Remarkable Improvement of In-field Performance in REBCO Coated Conductors

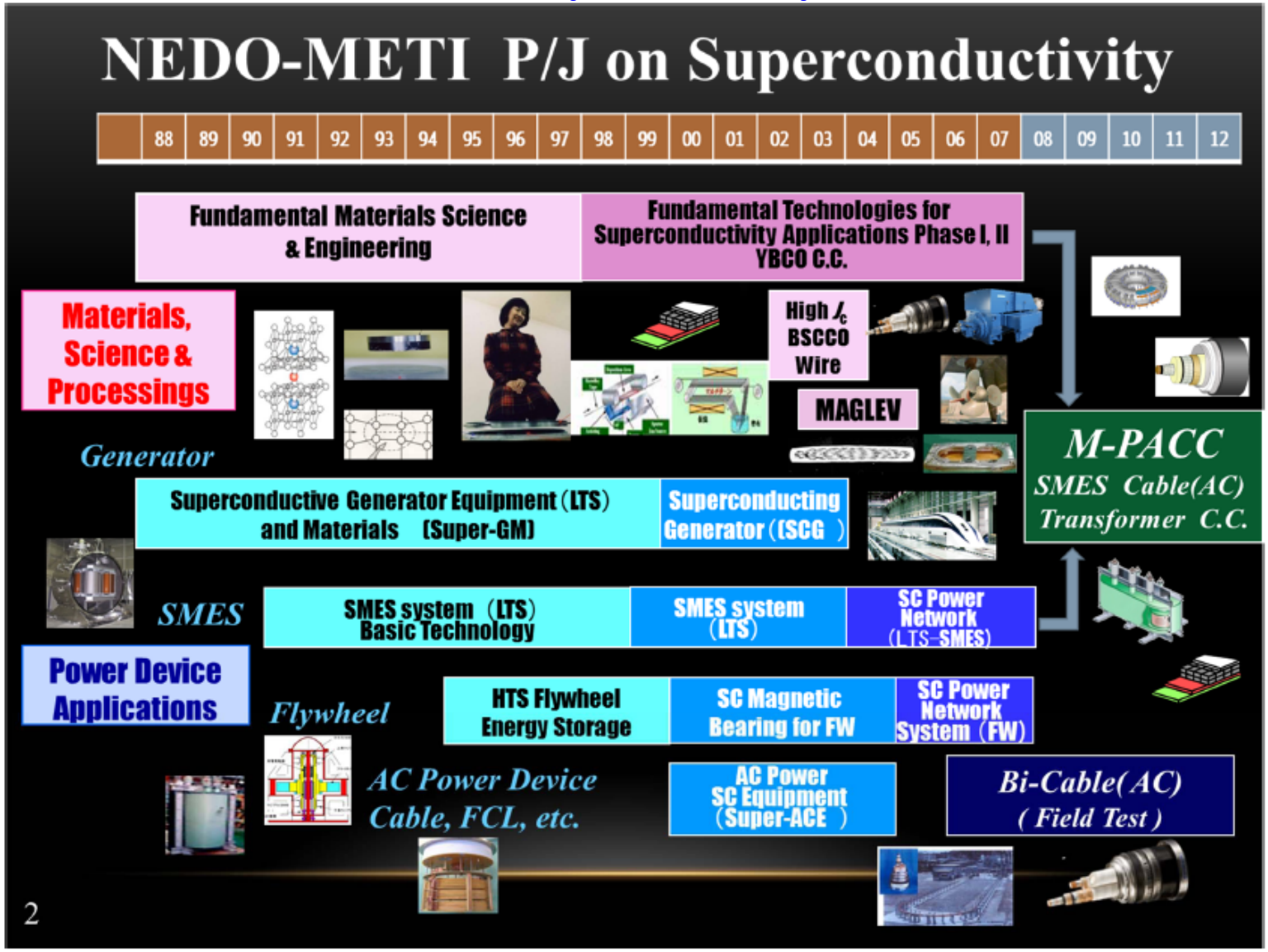
Teruo IZUMI[1,2]

T. Yoshida[1,2], A. Ibi[1,2], T. Nakamura[1,2], K. Kimura[2,3],
M. Yoshizumi[1,2], T. Kato[4], Y. Shiohara[1,2]

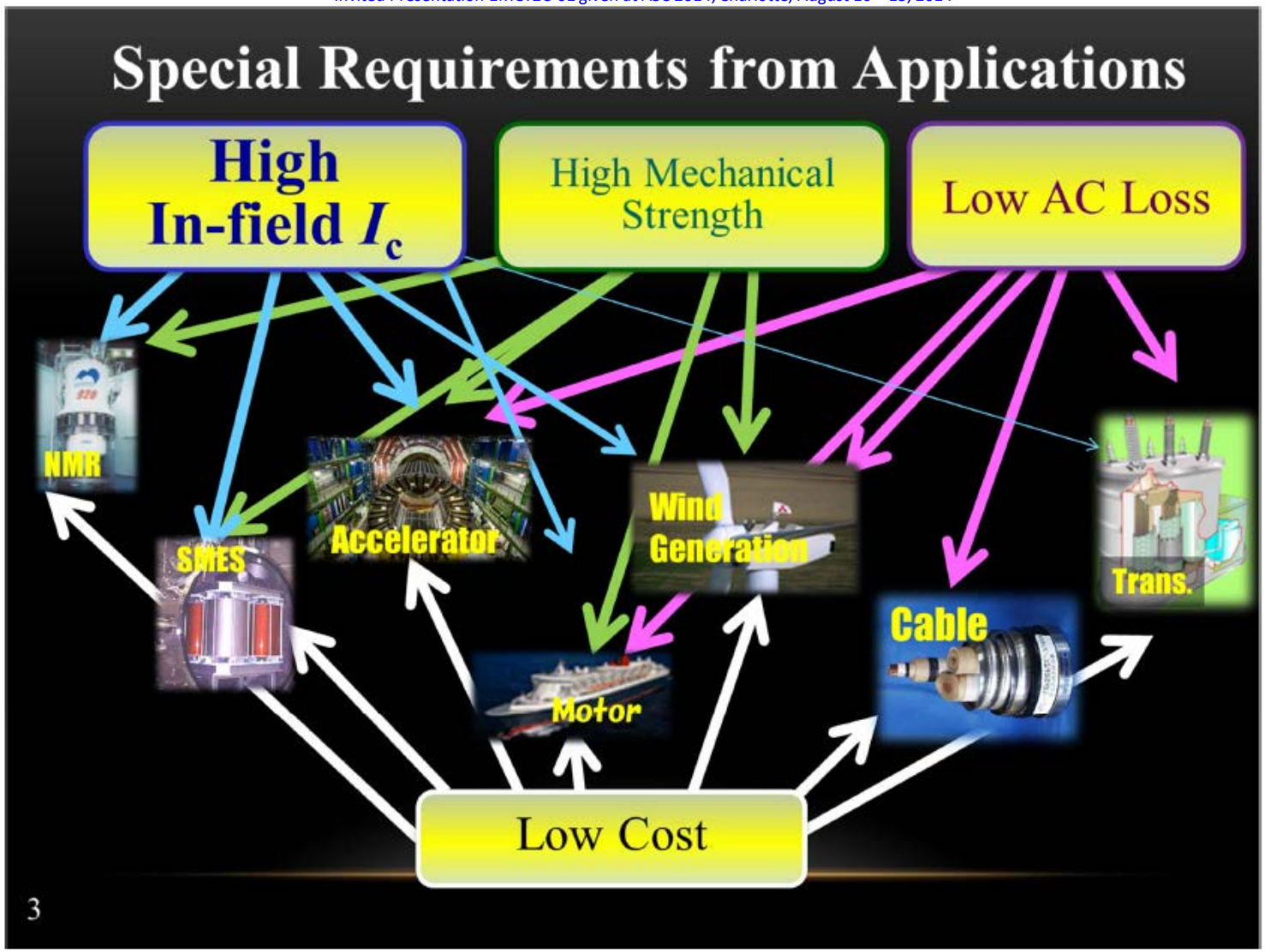
1International Superconductivity Technology Center,
2IndustrialSuperconductivity Technology Research Association
3SWCC Showa Cable Systems Co. Ltd.
4Japan Fine Ceramics Center

1

Annotation: ASC2014 Monday, August 11, 2014 1MOr2C-01 [Invited]



Annotation: After several national projects in Japan, the M-PACC project was started.
In this project, some small scale demonstrations of electric power devices such as SMES, cable and transformer using CC were developed.
In parallel, R&D of CC was also continued as one theme of this project.

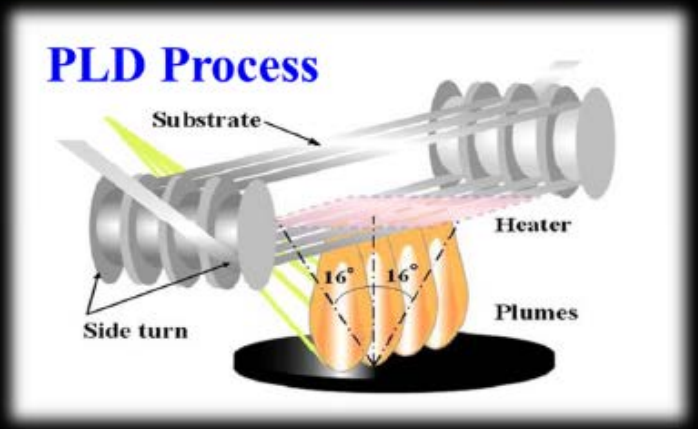


Annotation: In the R&D of CC in the M-PACC project, we made efforts to satisfy the special requirements from the applications such as "High in-field Ic", "High mechanical strength", "Low AC loss", "Low cost" etc. In all fields, marvelous progresses has been achieved.
In this paper, those for "High in-field Ic" will be shown.

Improvement of In-field I_c in IBAD-PLD C.C.

(High Performance Type)

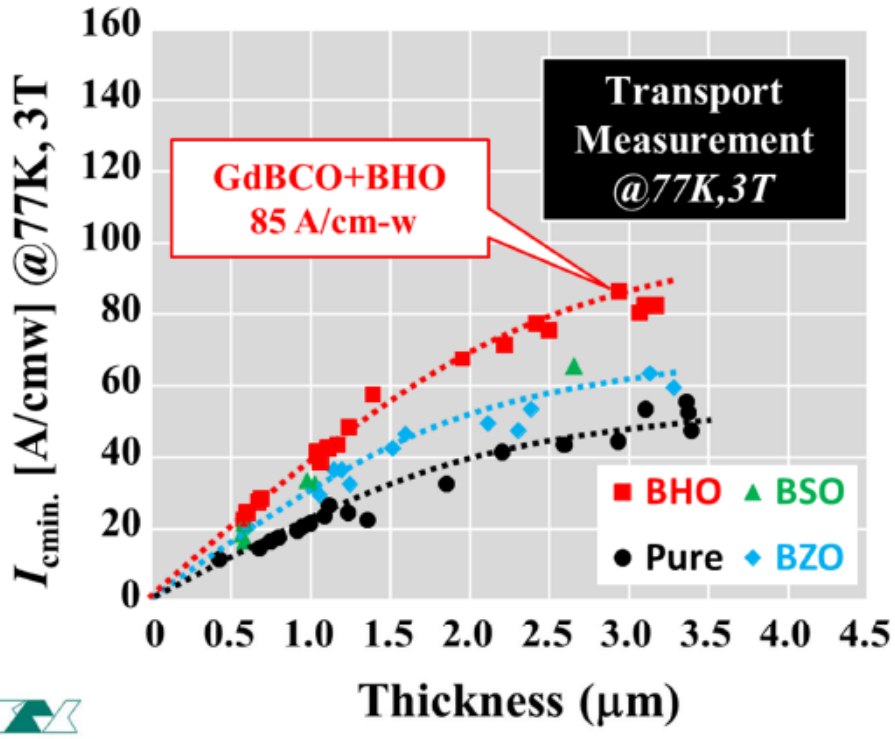
PLD-REBCO
Epitaxial CeO_2
IBAD –MgO etc.
Untextured Metal Hastelloy™



4

Annotation: ASC2014 Monday, August 11, 2014 1MOr2C-01 [Invited]

Effective APC Materials for IBAD-PLD C.C.

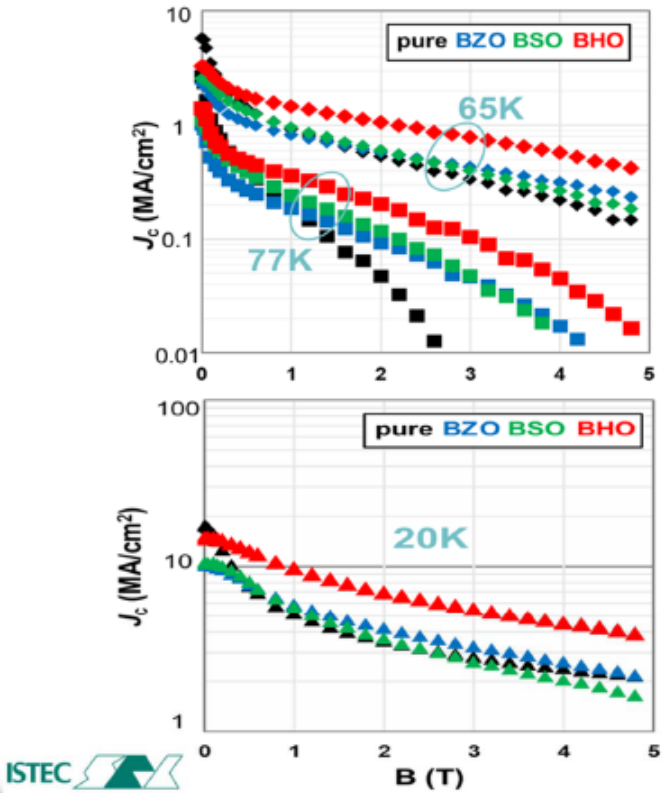


5

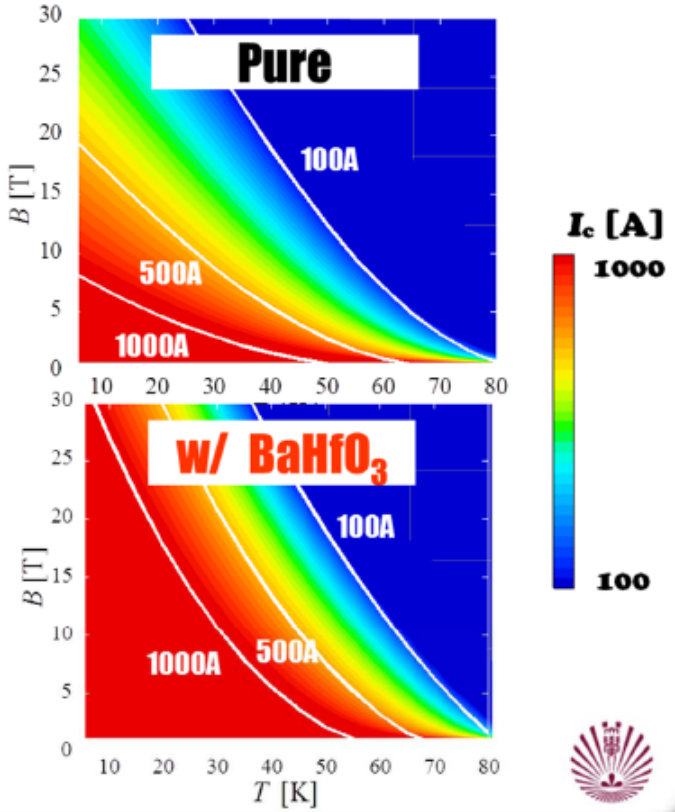
Annotation: Clear improvement in the Ic(B) performance due to the additions of BZO & BSO can be confirmed.
However, the Ic(B) values become saturated with increasing thickness.
It was found that the above tendency was suppressed by using BaHfO3 as an APC material.

I_c-B-T in BHO doped IBAD-PLD GdBCO C.C.

Comparison with other BMO

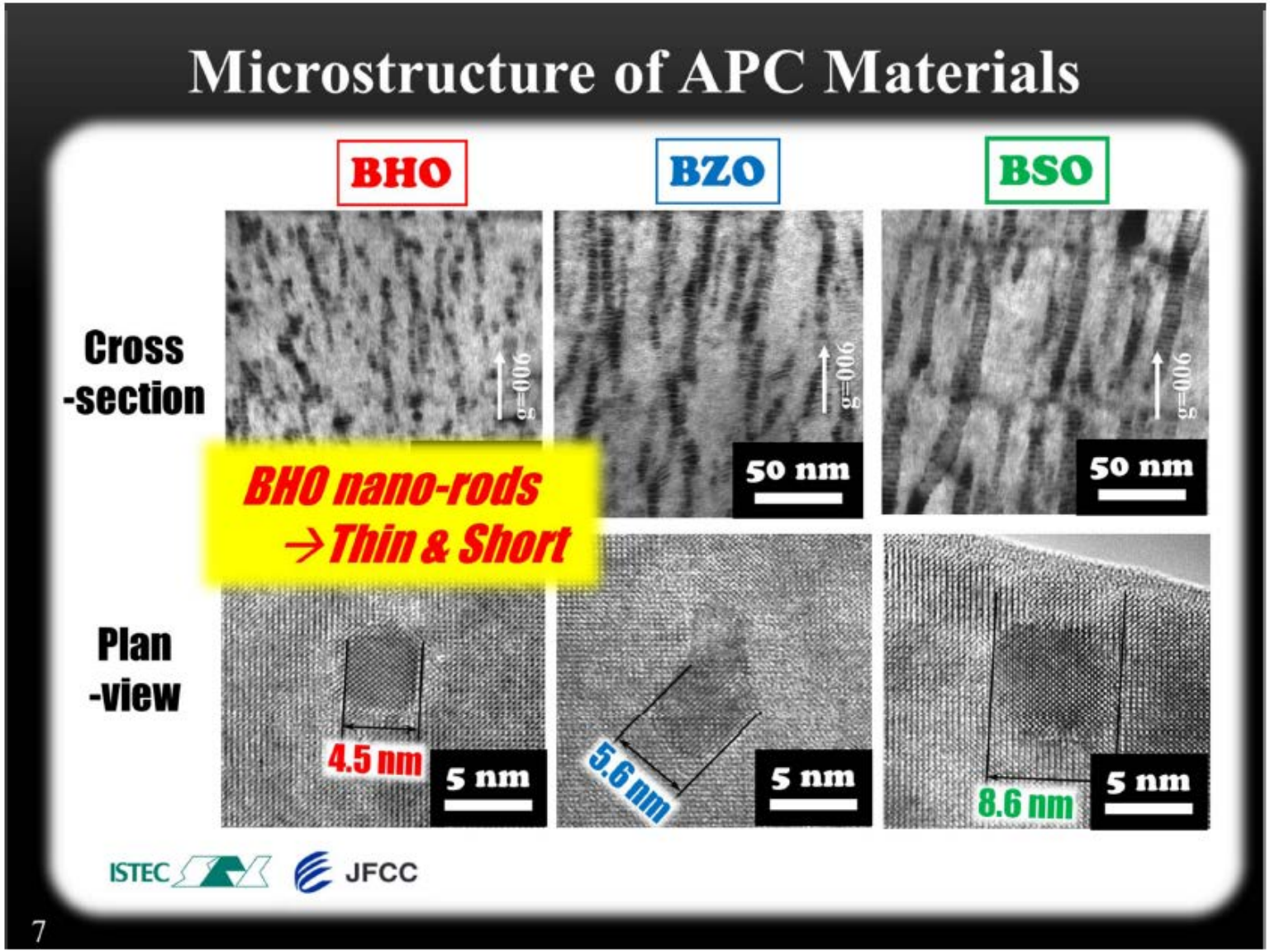


I_c – B – T Mapping Image



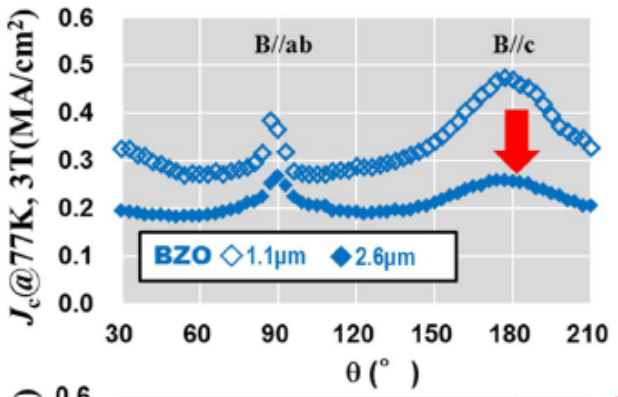
6

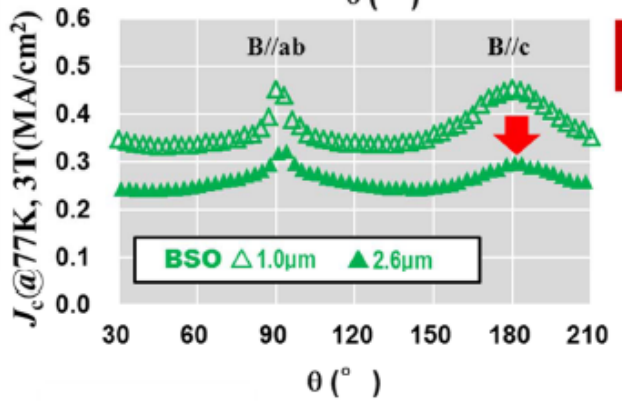
Annotation: The BHO addition has several desirable features.
One of them represent the advantageous Ic(B) properties for a wide range of temperatures and magnetic fields.



Annotation: The observation of the microstructure tells us one reason for the higher Ic(B) performance: The diameter of the BHO rods is smallest and shortest.

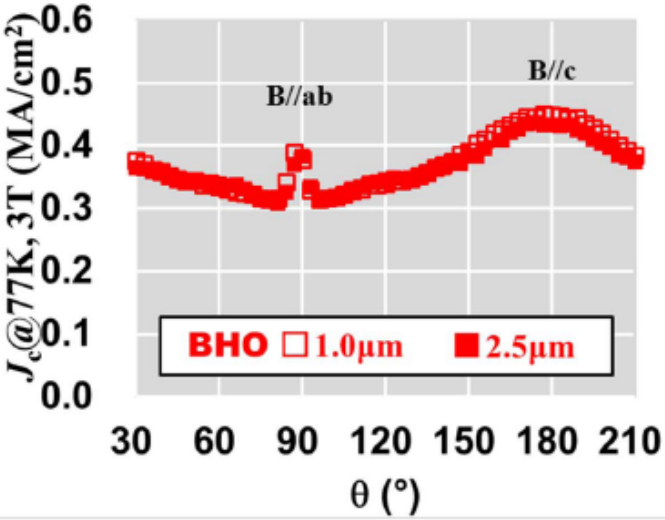
Thickness dependence of J_c-(B)-θ





ISTEC

Transport Measurement

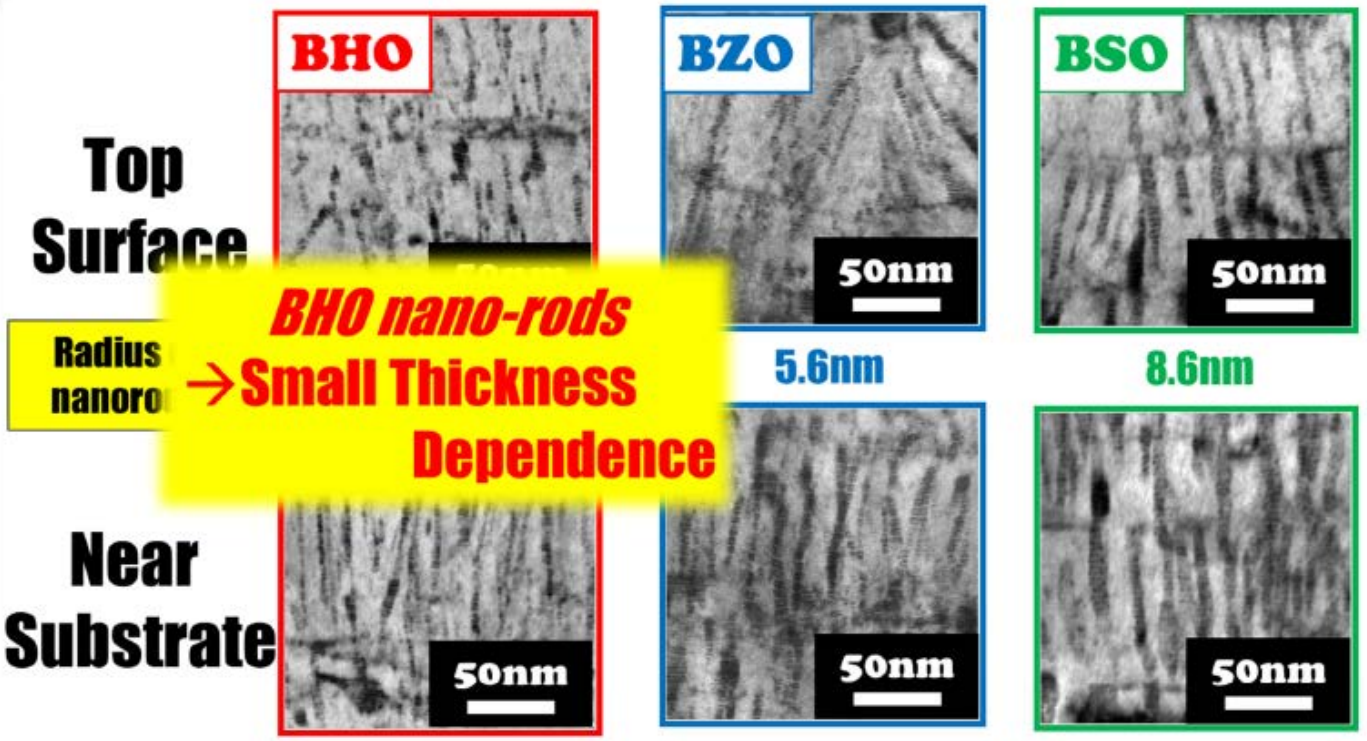


Similar J_c-(B)-θ profiles in BHO doped films even with different thicknesses

8

Annotation: Another desirable feature is the performance in thick films.
There is no difference between the Ic-B-theta properties of thin and thick films for the BHO addition.

Thickness Dependence of Microstructure

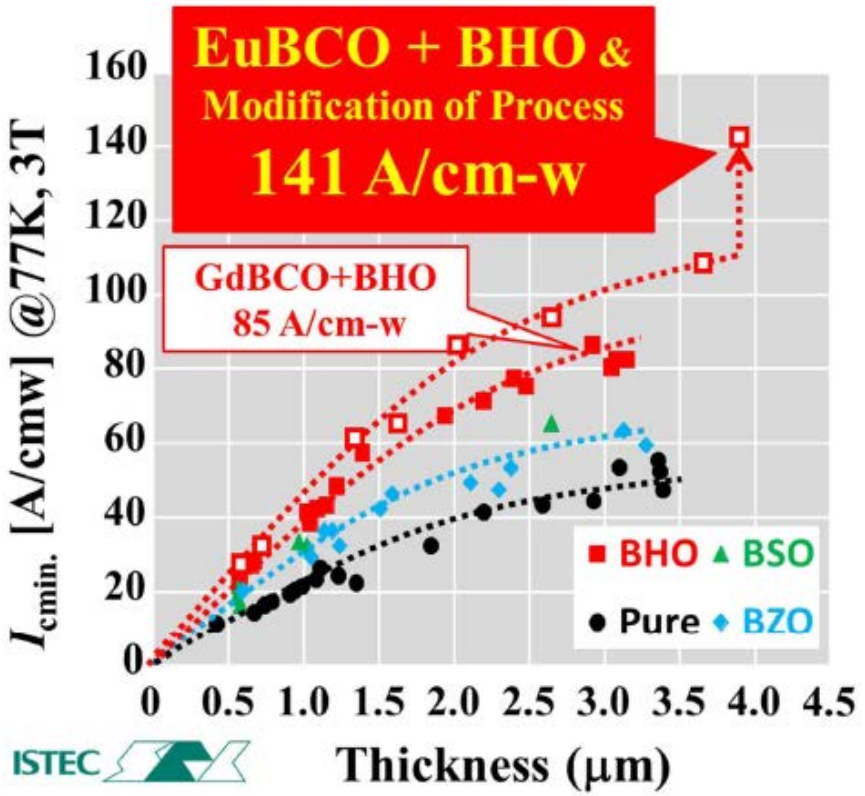


ISTEC JFCC

9

Annotation: The films with BHO addition have a special feature of their microstructures. It is the small thickness dependence of the nano-rod structures for BHO additions.

Further Improvement of In-field I_c for IBAD-PLD C.C.



I_c Values of EuBCO + BHO

	3 T	10 T
77 K	141	
65 K	616	
50 K	1400	500
30 K	2730	1180
20 K		1630

(A/cm-width)

10

Annotation: Most recently, we found that a new combination of EuBCO and BHO is even more effective to suppress the degradation of the in-field Jc with increasing thickness.
The Ic value of 141A/cm-width @ 77K and 3T, which is the highest value in the world, was obtained.

What can be expected in MRI ?

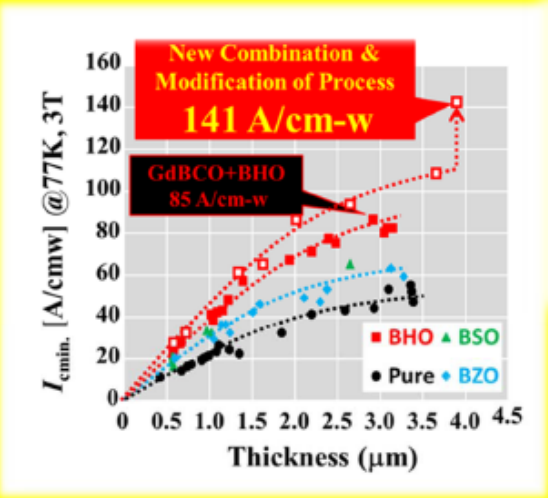
Conductor Specification for 3T-MRI :

(From conceptual design of Prof. Fukuyama for BSCCO @ 20K 3.6T)

BSCCO: I_{op}=185A@3.6T *Load Factor* =0.77 S=4.5x0.3mm^2

$\Rightarrow$ I_c = 185/0.77 x (10mm/4.5mm) = **534 A/cm-w**

Estimation of Operation Temperature:



141 A/cmw@77K,3T

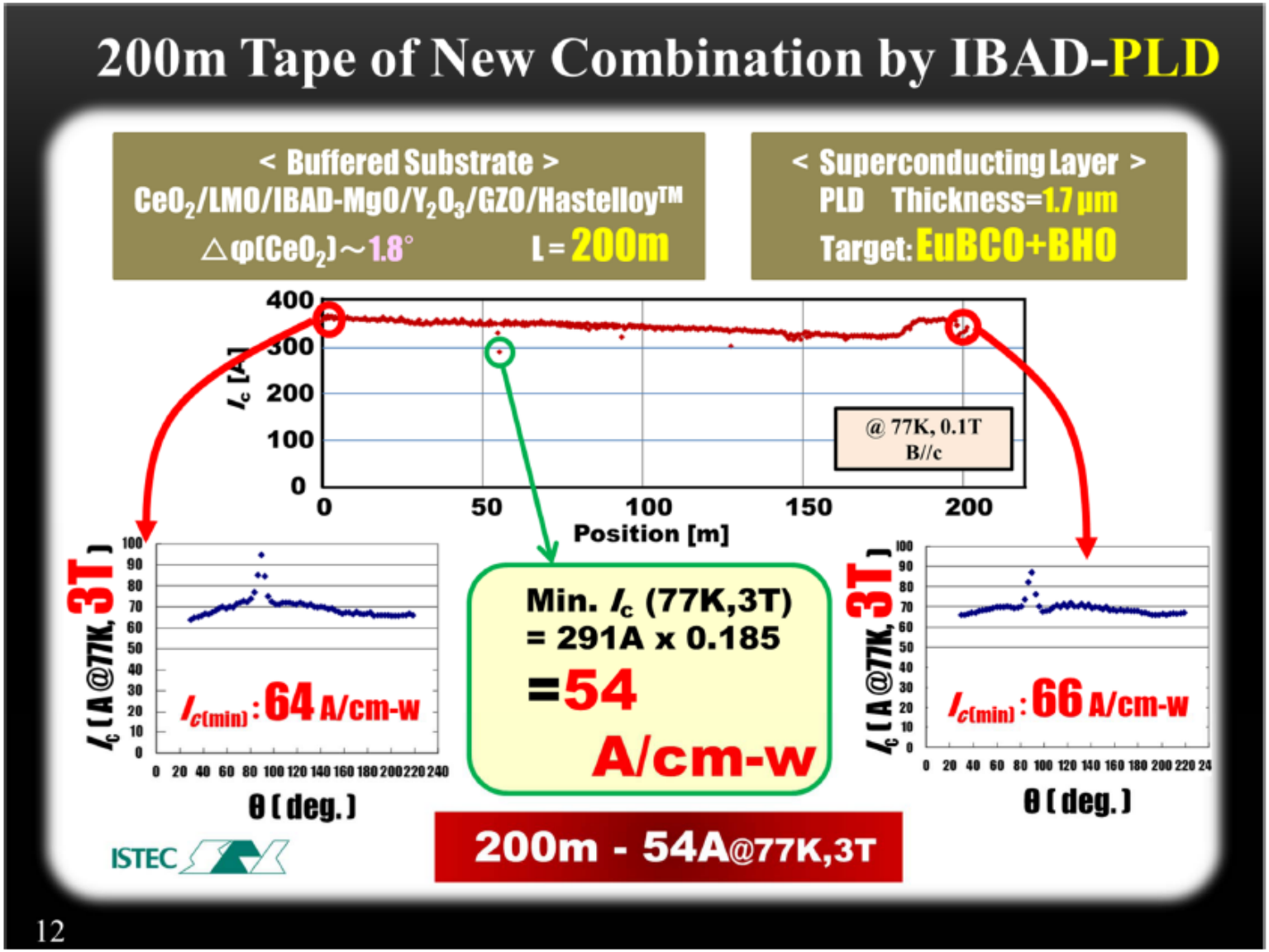
$\Rightarrow$ **527** A/cm-w

@65K,3.6T

3T-MRI in Liq. N_2

11

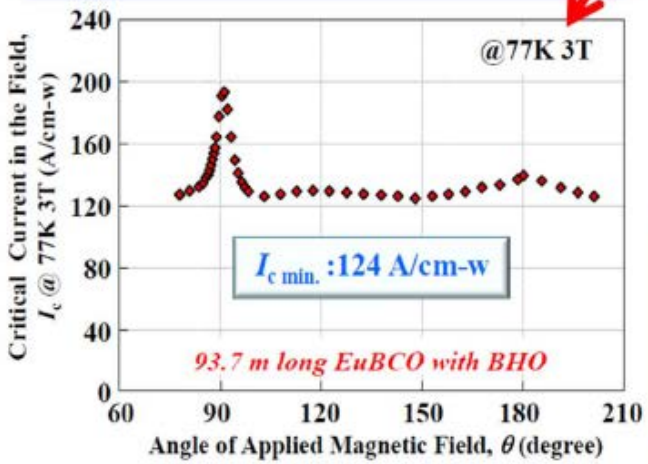
Annotation: According to the progress in the EuBCO+BHO, it can be expected that the 3T-MRI can be operated in Liq. N2 by utilizing this performance.

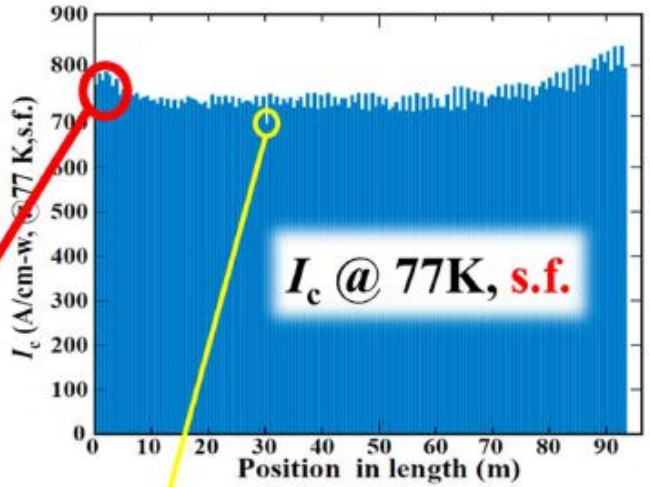


Annotation: The new combination of EuBCO+BHO was applied to long tape processing.
A reasonably high and uniform performance was confirmed in a 200m long tape.

Higher I_c(B) Performance in Long Tapes

94m long C.C. with *Thick* EuBCO + BHO film (3.6 μm)





I_c = 780 A/cm-w (77 K, s. f.)

↓

$I_{c\ min.}$ =108A/cm-w (77 K, 3 T)

Estimation

$I_{c\ min.}$ > **500** A/cm-w (65K, 3 T)

ISTEC

13

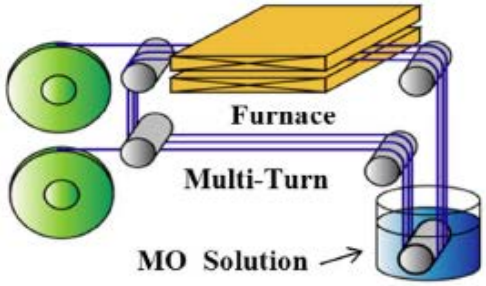
Annotation: The thickness of the film in the long tape was enlarged in order to improve the in-field Ic value.

Improvement of In-field I_c in IBAD-MOD C.C.

(Low Cost Type)

MOD-REBCO
Epitaxial CeO_2
IBAD –MgO etc.
Untextured Metal Hastelloy™

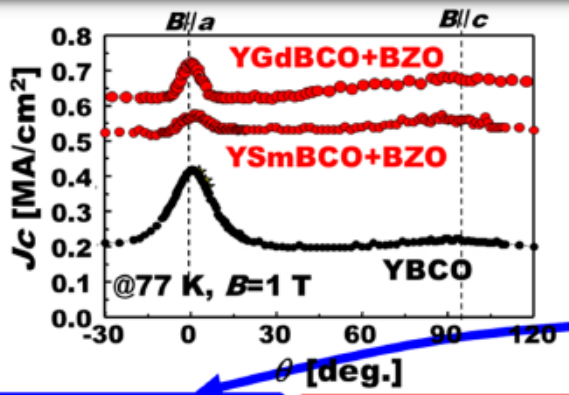
TFA-MOD Process

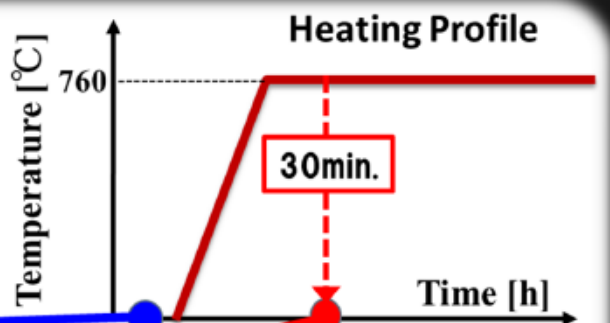


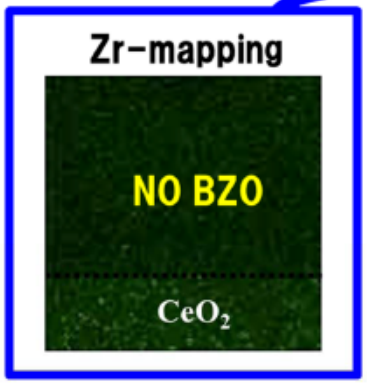
14

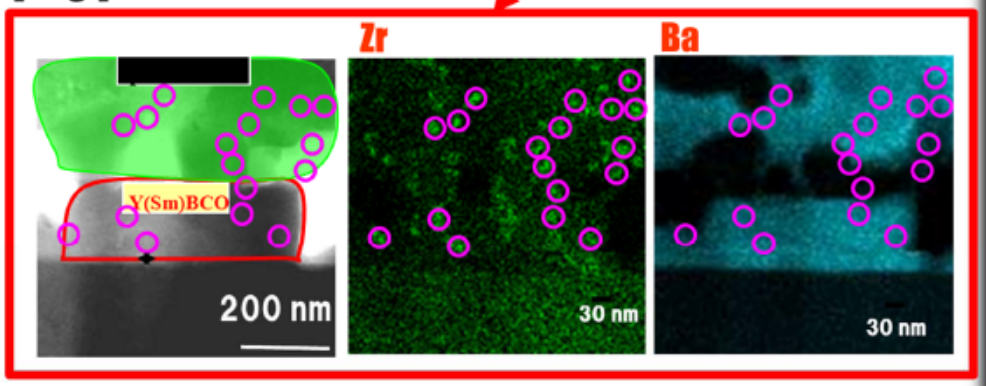
Annotation: ASC2014 Monday, August 11, 2014 1MOr2C-01 [Invited]

Improvement of In-field Performance (BZO nano-dots in IBAD-MOD YREBCO)









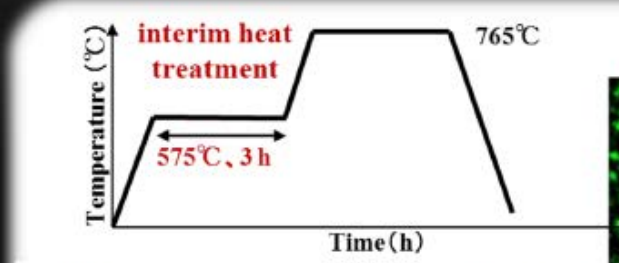
ISTEC JFCC

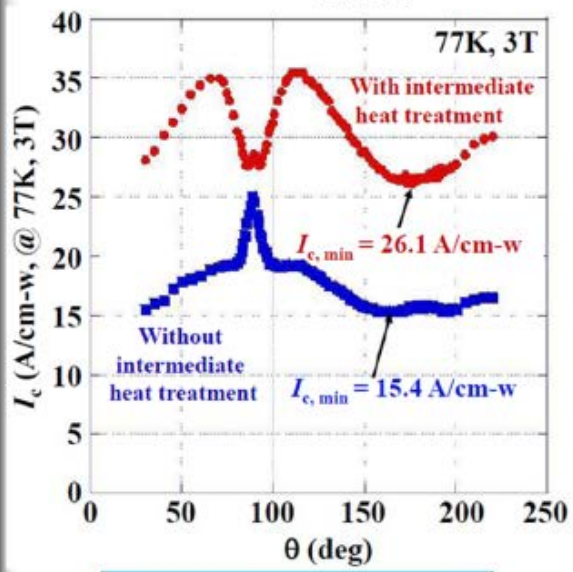
Formation of BZO in the film before crystallization of YREBCO phase

15

Annotation: The introduction of BZO particles was also successfully employed for the MOD process, and the Jc(B) performance could be improved.
In order to realize higher Ic(B), the films were quenched during a heat treatment and the microstructure was observed.
The analysis tells us that the BZO was crystallized before formation of the superconducting phase.

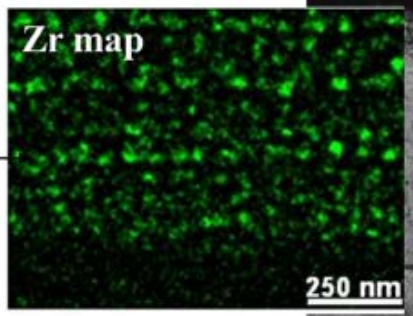
Effect of Interim Annealing in TFA-MOD Process for Size & Dispersion Control of BZO Particles

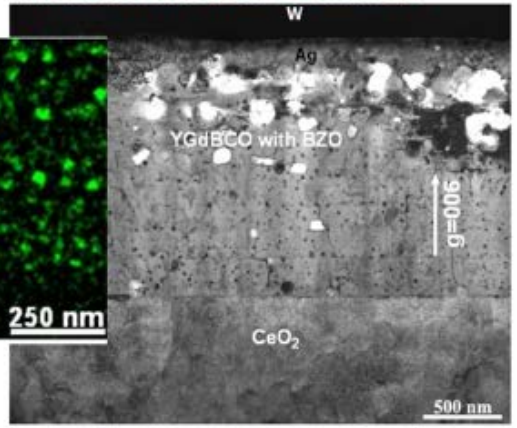




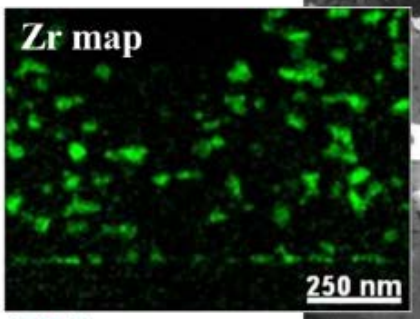
I_c - B - θ properties

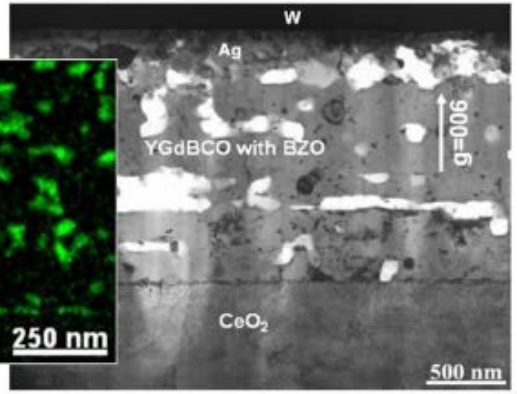
With interim heat treatment





Without interim heat treatment





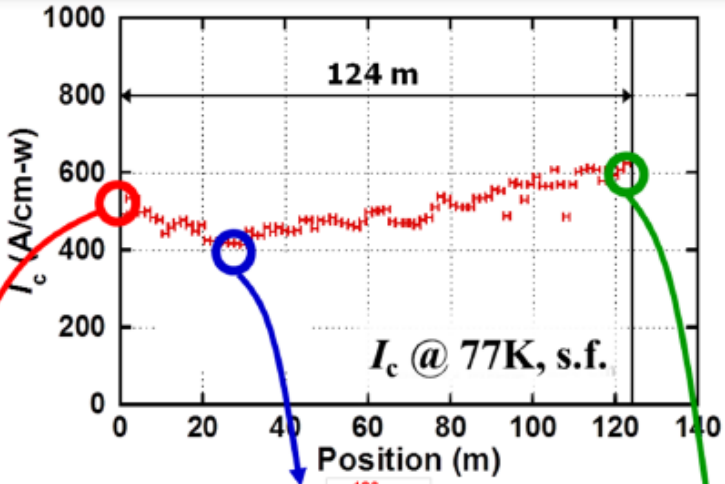
ISTEC

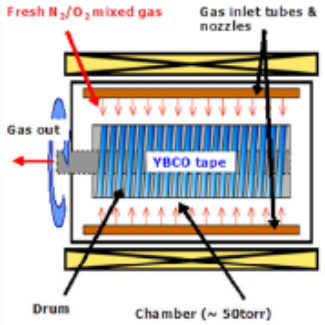
16

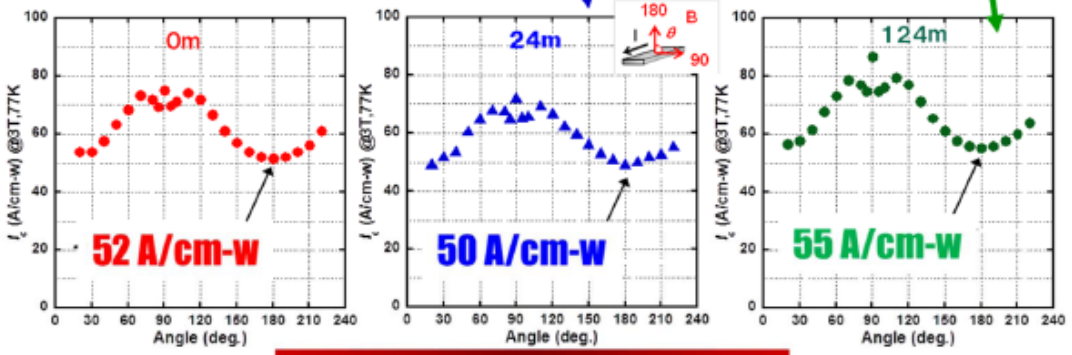
Annotation: Through the investigation of the influence of the heating pattern on the in-field performance, it was found that the addition of the interim annealing step is effective to improve the Ic(B) performance through the finer and well-dispersed BZO particles.

Long Tape Fabrication of IBAD-MOD with APC

Length : ~124m
Superconducting Layer : YGdBCO+BZO (20mML)
Thickness : 2.5μmt
Interim Annealing : Yes
Furnace : Batch Type







124m-50A@77K,3T

17

Annotation: The new finding was applied to the long tape fabrication of MOD process, and reasonable high in-field Ic values over 50A/cm-width @ 77K & 3T were confirmed in the long tape.

Comparison & Summary

18

Annotation: ASC2014 Monday, August 11, 2014 1MOr2C-01 [Invited]

Comparison

		Institution	ISTEC		U. Houston SuperPower	amsc
		Process	PLD	TFA-MOD	MOCVD	TFA-MOD
		Material	EuBCO+BHO	YGdBCO +GZO	GdBCO+BZO	Y(Dy)BCO?
Short Tapes	30K 3T(B//c)				2413 A/cm (2895 A/12mm)	720 A/cm
	30K 3T(min.)		2730 A/cm		~1743 A/cm	
	65K 3T(min.)		616 A/cm			
	77K 3T(min.)		141 A/cm	70 A/cm		
Long	65K 3T(min.)		500 A/cm (94m)			
	77K 3T(min.)		108 A/cm (94m)	50 A/cm (124m)	14 A/cm (50m)	

19

Annotation: ASC2014 Monday, August 11, 2014 1MOr2C-01 [Invited]

Summary

IBAD-PLD C.C.

BHO introduction has desirable features !

→ High J_c(B) in Thick Films

→ Higher I_c(B) even in Low Temp. & High Field

EuBCO +BHO revealed "HIGHEST Ic(B) value"!

→ 141 A/cm-w@77K, 3T 616 A/cm-w@65K, 3T
2730 A/cm-w@30K, 3T (short tapes)

EuBCO+BHO can be applied to LONG TAPES !

→ 94m – 108 A/cm-w@77K,3T & 500 A/cm-w@65K, 3T

IBAD-MOD C.C.

BZO + "Interim Annealing" realized high Ic(B) even in "LONG TAPE"!

→ 124 m – 50 A/cm-w@77K, 3T

20

Annotation: ASC2014 Monday, August 11, 2014 1MOr2C-01 [Invited]

End

Thank you for your attention!

Part of this work was supported by the New Energy and Industrial Technology Development Organization and/or Ministry of Economy, Trade and Industry.

21

Annotation: ASC2014 Monday, August 11, 2014 1MOr2C-01 [Invited]