SuperOx
HTS development and idustrialisation

Workshop on Accelerator Magnets in HTS

21-23 May, 2014 – Hamburg, Germany

SuperOx

Outline

+ The SuperOx group of companies

+ SuperOx 2G HTS tape properties

+ Focus on customisation

+ HTS devices with SuperOx tape inside

+ Product specifications

+ Workshop Q&A

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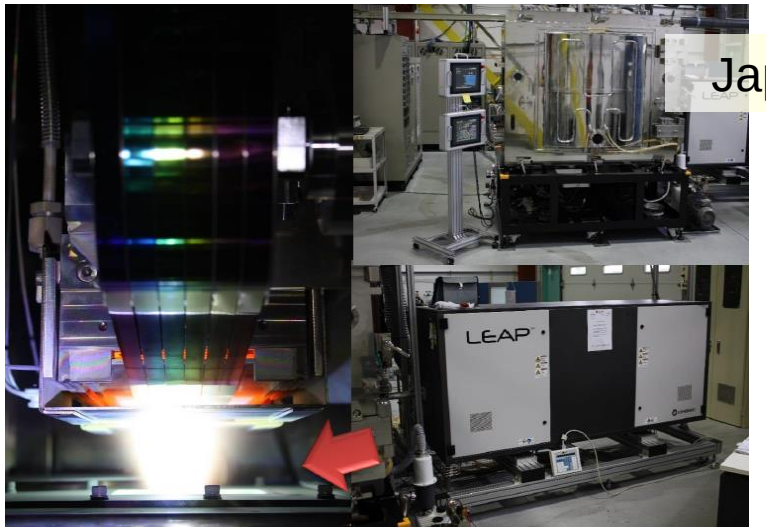
SuperOx

+ 2006: SuperOx founded in Moscow

+ 2011: SuperOx Japan LLC founded in Tokyo

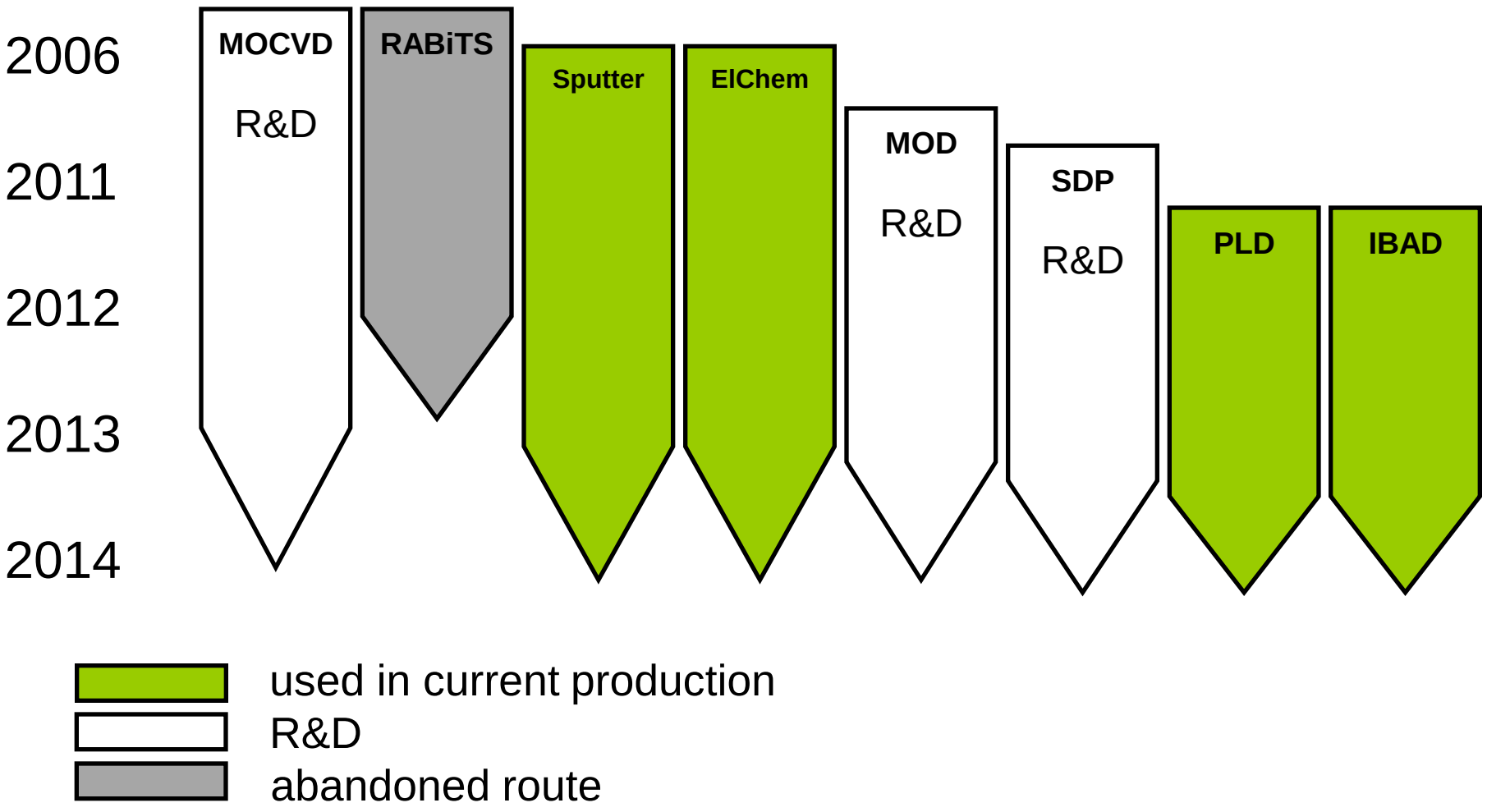
+ 2013: began sales of 2G HTS tapes made jointly in Russia and Japan

Russia



Japan

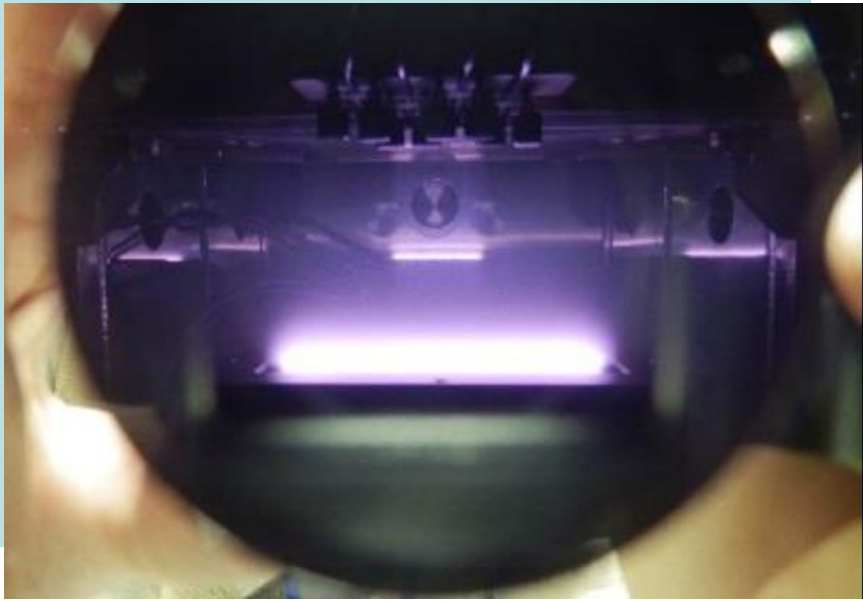
Technology profile



SuperOx Japan LLC (Tokyo)

- RF sputtering: buffer layers
- IBAD-MgO
- PLD: CeO_2 & HTS
- DC sputtering: silver
- I_c measurements

220 sqm / 5 employees

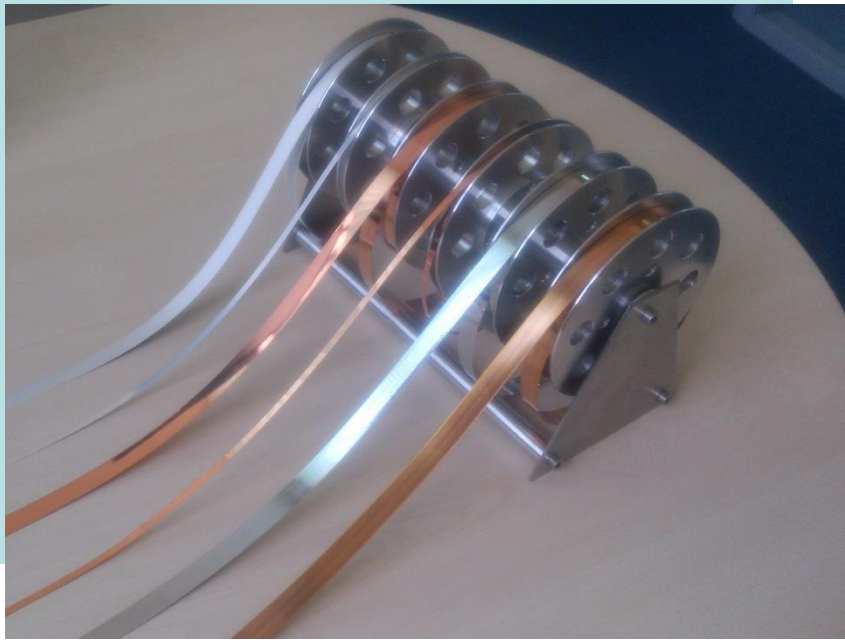


Focus on PVD methods

SuperOx (Moscow)

- Electropolishing
- Silver DC sputtering
- Copper electroplating
- Solution deposition (MOD & SDP)
- MOCVD (R&D)
- Polyimide insulation
- Solder plating & lamination
- Quality testing, etc.

850 sqm / 20 employees



Focus on chemistry and customisation

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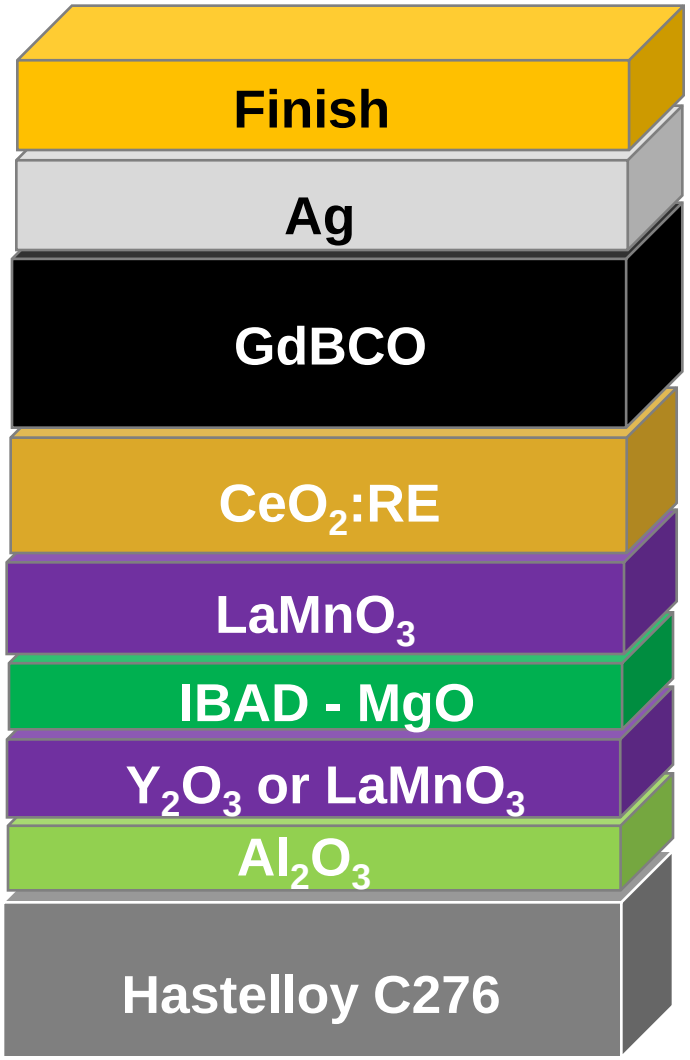
SuperOx 2G HTS tape



Customised finish tailored to application

DC sputtering (custom thickness)

PLD-2 (1-3 microns)

PLD-1 (100-200 nm)

Dual-Chamber: PLD system

RF sputtering (30-50 nm)

IBAD with RF sputtering (5-7 nm)

RF sputtering (30-50 nm)

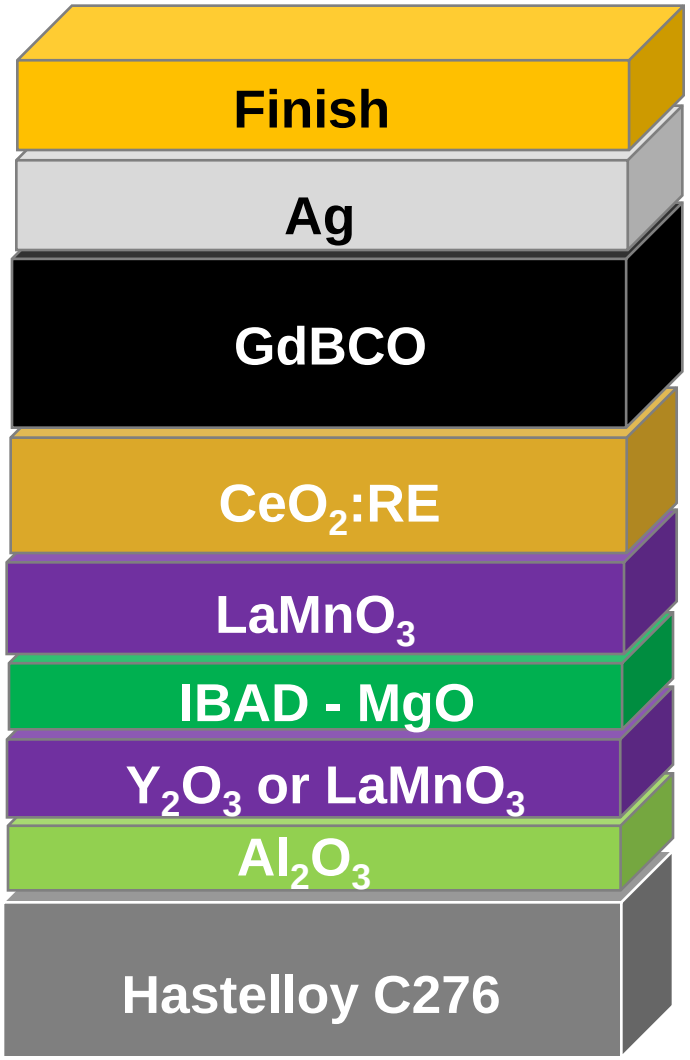
RF sputtering (50 nm)

Single Chamber: RF sputter + IBAD

Cold rolled & electro polished (60-100 microns)

SuperOx

SuperOx 2G HTS tape



Customised finish tailored to application

DC sputtering (custom thickness)

PLD-2 (1-3 microns)

PLD-1 (100-200 nm)

Dual-Chamber: PLD system

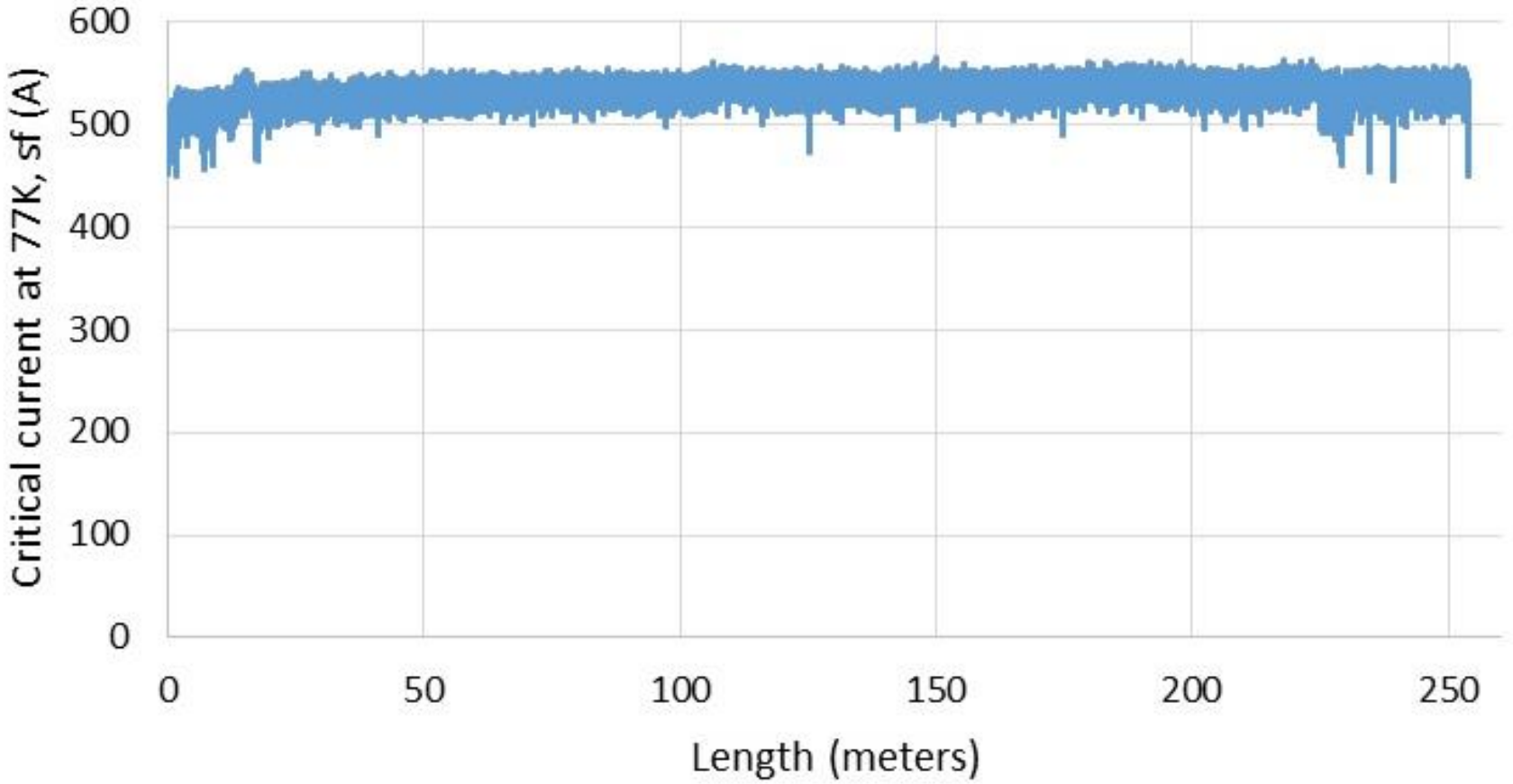
Q4 2014:
New buffer deposition line
Individual chambers per each process
2+ times higher throughput

Cold rolled & electro polished (60-100 microns)

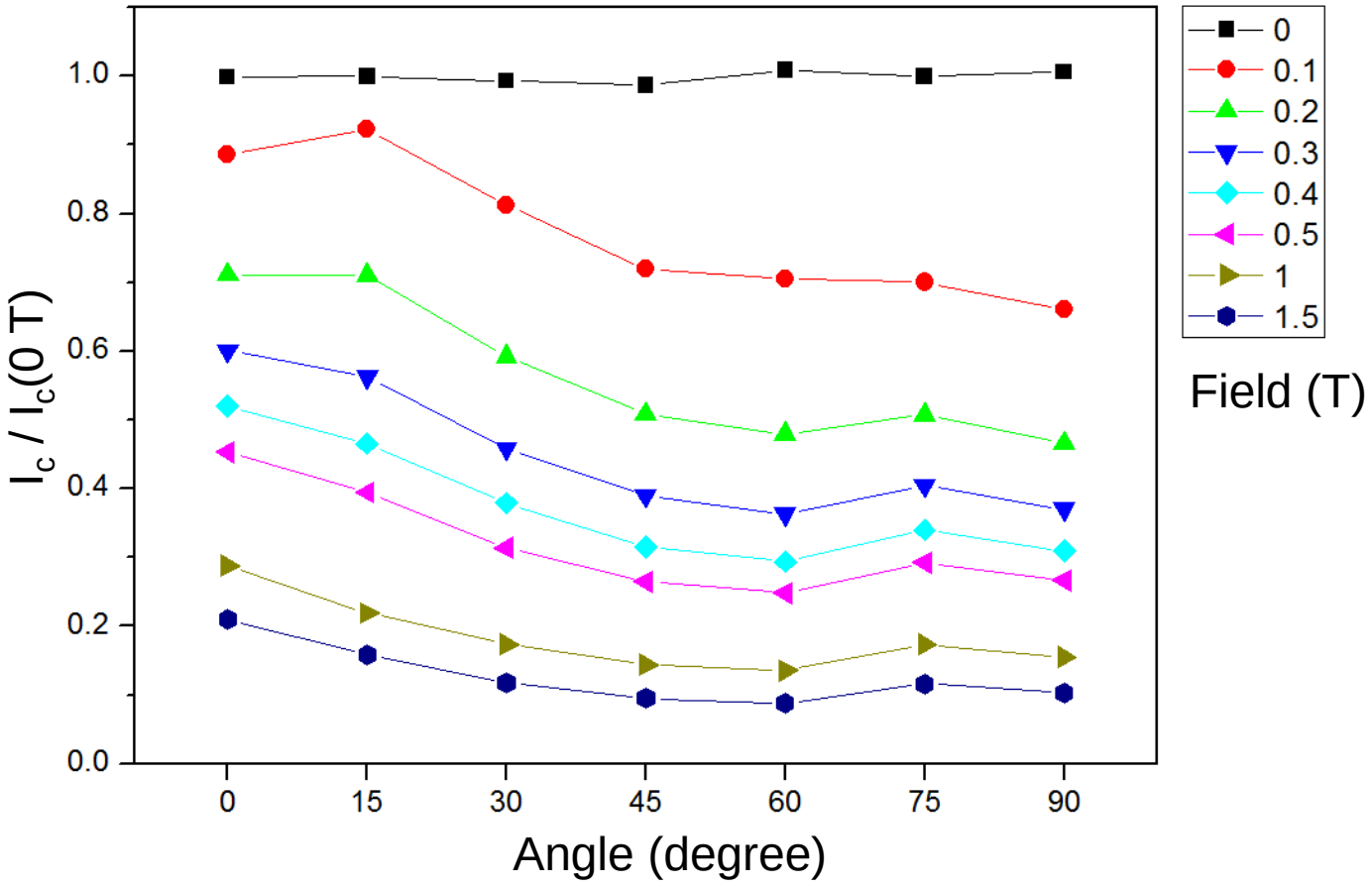
SuperOx

Current status of HTS tape production

Over 100,000 Ampere-metres, repeatedly

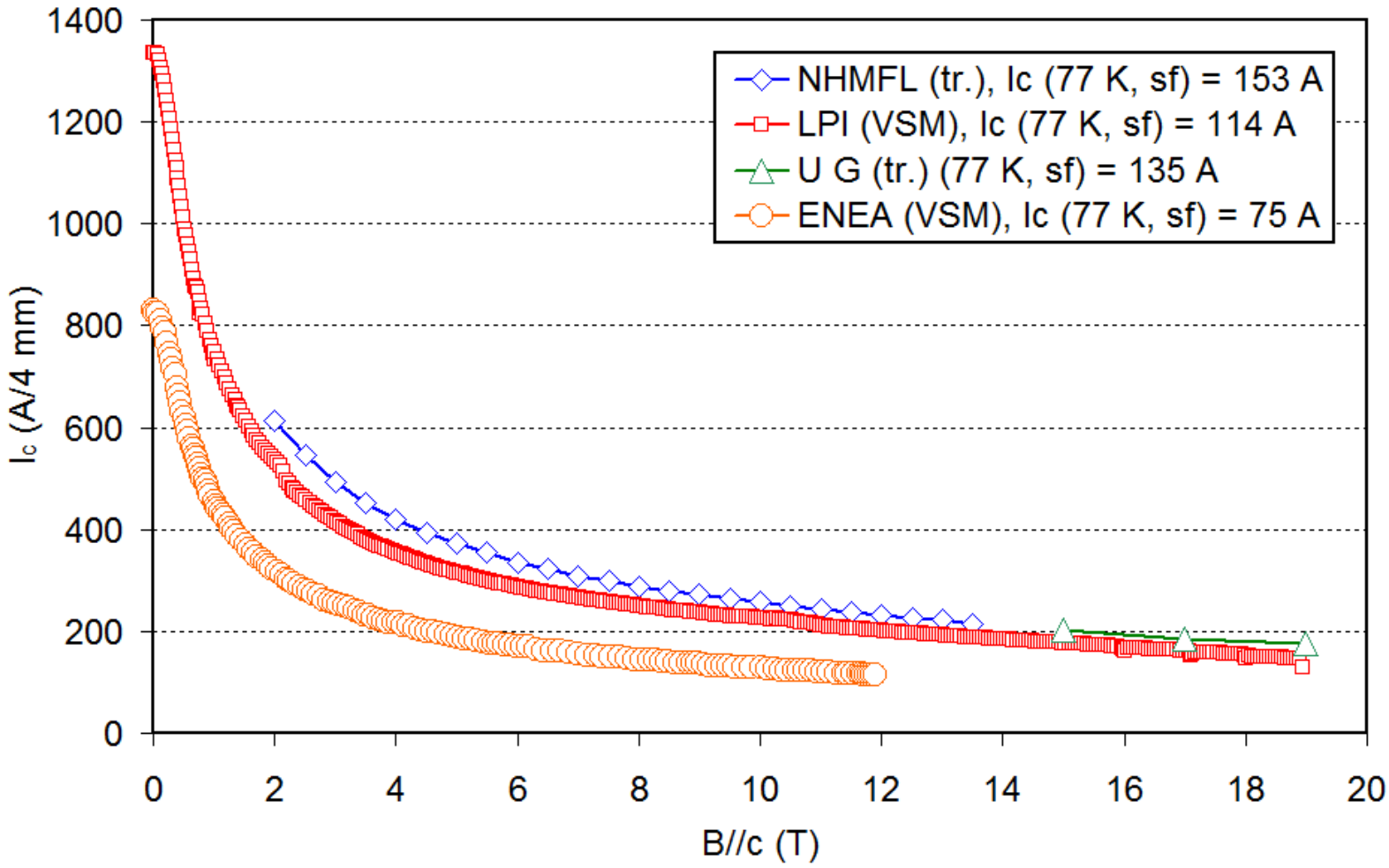


In-field performance: angular dependence at 77 K

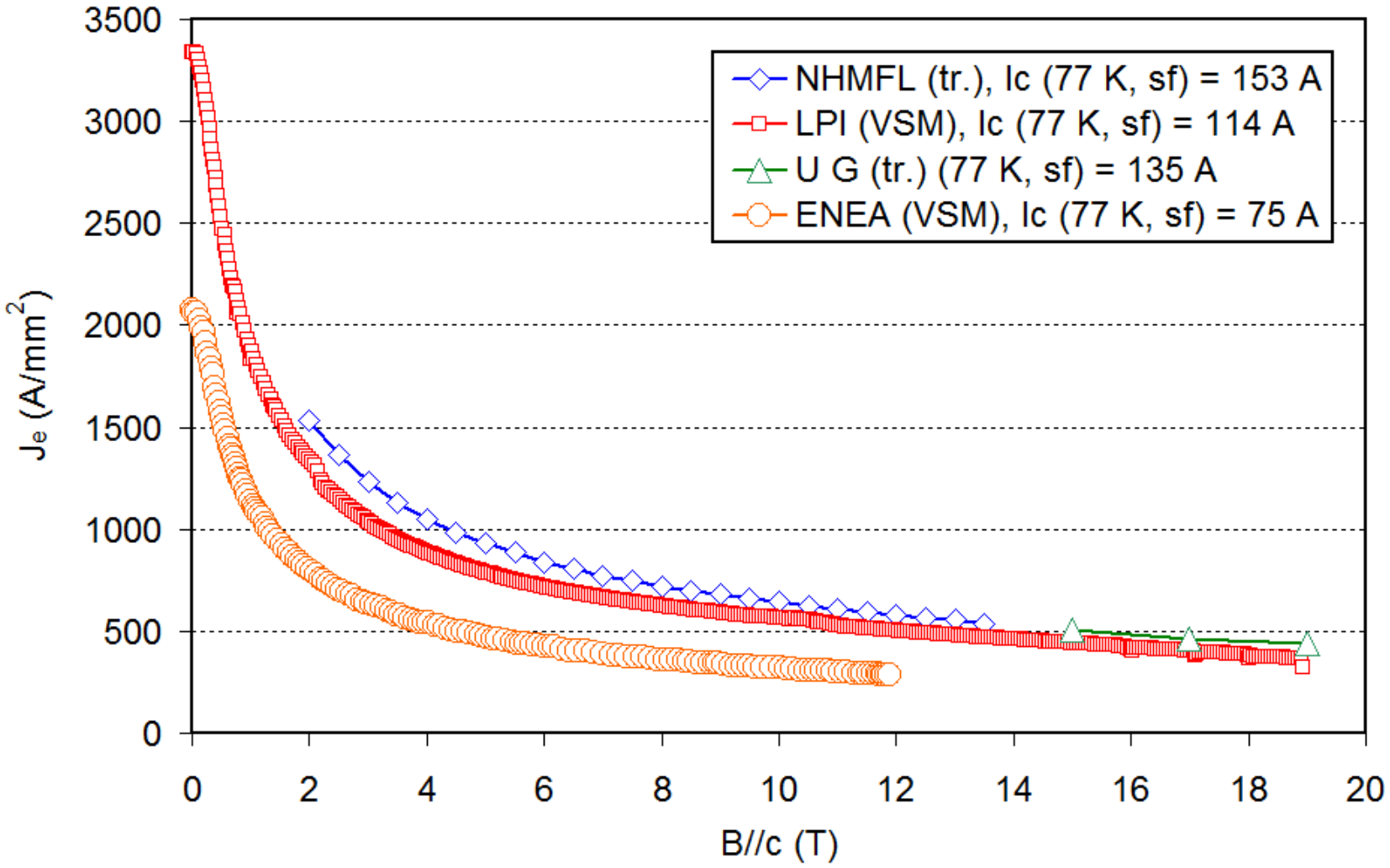


No artificial pinning centres
Very isotropic in-field behaviour

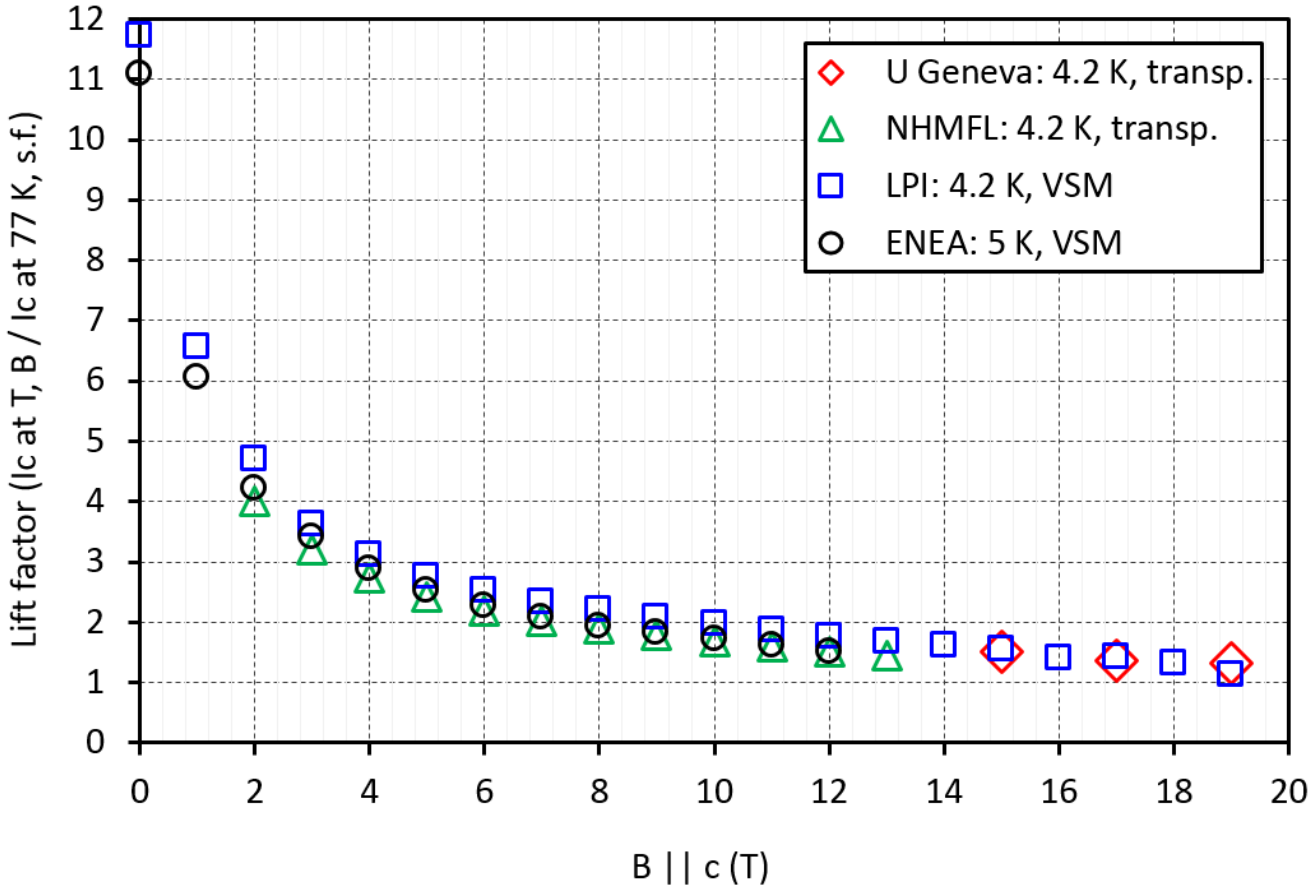
In-field performance: Ic in 4 mm tapes (H//c)



In-field performance: Je in 100 micron thick tapes (H//c)



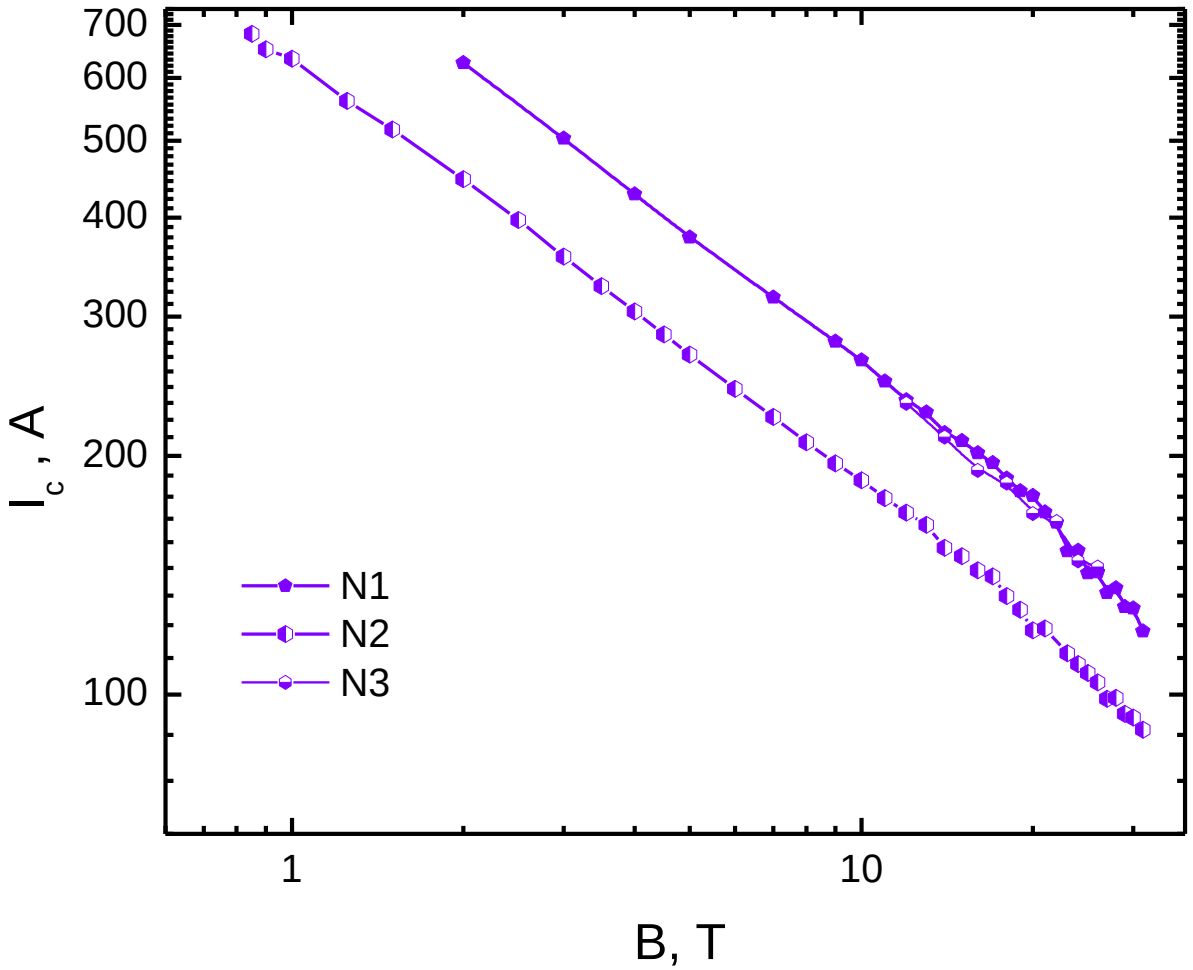
In-field performance: lift factors at 4.2 K (H//c)



B||c (T)	LPI	NHMFL	ENEA (5 K)	U Gen.
0	11.72		11.09	
1	6.55		6.06	
2	4.71	4.00	4.216	
3	3.63	3.21	3.41	
4	3.12	2.73	2.88	
5	2.77	2.42	2.52	
6	2.52	2.19	2.28	
7	2.33	2.02	2.08	
8	2.20	1.89	1.93	
9	2.07	1.78	1.82	
10	1.98	1.68	1.72	
11	1.86	1.59	1.61	
12	1.77	1.52	1.50	
13	1.69	1.45		
14	1.62			
15	1.56			1.50
16	1.41			
17	1.42			1.37
18	1.33			
19	1.14			1.31

Excellent agreement in lift factors by different groups

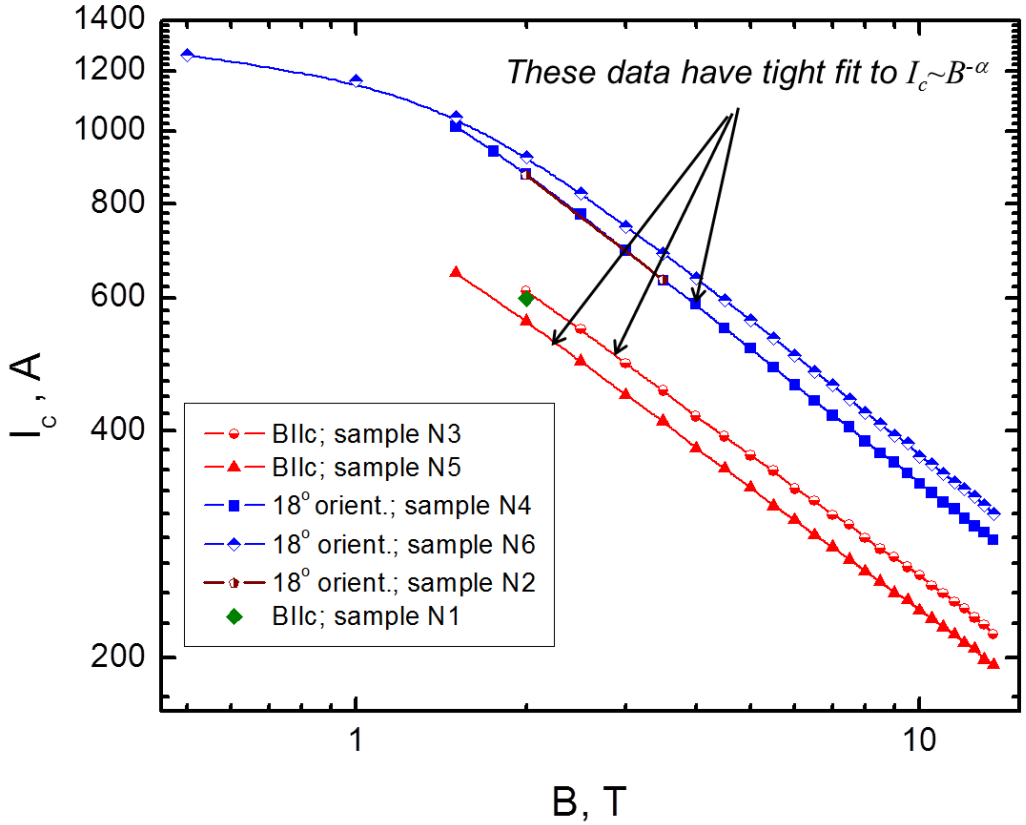
In-field performance: Ic in fields up to 31 T (B || c)



Measurements by D. Abraimov and J. Jaroszynski, NHMFL

In-field performance: alpha values (B || c)

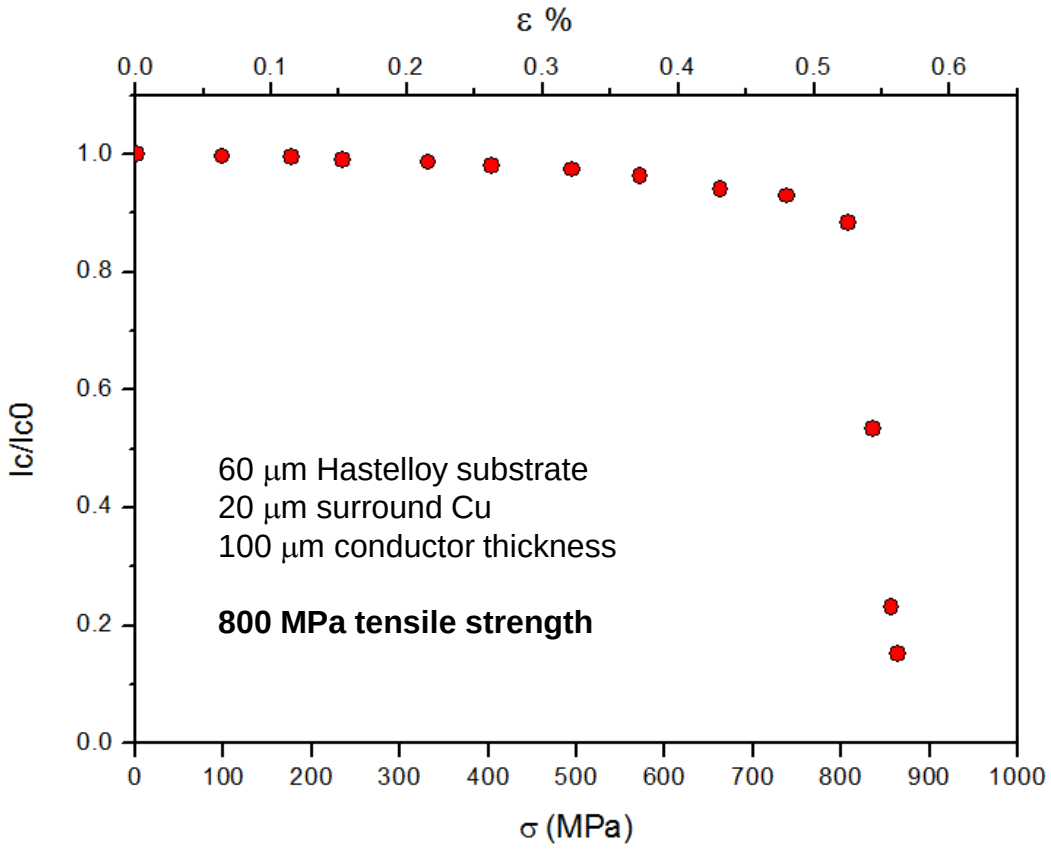
NHMFL: transport measurements of SuperOx 4 mm wide samples
Magnetic field dependence of critical current @ 4.2 K (in He bath)



T	Alpha
77 K	0.52
65 K	0.55
40 K	0.54
20 K	0.56
4.2 K	0.54

Consistent alpha values throughout cryogenic temperature range

Mechanical properties: tensile strength



High tensile strength ensured by Hastelloy substrate

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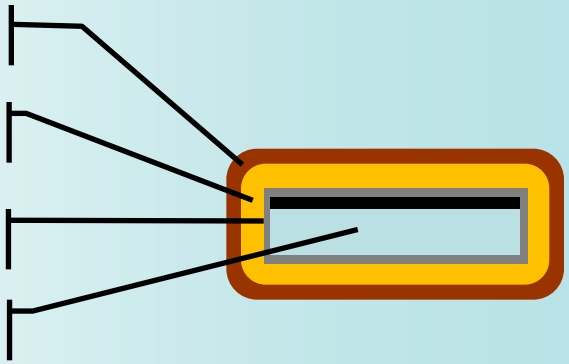
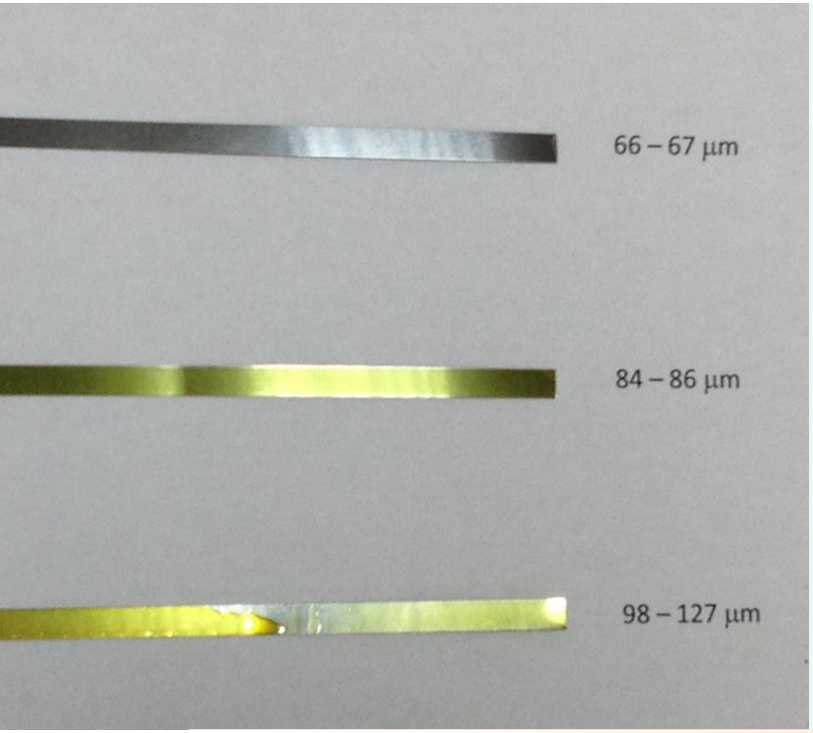
Surround polyimide insulation

Polyimide coating
(thickness on request 2 to 20 μm)





bare tape

new SuperOx process (8-10 μm / side)

standard dip coating

Continuous surround coating: an advanced alternative to Kapton wrapping

Surround polyimide insulation

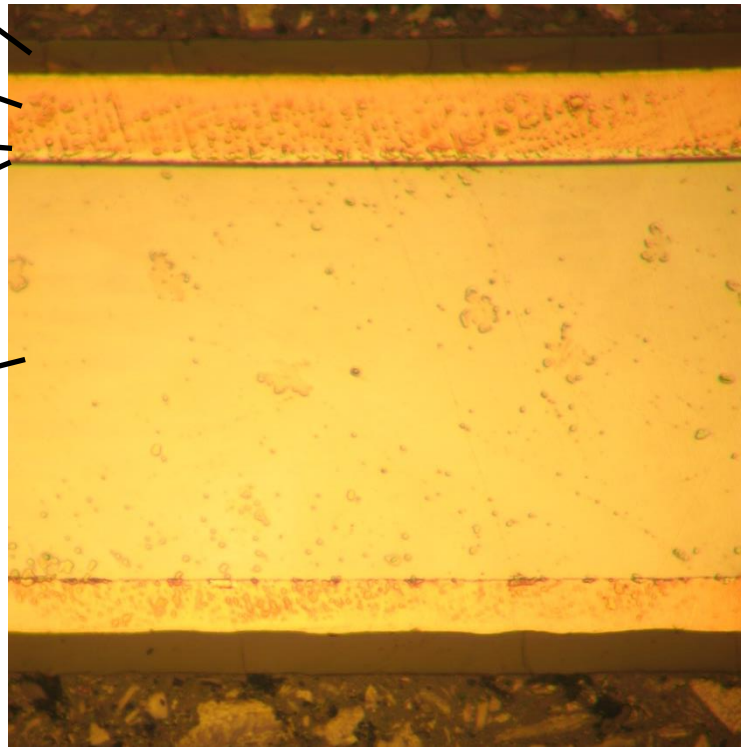
Polyimide coating
(5 μm)

Copper
(10 μm)

Silver
(1 μm)

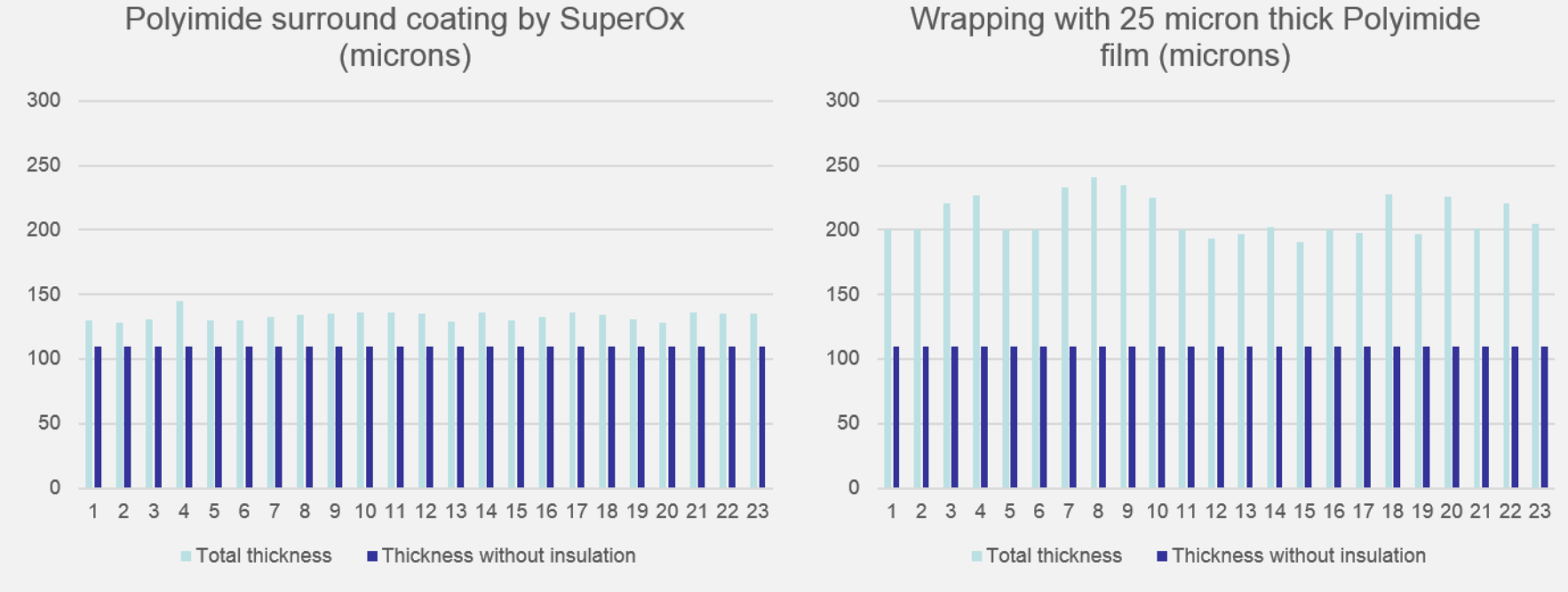
Buffers + HTS
(2 μm)

Substrate
(60 μm)



Dielectric performance is being tested now

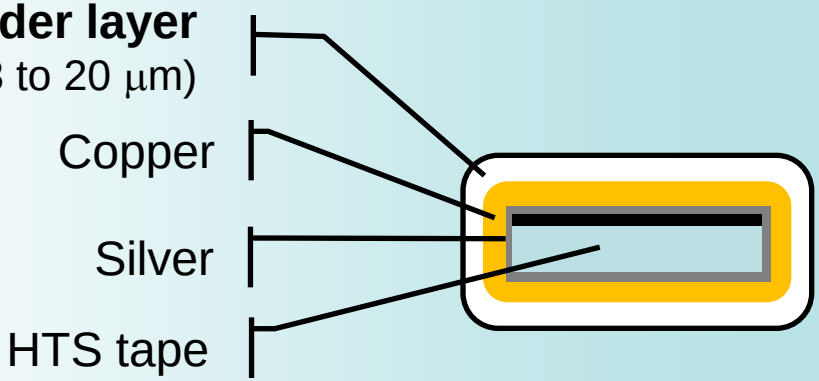
Surround polyimide insulation

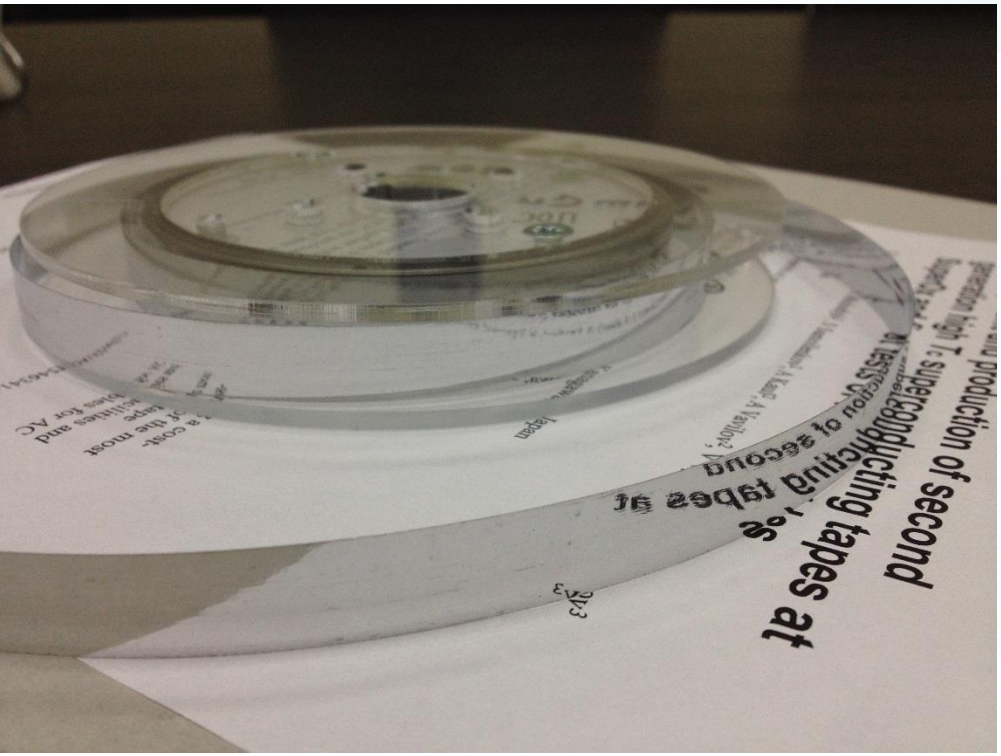


Thin, continuous, and regular insulating coating

Solder plating

Solder layer
(thickness on request 3 to 20 μm)





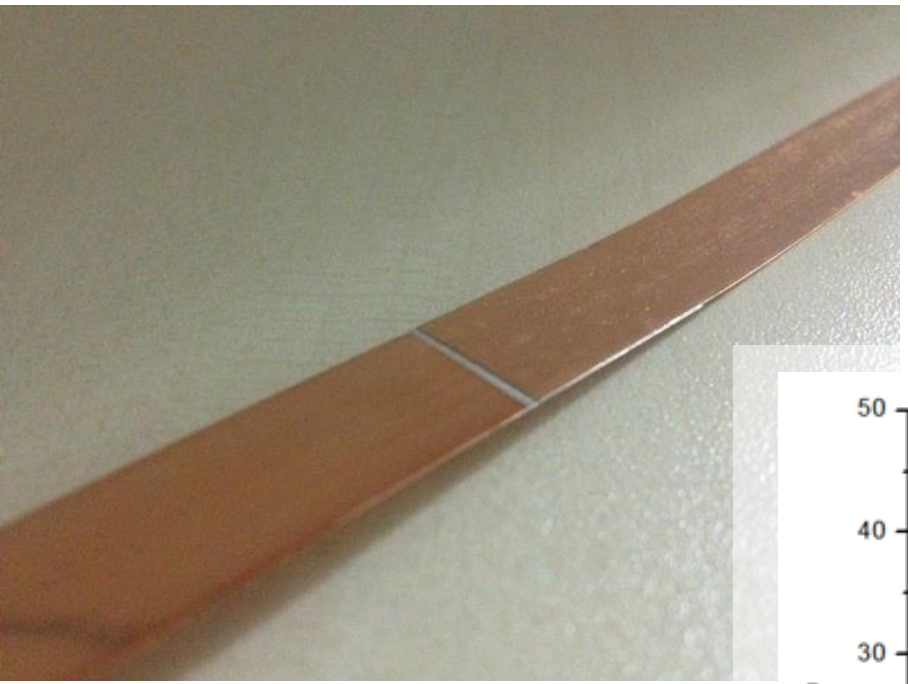
~ 200°C PbSn

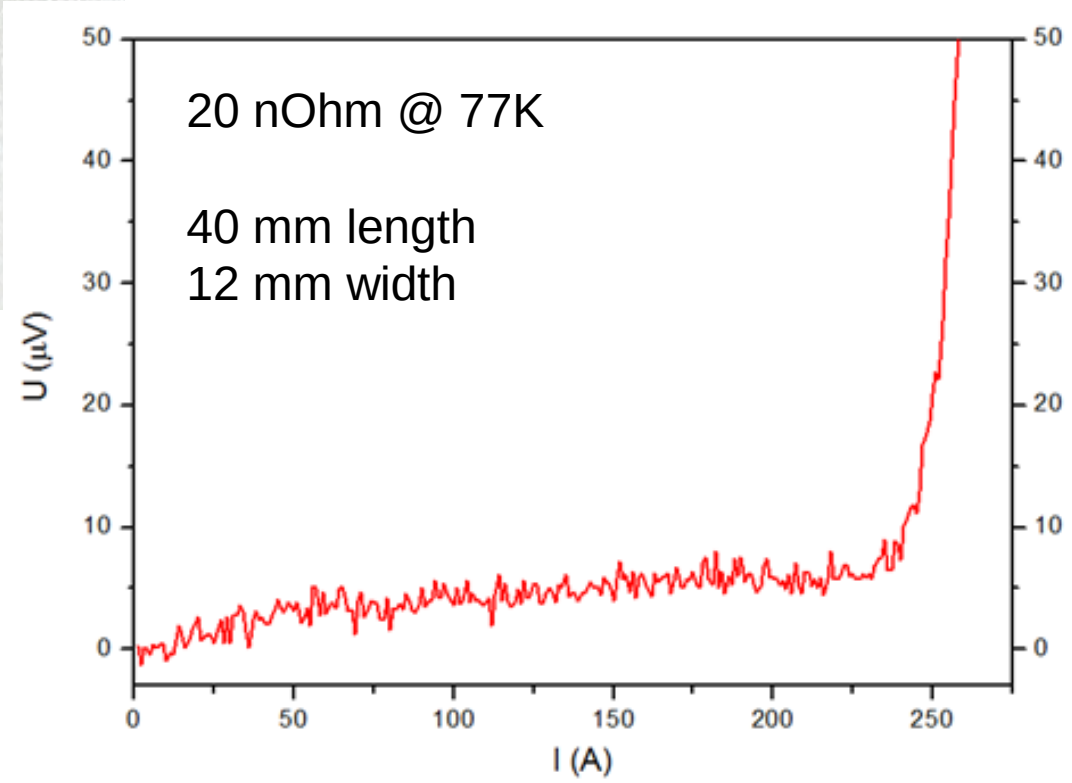
~ 120°C SnIn

~ 100°C PbBiSn (Rose's metal)

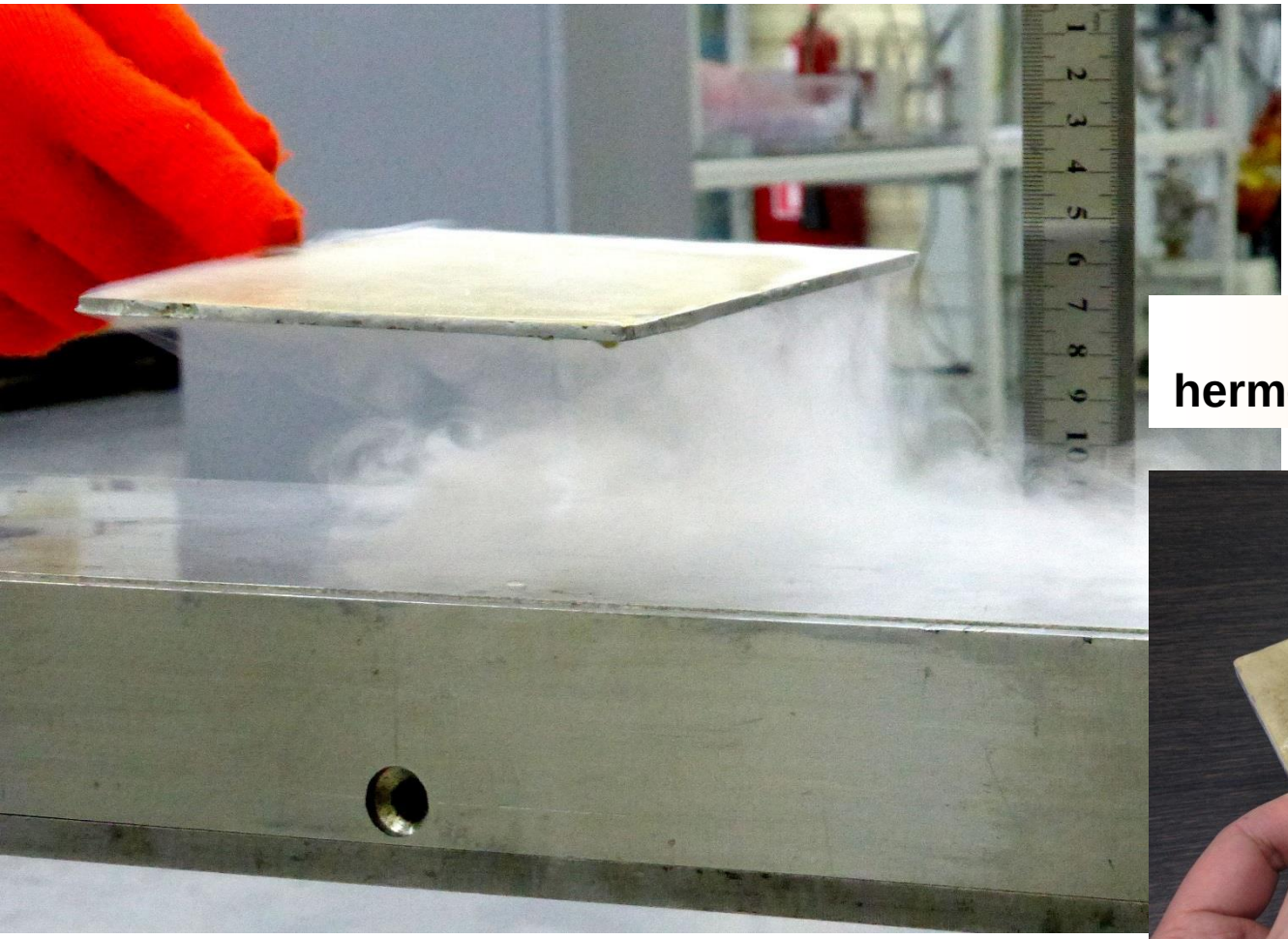
etc…

Low resistance joints of any type

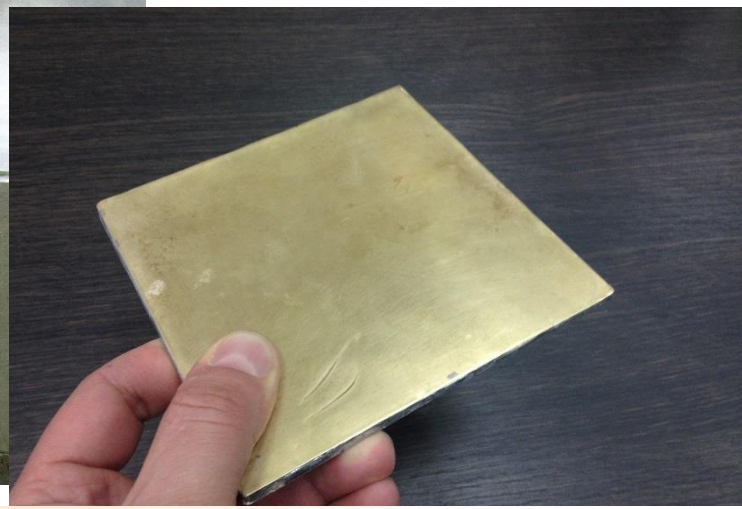




Multi-layer stacks of 2G HTS tape



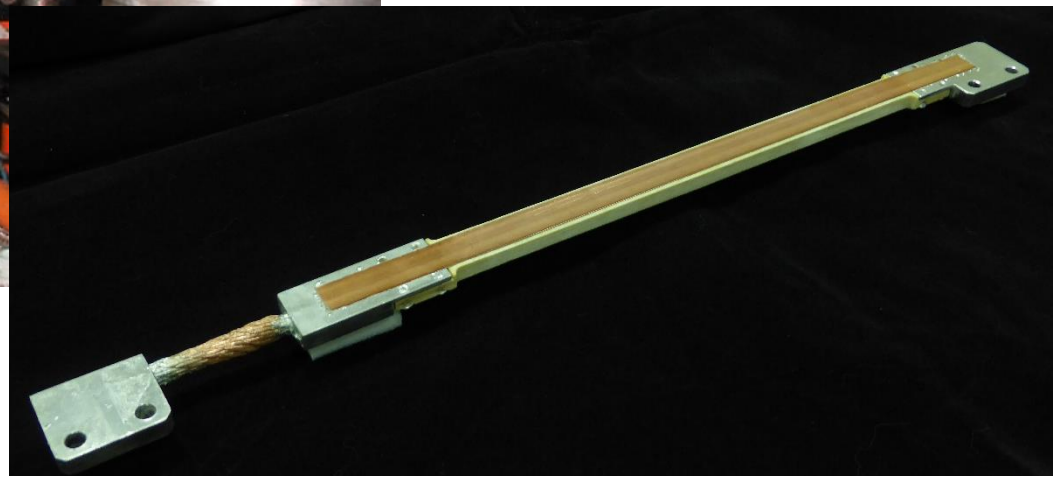
40 layers of 2G HTS tape hermetically soldered in brass



Levitation of 2G HTS tape soldered stacks above permanent magnets

Current leads for accelerator magnets

Nuclotron LTS magnets
NICA collider, Dubna



SuperOx's 100 A HTS current lead for a correction coil of an LTS magnet

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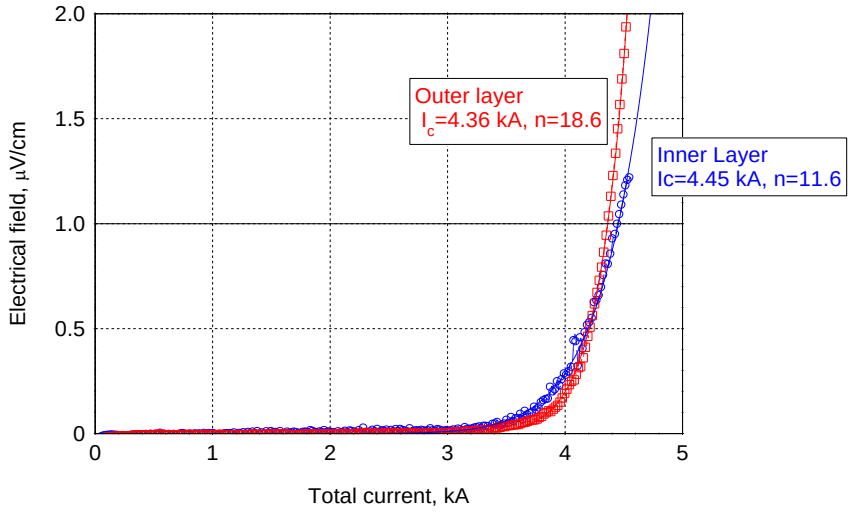
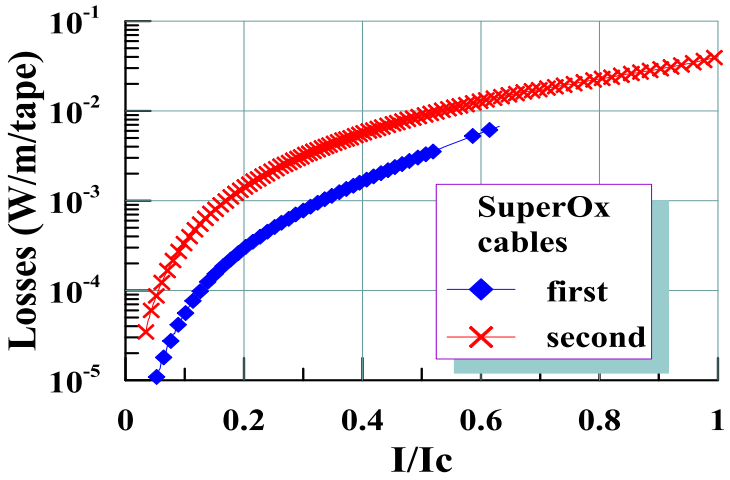
Over 20 km of tape shipped in last 9 months

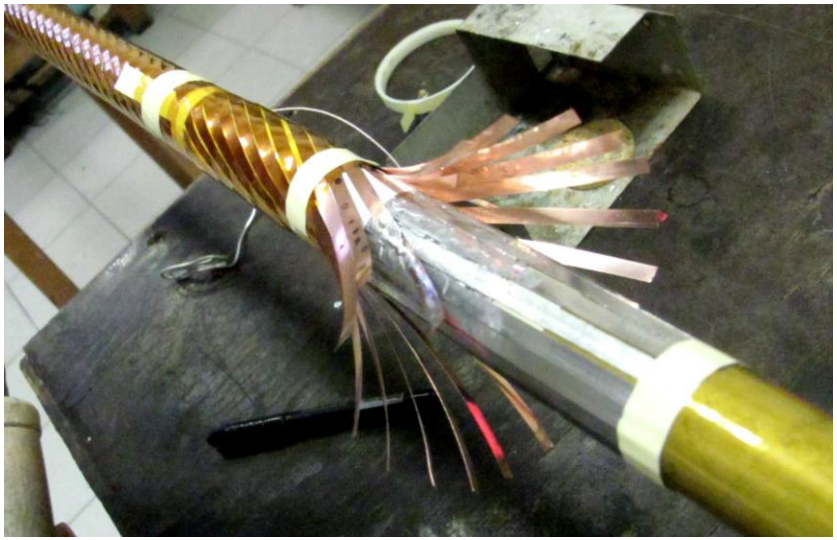
Cable applications:

Device	Parameters	SuperOx tape inside	
Current lead cable (twisted stack)	100 kA, 4.2 K, 12 T	Width:	4 mm
		Single piece length:	50 m
		I_c (77 K, s.f.):	130+ A
		I_c (4.2 K, 12 T B||c):	200+ A
		Finish:	PbSn plated / 20 μm Cu / 1 μm Ag
Roebel cable	Research	Width:	12 mm
		Single piece length:	50 m
		I_c (77 K, s.f.):	300+ A
		Finish:	1 μm Ag; 20 μm Cu / 1 μm Ag
AC cable	4 kA	Width:	4 mm
		Single piece length:	50 m
		I_c (77 K, s.f.):	120+ A
		Finish:	20 μm Cu / 1 μm Ag

2 models of HTS AC cables





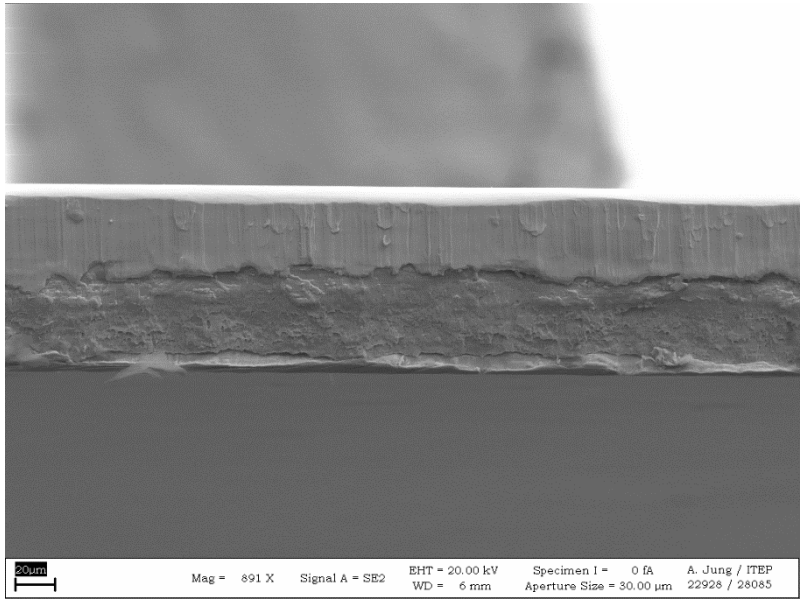


VNIIKP made 2 model AC cables with I_c of **3.0 кА** and **4.5 кА**

Roebel cables

Route 1: Punch Ag-finished tape, then electroplate Cu

Route 2: Punch Cu-finished tape



Strand Cu-finished	I_c (A)		
	Meas.1	Meas.2	Meas.3
1	207	208	206
2	204	205	203
3	198	198	198

Smooth cross-section of the punched edge
Cu gets smeared over the HTS layer

No I_c degradation after repeated thermal cycling

Over 20 km of tape shipped in last 9 months

Fault current limiter applications:

Device	Parameters	SuperOx tape inside	
FCL (resistive)	3.5 kV, 2 kA	Width:	12 mm
		Single piece length:	30 m
		I_c (77 K, s.f.):	300 A ± 10%
		Finish:	3 μm Ag
FCL (inductive)	35 kV, 1 kA	Width:	12 mm
		Single piece length:	30 m
		I_c (77 K, s.f.):	250+ A
		Finish:	1 μm Ag

Over 20 km of tape shipped in last 9 months

Rotating machinery applications:

Device	Parameters	SuperOx tape inside	
Motor	200 kW	Width:	4 mm
		Single piece length:	100 m
		I_c (77 K, s.f.):	100+ A
		Finish:	40 μm Cu / 1 μm Ag
Wind generator	1 MVA	Width:	4 mm
		Single piece length:	100 m
		I_c (77 K, s.f.):	100+ A
		Finish:	40 μm Cu / 1 μm Ag

Over 20 km of tape shipped in last 9 months

Energy storage applications:

Device	Parameters	SuperOx tape inside	
Flywheel	5 MJ	Width:	4 mm
		Single piece length:	100 m
		I_c (77 K, s.f.):	100+ A
		Finish:	40 μm Cu / 1 μm Ag
SMES	1 MJ	Width:	12 mm
		Single piece length: 20 nOhm each	350 m with up to 2 solder joints,
		I_c (77 K, s.f.):	300+ A
		Finish:	20 μm Cu / 1 μm Ag

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Product specifications

Parameter	Value	
Production Length	up to 200 meters	
Substrate Thickness	60–100 µm	
Tape width	4 mm	12 mm
Critical Current @ 77K, s.f.	100-150 A	300-500 A
Current Uniformity	±10%	±10%

Customisation:

- Variable silver thickness
- Variable copper thickness
- Lamination
- Insulation
- Artificial pinning centres
- Solder plating
- Solder joints
- ... just ask

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Workshop template table

Tape description	SuperOx 2G HTS tape Production status as of May 2014
Width range	4–12 mm
Production length range	2014: up to 350 m 2016: 500+ m 2020: 1000+ m
Unit length	Single piece length: up to 200 m
Substrate, buffer, SC, barriers, protections (materials, techniques)	Optional Polyimide or solder/Cu/Ag/PLD-GdBCO/PLD-CeO_2/LMO/IBAD-MgO/LMO/Al_2O_3/Hastelloy
REBCO thickness range	0–3+ μm
Copper thickness range	1–50+ μm
Ic at 77K, SF	500+ A/12 mm 100+ A/4 mm
Je at 77K, SF	400+ A/mm^2at 0.1 mm conductor thickness
Je at 4.2 K, 20 T	300-500 A/mm^2 at 0.1 mm conductor thickness
Jc at 77K, SF	25000
Jc at 4.2 K, 20 T	30000 A/mm^2, 3 MA/cm^2
Critical current variation over a unit length	± 10% over entire shipped length or better
Tensile stress	800 MPa/0.55%

Workshop Q&A

Q: Because of the cable topology, the 5 mm strips need to be punched from a wider tape, 10 to 12 mm minimum, or other multiples of 5 to 6 mm. Is this compatible with your production process?
A: Yes.

Q: Would it be possible to deposit the superconducting layer on a tape already shaped in the final meander that we require?
A: Yes. But makes more sense to punch silver-coated tape and then electroplate copper (experiment in progress with KIT).

Q: Another issue that we would like to understand is the possibility of adding copper or another stabilizer: what is the Cu thickness range you can provide?
A: 1-50+ microns.

Q: Do you also provide additional copper via soft soldering?
A: Not at the moment, but can develop it if we see demand. On the other hand, we can electroplate as much copper as needed.

Workshop Q&A

Q: What qualification do you provide on a delivered unit piece length?
A: At present: (1) positional non-contact measurements of the entire length and (2) transport measurements of 1 m sections with minimum Ic of the length.
By the end of 2014: positional transport measurements of the entire length.

Q: Ideally we would like 100 m at present, then 200 m in two years and possibly 500 to 1000 m in 5 years. Is this compatible with what you can realistically forecast?
A: Yes and even sooner: 100-200 m at present, 500 m in 2 years, 1000 m in 5 years.

Q: Can you give us realistic cost expectations?
A: We expect evolutionary price reduction. We believe that at present tape manufacturers need to work together to create a real market for 2G tape, and only after that they should really begin competing.

Q: Would it be possible to imagine a round or squared configuration one day for this superconductor, even if at the cost of a slightly reduced performance? And what about a layered architecture, i.e., multiple layers of ReBCO in a sandwich?
A: In my opinion, manufacturing companies will unlikely invest into this unless there is preliminary properly funded university level research into these topics.