UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

EuCARD²

Overview of the critical surface of industrial CC for EuCARD-2

C. Senatore, C. Barth, M. Bonura, G. Mondonico, M. Kulich

Outline

- *Scope of WP10.2 in EuCARD-2*
- *Research on coated conductors @ UNIGE*
- *Overview of the industrial CCs*
- *$I_c(B,T,\theta)$ surface*
  - *Bruker HTS tapes for EuCARD-2*
  - *comparison with other manufacturers*

Scope of WP10.2 in EuCARD-2

- ***WP10 goal** is the development of an accelerator-quality **dipole** demonstrator magnet based on **HTS** (**5T** in a 15T background)*

- ***Task 2 of WP10 objectives**:*
    - *Improve the performance of the 2 candidate HTS materials (RE123 and Bi2212)*
    - *Characterize electrical and mechanical properties of the basic materials (wires and tapes) and cables*
    - *Select concepts & produce 10kA-20T HTS cable for coil winding*

- ***Laboratories in WP10.2**: CERN, KIT, INPG, SOTON, UNIGE, UTWENTE*

- ***Industrial partner**: Bruker HTS*

- *J_{eng}**(4.2K,15T) target** for the **RE123 tape**: 450 A/mm^2*

Research on coated conductors @ UNIGE

- Investigation of the $I_c(B,T,\theta)$ surface at high field/low temperature
- Electromechanical properties : $I_c(\varepsilon)$ and $\sigma(\varepsilon)$
- Thermophysical properties: longitudinal and transverse $\kappa(B,T)$

Overview of the industrial CCs

	AMSC	B-HTS	Fujikura	SuNAM	SuperOx	SuperPower
	MOD Dip-coating	*PLD*	*PLD*	*RCE Co-evaporation*	*PLD*	*MOCVD Chemical vapor*
RABiTS	X					
IBAD		X	X	X	X	X
physical deposition		X	X	X	X	
chemical deposition	X					X
in situ *process*		X	X		X	X
ex situ *process*	X			X		
substrate	NiW 75 μm	SS 100 μm	Hastelloy 75 μm	Hastelloy 60 μm	Hastelloy 60 μm	Hastelloy 50 μm
thermal stabilization	Laminated (2 sides)	Electroplated	Laminated (1 side)	Electroplated	Electroplated	Electroplated

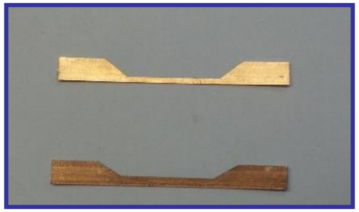
$I_c(B,T,\theta)$ characterization protocol

Three orientations

$\theta = 0°$ (B//c)

$\theta = 45°$

} full width samples



$\theta = 90°$ (B//ab) } reduced width

- EDM (spark erosion)
- Photolitography + chemical etching

I_{max}: 1000A @ 4.2K
~250A @ >4.2K

Four temperatures 4.2K - 20K - 30K - 40K

T < 40K	only at high fields (~10T < B < 19T)
T = 40K	down to B = 0T (when possible)

Test of the tapes from Bruker HTS

	T002	T150	T191
Width	4.05 mm		4.2 mm
Thickness	150 µm		200 µm
Substrate material	Stainless steel		
Substrate thickness	97 µm		
Buffer layer	ABAD-YSZ + PLD CeO2		
ReBCO thickness	3.8 µm	0.9 µm	2.0 µm
Ag *thickness*	1.0 µm		1.8 µm
Cu *thickness*	50 µm	30 µm	100 µm
I_c(77K,s.f.)	109 A	25 A	54 A

High speed deposition non-doped (T002)

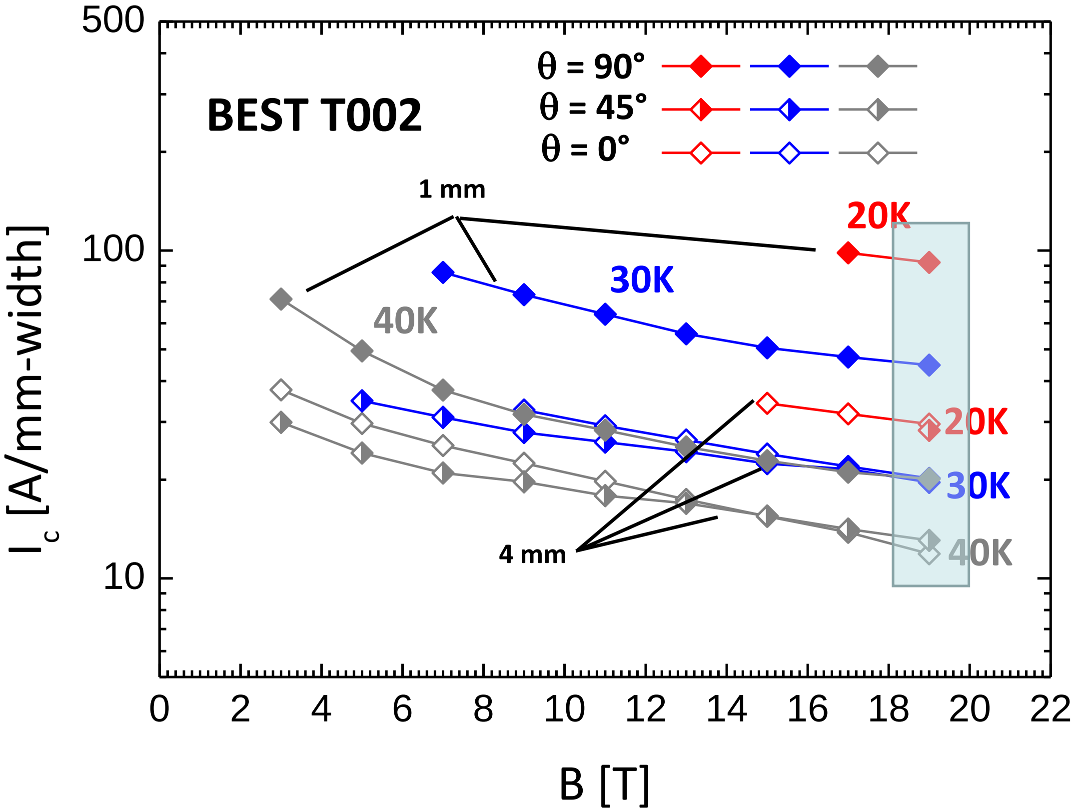
Artificial pinning (T150, T191)

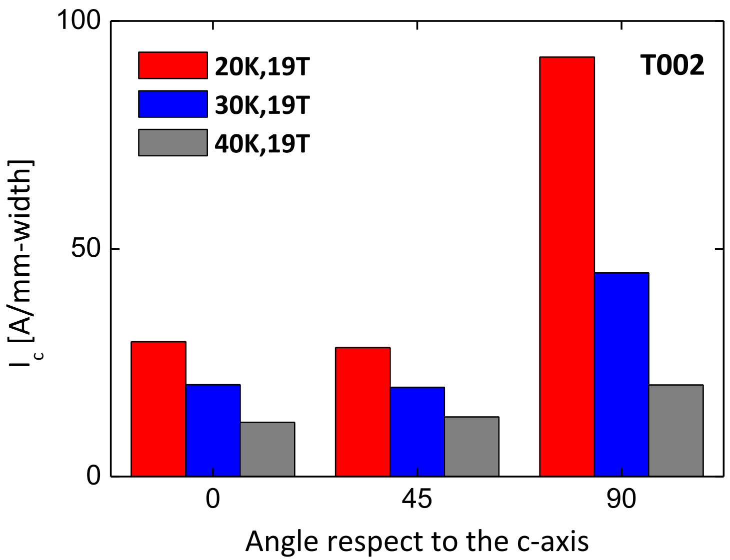
Bruker HTS GmbH - A. Usoskin, A. Rutt

B-HTS Tape T002

I_c(77K,s.f.) =109 A – width = 4 mm

RE123 thickness = 3.8 μm





I_c(4.2K,19T) = 270 A/mm-width B//ab

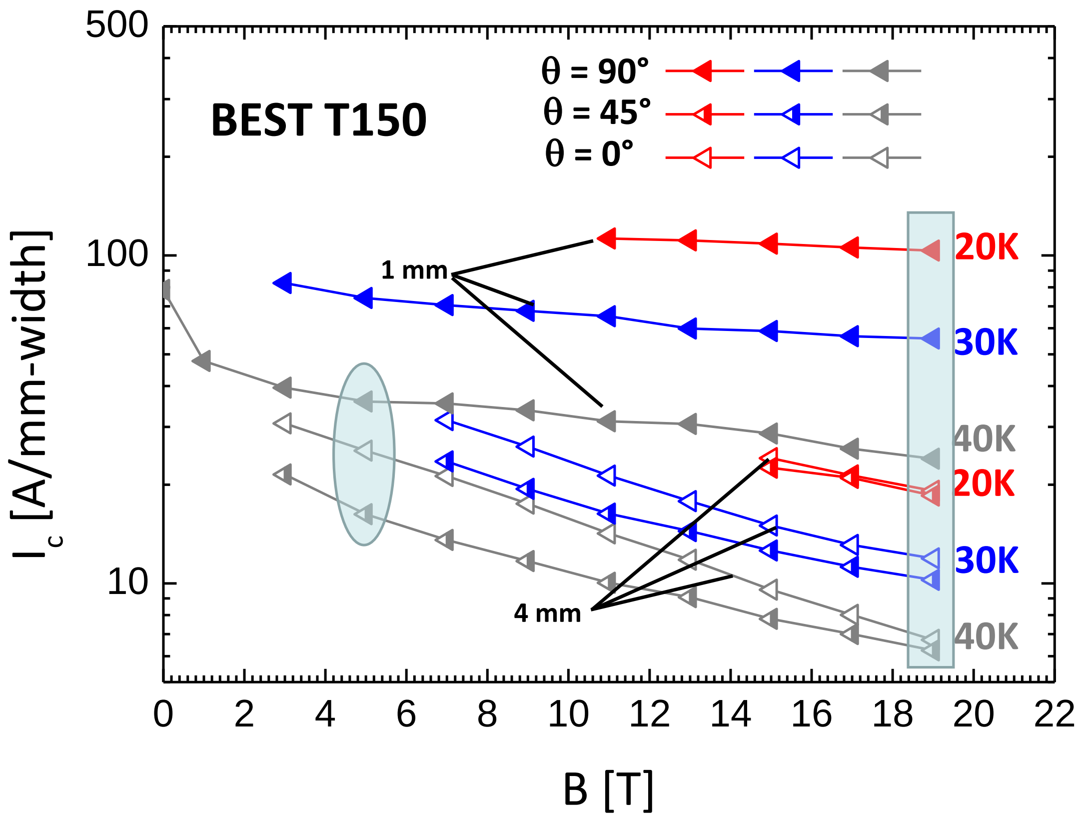
I_c(4.2K,19T) = 55 A/mm-width B//c

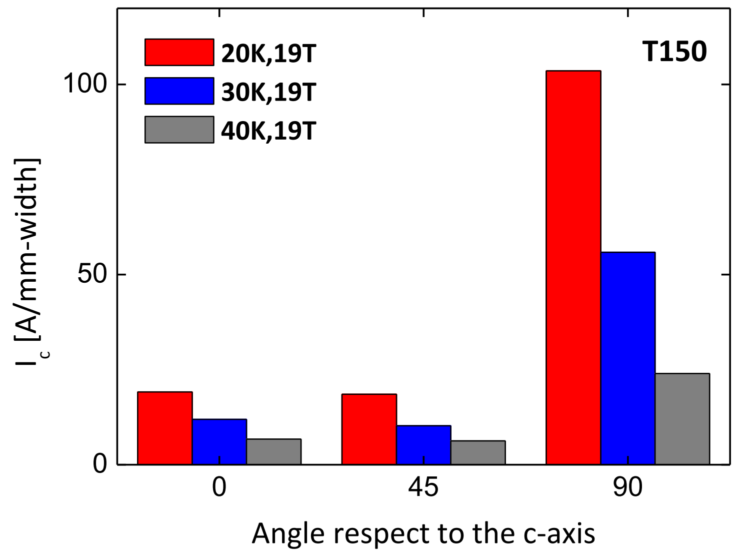
For θ = 90° (B//ab), samples with reduced width (1 mm) were prepared by etching

B-HTS Tape T150

I_c(77K,s.f.) =25 A – width = 4 mm

RE123 thickness = 0.9 μm





I_c(4.2K,19T) = 155 A/mm-width B//ab

I_c(4.2K,19T) = 37 A/mm-width B//c

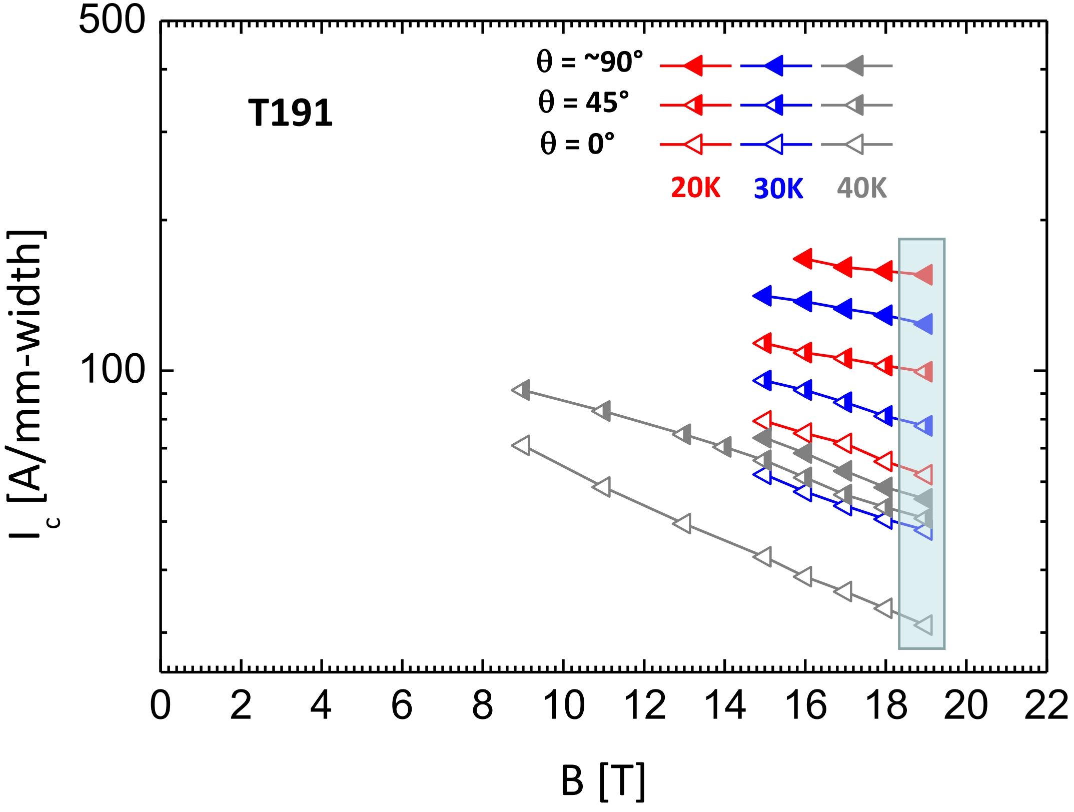
Artificial pinning ⇒ I_c(0°)>I_c(45°) @ low B and/or high T

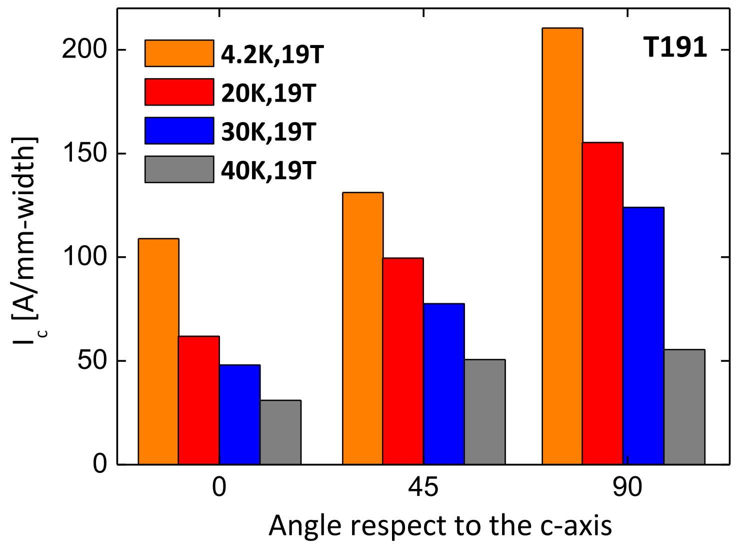
For θ = 90° (B//ab), samples with reduced width (1 mm) were prepared by etching

B-HTS Tape T191

I_c(77K,s.f.) =54 A – width = 4 mm

RE123 thickness = 2.0 μm





I_c(4.2K,19T) = 210 A/mm-width B//ab

I_c(4.2K,19T) = 109 A/mm-width B//c

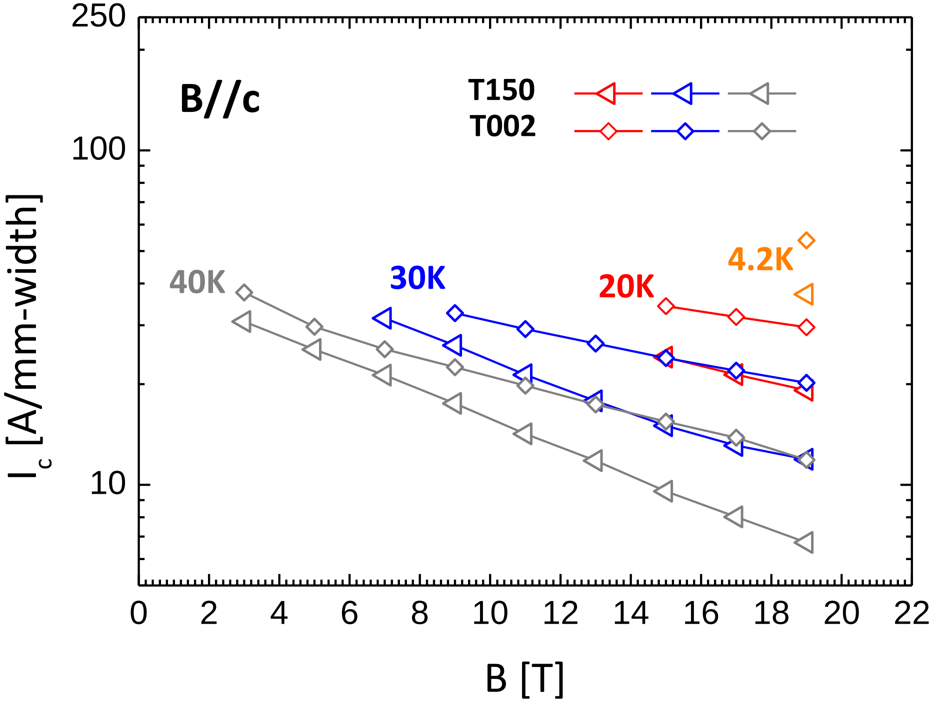
Artificial pinning ⇒ I_c(45°)>I_c(0°)

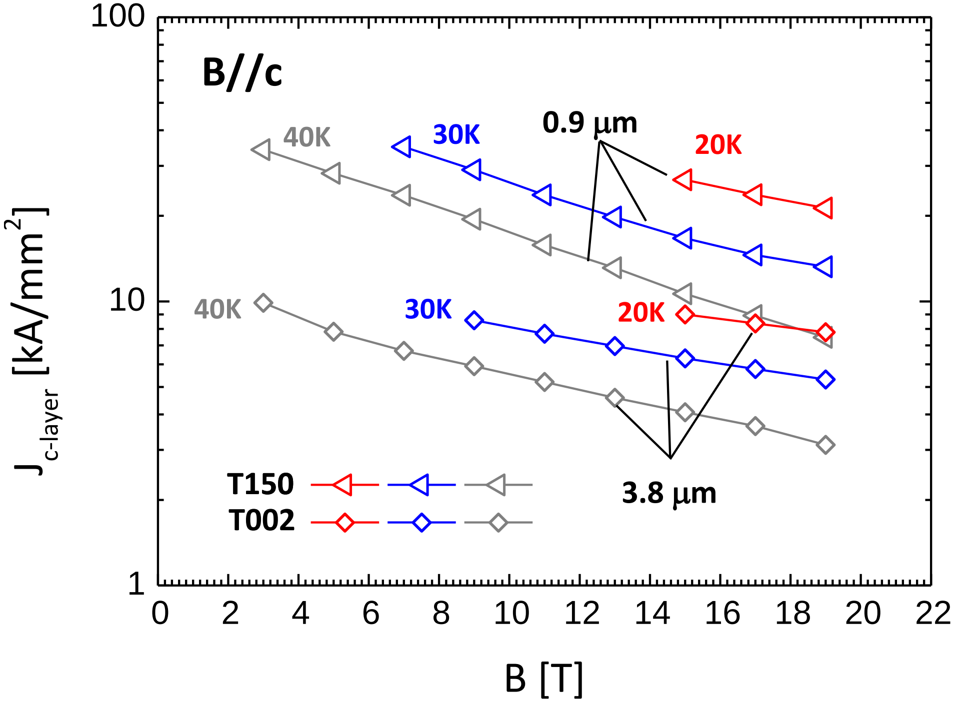
For θ = 90° (B//ab), samples with reduced width (1 mm) were prepared by etching

B-HTS tape T150 vs. tape T002

I_c(77K,s.f.) = 25 A
RE123 thickness = 0.9 μm
I_c(4.2K,19T) = 37 A/mm-width

I_c(77K,s.f.) = 109 A
RE123 thickness = 3.8 μm
I_c(4.2K,19T) = 55 A/mm-width

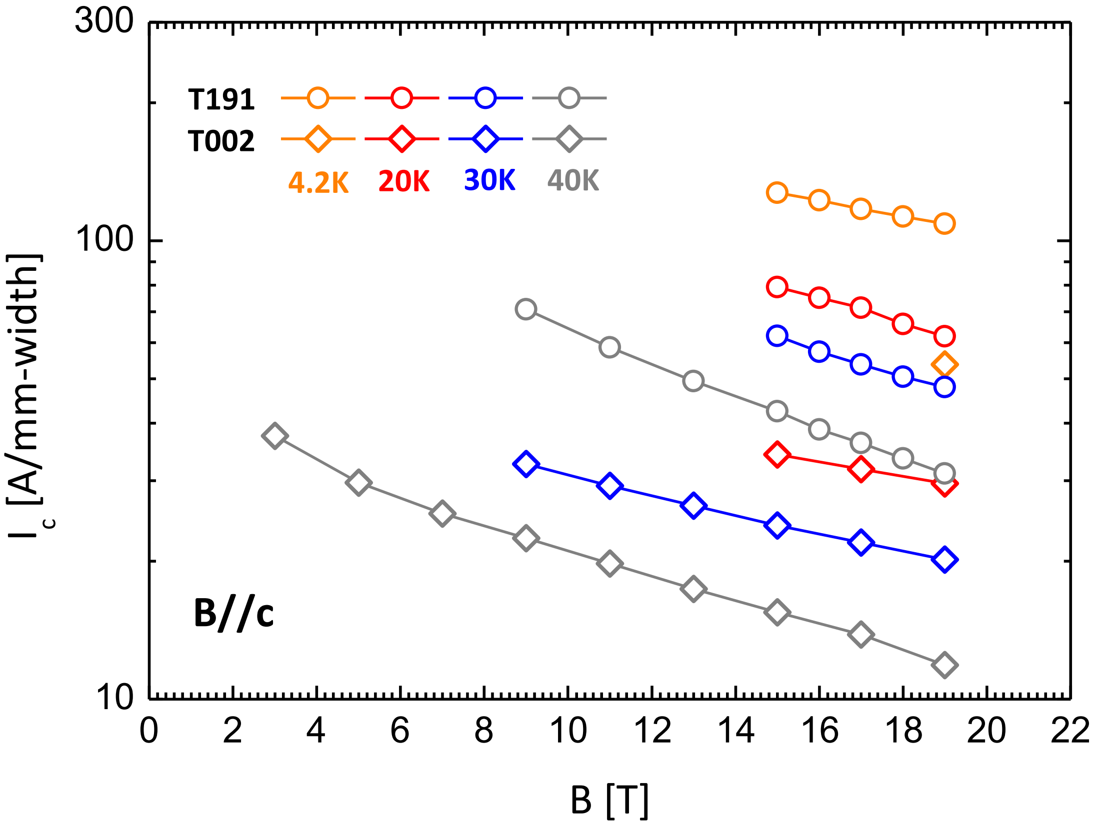




T002: Thicker RE123 layer, higher I_c but lower J_c in the superconductor

B-HTS tape T191 vs. tape T002

I_c(77K,s.f.) = 54 A	***I_c(77K,s.f.) = 109 A***
RE123 thickness = 2.0 μm	***RE123 thickness = 3.8 μm***
I_c(4.2K,19T) = 109 A/mm-width	***I_c(4.2K,19T) = 55 A/mm-width***

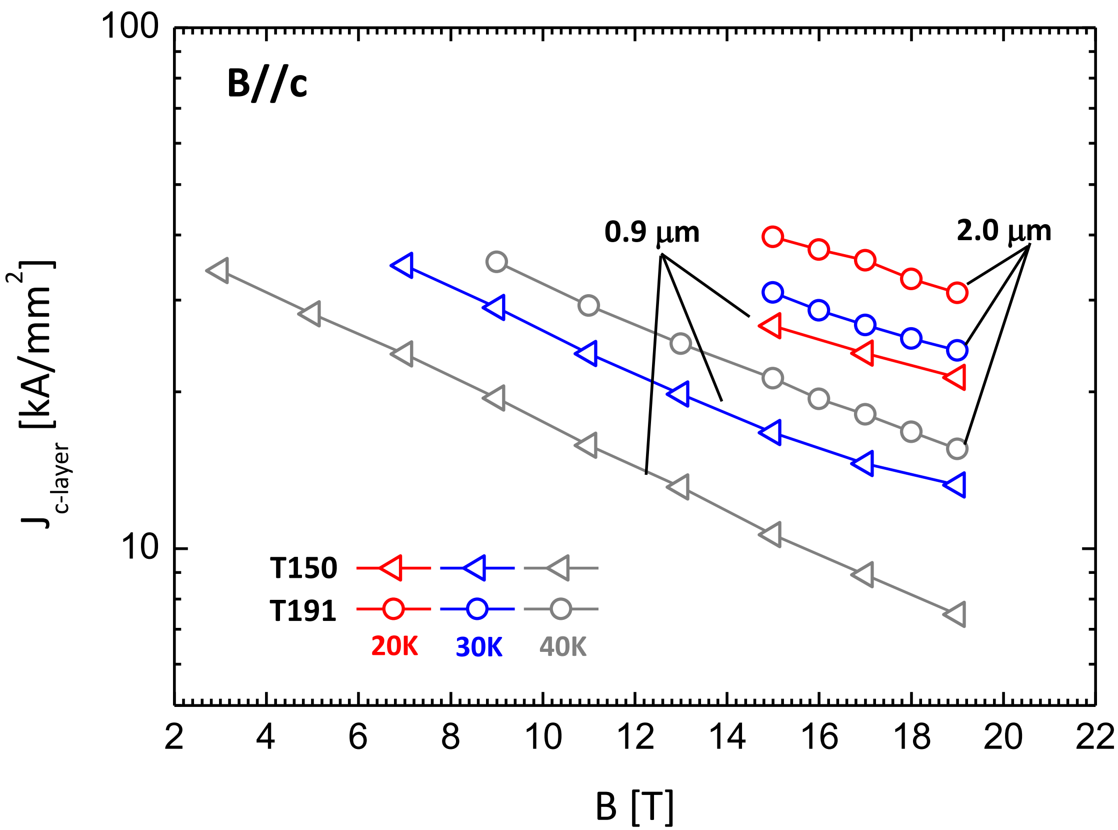


T191 (artificial pinning) has 2 x I_c(4.2K,19T) of T002

B-HTS tape T191 vs. tape T150

I_c(77K,s.f.) = 54 A
RE123 thickness = 2.0 μm
I_c(4.2K,19T) = 109 A/mm-width

I_c(77K,s.f.) = 25 A
RE123 thickness = 0.9 μm
I_c(4.2K,19T) = 37 A/mm-width



Artificial pinning for both tapes, 20% higher layer J_c(20K) for T191

B-HTS tapes: Summary table

	T002	*T150*	*T191*
RE123 thickness	3.8 μm	0.9 μm	2.0 μm
Artificial pinning	no	yes	yes
I_c(77K,s.f.)	109 A	25 A	54 A
I_c(4.2K,19T,⊥)	55 A/mm-width	37 A/mm-width	109 A/mm-width
J_{eng}(4.2K,19T,⊥)	280 A/mm^2	190 A/mm^2	540 A/mm^2
$J_{c\text{-}layer}$(4.2K,19T,⊥)	14 kA/mm^2	41 kA/mm^2	54 kA/mm^2

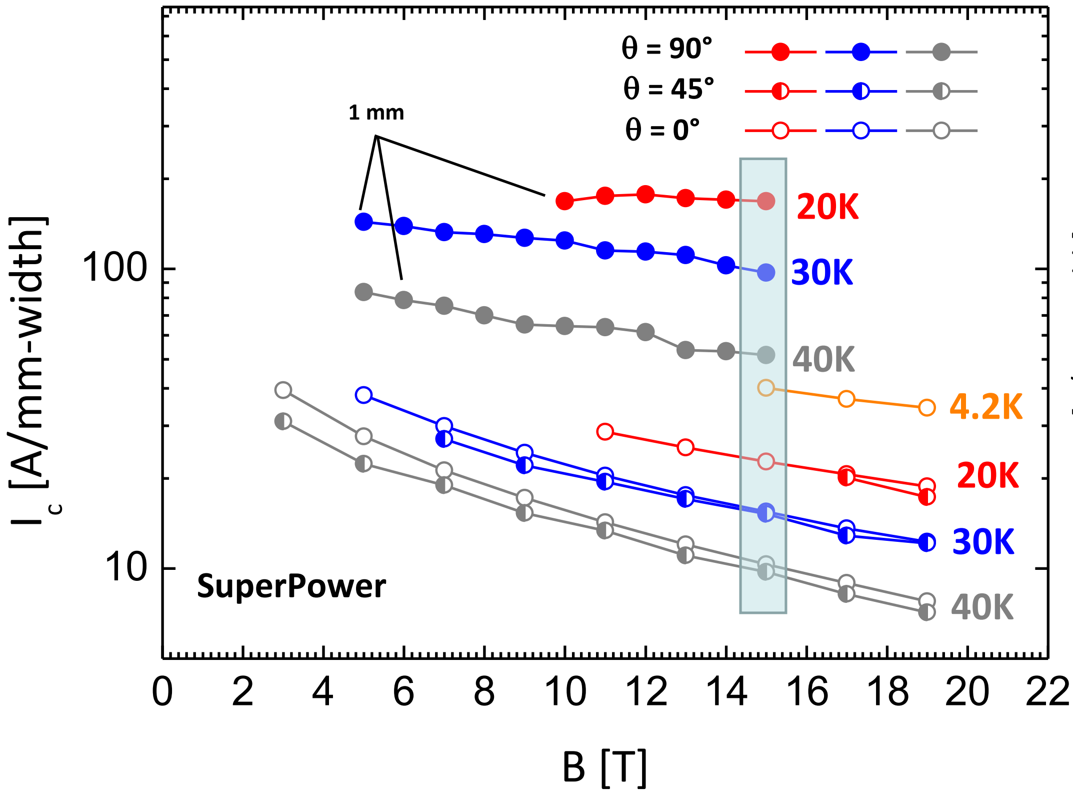
Our target performance for RE123 tape : J_{eng}(4.2K,15T) = 450 A/mm^2

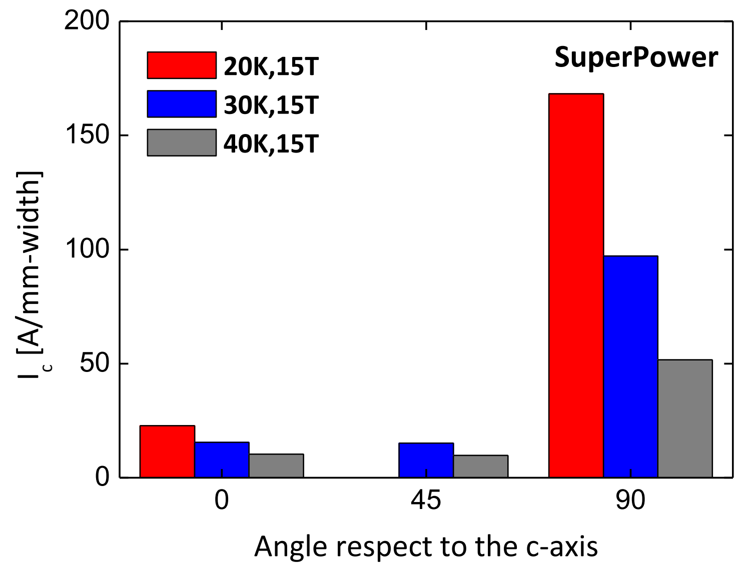
SuperPower – Advanced Pinning

SuperPower Inc. A Furukawa Company

I_c(77K,s.f.) = 90 A – width = 4 mm

RE123 thickness = 1.4 μm





I_c(4.2K,19T) = 35 A/mm-width B//c

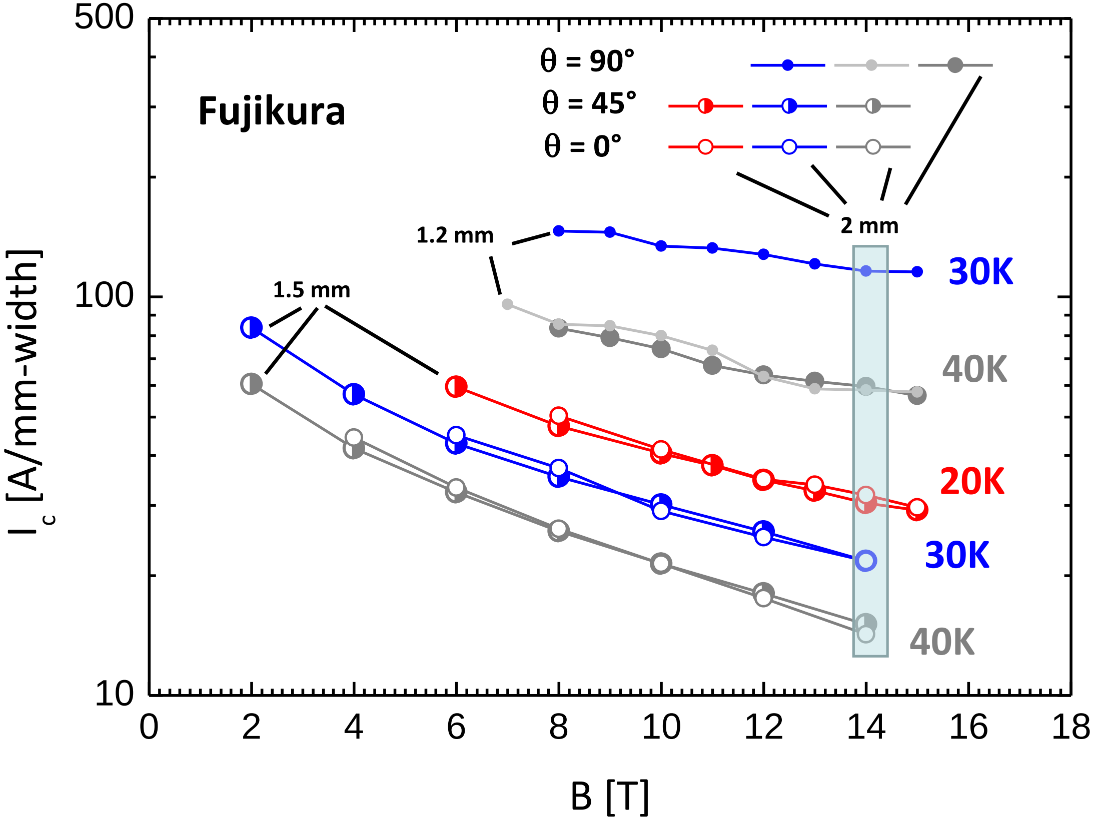
BZO increases the I_c(B//c) and reduces the anisotropy at 77K

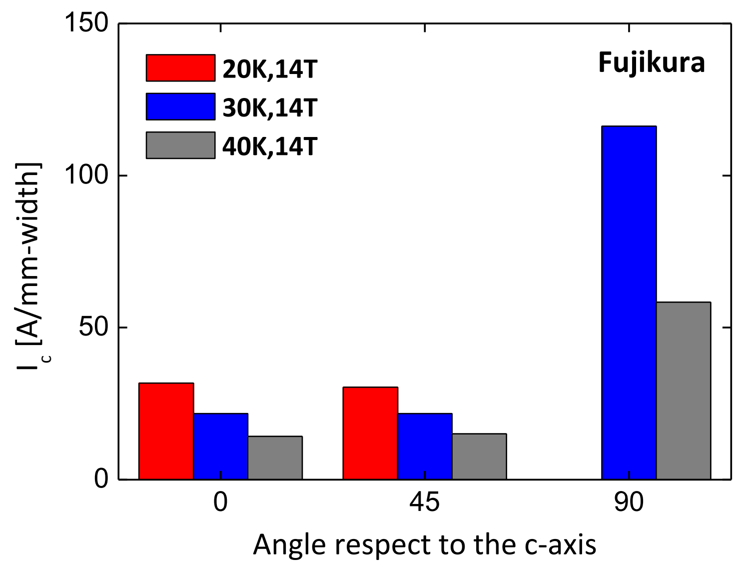
There is no effect of BZO on low T anisotropy

Fujikura

I_c(77K,s.f.) = 302 A – width = 5 mm

RE123 thickness = 2.0 µm





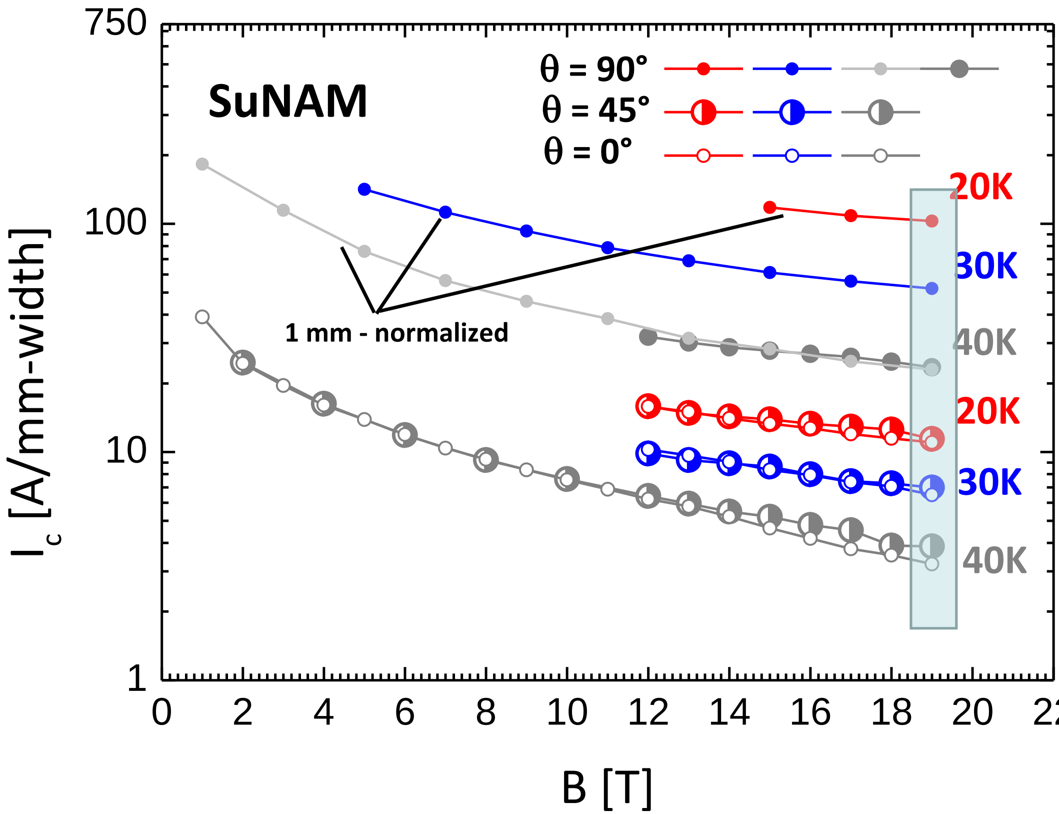
I_c(4.2K,19T) = 50 A/mm-width B//c

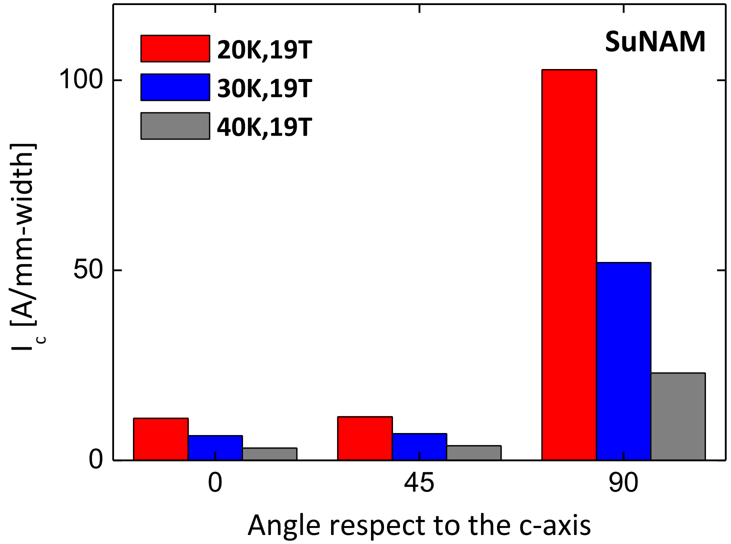
Three different slit width, 1.2, 1.5 and 2 mm, cut by EDM

SuNAM

I_c(77K,s.f.) = 250 A – width = 4 mm

RE123 thickness = 1.4 μm





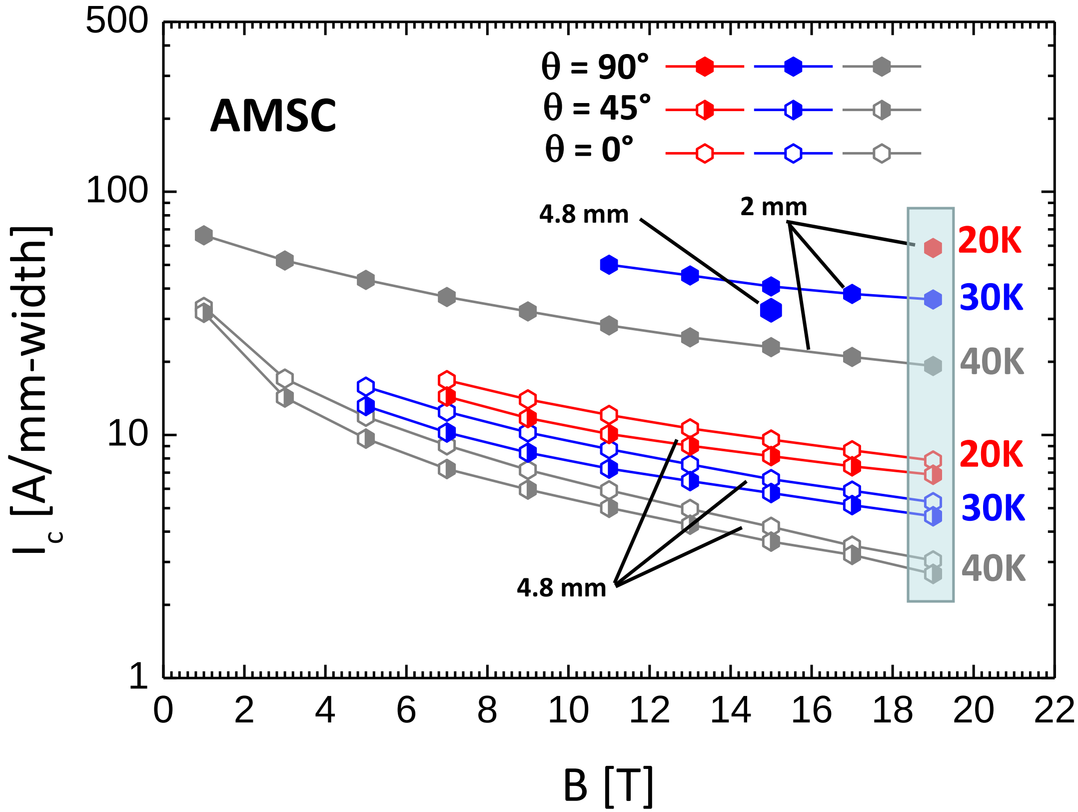
I_c(4.2K,19T) = 24 A/mm-width B//c

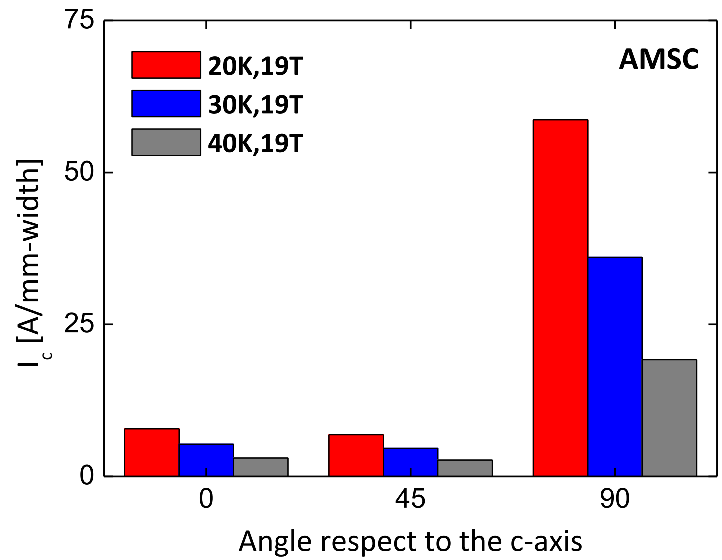
AMSC

I_c(77K,s.f.) = 100 A – width = 4.8 mm

RE123 width = 4 mm

RE123 thickness = 0.8 μm





I_c(4.2K,19T) = 16 A/mm-width B//c

For θ = 90° (B//ab), samples with reduced width (2 mm) were prepared by EDM

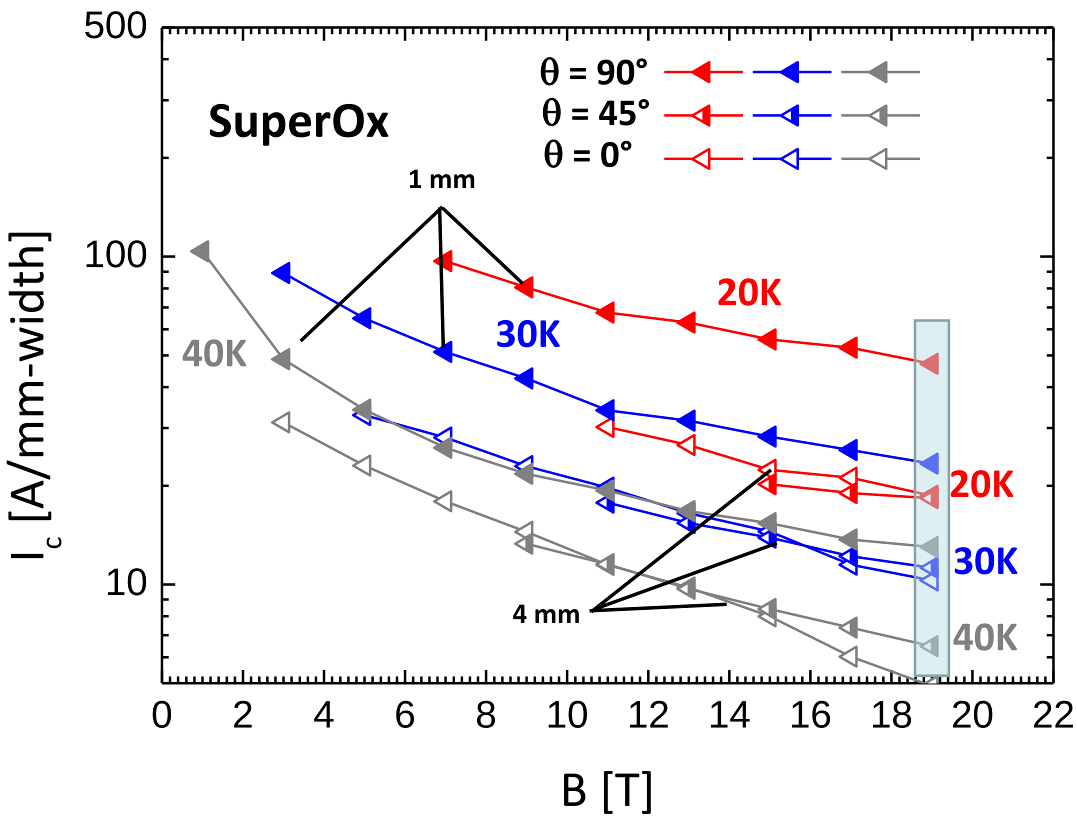
I_c(30K,4.8mm)[A/mm-width] < I_c(30K,2mm)[A/mm-width]

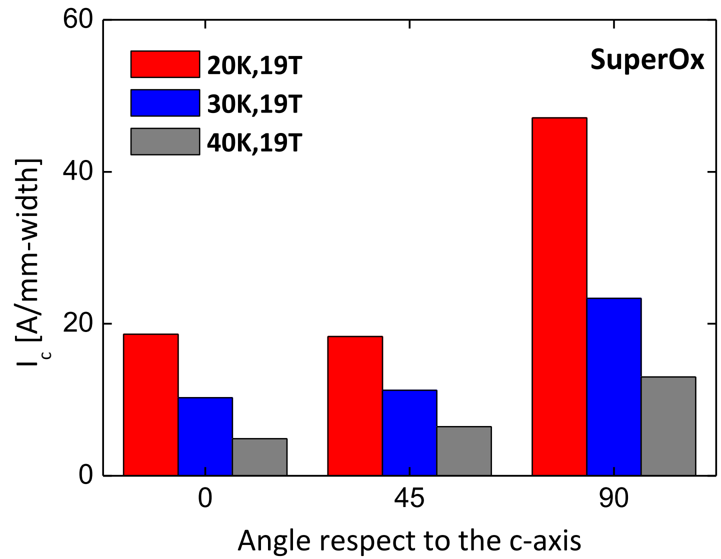
This is a consequence of the slitting process during the conductor fabrication

SuperOx

I_c(77K,s.f.) =110 A – width = 4 mm

ReBCO thickness = 1.2 μm



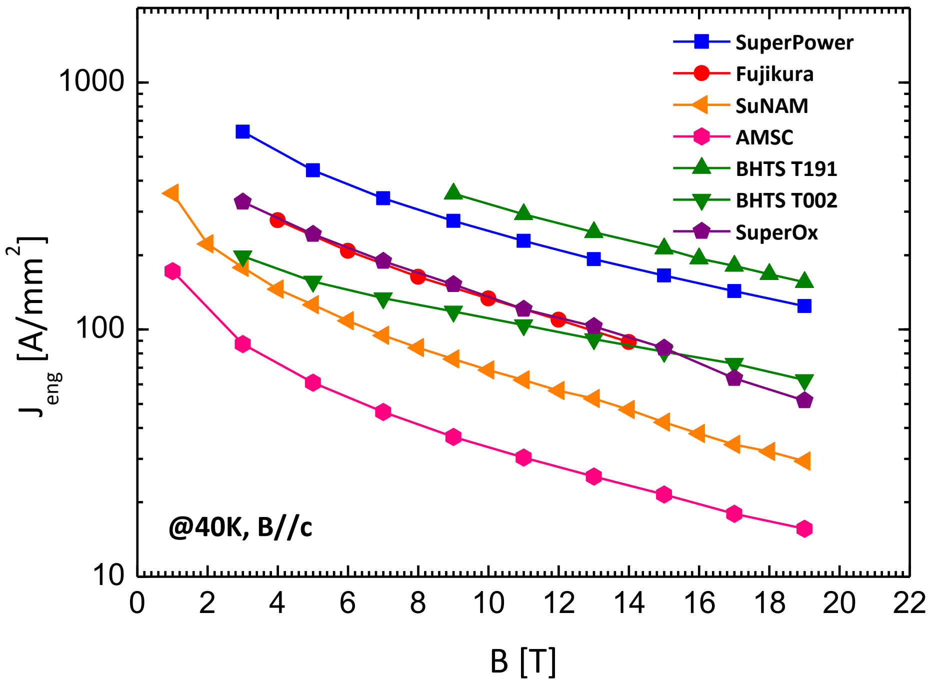


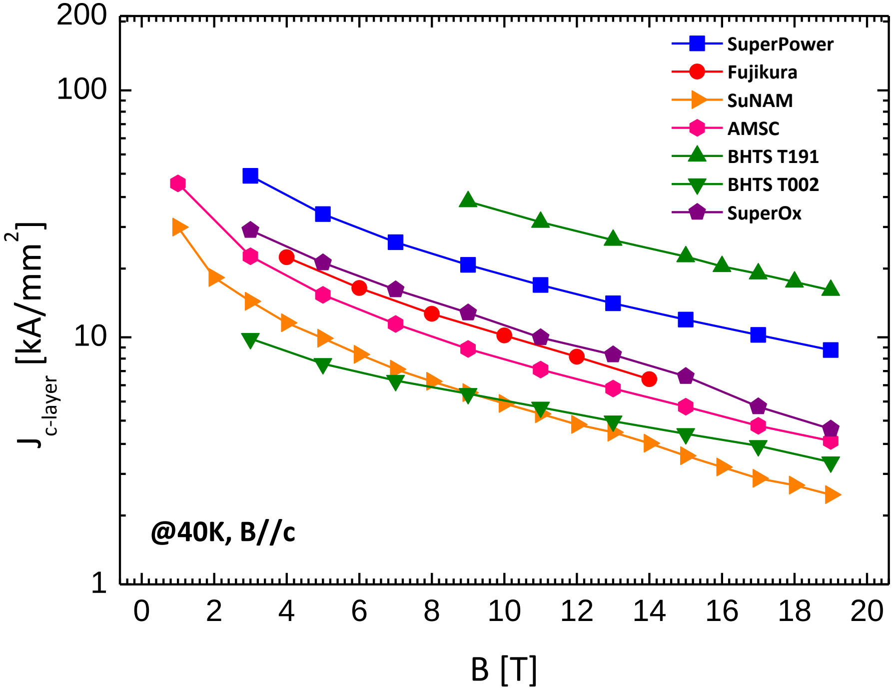
I_c(4.2K,19T) = 119 A/mm-width B//ab

I_c(4.2K,19T) = 42 A/mm-width B//c

For θ = 90° (B//ab), samples with reduced width (1 mm) were prepared by etching

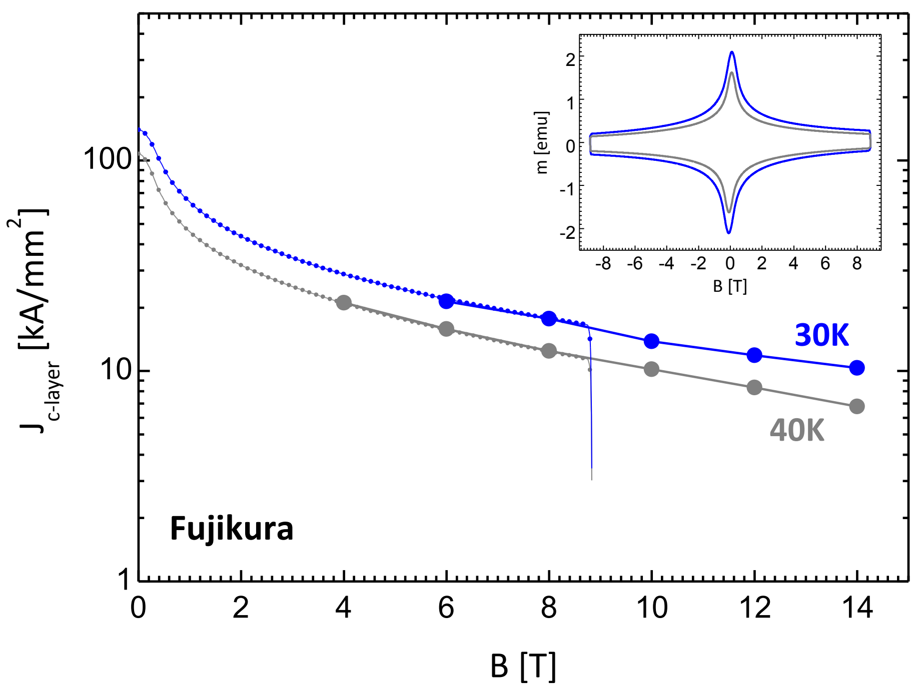
Engineering J_c and layer J_c : Overall comparison

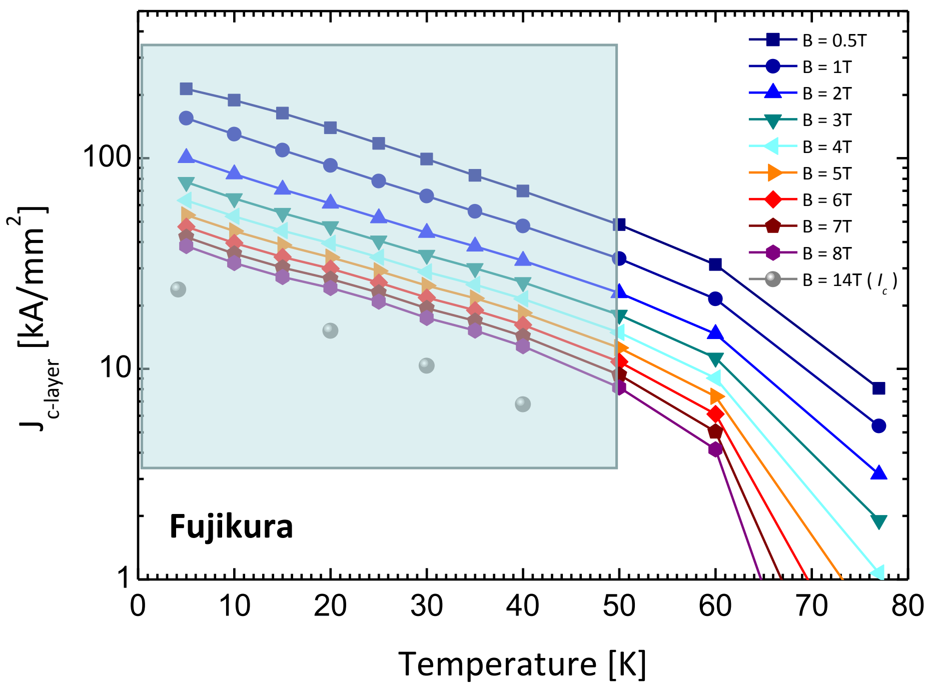




Comparison performed at 40K in perpendicular field

Temperature dependence of J_c from magnetization



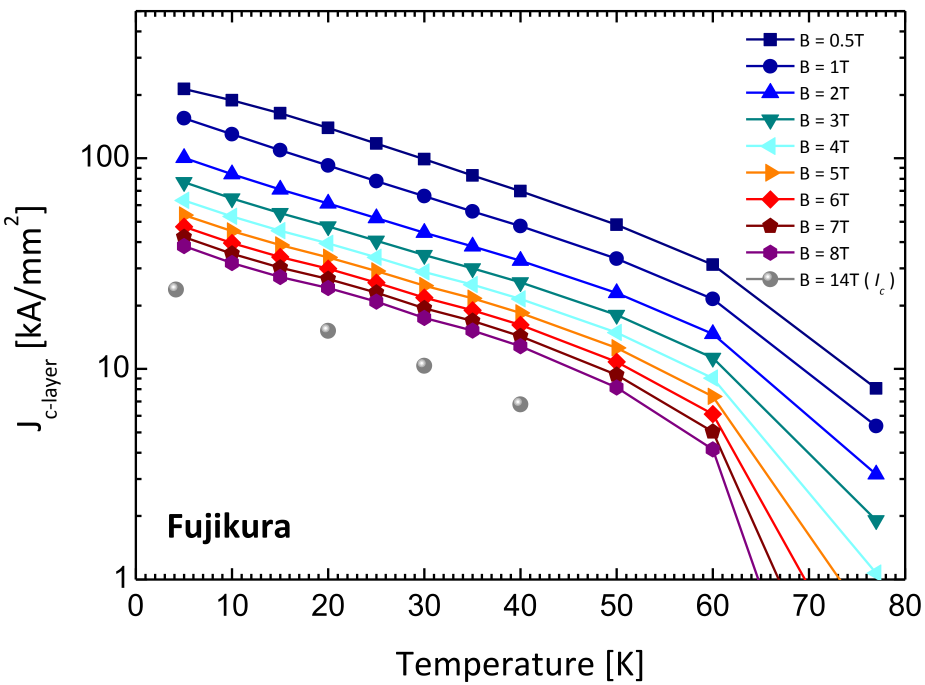


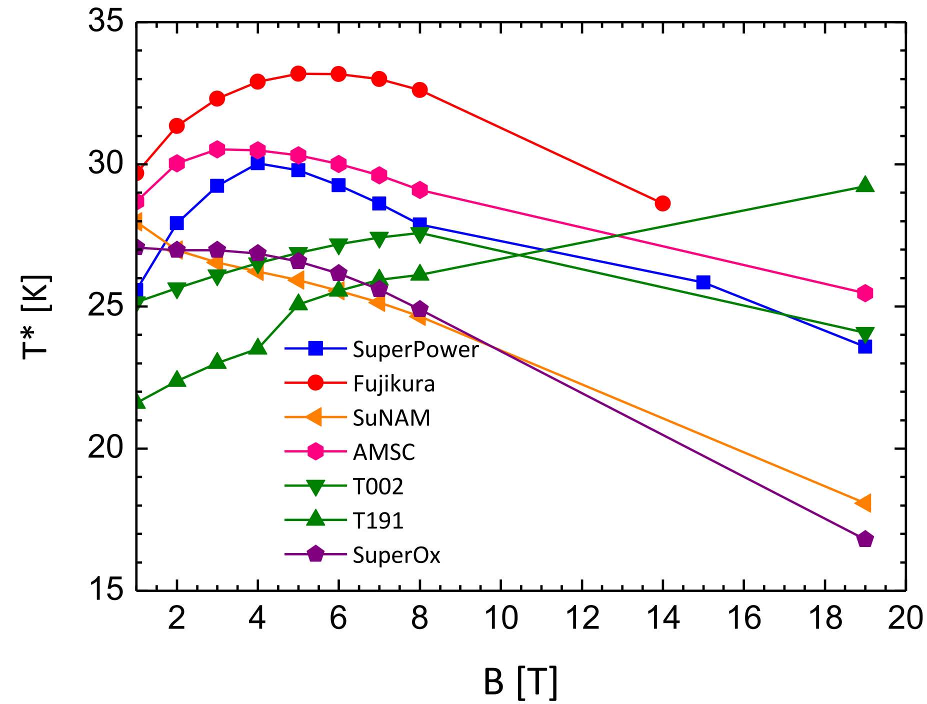
Magnetization measurements to explore a larger portion of the critical surface

- *5K < T < 77K*
- *-9T < $B_\perp$ < 9T*

Temperature scaling law $J_c(B,T) = J_c(B,T=0)\,e^{-\frac{T}{T^*}}$

Temperature dependence of J_c from magnetization

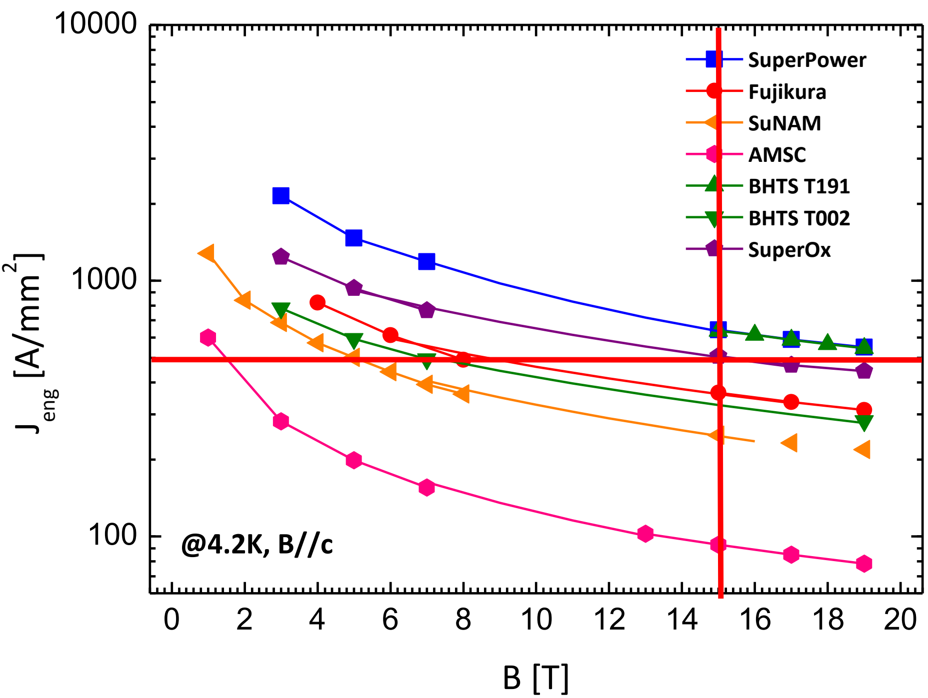


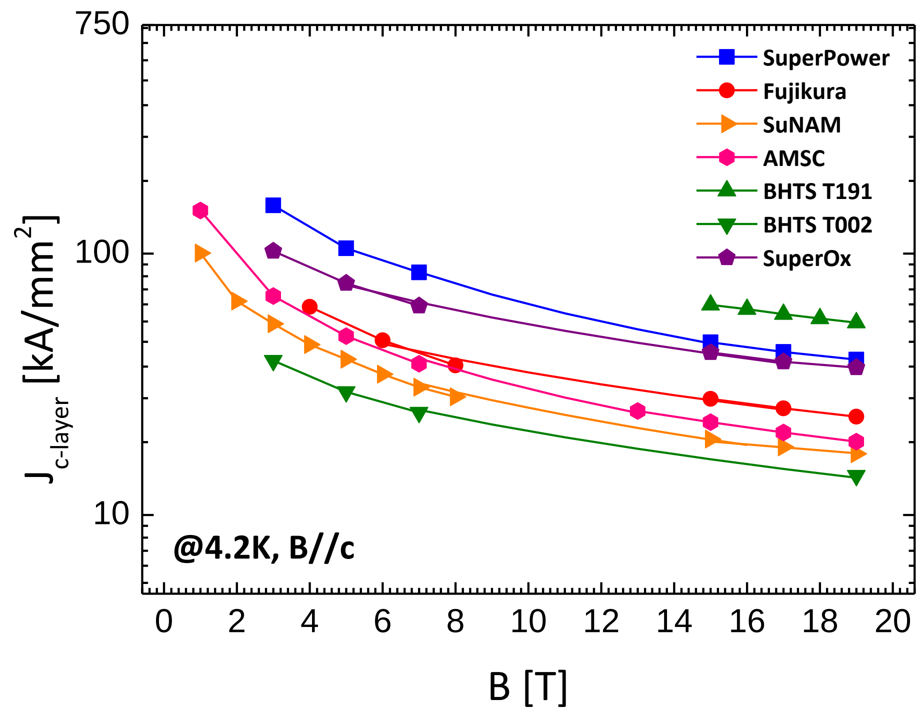


Temperature scaling law $J_c(B,T) = J_c(B,T=0)e^{-\frac{T}{T^*}} \Rightarrow \frac{J_c(B,T_1)}{J_c(B,T_2)} = e^{-\frac{T_1-T_2}{T^*}}$

T ranges between 15K and 35K – it depends on field*

Engineering J_c and layer J_c : Overall comparison @4K

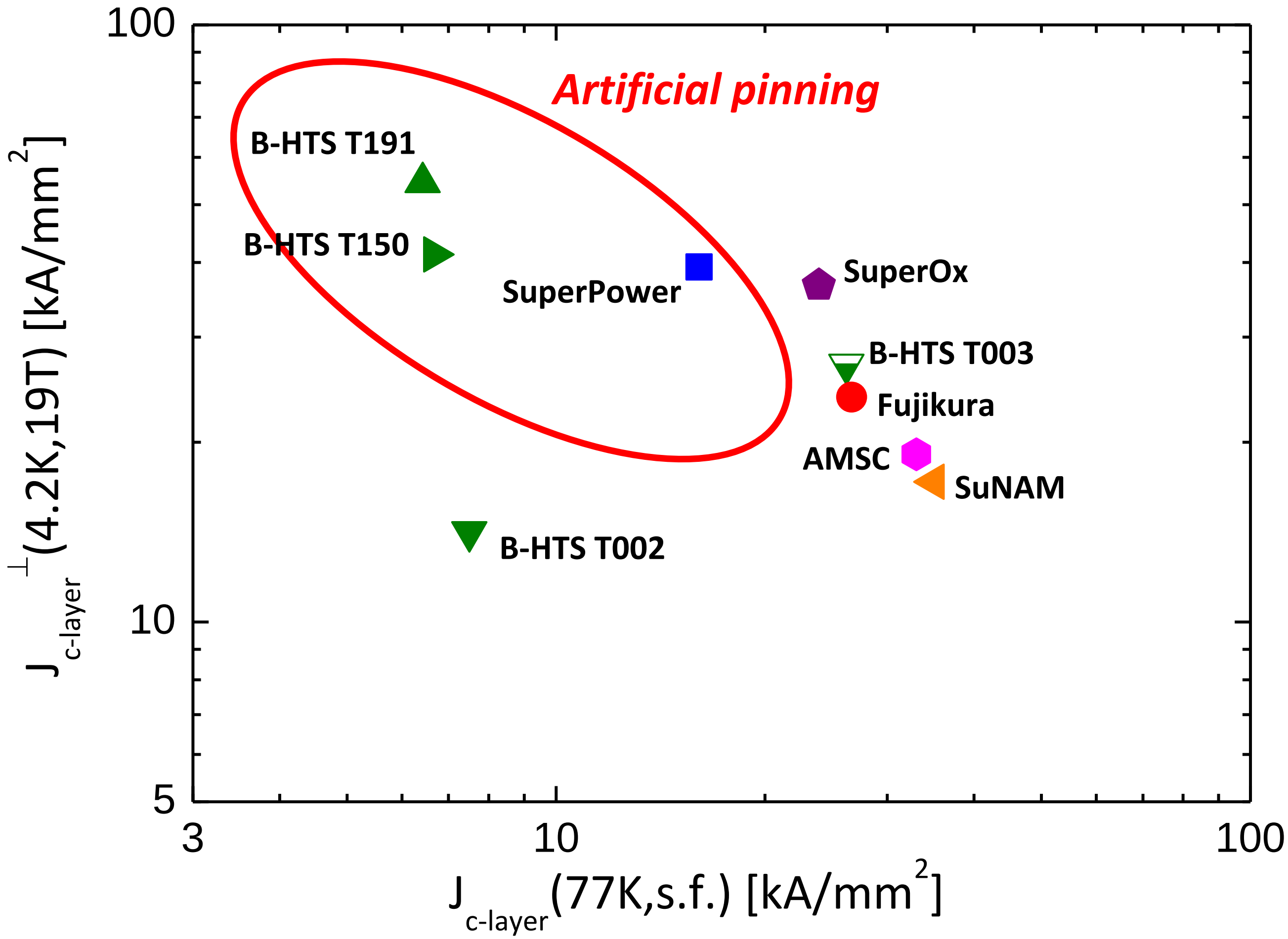




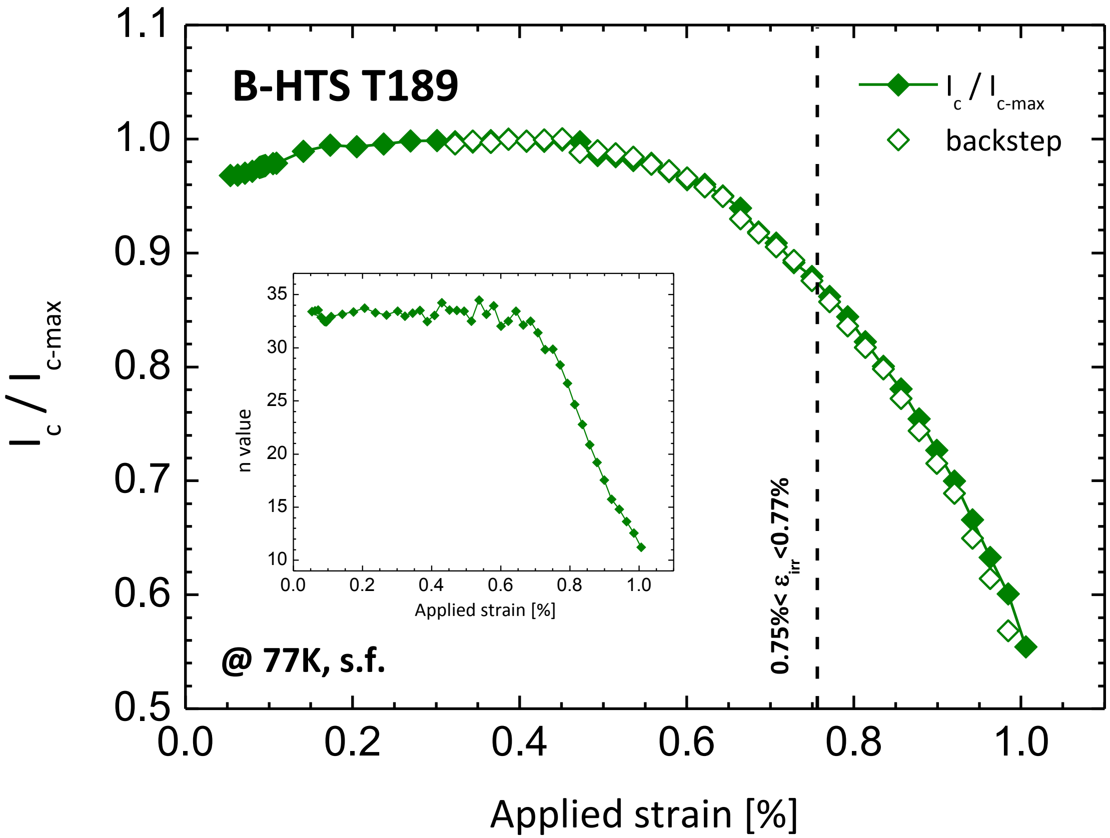
The line in the gap is a $\dfrac{1}{B+B^*}$ *fit of the data*

Our target performance for RE123 tape : $J_{eng}(4.2K,15) = 450\ A/mm^2$

Master Plot: J_c(77K,s.f.) vs. J_c(4.2K,19T)



WASP measurements preview



C. Barth, C. Calzolaio, CS, ASC2014

Summary

- *Examined tapes from 6 manufacturers*
- *All manufacturers exhibit $J_{c\text{-}layer}$(4.2K,19T) > 10 kA/mm^2*
- *But CC layout determines J_{eng}*
- *EuCARD-2 WP10.2 : B-HTS tape T191 exceeded the target performance of 450 A/mm^2 for J_{eng}(4.2K,15T)*
- *Performance at 77K/s.f. and at low T/high B are not univocally correlated: mapping is ongoing*