上海市高温超导重点实验室

Shanghai Key Laboratory of High Temperature Superconductors

上海大学 Shanghai University

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Long-length REBaCuO Coated Conductors Derived by Reel-to-Reel Metalorganic Solution and Ion-beam Assisted Deposition

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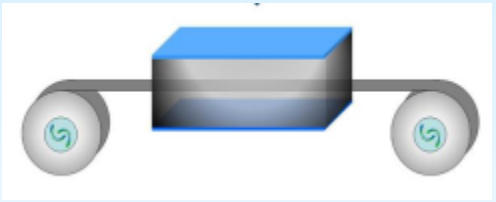
Outline

- Technology routes selected and R2R pilot line for kilometer tape built up
- Effort on improvement of processing efficiency and HTS layer thickness
- Development and state of the art for long-length MOD Coated Conductors

HTS Coated Conductors
@Shanghai University & Spinning-off Company, SCSC

- Textured Oxide Buffers on Untextured or Textured Tape via IBAD or RABiTS
- Epitaxial (Y,RE)123 Layers on Textured Oxide Buffers via MOD

上海上创超导科技有限公司
Shanghai Creative Supercond. Technol. Co. Ltd



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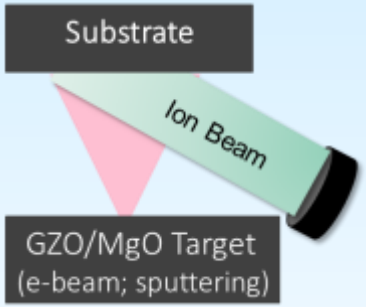
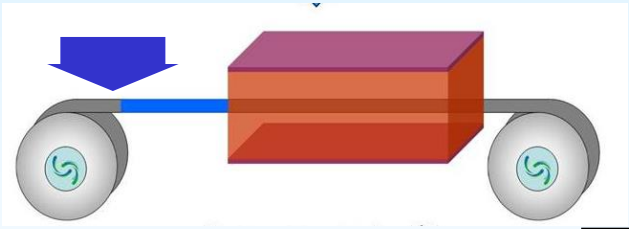
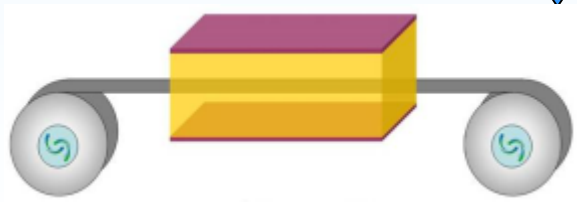


Oxide Buffer on
Textured or Untextured

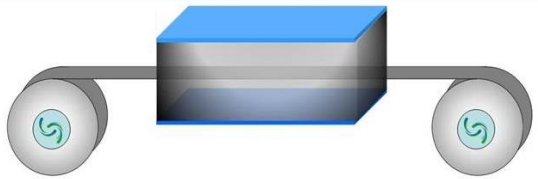
MOD-HTS Layer



Coating &
Pyrolysis



Crystallization



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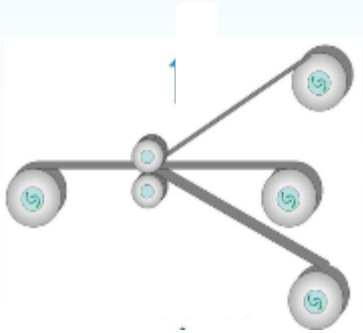


Slitting & Package

Reel-to-Reel Production Line Spinning off from Shanghai University

Spin-off

For buffer layers

Research Level R2R Sputtering System

Industry-level Sputtering Pilot Line ~ km

NSFC、MOST-863/973 Project → STCSM-Key Project → Shanghai Municipal Key Project

Spin-off

For HTS layers

Research Level R2R MOD System

Industry-level MOD Pilot Line ~ km

High-efficiency Technology Route Developed at Shanghai Uni. & Production Line at Shanghai Creative Supercond. Technol. Co. Ltd.(SCSC)

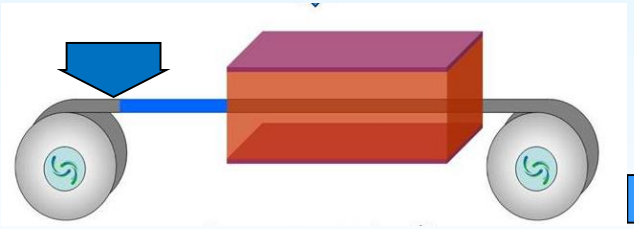
● Electopolish of Substrate

● Sputtering buffer/ E-beam IBAD-MgO/epi-MgO

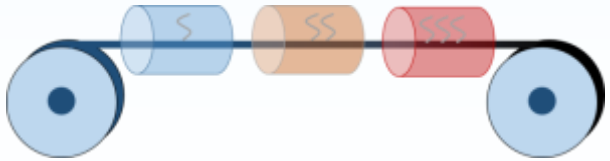
● MOD HTS Layer

● Lamination

Coating and Low-temperature Pyrolysis



MOD-RBaCuO



High-temperature Crystallization

➢ **Cost-effective MOD**

- Non-vacuum, low cost tools
- Easy and accurate to modify composition
- 100% utilization of precursor solution
- Readily scale up for wide-web process
- “Dirty” films, but helpful for pinning

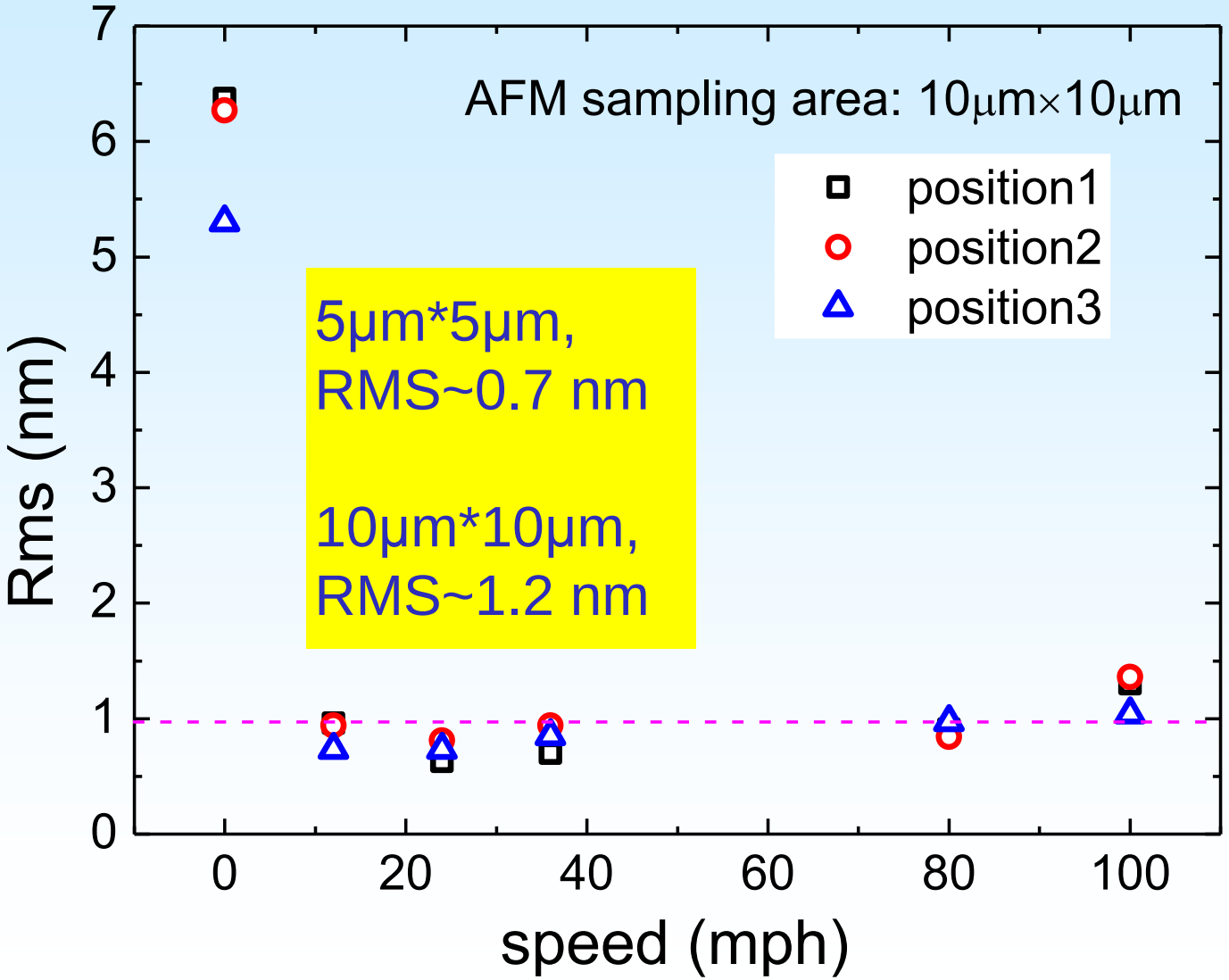
➢ **Independently home-made pilot lines**

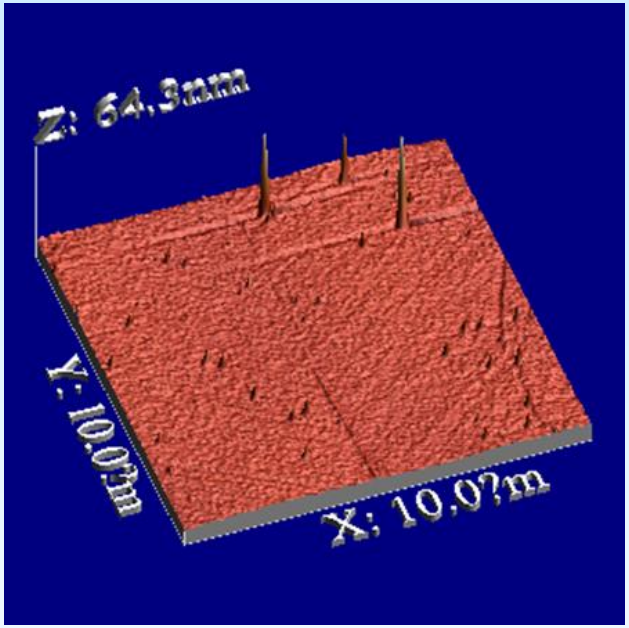
- Smart control system
- In-situ quality inspection

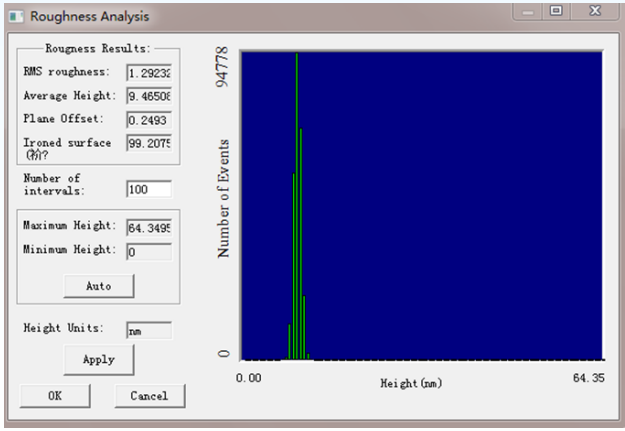
Scale up of substrate process by R2R contactless electropolish

- Environmental friendly polishing liquid
- Self-designed production-scale EP rig
- In-situ process and quality monitoring
- Low surface roughness
- High speed~ 100 mph
- Width up to 40 mm
- Multi-lane available

Surface roughness vs. EP speed



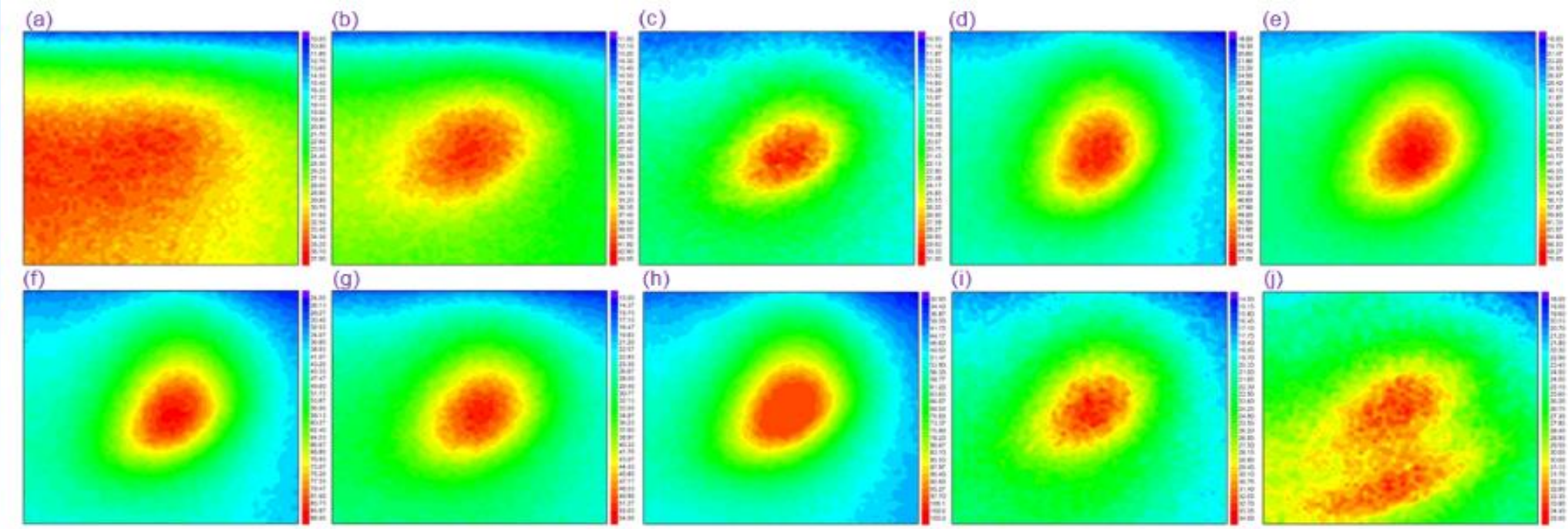




In-situ RHEED Observation for Texture Evolution of Oxide Buffer on Untextured Tape

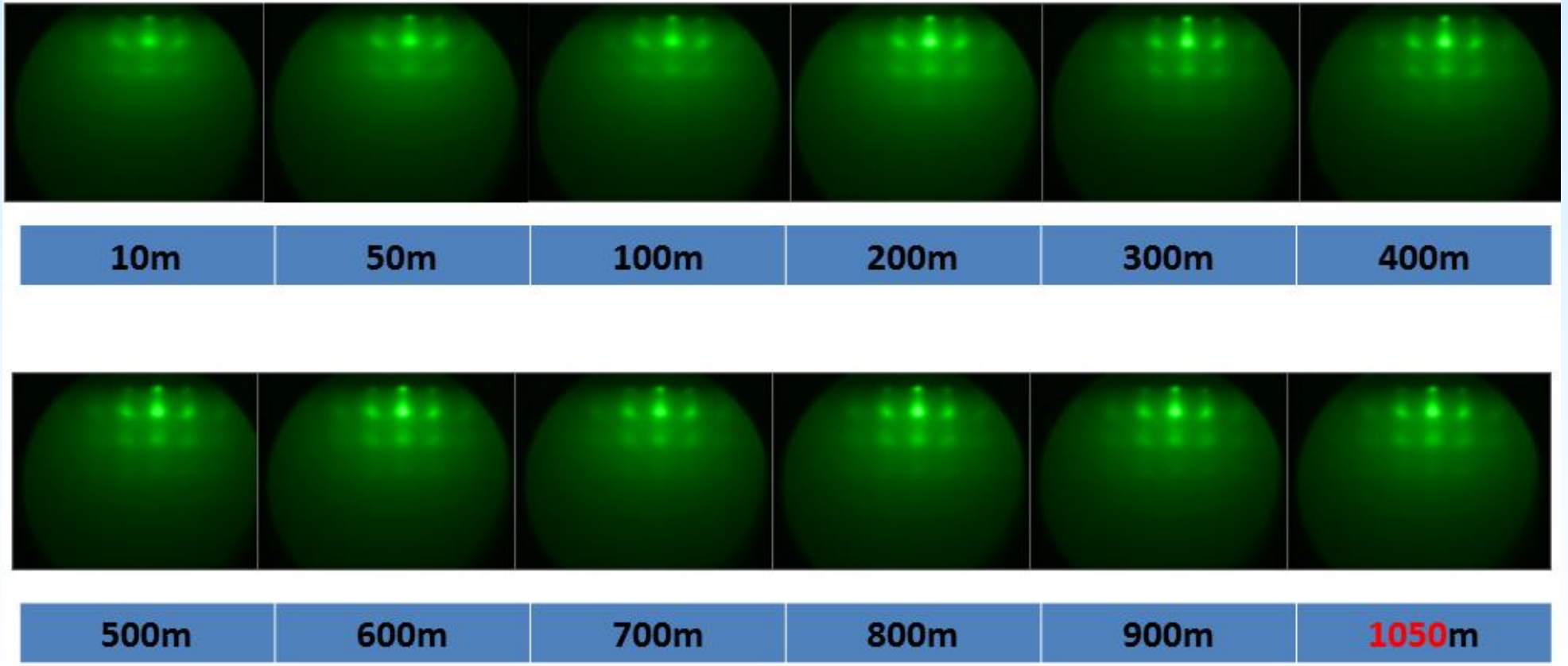
- Peak intensity of RHEED patterns for (024) MgO
- Increasing intensity at proper time widows

50s



220s

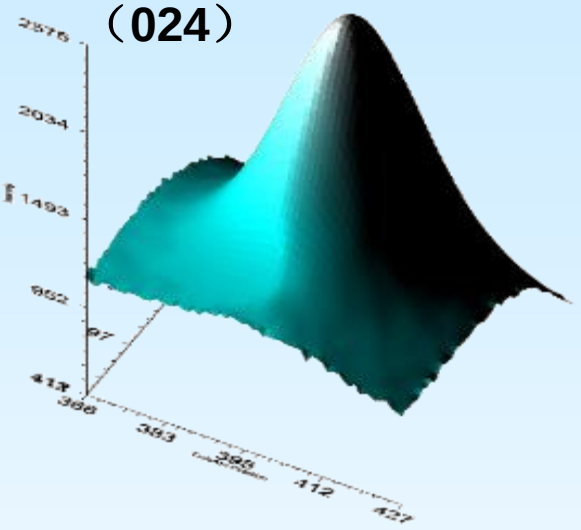
In-situ RHEED Observation for Texture Evolution of Oxide Buffer on Untextured Tape

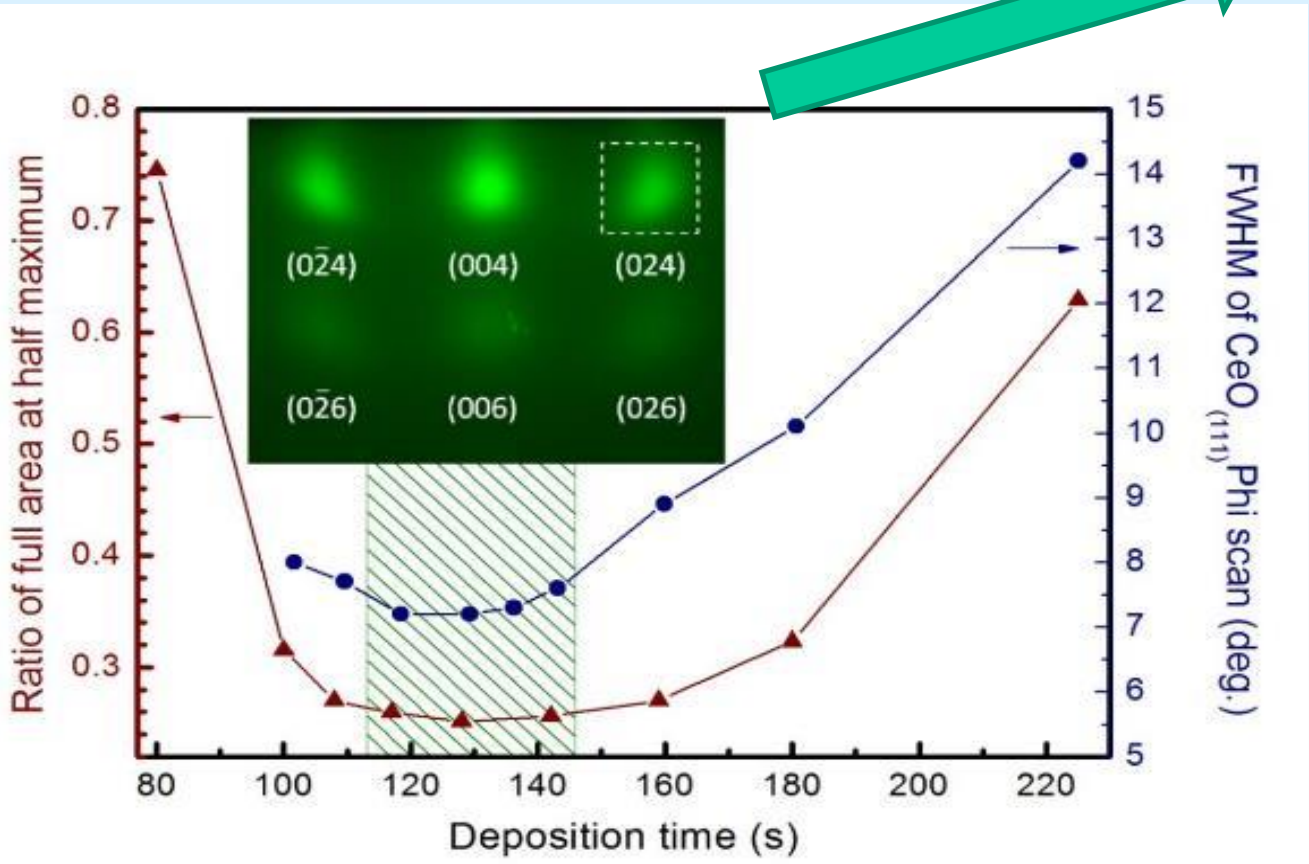


- More than kilometer buffer growth controlled and checked by RHEED patterns

Evaluation Method Developed for Texture of Oxide Buffer

- **Direct comparison of time dependence of In-situ RHEED pattern and ex-situ x-ray Phi scanning**

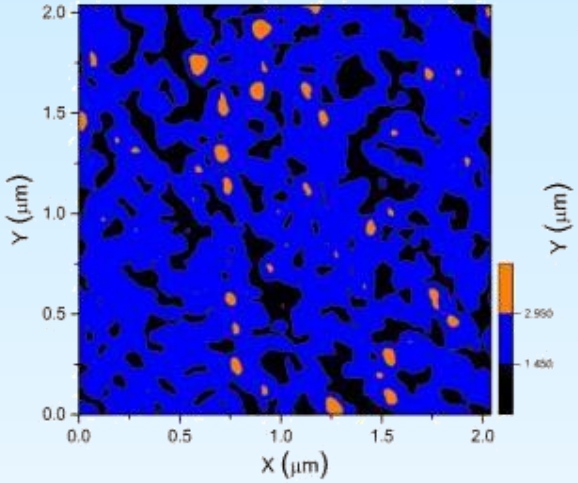




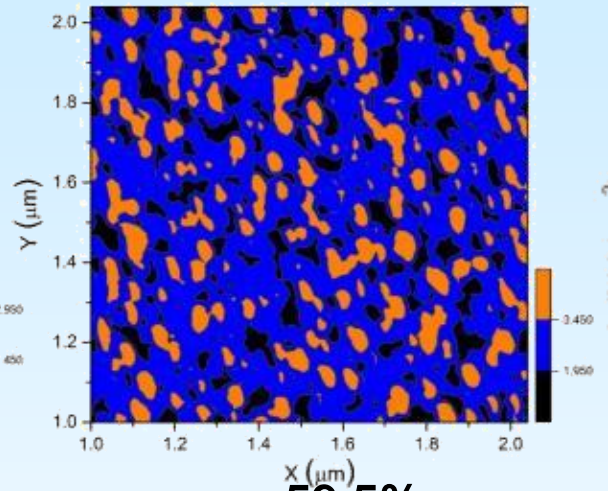
- **Characteristic Method Developed For in-situ Check of Texture**

Buffer Surface Quality vs. Resultant SC Performance

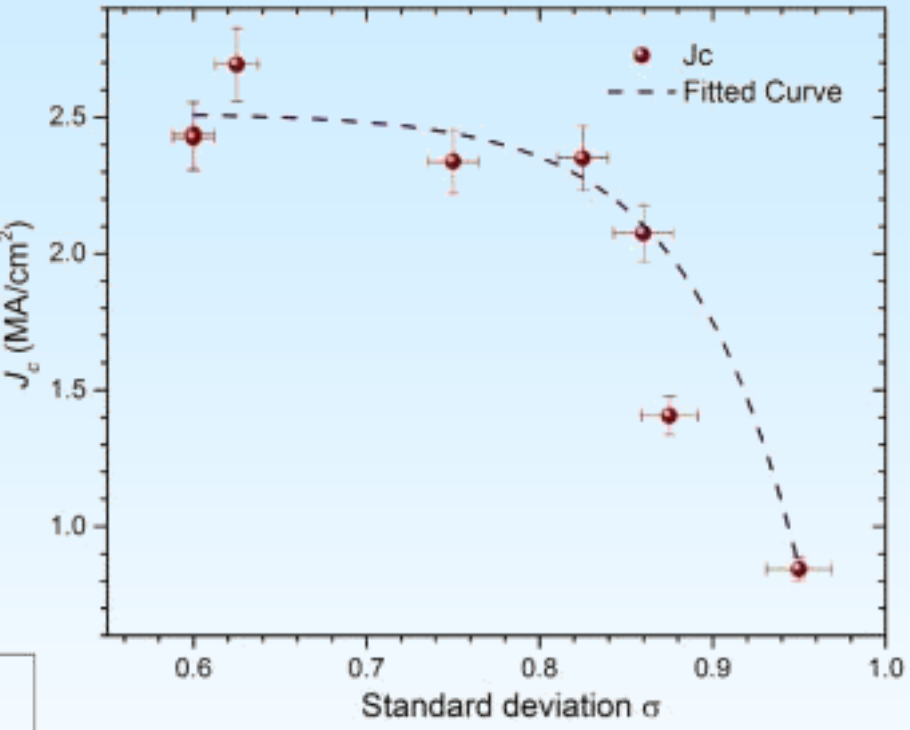
Flat area percent based on AFM



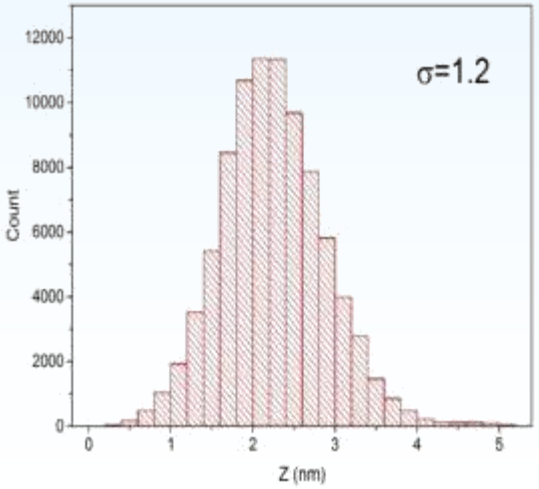
69.0%



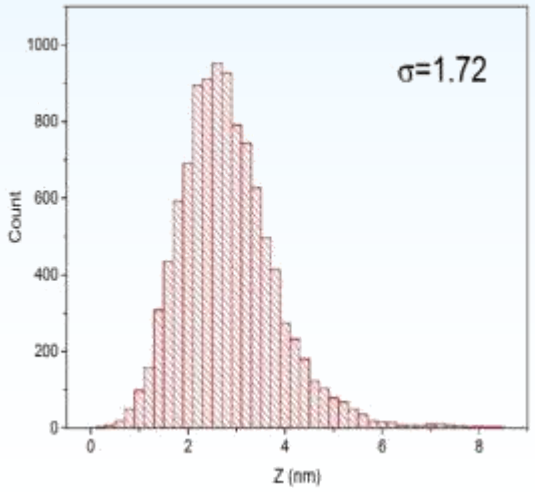
59.5%



Profile height distribution



J_c=2.4 MA/cm^2



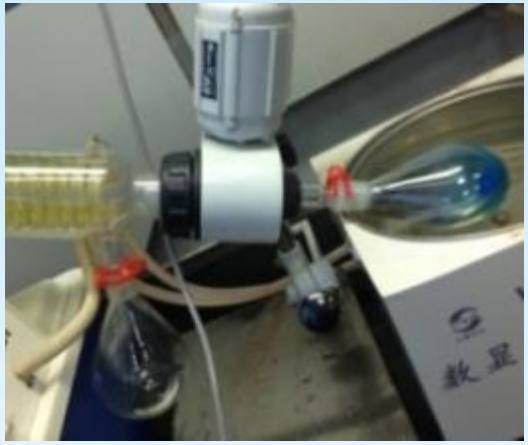
J_c=2.0 MA/cm^2

- **Dependence of *Jc* on the standard deviation of profile height distribution for the buffer surface**

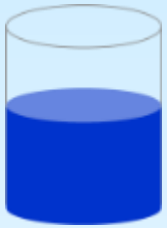
Outline

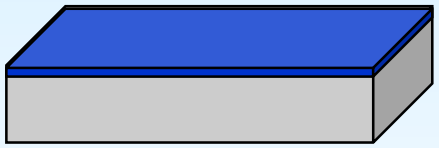
- Technology routes selected and R2R pilot line for kilometer tape built up
- **Effort on improvement of processing efficiency and HTS layer thickness**
- Development and state of the art for long-length HTS Coated Conductors

Industrial Process for MOD-REBaCuO Coated Conductors



Solution Preparation





Coating + Low temperature Pyrolysis

High-temperature Crystallization

Oxygenation

Key Issues for MOD-derived YBCO Coated Conductors

◆ To increase the production rate

- **Less Pyrolysis Time:**

  -- Low-fluorine（ISTEC/AMSC/SHU…);TFA-Anhydride(ICMAB);

  --Additions such as DEA/TEA (SNL/SHU…); /PEG(ICMAB,Tsinghua…)

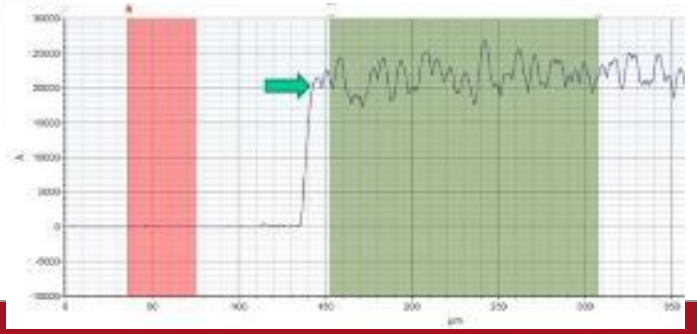
- **Less Crystallization Time:**

  --Low ambient pressure(SNL/AMSC…); Fast gas flow

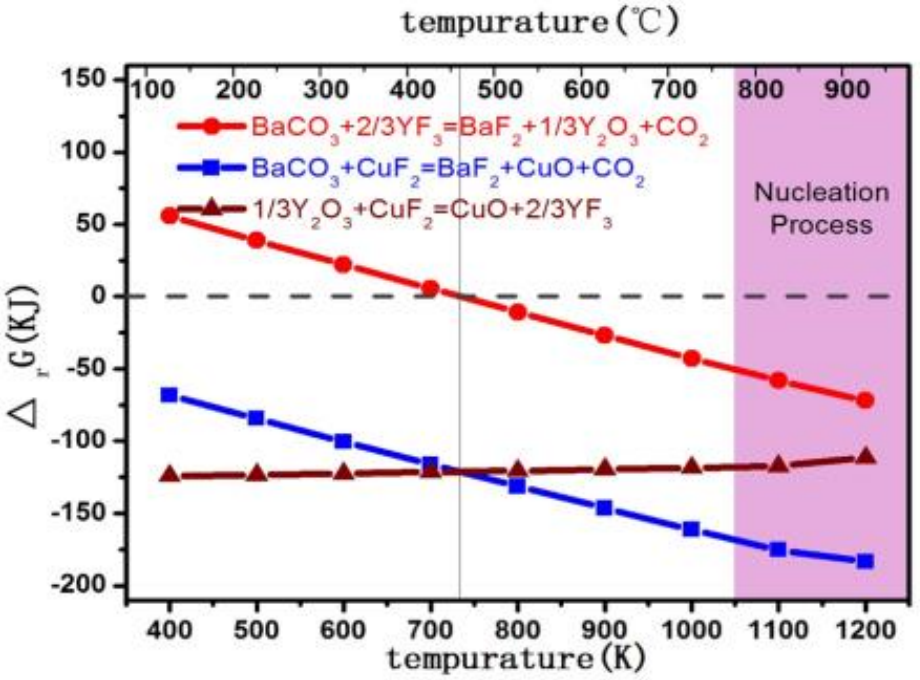
◆ To improve performance

- Increased thickness of YBCO layer
- Improved surface morphology via doping
- Enhanced flux pinning via doping

1.4-2.1μm YBCO by single MOD coating developed in SHU



Dramatic Reduction in Pyrolysis Time of MOD



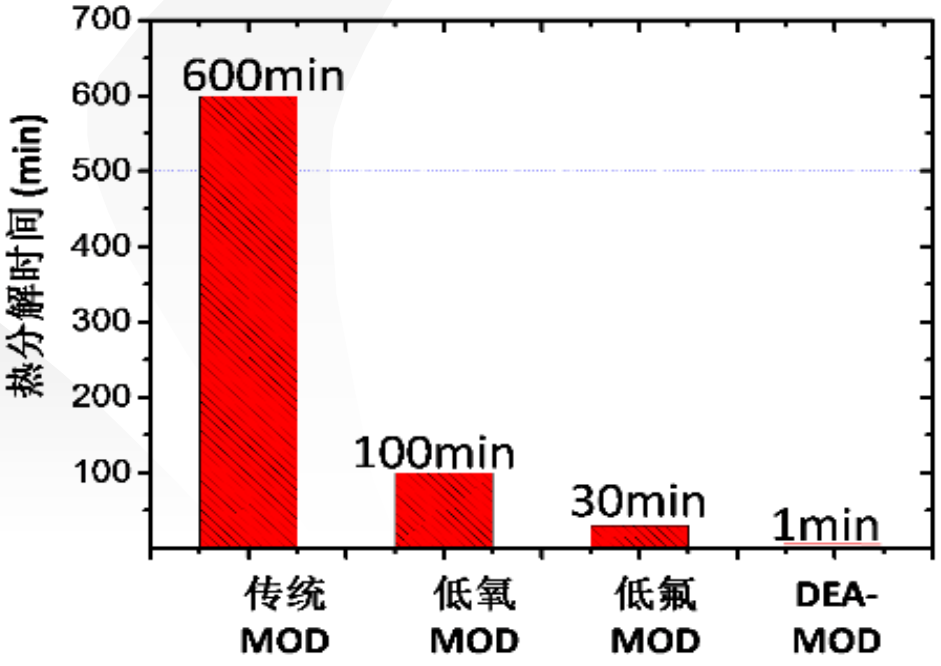
Li et al., IEEE Trans. Appl. Supercond. 25(3)(2015)pp1-4

$$\Delta G_T^\theta = \sum \nu \Delta G_{f,T}^\theta(products) - \sum \nu \Delta G_{f,T}^\theta(reactants)$$

ΔG < 0， Possible reaction

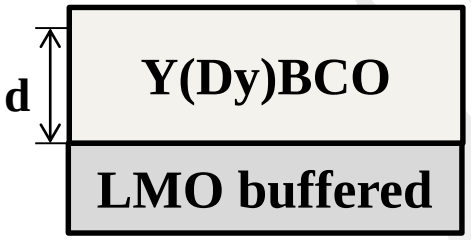
ΔG = 0， Balanced reaction

ΔG > 0， Impossible reaction



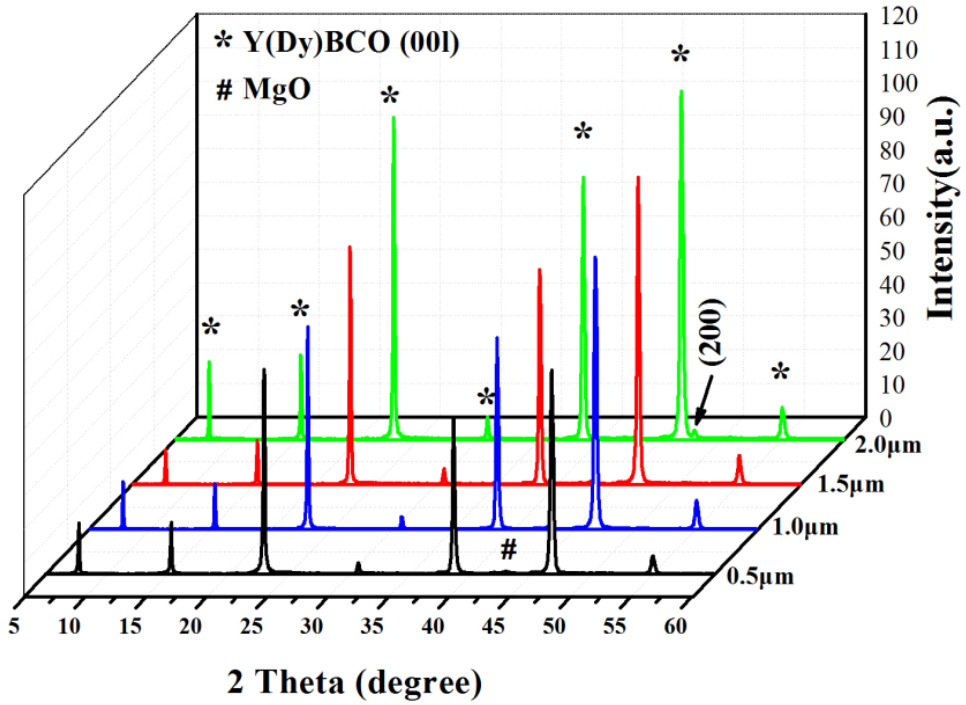
- **Smooth and dense films achieved with doping at a pyrolysis rate as high as 25-50 K/min**
- **Pyrolysis time reduced to be as short as one minute using extremely low F-content solutions**

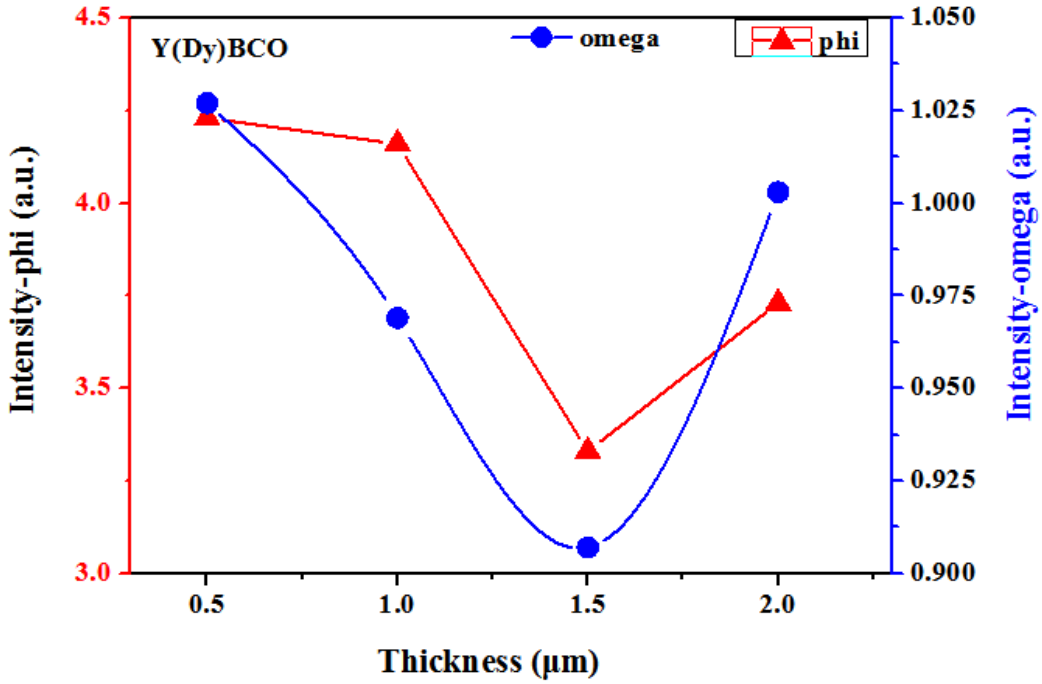
Thickness Issues: Monolayer of Y(Dy)BaCuO



d= 0.5 μm
1.0 μm
1.5 μm
2.0 μm

- Various thicknesses (0.5 μm-2.0 μm)
- Prepared by SLF-MOD method

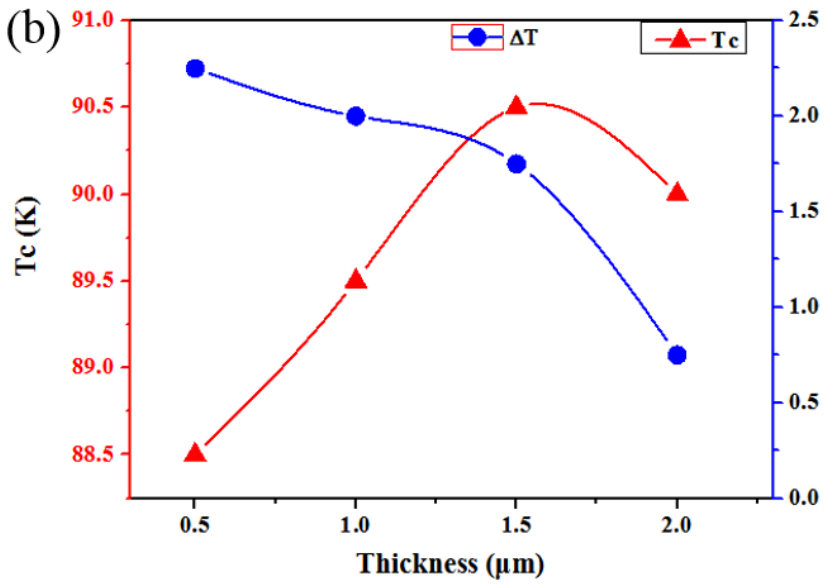


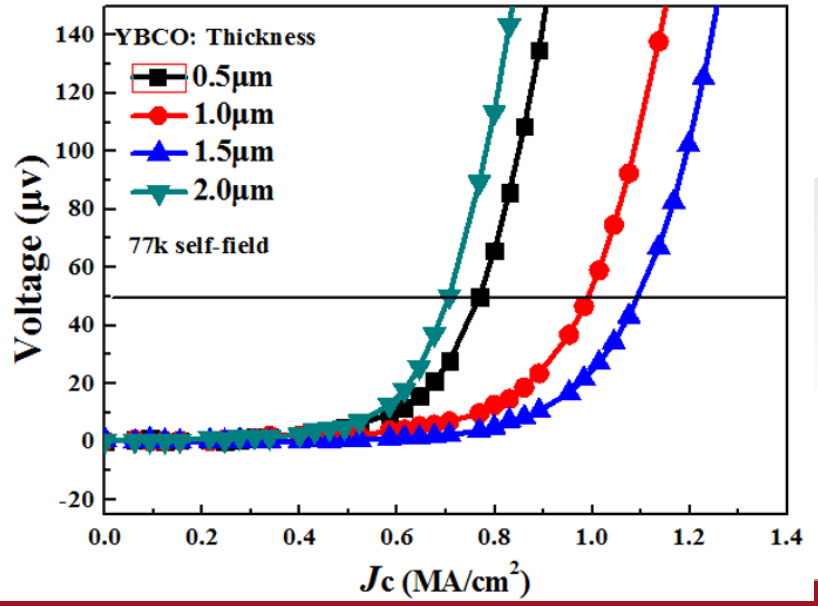


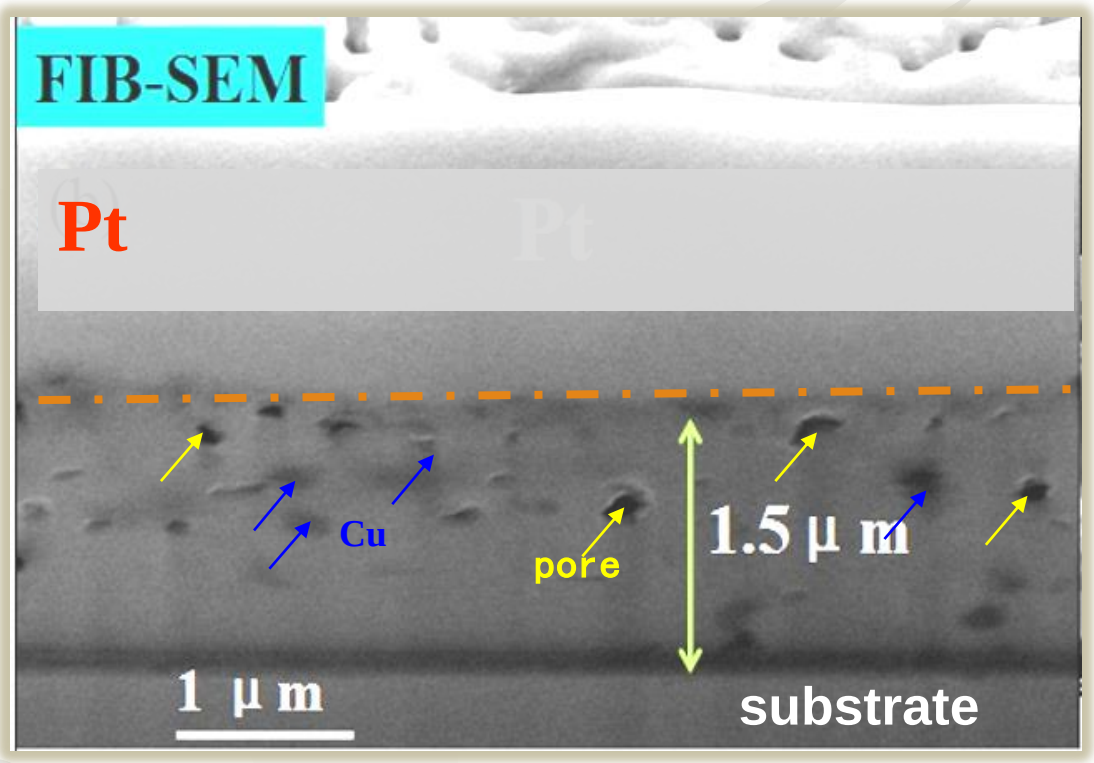
With the film thickness increases, *a*-axis grains appear

Thickness dependence of In-plane and out-of-plane Textures

Thickness Issues: Monolayer of Y(Dy)BaCuO

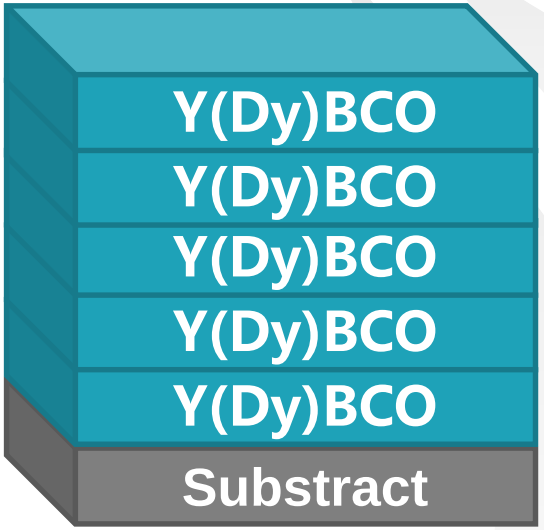




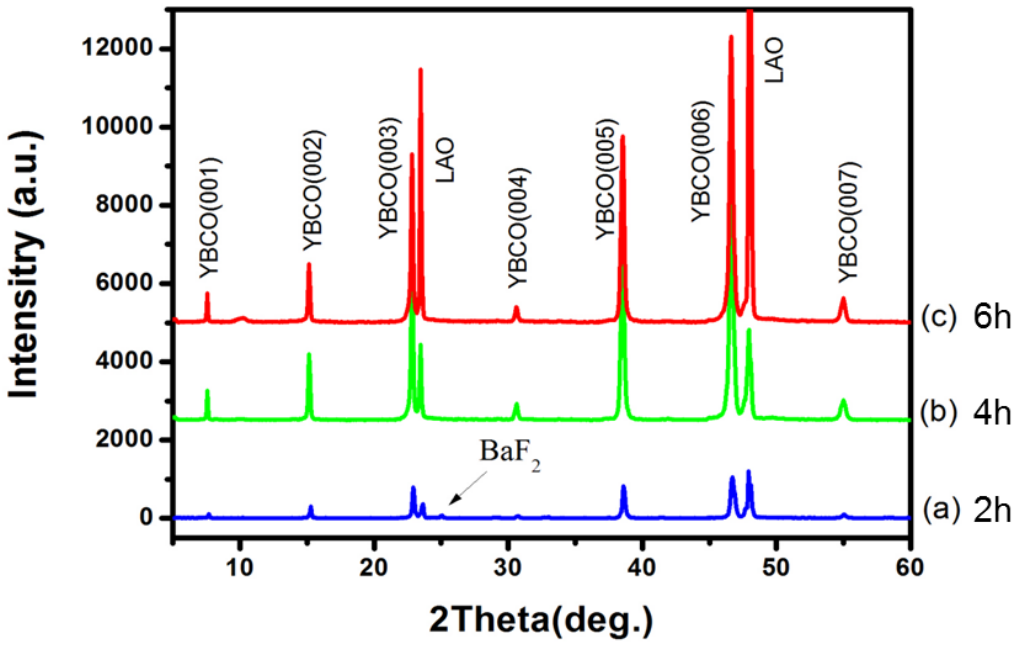


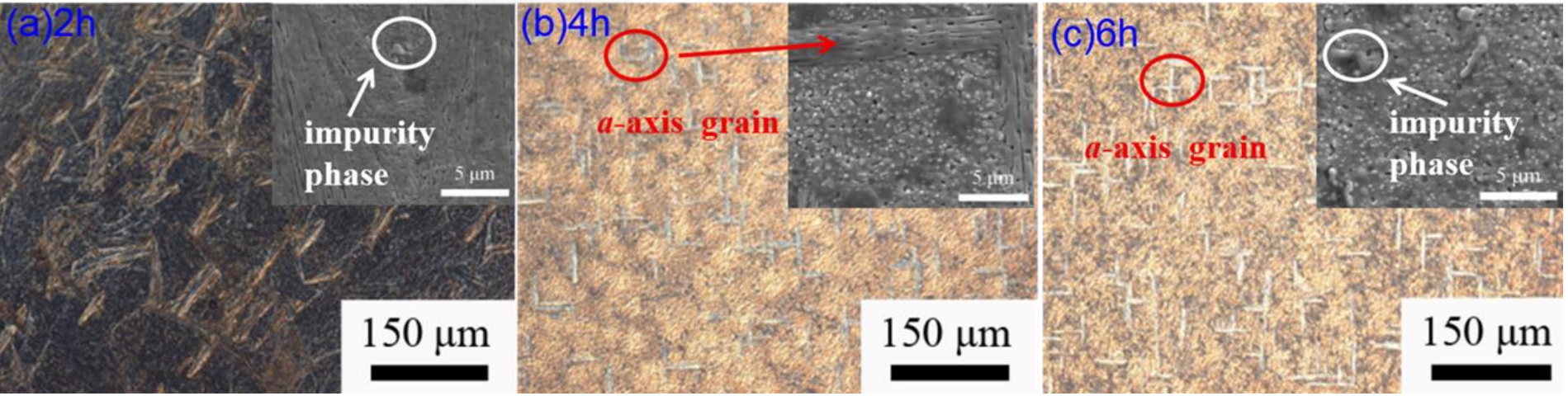
- As the film thickness increasing, a-axis grains, pores and element segregation of YBCO films were formed.
- YBCO films with proper thickness as 1.5 μm, appear better.

Thickness Issues: Mulitlayer of Y(Dy)BaCuO



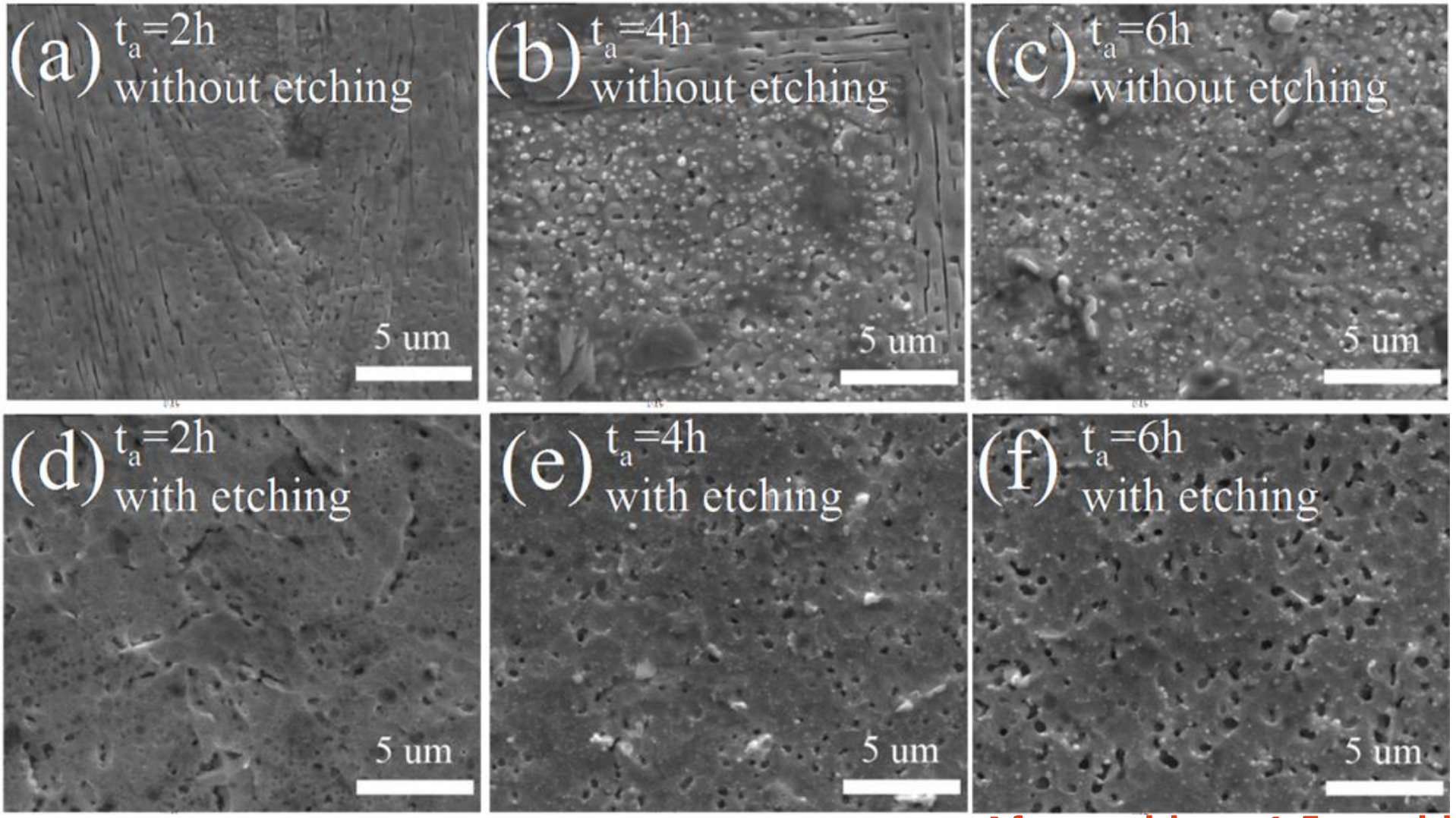
Five-layer flat and crack-free YBCO films with a thickness of more than 2.5 μm





Thickness Issues: Mulitlayer of Y(Dy)BaCuO

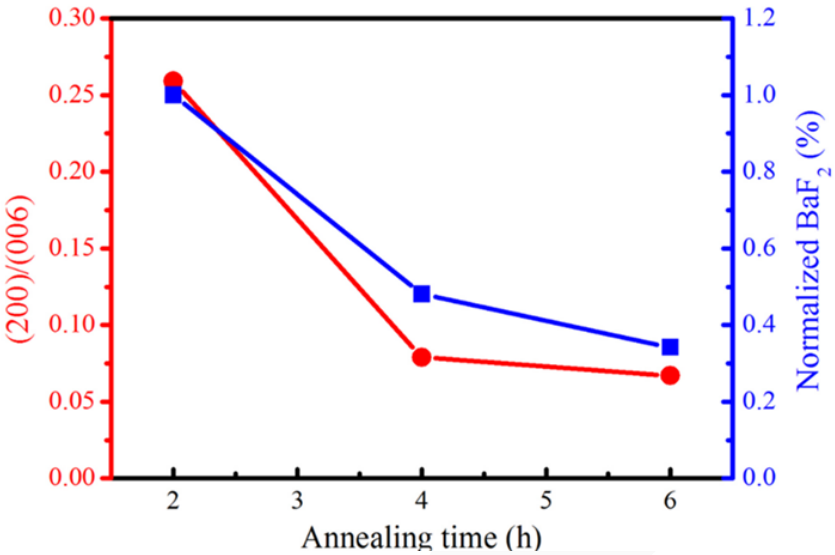
before etching ~2.5 μm thick

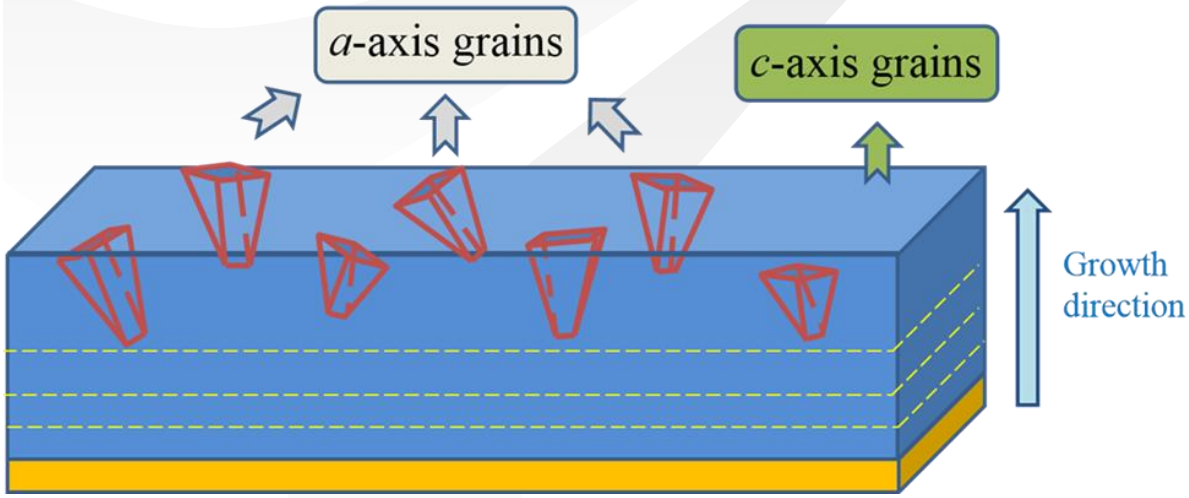


After etching ~1.5 μm thick

Thickness Issues: Mulitlayer of Y(Dy)BaCuO

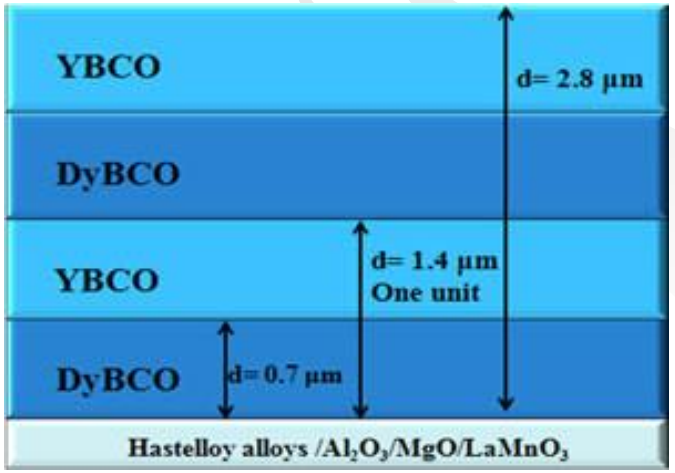
Illustration of *a*/*c*-axis growth along the thickness direction and time applied

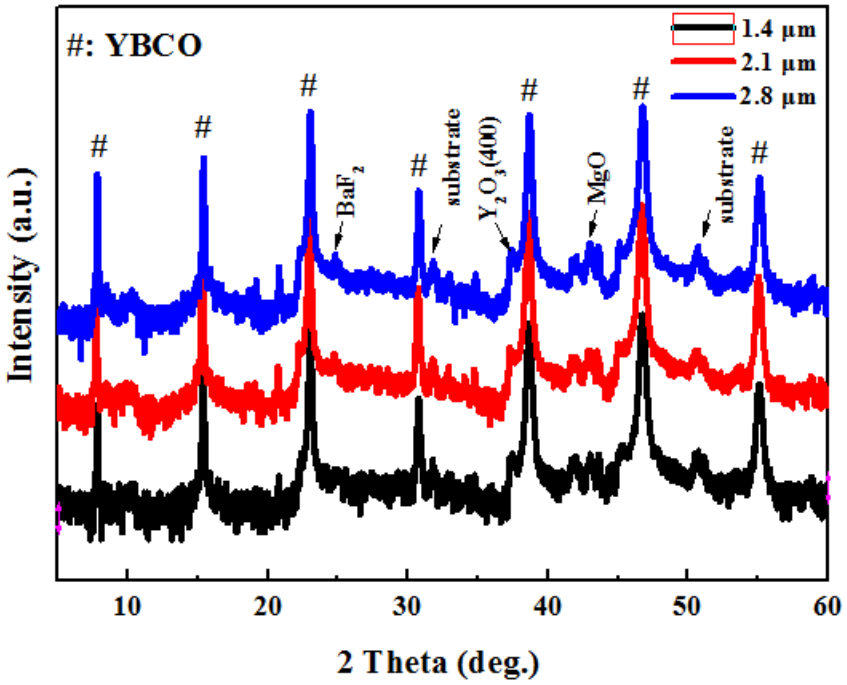




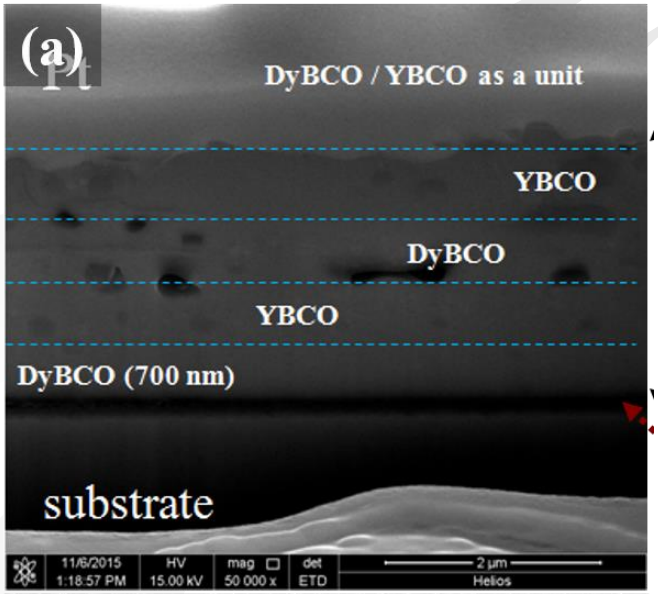
- A pure *c*-axis growth may occur at the bottom of the resultant film because the less *a*-axis grains are present after the film surface is etched.
- At the beginning, the *c*-axis growth is dominated. With increasing time for thick films, *a*-axis grains nucleate, grow, and enlarge along the thickness direction, together with impurity particles.

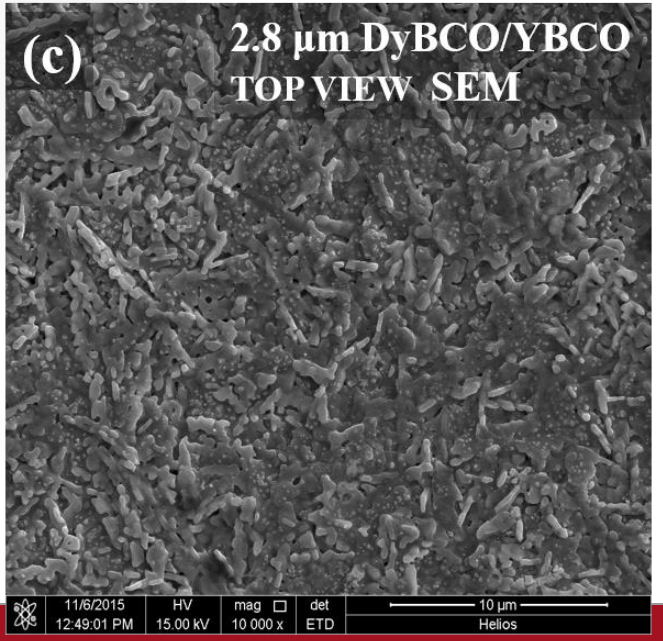
Thickness Issues: Mulitlayer of DyBaCuO/YBaCuO



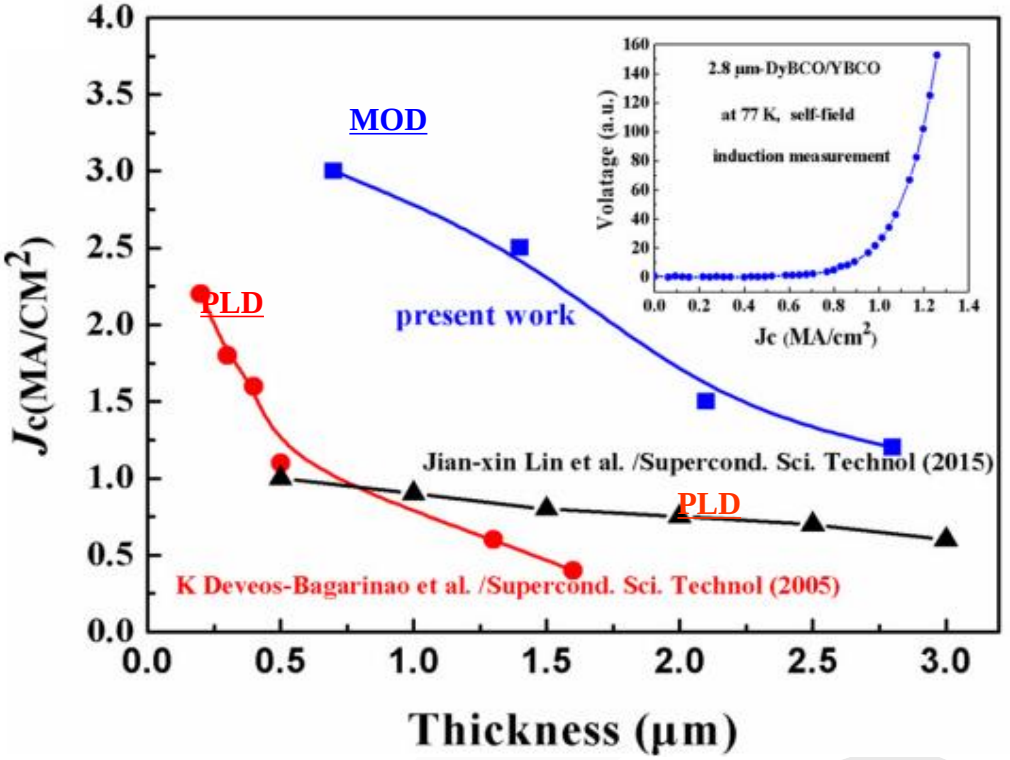


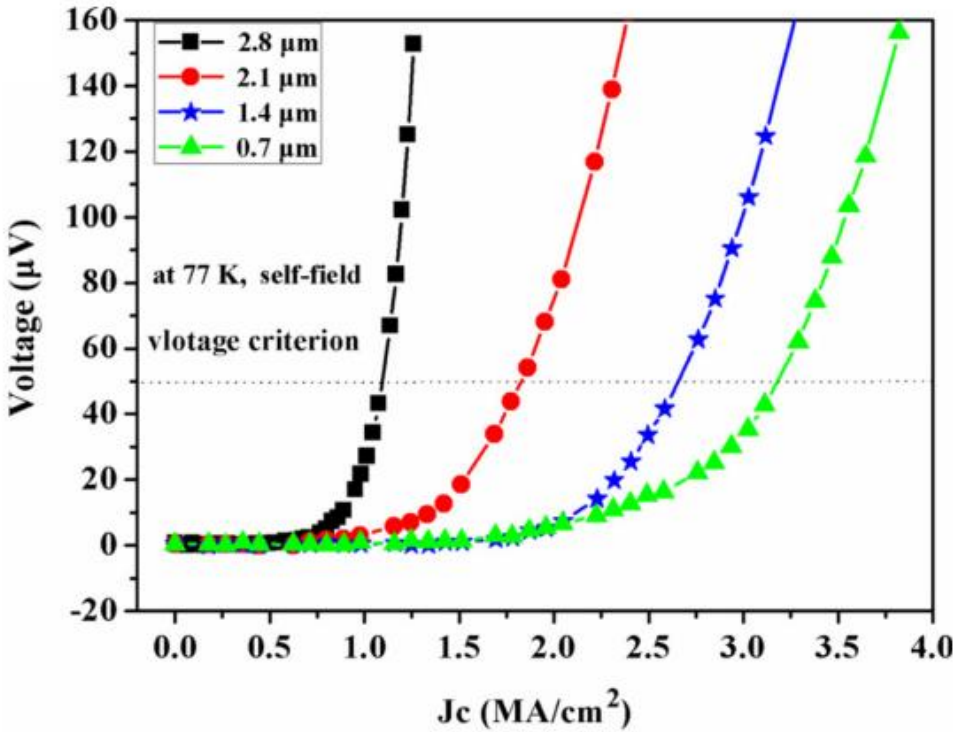
2.8 μm





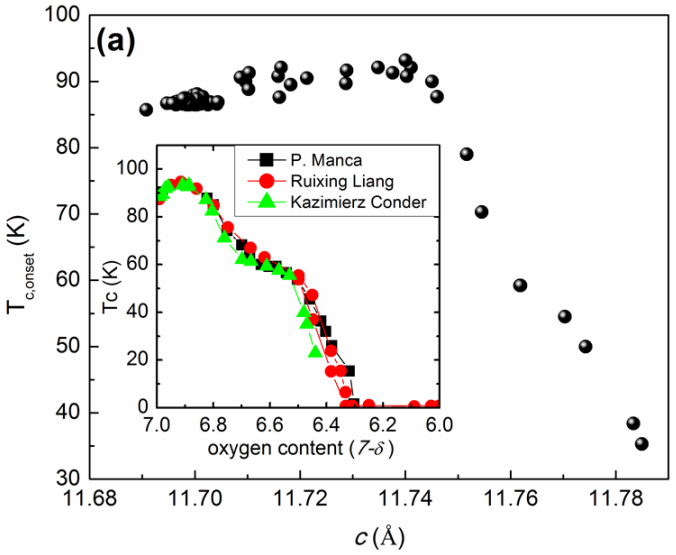
Thickness Issues: Multilayer of DyBaCuO/YBaCuO

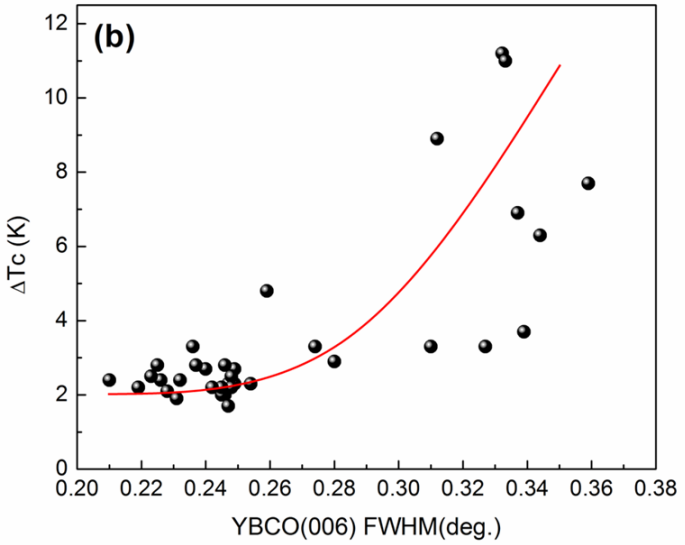


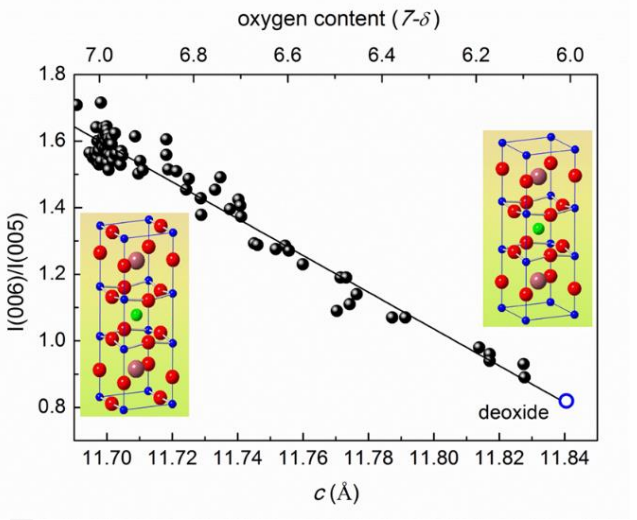


- Compared with the monolayer thick (Ydy)BaCuO, the multiayer of DyBCO/YBCO exhibits a better texture, surface morphology and critical currents.
- Higher critical current for thick multilayer can be improved with optimal oxygenation

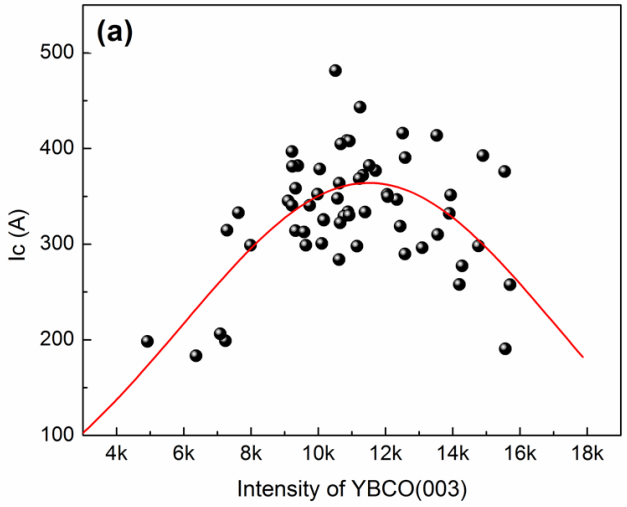
Oxygen Content & Resultant *Ic* evaluated by XRD Peak Intensity for Thick HTS Films Covered by Silver

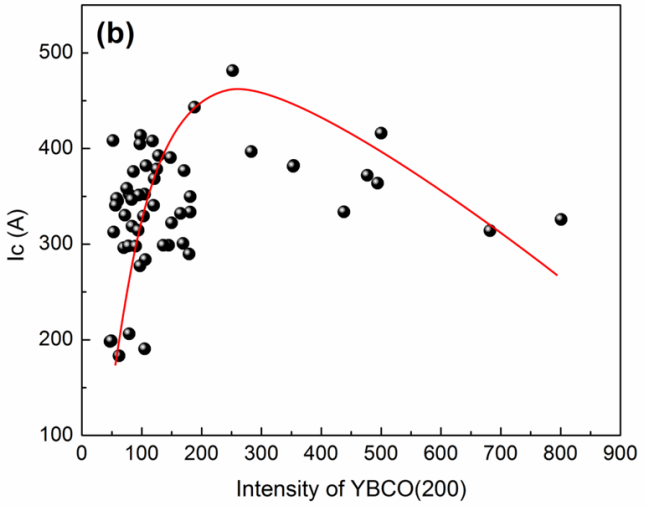


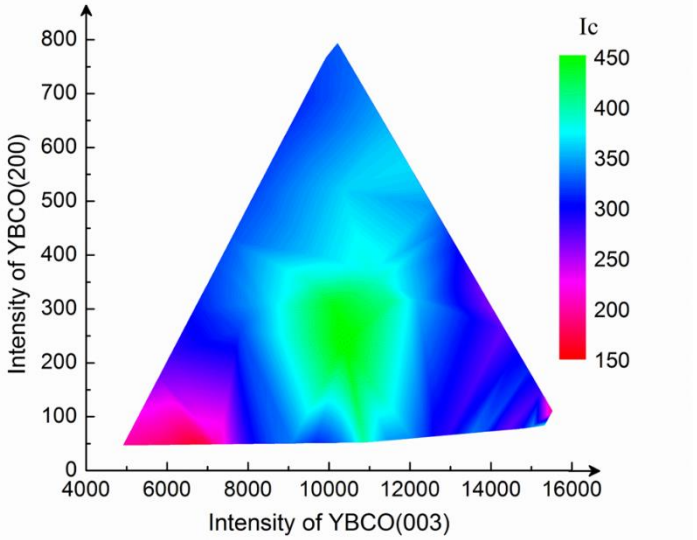




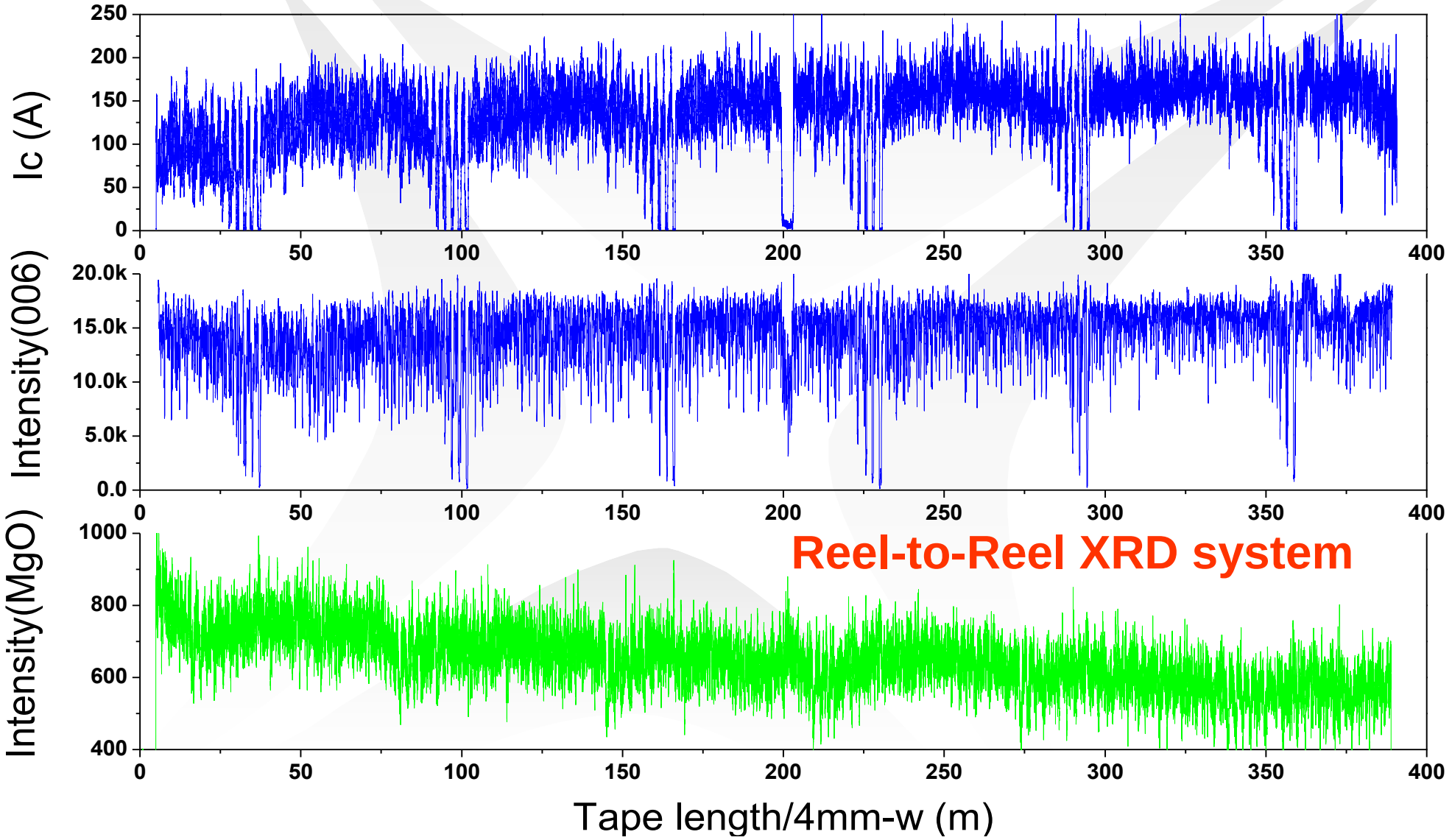
H. Jian, C. Cai et al.
Physica C, 538(2017)40-45







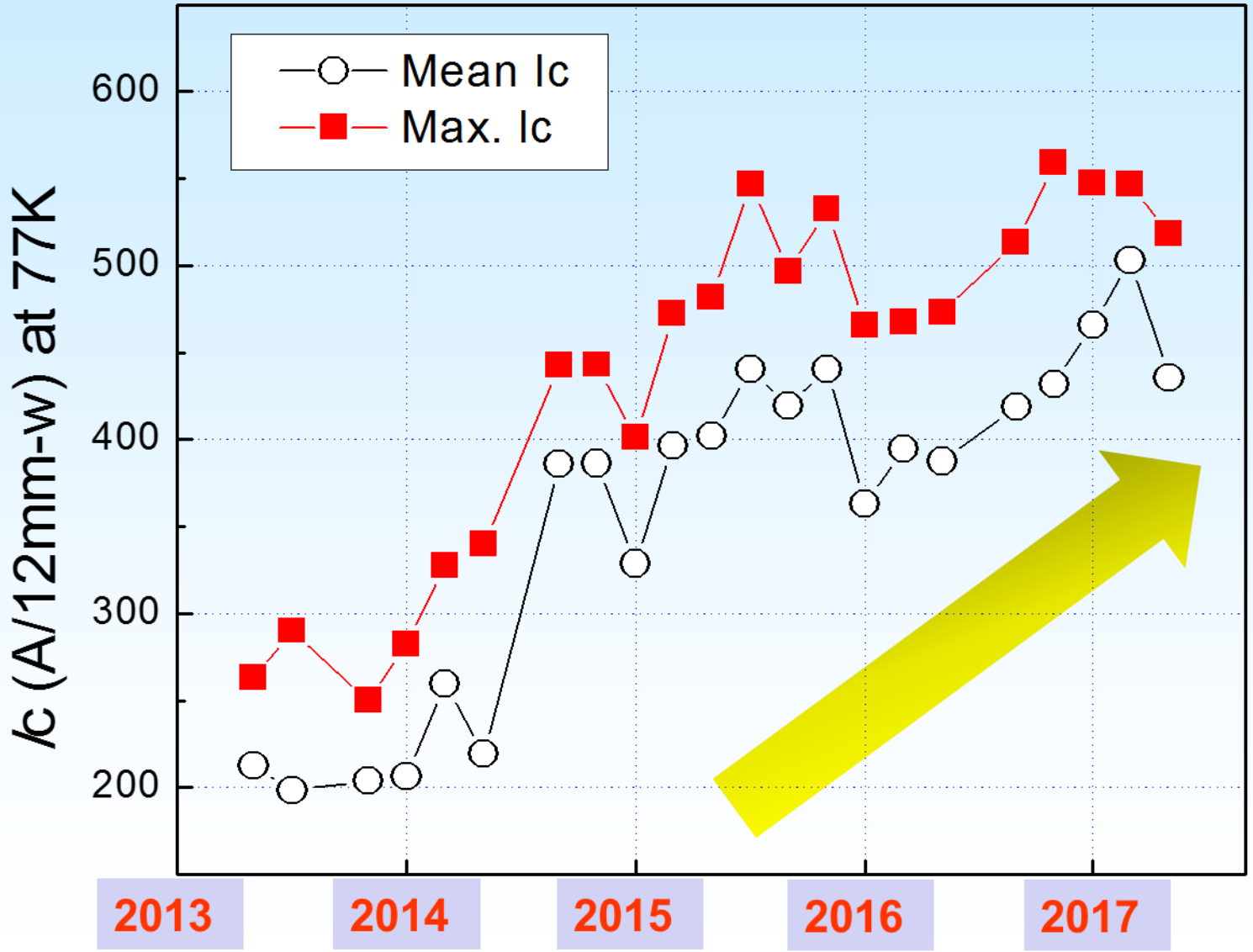
Good Agreement between (006)YBCO Intensity and Resultant Performance



Outline

- Technology routes selected and R2R pilot line for kilometer tape built up
- Effort on improvement of processing efficiency and HTS layer thickness
- **Development and state of the art for long-length HTS Coated Conductors**

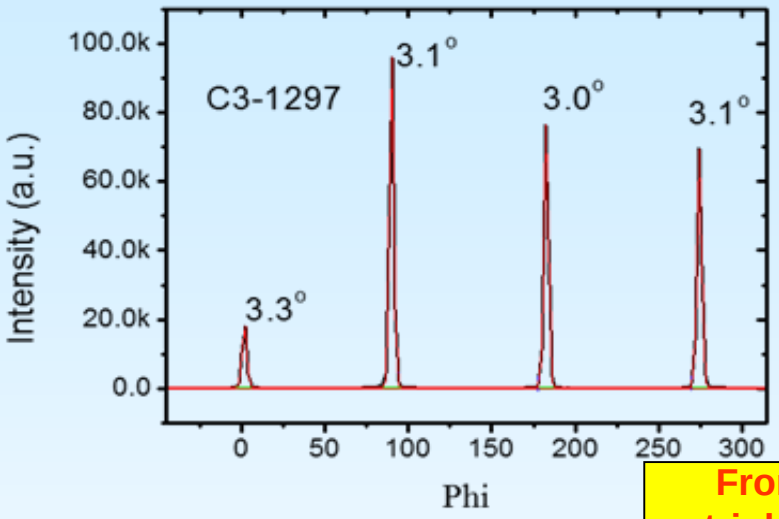
Development for long-length Tapes at SCSC

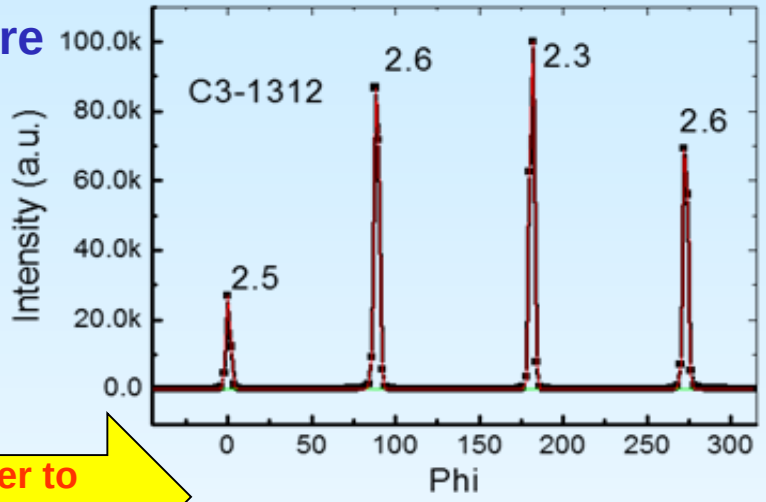


Long-length Performance improved in past years

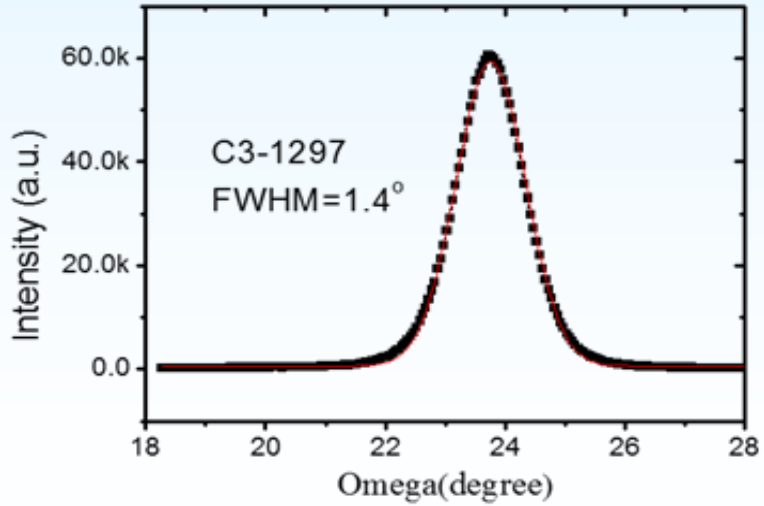
Texture Properties for Bilayer and Triple HTS

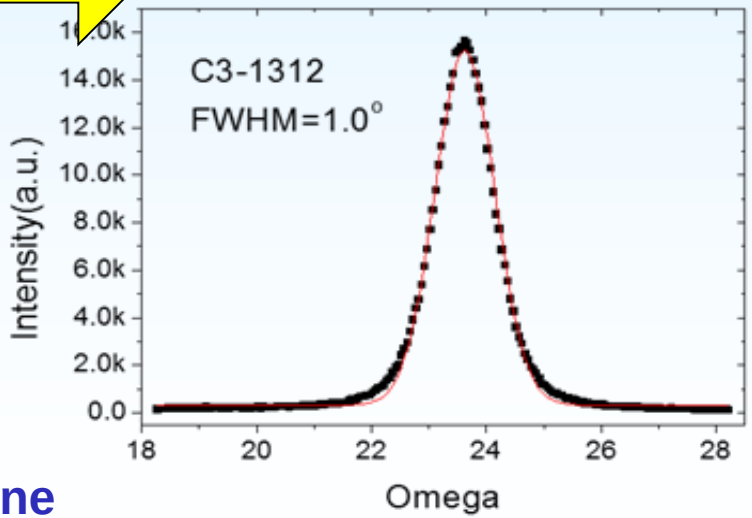
In-plane texture





From bilayer to triple HTS layers





Out-plane texture

VS. Most Others

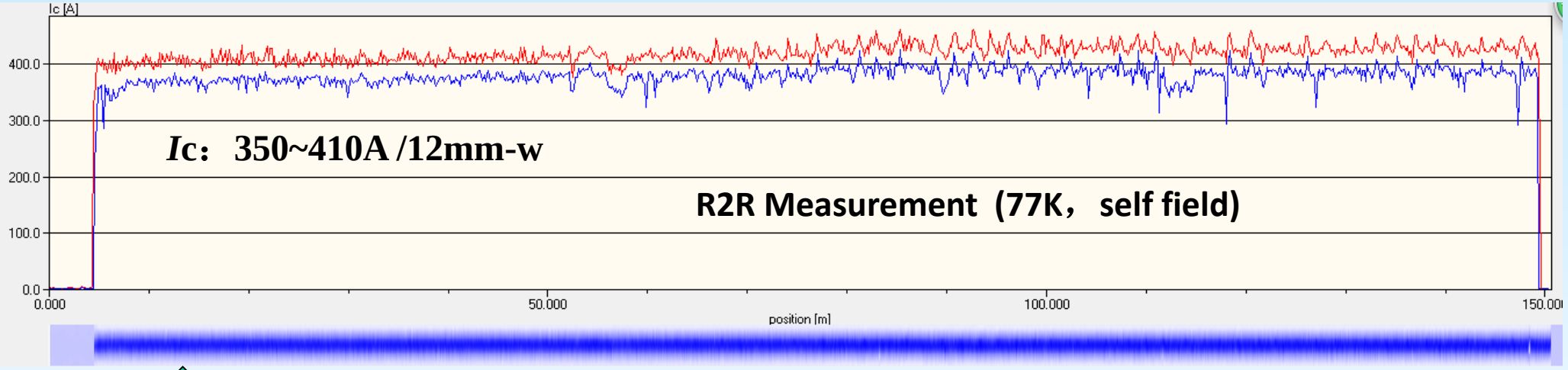
$\Delta\phi \sim 4°$

$\Delta\omega \sim 2°$

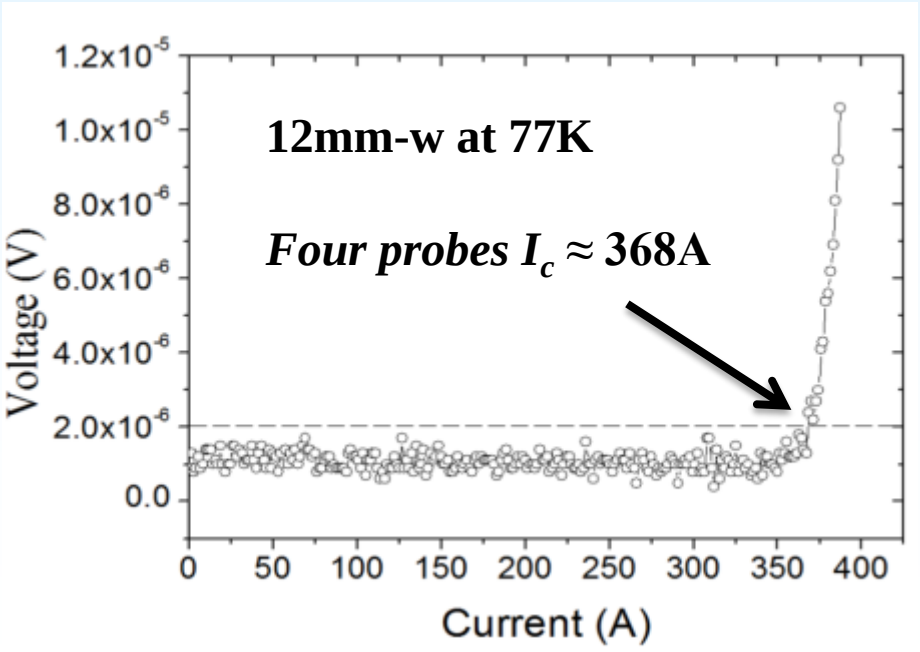
HTS Bilayer (~1 μm thick)

HTS Trilayer (~2 μm thick)

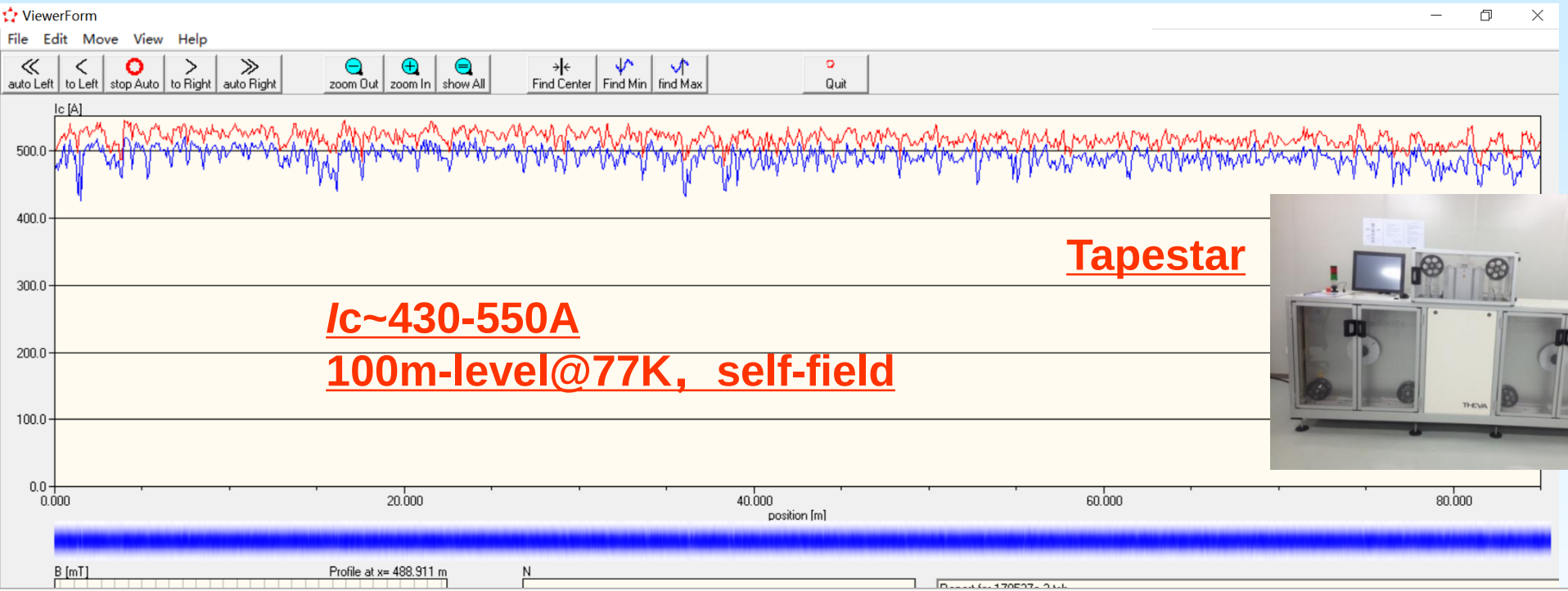
Critical Current for Typical as-grown Tapes at SCSC



Tested by THEVA Tapestar



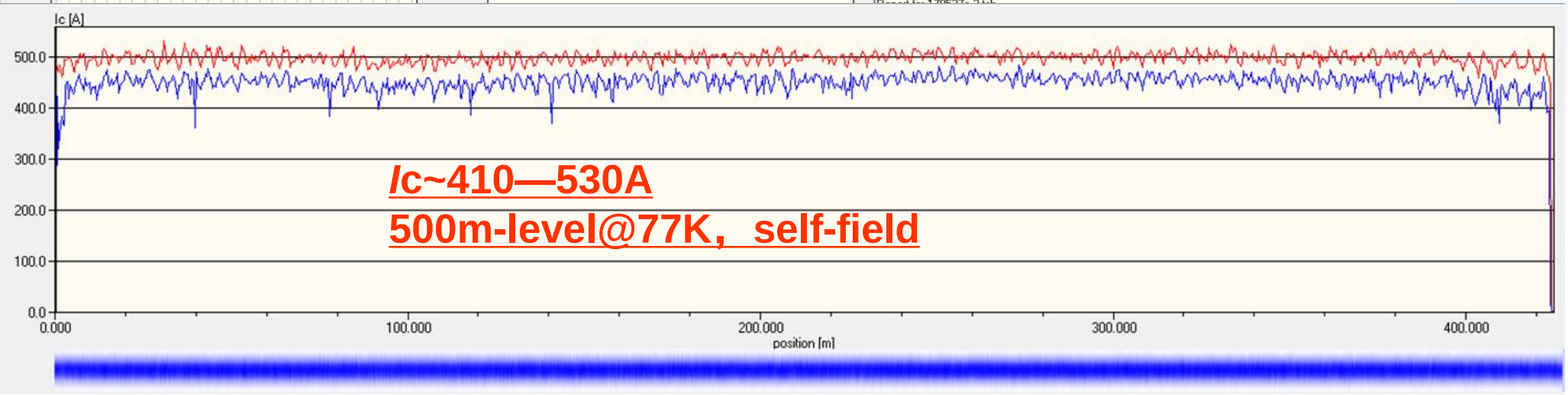
Critical Current for Modified MOD-HTS Tapes at SCSC



Tapestar

Ic~430-550A

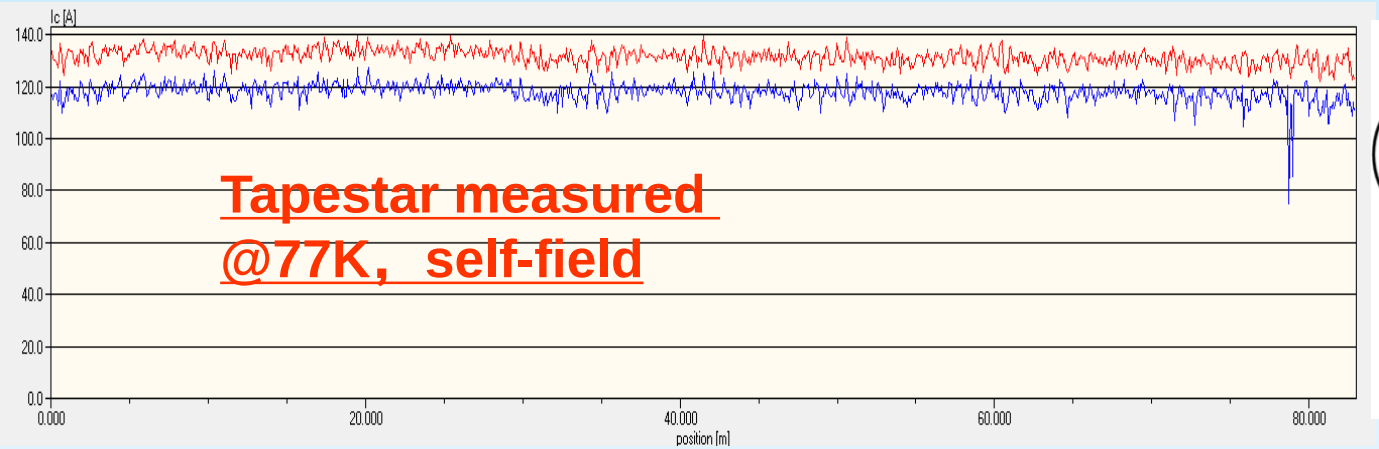
100m-level@77K，self-field

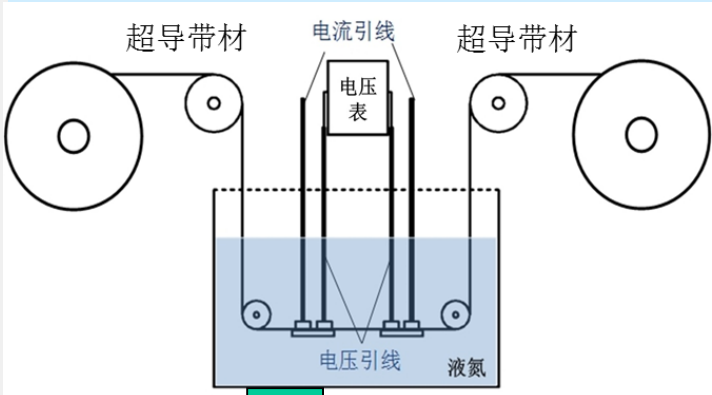


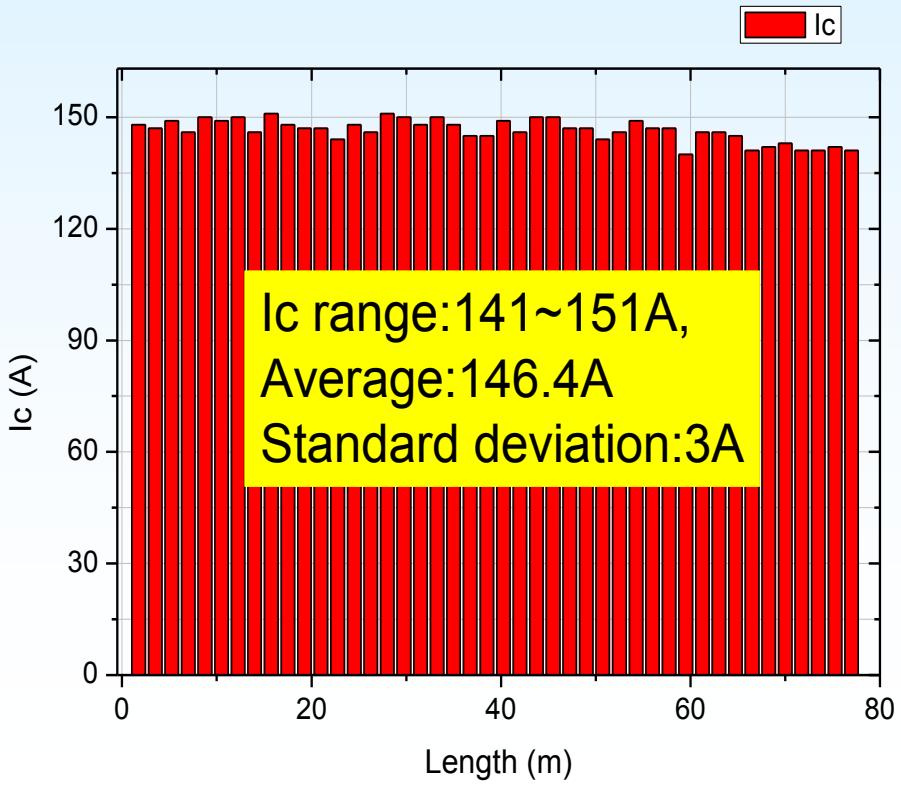
Ic~410—530A

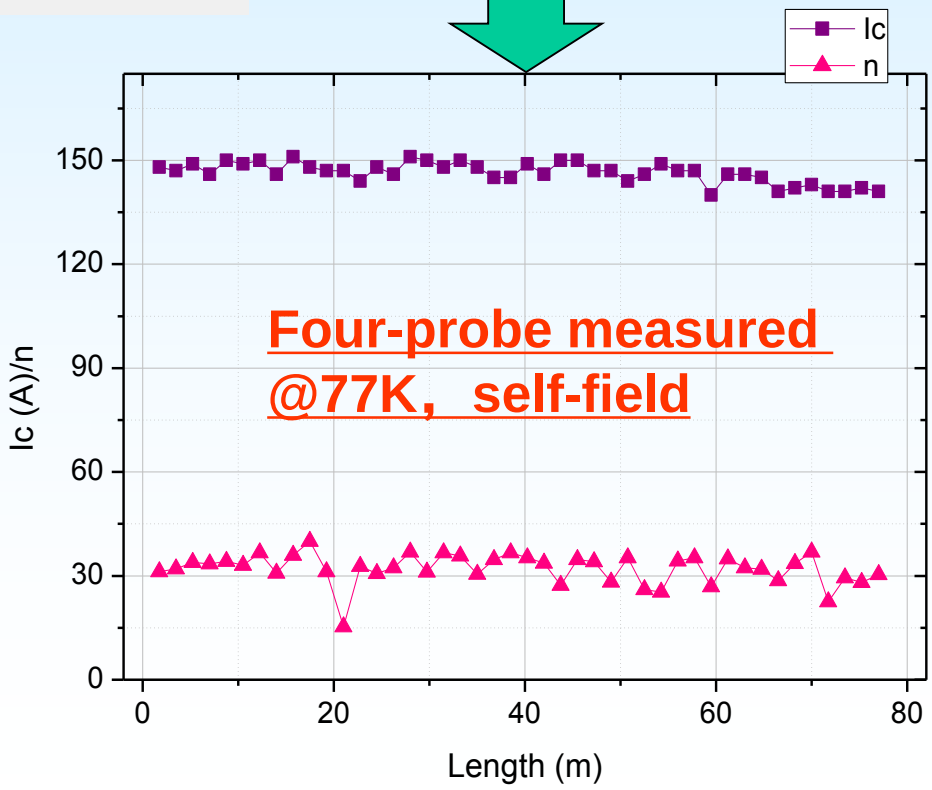
500m-level@77K，self-field

Sliced and Laminated Products with 4mm/w-HTS



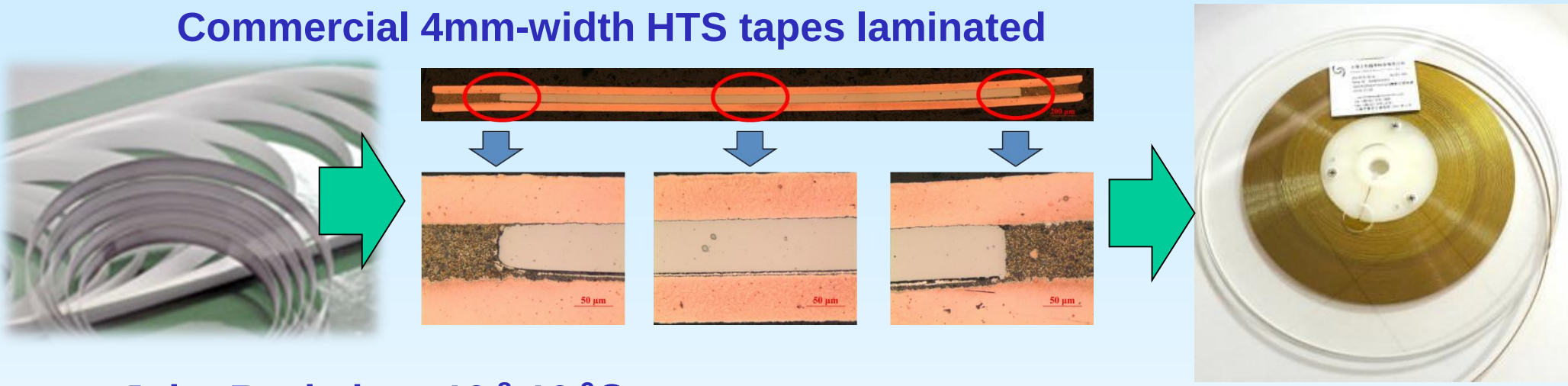




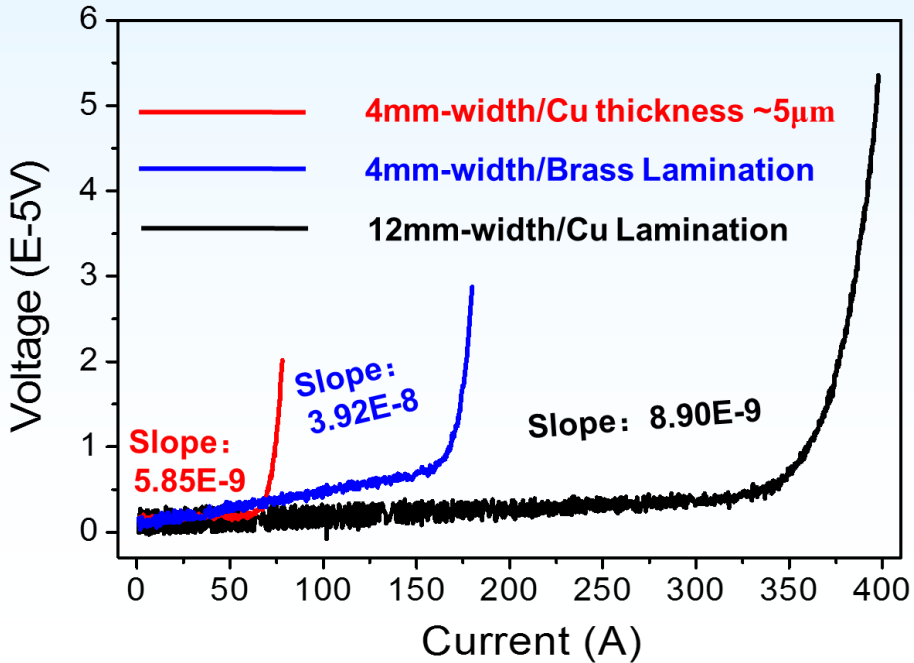


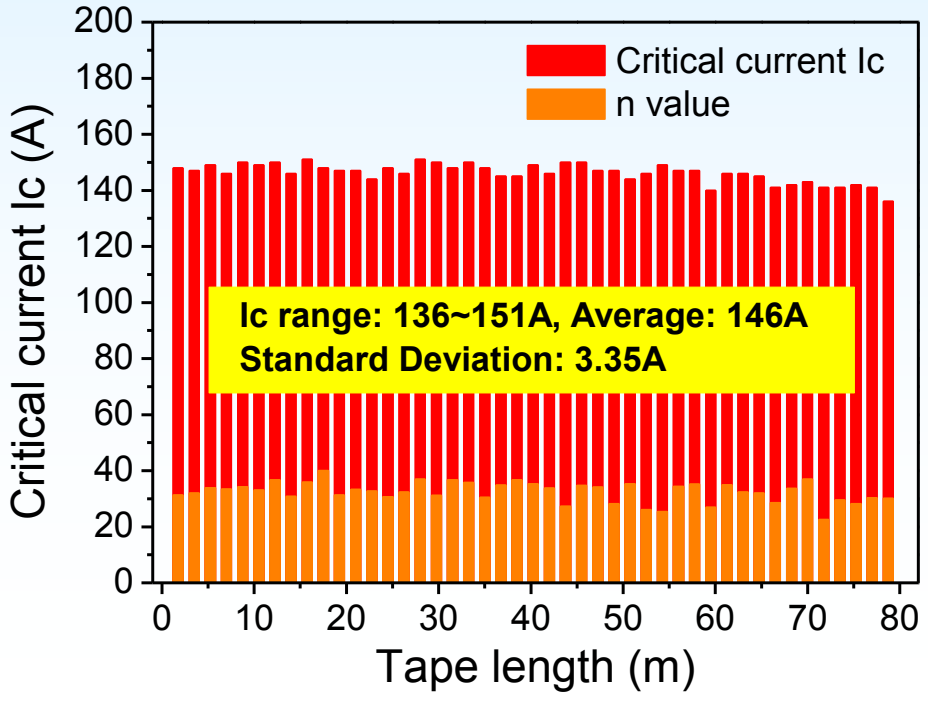
Laminated with Brass/Polyimide and Joint Techniques

Commercial 4mm-width HTS tapes laminated



Joint Resistive~ 10^{-8}-$10^{-9}\Omega$





Summary

- Processing routes for 2G HTS tapes, including IBAD buffer and MOD HTS technologies, and R2R pilot line are developed well in Shanghai University and spinning off company, SCSC.
- XRD measurements show both in-plane and out-of-plane textures are as good as 3 degree, and the critical currents along five hundreds of meters tape reach 370-420 A/cm-width at 77 K, making a solid evidence after AMSC and D-Nano, for the cost-effective MOD applicable and promising for long-length high-quality coated conductors.
- Commercial laminated 2G tape are scaling up, with typical critical current of around 110-150 A/4mm-w (77K, self field), showing the chemical solution approach competitive with the vapor deposition technique using vacuum.

Acknowledgement:

-- Z.Y. Liu, Y. M. Lu, M. J. Li, Y. Q. Guo, C. Y. Bai, Z. G. Zeng et al., at Shanghai University,
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Thank you for your attention

Spinning off