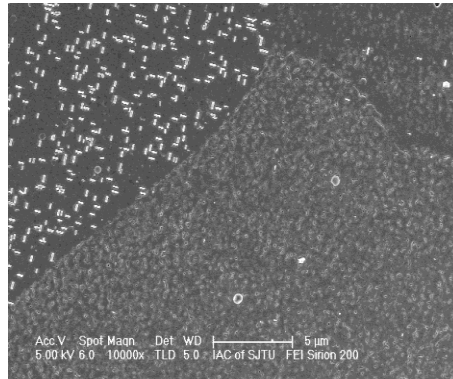


YBCO film microstructure evolution as
the increase of thickness on IBAD tapes

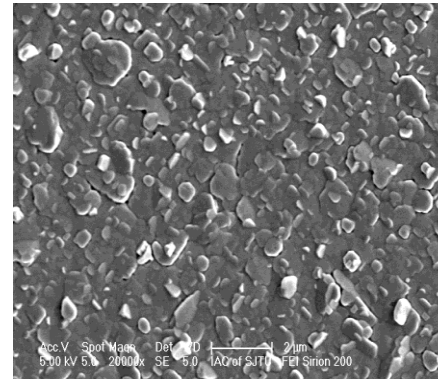
0.4 μm



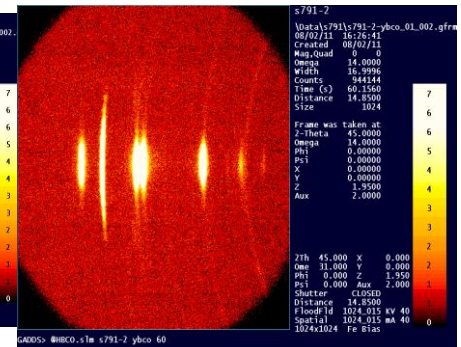
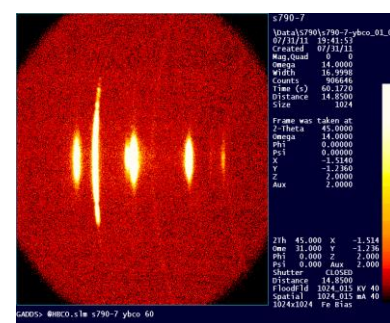
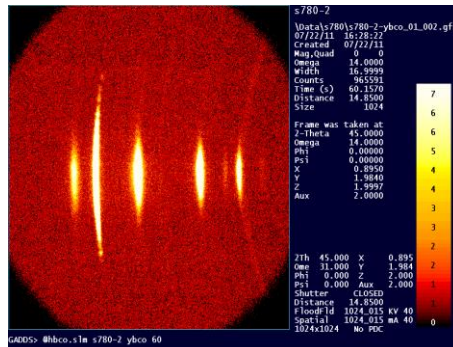
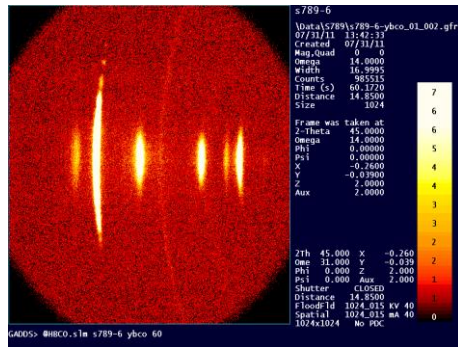
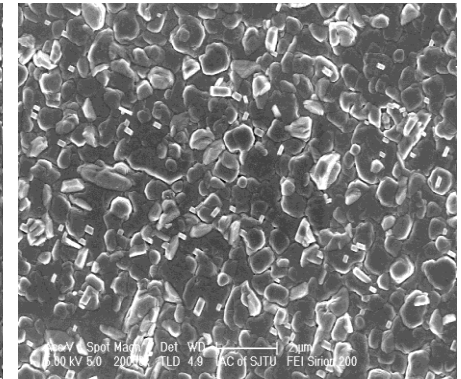
0.8 μm



1.2 μm



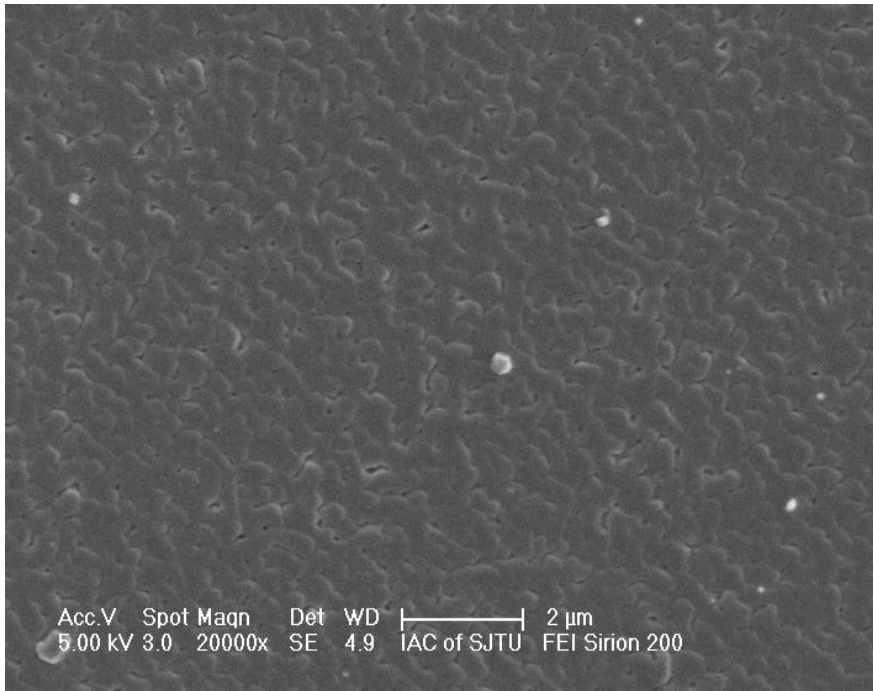
2.0 μm



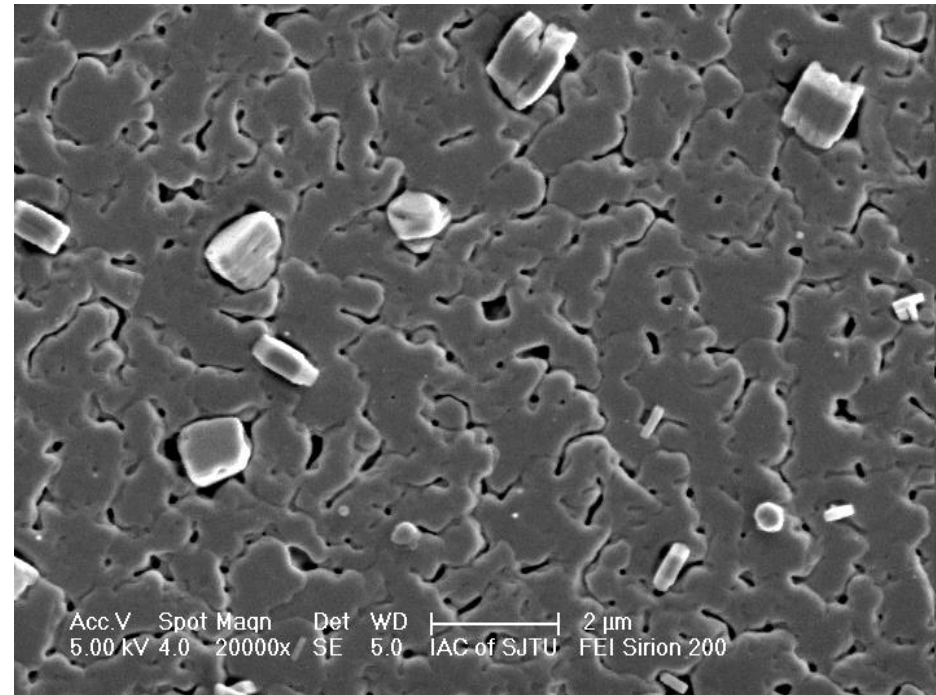
YBCO film microstructure evolution as the
Increase of thickness on RABiTS tapes

Thick and thinner films have similar surface morphology

0.4 μm

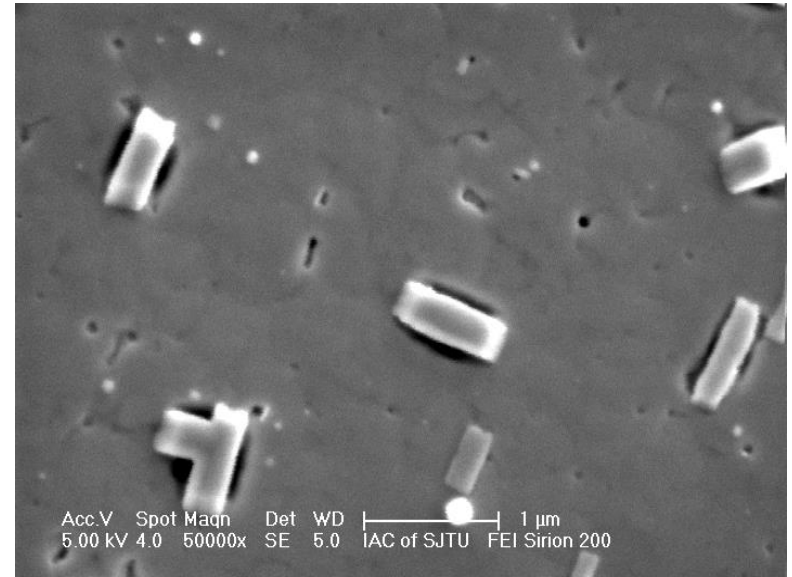
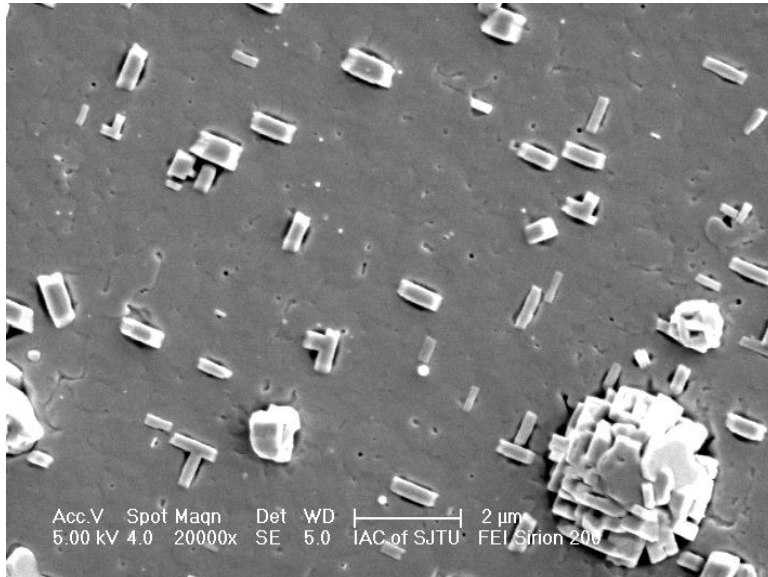


2.0 μm



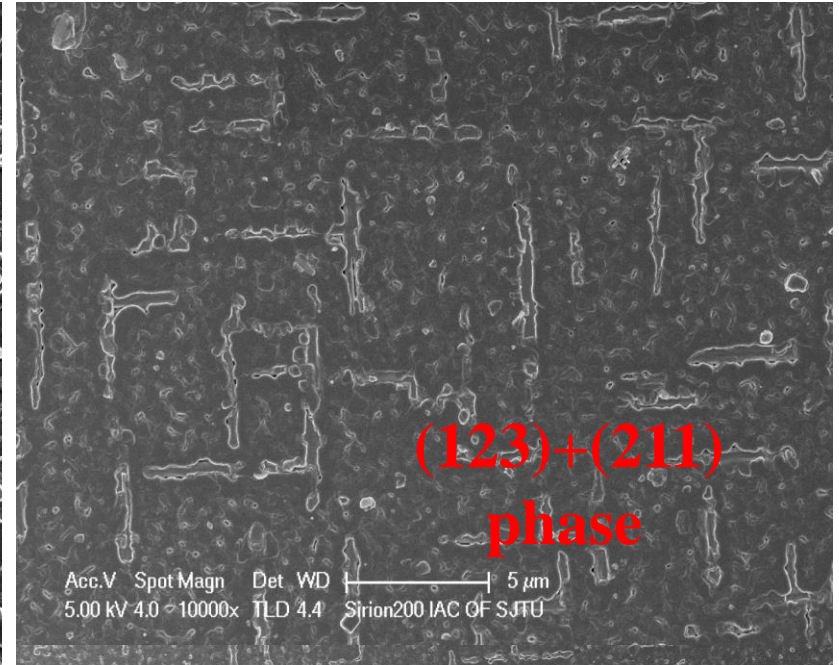
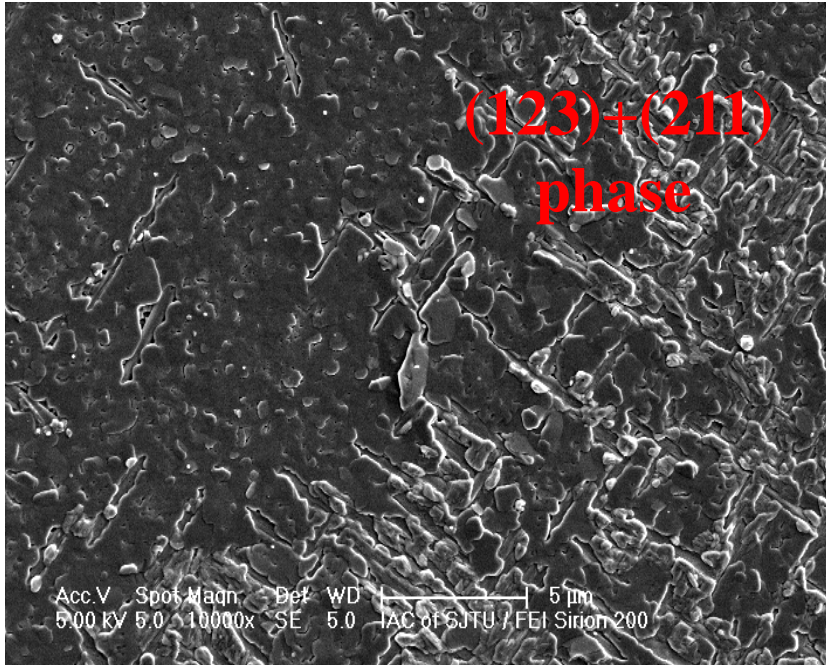


Deviated lower T_s caused a-axis orientation



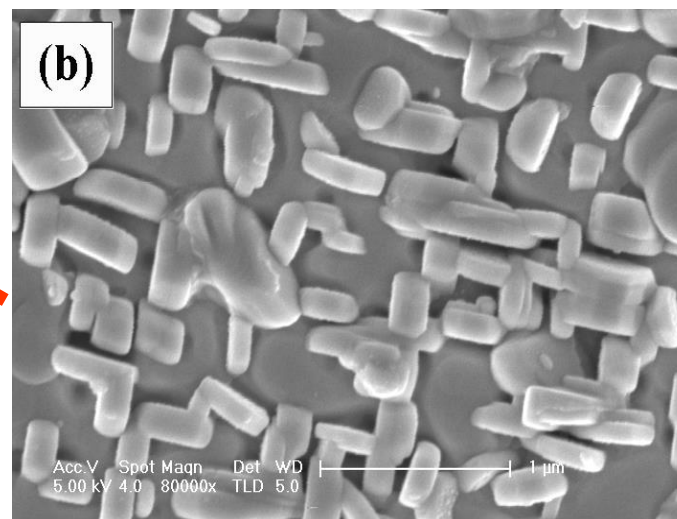
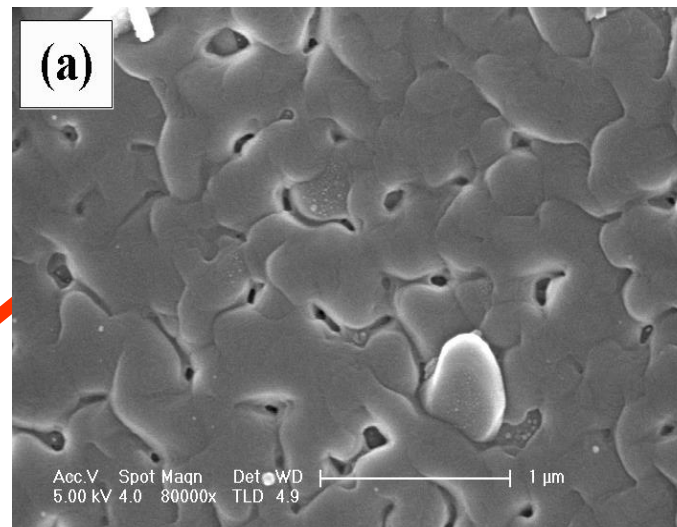
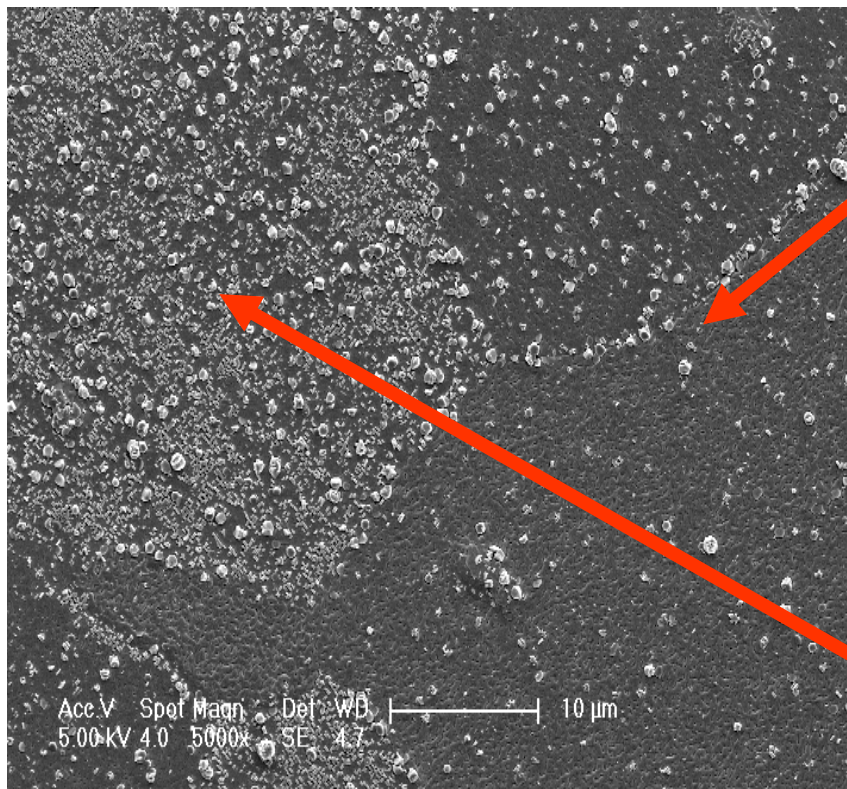


REBCO films deposited at deviated higher T_s

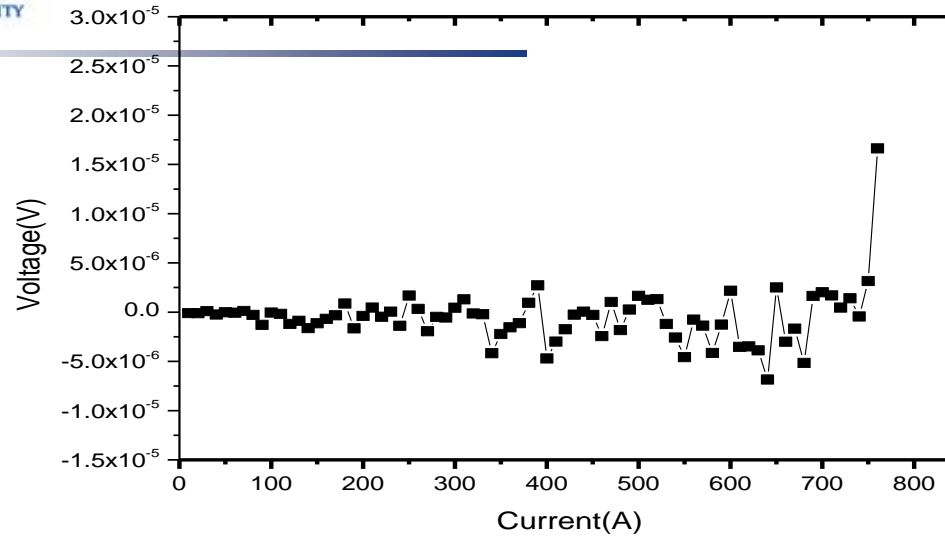


RE-rich REBCO films deposited at higher T_s on IBAD-MgO

Different surface morphology on different grain.

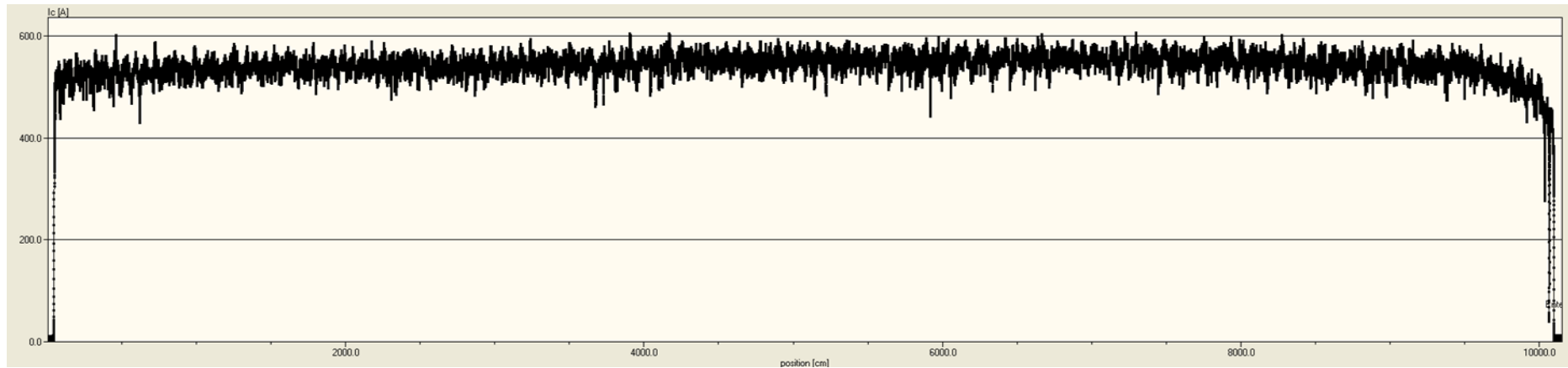


$>1.0\mu\text{m}$ thick YBCO films, $I_c \sim 300\text{A}$; $J_c < 3 \times 10^6 \text{ A/cm}^2$



On IBAD tapes, when REBCO thickness increased to $2.0\mu\text{m}$, I_c is still nearly linearly increasing with thickness. So far, we have achieved I_c of 780A. Further research work on increasing REBCO layer thickness is ongoing.

100m long coated conductor



- ⊗ Magnetic, non-contact measurement
- ⊗ Reel to reel measurement
- ⊗ I_c is about 500A/cm and uniform along the length. (77K)

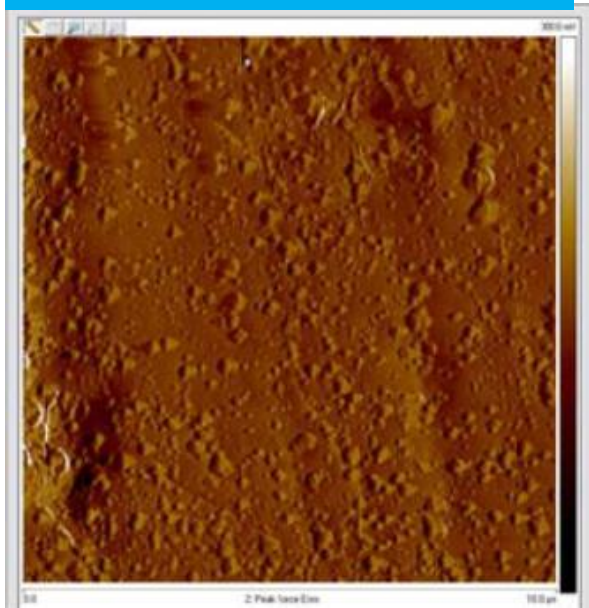
Scale-up processes for fabrication at SSTC



Long tape fabrication process development and results

Pilot Electro-polishing Process

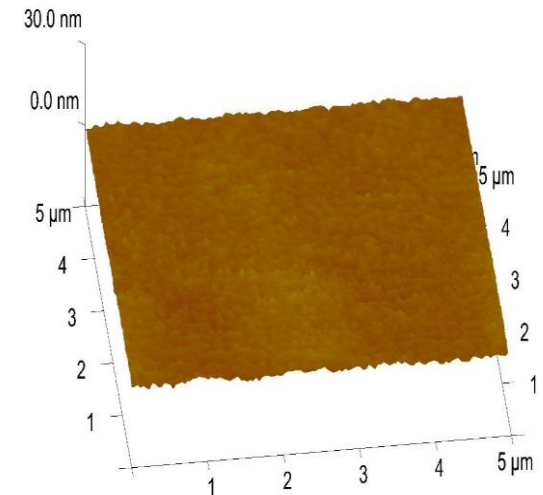
Original Tape



Polished tape



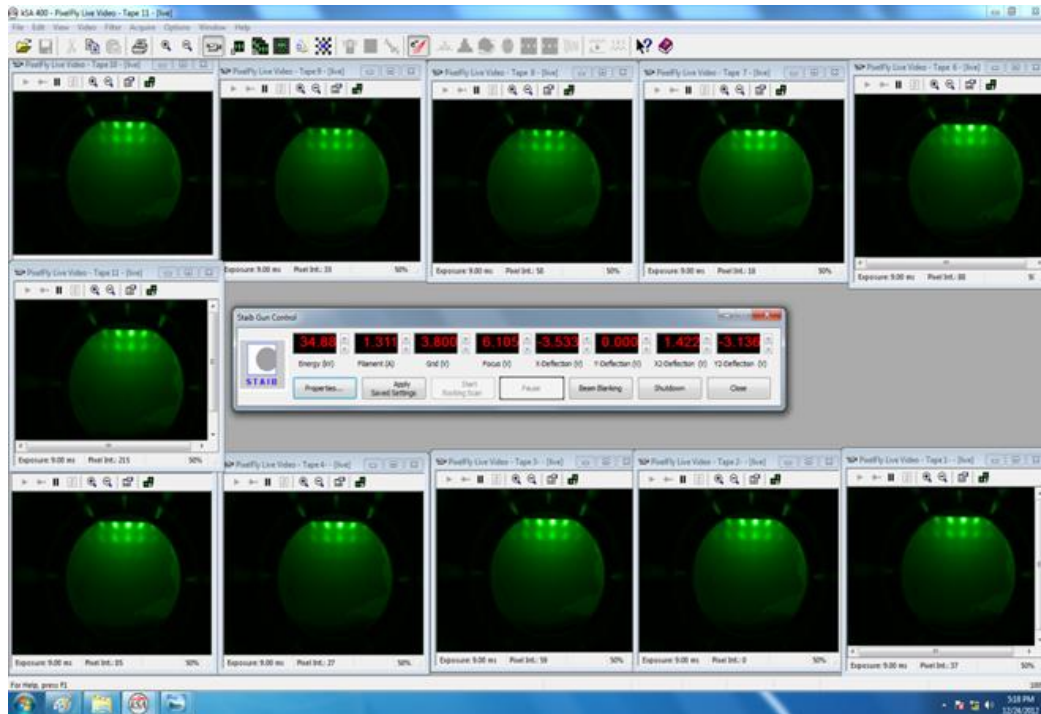
Roughness:
 $5\mu\text{m} \times 5\mu\text{m}$, $R_q = 0.7\text{nm}$



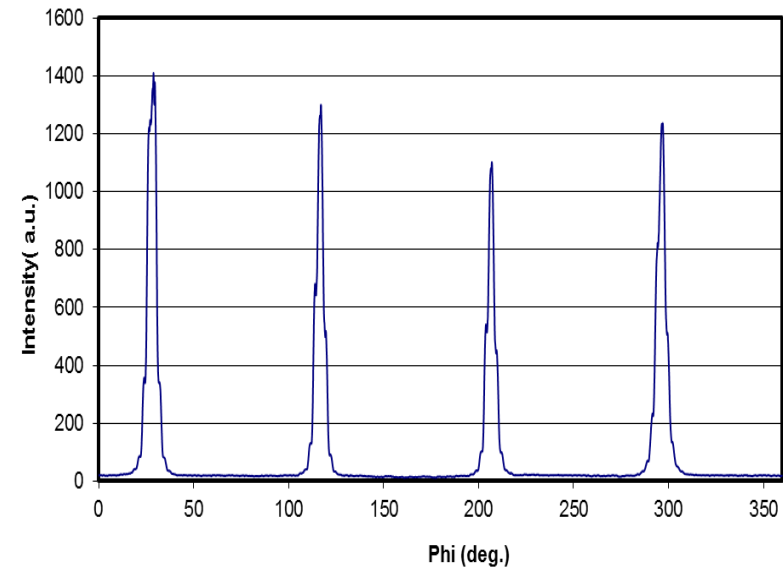
Tape speed $> 200\text{m/h}$

Pilot IBAD-MgO Process

IBAD-MgO on-line in-situ RHEED pattern.

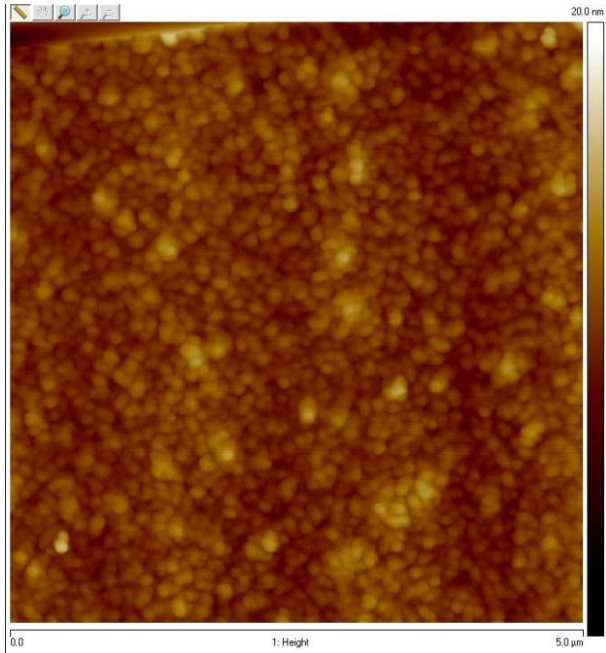


ϕ -scan XRD pattern from PLD-
 CeO_2 film grown on IBAD-MgO
 template, $\Delta\phi=4.0^\circ$

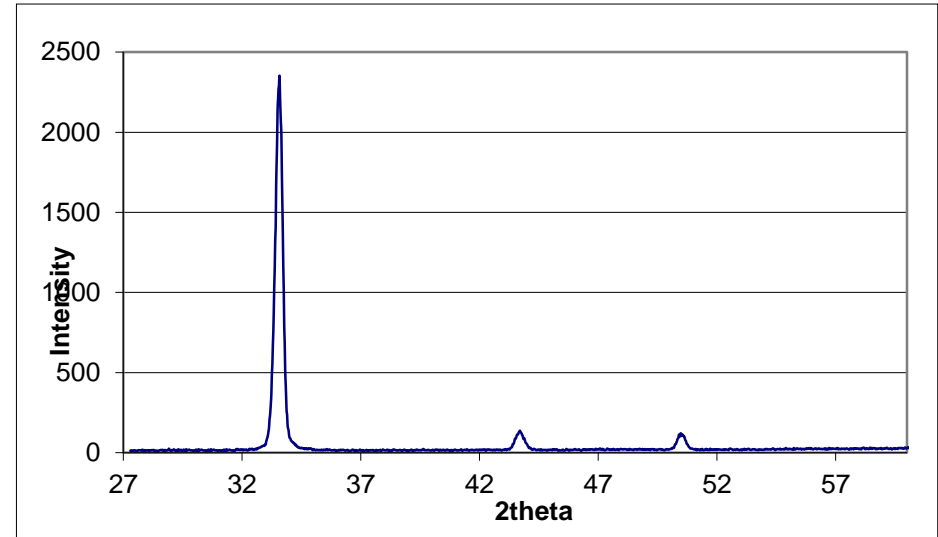




CeO₂ single Cap-layer Process

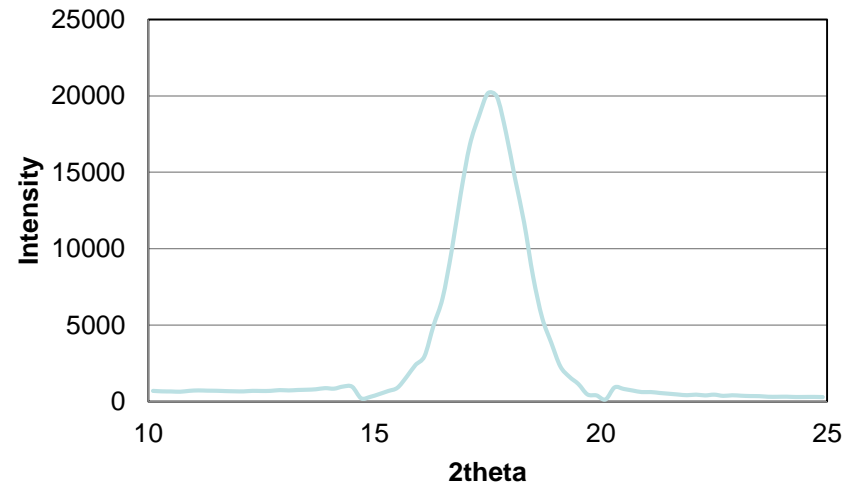
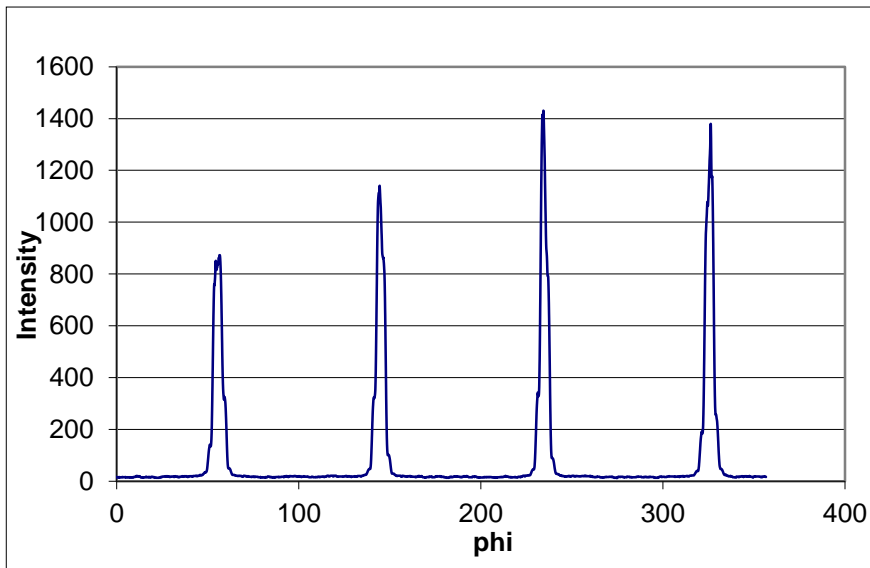


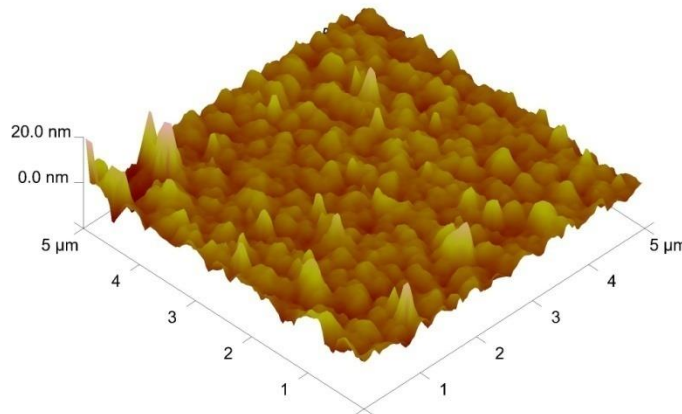
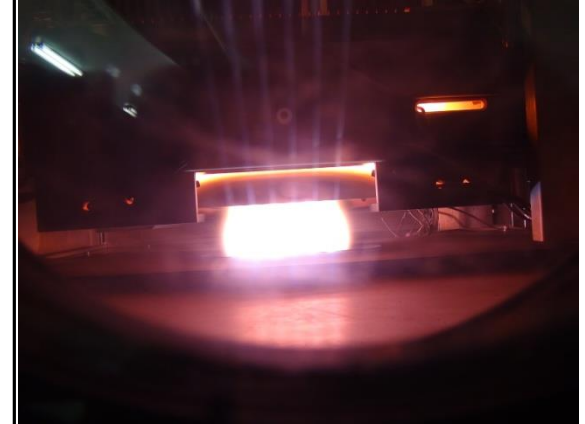
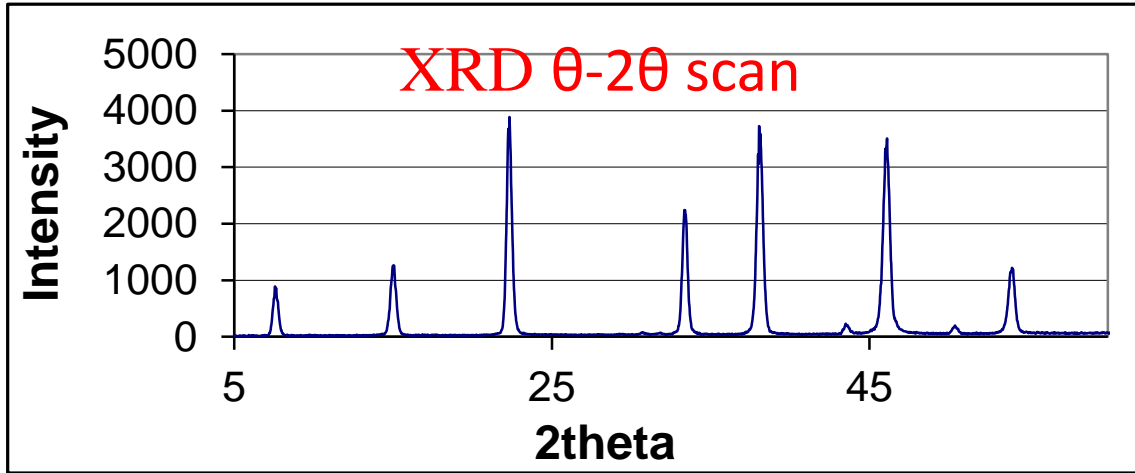
CeO₂ film has very smooth surface
RMS= 0.908nm(5μm × 5μm)



XRD θ - 2θ scan of CeO₂
films deposited on
IBAD-MgO

**Km class CeO_2 long tape has high texture,
 $\Delta\Phi < 4.0^\circ$, $\Delta\omega < 1.5^\circ$**

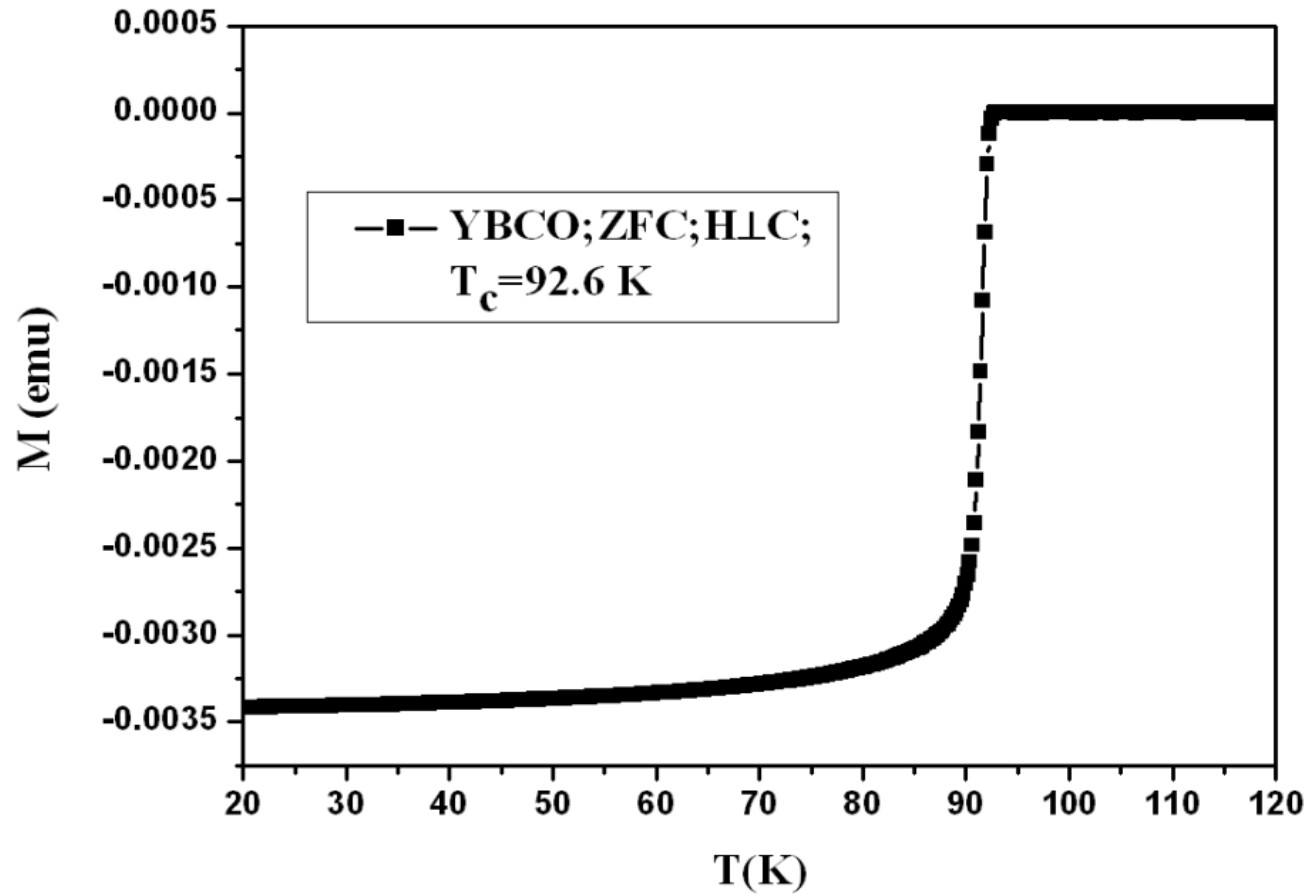




REBCO film deposited by PLD

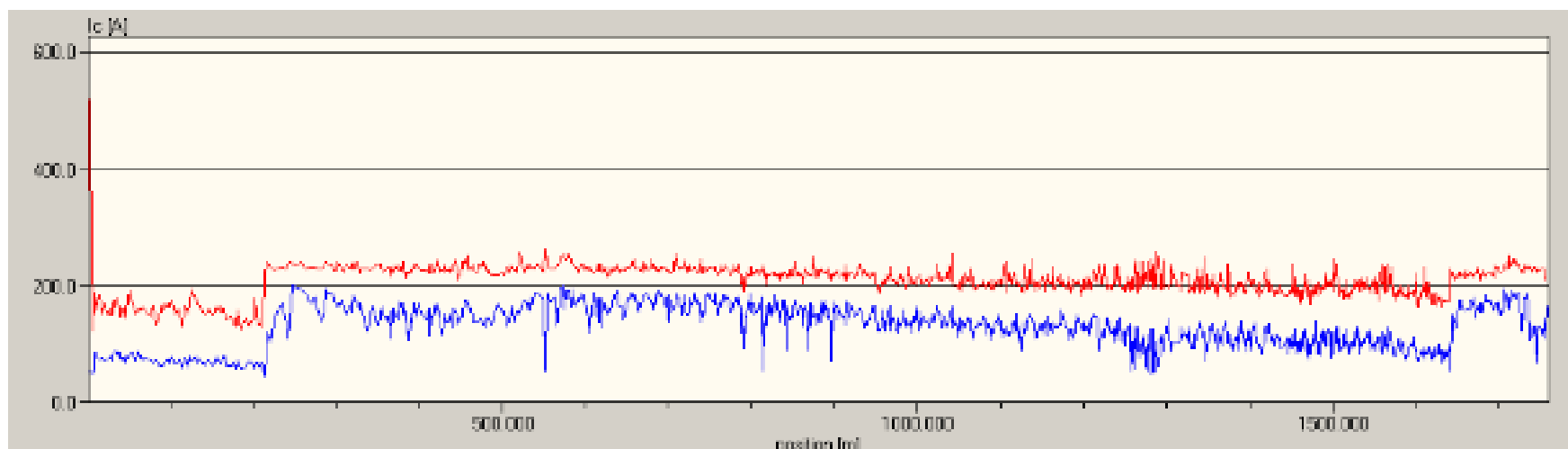
- ⊙ The surface of REBCO films is smooth
- ⊙ $\text{RMS}=2.2 \text{ nm}(5\mu\text{m} \times 5\mu\text{m})$
- ⊙ Pure c-axis orientation

T_c of Standard Tape

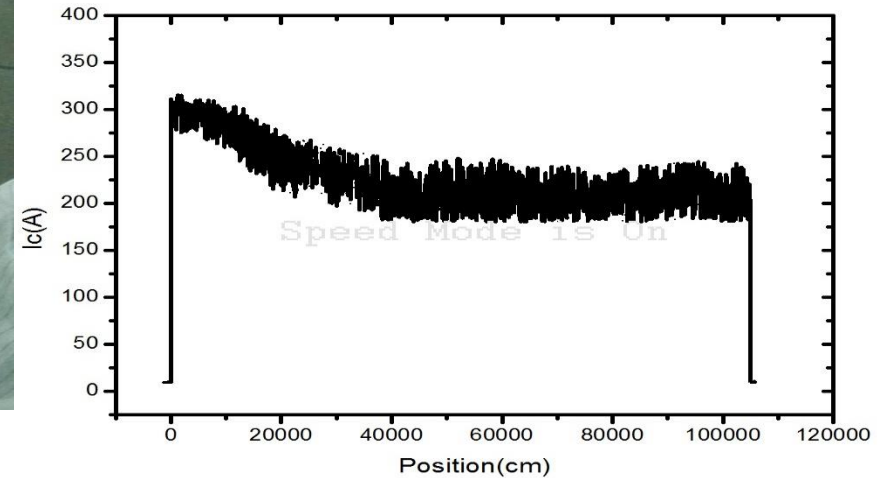
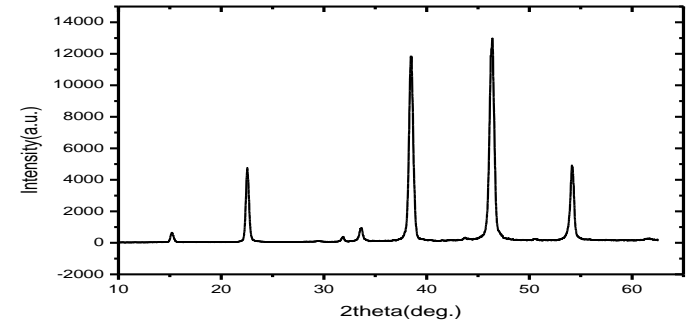
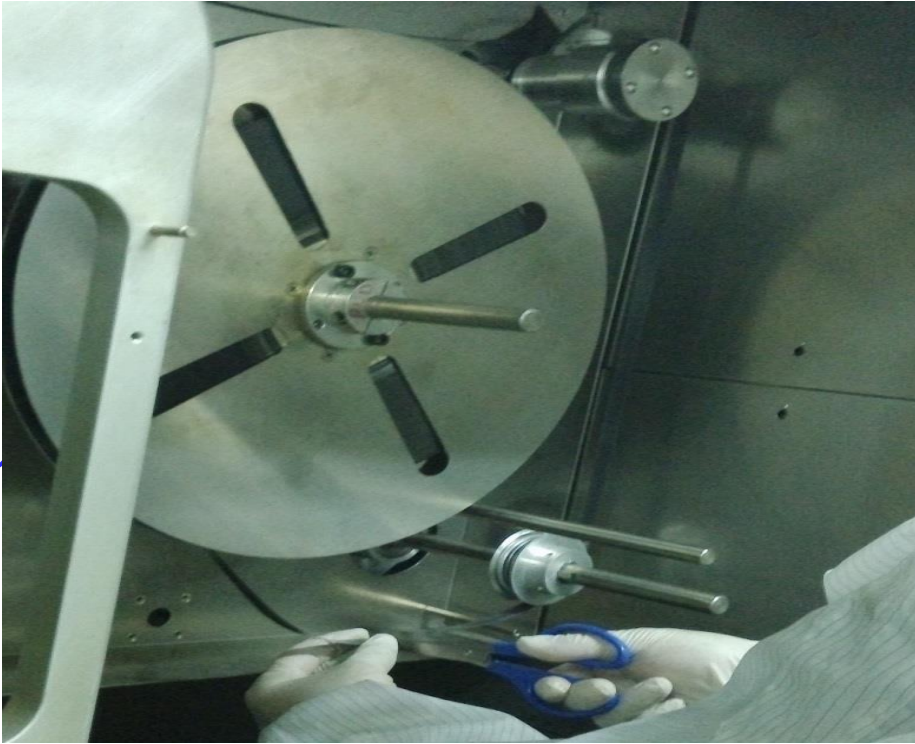


T_c=92.6 K

1000 m Long REBCO Tape Fabrication



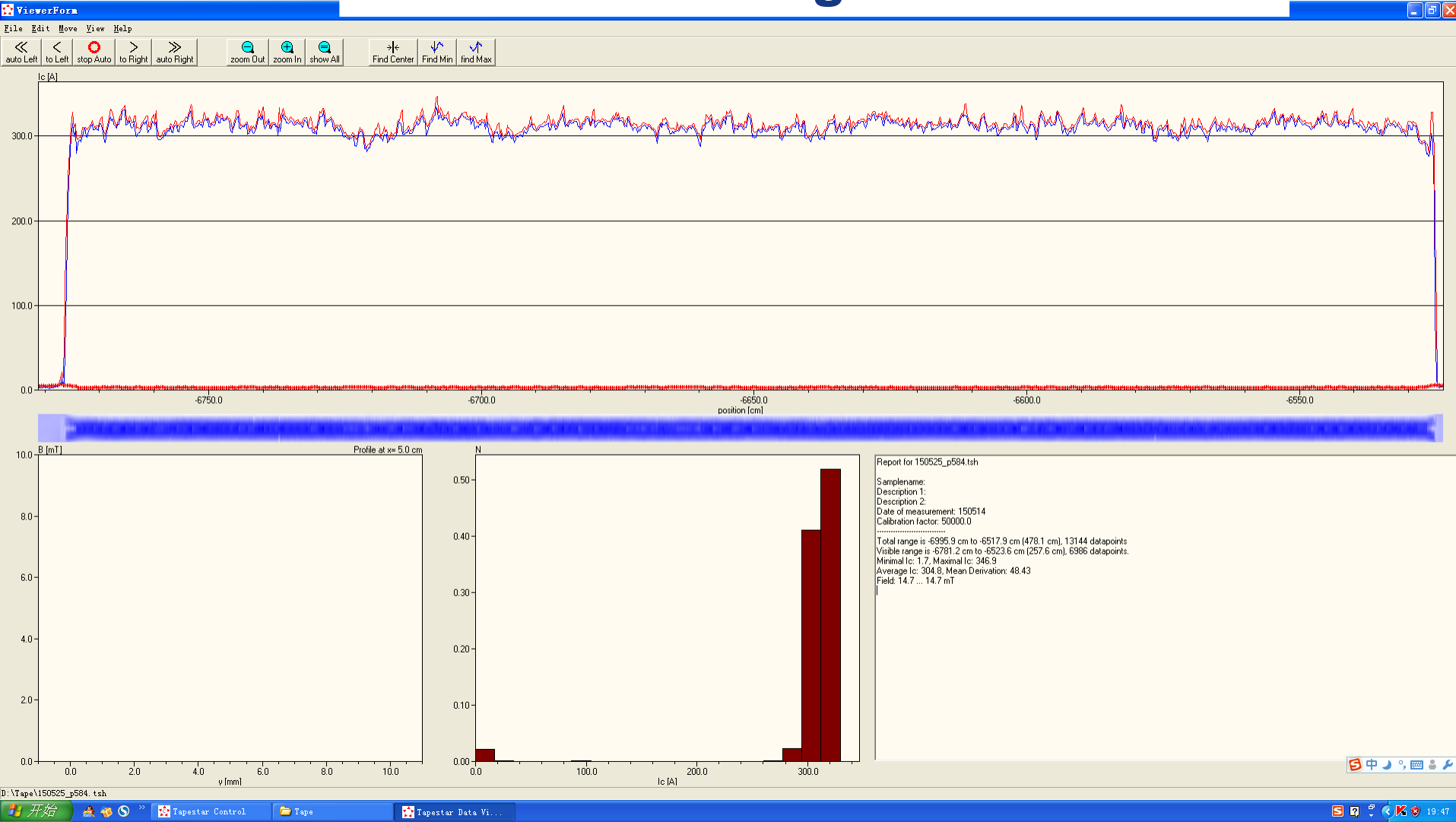
In August 2014, first kilometer long REBCO tapes was fabricated.



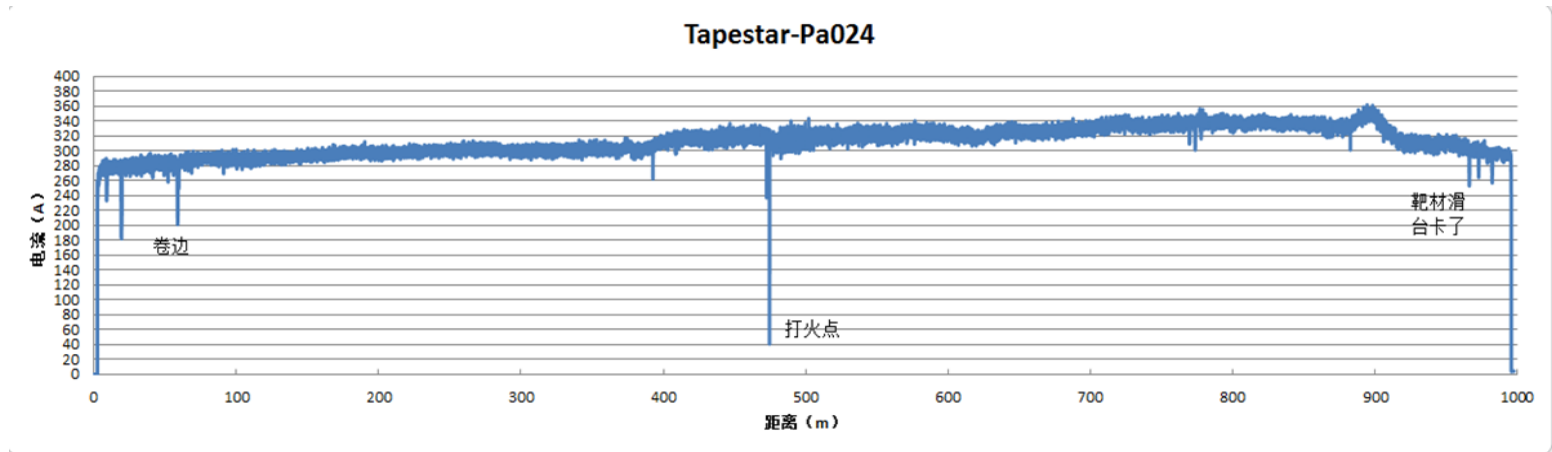
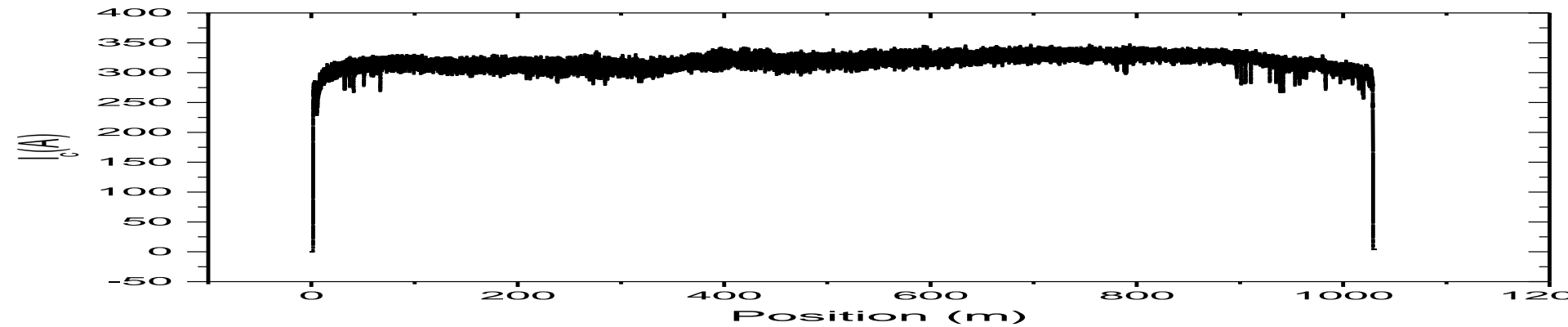
- ④ In October 2014, the third kilometer long REBCO tapes, $I_C > 200\text{A}$.

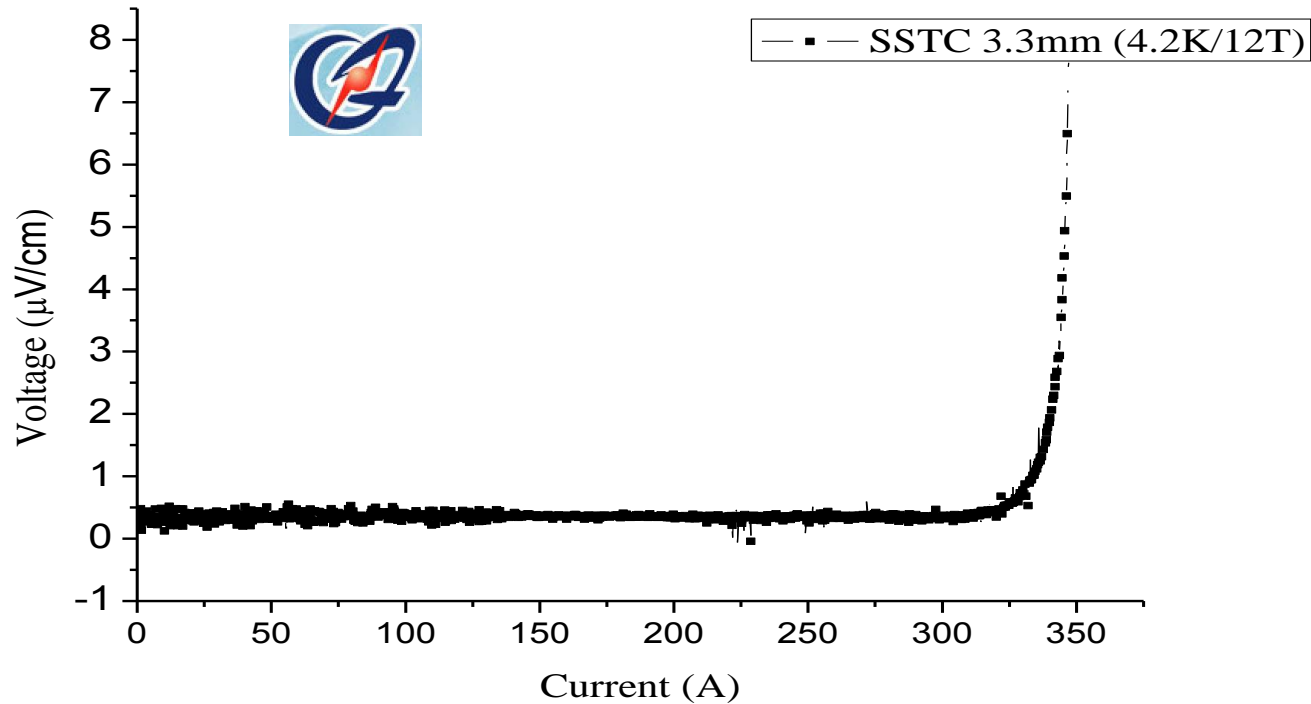


Improvement of uniformity along length



Ic Profile Over km Long Tapes





SSTC standard REBCO tape: $I_c=1020\text{A}/\text{cm}$, at 4.2K and 12T, H//c.
 I_c measured at Institute of Plasma Physics, Chinese Academy of Sciences

Goal: $I_c>2000\text{A}/\text{cm}$, at 4.2K and $H>10\text{T}$, H//c, $J_c>2\times 10^7/\text{cm}^2$

- ④ SJTU successfully developed hundred meter long class CC tapes with over 500 A/cm (at 77 K, self field) based on PLD deposition processes.
- ④ A pilot PLD/IBAD-MgO process CC fabrication line was set up at SSTC in 2013.
- ④ Reel-to-reel PLD process with high deposition rate was already scaled up to >100 m/h tape speed.
- ④ Kilometer long coated conductor tapes with over 300A/cm performance have been routinely fabricated at SSTC.
- ④ Next step will be focused on REBCO tape fabrication for high-field applications.

Thanks
For Your Attention
