

Long Coated Conductors with Uniform and High In-field Performance - Ultra-Thin Once Coating (UTOC) MOD -

**T. Izumi, K. Nakaoka, T. Machi (AIST),
M. Miura (Seikei Univ.),
T. Kiss, M.Inoue(Kyushu Univ.), T. Kato (JFCC)**

2016.9.21

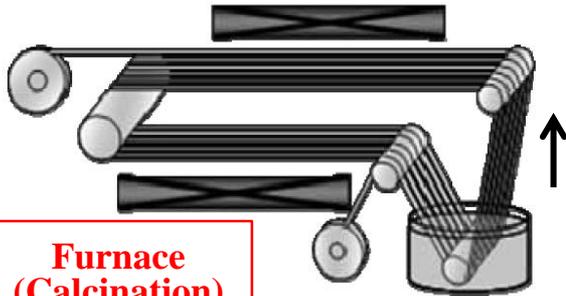
*13th European Conference on Applied Superconductivity
@ Geneva, Switzerland*

Ultra-Thin Once Coating MOD

UTOOC-MOD

TFA-MOD Process

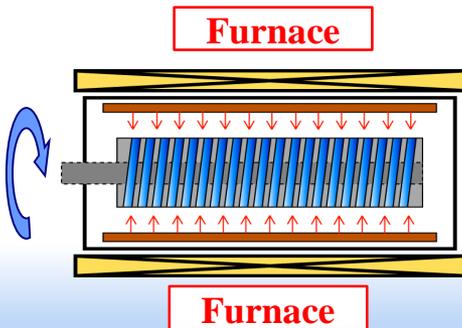
Coating & Calcination



Furnace
(Calcination)

Dip Coater
(Multi-Lanes)

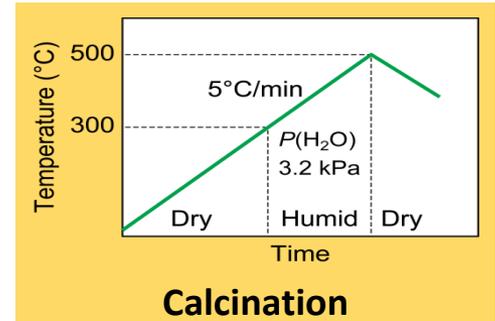
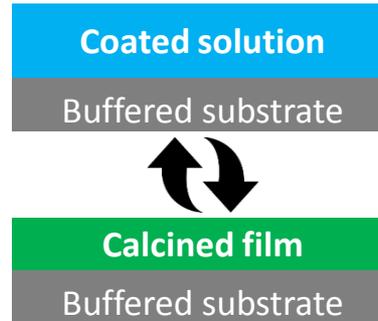
Crystallization



Furnace

Furnace

Multiple-coating/calcination



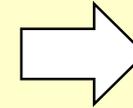
Ultra-Thin Once Coating MOD (UTOC-MOD)

Conventional
($d_{\text{once}} \sim 150\text{nm}$)



d_{once} ↑

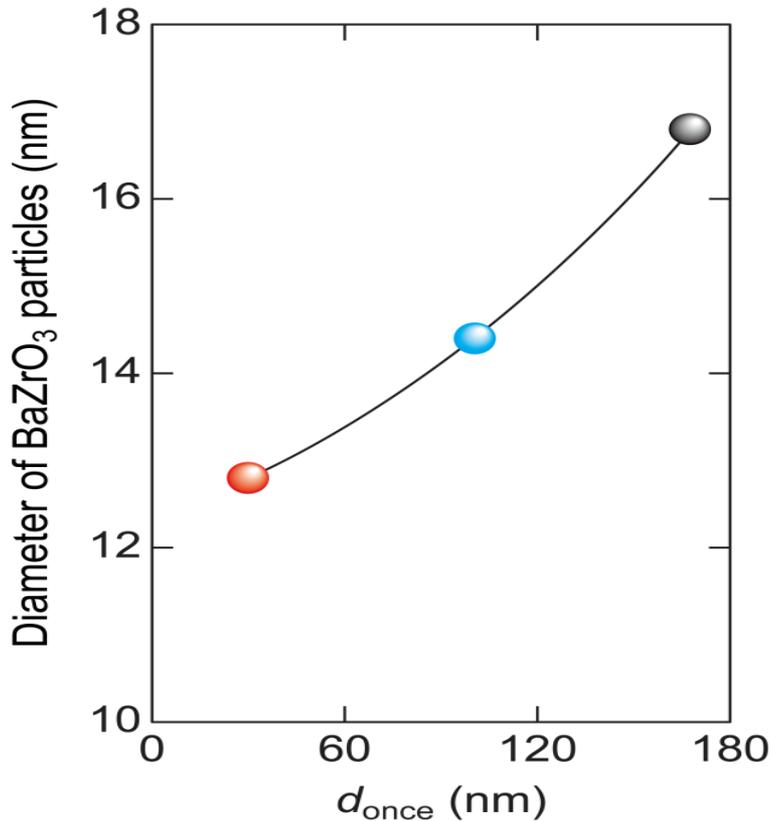
UTOC-MOD
($d_{\text{once}} \sim 30\text{nm}$)



Higher $J_c(B)$

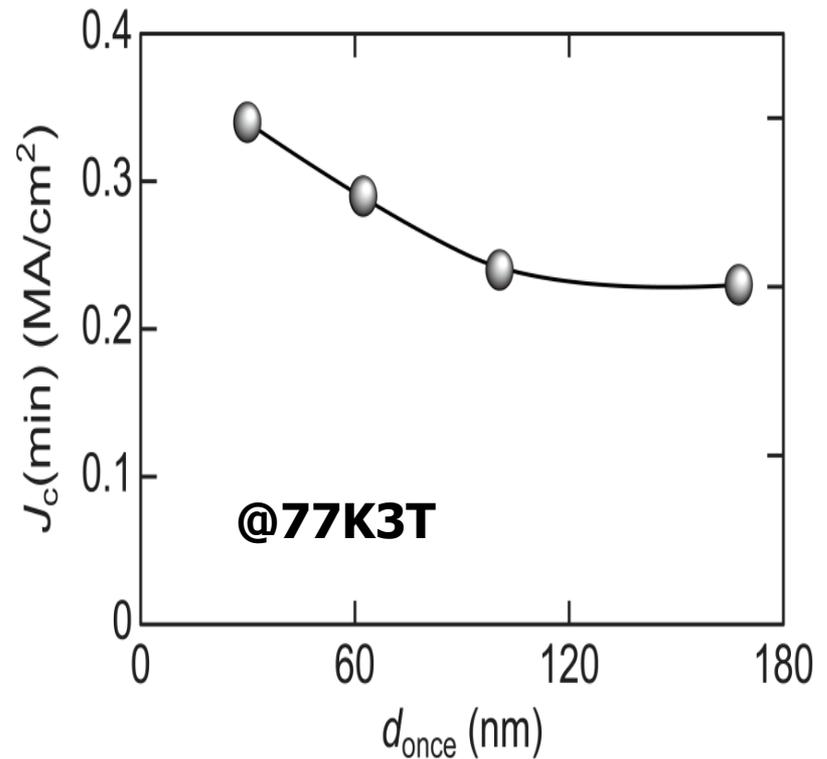
UTOOC – MOD Process

d_{once} dependence
of *BZO-size*



Size of BZO particles became finer as d_{once} decreased.

d_{once} dependence
of J_c (B)

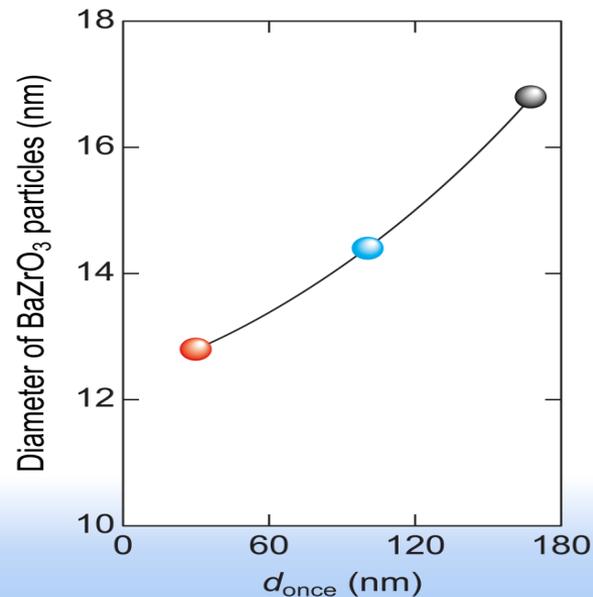


J_c (B) increased as d_{once} decreased.

UTOOC-MOD Related Information

- **Refining Mechanism**
- **In-field Performance (**Jc-B-T**)**
- **Uniformity**
- **Delamination Strength**
- **Long Tape Processing**
- **Further Improvement of Jc (B)**

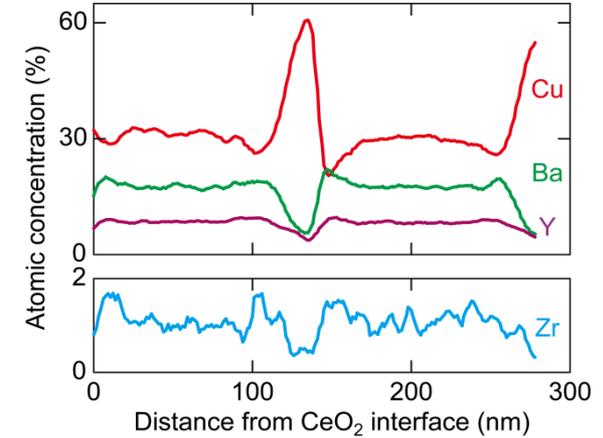
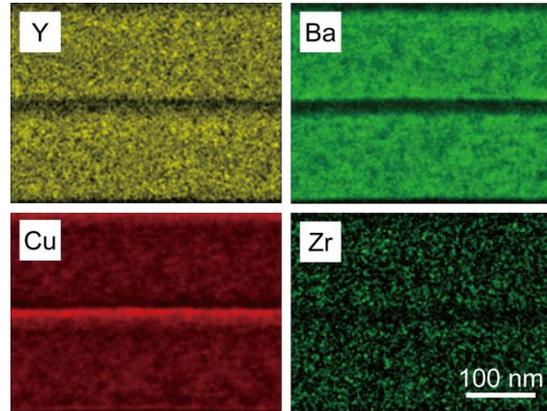
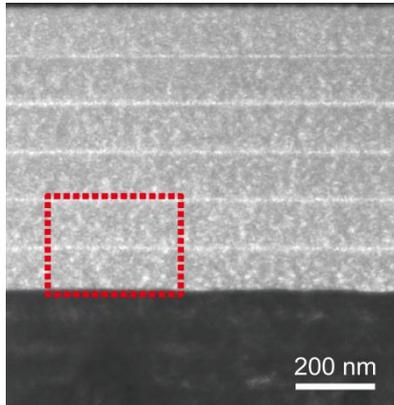
Refining Mechanism in UTOC-MOD



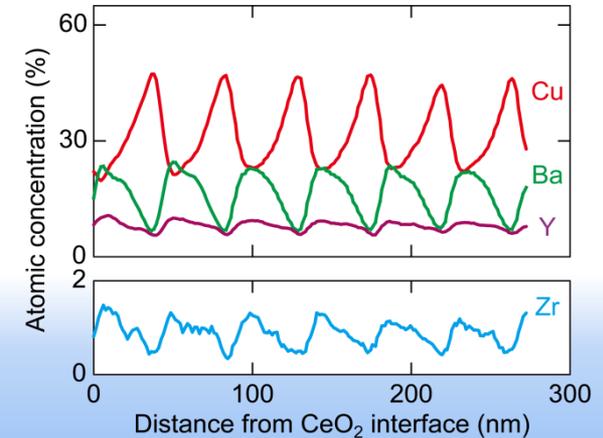
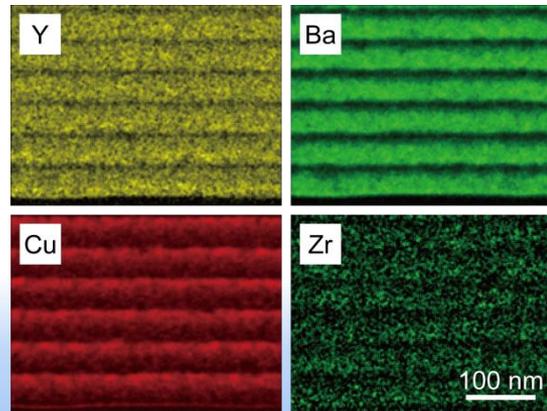
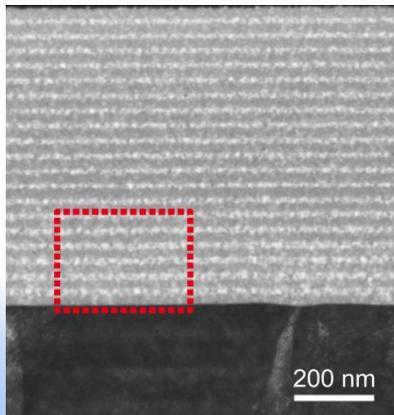
Concentration Distribution along Depth Direction



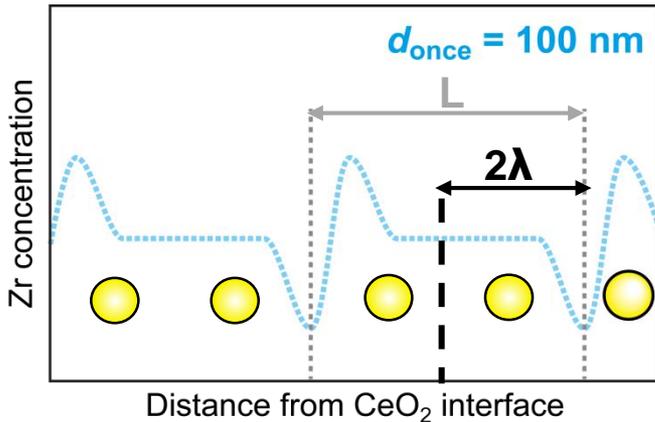
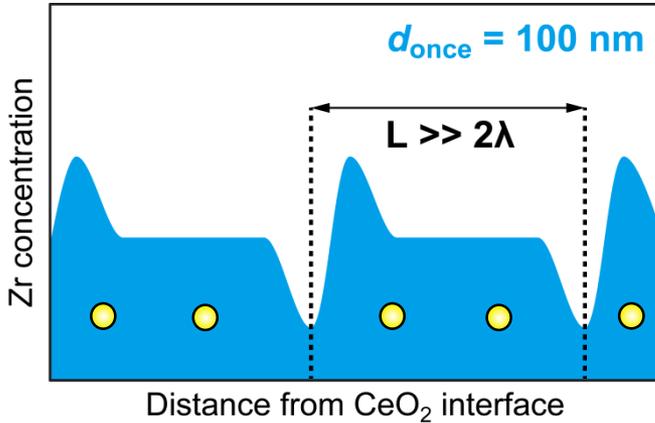
Conventional
 d_{once}
100 nm
X
6 times



UTOC-MOD
 d_{once}
30 nm
X
20 times

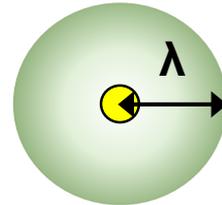


Conventional



BZO
particle

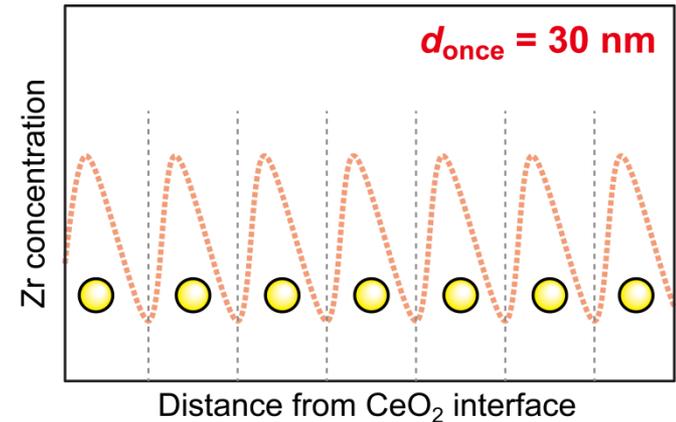
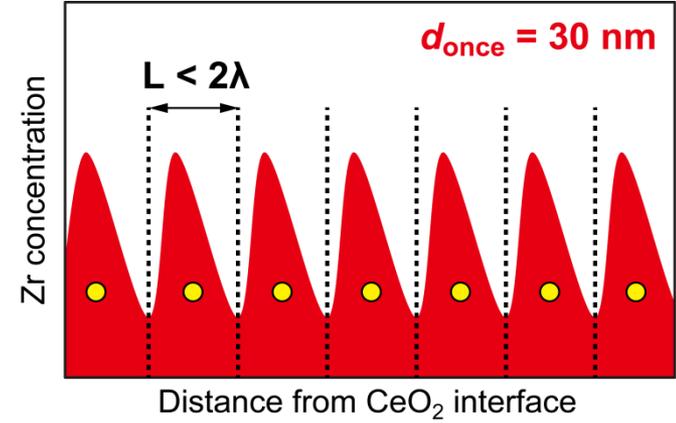
Free Growth



$$\lambda = 2D/V$$

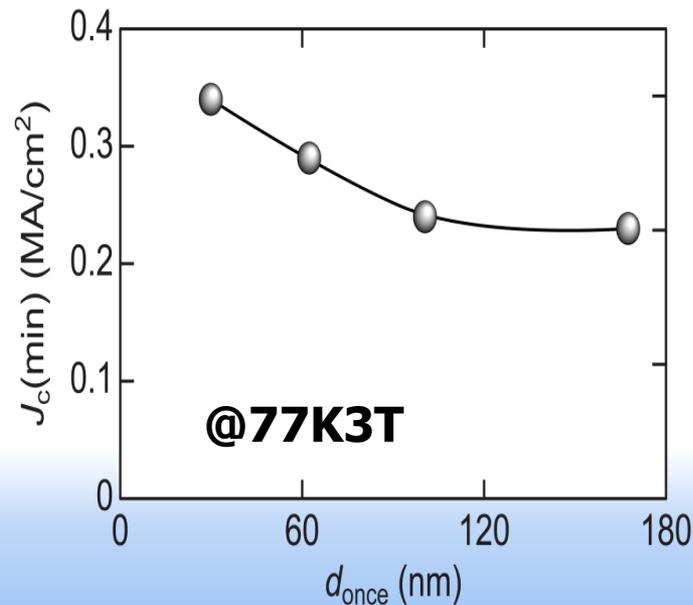
λ : Diffusion
Characteristic length
 D : Diffusivity
 V : Growth velocity

UTOOC-MOD



Diffusion of elements is *limited by valleys*.
→ BZO particles become *finer* !

In-field Performance of UTOOC-MOD FILMS



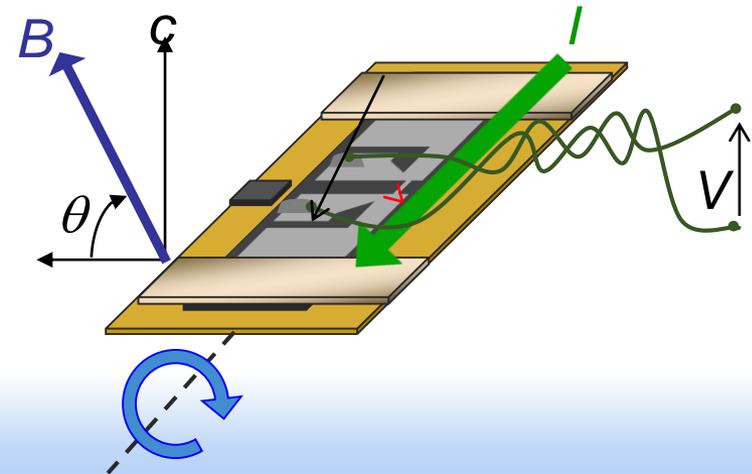
Superconducting layer	Once-coated-layer-thickness	Total thickness	$J_c@77K, 3 T$ $B//c$
YGdBa ₂ Cu ₃ O _{7-δ} +BaZrO ₃ (UTOC-MOD)	30 nm	0.53 μm	0.25 MA/cm ²
YGdBa ₂ Cu ₃ O _{7-δ} +BaZrO ₃	170 nm	0.75 μm	0.13 MA/cm ²

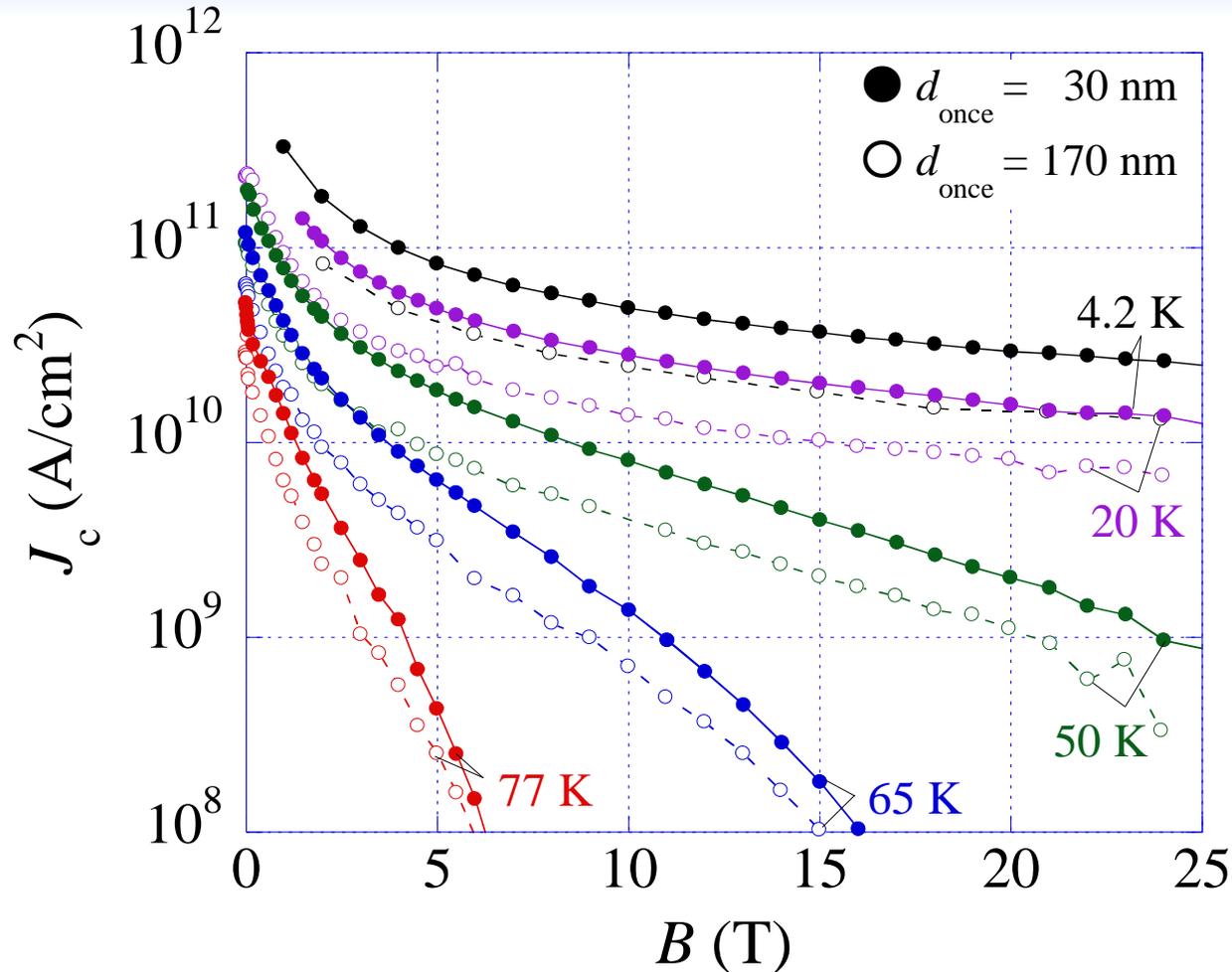
• *E*-*J* measurement

Temperature: 4.2 ~ 77K

Magnetic field: s.f. ~27T

Field angle: -30 ~ 120° ($B//c=90^\circ$)





REBCO CC using $d_{\text{once}} = 30 \text{ nm}$ (UTOC-MOD) shows superior in-field J_c in all measured conditions of temperature and magnetic field than that of previous standard coating using $d_{\text{once}} = 170 \text{ nm}$.

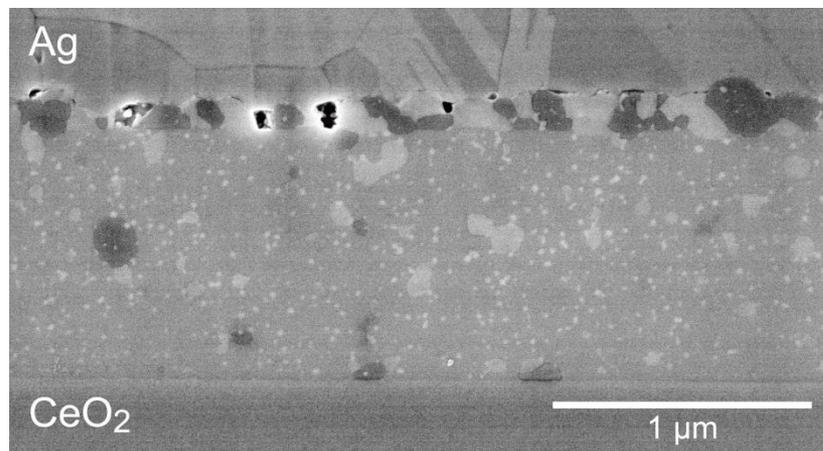
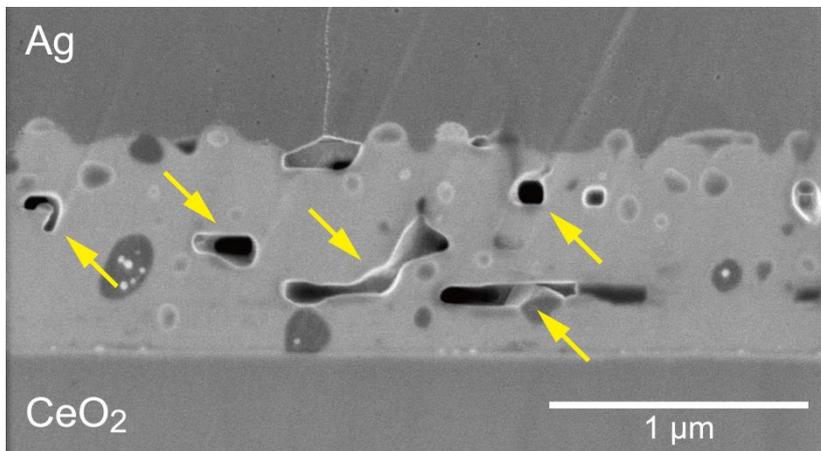
Uniformity of UTOOC-MOD FILMS

Uniformity

Cross-sectional Microstructures by Optical Microscopy

$d_{\text{once}} = 170\text{nm}$

$d_{\text{once}} = 30\text{nm}$
(**UTOC-MOD**)

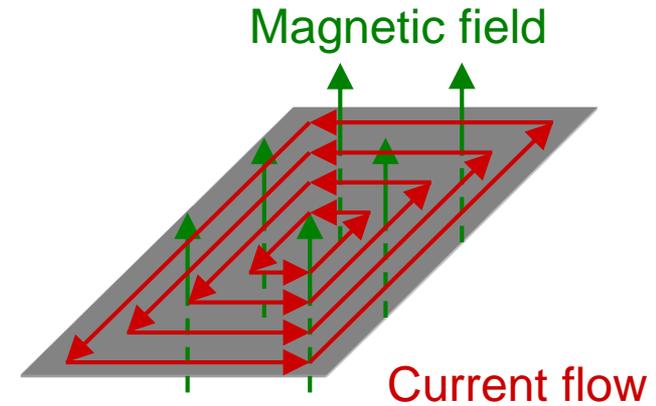


Pores

Pore-free

Scanning Hall-probe Microscopy(SHPM)

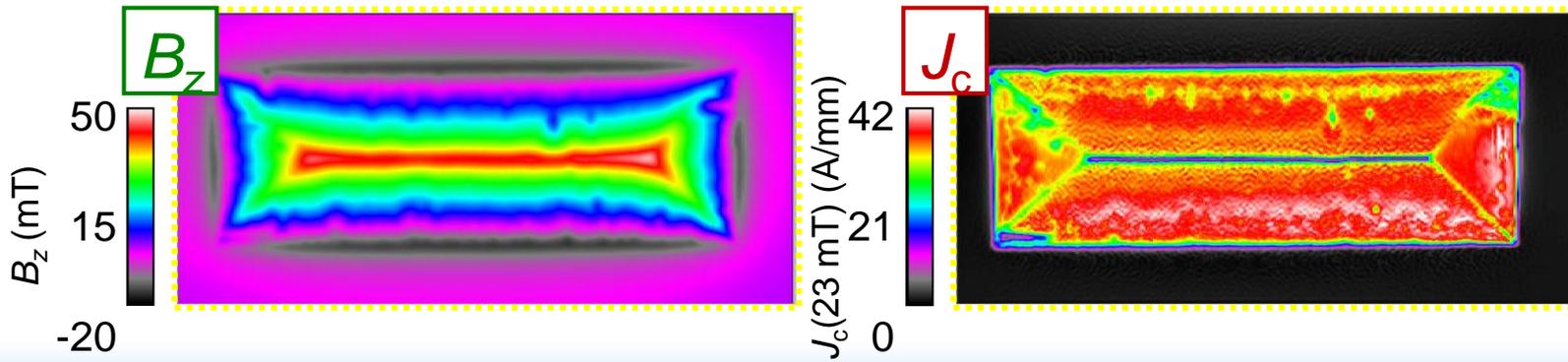
- According to the critical state model,
- if the **magnetic field** is sufficiently trapped,
- the corresponding **current flows at J_c**
- almost in all the area in the sample



Magnetic field imaging

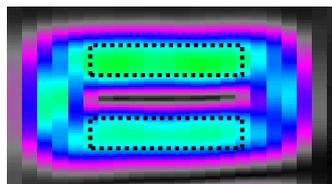


Inhomogeneity in J_c

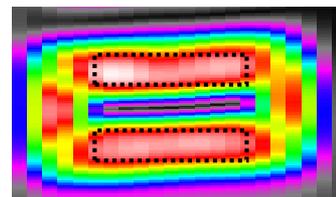


Characterization example for RE-123 coated conductor by another SHPM system than this study's
(K. Higashikawa et al., Physica C, vol. 471 (2011) pp. 1036-1040.)

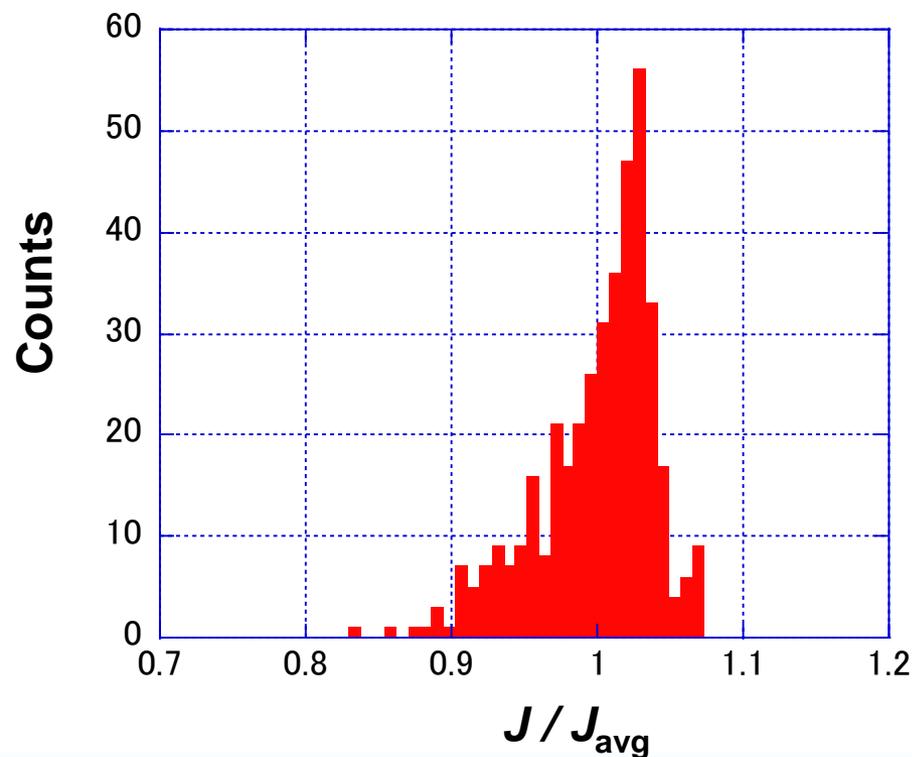
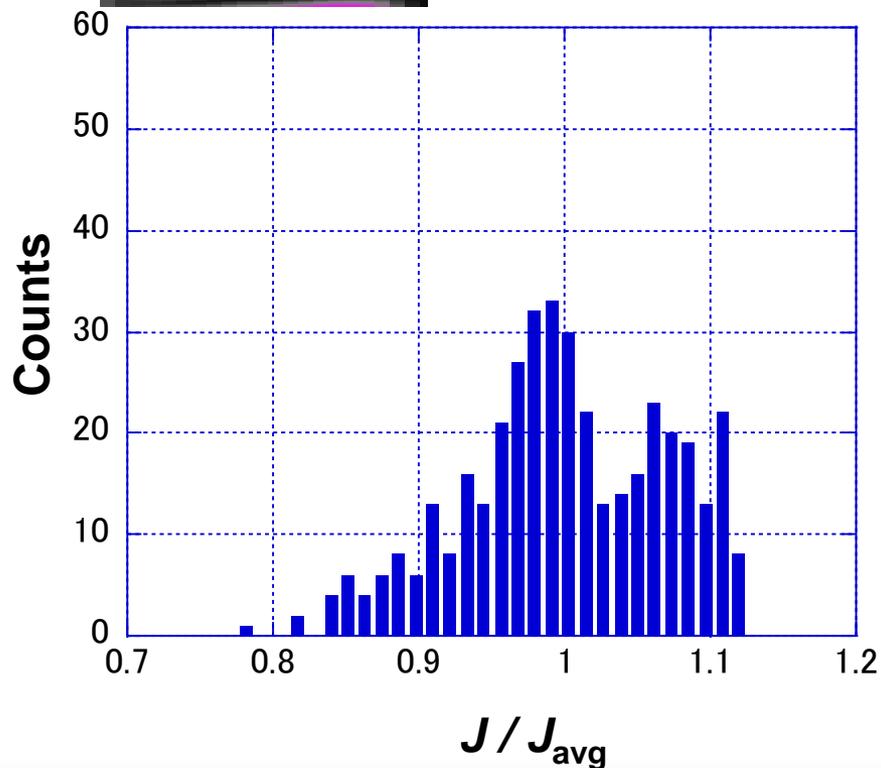
Scanning Hall-probe Microscopy (SHPM)



$d_{\text{once}} = 170 \text{ nm}$



$d_{\text{once}} = 30 \text{ nm}$
(UTOC-MOD)

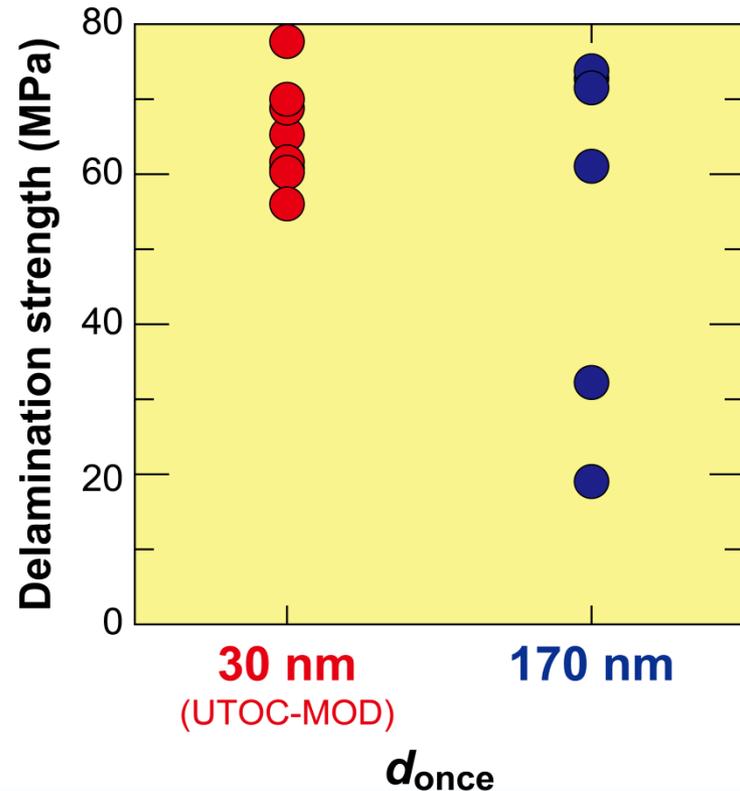
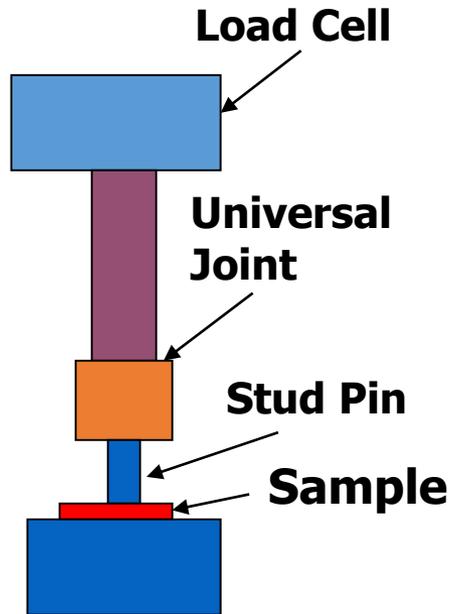


In-plane J_c distribution in UTOC-MOD shows higher uniformity.

Delamination Strength of UTOC-MOD

Delamination Strength

Evaluation by Stud-pull Instrument (Preliminary Results)



Films by UTOC-MOD shows uniform delamination-strength.

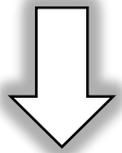
Long Tape Processing

by

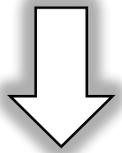
UTOOC-MOD

Long Tape Processing

Ultra-thin Coating Process

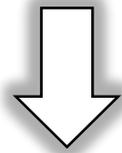


Finer BMO

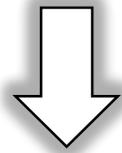


Higher $J_c(B)$

Positive!



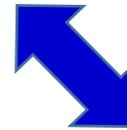
Increase of Coating #



Higher Cost

**Negative!
(to be solved)**

**to keep
Throughput
Rate!**

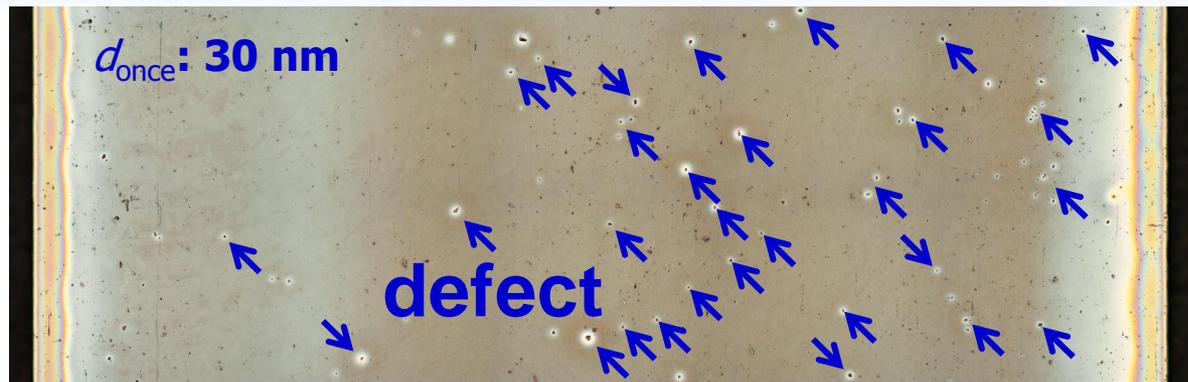


**[Solution]
Higher
Travelling
Rate**

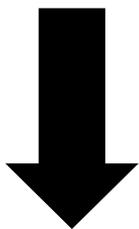


Previous Solution

Y(TFA)₃
Ba(TFA)₂
Cu(2-ethylhexanoic acid)₂

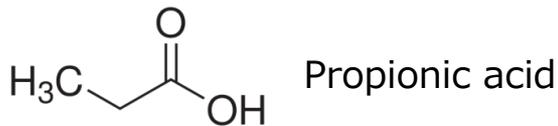


Withdrawal rate: **5**→**20 m/h**
Ramp rate (Calcination): **20°C/min**



F: **-50%**
C: **+5%**

New Solution



Y(**Propionic acid**)₃

Ba(TFA)₂

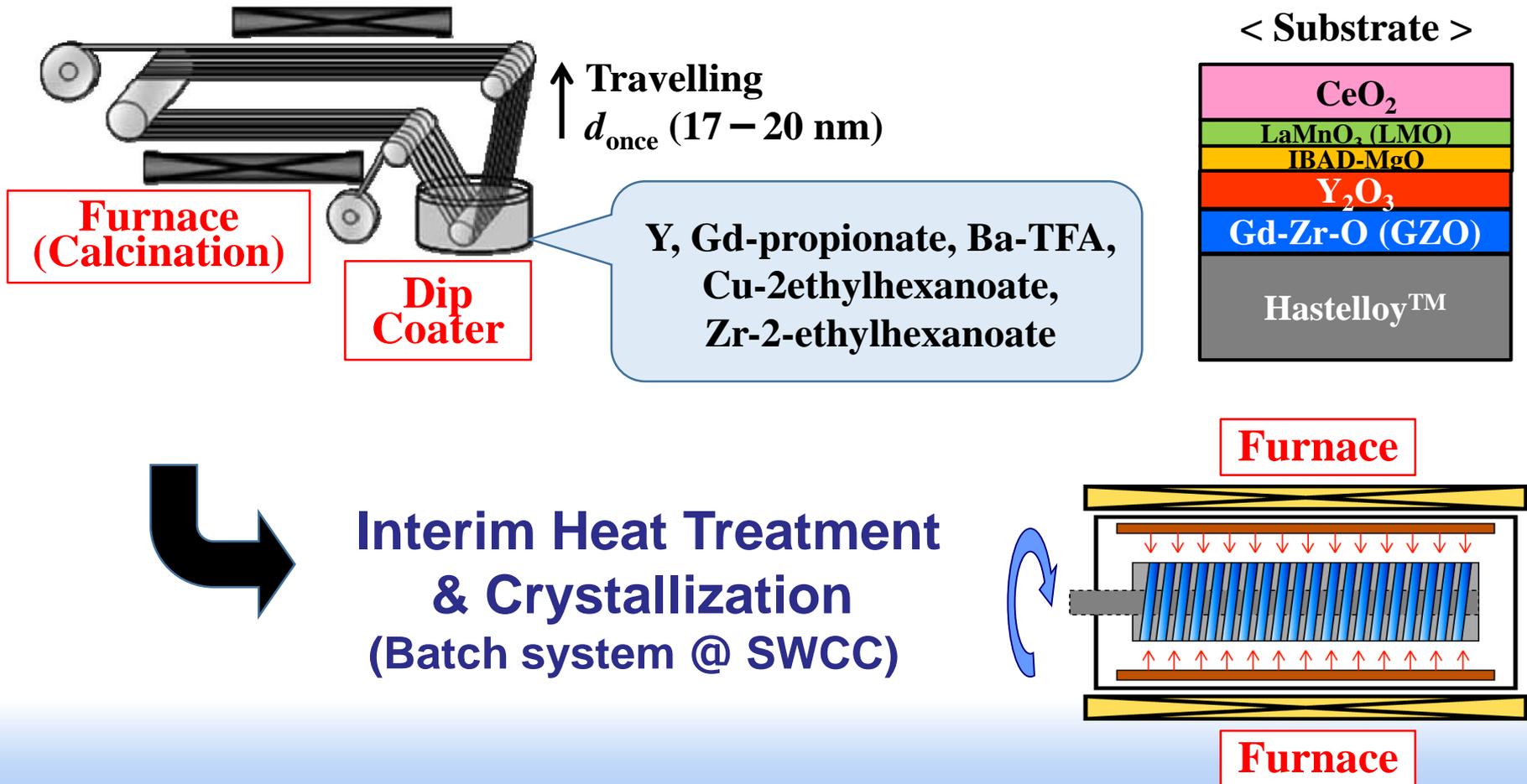
Cu(2-ethylhexanoic acid)₂



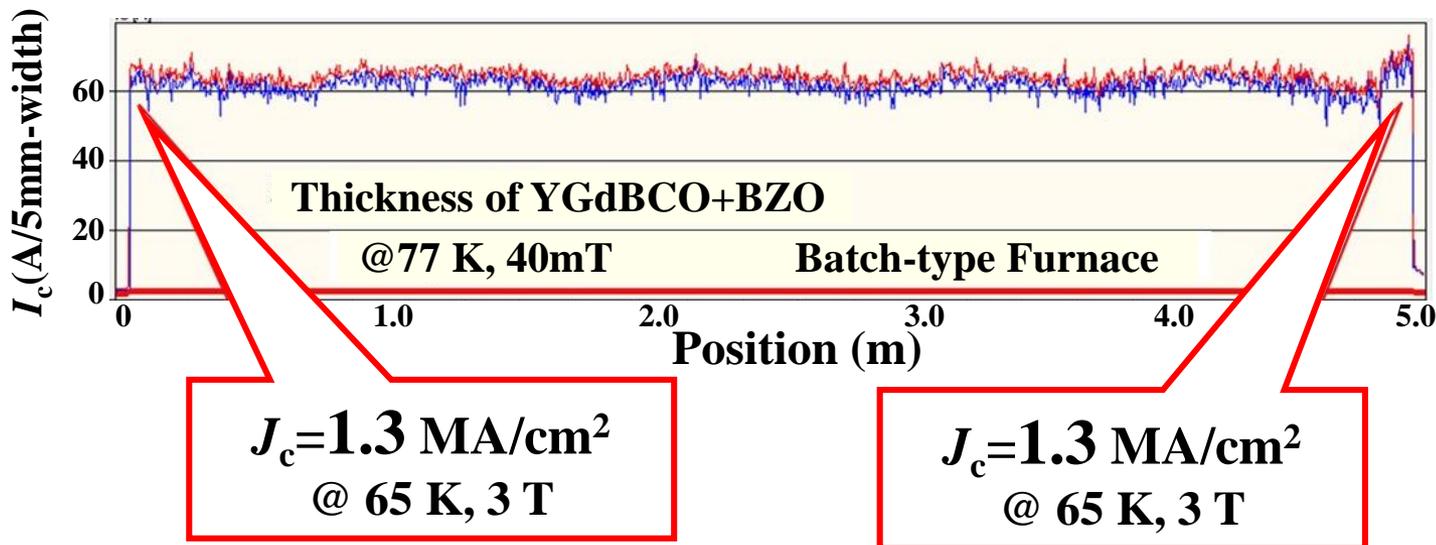
Withdrawal rate: **50 m/h**
Ramp rate (Calcination): **40°C/min**

Long Tape Processing by UTOC-MOD

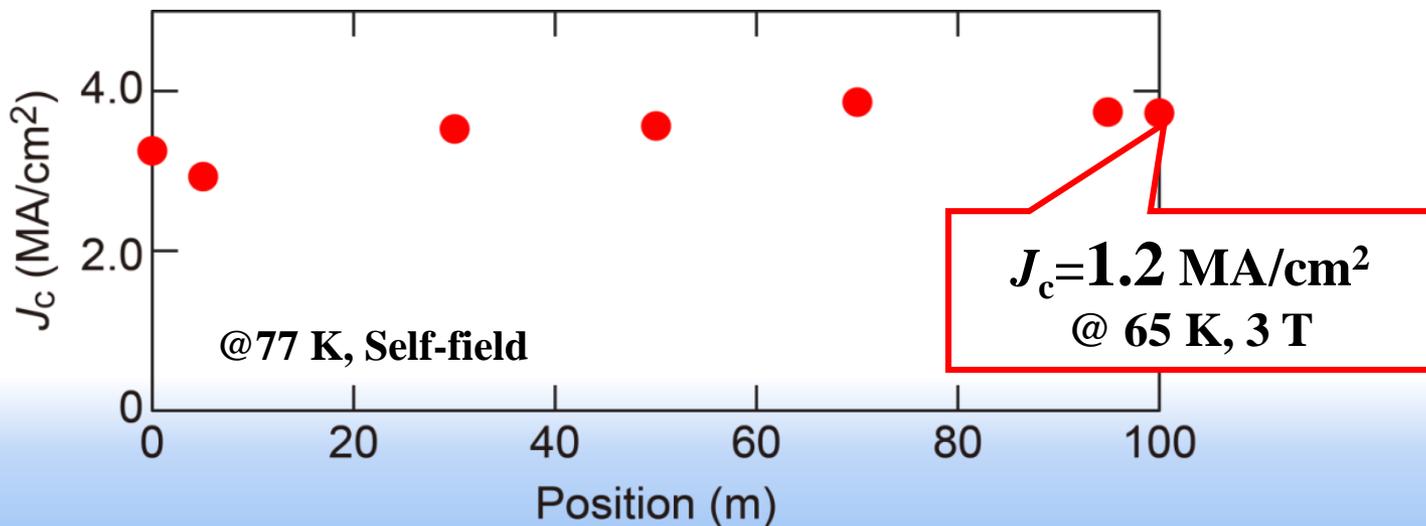
Coating & Calcination (Reel-to-Reel system @ AIST)



**5 m Long
Tape**

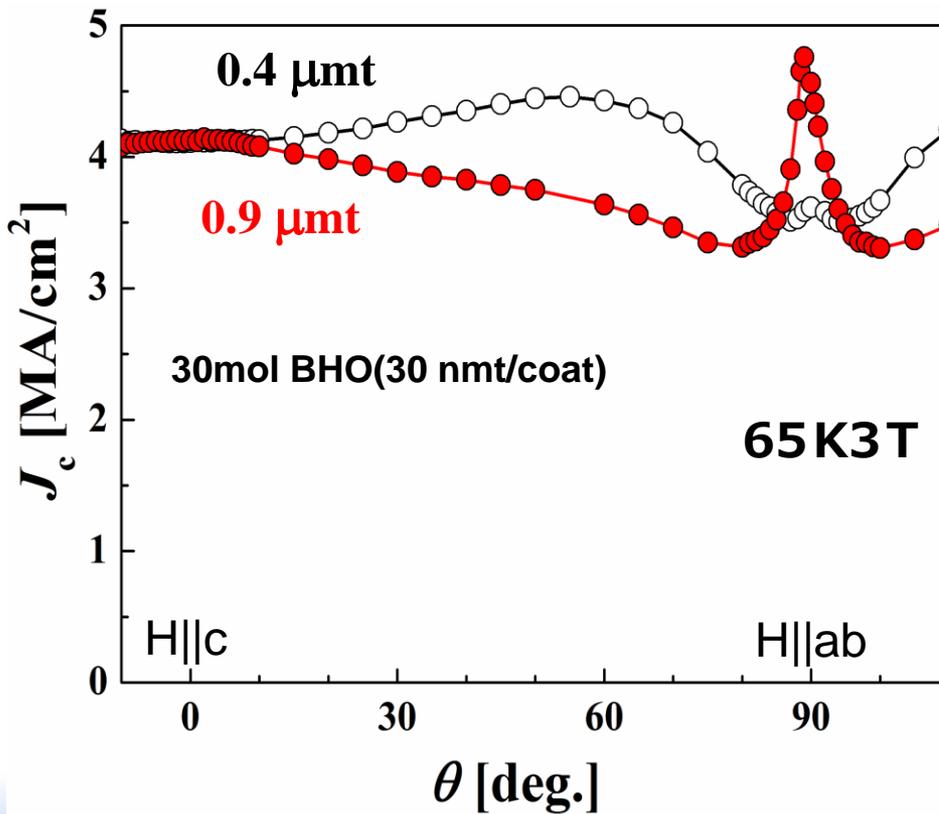


**100 m
Patch
Tapes**



Further Improvement of $J_c(B)$ by UTOC-MOD

- 1) Material : $\text{BaZrO}_3 \rightarrow \text{X}$
- 2) Doping Concentration : **15** \rightarrow **30 mol%**



$J_c @ 65\text{K} 3\text{T} [0.9 \mu\text{mt}]$

4.1 MA/cm² (B//c)

3.3 MA/cm² (min.)



$I_c(\text{min.}) = 300 \text{ A/cmw}$
@65 K, 3 T

[Estimation]

$I_c(\text{min.}) = 660 \text{ A/cmw}$
@65K, 3T by 2.0 μmt

Reduction of d_{once} → Finer BZO-particles → Higher $J_c(B)$

◆ **REFINING MECHANISM OF APC PARTICLES**

Concentration **Peak/Valleys** → Limitation of BZO Growth

◆ **IN-FIELD PERFORMANCE**

Superior in All Conditions of Temp. and Magnetic Field

◆ **UNIFORMITY**

Pores → **Pore-Free** & **Uniform J_c** Distribution in SHPM

◆ **MECHANICAL STRENGTH**

Uniformly High Strength (suppressing low strength parts)

◆ **LONG TAPE PROCESSING**

New Solution → **Continuous** Fabrication with **High Rate**

◆ **FURTHER IMPROVEMENT OF $J_c(B)$**

New APC Material with Heavy Doping

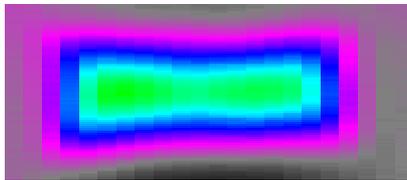
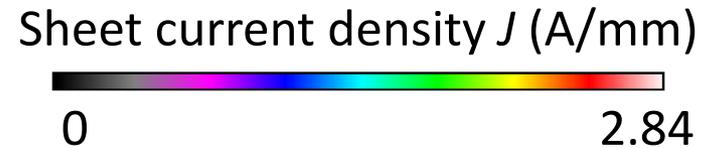
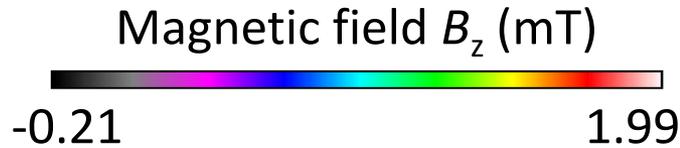
→ **$J_c(B) = 4.0 \text{ MA/cm}^2$ at 65 K, 3 T**

Thank you for your attention !

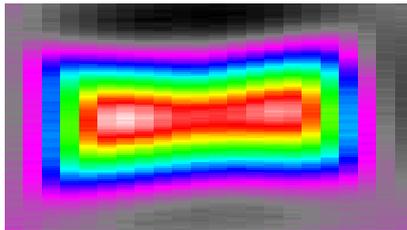
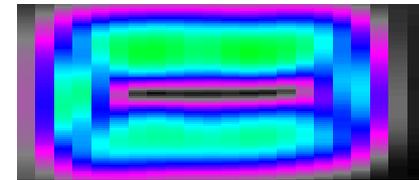
Acknowledgement

**A part of this work was supported by
METI, AMED and NEDO.**

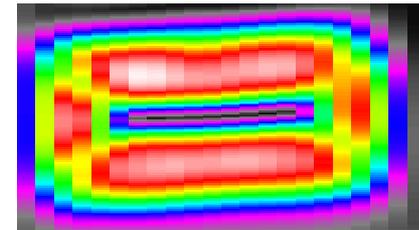
Scanning Hall-probe Microscopy (SHPM)



$d_{\text{once}} = 170 \text{ nm}$



$d_{\text{once}} = 30 \text{ nm}$
(UTOC-MOD)



In-plane J_c distribution shows **high uniformity** (free from defect/crack formation).

Summary

◆ DEVELOPMENT OF NEW TFA-MOD PROCESS

Reduction of d_{once} → Finer BZO-particles → Higher $J_c(B)$

< YGdBCO+BZO $d_{\text{once}} = 30 \text{ nm}$ >
 $J_c(B) = 1.6 \text{ MA/cm}^2$ at 65 K, 3 T

*Comparable $J_c(B)$
to Vapor Process !*

◆ REFINING MECHANISM OF APC PARTICLES

Concentration Peak/Valleys in Precursor

→ Diffusion Barrier → Limitation of BZO Growth

◆ FURTHER IMPROVEMENT OF $J_c(B)/I_c(B)$

Thinner d_{once} Condition : 30 nm → 17 nm

→ Lower $J_c(B)$ ← Shallow Valley

Change of APC Material : BZO → X

Increasing APC Concentration : 15 → 30 mol%

< YGdBCO+X(30mol%) $d_{\text{once}} = 30 \text{ nm}$ >
 $J_c(B) = 3.3 \text{ MA/cm}^2$ $I_c(B) = 300 \text{ A/cm-w}$
 at 65 K, 3 T

*Superior $J_c(B)$ to
Vapor Process !*