



集成电路科学与工程学院
(示范性微电子学院)
School of Integrated Circuit Science and Engineering
(Exemplary School of Microelectronics)

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Highly Efficient Preparation of Double-sided YBCO thin films with MOCVD

Bowan Tao, Ruipeng Zhao and Yudong Xia

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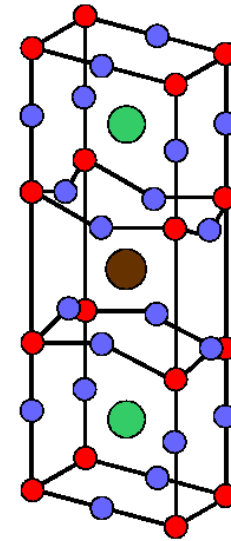
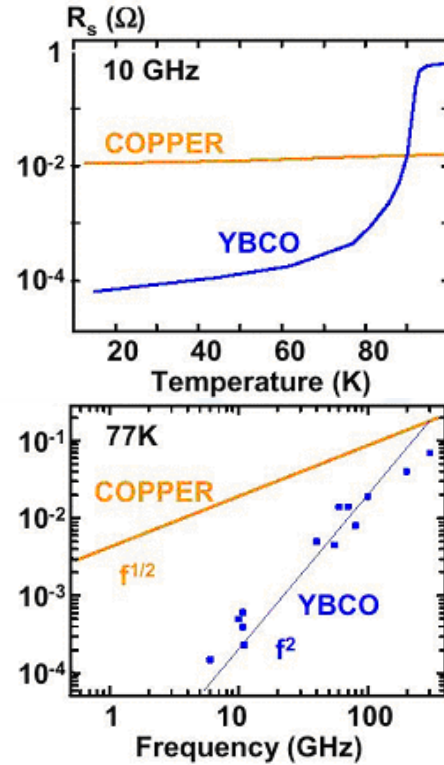
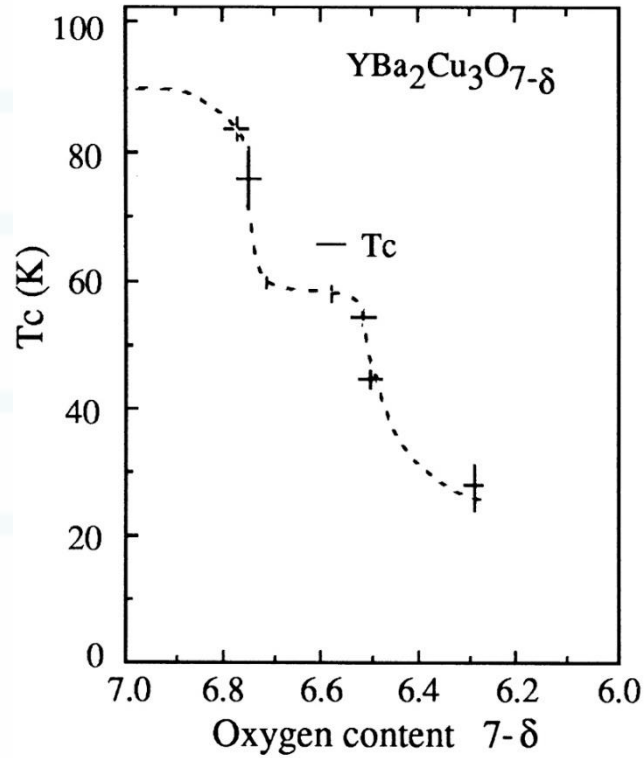
04

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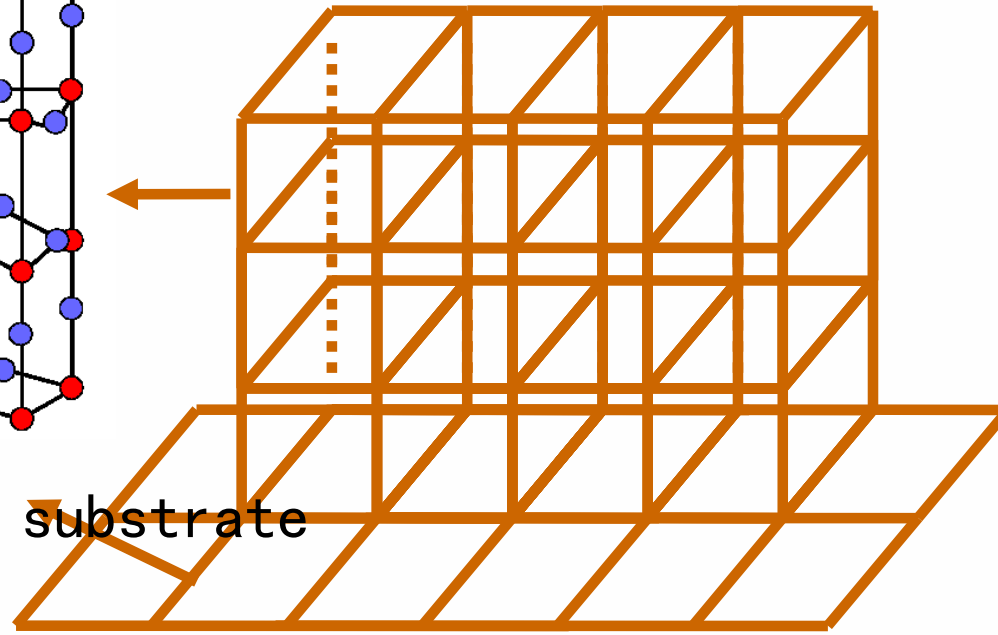


01 Technical background

1、YBCO thin films performance



Texture substrate



$$T_C \sim 90 \text{ K}$$

Liquid nitrogen temperature

$$R_{S(10\text{GHz}, 77\text{K})} < 1\text{m}\Omega$$

Low microwave surface resistance

$$J_{C(77\text{K}, 0\text{T})} \sim 1\text{-}5 \text{ MA/cm}^2$$

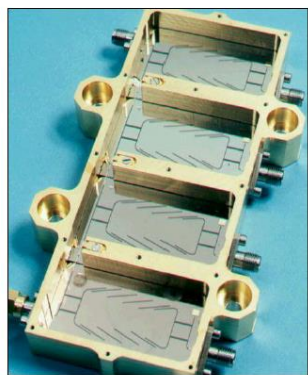
High critical current density



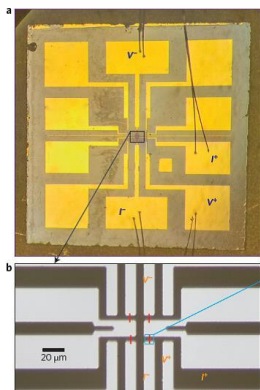
2、Application of YBCO thin films

- Microelectronic devices

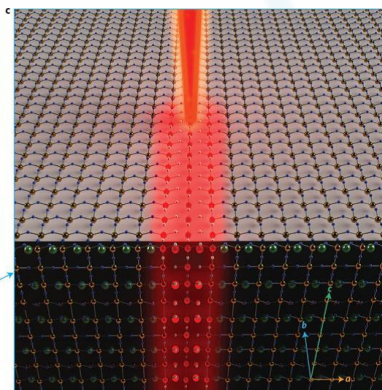
- Low R_s , Strong anti-interference
- Low loss and high sensitivity
- Deposited on single crystal



Microwave device



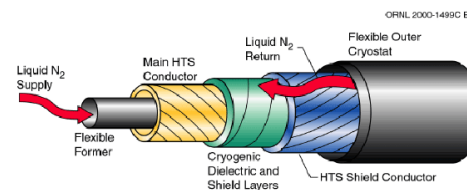
Josephson Junctions



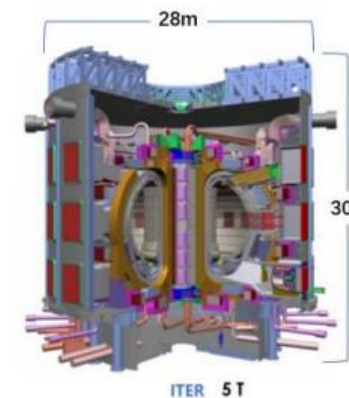
...

- Coated conductors

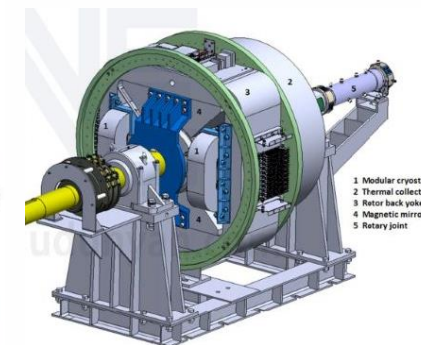
- High field, high J_c
- Mechanical properties
- Deposited on flexible substrate



Cable



Nuclear fusion



Motor ...

Demand: Large area, double sided thin films

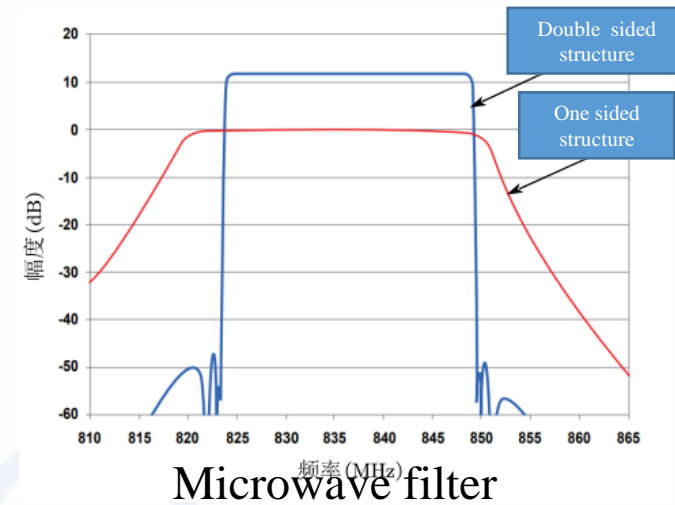
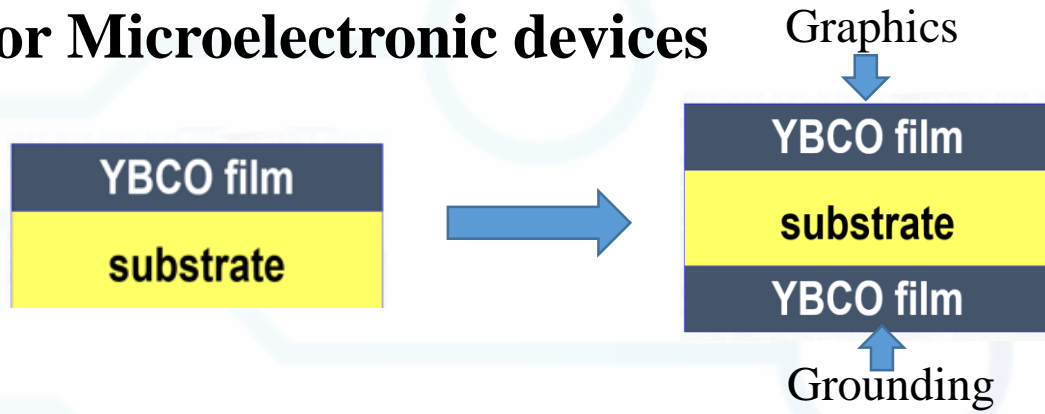
Demand :High efficient preparation, doping other elements

Thickness: Hundreds of nanometers

Thickness: Several micrometers

3、 Why double sided structure?

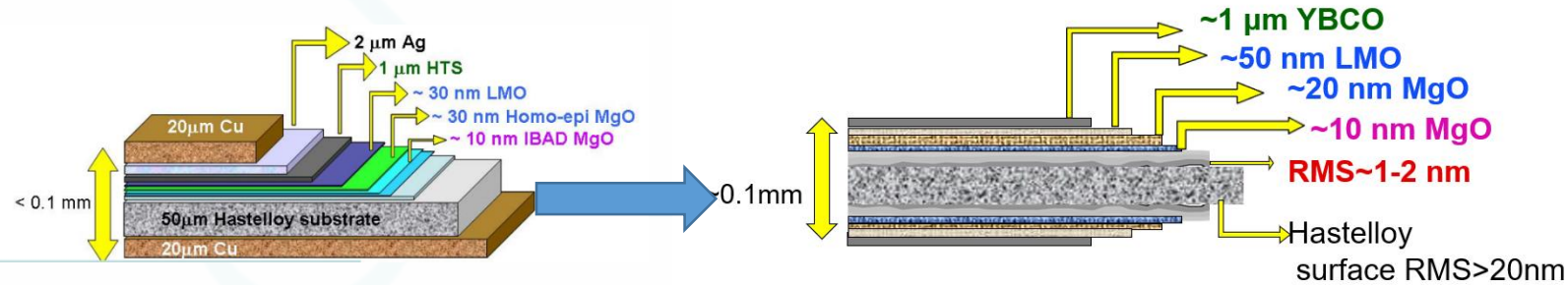
• For Microelectronic devices



Advantage of Filter

- Lower insertion loss
- Smaller bandwidth
- Sharp edge steepness

• For coated conductors



Same thickness

- Double current
- Smaller volume
- Lower cost of cooling

Same current

- Half of YBCO thickness
- Easier to prepare
- Lower Lorentz force

Substrate polish – double sided
Protective layer – double sided
Buffer and YBCO layer – single sided

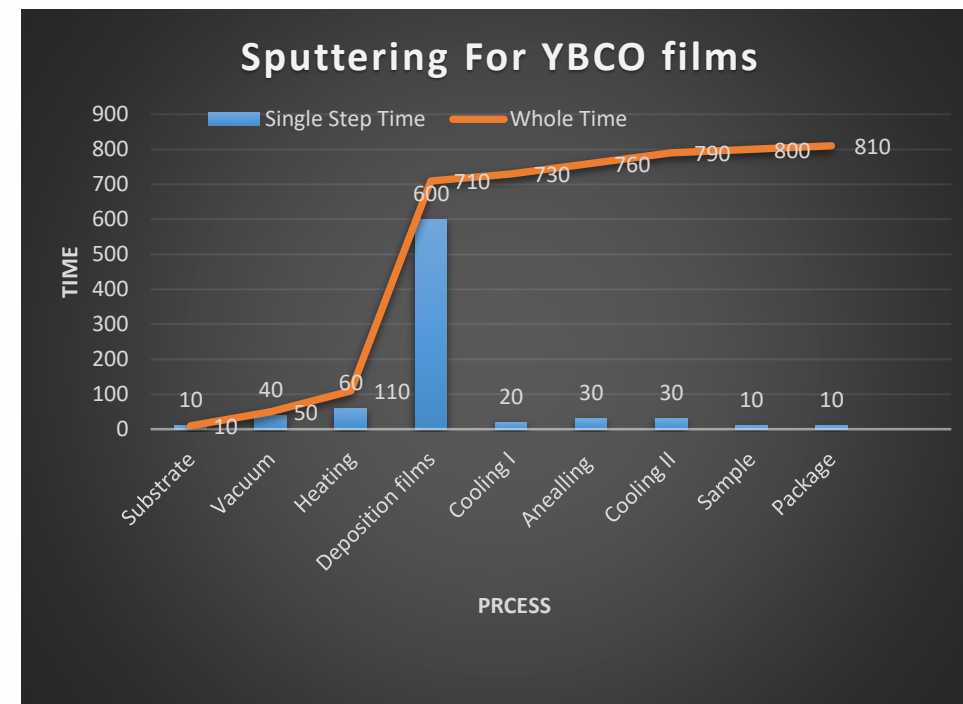
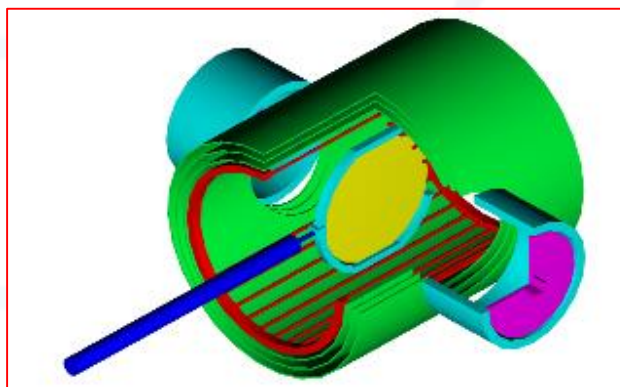
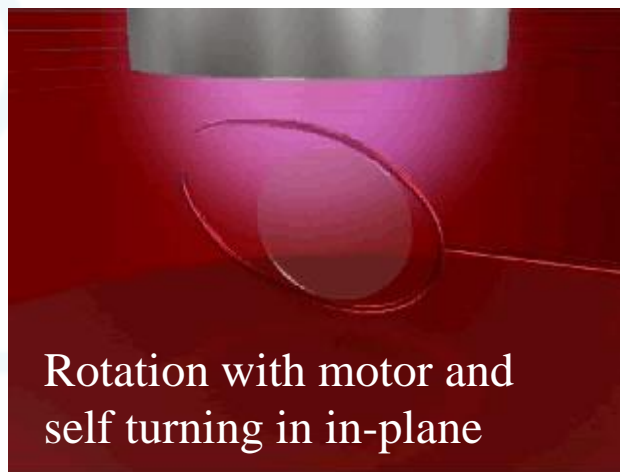
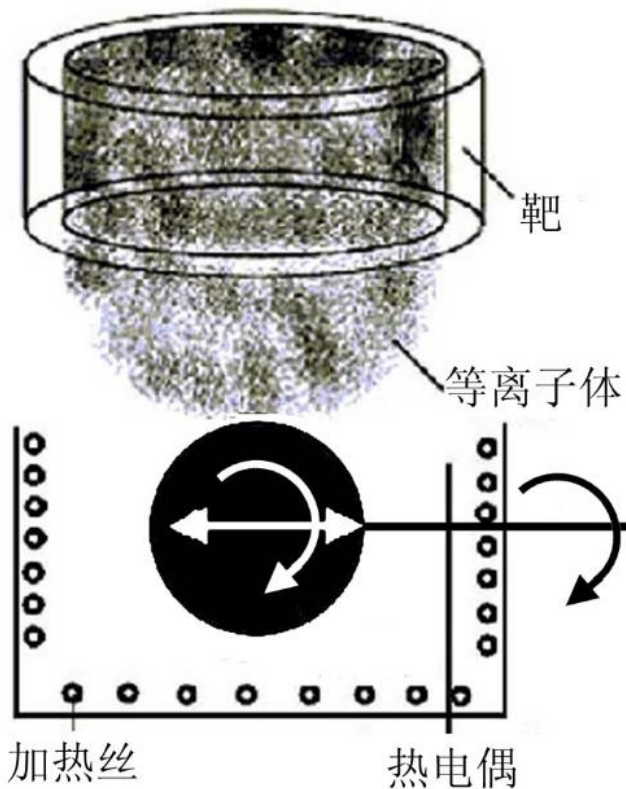
Can we make all double sided structure?

Which technology suitable for large scale preparation of YBCO films/conductors?



Thin films as example to compare

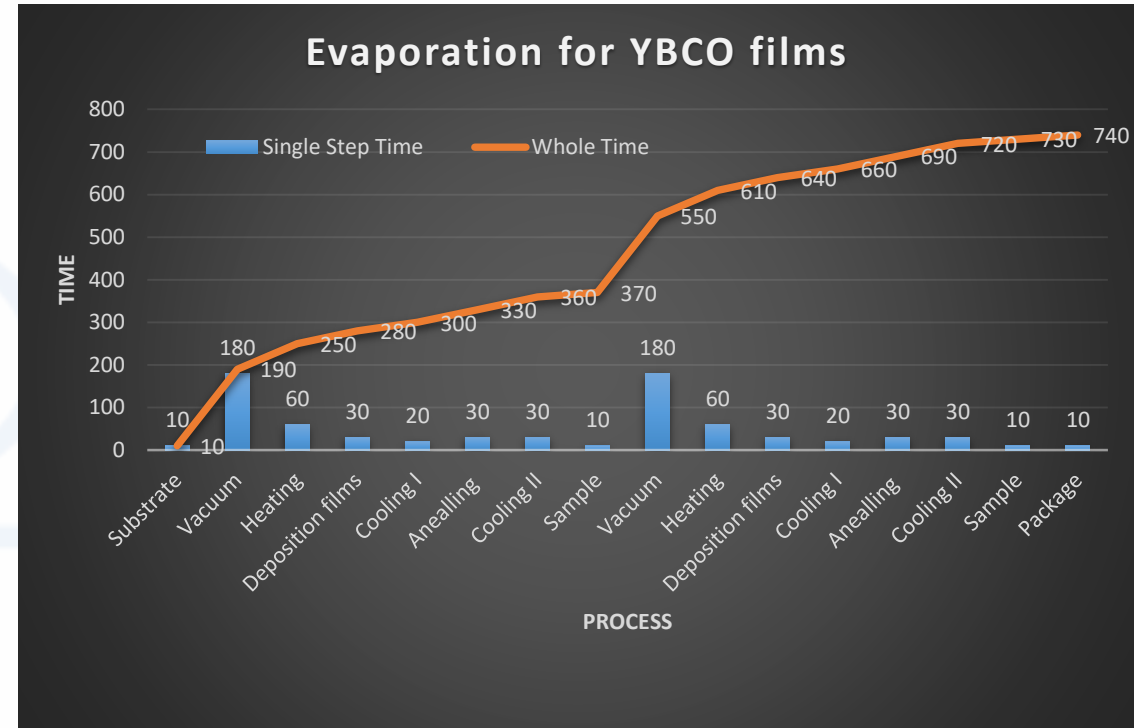
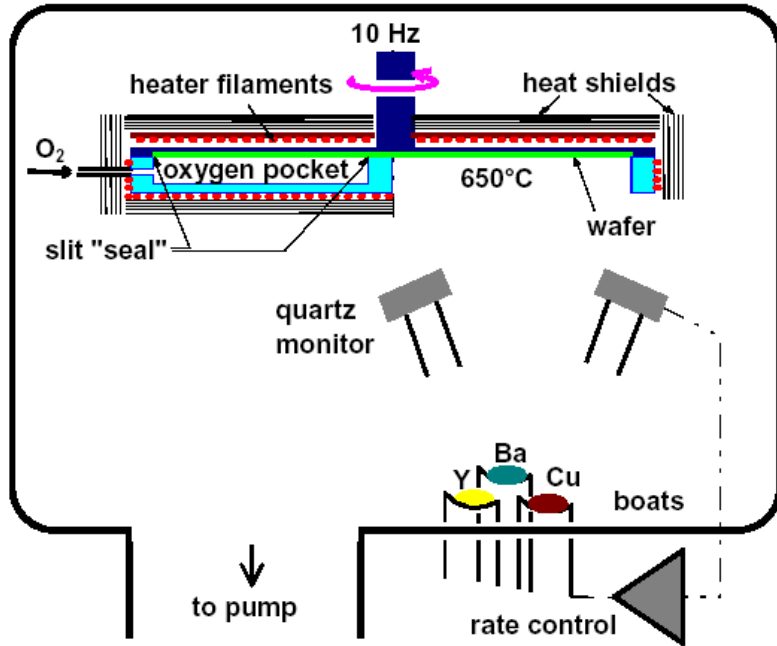
4-1、YBCO deposited technology-Sputtering (UESTC)



Low deposition rate, 50nm/h
Small scale 1 sample 2inch.

Double-sided deposition
Short vacuum time

4-2、YBCO deposited technology-Evaporation(Ceraco)



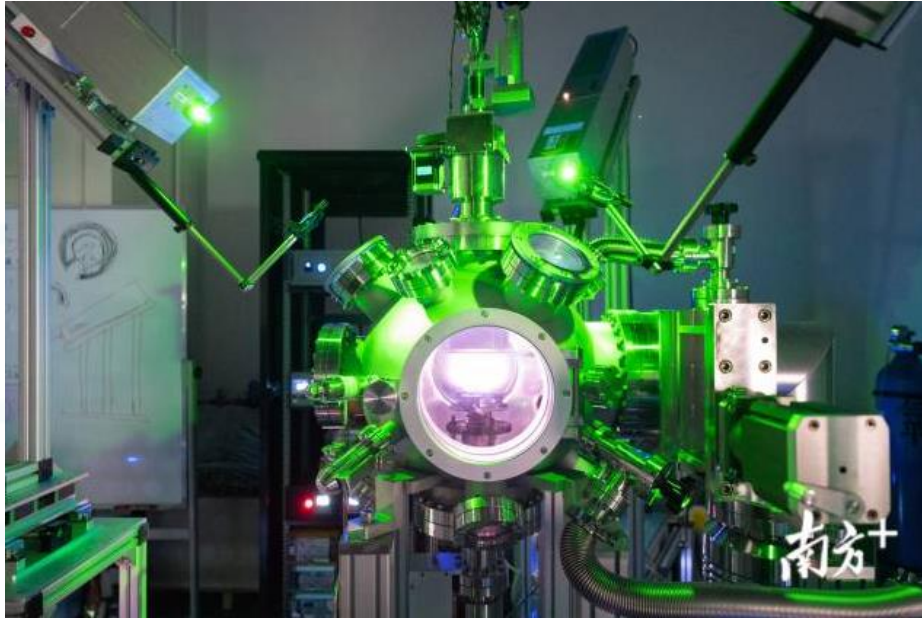
High deposition rate **20 - 30**
nm/min.

Large scale **12 samples 2inch.**

One sided deposition
More vacuum time



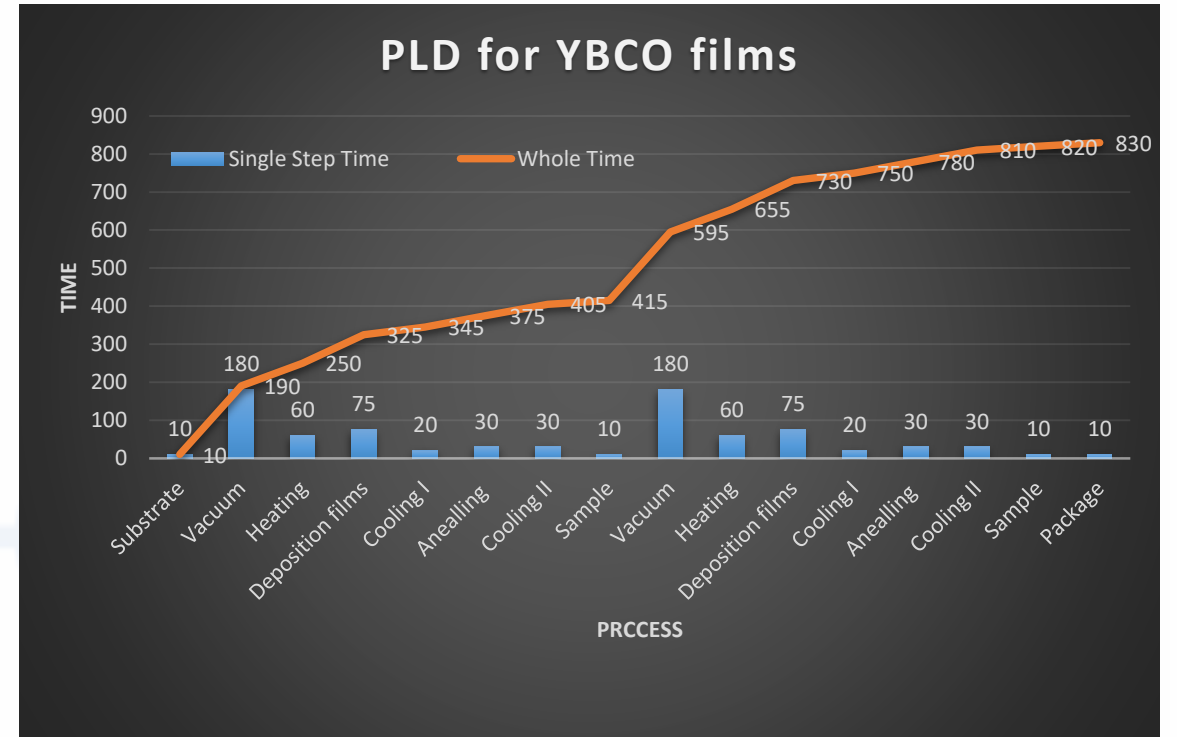
4-3、YBCO deposited technology-PLD(SLAB)



Triple Pulsed Laser Co-deposition system(SLAB)

Middle deposition rate **6.7 nm/min.**

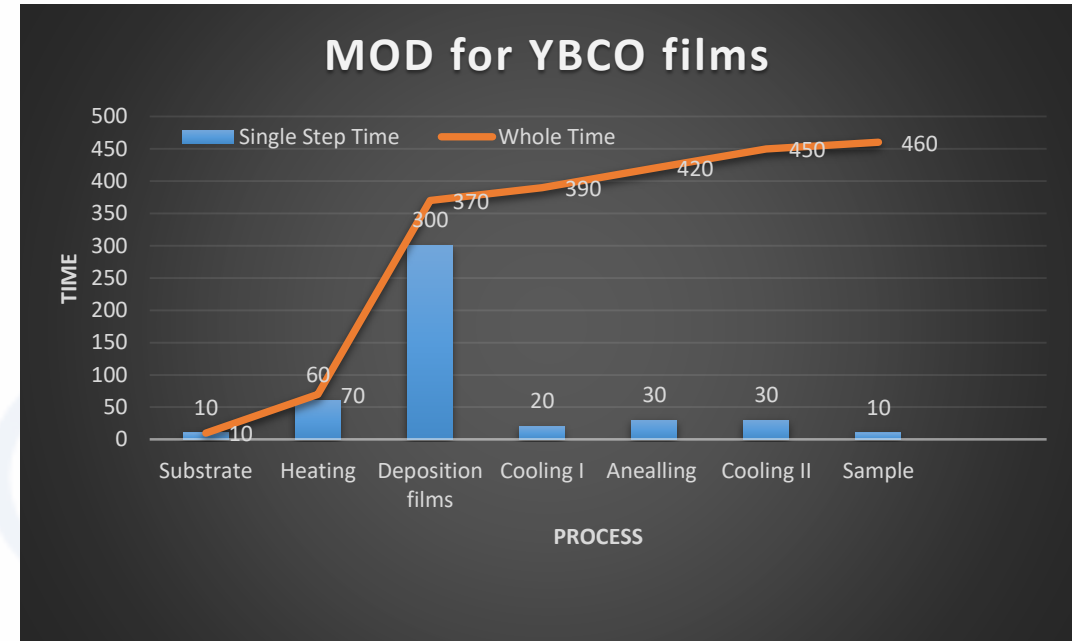
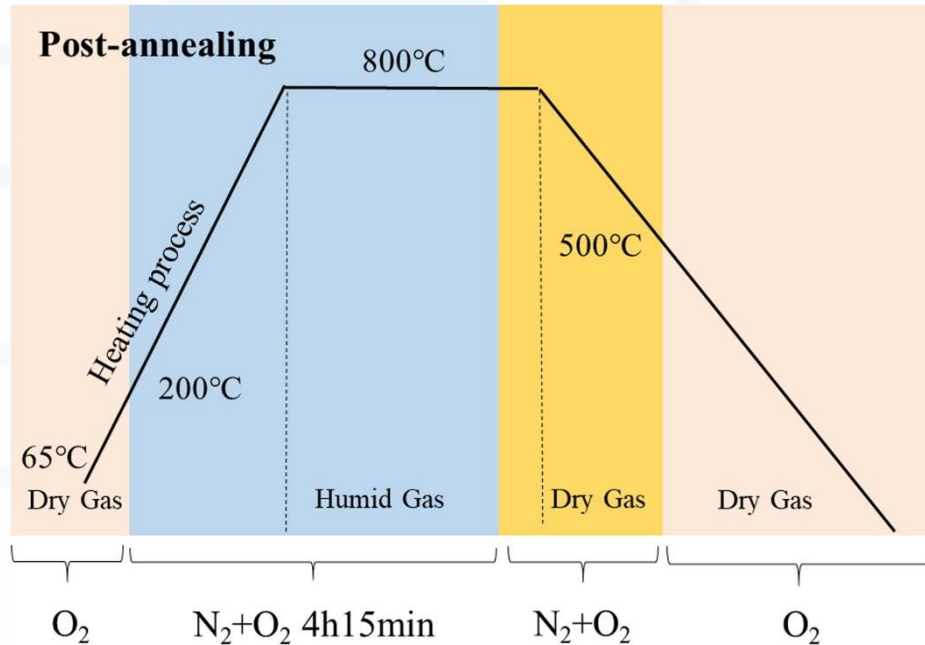
small scale **1 sample 2inch.**



One sided deposition
More vacuum time



4-4、YBCO deposited technology-MOD (estimate)



Low deposition rate **1~3 nm/min.**

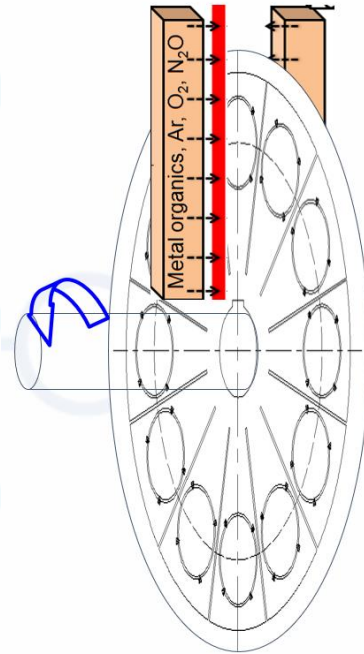
Small scale **1 sample 2inch.**

Double sided deposition
No vacuum time

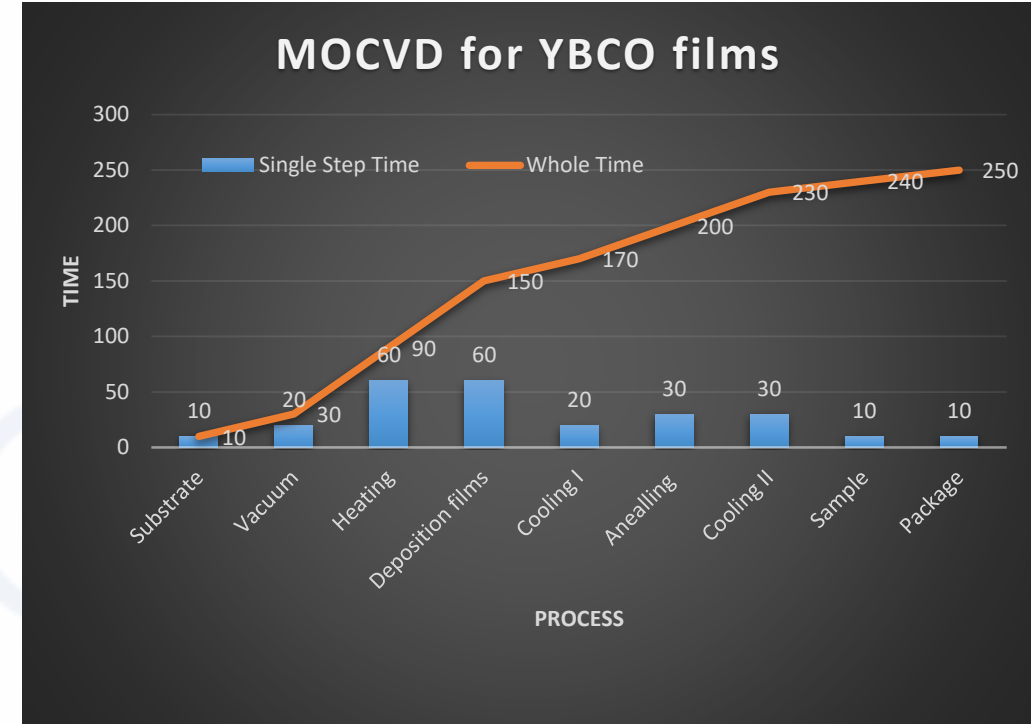


4-5、YBCO deposited technology-MOCVD (UESTC)

U-type nozzle



Planetary holder



High deposition rate **20~30 nm/min.**

Large scale **12 × 2inch or 6 × 3inch.**

Double sided deposition
Short vacuum time



4-6、YBCO deposited technology-compare

Technology	Deposition rate(nm/min)	Deposition area	Vacuum	Equipment investment	Cost of materials	Large scale	Double sided
Evaporation	20-30	large	high	high	low	easy	No
PLD	6-30	small	high	high	middle	hard	No
Sputtering	~1	large	high	middle	middle	hard	YES
MOD	1-3	large	none	low	low	hard	YES
MOCVD	20-60	large	low	middle	high	easy	YES

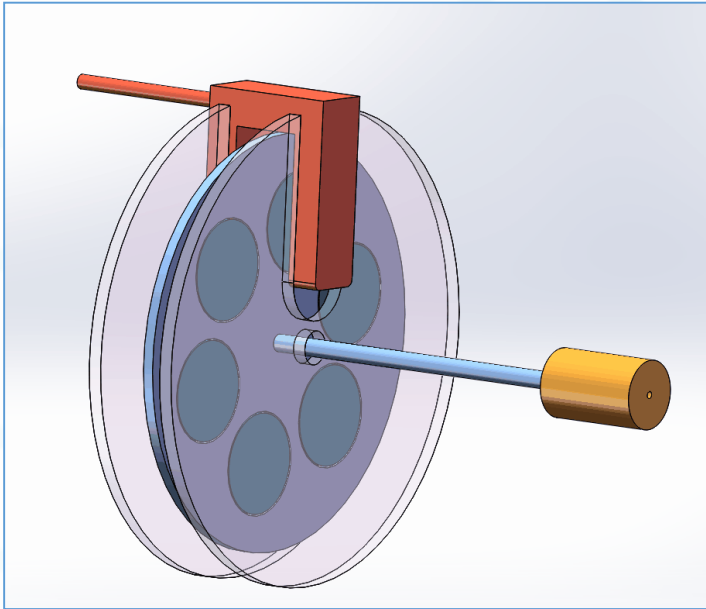
MOCVD May be a better choice for YBCO deposition



02 Double-sided YBCO thin films on crystal substrate with MOCVD

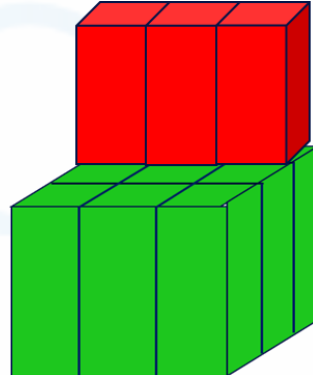
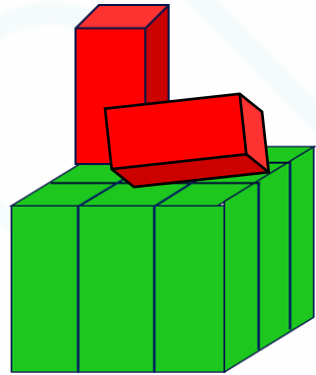


1、MOCVD deposited double sided YBCO thin films



schematic diagram of MOCVD system

Sub.	Lattice(nm)	Misfit to YBCO(%)	ϵ	$\tan\delta$
LaAlO ₃	0.3788	-2.7	24	$<5 \times 10^{-4}$
SrTiO ₃	0.3905	2.2	1900	3×10^{-2}
MgO	0.4212	8.55	9.6	4×10^{-5}
YSZ	0.516	6.2	25	7.5×10^{-3}
Al ₂ O ₃	a=0.4763, c=1.3	23.6	9.5-11	1.5×10^{-6}

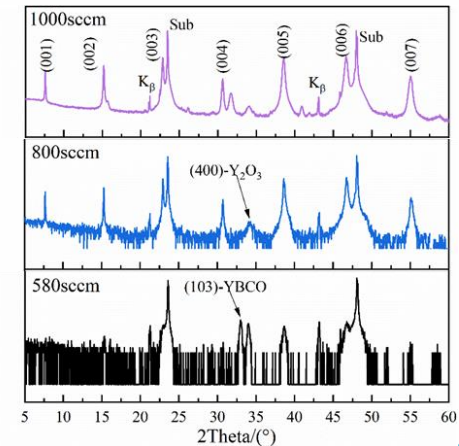
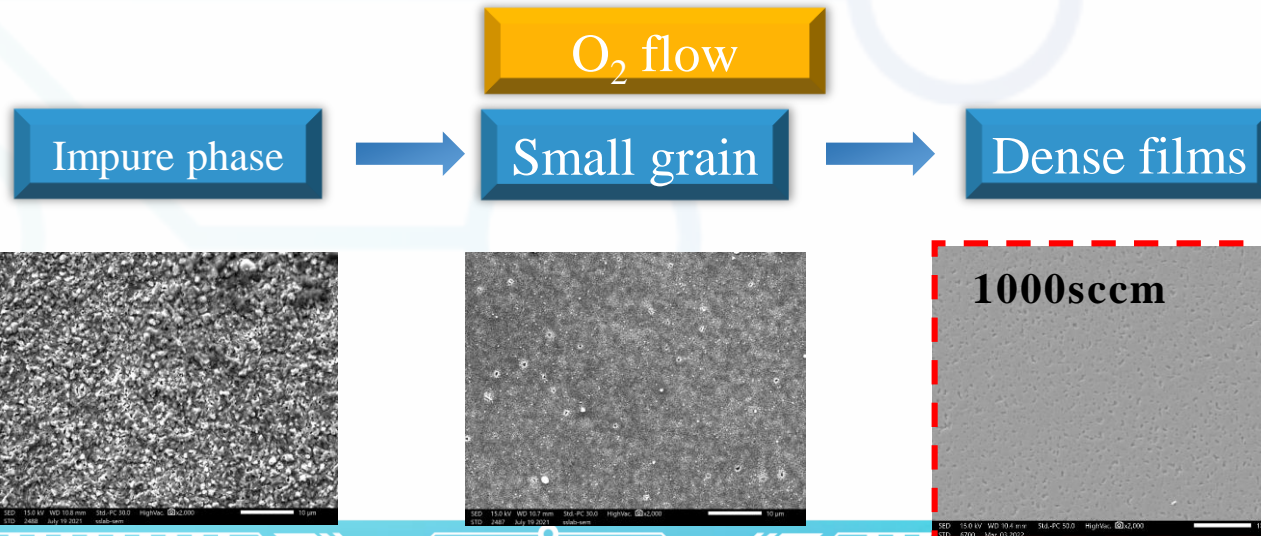
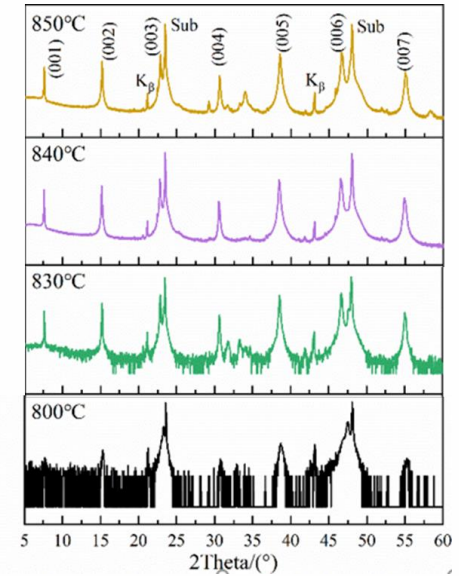
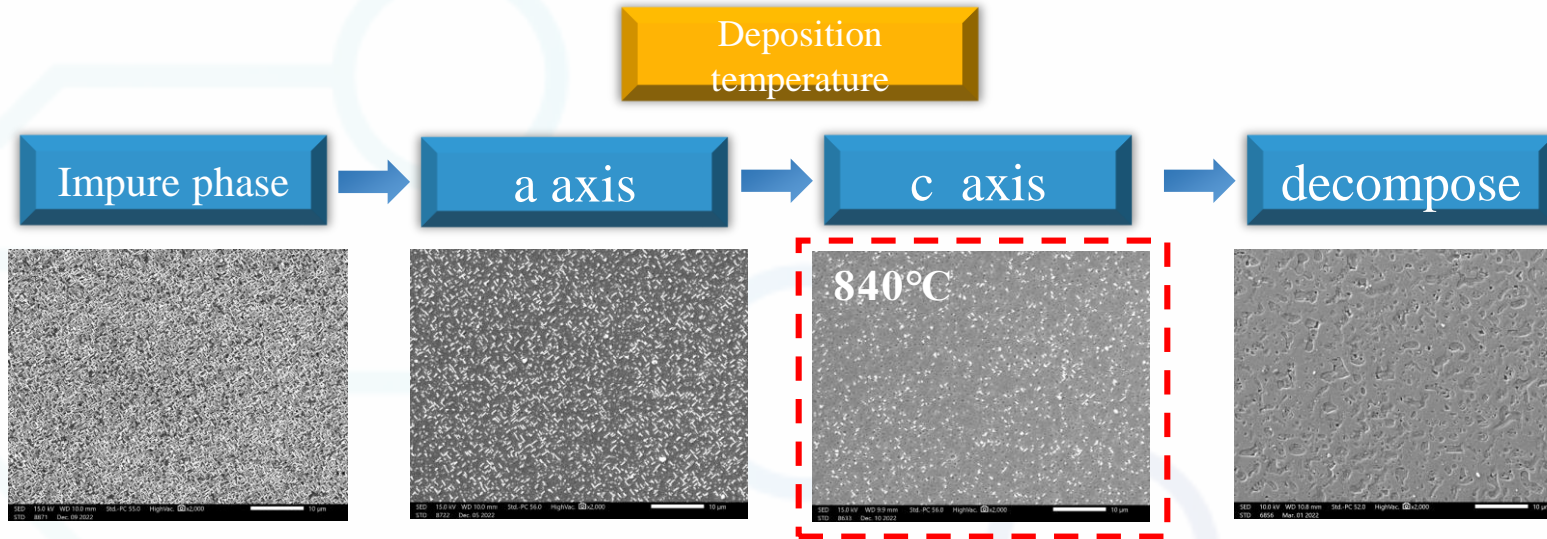


Epitaxial growth

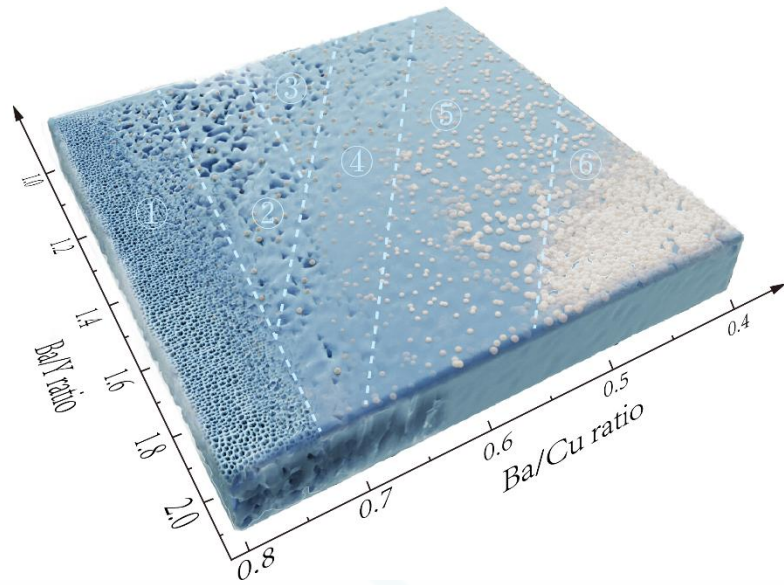
- LaAlO₃ substrate small misfit
- LaAlO₃ suitable for microwave device
- LaAlO₃ substrate easy to recycle



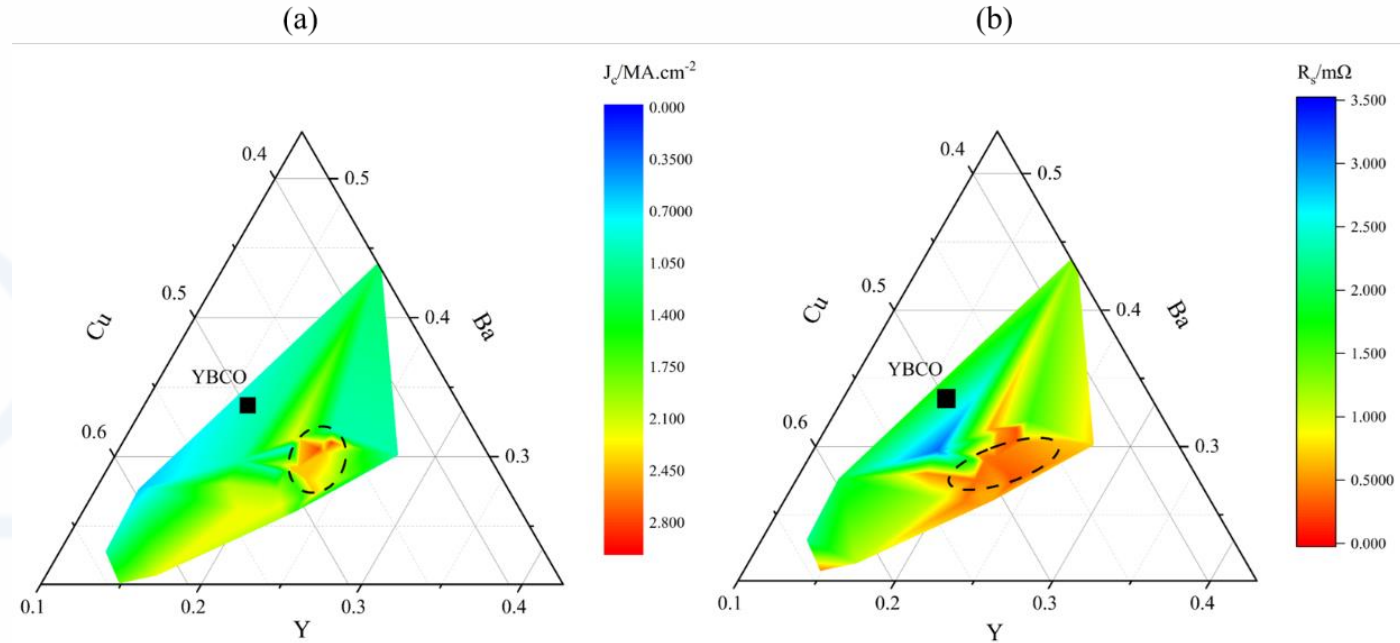
2、 Optimization of deposition parameter on LAO substrate



2、 Optimization of deposition parameter on LAO substrate



- ① desert
- ② groove
- ③ pore
- ④ dense film
- ⑤ samll outgrowth
- ⑥ large outgrowth



The growth evolvement diagram of YBCO film morphology with composition changes

$\frac{1}{2}Y_2O_3 - BaO - CuO$ ternary phase diagram. J_c and R_s distribution depending on the film composition marked with various colors.

Ba : Y=1.3-1.5; Ba : Cu=0.56-0.61

Surface and J_c
ternary phase
diagram

guidance

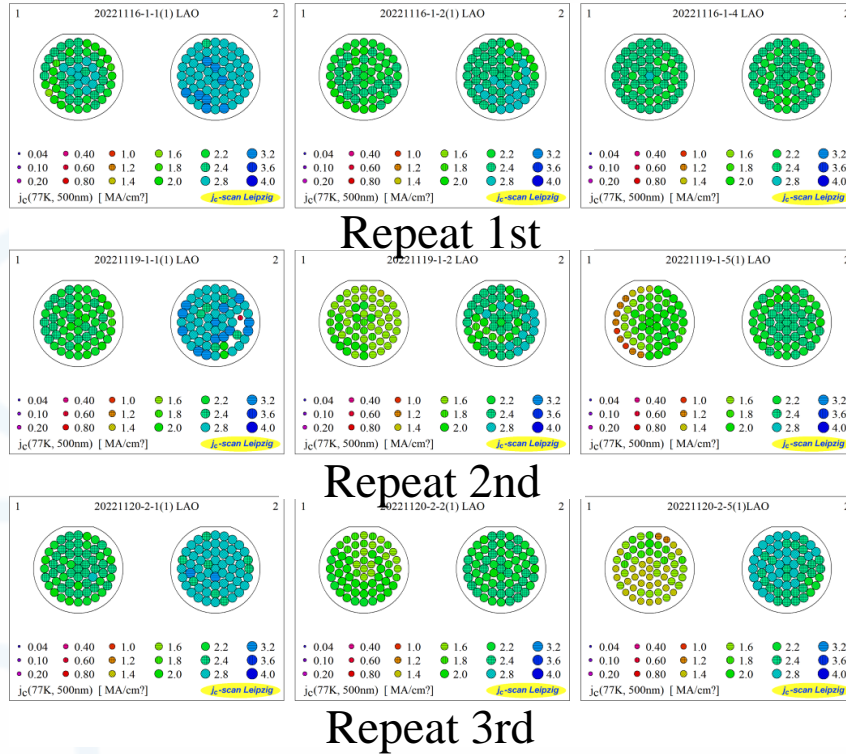
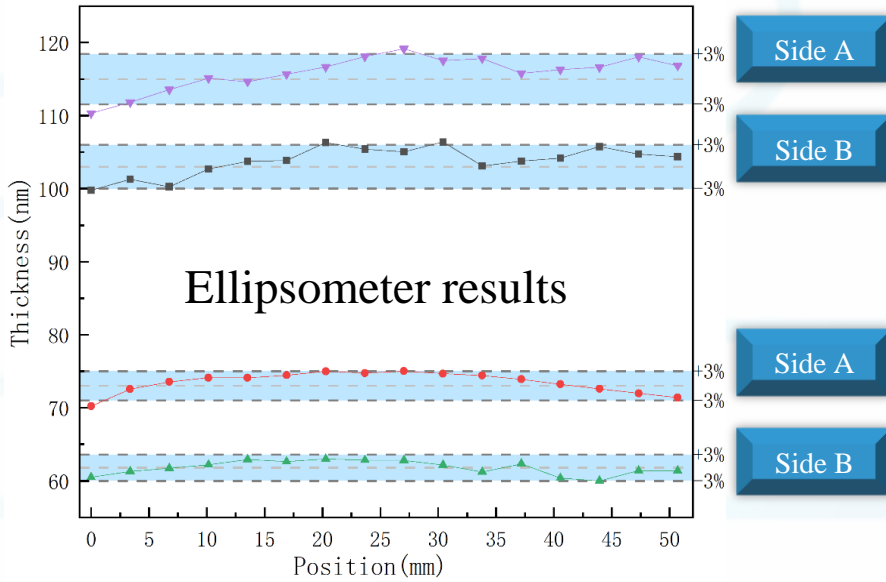
composition

optimize

High quality
YBCO films



3、MOCVD results of YBCO films



$R_s < 0.5 \text{ m}\Omega$

$J_c > 2 \text{ MA/cm}^2$

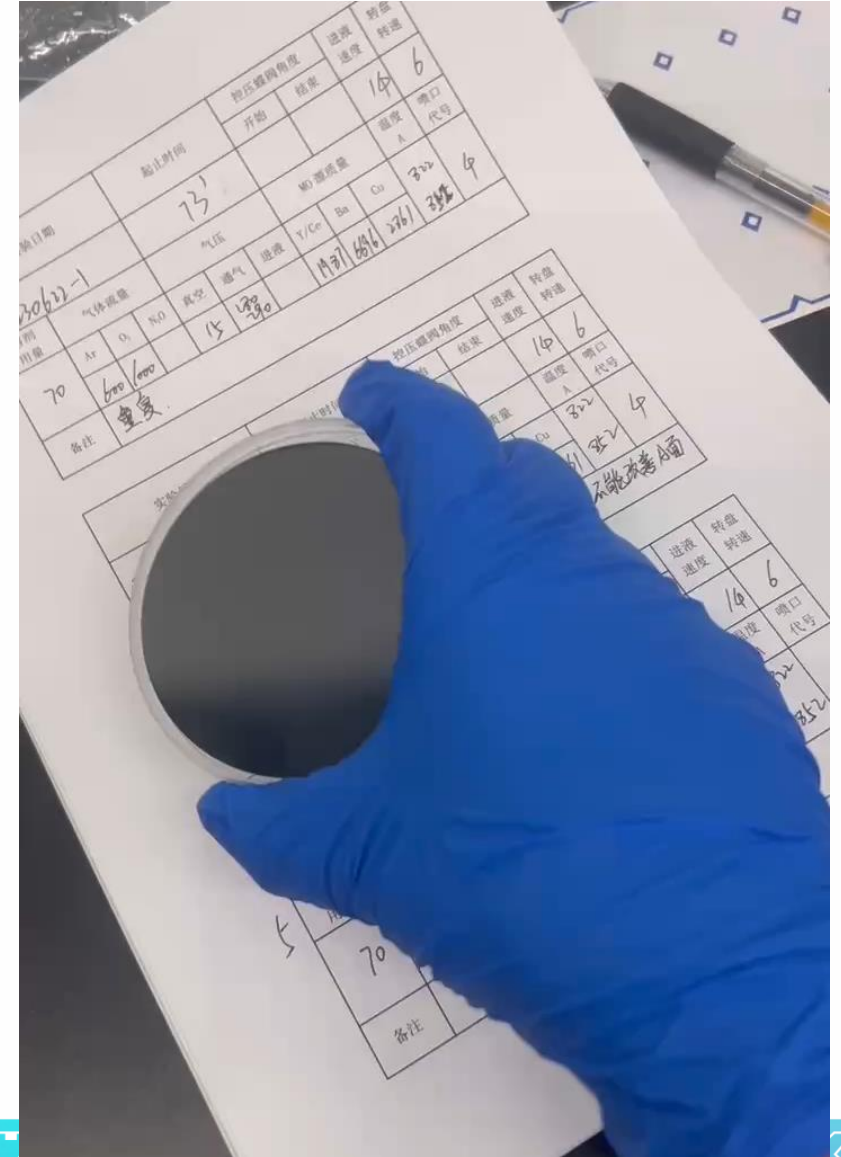
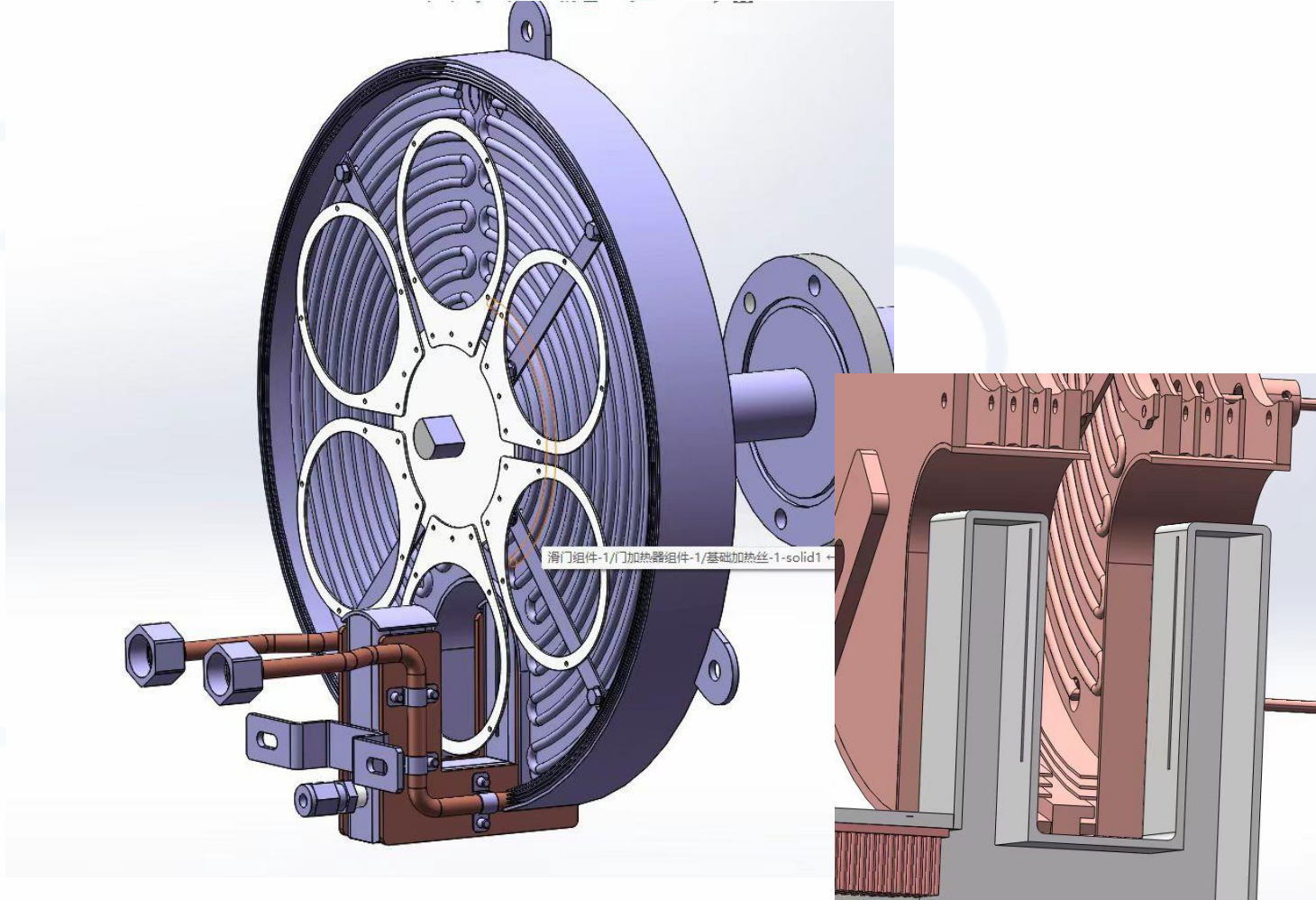
Filter fabrication for
verification of the
YBCO films

- 2inch thickness deviation $\pm 3\%$
- 500nm thickness deviation $\pm 10\%$

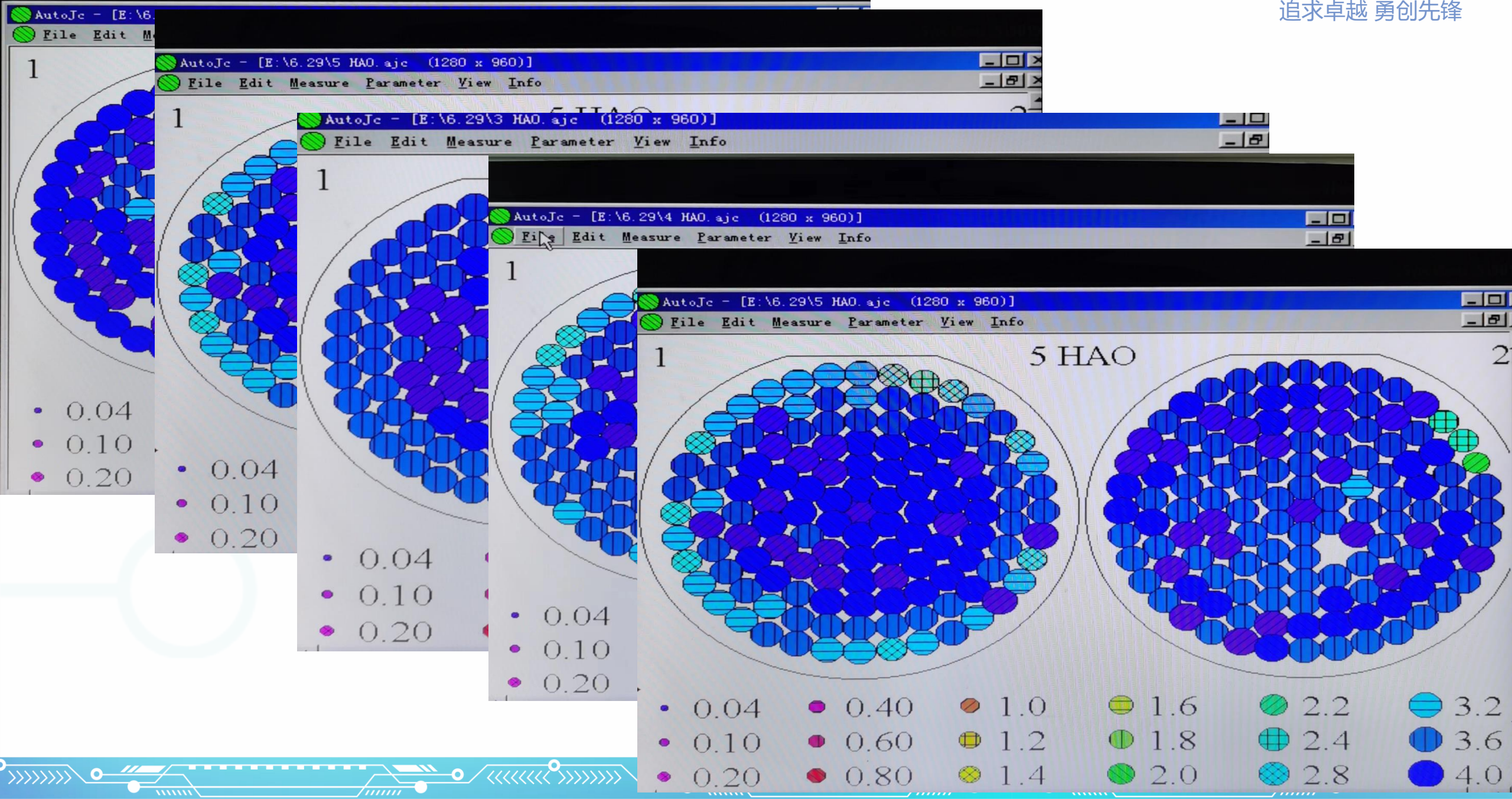
- Forming a stable production process flow



4、MOCVD deposition 3inch double sided YBCO thin films



Equipment improvement: deposited 3 inch YBCO films



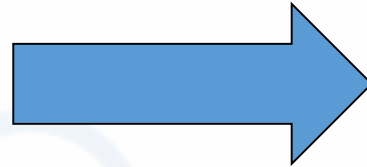


03 Double-sided YBCO coated conductor with MOCVD

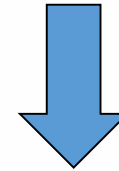


1、Challenge of double-sided coated conductor

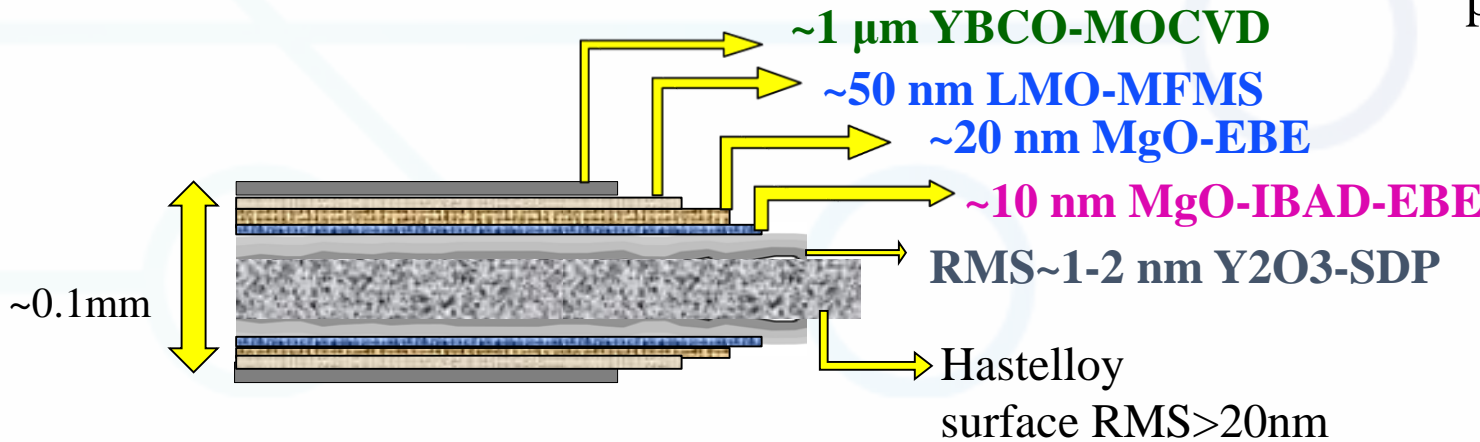
- ❑ Protect back side surface when double sided deposition?
- ❑ Keep double-sided consistency?
- ❑ Achieve long tapes preparation?
- ❑ Achieve high performance ?



- ❑ Which technology be choose?(buffer and YBCO)
- ❑ How to heat the double-sided structure?
- ❑ How to reel to reel the long tapes
- ❑ Biaxial texture, surface roughness and flux pinning?



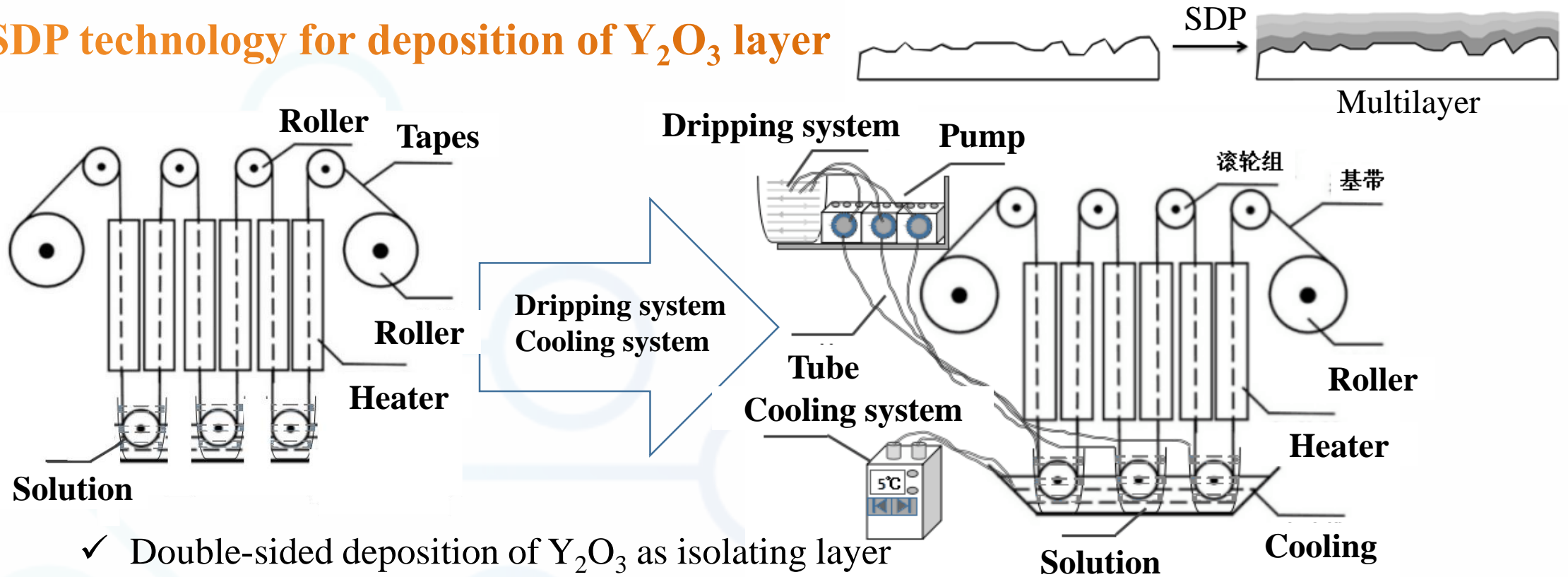
- ✓ Fully independent reel to reel system
- ✓ Deposition of double-sided simultaneous
- ✓ Constant speed and tension in reel to reel system
- ✓ Substrate self heating technology



We need all the layers with double-sided structure!



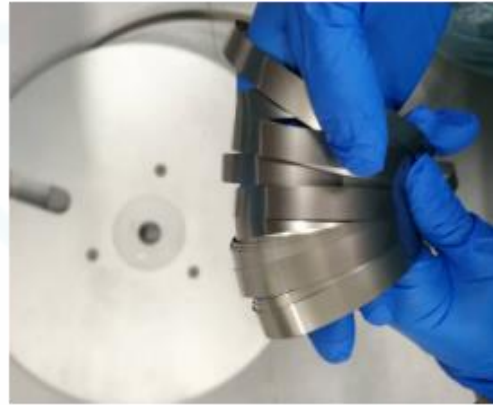
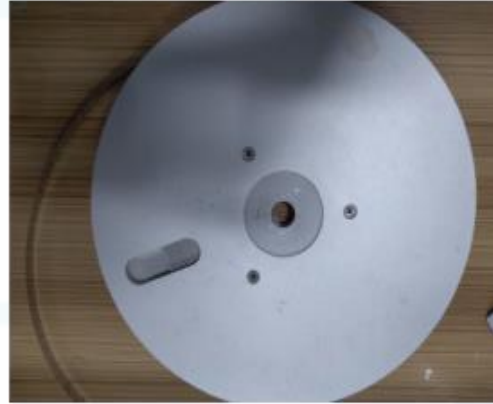
2、SDP technology for deposition of Y_2O_3 layer



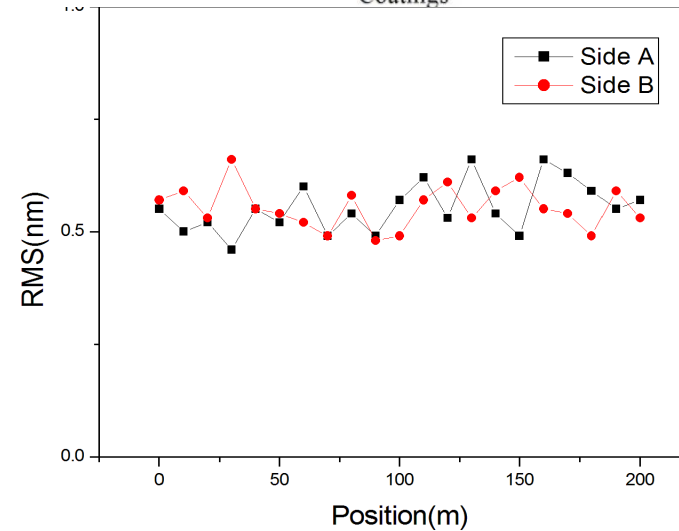
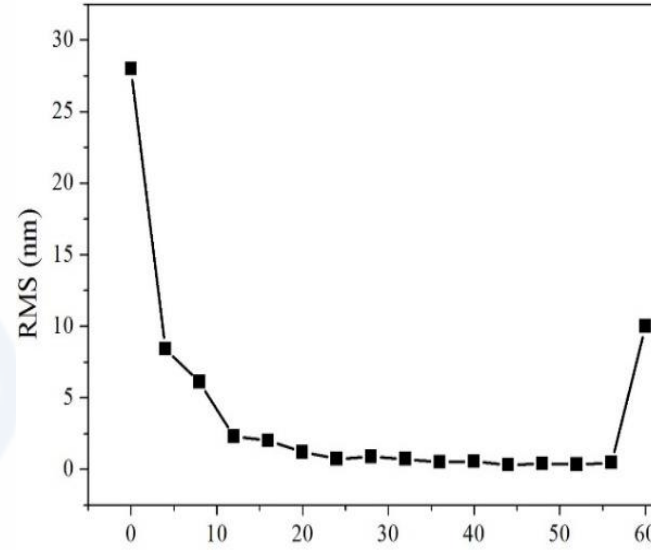
- ✓ Double-sided deposition of Y_2O_3 as isolating layer
- ✓ Increase stability of the solution (10 hours to several days)
- ✓ Keep solution concentration
(solution concentration drop to 40% to almost unchanged)
- ✓ Long tapes preparation (100 m to 500 m)



2、SDP technology for deposition of Y_2O_3 layer



SDP system and samples



500m results:

A side

$RMS_{min}=0.46$ nm,

$RMS_{max}=0.66$ nm,

$RMS_{avg.}=0.55$ nm

B side

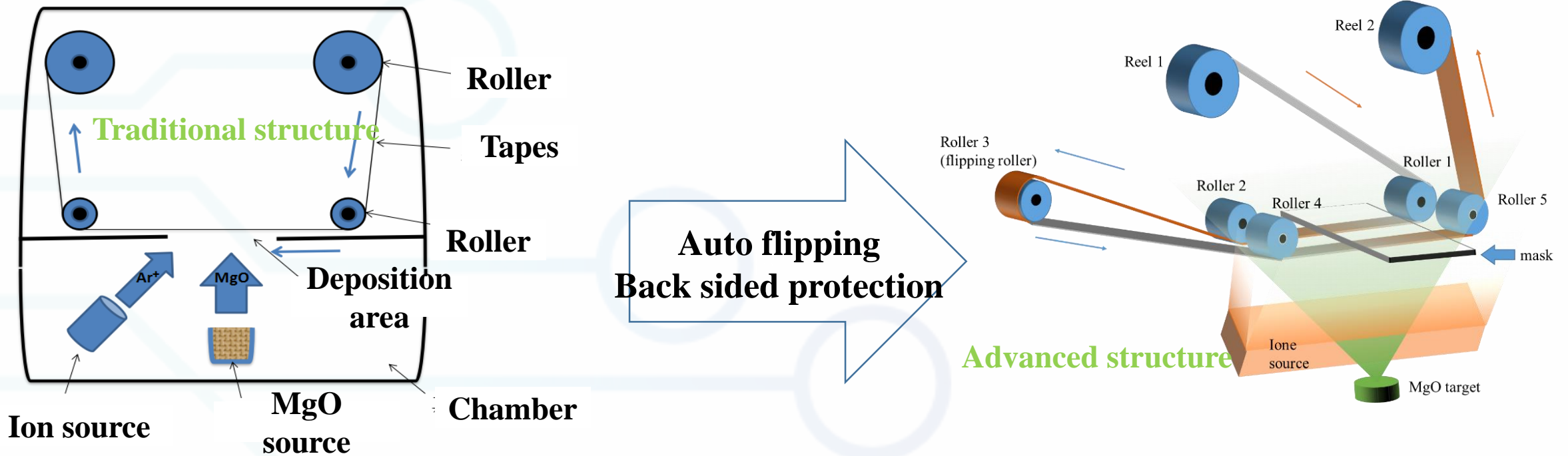
$RMS_{min}=0.48$ nm,

$RMS_{max}=0.66$ nm,

$RMS_{avg.}=0.55$ nm



3、IBAD technology for deposition of MgO films with Auto flipping



Advantage:

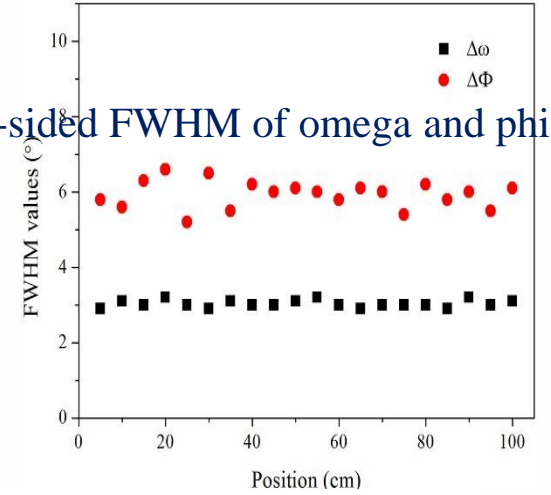
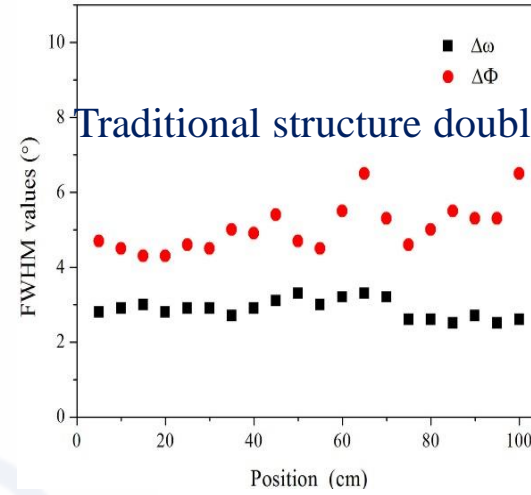
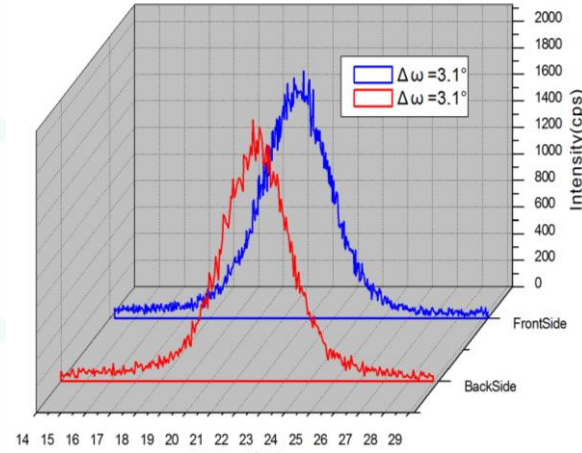
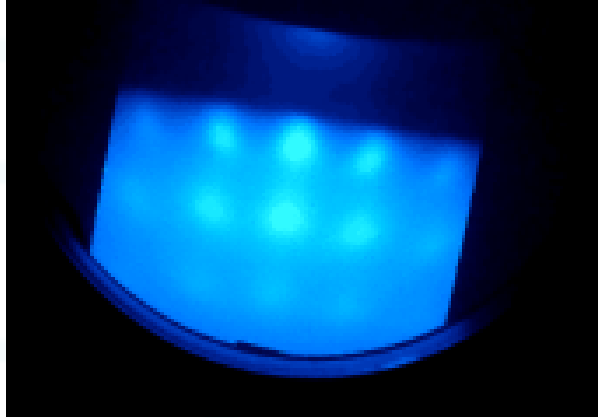
- ✓ Reduce process(vacuum) steps
- ✓ Reduce atmospheric exposure
- ✓ Improve double-sided consistency

Double-sided R to R system: Deposition of double-sided simultaneous

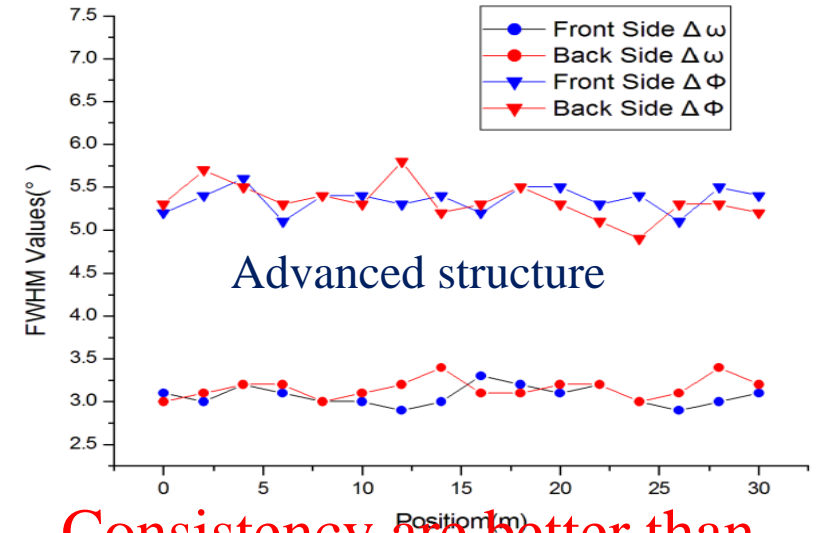
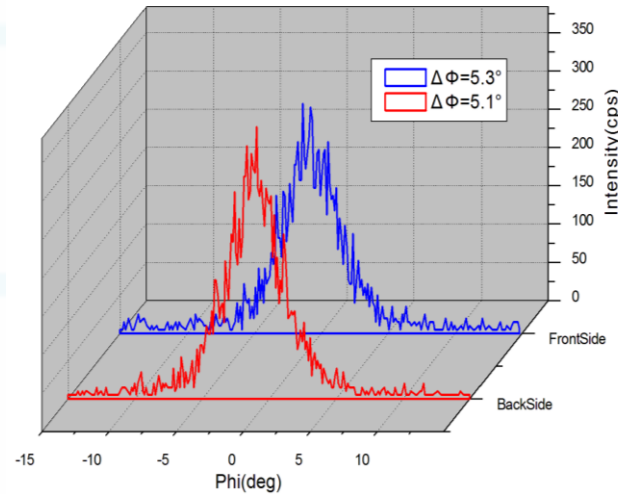
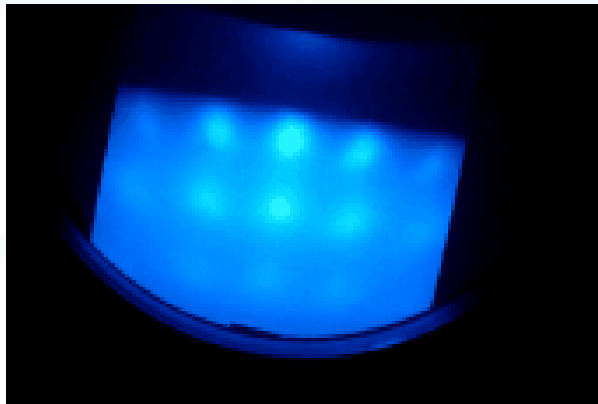
Back sided protection : protect the back side for cleaning



3、IBAD technology for deposition of MgO films with Auto flipping



Traditional structure double-sided FWHM of omega and phi



Advanced structure

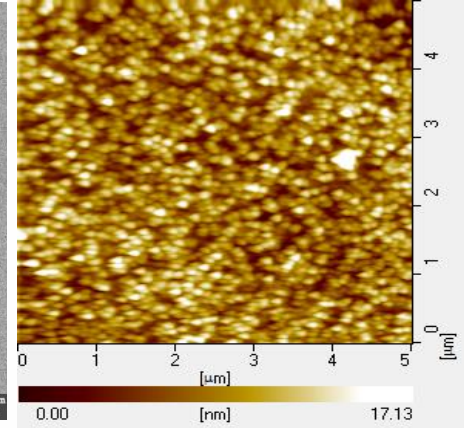
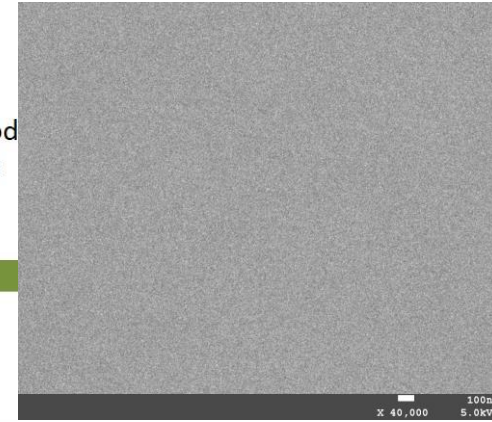
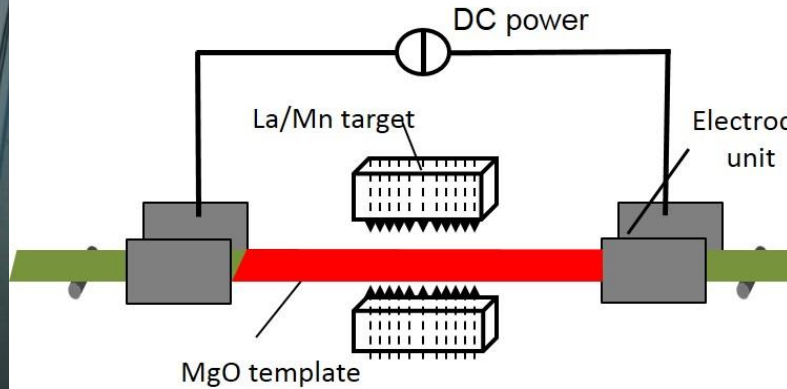
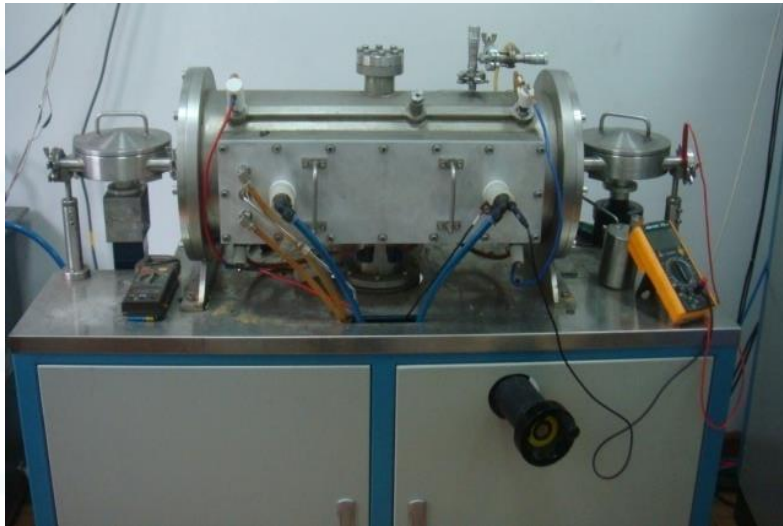
Double-sided IBAD-RHEED

Epi-MgO-XRD omega and phi scan

Consistency are better than traditional system

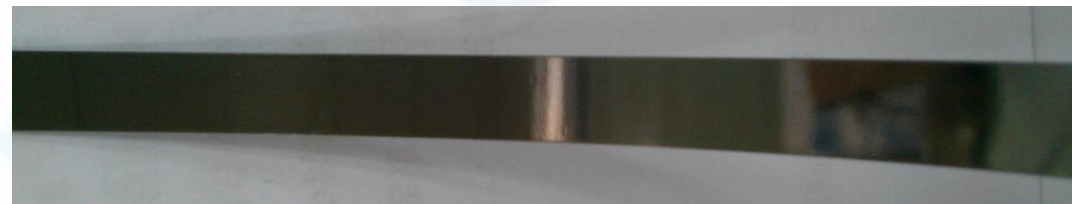
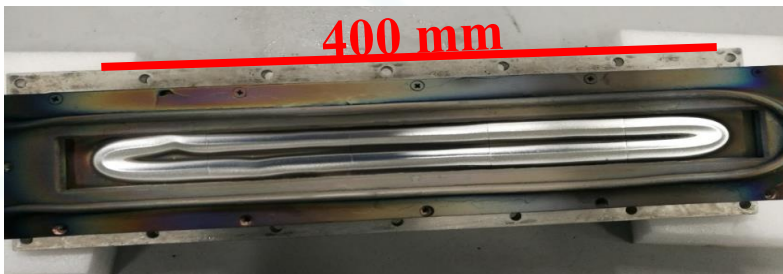


4、Medium frequency reactive sputtering for deposition of LMO



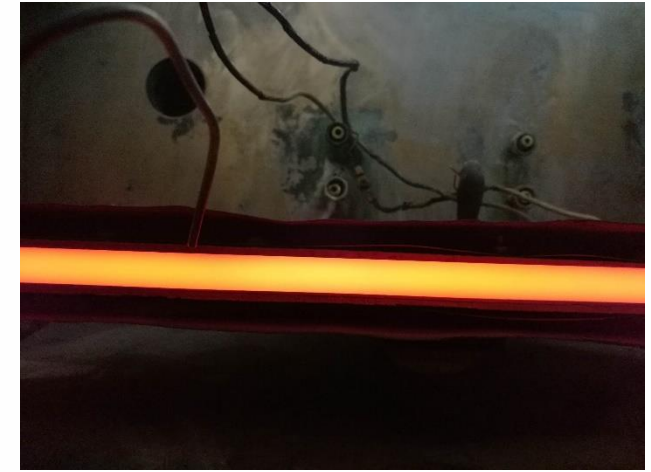
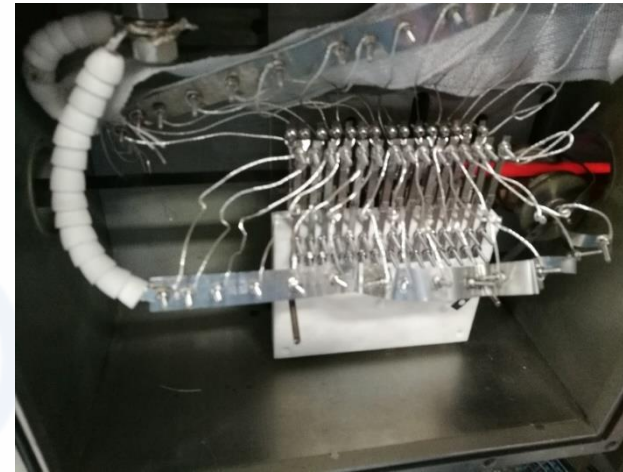
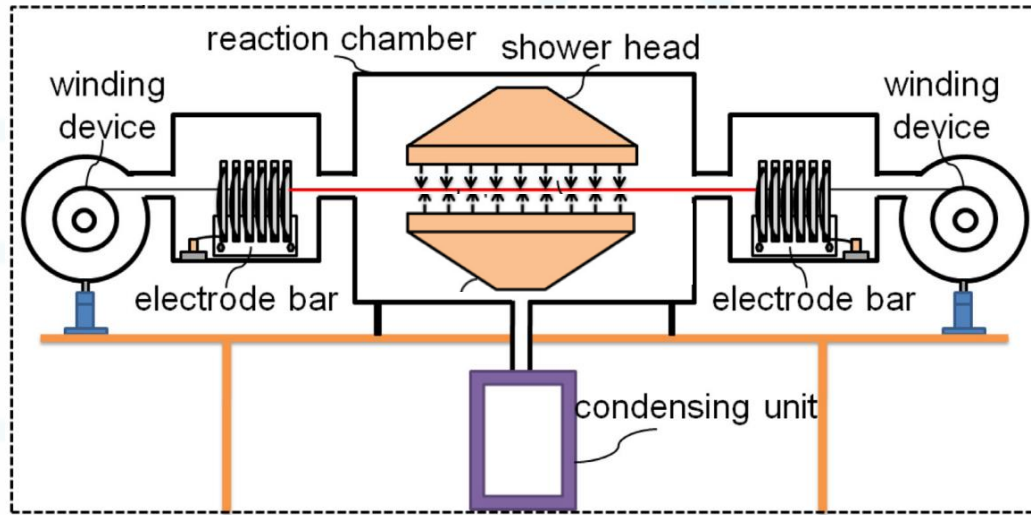
$$\Delta\omega=2-3^\circ, \Delta\Phi=3-4^\circ$$

$$R_{rms}=1.6 \text{ nm}$$



- ◆ High R to R speed (50 m/h)
- ◆ Two metal target for double-sided deposition

5、MOCVD for YBCO coated conductor deposition



Double-sided YBCO coated conductor deposition system

Photo of self heating system

Photo of tapes heating

- ✓ **Self heating system** was used for double-sided deposition
- ✓ Shower is very closed to tapes for Mo source **utilization**
- ✓ The self heating technology have **Very high heating efficiency**
- ✓ The self heating technology have **Very high heating speed**

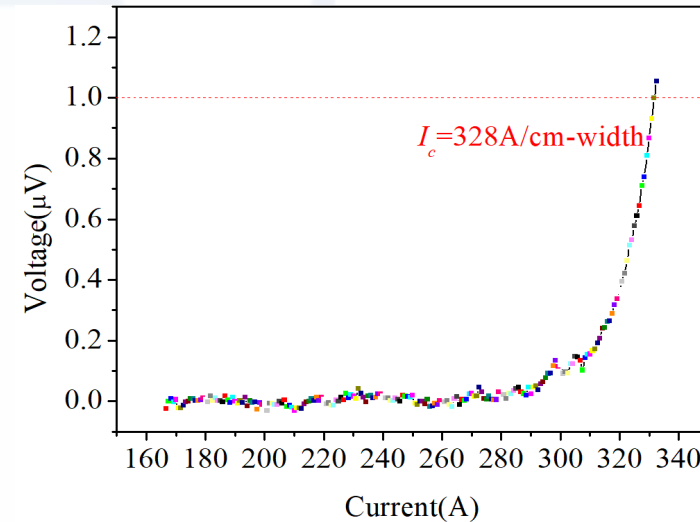
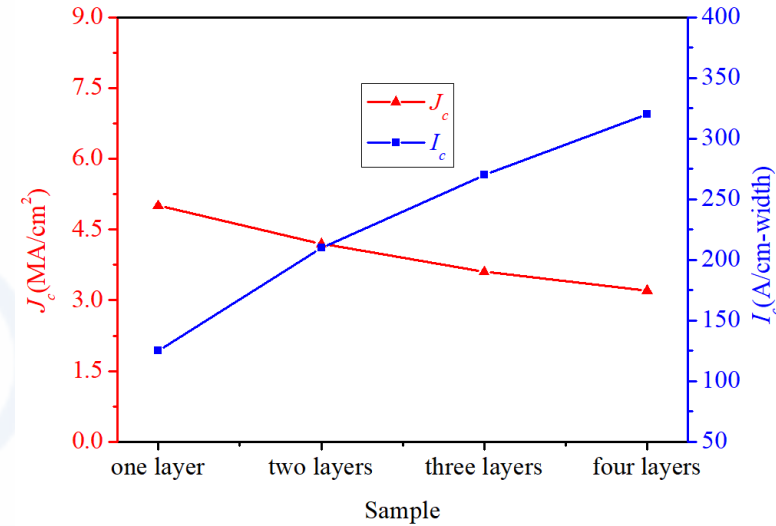
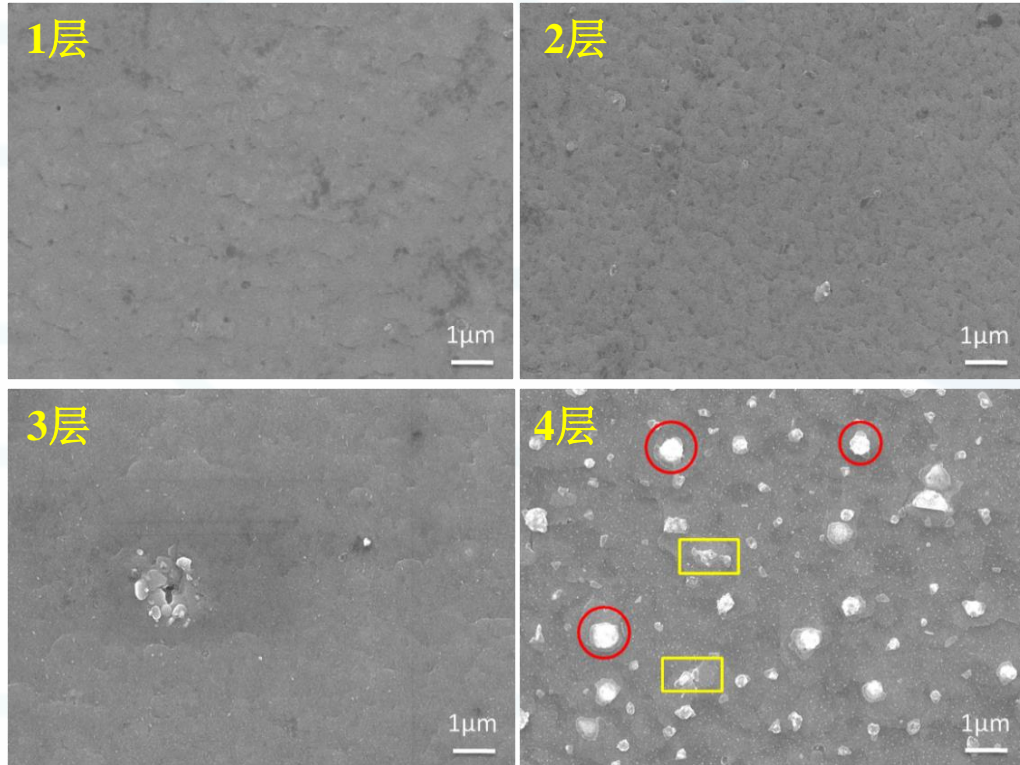
700 W/m, about 850°C

No other heater

Tradition heater need 5 kW/m



5、MOCVD for YBCO coated conductor deposition

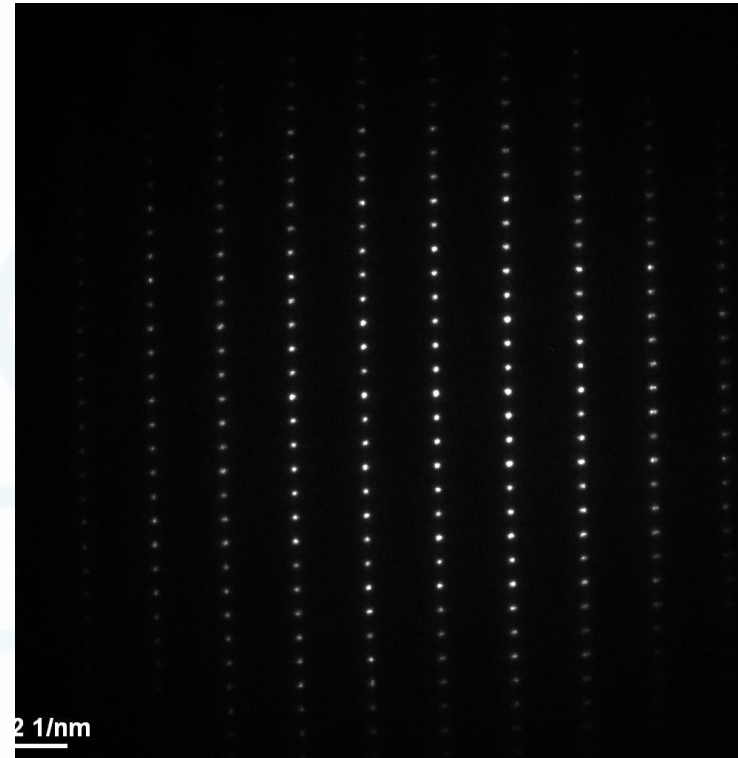
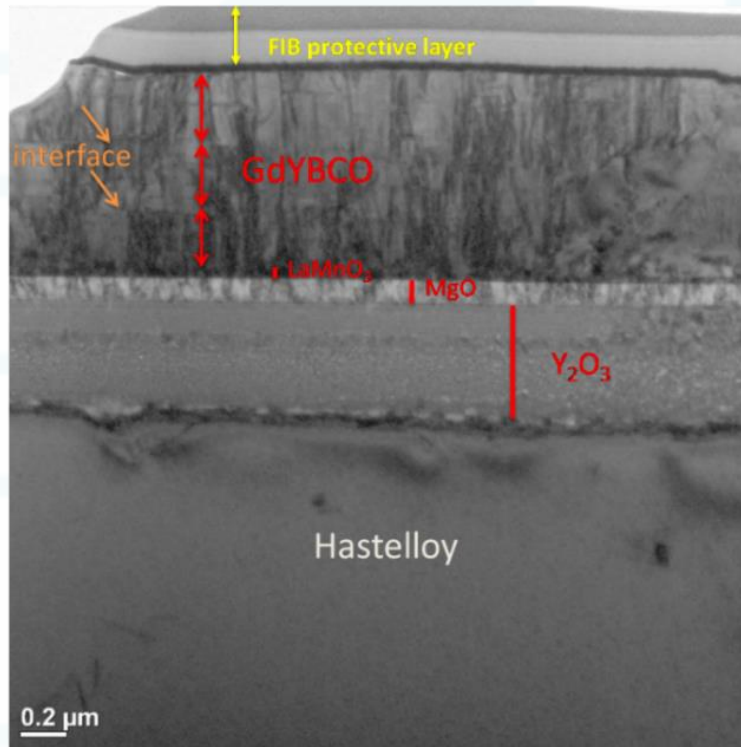


- multilayer films of ReBCO films
- 77K、0T, single side $I_c = 328$ A/cm

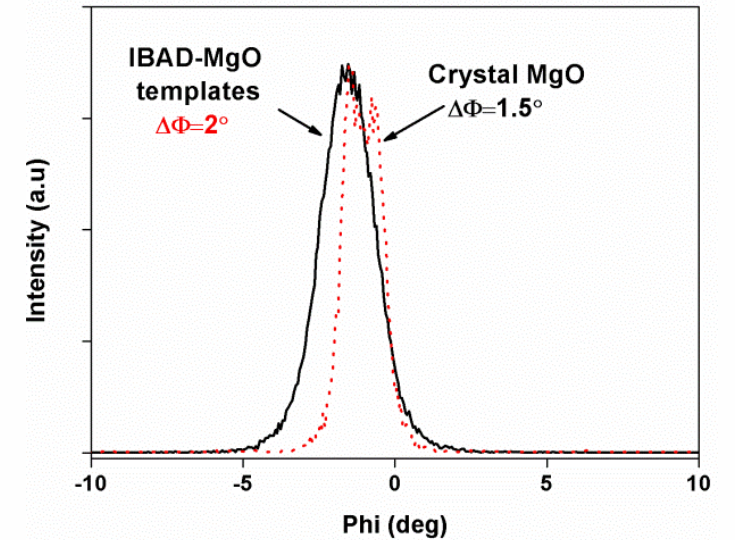
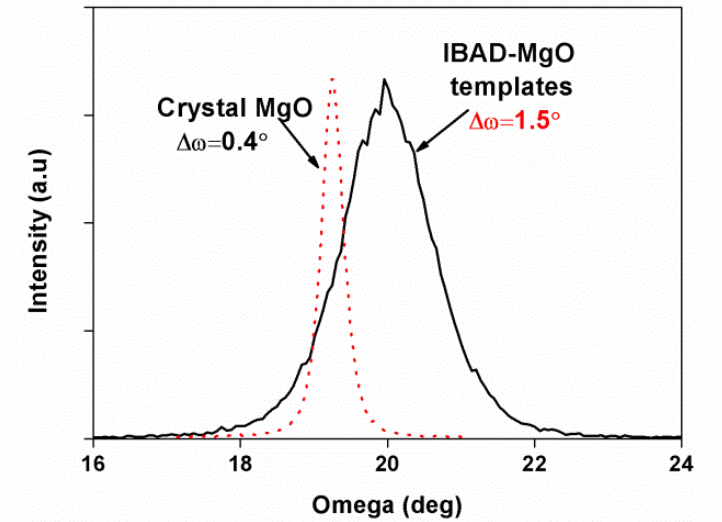
Photo of MOCVD system deposited YBCO coated conductors



5、MOCVD for YBCO coated conductor deposition

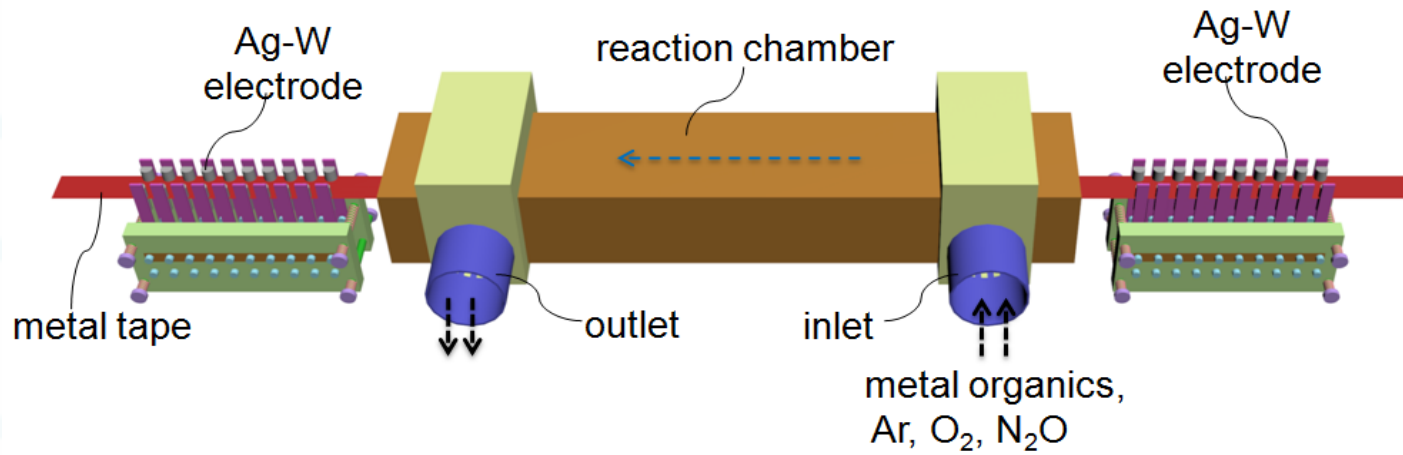


TEM results of the YBCO coated conductor with self heating system

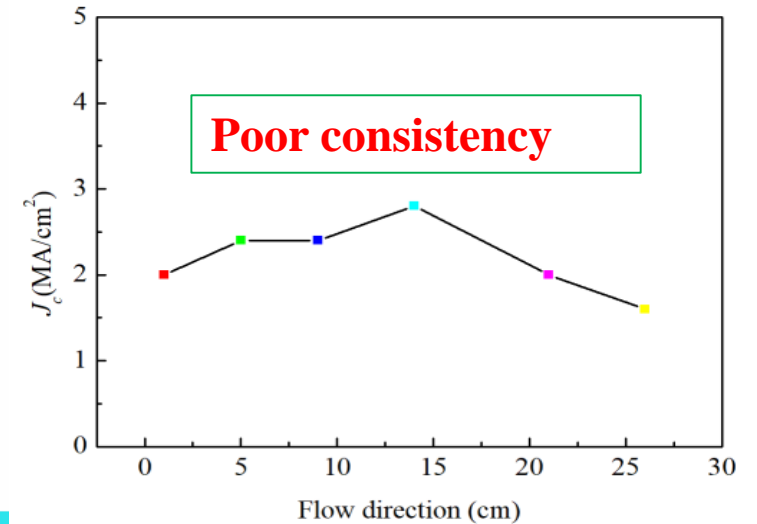
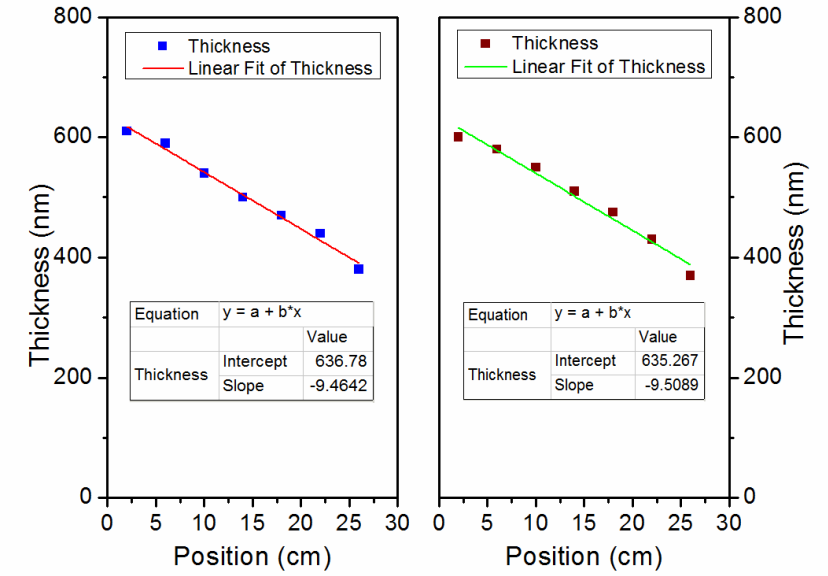
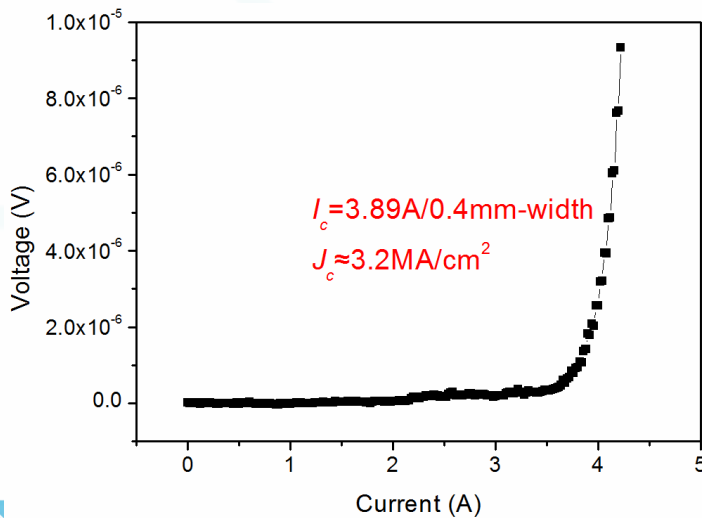


Compare with MgO single crystal

6、Developing a narrow channel chamber to improve the utilization of Mo source

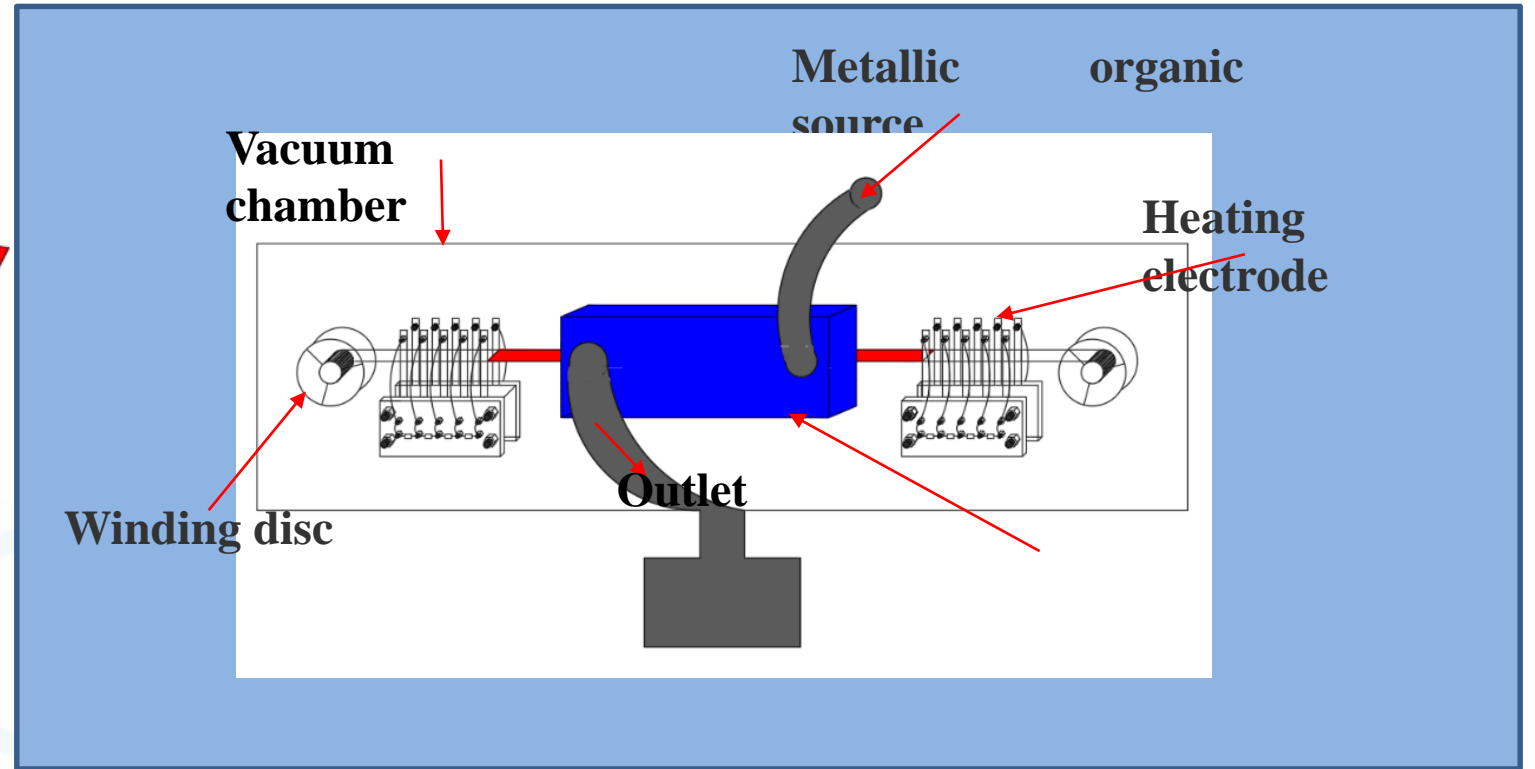
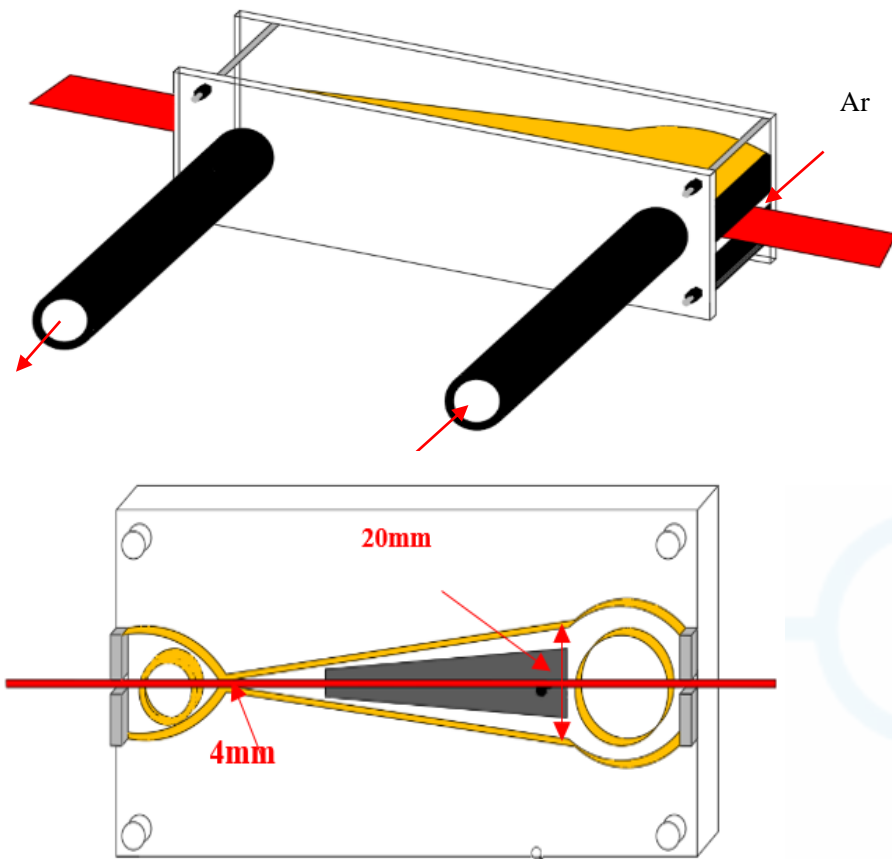


Narrow channel chamber , utilization of MO source > 31%





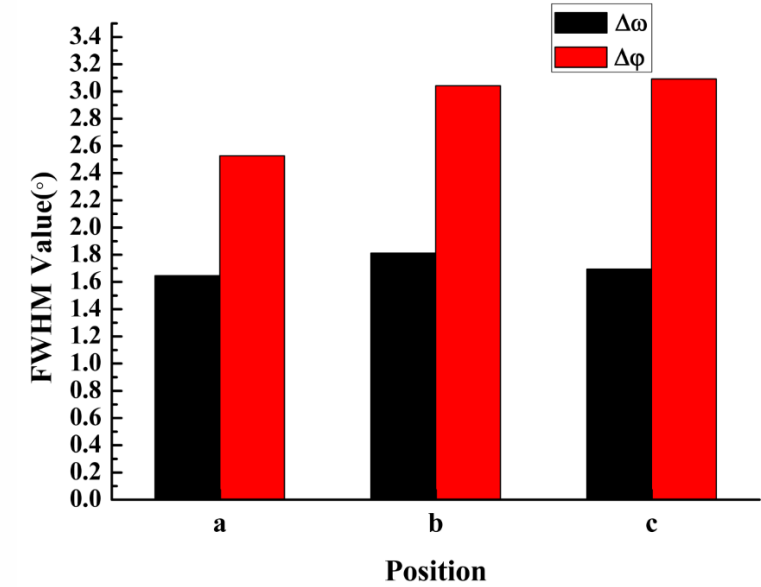
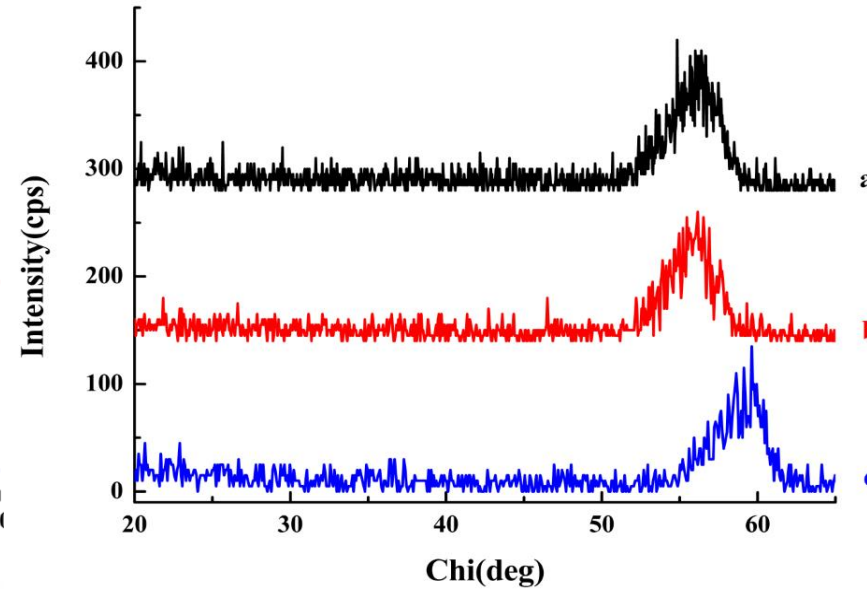
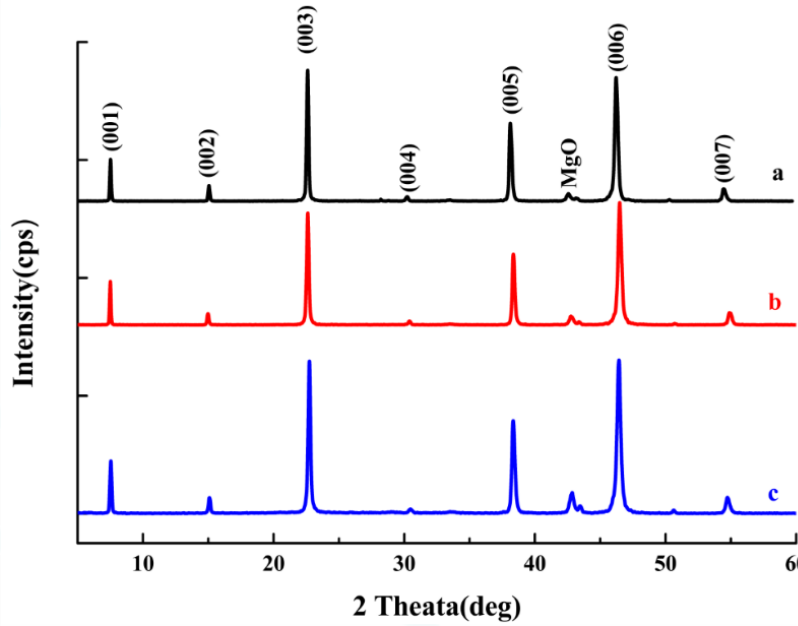
7、Improvement structure of Narrow channel chamber



New Narrow channel chamber MOCVD system

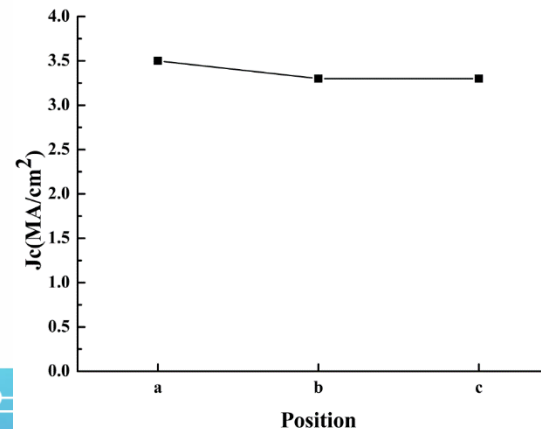
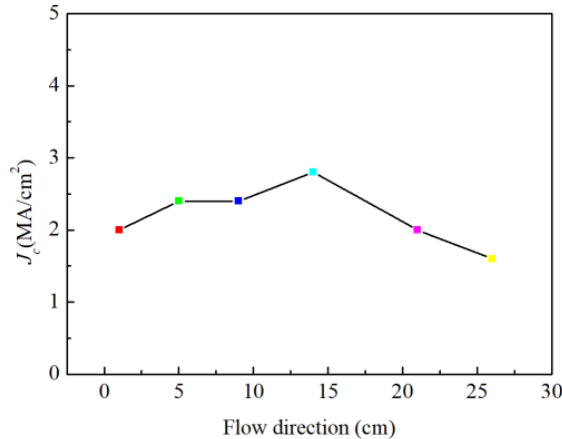


8、Results of different position of narrow channel chamber



$$\Delta\text{FWHM}(\Delta\omega) < 0.2^\circ$$

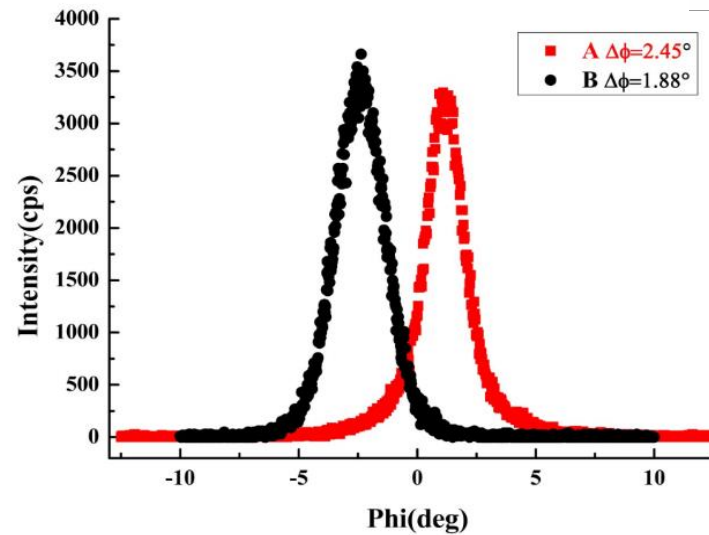
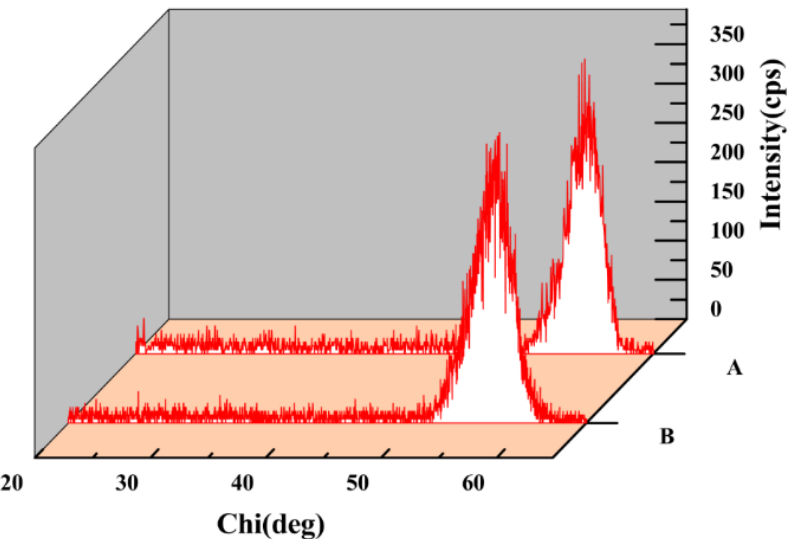
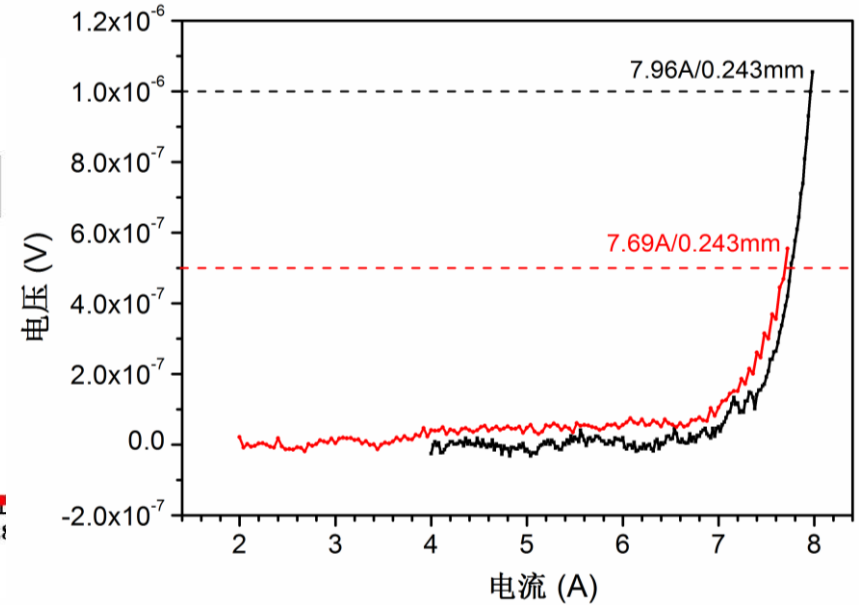
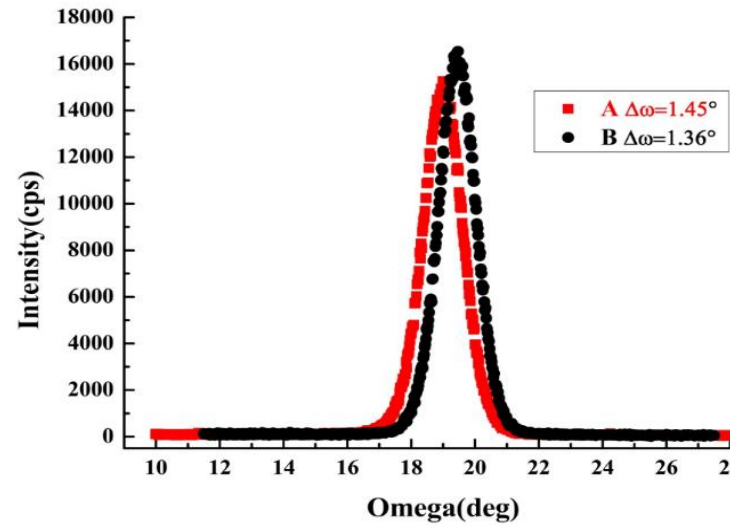
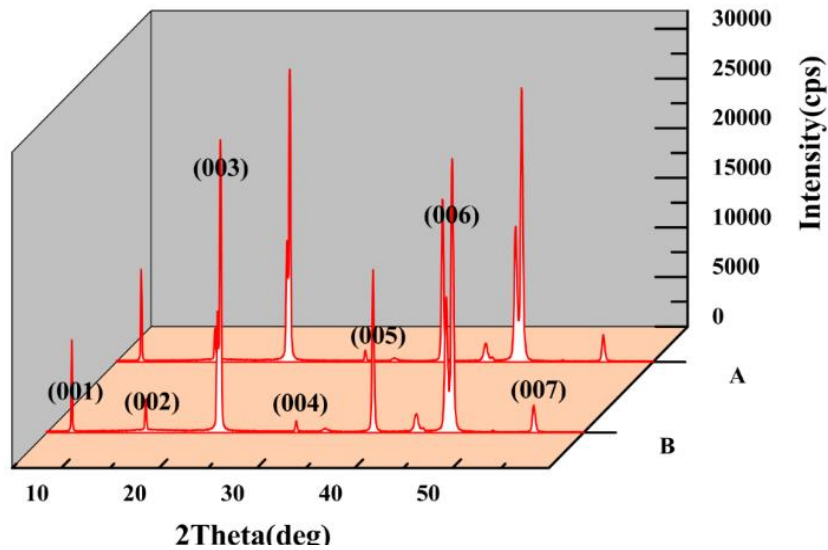
$$\Delta\text{FWHM}(\Delta\phi) < 0.5^\circ$$



Significant improvement in consistency of thickness and J_c performance



9、Double sided results of YBCO coated conductors



$I_c \approx 327$ A/cm-width
 $J_c \approx 3.2$ MA/cm²
(~1000 nm)

Double sided results
is very closed,



04 Conclusion



Conclusion

For Thin films

1. Developed a double-sided deposition **MOCVD system**
2. Achieved high uniformity double-sided **YBCO thin films**

For coated conductors

1. Developed a **fully double-sided structure** for coated conductors
2. One-time experiment with single-source single-ion beam finish the preparation of **double-sided IBAD-MgO** seed layers
3. A new narrow channel chamber has been developed for improving the utilization of **MO source**



集成电路科学与工程学院
(示范性微电子学院)
School of Integrated Circuit Science and Engineering
(Exemplary School of Microelectronics)

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Thank you!

