High field superconducting characteristics at low temperature of $SmBa_2Cu_3O_x$ coated conductor with artificial pinning center

Yutaka Yoshida

Nagoya university

Japan

EUCAS 2017

Co-researchers

Y. Tsuchiya, Y. Ichino, S. Miura
(Nagoya university)
S. Awaji (Tohoku university)
K. Matsumoto (Kyushu institute of tech.)
T. Izumi
(National Institute of Advanced Industrial Science and Technology)
A. Ichinose
(Central Research Institute of Electric Power Industry)

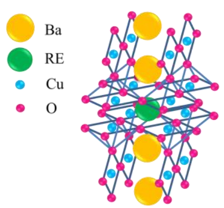
Acknowledgment

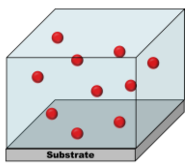
This work was partly supported by a Grant-in-Aid for Scientific Research (15H04252, 15K14301,15K14302 and 16H04512). A part of this work includes the results supported by the ALCA project of the Japan Science and Technology Agency (JST) and NU-AIST alliance project.

Lattice constant of various APC materials

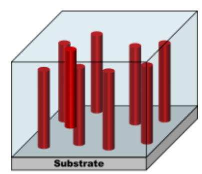
Lattice constant [Å]

3.85~3.90*	3.989	4.117	4.171	4.192	4.244**	4.397
$SmBa_2Cu_3O_y$	$BaTiO_3$	$BaSnO_3$	$BaHfO_3$	$BaZrO_3$	Ba_2SmNbO_6	$BaCeO_3$

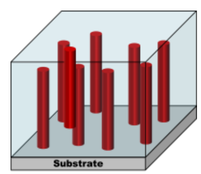


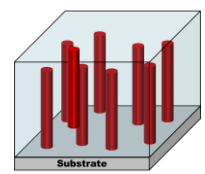


Particles

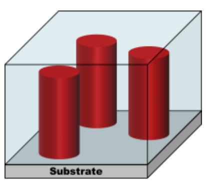


~ 15 nm

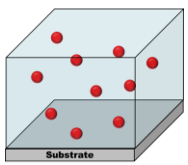




~ 3-12 nm



~ 30 nm



Particles

← **Nanorod** →

6.4% ← **misfit** → 9.7%

Y. Shingai, Physica C 445,841 (2006).
P. Mele, SuST 21, 032002 (2008).
A Tsuruta SuST 27, 065001 (2014).
H. Tobita SuST 25, 062002 (2012).
A. Tsuruta IEEE TAS 23, 8001104 (2013).
M. Mukaida JJAP 44, L952 (2005).
R. Teranishi Physica C 468, 1522 (2008).
K. Yamada Physica C 445 660 (2006).
H. Kai SuST 23 025017 (2010).
S.H. Wee APEX 3, 023101 (2010).
A.K. Jha SuST 27, 025009 (2013).
Y. Ichino JJAP 56 73101(2017)
M. Malmivirta, IEEE TAS **25**, 6603305 (2015).

YBCO + $BaYNbO_6$[12]
~ 15 nm
misfit ~ 9.5%

(Y,Gd)BCO + $Ba(Y,Gd)TaO_6$[11]
~ 7 nm
Misfit ~ 9-12%

✓ **Misfit of 6-12%⇒ Nano rod**

* 11.72 Å1/3 ~ 3.90 Å (RT)

[11] G. Ercolano *et al.*: Supercond. Sci. Technol. **24** (2011) 095012 [12] D M Feldman *et al.* : Supercond. Sci. Technol. **23** (2010) 095004

Table of the Contents

- ✓ **Motivation**

  Early studies of the film on single crystalline substrate

- ✓ **Experimental**

  Reel to reel system by PLD

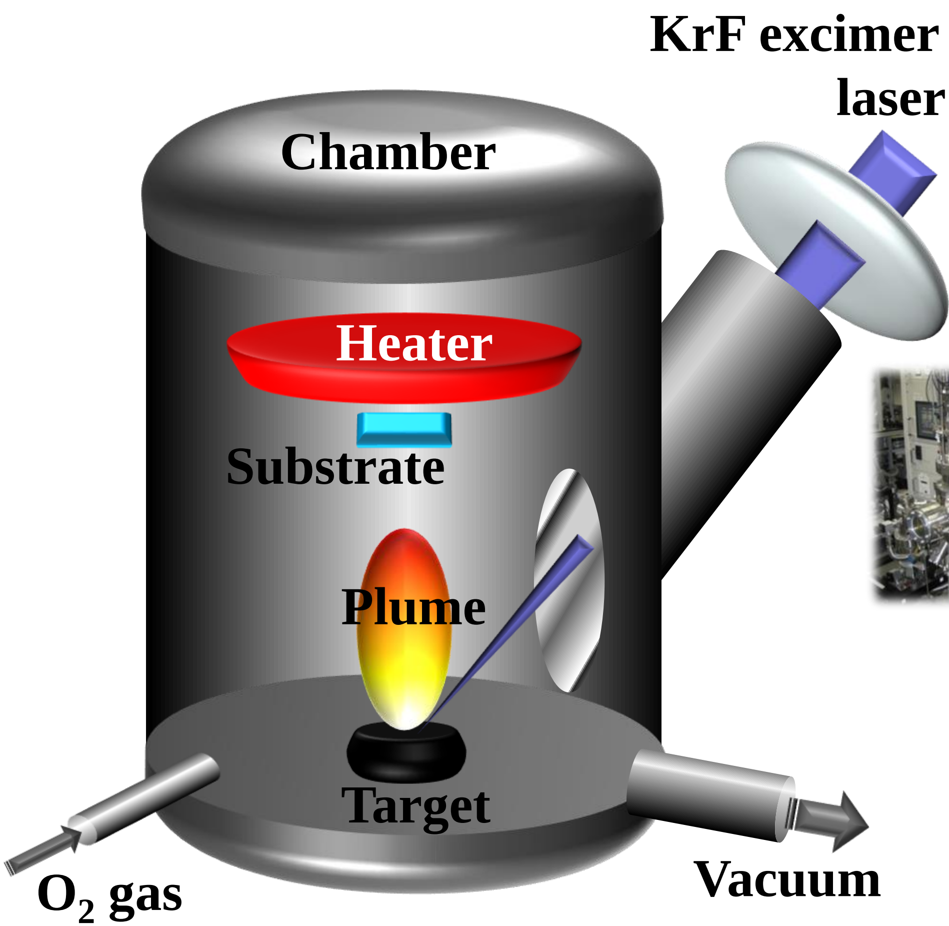
  novel PLD technique

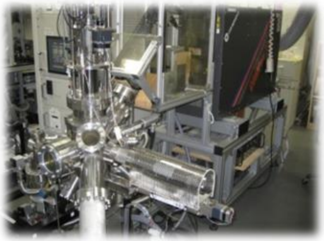
- ✓ **Highlight data**

  Coated conductor on IBAD tape

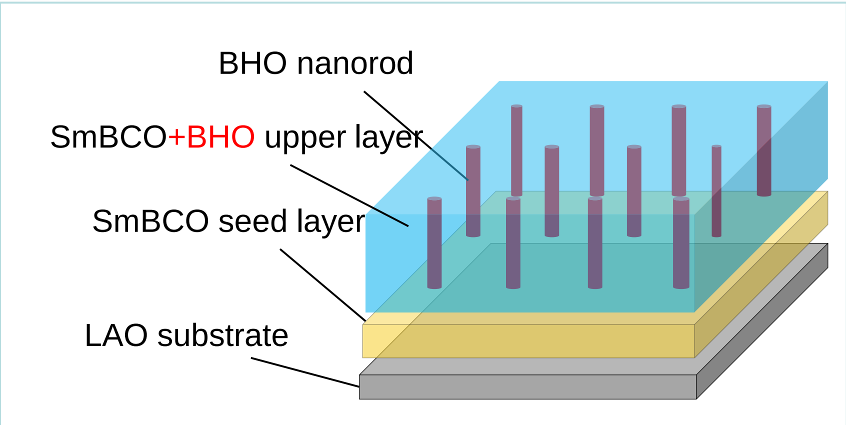
- ✓ **Summary**

Experimental facility





Parameters	Condition
Laser source	KrF eximer laser (λ = 248 nm)
Substrate	$LaAlO_3$(100) IBAD tape
Substrate temperature	700~950 ˚C
Oxygen partial pressure	0.4 Torr
Laser fluence	2 J/cm^2
Repetition late	10 Hz

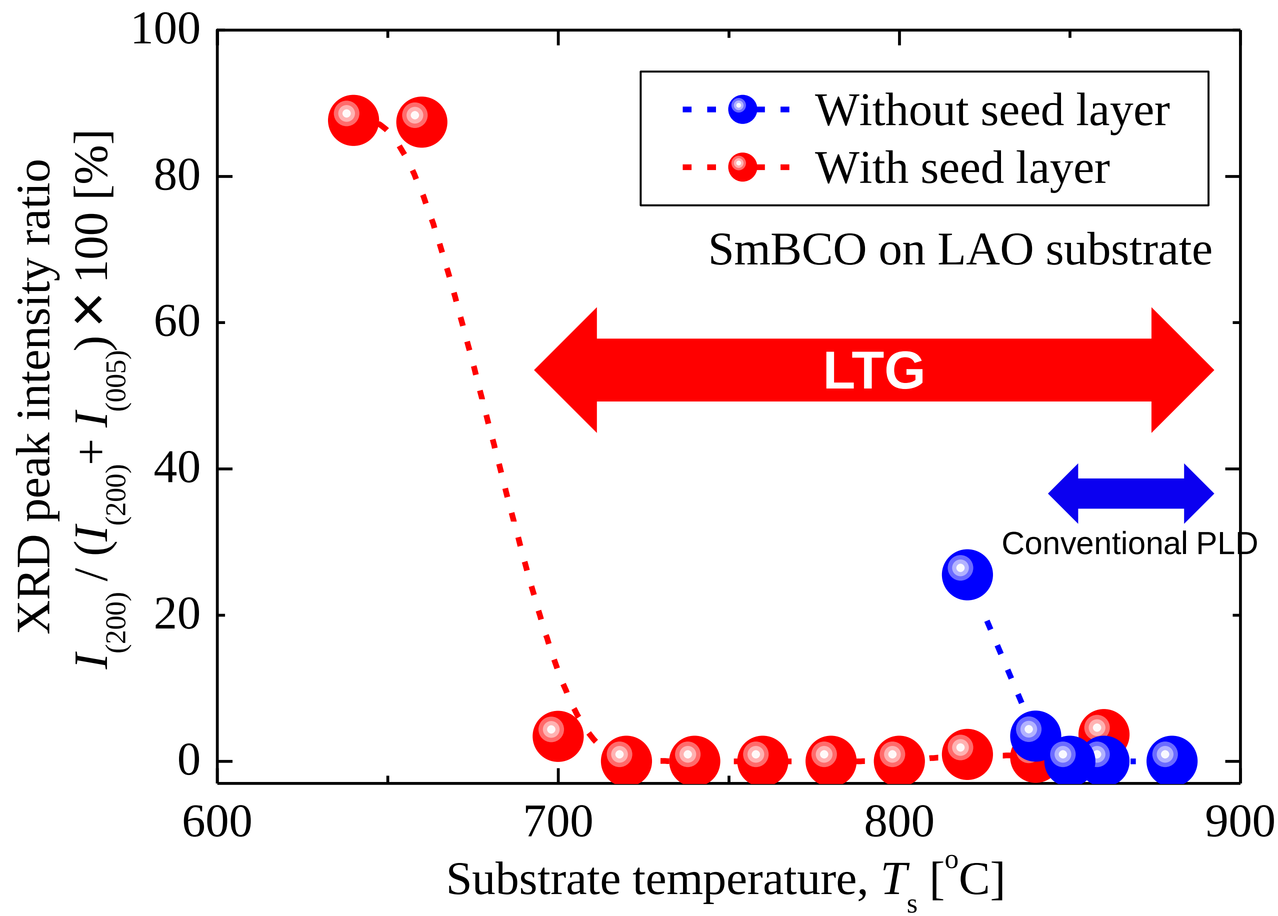


LTG low temperature growth technique

…tivity,

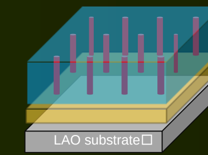
NAGOYA UNIVERSITY

Advantage of LTG technique

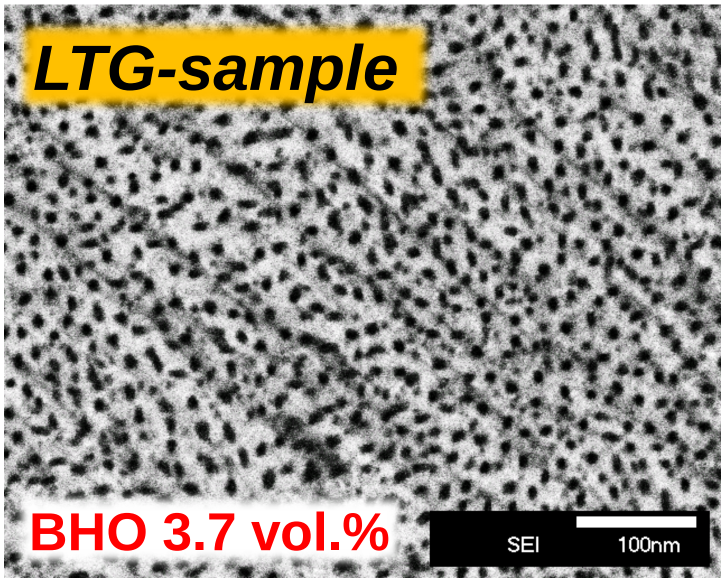


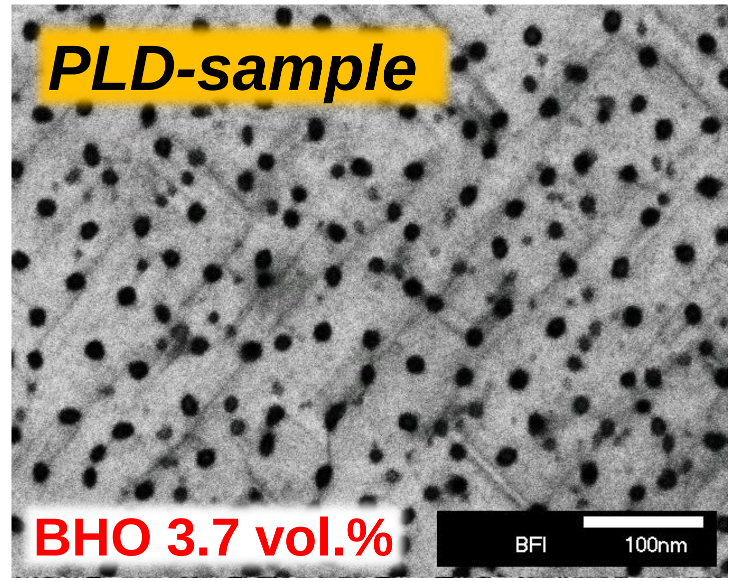
With seed layer, we can fabricate purely *c*-axis oriented films at lower T_s

Plane-view images of the TEM



LaAlO$_3$ single crystalline substrate



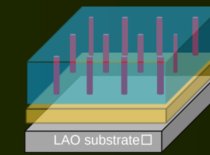


S. Miura, Y. Yoshida *et al.*: Jpn. J. Appl. Phy. **53**, 090304 (2014)

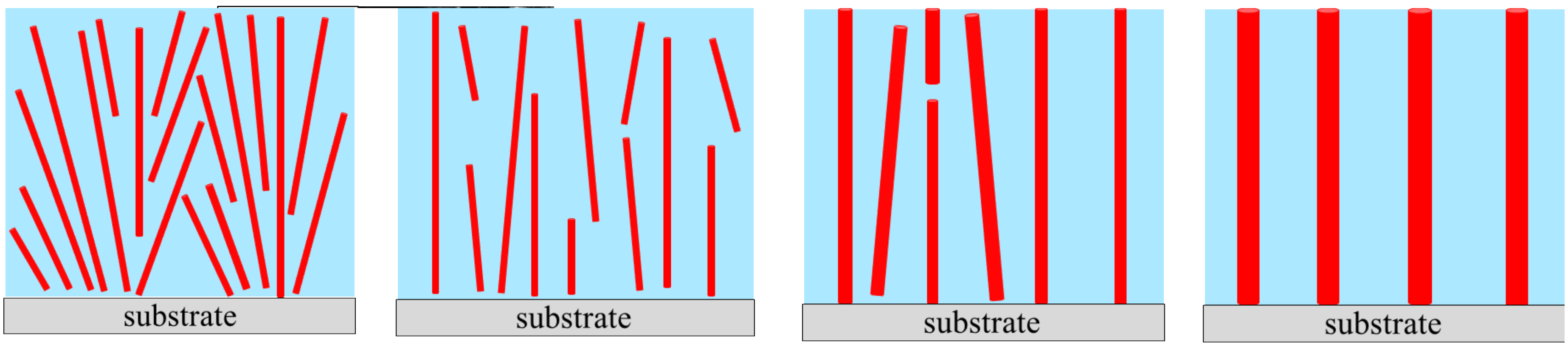
film	diameter [nm]	Density [/μm^2]	B_ϕ [T]
LTG-sample	7.0	2800	5.8
PLD-sample	13.5	708	1.5

[5] A. Tsuruta *et al.*: IEEE. Trans. Appl. Supercond. 23 (2013) 8001104
[6] A. Ichinose *et al.*: TEION KOGAKU 48 (2013) 485

Microstructure in SmBCO+BMO film



Growth temperature

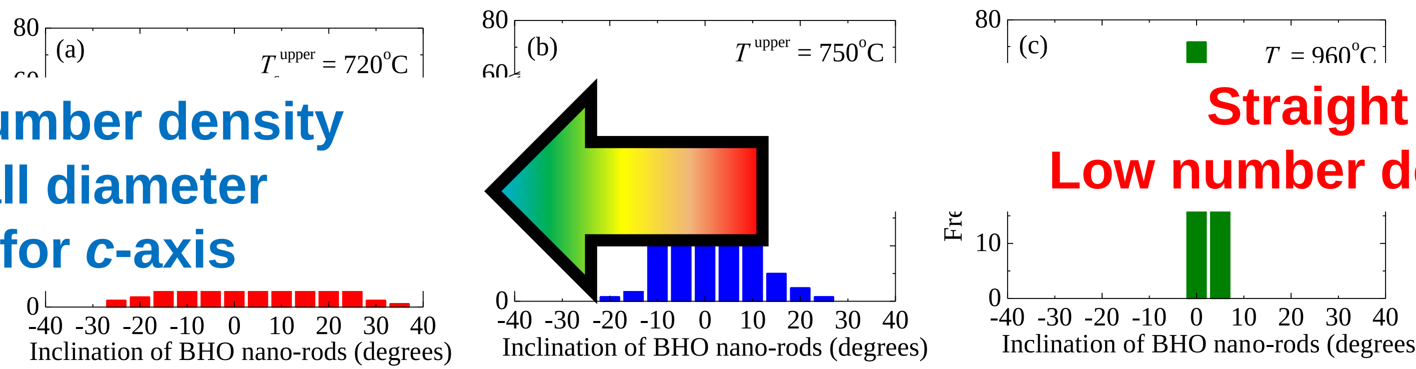


Diameter: 4 nm
Number density: 3100 /μm^2
Maximum tilt angle: ~35°
Discontinuity

Diameter: 6 nm
Number density: 2300 /μm^2
Maximum tilt angle: ~25°

Diameter: 13.5 nm
Number density: 710 /μm^2
Maximum tilt angle: ~5°

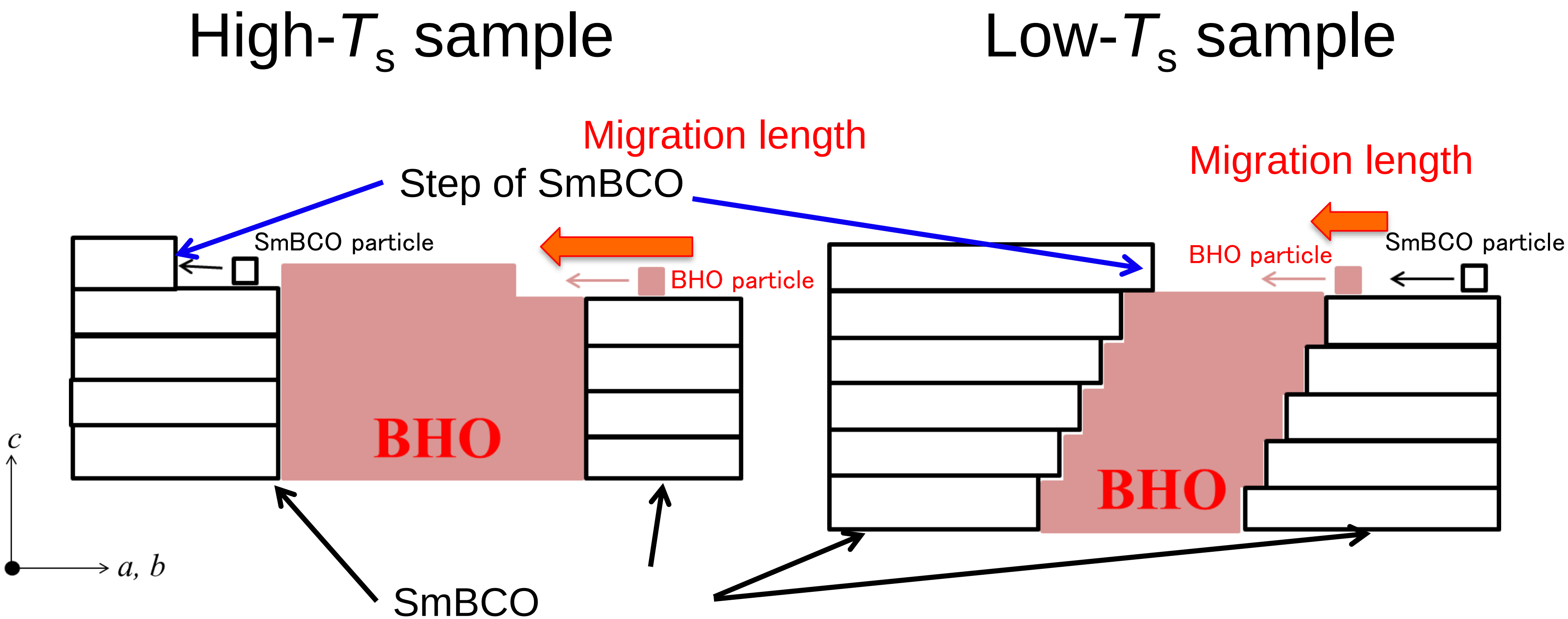
Distribution of inclination angles of the BHO nano-rods



High number density
Small diameter
tilt for *c*-axis

Straight
Low number density

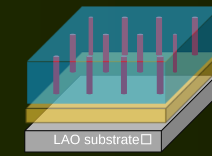
A diagram of the growth process of BHO nanorods in growth-kinetics



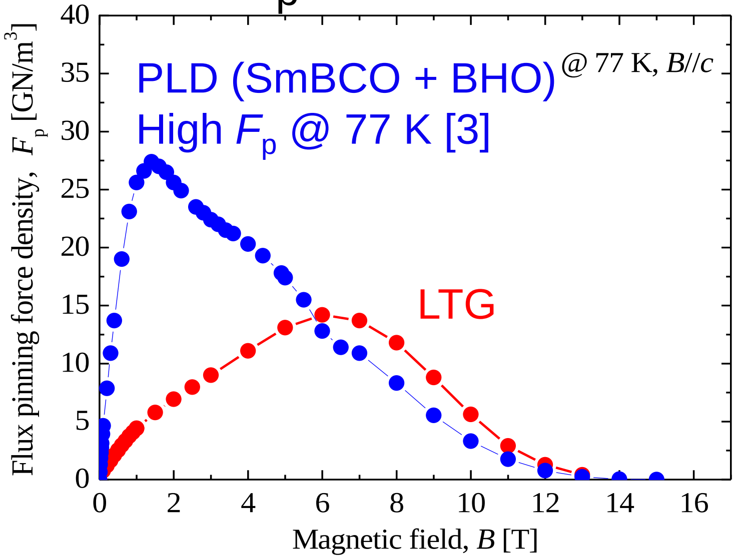
<u>High−T_s sample</u>
Migration length of BHO and SmBCO is large, Nucleation grows up at BHO only. **Straight**

<u>Low−T_s sample</u>
Migration length of BHO and SmBCO is small, and the crystal nucleation frequency of BMO increases, and high density BMO nanorods grow. So growth rate of BMO is low in the *c*−axis direction.
Nucleation grows up in every step and terrace **tilt for *c*-axis**

F_p–B at 77 K and lower temperatures



F_p-B at 77 K



F_p-B at lower temperatures

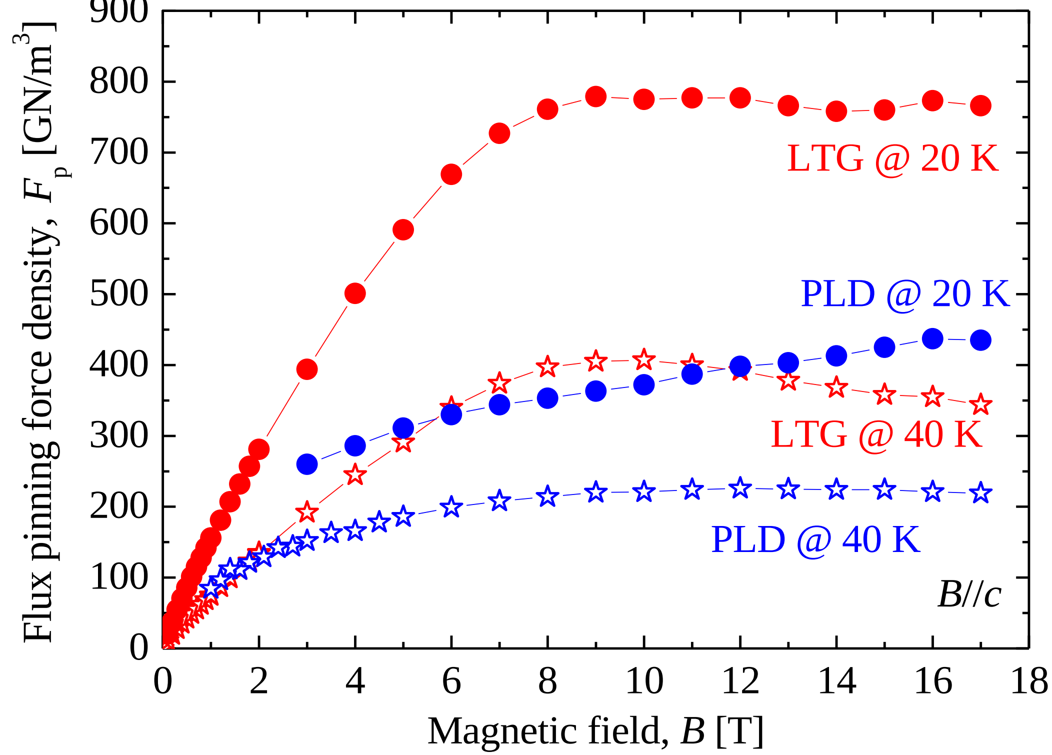


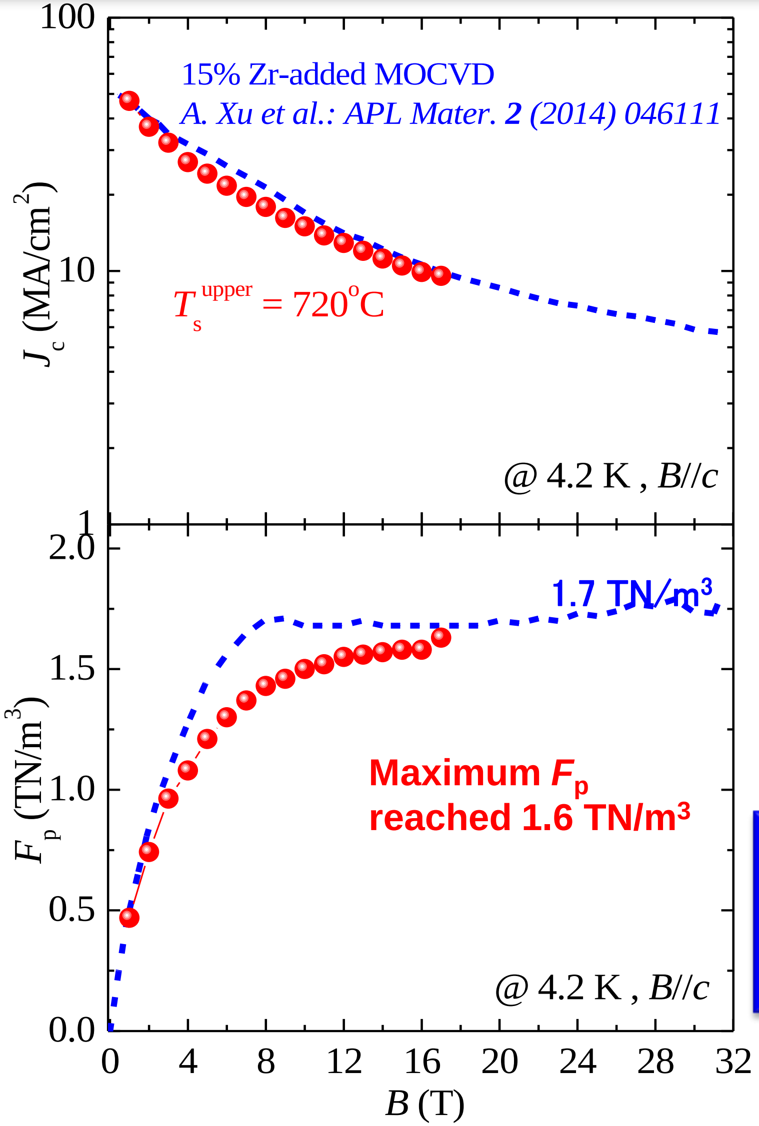
Fig. Magnetic field dependence of F_p of the LTG and PLD high F_p films.

Table Maximum F_p of the LTG and PLD high F_p films.

Film	F_p^{MAX} at 77 K	F_p^{MAX} at 40 K	F_p^{MAX} at 20 K
LTG 5.6vol%	14.2 GN/m^3	**407** GN/m^3	**779** GN/m^3
PLD high F_p sample	**28.0** GN/m^3	226 GN/m^3	437GN/m^3

S. Miura, Y. Yoshida et. al. , Supercond.Sci.Technol.28 (2015) 114006

J_c–B & F_p of the LTG-SmBCO+BHO films @4.2K



✓ F_p of 1.6 TN/ m^3 was realized; this value was comparable to the highest value recorded at 4.2 K and under 17 T.

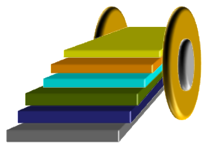
NAGOYA UNIVERSITY

S. Miura, Y. Yoshida et. al. ; APL mater. 4 (2016) 016102

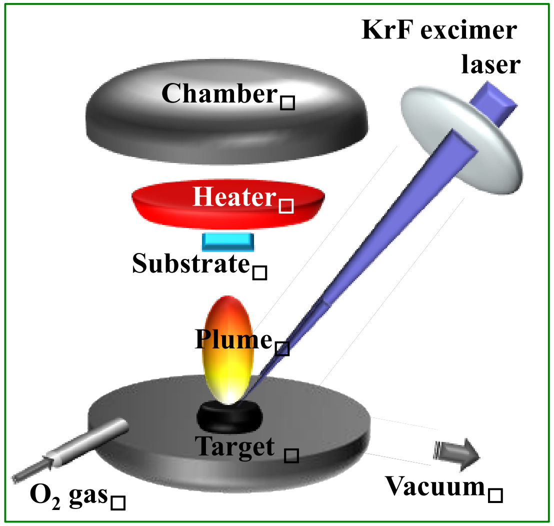
Main Topics

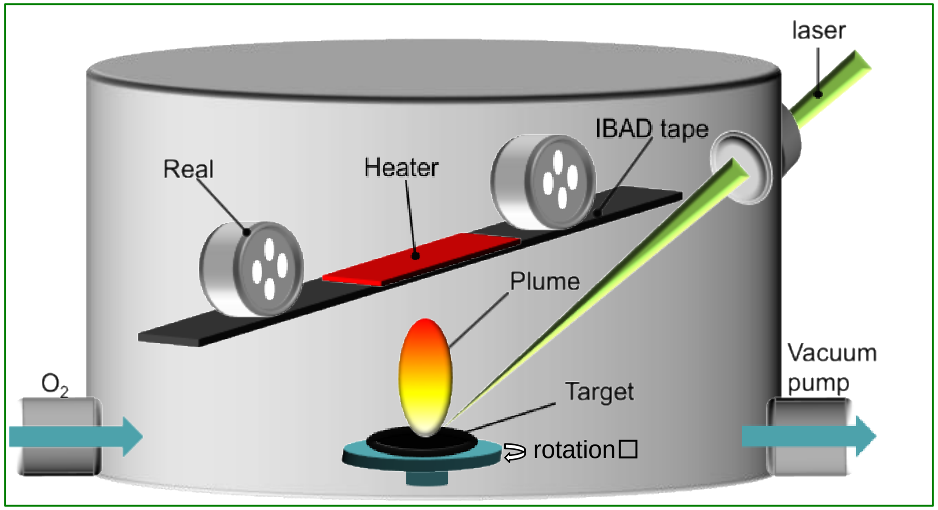
Improvement of the superconducting properties and controlling microstructures of the REBCO coated conductor with BMO nanorods on IBAD tape

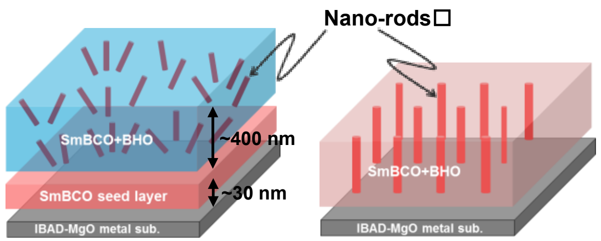
- Improvement of *F*p at 4.2K and 20K of SmBCO+BHO on IBAD tape fabricated LTG
- Growth mechanism and sharp of the BMO nanorods fabricated with the high-speed growth technique



SmBCO+BHO / IBAD tape fabricated by RTR system







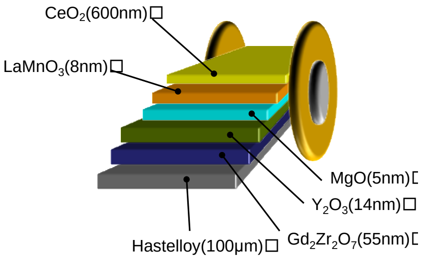
LTG film

Seed growth temp.: 840 ℃

Upper growth temp.: 750 ℃

HTG film

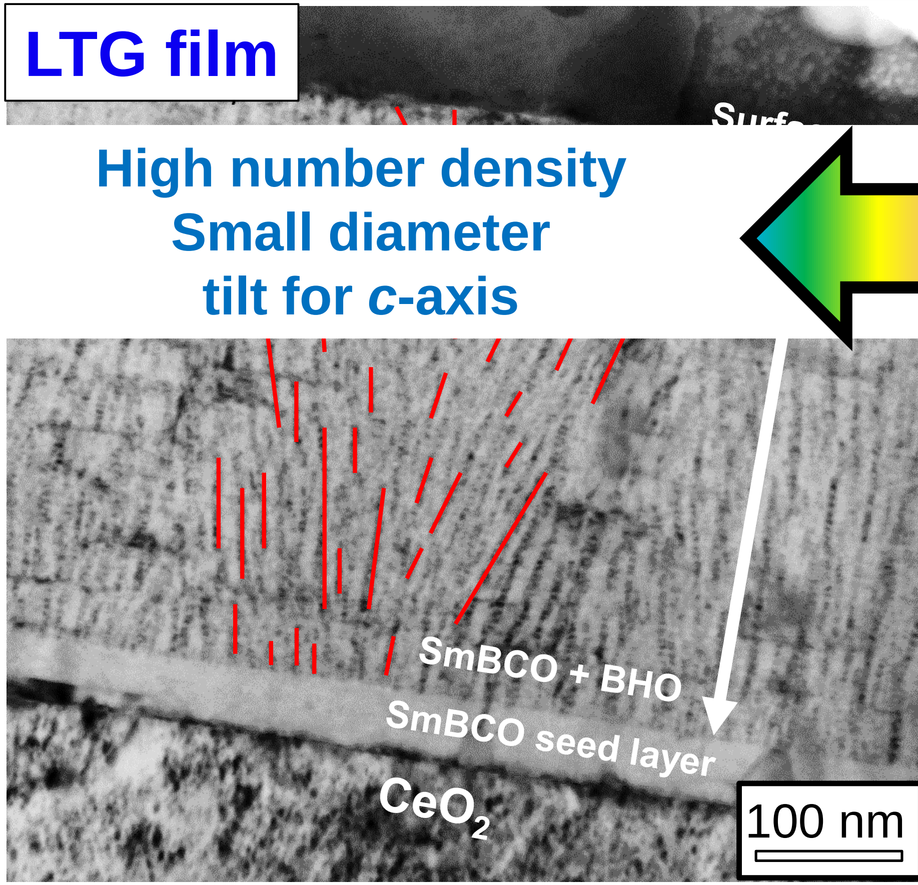
Growth temp.: 840 ℃



parameter	condition
Deposition method	ALT-PLD + LTG
substrate	IBAD-MgO
targets	$SmBa_2Cu_3O_y$
	$BaHfO_3$
O_2 pressure	0.4 Torr
Laser frequency	10 Hz
Energy density	1.7 J/cm^2
Laser source	KrF eximer laser (λ = 248 nm)
BHO content	3.8vol.%
Thickness	240-440 nm
The number of laser pulses in each cycle (SmBCO : BHO)	30 : 5

BHO nano-rods morphology
LTG versus HTG film on IBAD

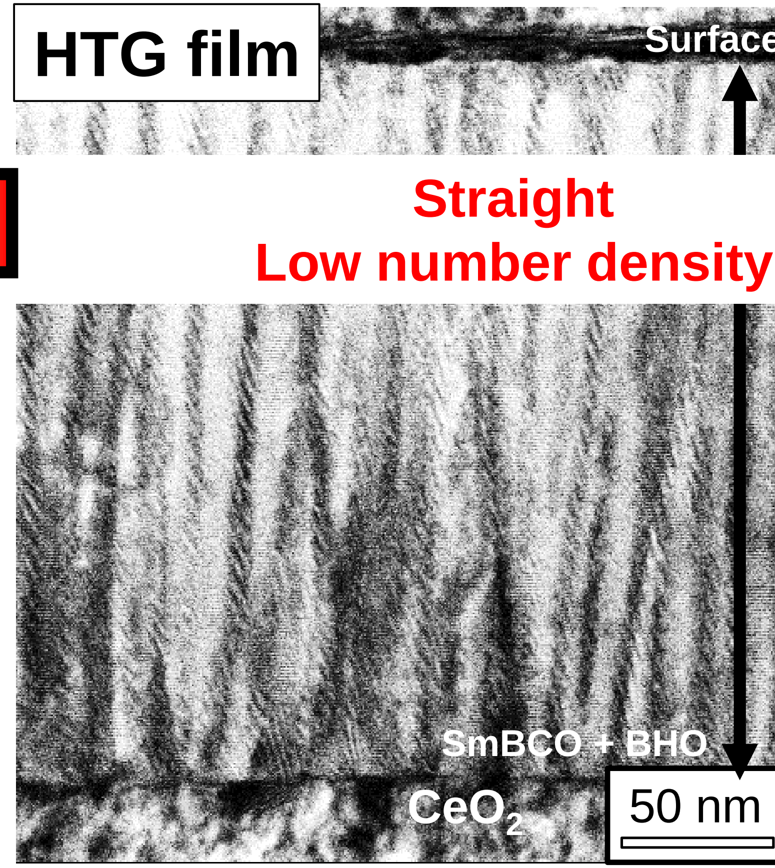
LTG film



High number density
Small diameter
tilt for *c*-axis

Discontinuous
Small diameter ~ 4 nm
<u>Fireworks structure</u>

HTG film



Straight
Low number density

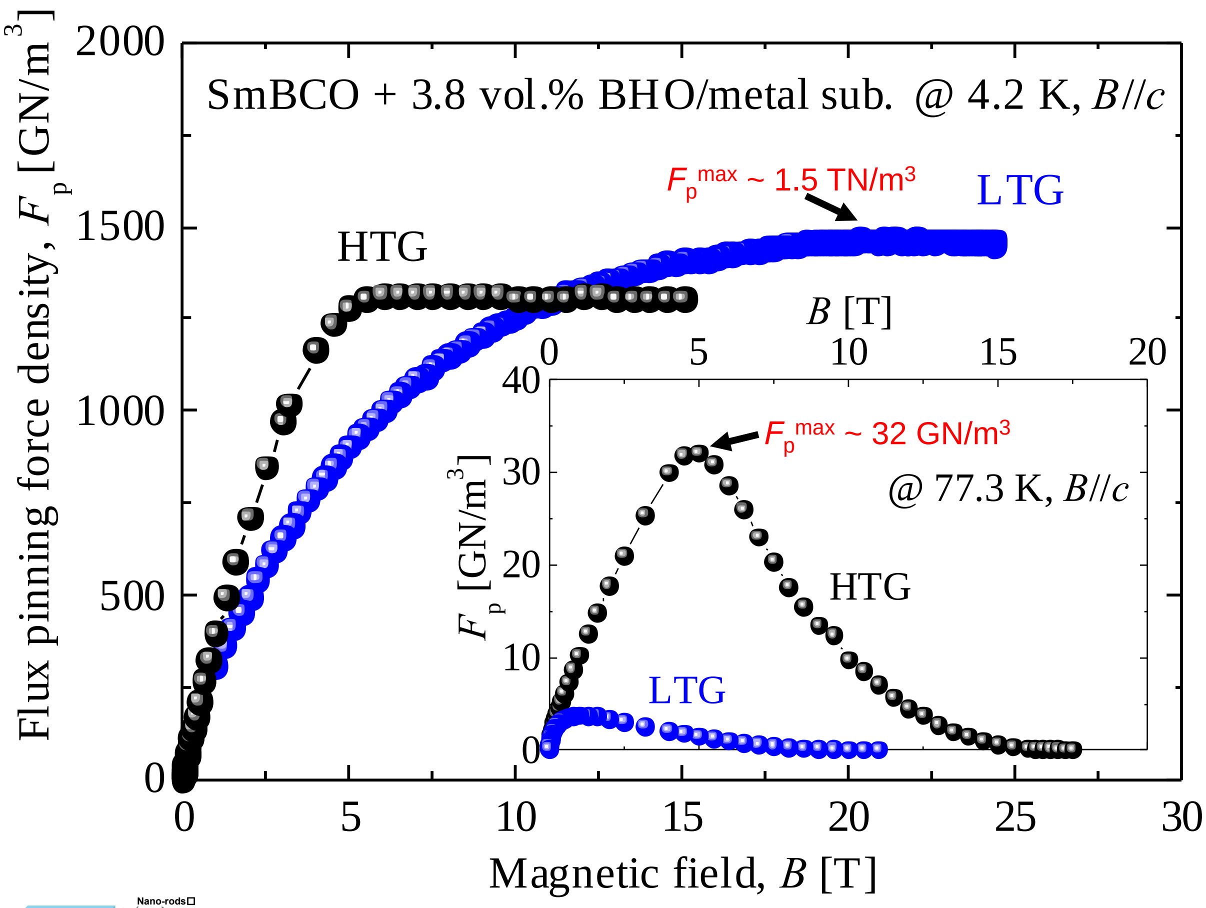
Straight and continuous
Diameter ~ 5.4 nm

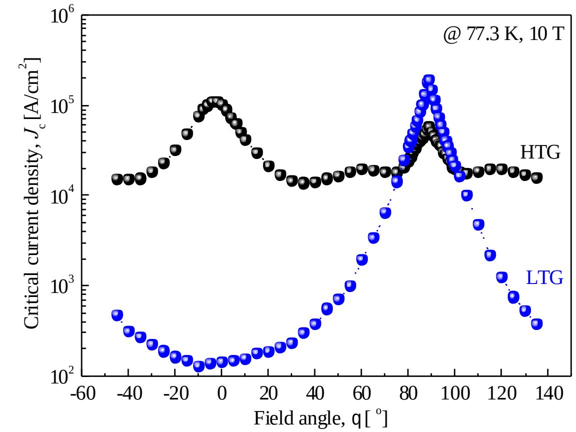
HTG film fabricated at high T_s by PLD (conventional PLD)

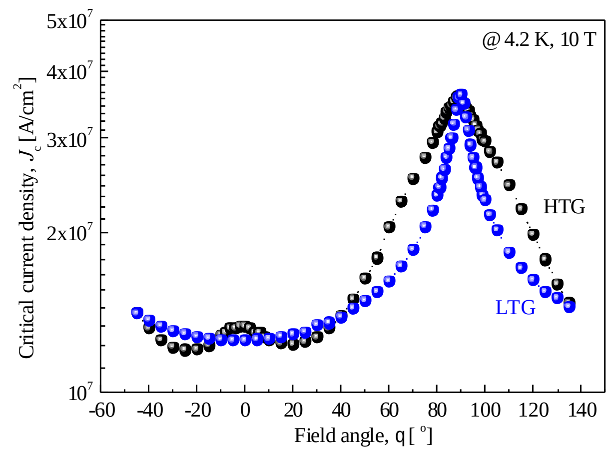
Nagoya University

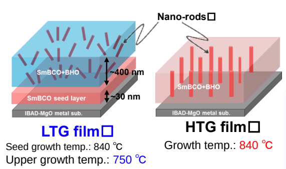
The TEM image on left figure was taken by Mr. Shun Ito at IMR, Tohoku Univ.
The TEM image on right figure was taken by Dr. Ataru Ichinose at CRIEPI.

Flux pinning force and field angle dependence of J_c @ 4.2 and 77.3 K









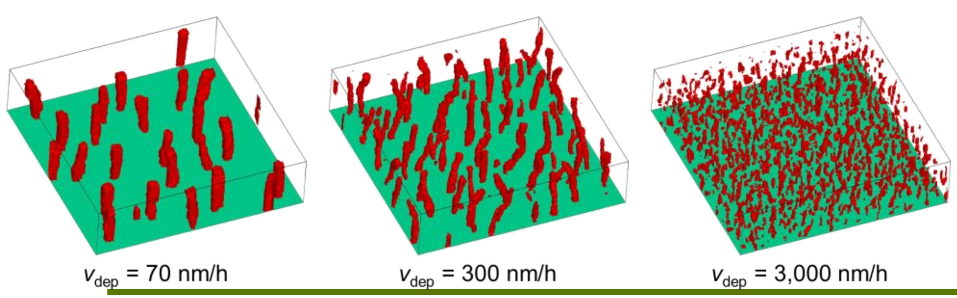
- ✓ HTG SmBCO+BHO on IBAD tape has F_p=32 GN m^{-3} at 77 K
- ✓ F_p at 77K of LTG SmBCO+BHO is low. However, F_p at 4.2K is 1.5TN m^{-3} at 4.2 K.

Main Topics

Improvement of the superconducting properties and controlling microstructures of the REBCO coated conductor with BMO nanorods on IBAD tape

- Improvement of *F*p at 4.2K and 20K of SmBCO+BHO on IBAD tape fabricated LTG
- Growth mechanism and sharp of the BMO nanorods fabricated with the high-speed growth technique

Growth rate□

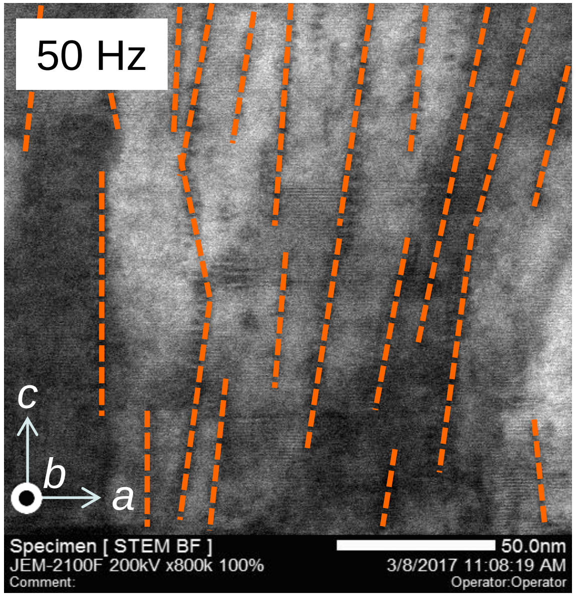


Simulation results

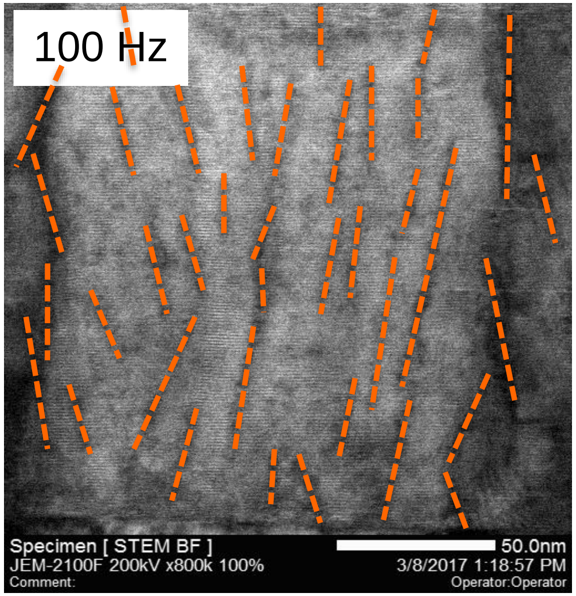
BHO Nano rod
high growth rate⇒ Miniaturization of nanorod

Y. Ichino IEEE Trans. Appl. Supercond., 27,4, 2017, 7500304.

The growth direction of the BHO nanorods by plotting a histogram of the inclination angles using High-speed growth technique

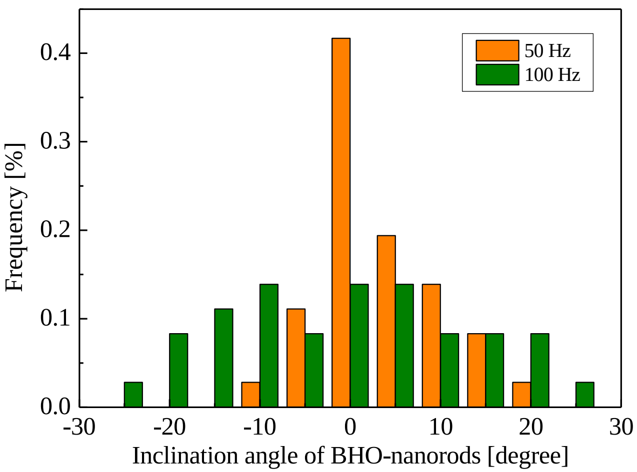


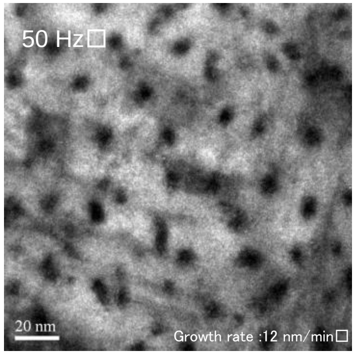
Growth rate :12 nm/min

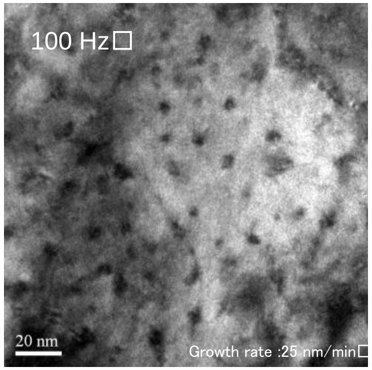


Growth rate :25 nm/min

BHO3.0vol.%-added SmBCO on IBAD-MgO
(Energy density:1.4 J/cm²)







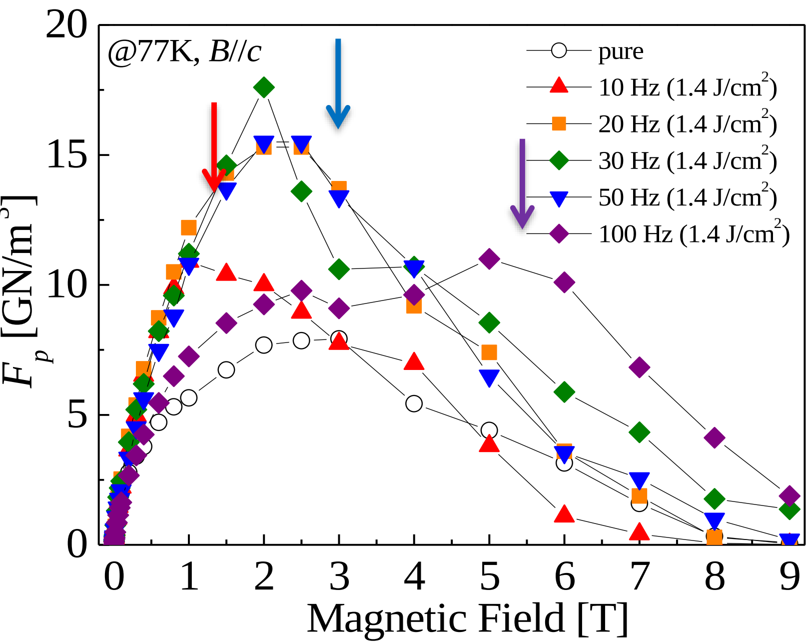
	50 Hz	100 Hz
Thickness of nanorod	4 ~ 6 nm	3 ~5 nm
density	2188 /μm	3281 /μm
B_{φ}	4.52 T	6.78 T

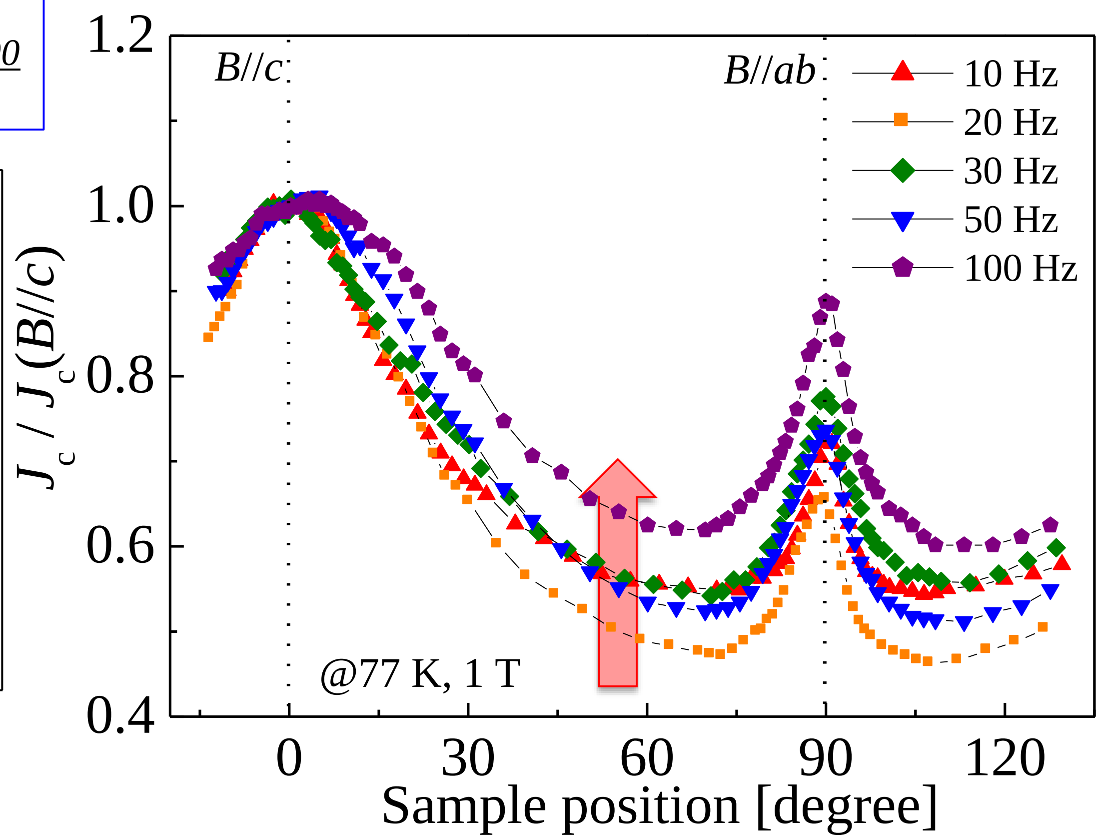
cf : 100 Hz Pure SmBCO
Growth rate : 100 nm/min

thinner diameter, higher number density, tilted

F_p and Field angle dependence of J_c of the SmBCO+BHO on IBAD by High-speed growth technique

- ✓ *We will describe the development of the coated conductor fabricated with a repetition rate of 100 Hz, changed from 10 Hz.*





- ✓ As increasing laser frequency, J_{cmin} of the SmBCO-coated conductor fabricated by high-speed growth was higher than the SmBCO-coated conductor by conventional speed growth.

Summary

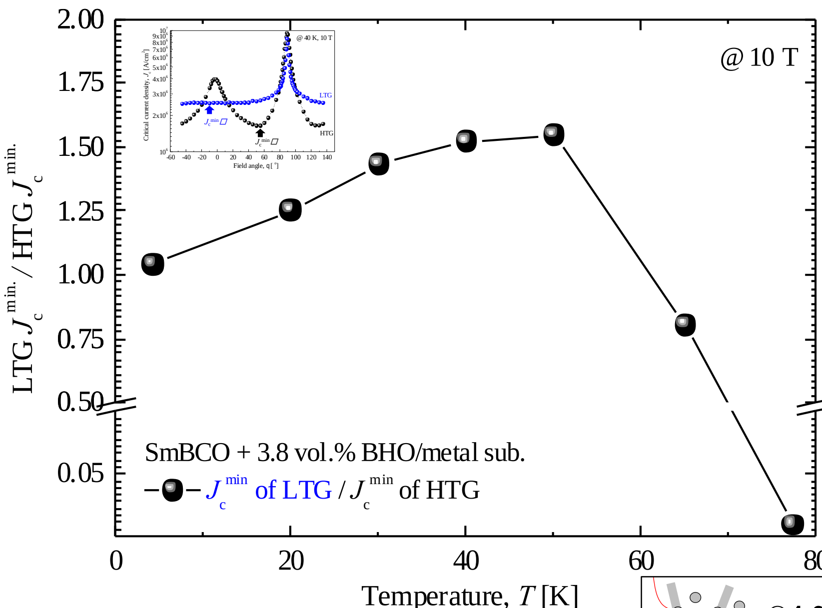
For the high J_c coated conductor, we have investigated the relationships among changing of T_c, J_c and B_{irr}, growth temperature, the variety of BMO materials, its amount of additive, the kind of substrate, the surface morphologies et.al.

- Using the low temperature growth technique with the seed layer, we can design and control the higher density and fine BHO nanorods grown in high quality SmBCO film, as changing lower substrate temperature.
- Higher F_p at 10K and 4.2K at optimum T_s and BMO volume. F_p at 77K of LTG SmBCO+BHO is low. On the other hand, F_p at 4.2K is 1.6TN m^{-3} at 4.2 K.
- LTG SmBCO+BHO on IBAD−MgO tape has F_p=260 GN m^{-3} at 40 K, 690GN m^{-3} at 20 K, and 1.5 TN m^{-3} at 4.2 K, respectively.

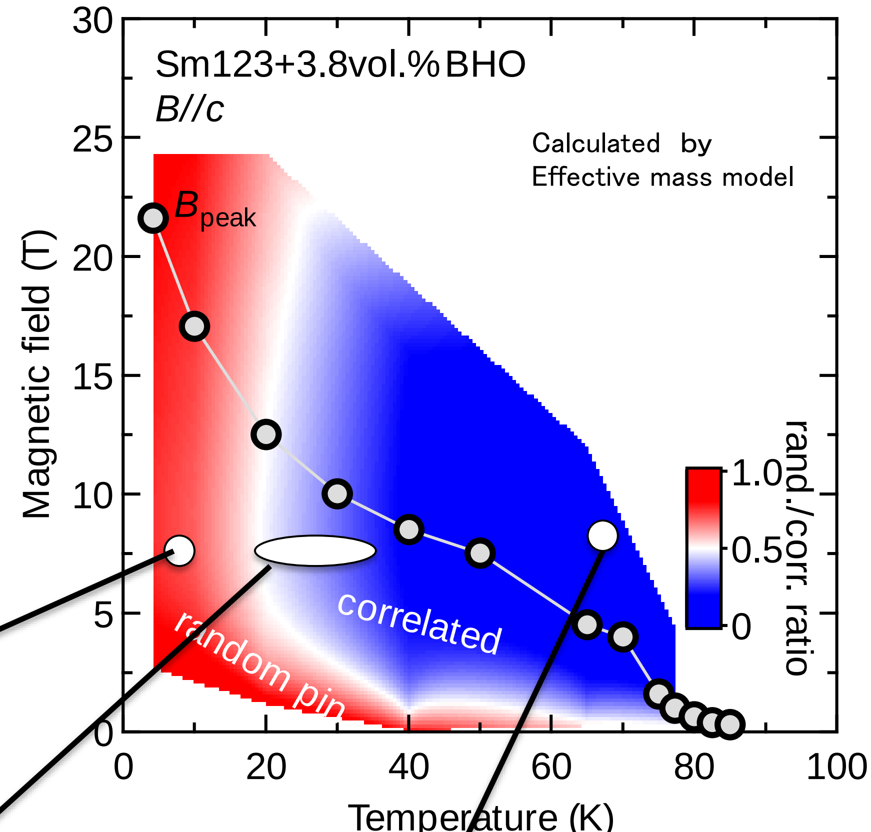
●The high-speed growth technique for high performance SmBCO coated conductor is an important subject. In this presentation, we described the development of the coated conductor fabricated with a repetition rate of 100 Hz, changed from 10 Hz. We discussed the details of microstructures and superconducting properties of BHO nanorods in SmBCO coated conductor using the laser system with high repetition rate.

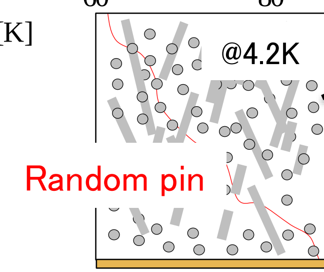
Thank you for your attention

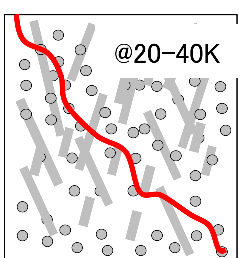
Field angle dependence of J_c and the pinning phase diagram of the ratio of J_c^{rand} to the total J_c as a function of the magnetic field and temperature



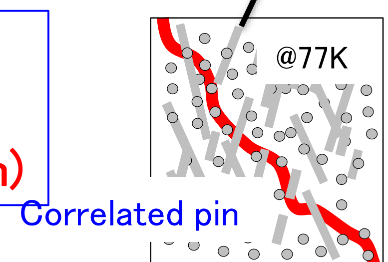
The range at 20-40K is advantage using LTG sample

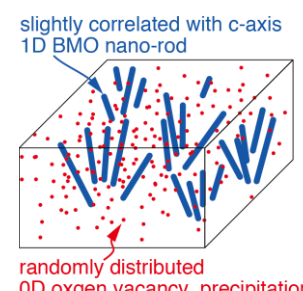




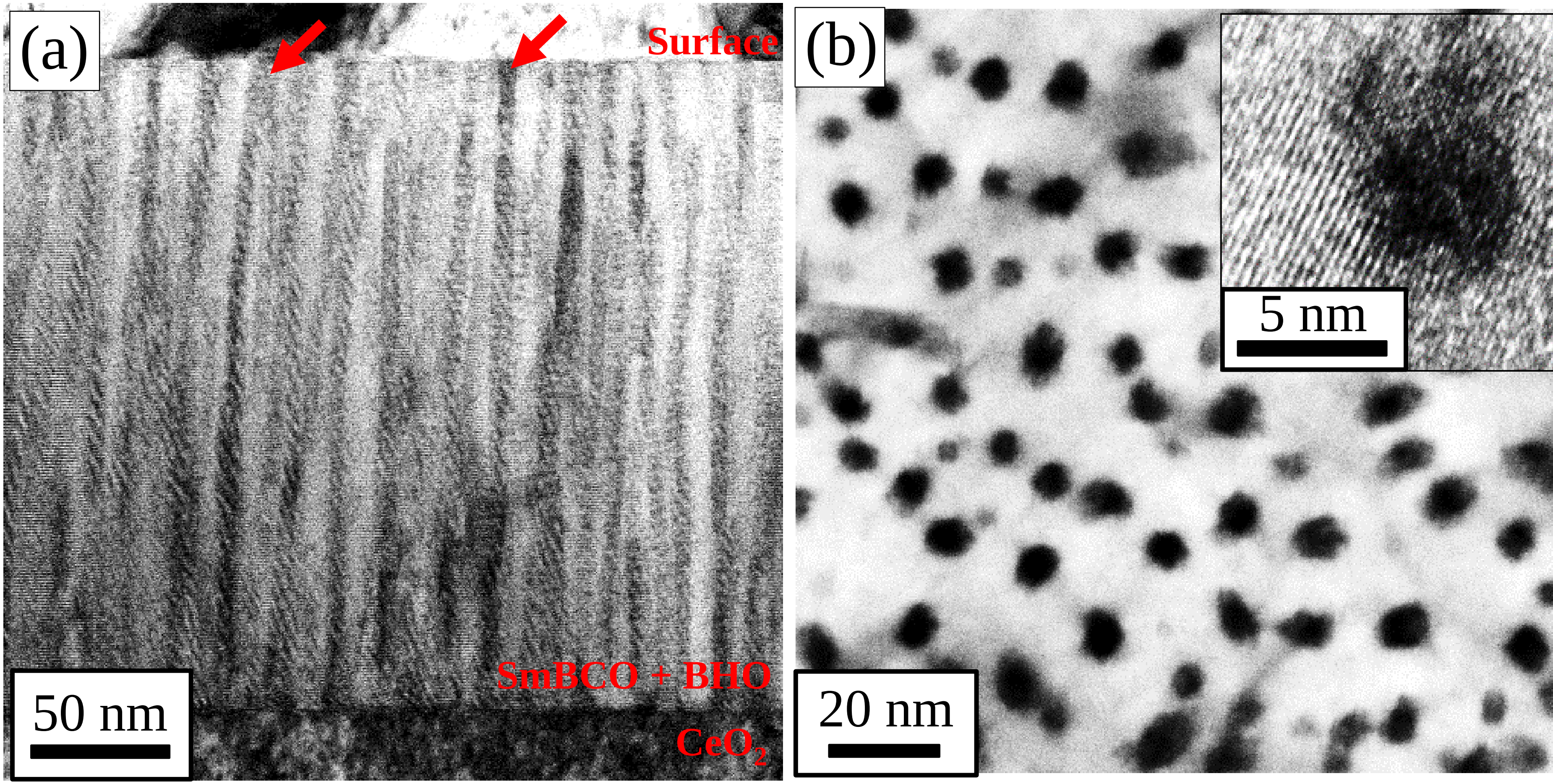


***Double* type pin**
(cooperated by
Random/correlated pin)





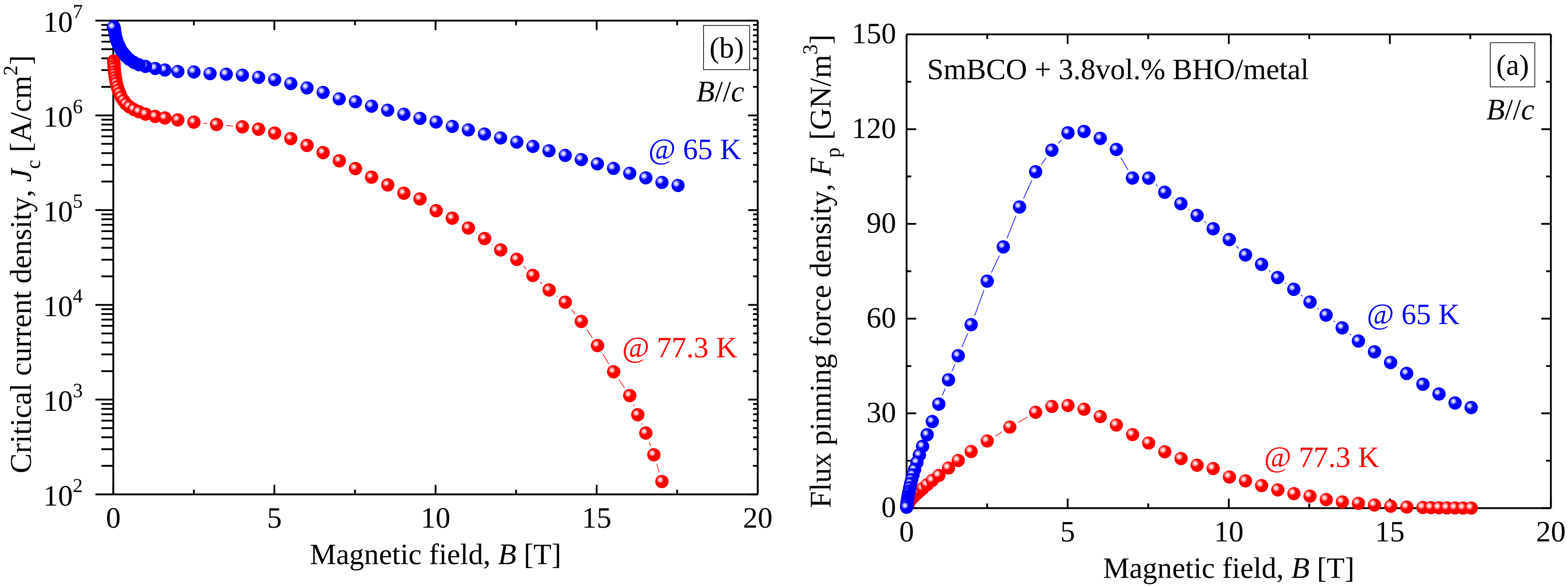
TEM images of the HTG SmBCO



d_{BHO} [nm]	n_{BHO} [$\times 10^3$ µm^{-2}]	B_ϕ [T]	FWHM [°]
5.4 ± 0.9	2.8 ± 0.1	5.8±0.3	1.1

straight-shaped BHO nanorods grow from the bottom to the surface.

J_c–B and F_p of the HTG-SmBCO+BHO on IBAD



- The J_c at the self-field are 8.4 MA/cm^2 and 3.5 MA/cm^2 at 65 K and 77.3 K
- The maximum F_p values of 120 GN/m^3 and 32.5 GN/m^3 were obtained at 65 K and 77.3 K.