Status of HTS wire and conductor production and development at SuperOx

Outline

2G HTS wire production

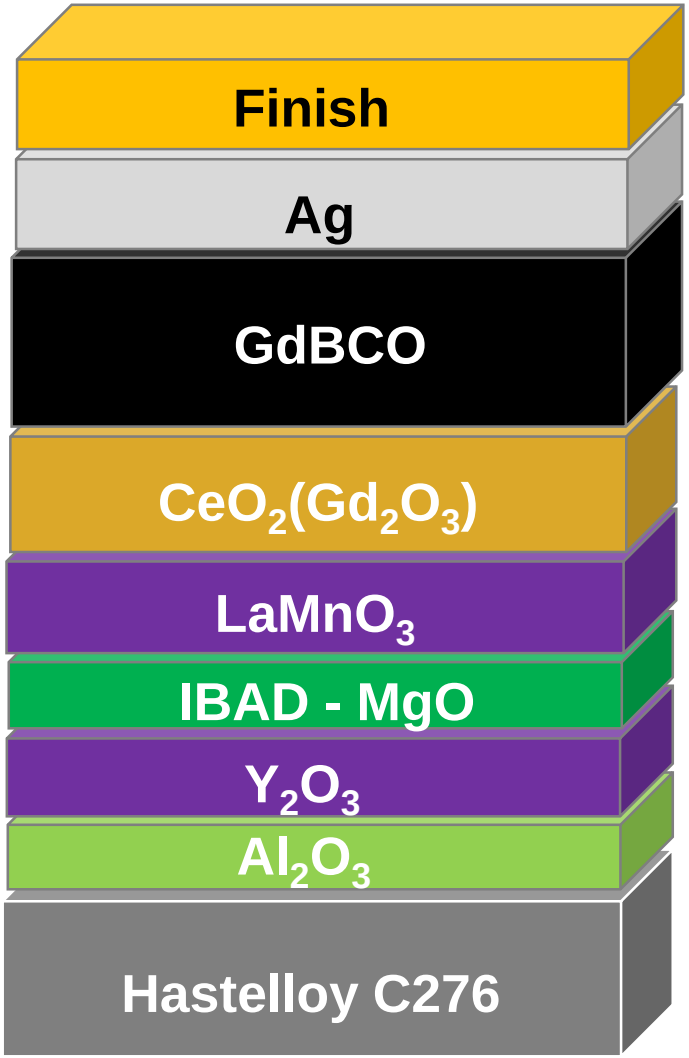
- Production facility expansion
- Consistent performance of production wire
- R&D in artificial pinning
- Filaments

Conductor development

- Commercial Punch-and-Coat 2G HTS Roebel cables

HTS dipole magnet

2G HTS wire architecture



Customised finish tailored to application

Sputtering (custom thickness)

PLD (1-3 microns)

PLD (100-200 nm)

Sputtering (30-50 nm)

e-beam IBAD (5-7 nm) + epi (50-150 nm)

Sputtering (5-10 nm)

Sputtering (30-50 nm)

Cold rolled & electro polished
(60 or 100 microns)

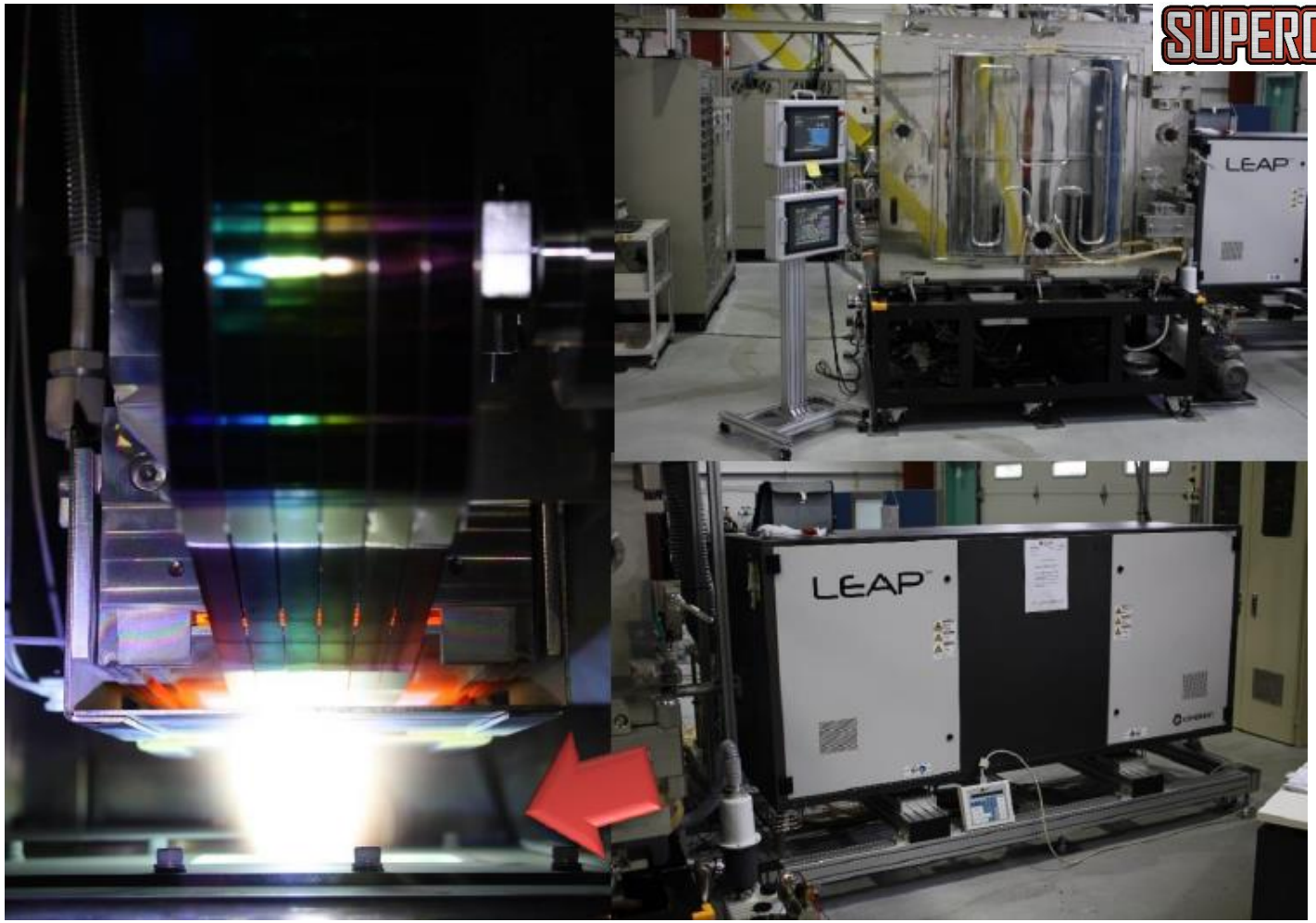
Production status and development

Originally: 2011-2015						
Moscow	Substrate			Ag	Cu	Finish
Tokyo		Buffer	HTS	Ag		

At present: 2017						
Moscow	Substrate	Buffer	HTS	Ag	Cu	Finish
Tokyo		Buffer	HTS	Ag	Cu	

Decisions to increase throughput are driven by demand

SuperOx Japan LLC: in operation since Nov 2011



Multiprocess one-chamber sputtering/IBAD system
Dual-chamber PLD-HTS system for CeO_2 and GdBCO

Japan: Cu e-plating line commissioned Jun 2016

SuperOx

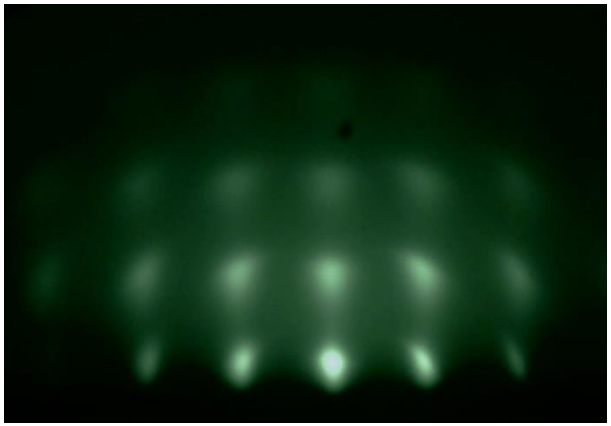
SUPEROX JAPAN

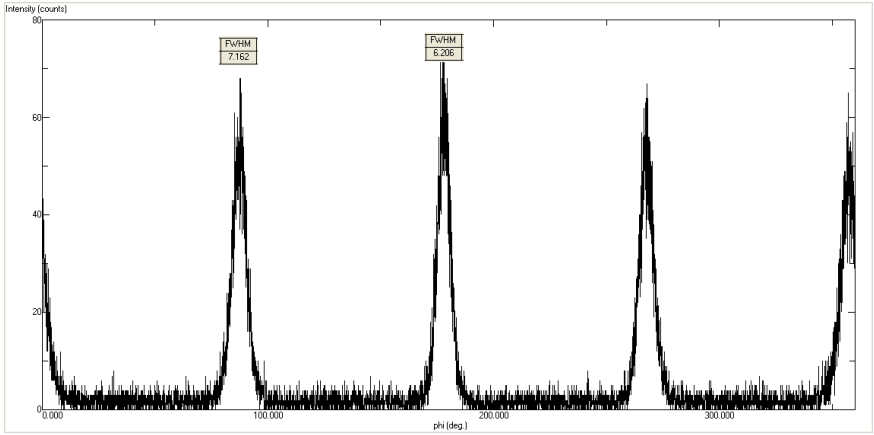
Moscow buffer layer line commissioned Jan 2016

SuperOx

e-Polished Hastelloy substrate in
Ready buffered tape with $LaMnO_3$ on top out

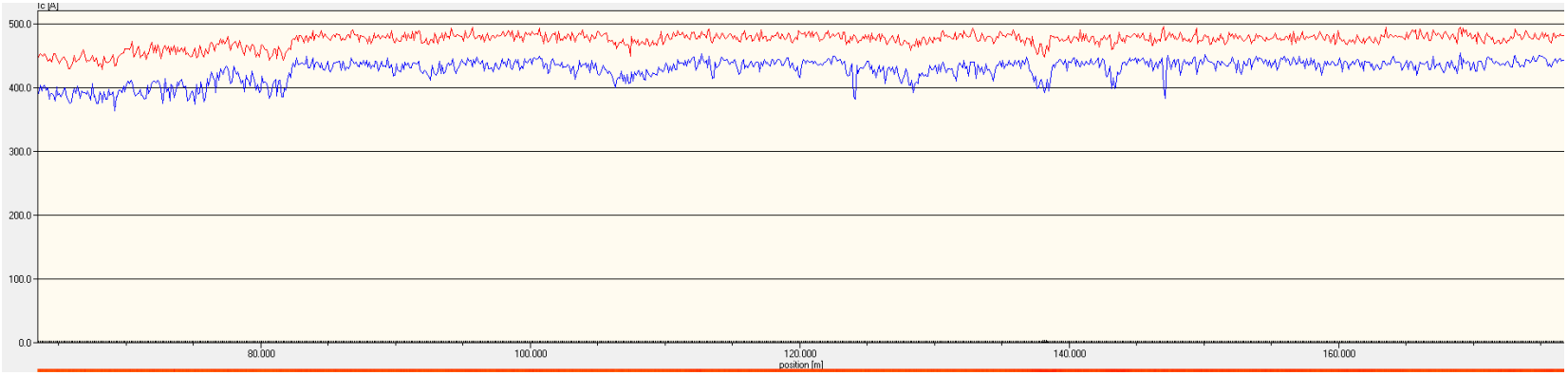
Moscow buffer layer line commissioned Jan 2016





Good IBAD-MgO RHEED patterns

$\Delta\phi$ (110) LMO < 7°



High I_c by PLD-HTS on Moscow buffer

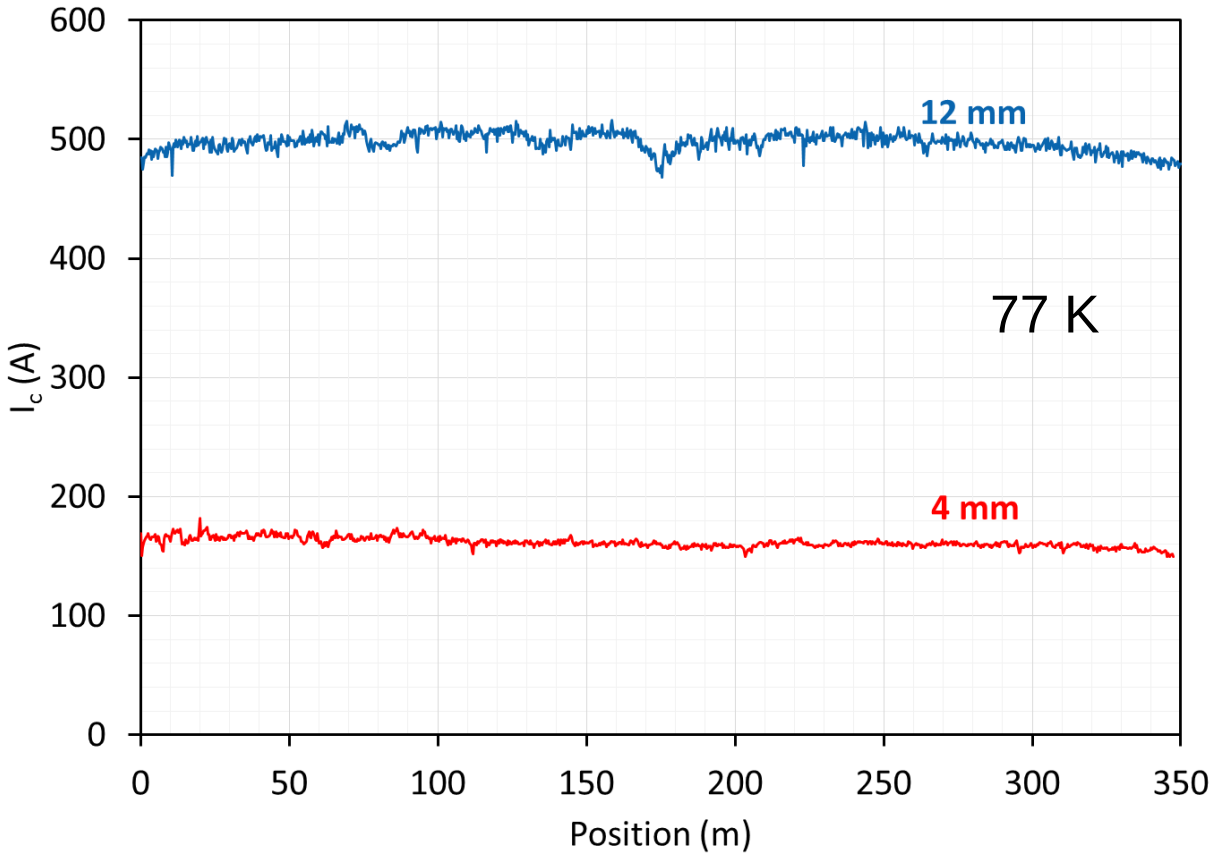
Moscow PLD-HTS line commissioned Dec 2016

SuperOx

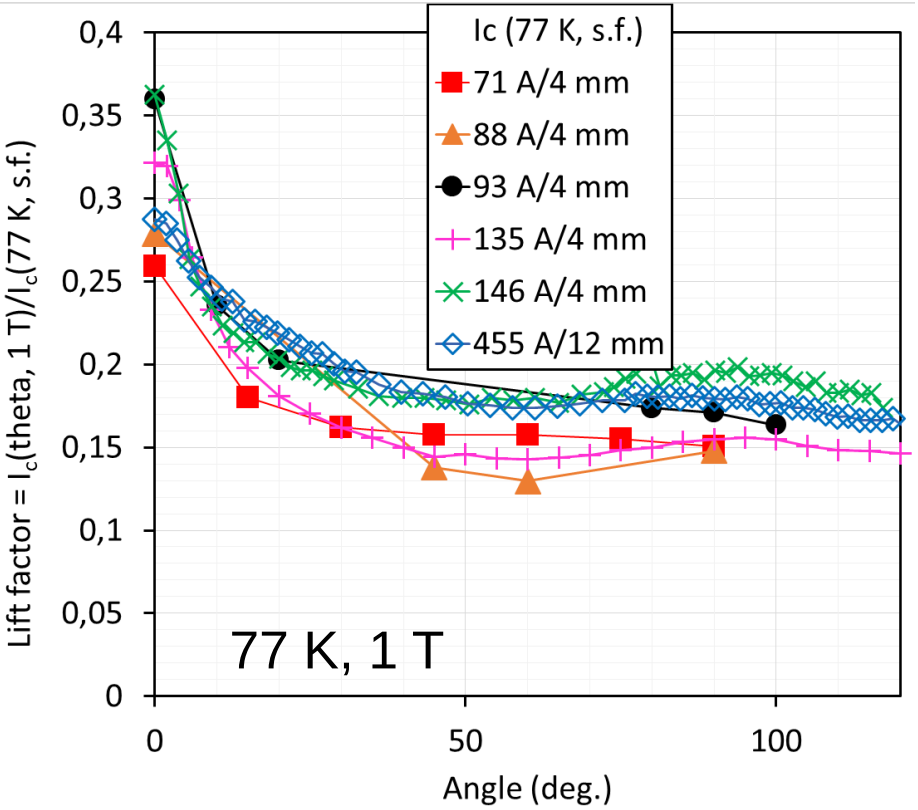
Quality control

	Substrate	Buffer	HTS	Ag	Cu	Finish
In-line	Optical	RHEED				
Off-line, full length				Non-contact I_c	Non-contact I_c	Non-contact I_c
Off-line, segments	AFM	XRD	XRD SEM EDX	Transport I_c	Transport I_c	Specific tests

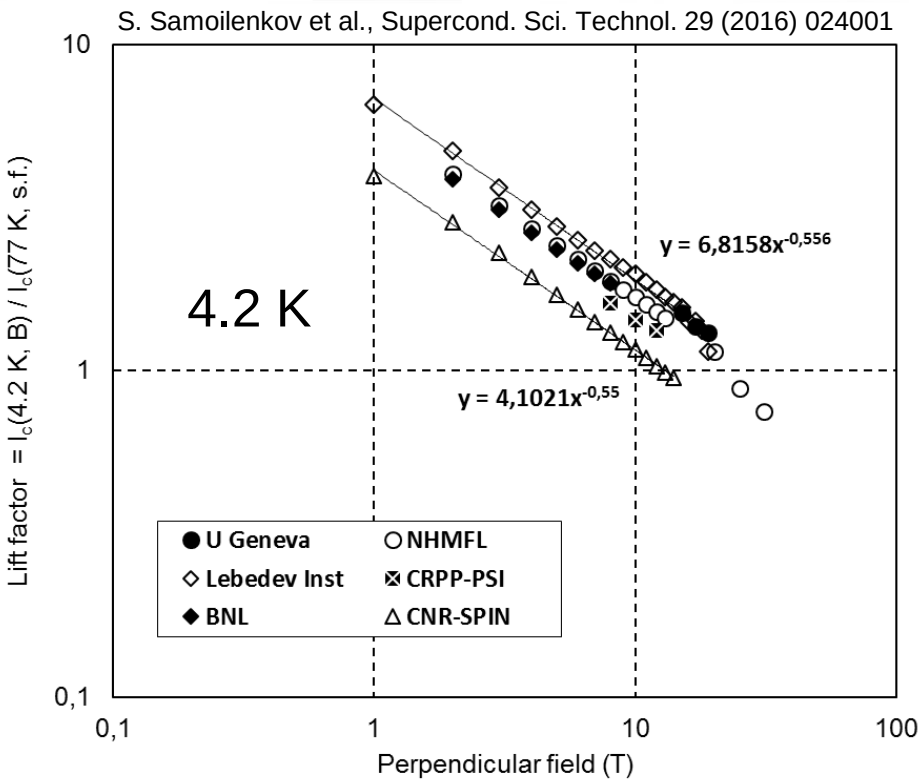
2G HTS wire: high I_c over long length



2G HTS wire: consistent performance



Low angular anisotropy

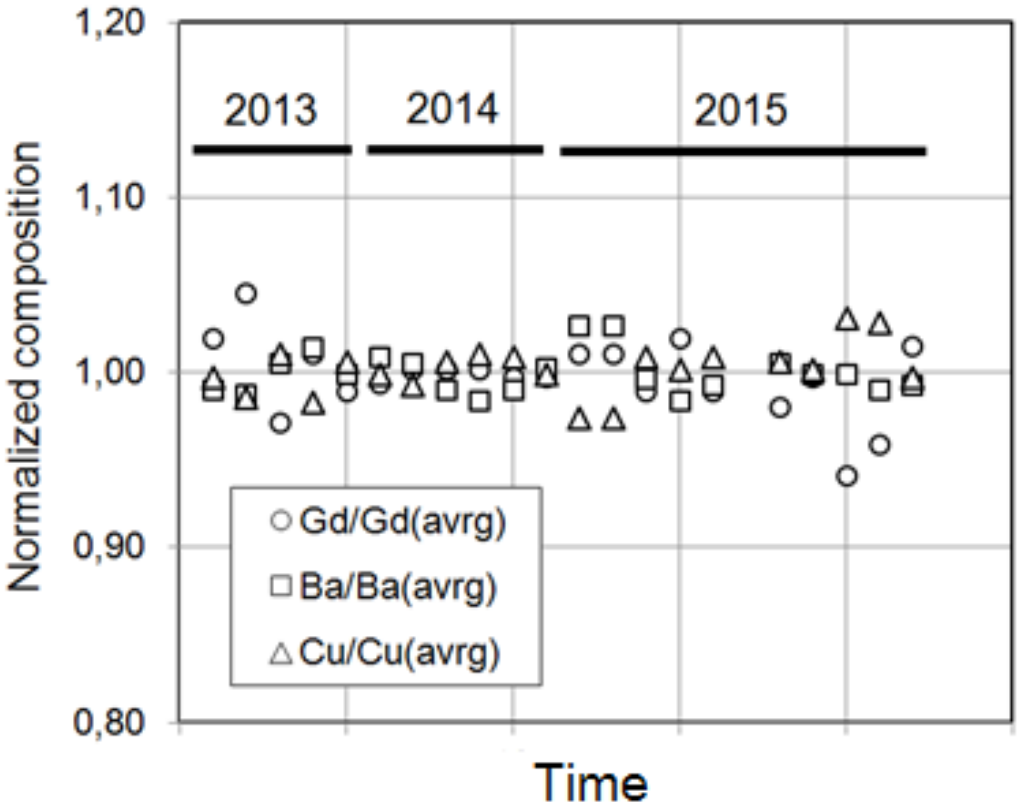


Reproducible lift factors

NO artificial pinning centres, only intrinsic Gd_2O_3 nanoparticles due to excess Gd

Data updated regularly, available for download at
http://www.superox.ru/en/products/974-vtspprovod/

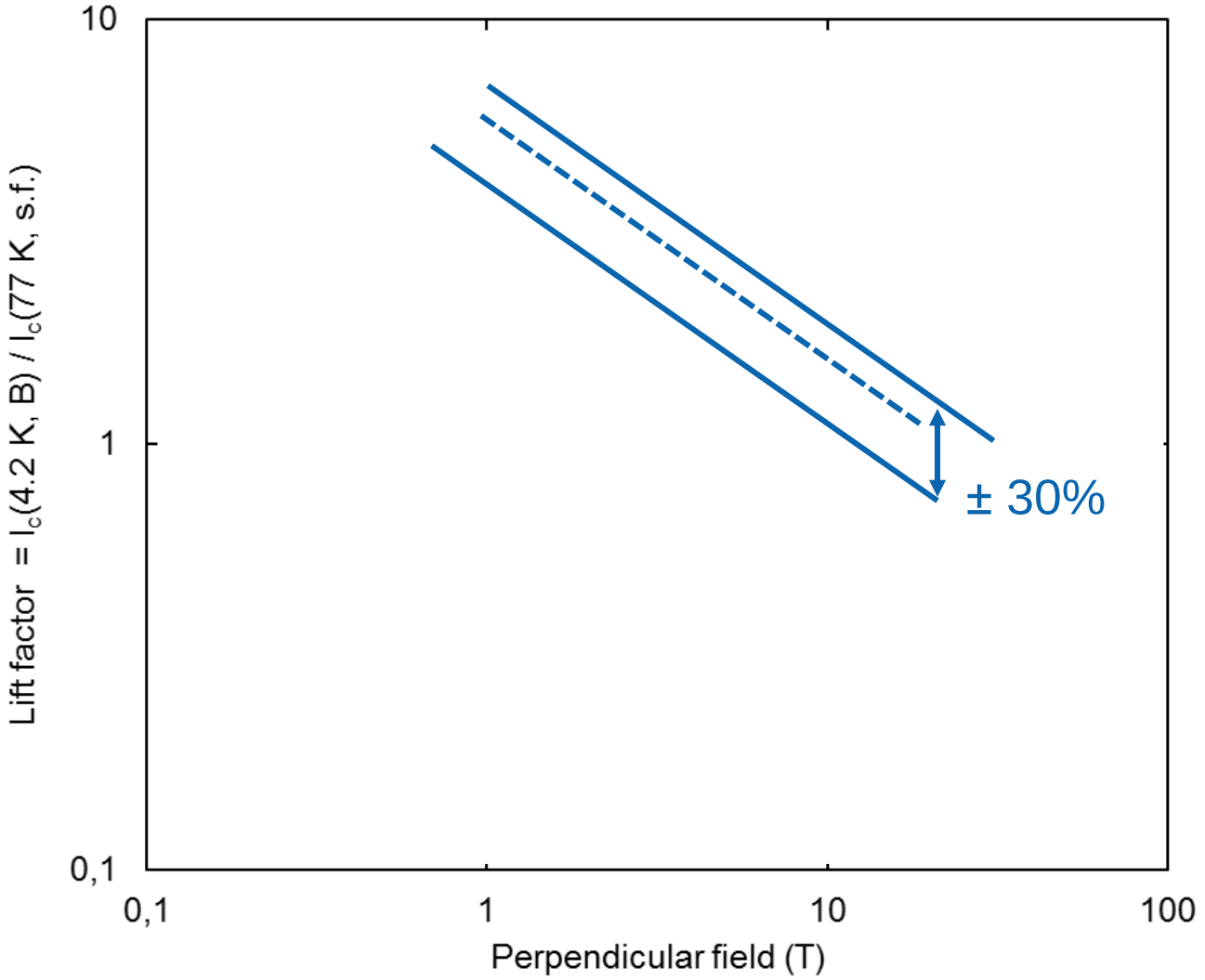
2G HTS wire: consistent HTS composition



Consistent composition and microstructure of the PLD-GdBCO layer over years of production result in consistent wire performance

2G HTS wire: artificial pinning in production?

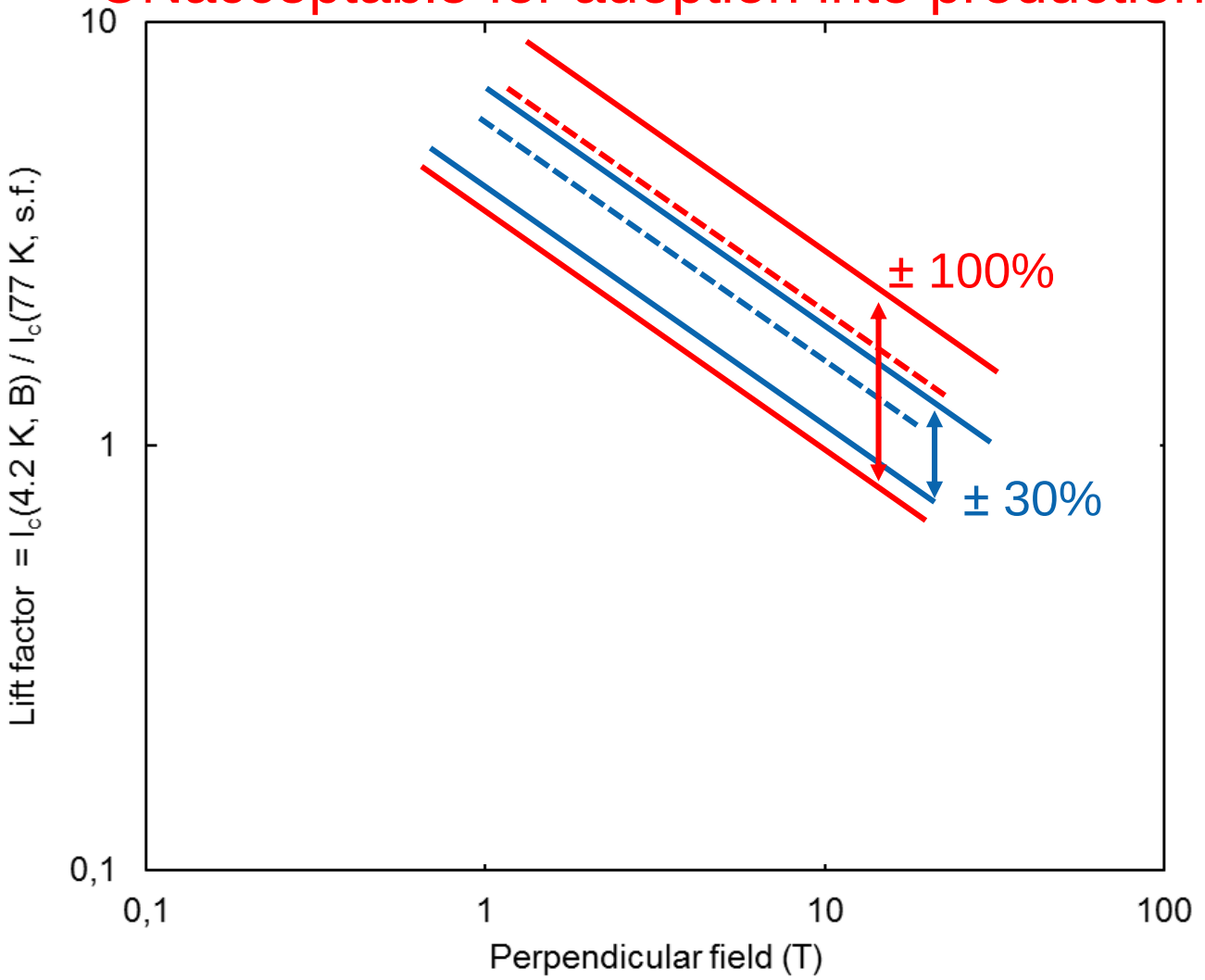
Present status: no artificial pinning



2G HTS wire: artificial pinning in production?

Scenario 1

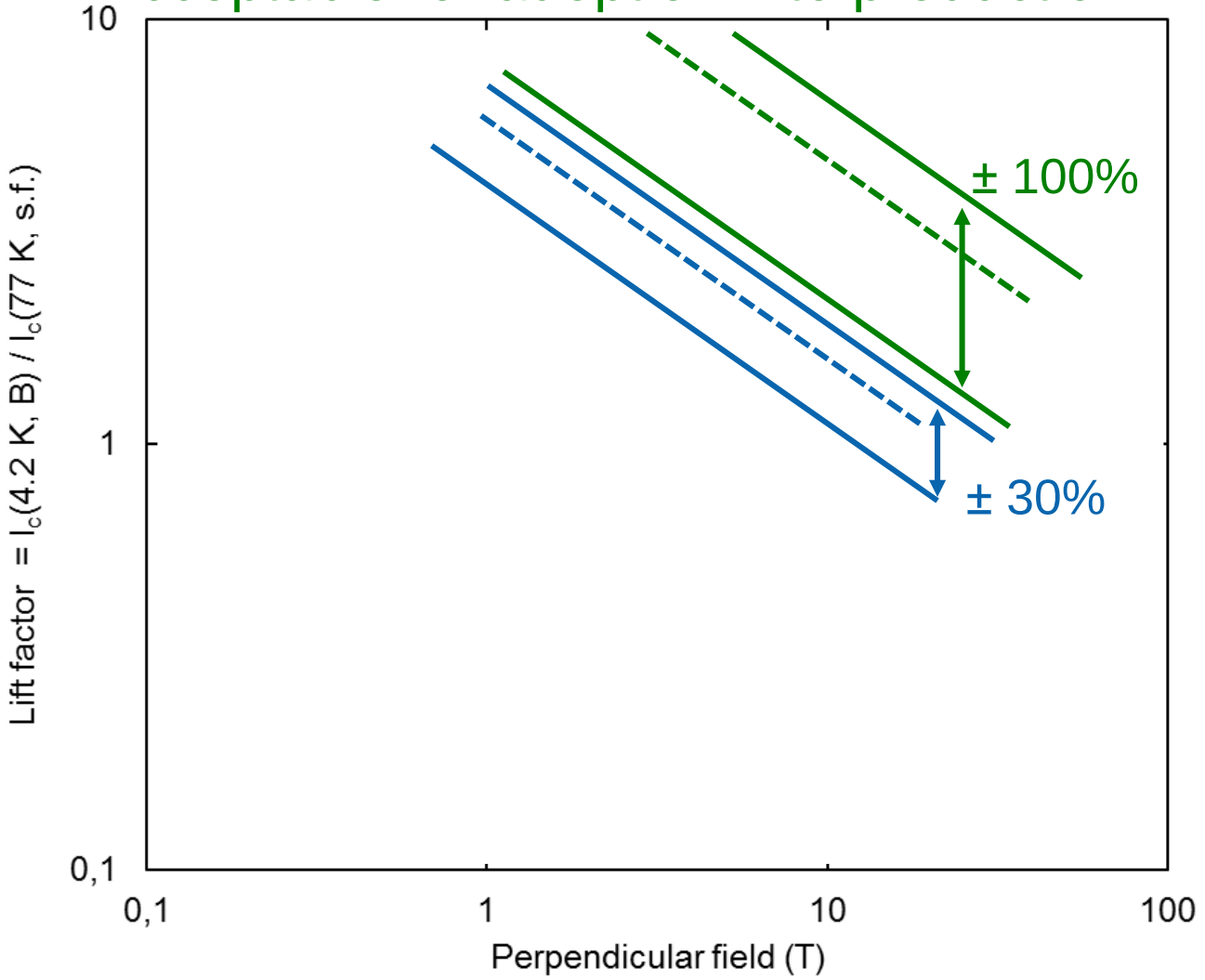
UNacceptable for adoption into production



2G HTS wire: artificial pinning in production?

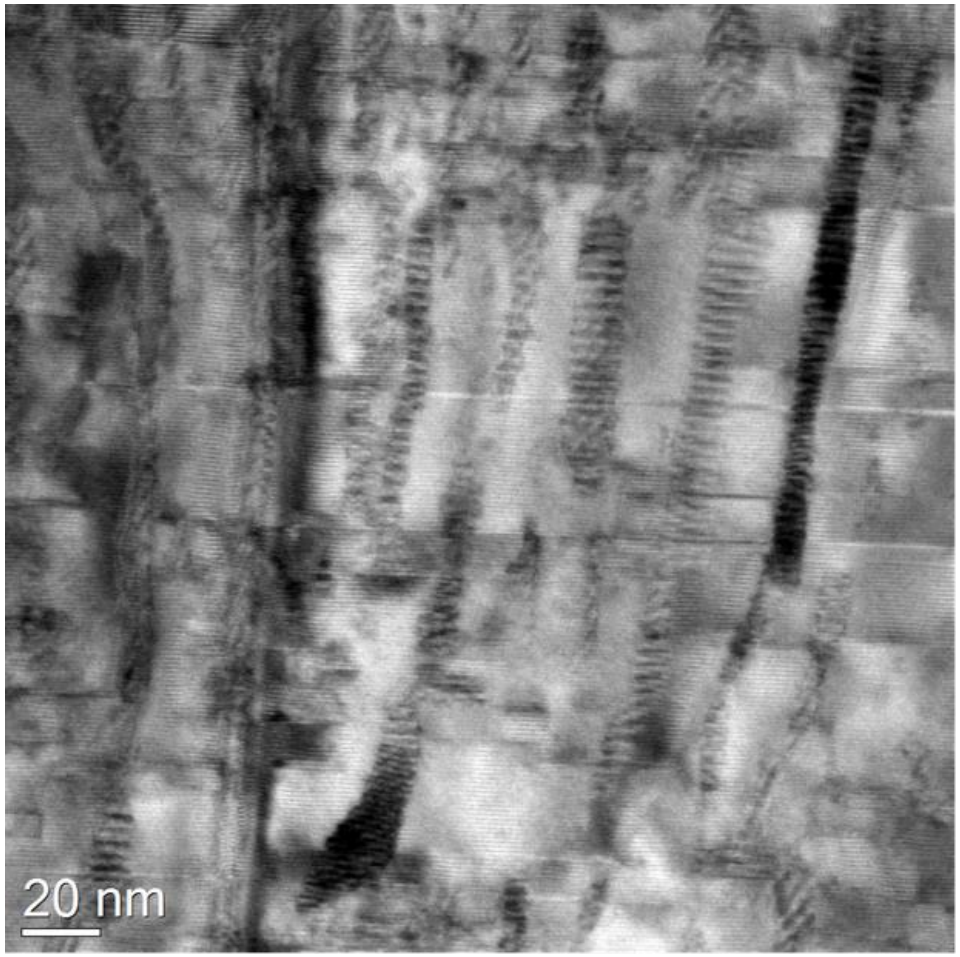
Scenario 2

Acceptable for adoption into production



2G HTS wire: artificial pinning in high rate PLD

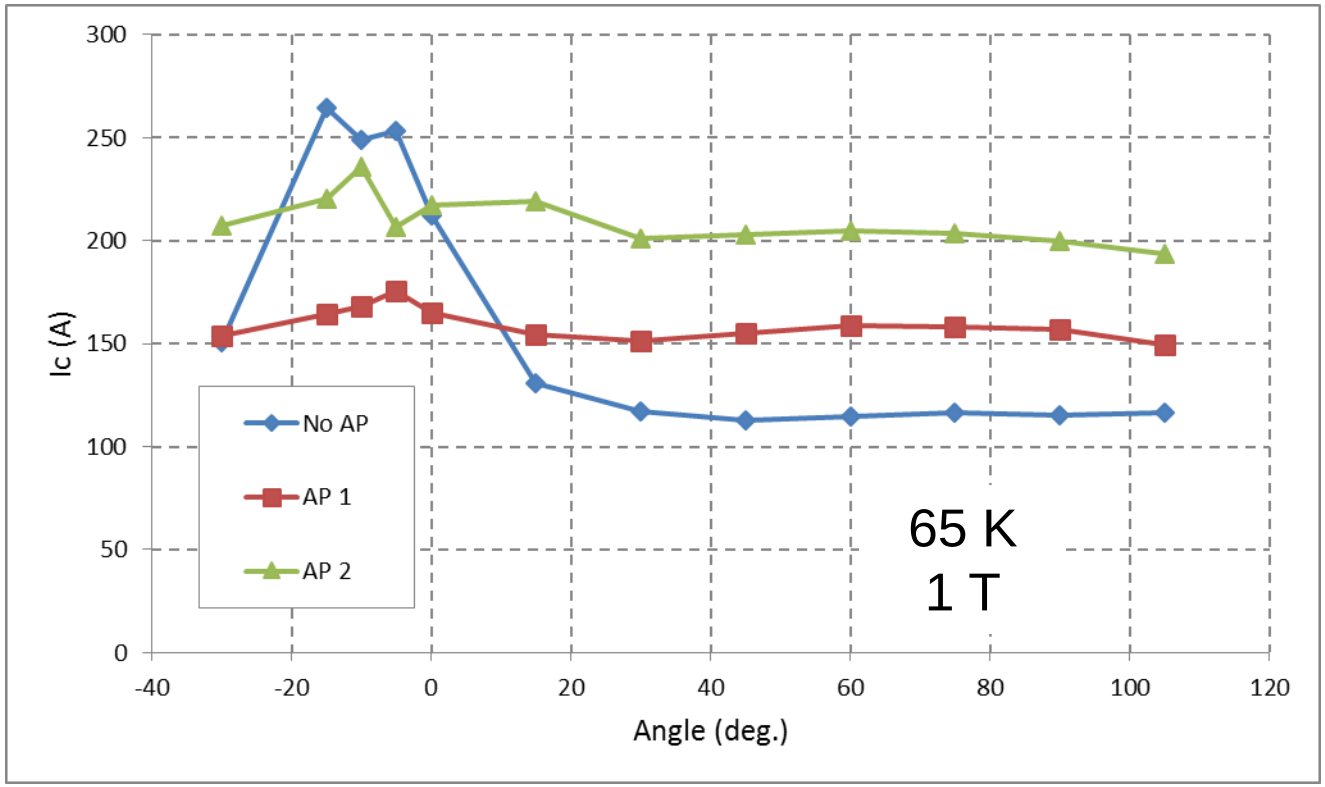
first R&D results



Production rate PLD. Classic nanocolumns of perovskite AP centres.

2G HTS wire: artificial pinning in high rate PLD

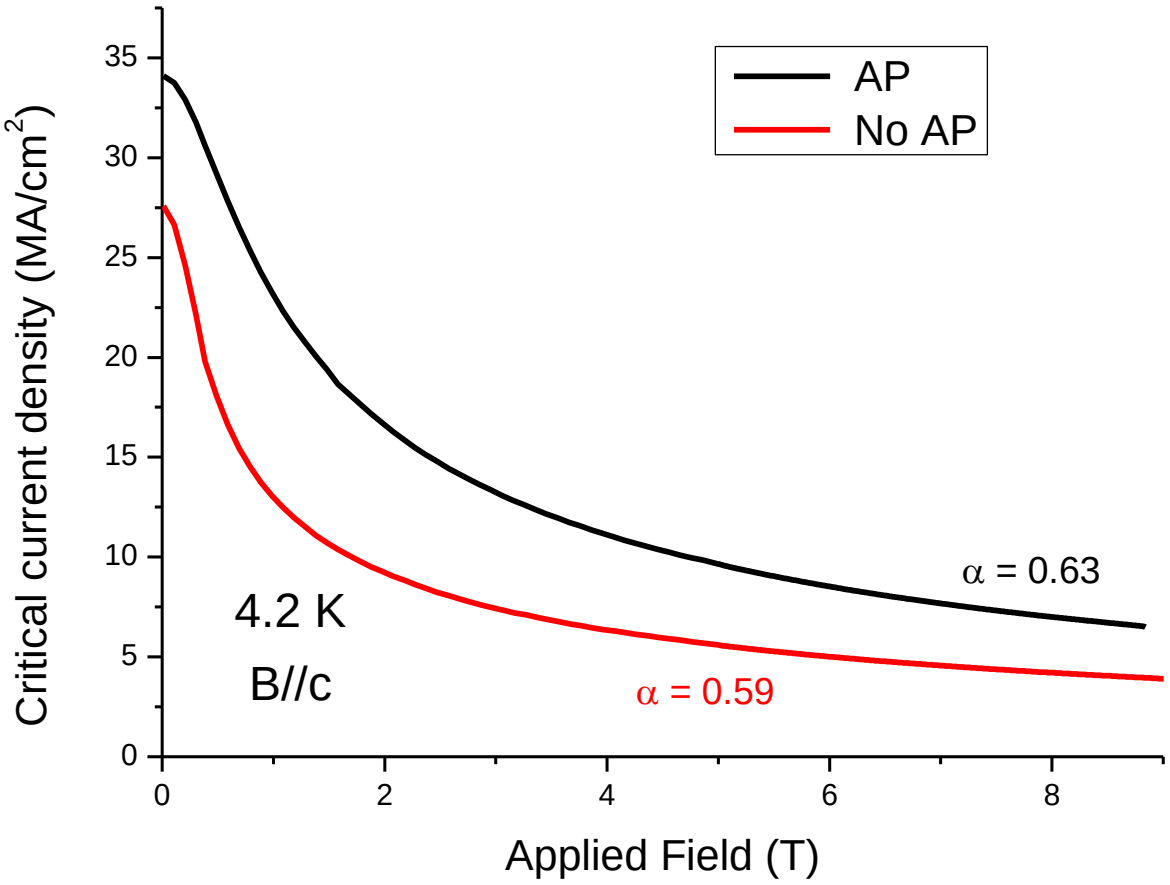
first R&D results



Less anisotropy and higher min. I_c in field with pinning

2G HTS wire: artificial pinning in high rate PLD

first R&D results



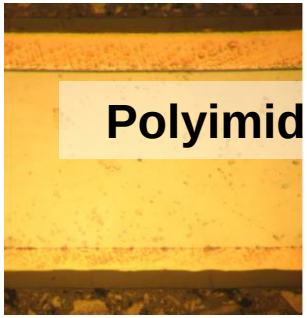
Higher J_c/I_c in liquid helium

Next steps:

- ❑ Optimise for specific T, B
- ❑ Verify reproducibility in production wires

2G HTS wire: customisation

Manufacturer	Customisation options							
	Silver	Copper plating	Lamination	Surround polyimide	Polyimide wrapping	Solder plating	Tape stacks	Filaments
AMSC	●		●		●			
Fujikura	●		●		●			
SuNAM	●	●	●		●			
SuperOx	●	●	●	●	●	●	●	●
SuperPower	●	●	●		●			



Polyimide deposition

Custom copper plating

Custom solder plating

Filamentisation for AC loss reduction

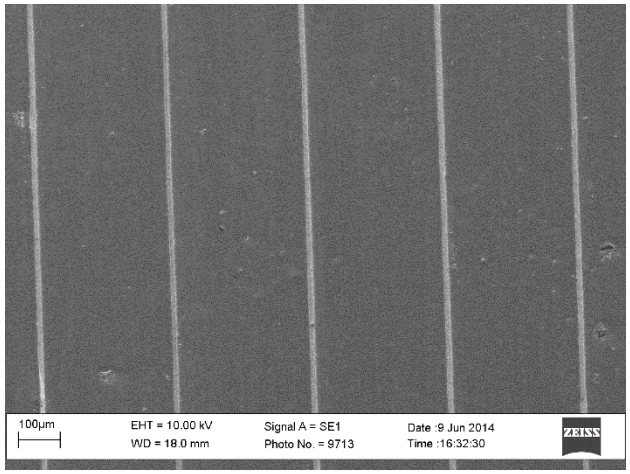
Collaboration with KIT

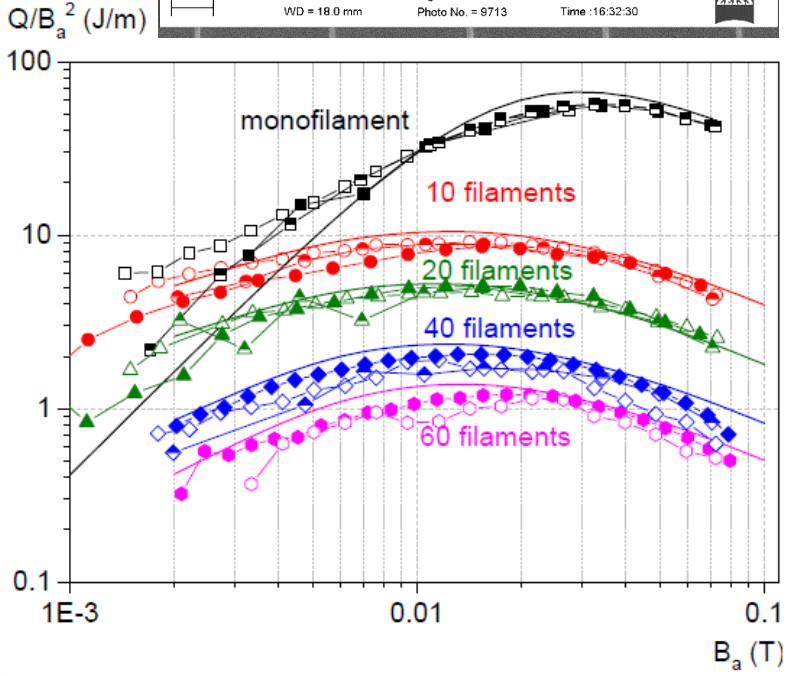
Finish-and-striate:

- SuperOx provides wire with different finish: 0-5-10-20 μm Cu
- KIT makes up to 120 laser striations and performs AC measurements

Striate-and-finish:

- KIT striates Ag-coated wire
- SuperOx electroplates 5-7-10 μm Cu





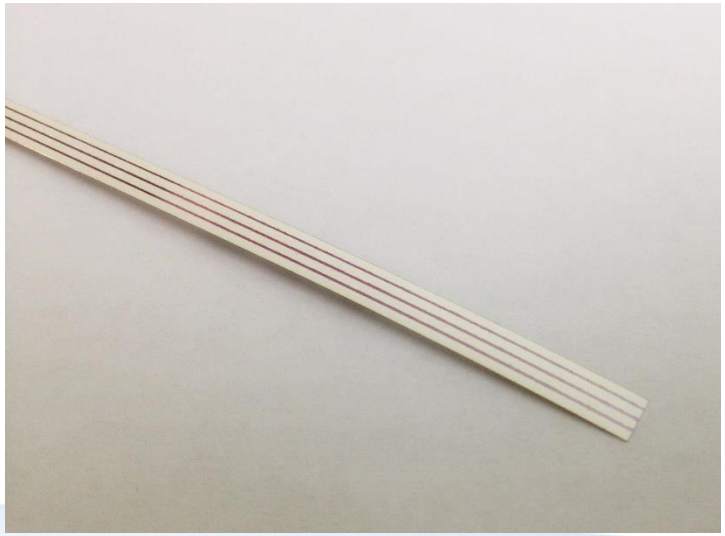
A. Kario, CCA-2014

Filamentisation: accepting orders

At SuperOx now:

- Available: reel-to-reel chemical etching
  0.1 mm grooves,
  0.9 mm filaments

- On the way: reel-to-reel laser scribing



2G HTS wire: specifications

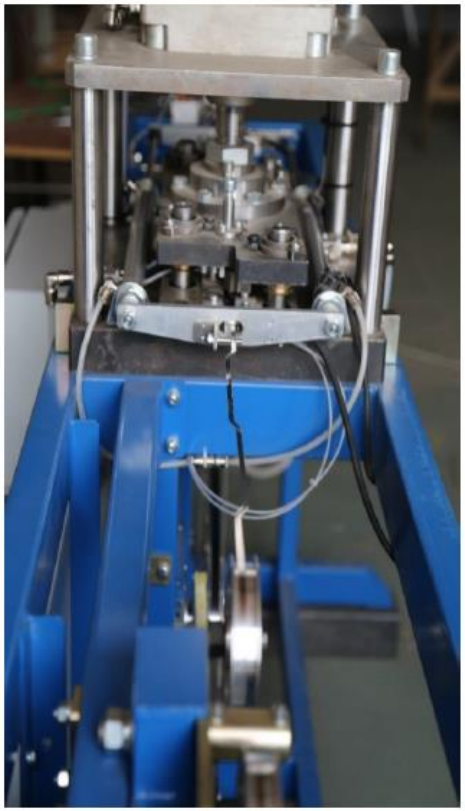
Parameter	Value	
Substrate Thickness	60 or 100 μm	
Tape width	4 mm	12 mm
Critical Current @ 77K, s.f.	100-150 A	300-500 A
J_e at 4.2 K, 20 T	> 400 A/mm^2	> 400 A/mm^2
Current Uniformity	±10%	±10%

Customisation:

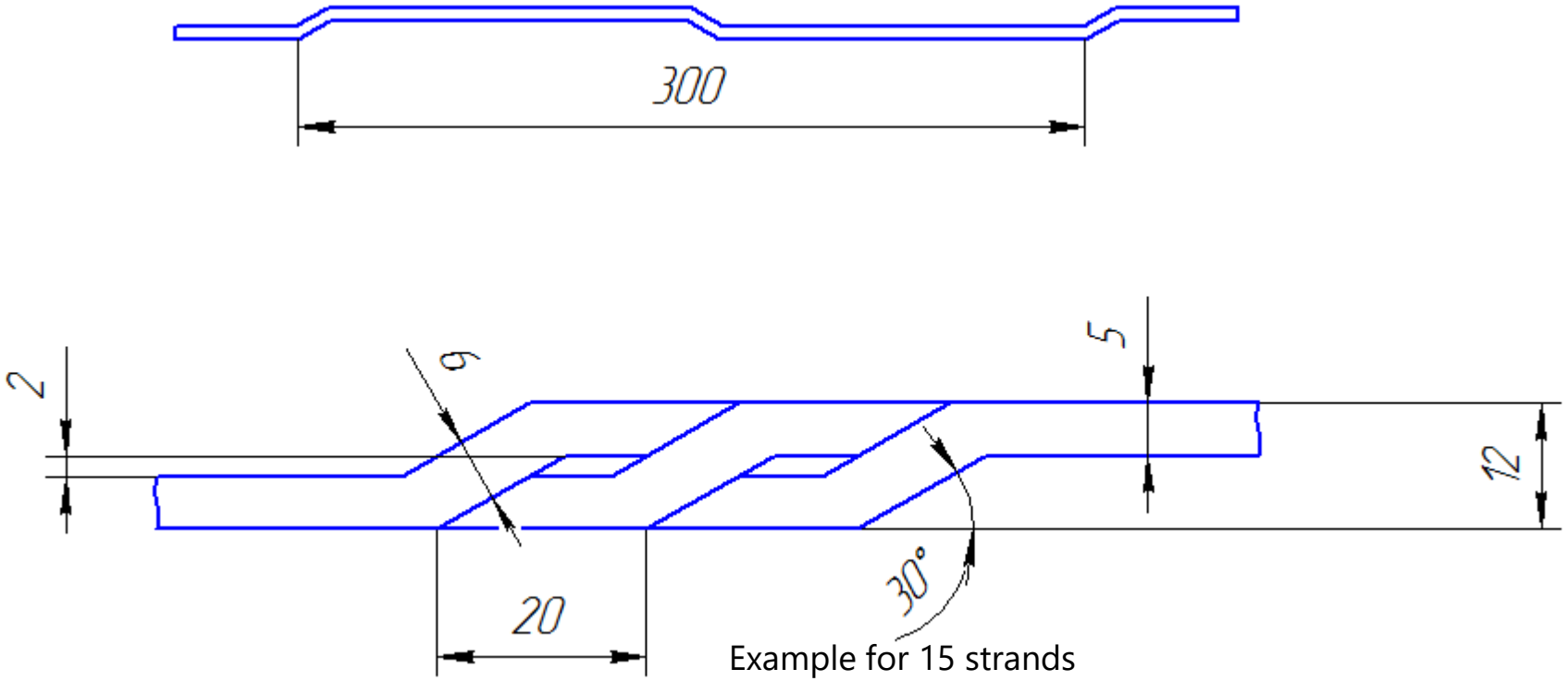
+ Variable silver thickness
+ Variable copper thickness
+ Lamination
+ Insulation
+ Solder plating
+ Low resistance splices
+ Filaments
+ … just ask

Commercial 2G HTS Roebel cables

- SuperOx acquired own machinery for Roebel cable fabrication
- Accepting orders on 2G HTS Roebel cable



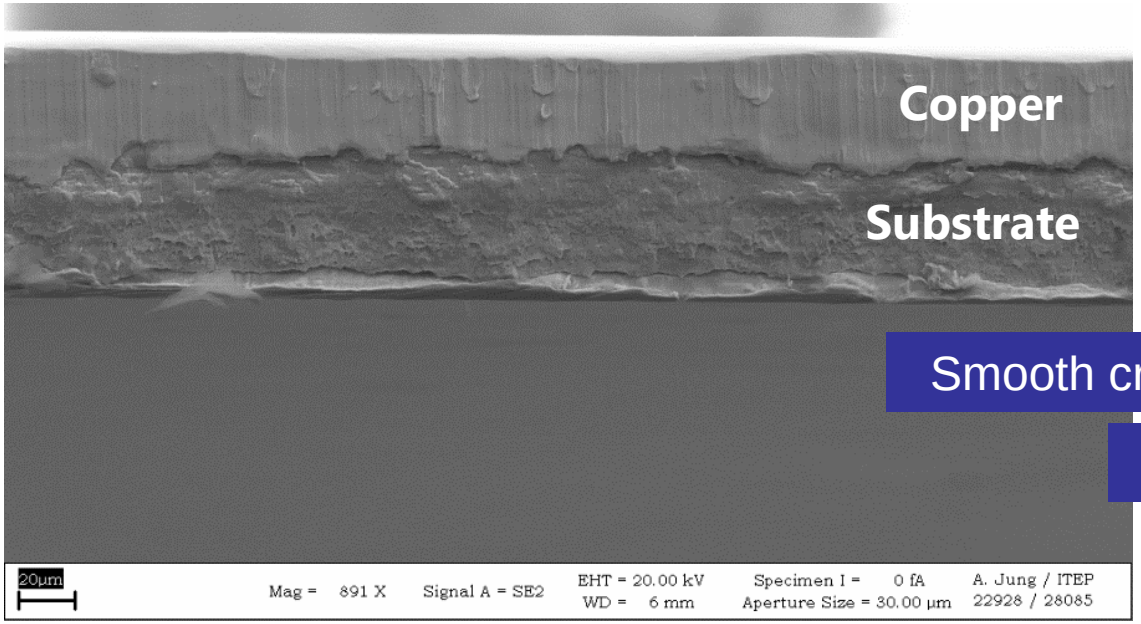
2G HTS Roebel cable and strand geometry

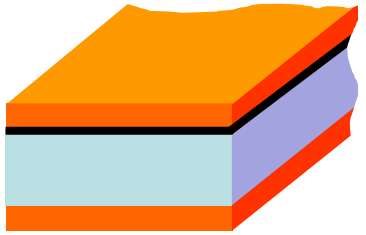


Example for 15 strands

Roebel cables: Coat-and-Punch

Standard way: punch copper plated 2G HTS wire





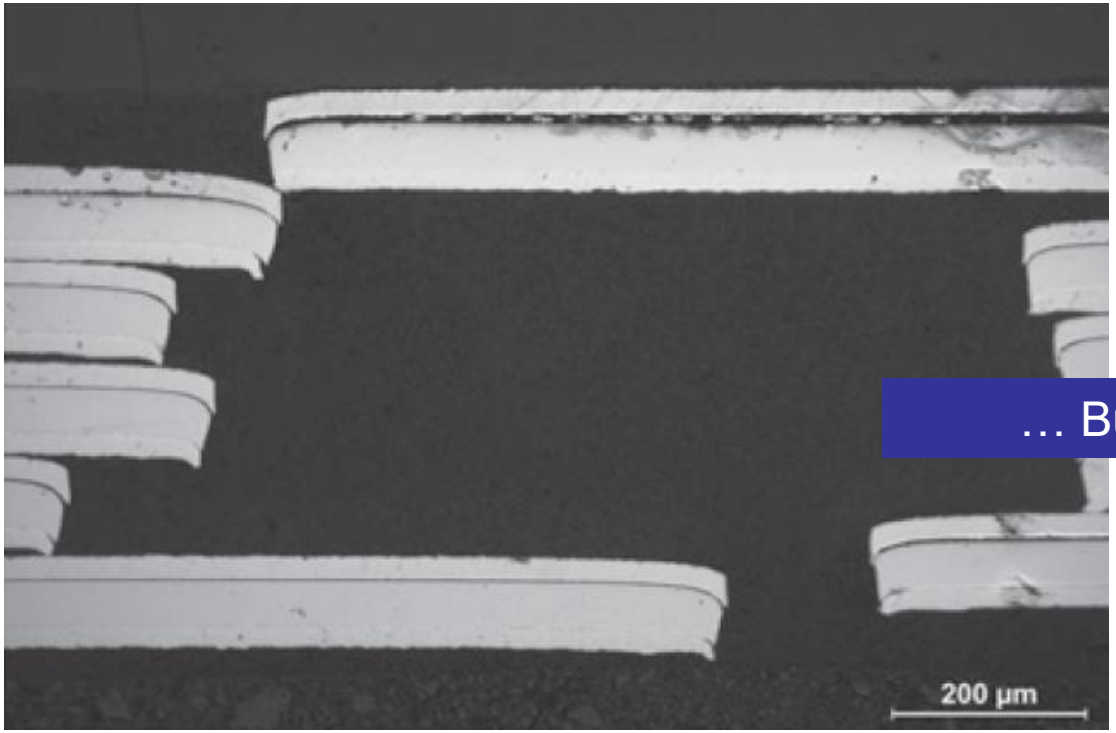
Smooth cross-section of the punched edge

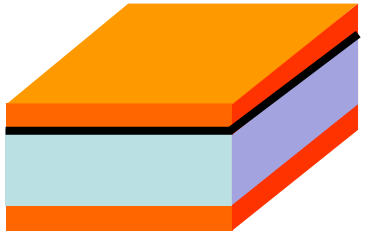
Cu gets smeared over HTS layer

Well, most times …

Roebel cables: Coat-and-Punch

Standard way: punch copper plated 2G HTS wire

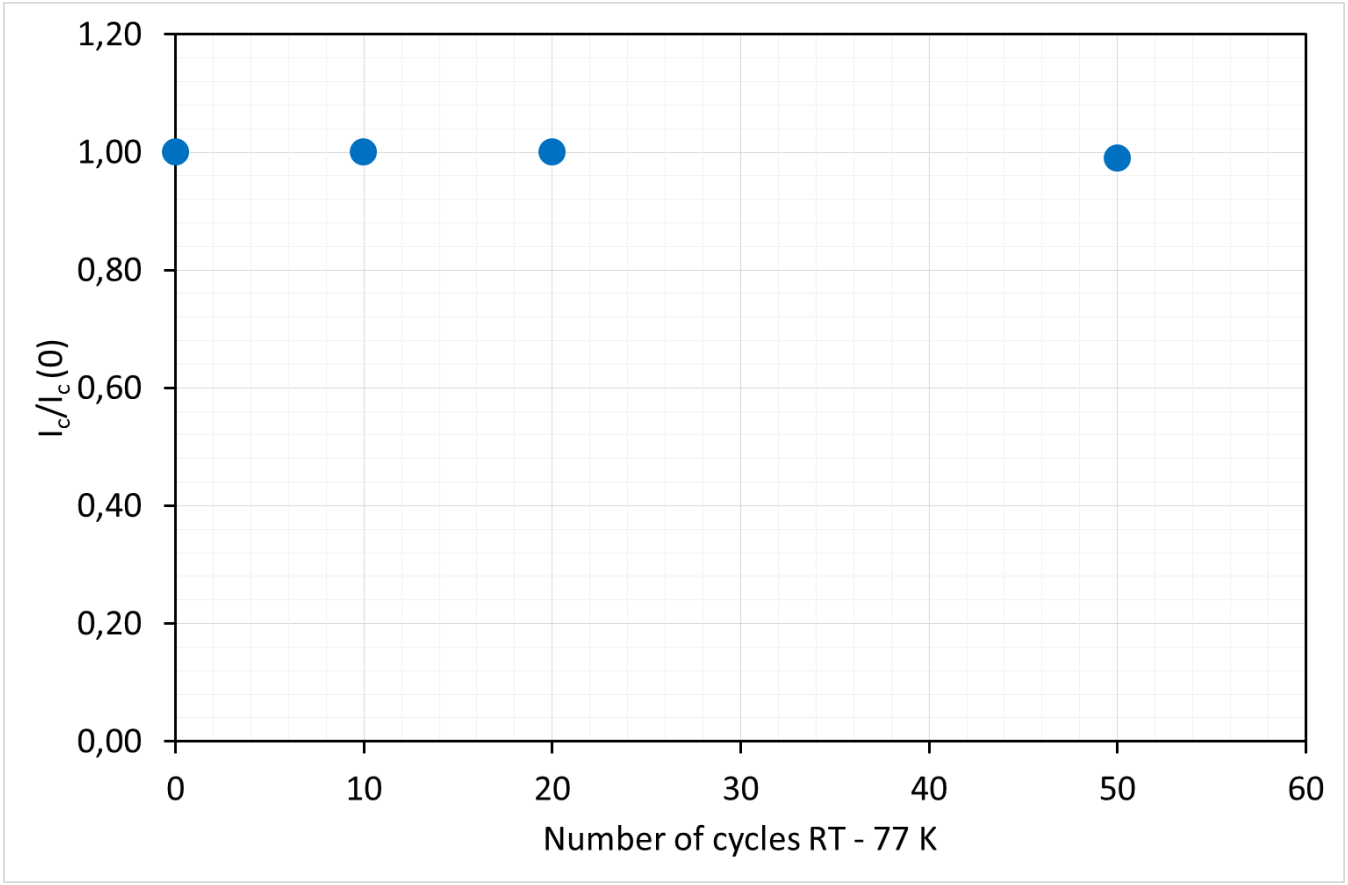




… But sometimes delamination occurs

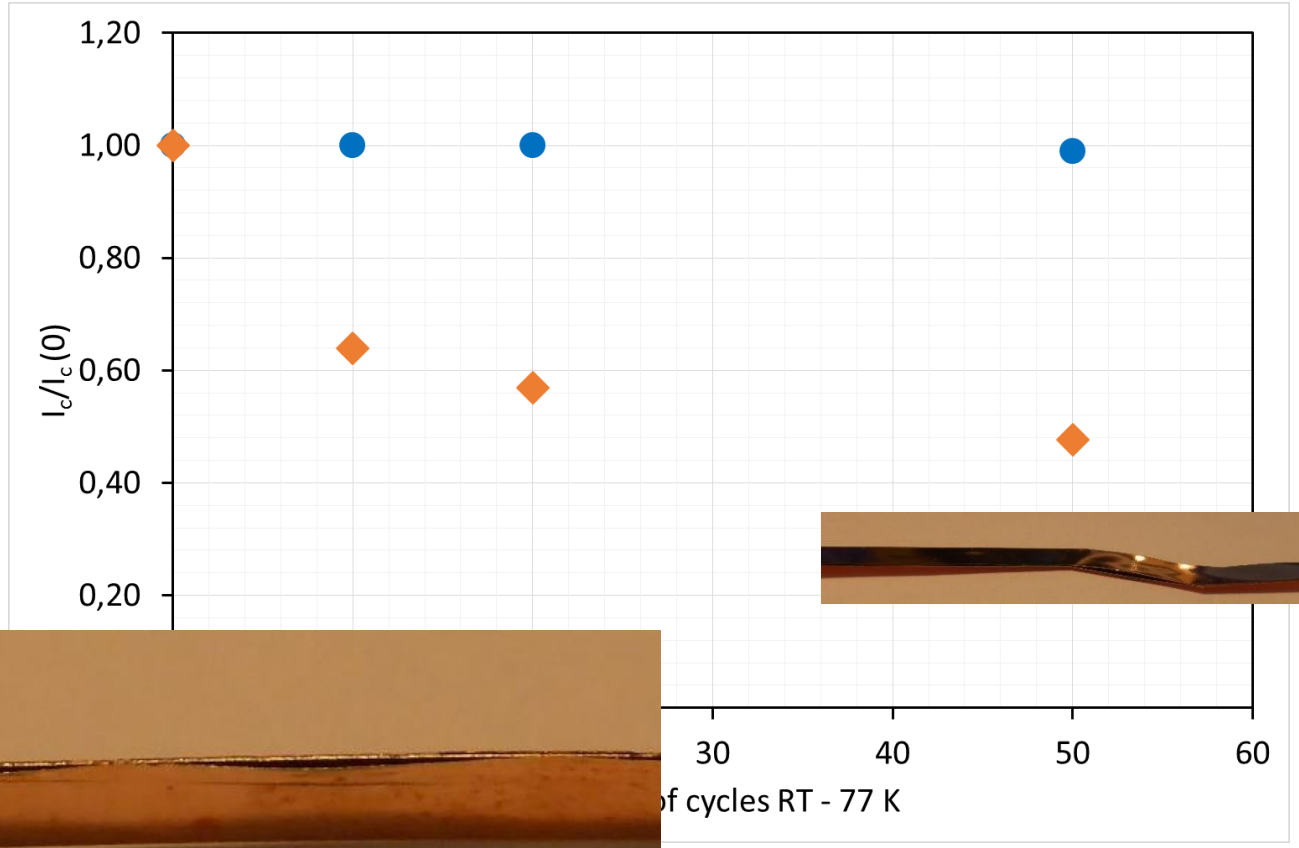
S. Otten et al., SUST 28 (2015) 065014

Roebel cables: Coat-and-Punch



Good section: no degradation in thermal cycling

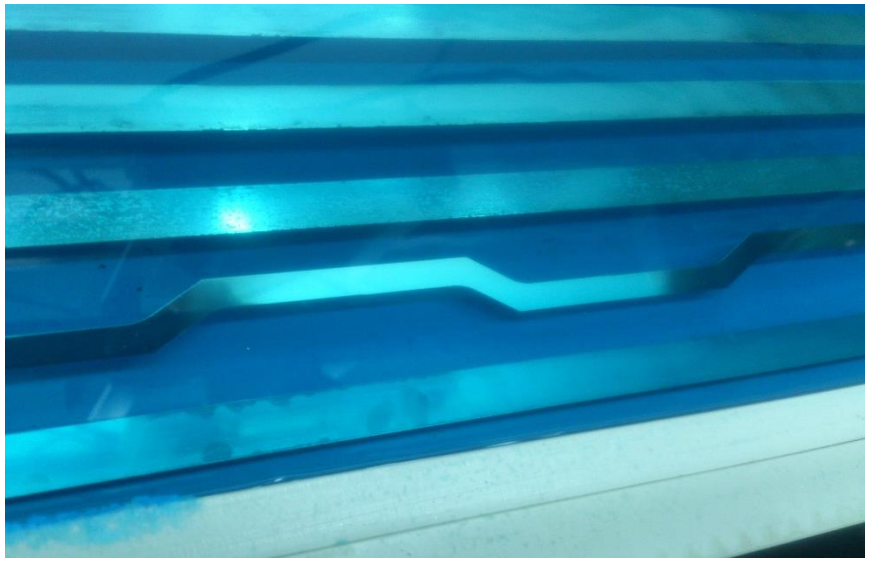
Roebel cables: Coat-and-Punch



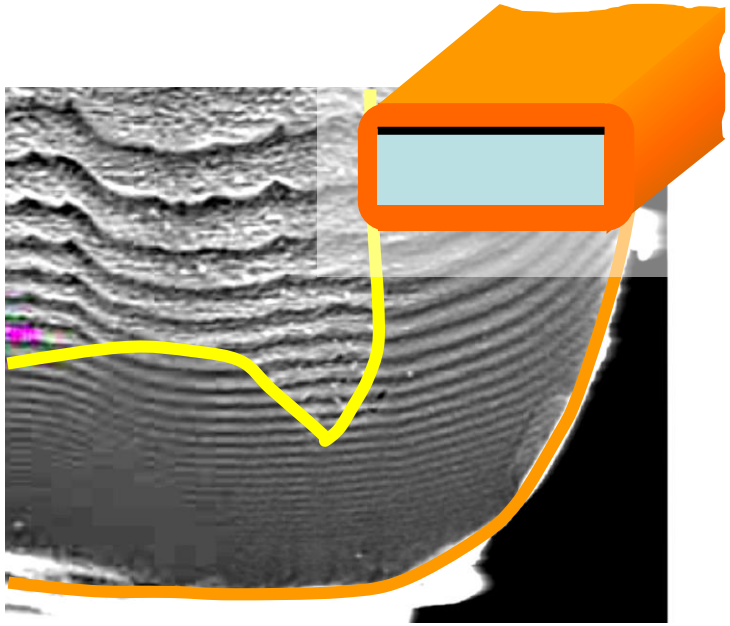
Poor section: significant degradation/delamination in thermal cycling

Roebel cables: Punch-and-Coat

Novel alternative: punch silver-coated wire and coat strand with copper

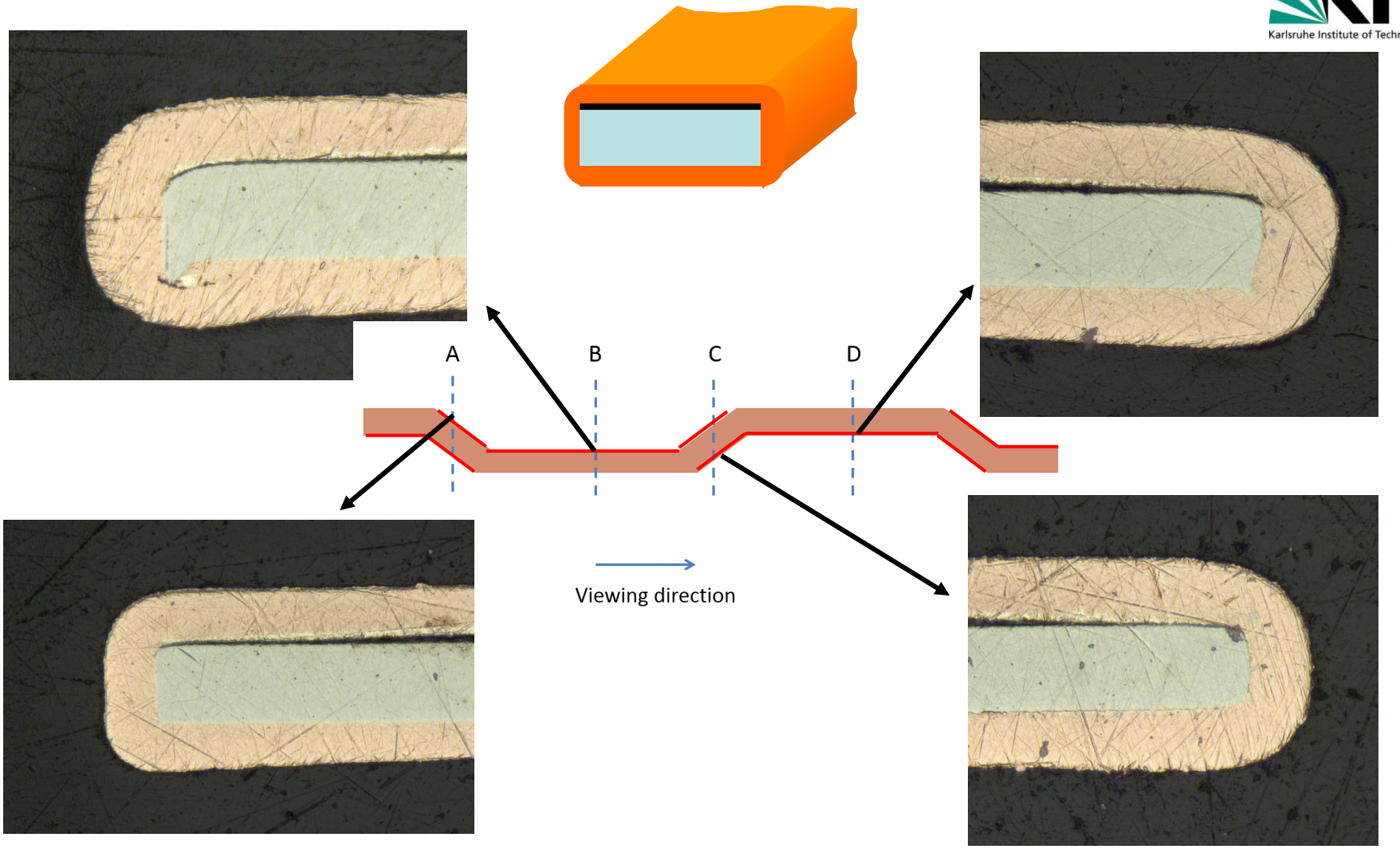


Cu-plating of a punched strand

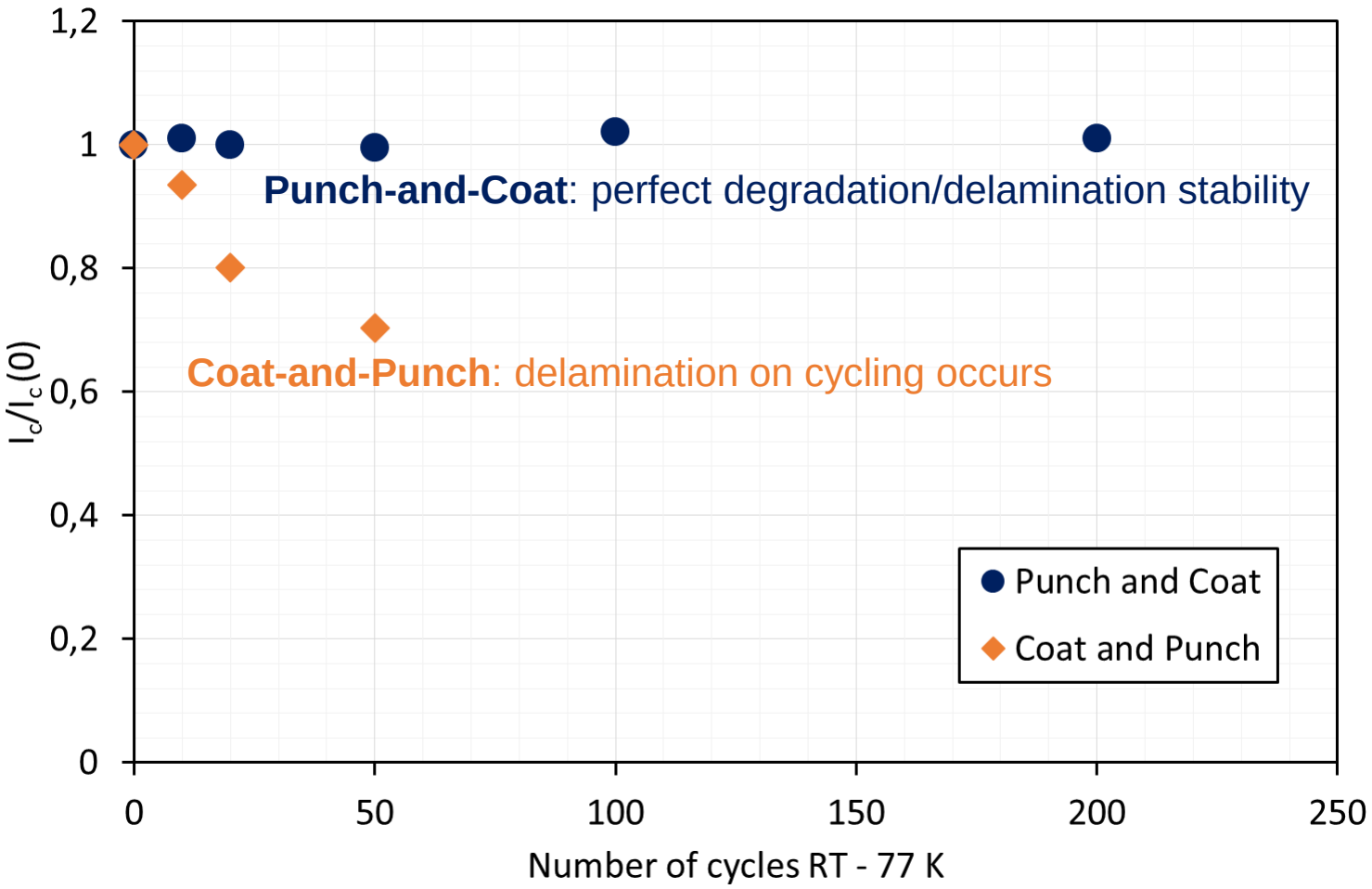


HTS layer fully enclosed
Sharp punch burr smoothened

Roebel cables: Punch-and-Coat

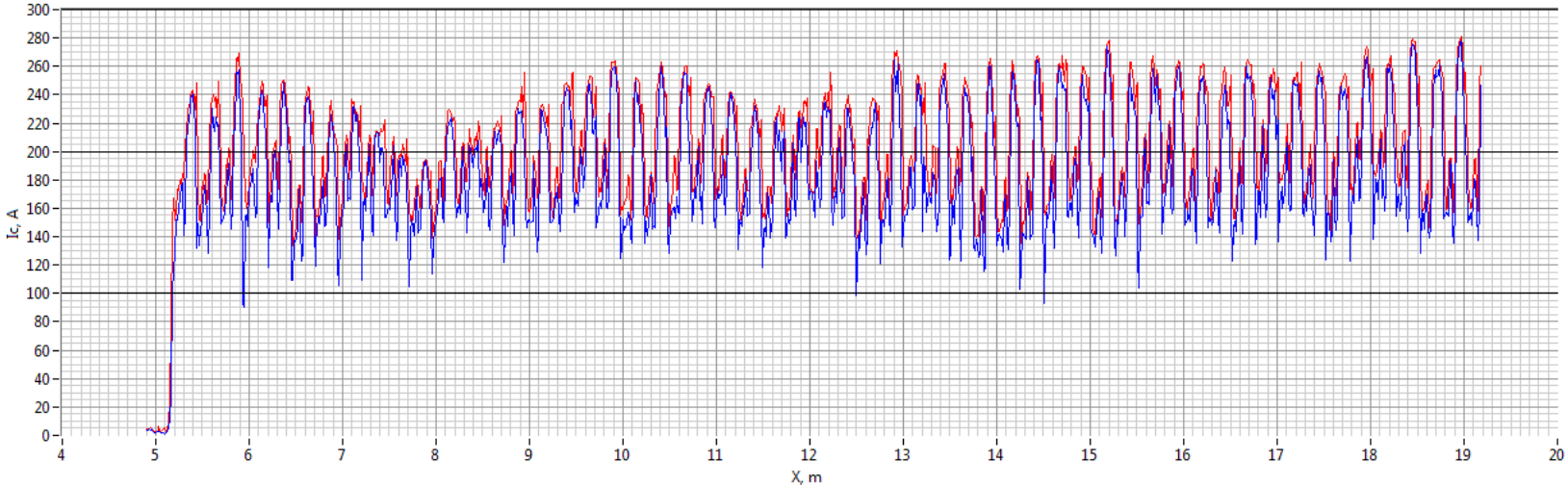


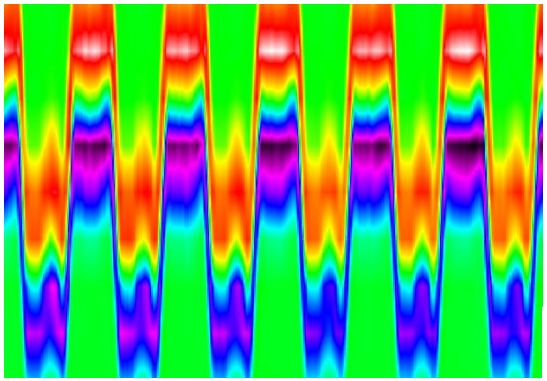
Roebel cables: PnC vs. CnP



PnC vs. CnP: superior degradation/delamination stability in thermal cycling

Roebel cables: strand characterisation



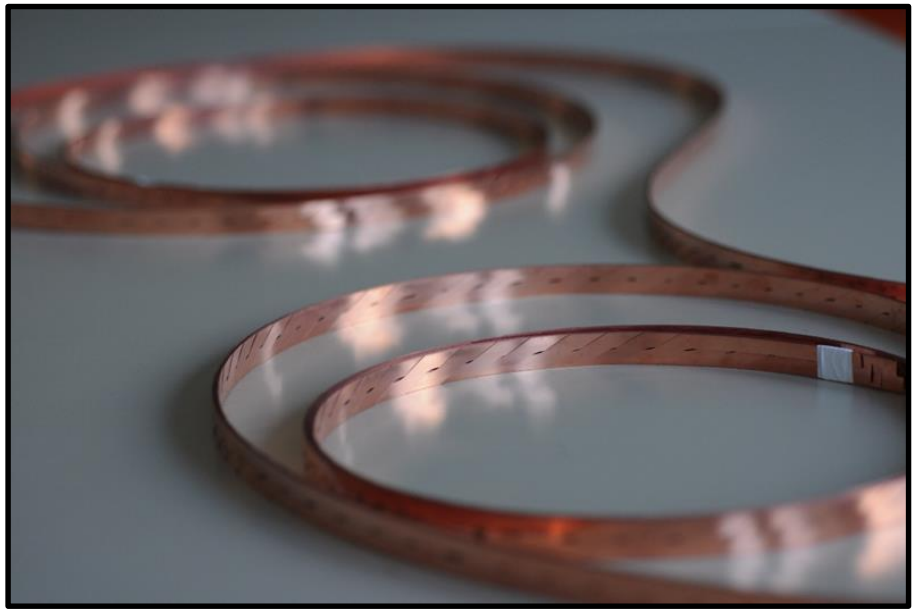


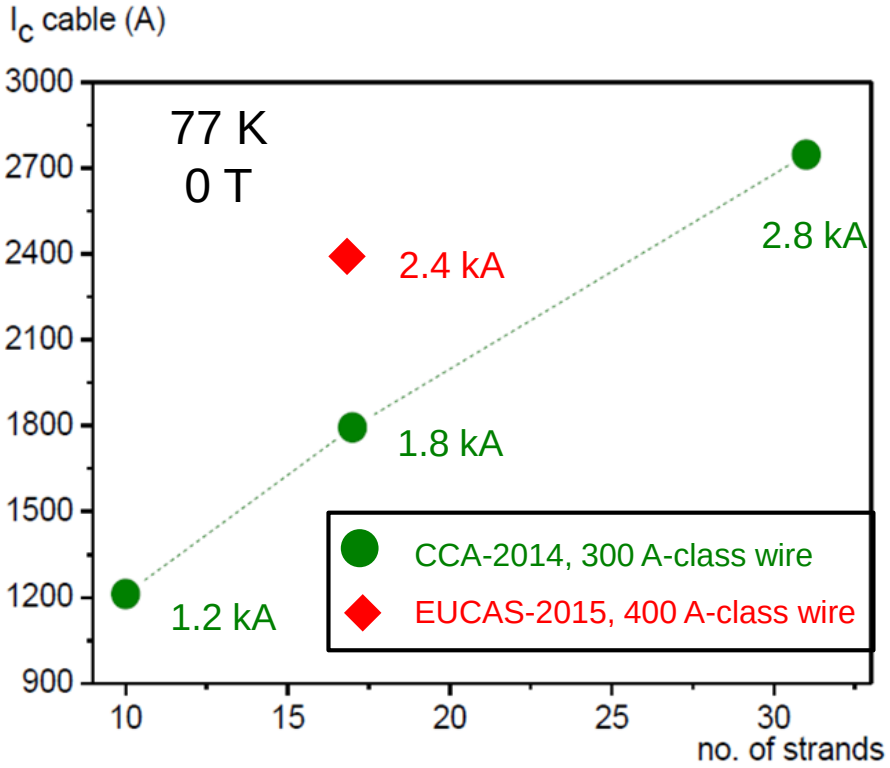
2D map

I_c over entire strand length:

- ❑ Non-contact reel-to-reel measurement
- ❑ Transport measurement

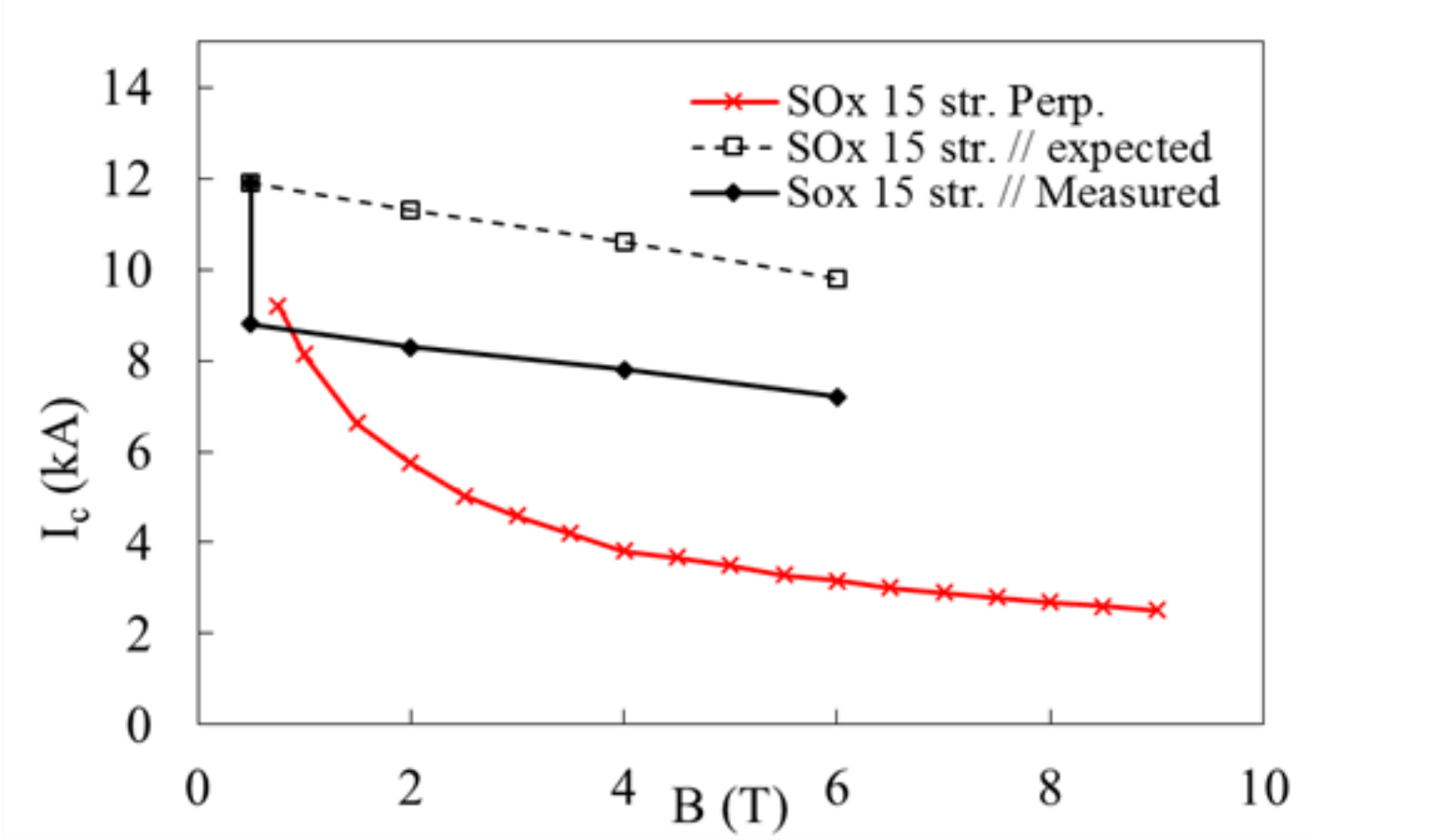
Roebel cables: critical current





Seeking partners for advanced measurements in LHe in field

Punch-and-Coat Roebel cable in LHe

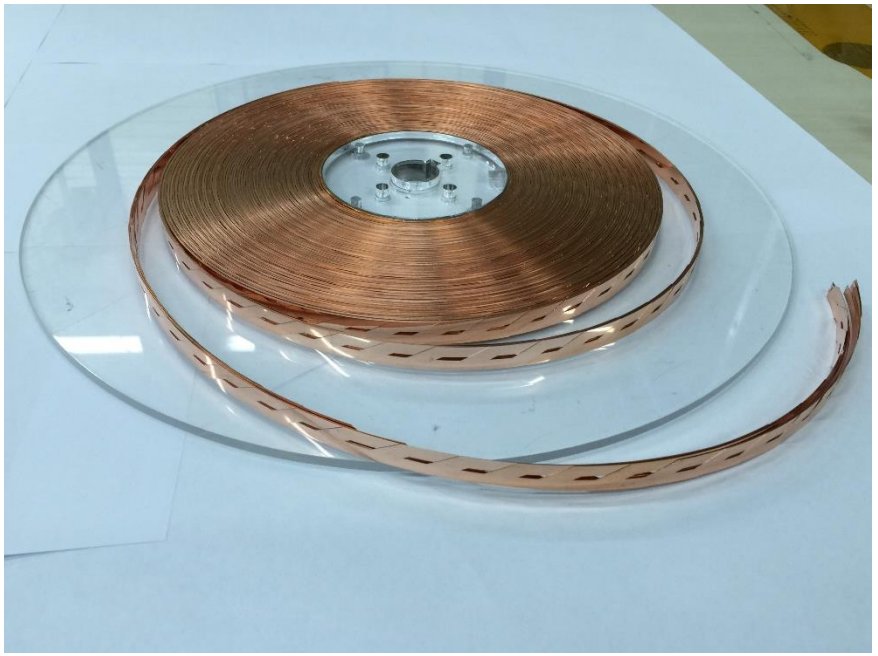


J. Fleiter et al. CERN Internal Note 2017_15, EDMS: 1757653

CERN results on the first SuperOx P-n-C Roebel cable in LHe in field

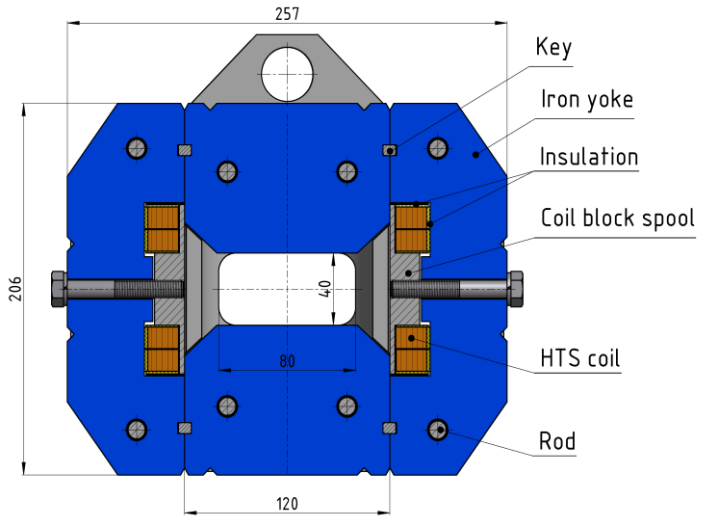
Commercial Punch-and-Coat Roebel cables

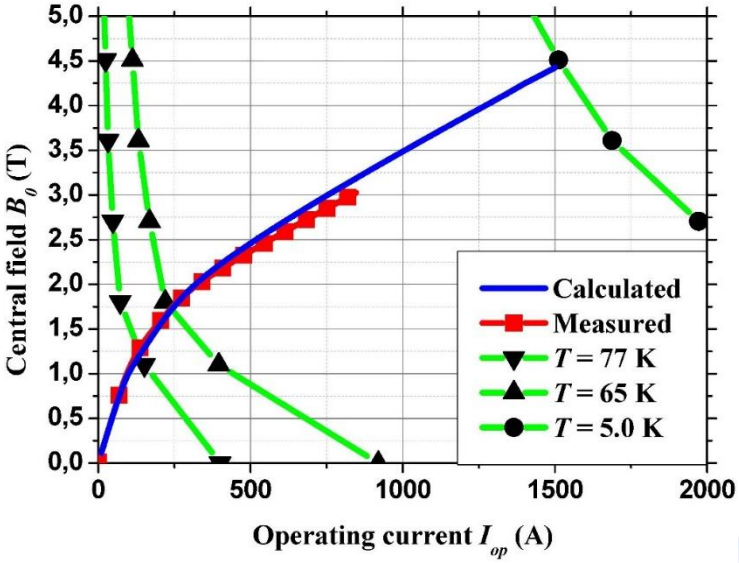
2.5 m PnC cable
provided to CERN for testing

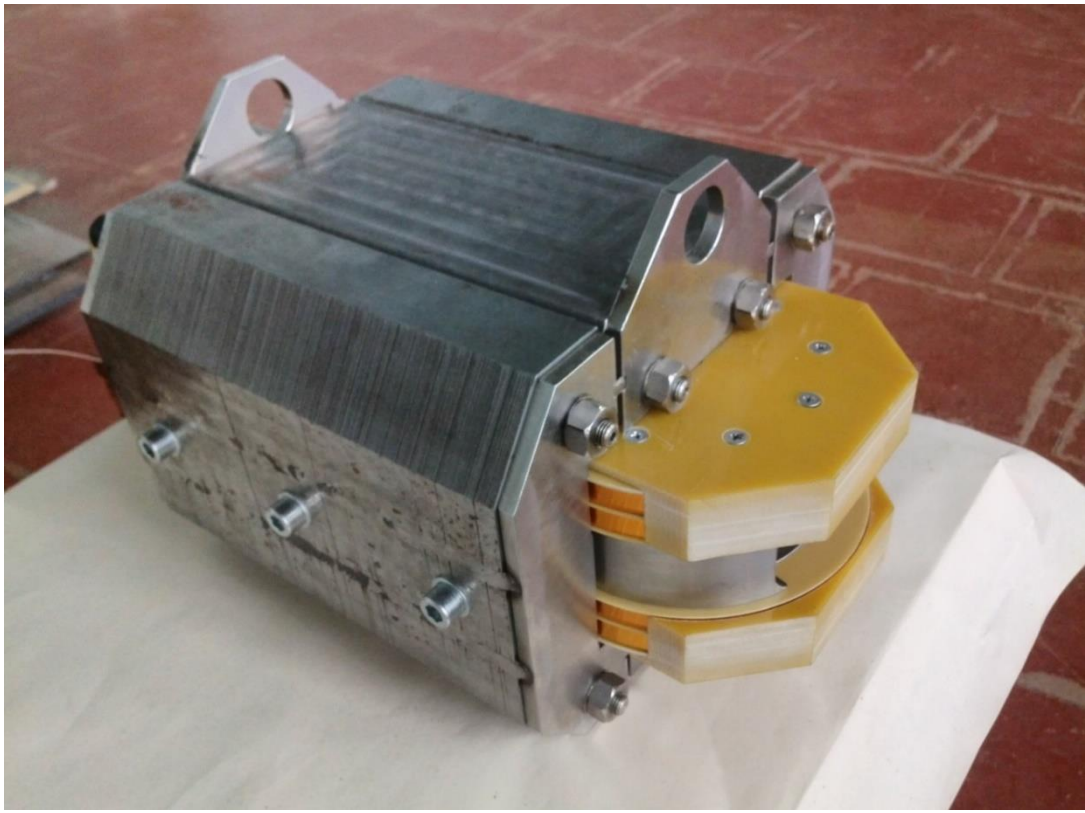


37 m PnC cable
supplied to CERN
for Feather 2 coil;
3 more on the way

HTS Dipole magnet







With SuperOx wire, HTS dipole magnet was made at High Energy Physics Institite, Protvino (2015)

Measured 3+ T field, limited by current source

I. V. Bogdanov et al., 2016 Supercond. Sci. Technol. 29 105012

Outline

2G HTS wire production

- Production facility expansion
- Consistent performance of production wire
- R&D in artificial pinning
- Filaments

Conductor development

- Cmmercial Punch-and-Coat 2G HTS Roebel cables

HTS dipole magnet

THANK YOU FOR YOUR ATTENTION

www.superox.ru