Magnet conductor development at S-Innovations

3 March 2021

SUPERCONDUCTOR TO THE FUTURE

US Magnet Development Program

Outline

S Innovations

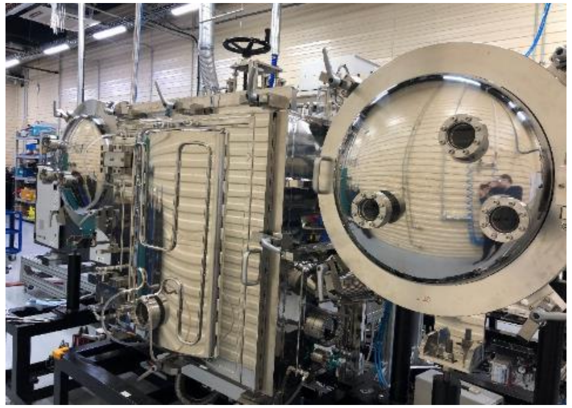
- The SuperOx group
- Production technology and capacity
- Wire for in-field use
- Laser slitting technology

The SuperOx group

S Innovations

S Innovations (Moscow) and SUPEROX JAPAN (Tokyo)

- 2G HTS wire production and development
  - Supply wire to SuperOx projects
  - Supply wire to outside customers



SuperOx (Moscow)

- HTS Applications development and commercialisation
  - FCL: first in the world resistive 220 kV FCL,
    in Moscow city grid since 2019
  - Coils
  - AC/DC cables

SuperOx 2G HTS wire: Technology

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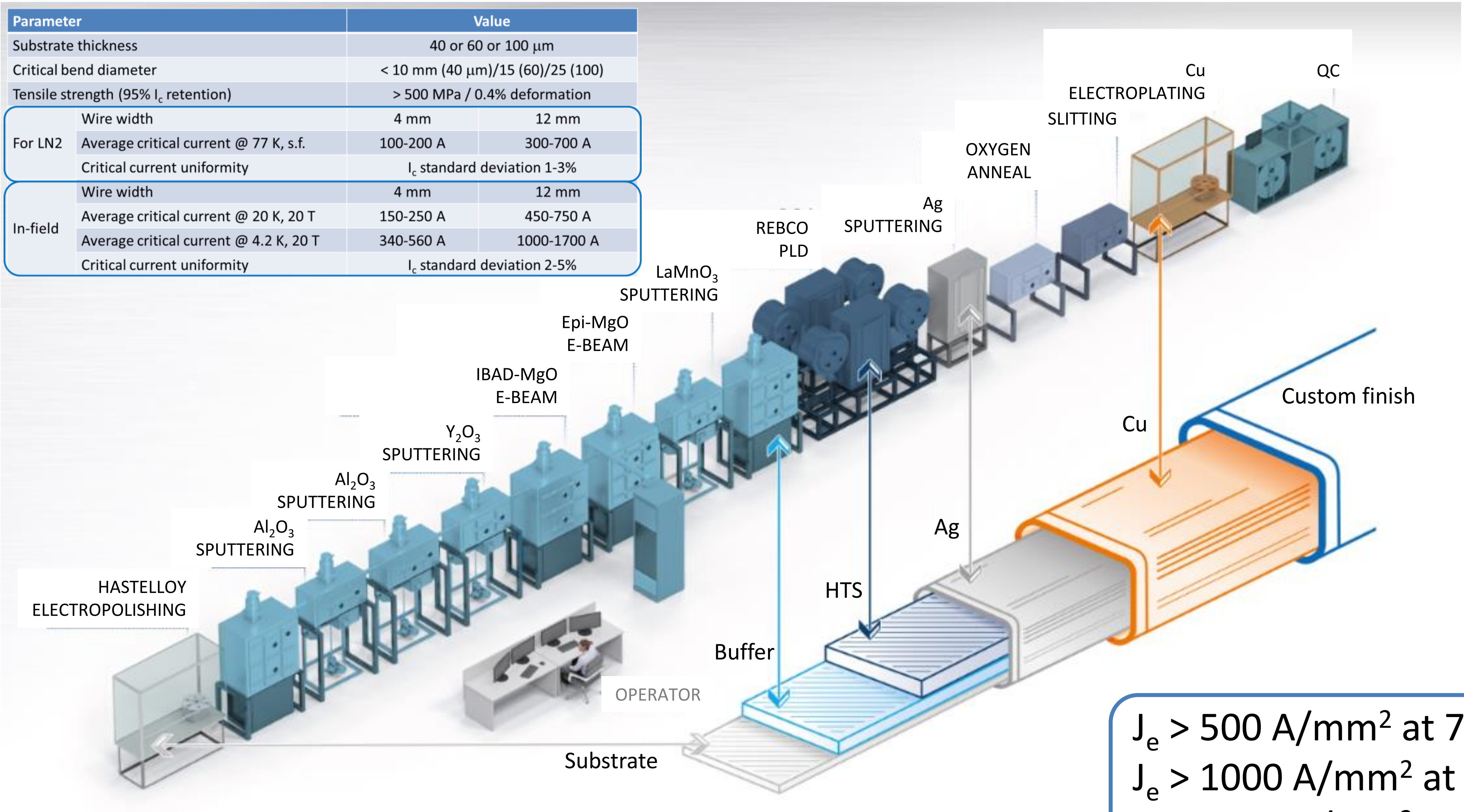
Parameter		Value	
Substrate thickness		40 or 60 or 100 µm	
Critical bend diameter		< 10 mm (40 µm)/15 (60)/25 (100)	
Tensile strength (95% I_c retention)		> 500 MPa / 0.4% deformation	
For LN2	Wire width	4 mm	12 mm
	Average critical current @ 77 K, s.f.	100-200 A	300-700 A
	Critical current uniformity	I_c standard deviation 1-3%	
In-field	Wire width	4 mm	12 mm
	Average critical current @ 20 K, 20 T	150-250 A	450-750 A
	Average critical current @ 4.2 K, 20 T	340-560 A	1000-1700 A
	Critical current uniformity	I_c standard deviation 2-5%	



J_e > 500 A/mm^2 at 77 K, s.f.
J_e > 1000 A/mm^2 at 20 K, 20 T
J_e > 2000 A/mm^2 at 4.2 K, 20 T

SuperOx 2G HTS wire: Production capacity

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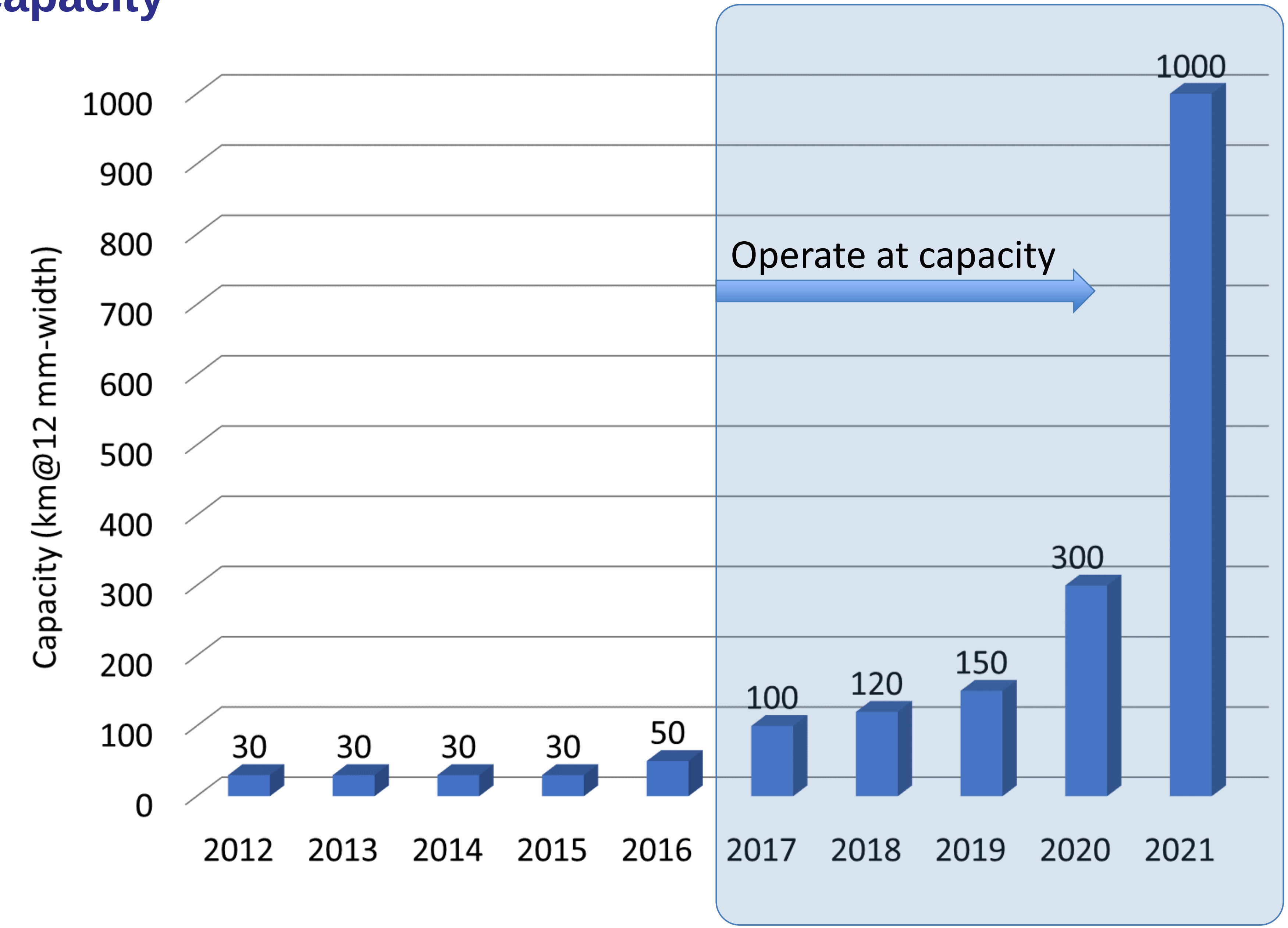

Demand drives capacity scale-up

SuperOx 2G HTS wire:
Intended applications

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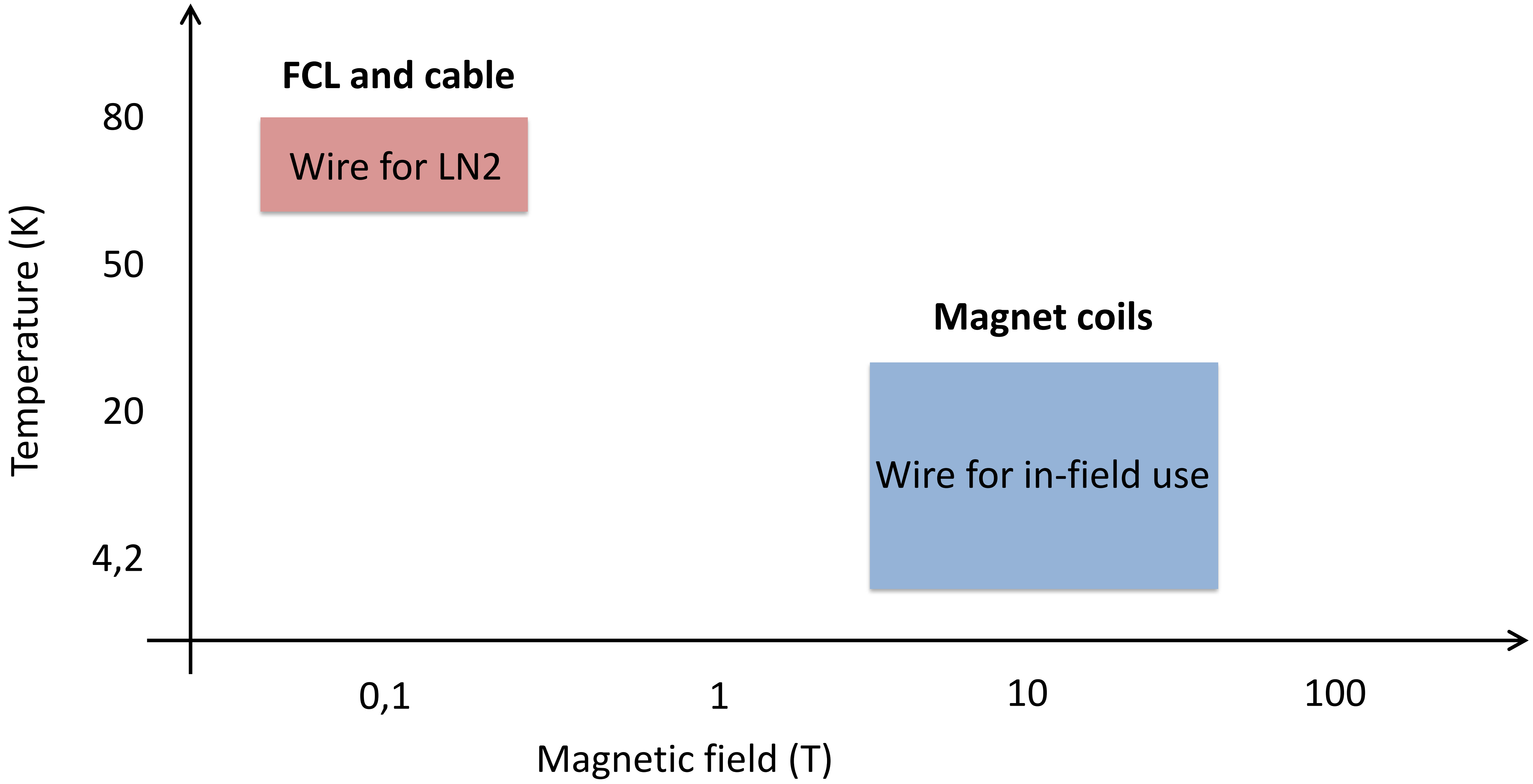

SuperOx 2G HTS wire: Specifications

S Innovations

Parameter		Value	
Substrate thickness		40 or 60 or 100 μm	
Critical bend diameter		< 10 mm (40 μm)/15 (60)/25 (100)	
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Customisation:

+ Variable copper thickness
+ Insulation: 10-20 μm thin polyimide varnish
+ Solder plating
+ Lamination
+ Low resistance splices
+ … just ask

SuperOx wire for in-field use

Sci Rep 11, 2084 (2021). https://doi.org/10.1038/s41598-021-81559-z

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Development and large volume production of extremely high current density $YBa_2Cu_3O_7$ superconducting wires for fusion

A. Molodyk[1,2]✉, S. Samoilenkov[1,2], A. Markelov[1], P. Degtyarenko[2,3], S. Lee[4], V. Petrykin[4], M. Gaifullin[4], A. Mankevich[1], A. Vavilov[1,2,4], B. Sorbom[5], J. Cheng[5], S. Garberg[5], L. Kesler[5], Z. Hartwig[6], S. Gavrilkin[7], A. Tsvetkov[7], T. Okada[8], S. Awaji[8], D. Abraimov[9], A. Francis[9], G. Bradford[9], D. Larbalestier[9], C. Senatore[10], M. Bonura[10], A. E. Pantoja[11], S. C. Wimbush[11], N. M. Strickland[11] & A. Vasiliev[12,13,14]

SuperOx CFS Massachusetts Institute of Technology NATIONAL MAGLAB TOHOKU UNIVERSITY UNIVERSITÉ DE GENÈVE FACULTÉ DES SCIENCES

S Innovations SUPEROX JAPAN Физический институт имени П.Н.Лебедева РОССИЙСКОЙ АКАДЕМИИ НАУК ФИАН TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI VICTORIA UNIVERSITY OF WELLINGTON Robinson Research Institute

SuperOx wire for in-field use: Concept

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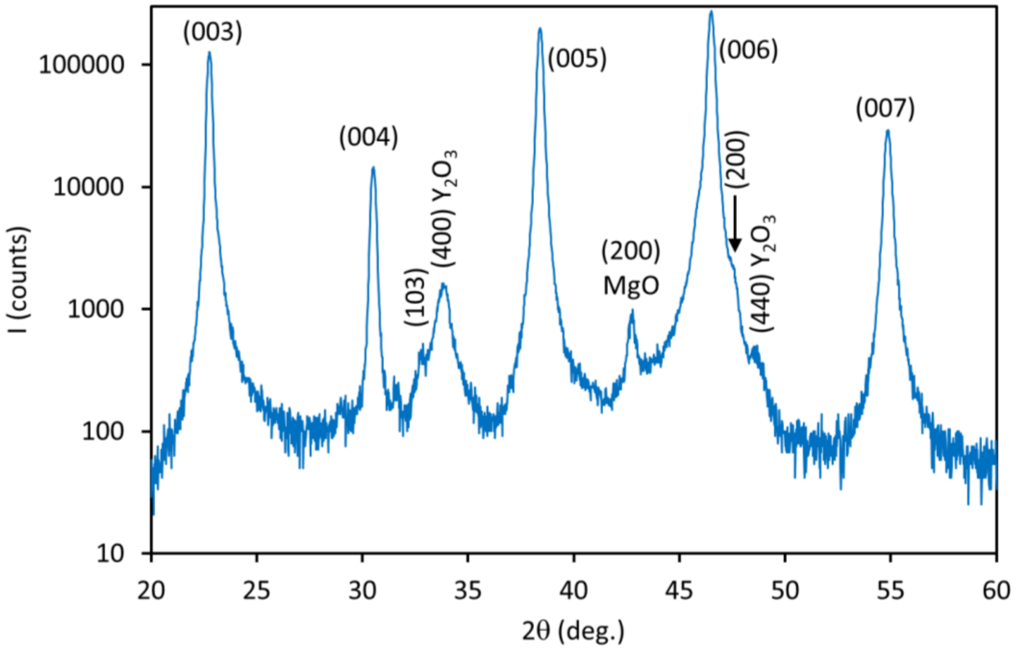
1. Yttrium as RE in REBCO. The smaller ionic radius of Y results in the higher charge carrier density and also in the lower electronic anisotropy and higher irreversibility field.

2. Y_2O_3 nanoparticles: uniformly distributed pinning centres, native to YBCO. Simple composition and microstructure facilitates reproducible fabrication. In contrast to the *c*-axis correlated extrinsic nano-columnar APC, a challenge to implement.

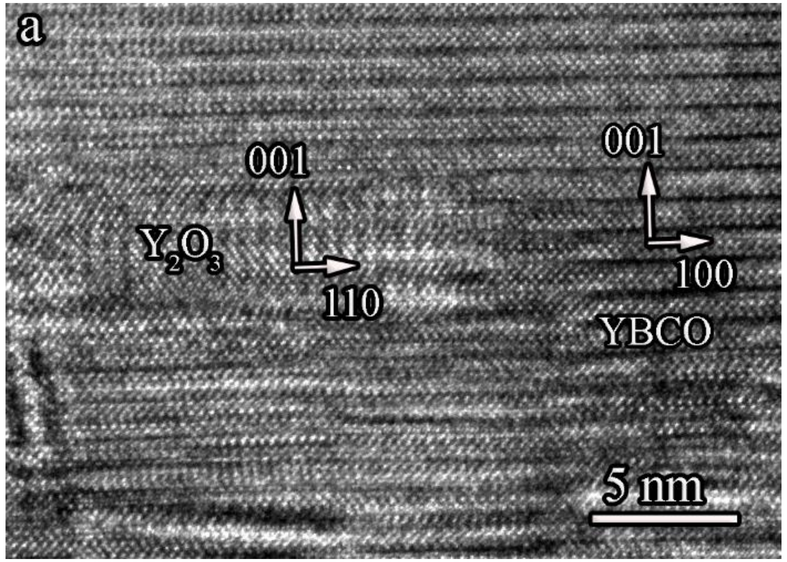
3. Very low neutron cross-section of Y (1.28 b) compared to those of Gd (49,000 b) and Eu (4570 b). This is of particular importance for fusion.

4. Higher J_e: 2+ μm thick YBCO films on 40 μm thin substrate.

SuperOx wire for in-field use:
Simple, easy to reproduce nanostructure

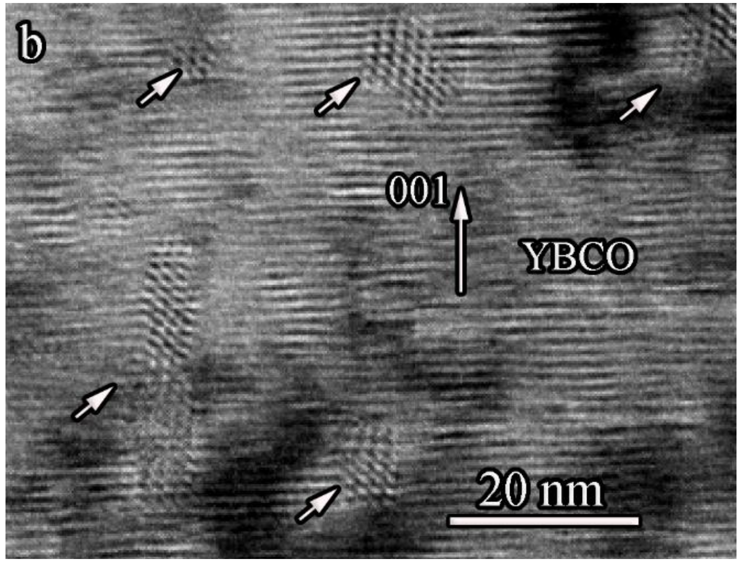


XRD: (001)- and (110)-oriented Y_2O_3 nanocrystals
20 nm mean size (001)



TEM: (001) Y_2O_3 nanoparticles

5-30 nm tall x 20-100 nm wide



TEM: (110) Y_2O_3 nanoparticles

5-20 nm, isotropic

- Randomly distributed Y_2O_3 nanoparticles
- High density: 4000 ± 2000 μm^{-2}

SuperOx wire for in-field use: Record I_c and J_e

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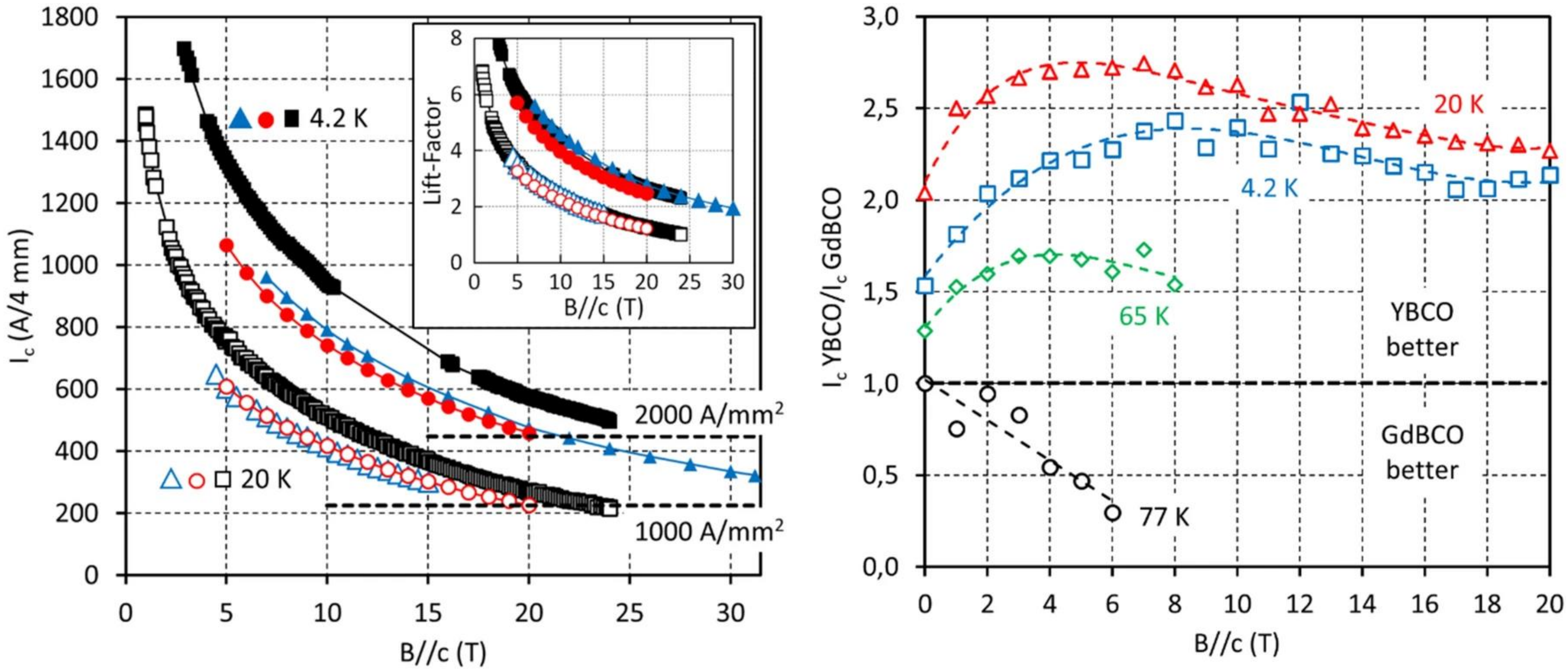

- J_e (40 μm sub, 2*5 μm Cu):
  - 1000+ A/mm² @ 20 K, 20 T;
  - 2000+ A/mm² @ 4.2 K, 20 T
- YBCO is 2-2.5 times better than SuperOx GdBCO at 20 and 4.2 K

SuperOx wire for in-field use: Minimum I_c is at B//c

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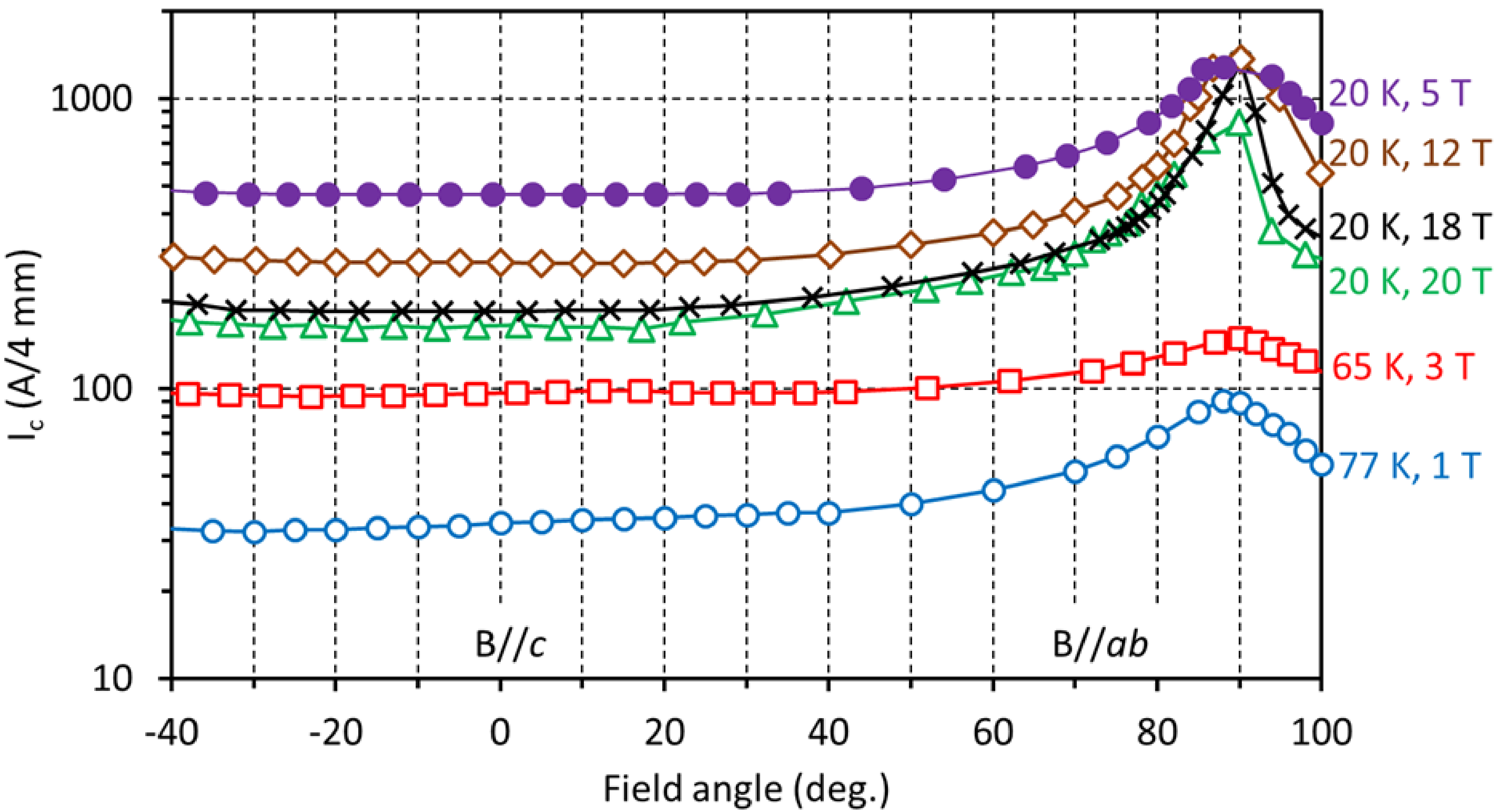

- NO columnar APC
- Pinning by Y_2O_3 nanoparticles

SuperOx wire for in-field use:
Best commercial wire for magnets today

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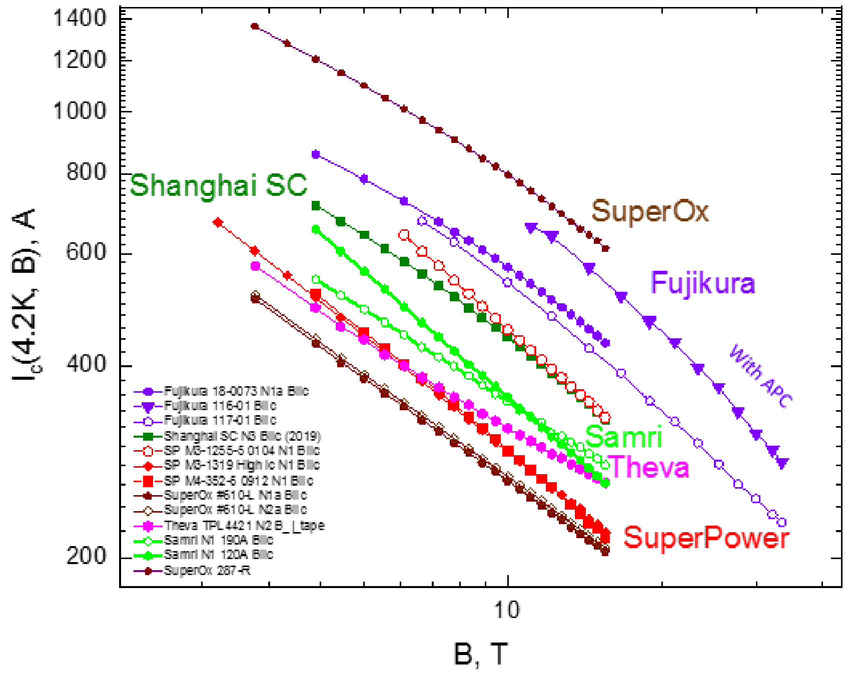

NATIONAL MAGLAB

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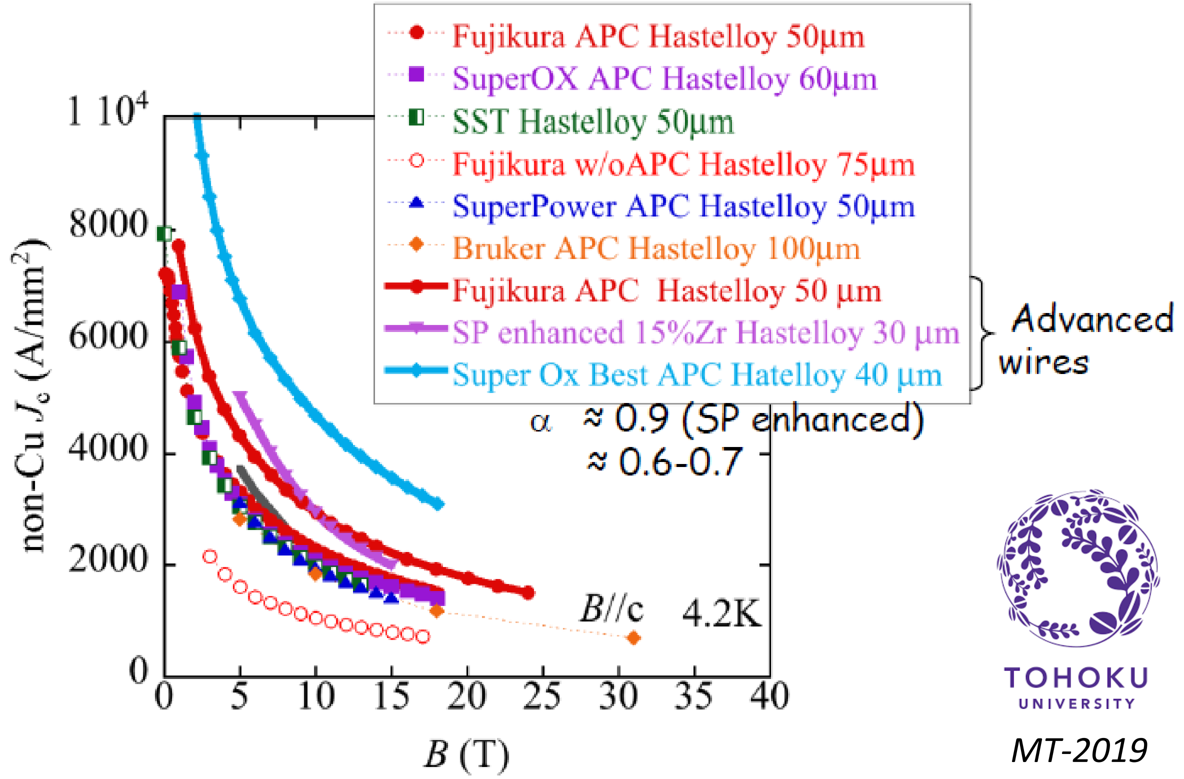
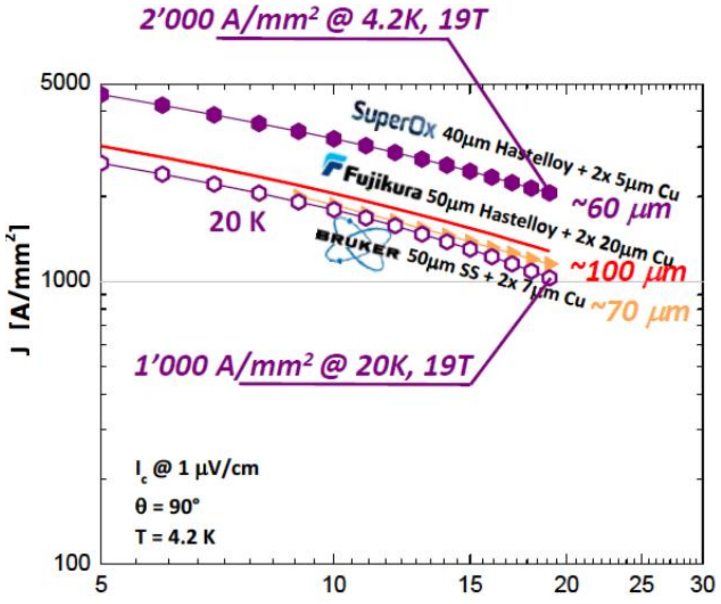


TOHOKU UNIVERSITY

MT-2019

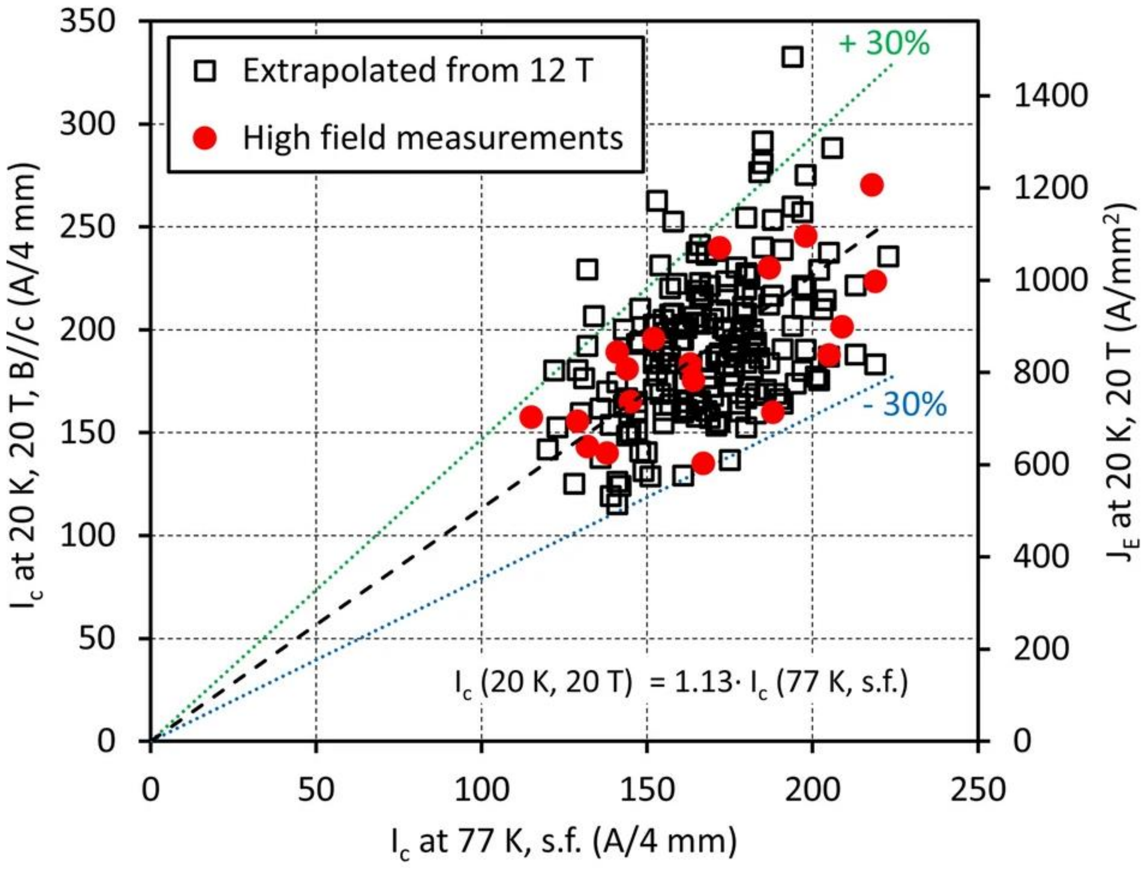


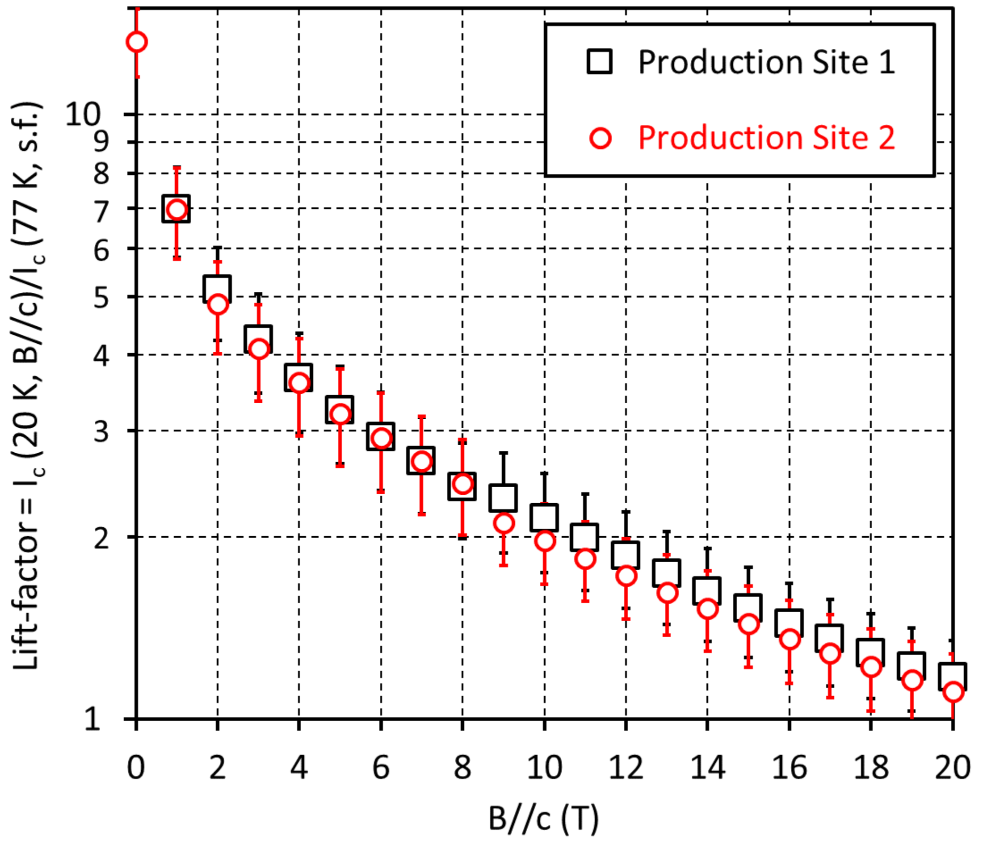
UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

FCC Week 2019

I_c 30% higher than competition

SuperOx wire for in-field use:
300+ km of 4 mm wire delivered to customers in 9 months





- Reasonable statistical spread of in-field properties: StD ~ 15%
- Wires fabricated at S-Innovations and SuperOx Japan are identical

SuperOx wire for in-field use: 30 µm thick substrate gives more J_e

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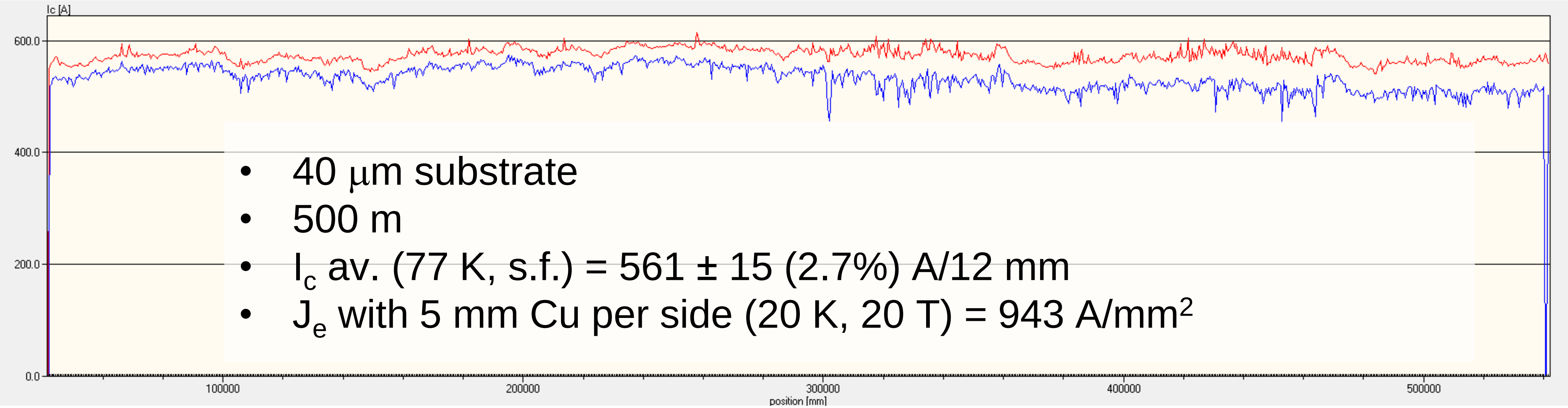
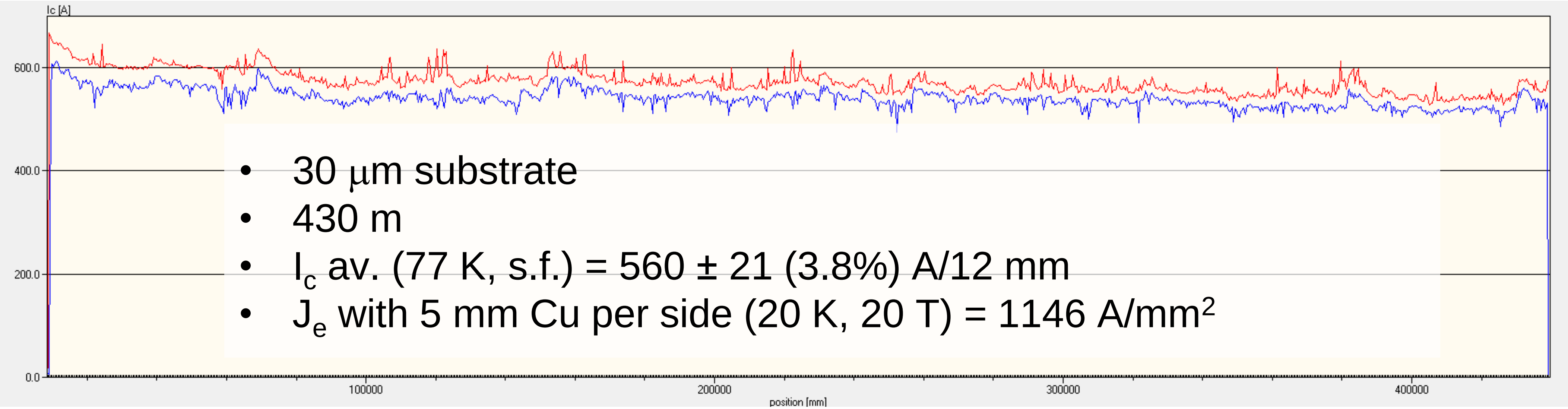


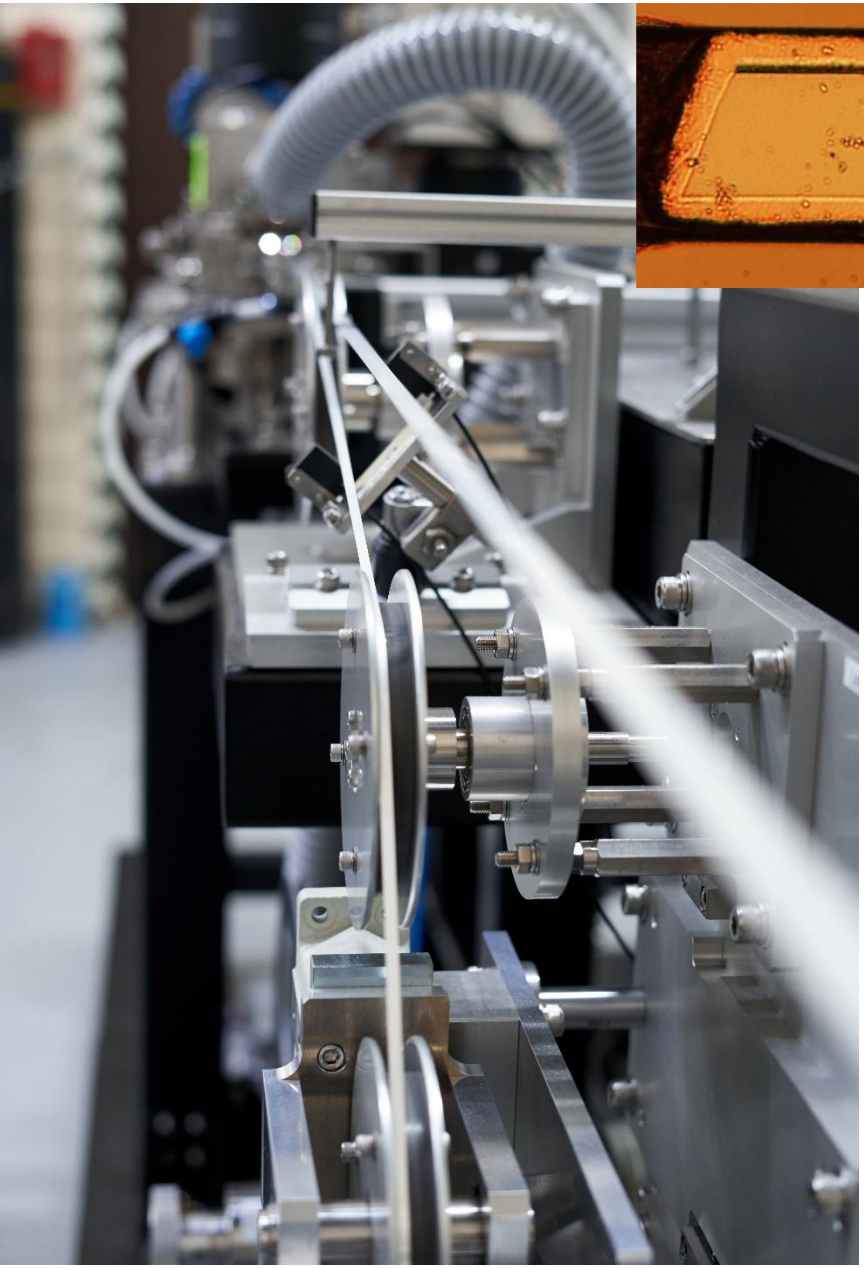
- 40 µm substrate
- 500 m
- I_c av. (77 K, s.f.) = 561 ± 15 (2.7%) A/12 mm
- J_e with 5 mm Cu per side (20 K, 20 T) = 943 A/mm^2

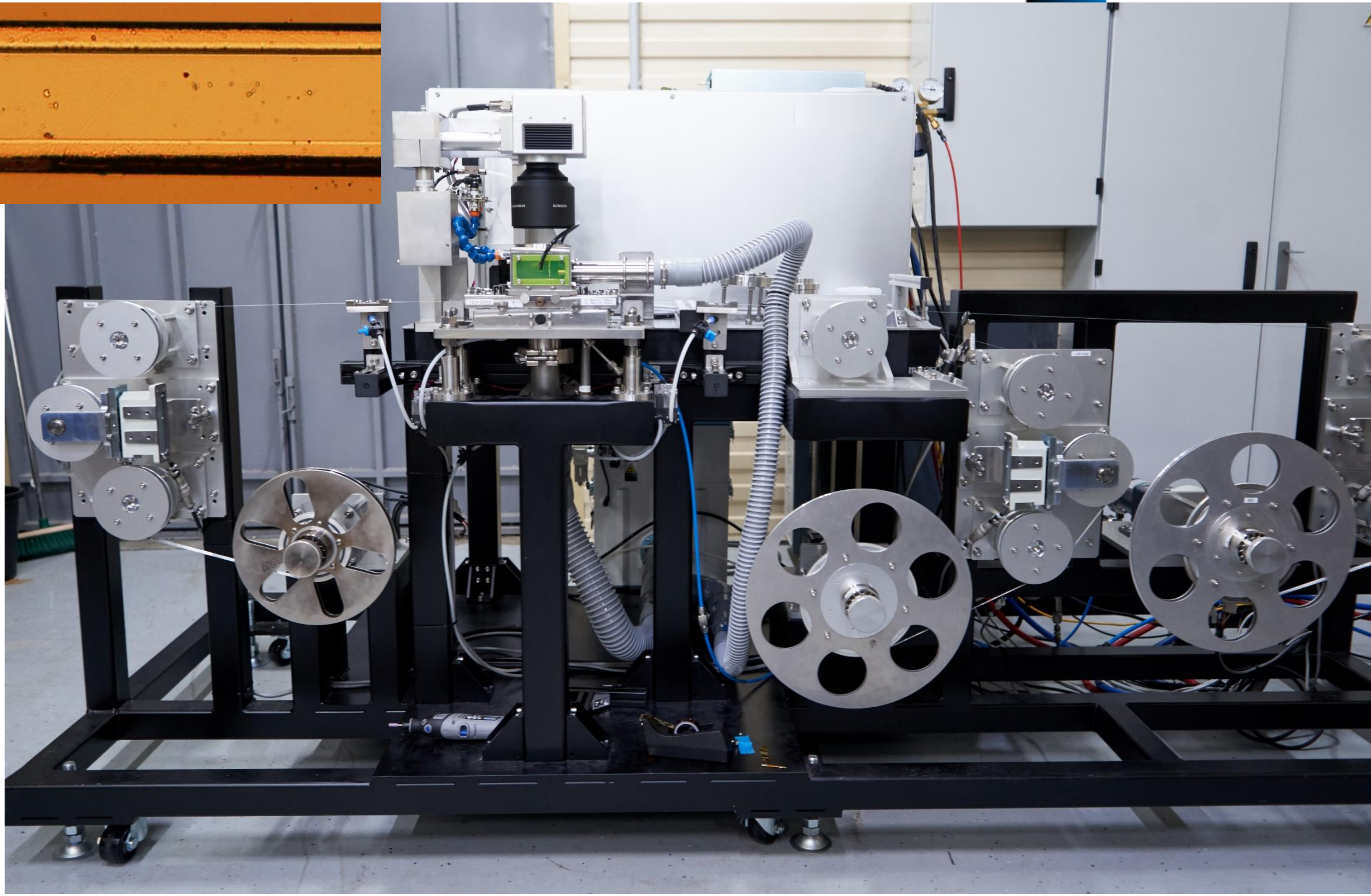


- 30 µm substrate
- 430 m
- I_c av. (77 K, s.f.) = 560 ± 21 (3.8%) A/12 mm
- J_e with 5 mm Cu per side (20 K, 20 T) = 1146 A/mm^2

Same performance, + 20% J_e with 5 µm Cu per side

Laser slitting





- Slit edge is clean and free of cracks
- Less mechanical damage due to stress in applications

Summary

- The SuperOx group:
  - Produce and sell 2G HTS wire
  - Commercialise HTS applications
- Production technology and capacity:
  - Operate at 100%, scale-up to reflect demand
- Wire for in-field use:
  - YBCO with Y_2O_3 nanoparticles
  - Produced daily in large volumes
  - Record commercial J_e: 1000+ A/mm^2 at 20 K, 20 T; 2000+ A/mm^2 at 4.2 K, 20 T
  - 30 μm substrate adds another 20% to J_e comparing to 40 μm substrate
- Laser slitting:
  - Clean slit edge

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Thank you for your attention

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