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WAMHTS-4 – Barcelona, Spain

2G HTS Wire Development at SuperPower

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February 16, 2017

FURUKAWA ELECTRIC GROUP

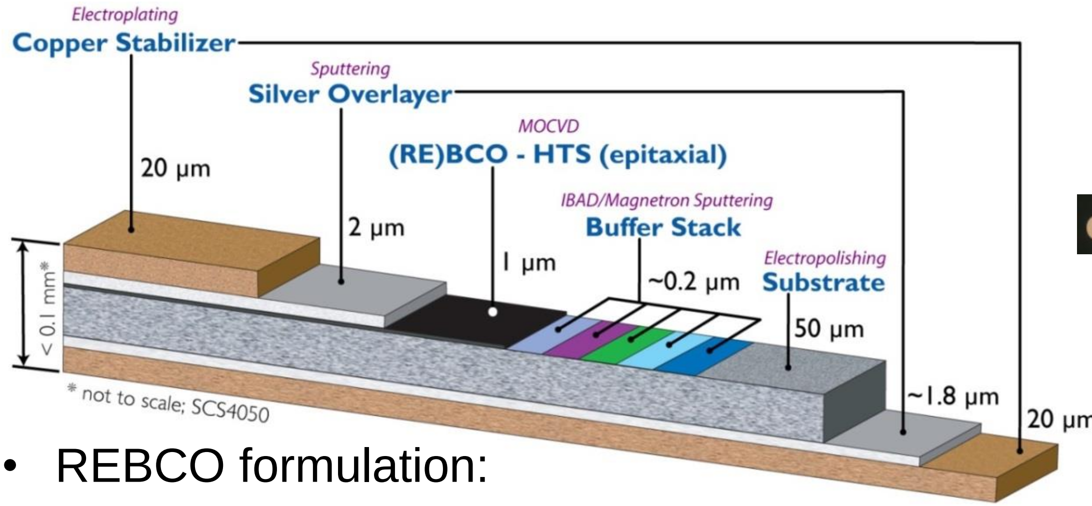
Acknowledgements

- I would like to acknowledge the contributions of the all the members of the SuperPower team, in particular….
  - Yifei Zhang (electromechanical characterization)
  - Ryusuke Nakasaki (pinning development)
  - Aarthi Sundaram (30 μm development)
  - Paul Brownsey (IcBT measurements)
  - Gene Carota (MOCVD)
  - Masayasu Kasahara (buffer development)
  - Allan Knoll (post MOCVD)

2G HTS Tape Production

2G HTS wire production at SuperPower

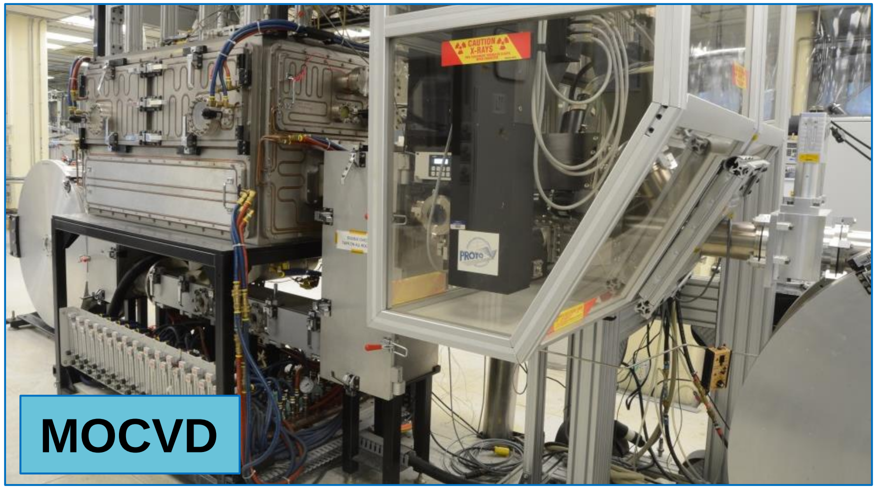
IBAD-MOCVD based REBCO wire on Hastelloy substrate

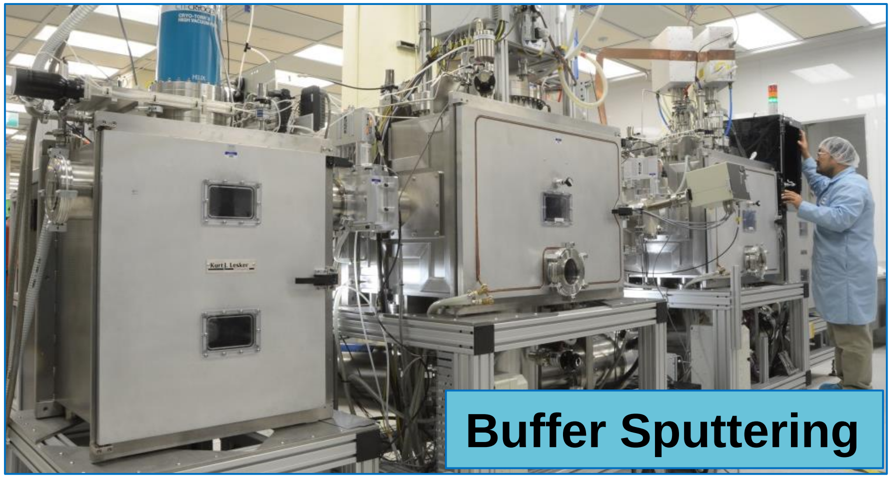


Cross-sectional image of a Cu-plated wire

- REBCO formulation:
  - **AP** (Advanced Pinning) – with enhanced in-field performance for B//c, targeting at coil applications such as high-field magnets, SMES, motors/generators
  - **CF** (Cable Formulation) – for cables, transformers, FCL
- I_c(77K, s.f.)/12mm = 400-600A, piece length = up to 500m.
- Variations in width (2-12mm), substrate thickness (30, 50 or 100µm) Ag thickness (1-5µm), Cu thickness (10-115µm), and insulation
- Bonding conductors : 2x2mm, 2x4mm, 2x12mm (face to face / back to back)

2G HTS wire has been produced since 2006
Continuous improvements introduced into processing





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Conductor development areas

- Manufacturing improvements are a current focus area
  - Longer uniform piece lengths
  - Run-to-run repeatability
  - Tightening process windows
  - Improving process hardware
  - Maximizing yield
- Enhancing understanding of pinning optimization for operating conditions (4K/high field, 20-50K/2-5 T, 65-77K, lower fields)
  - Artificial pinning centers (BZO, others)
  - Process control (temperature, growth rate, precursor delivery, etc….)
- Maximizing Je
  - Thinner substrates
  - Thicker films

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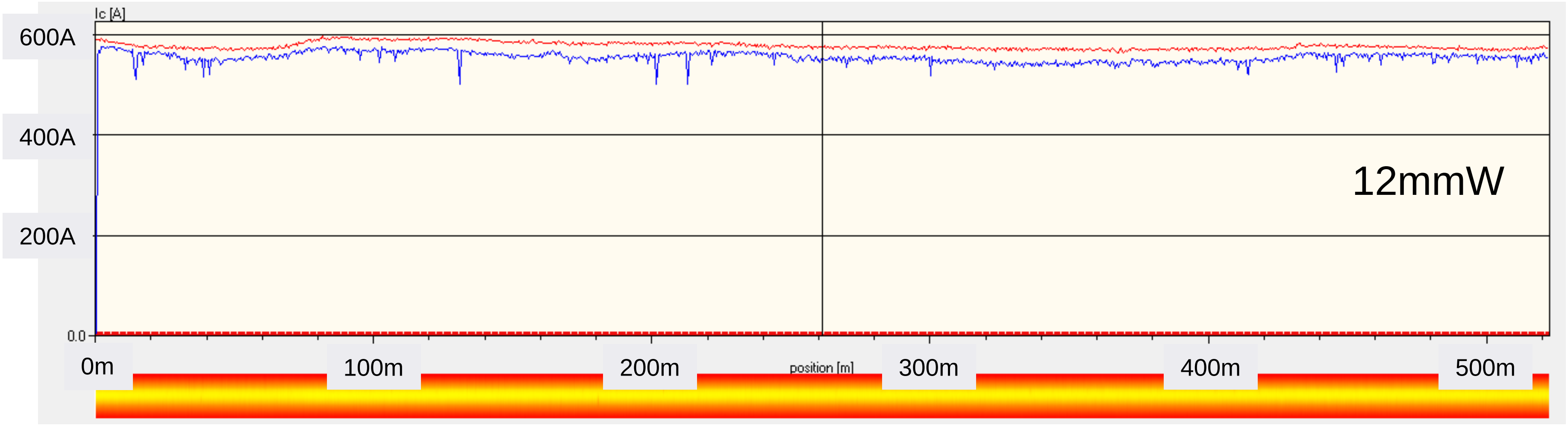
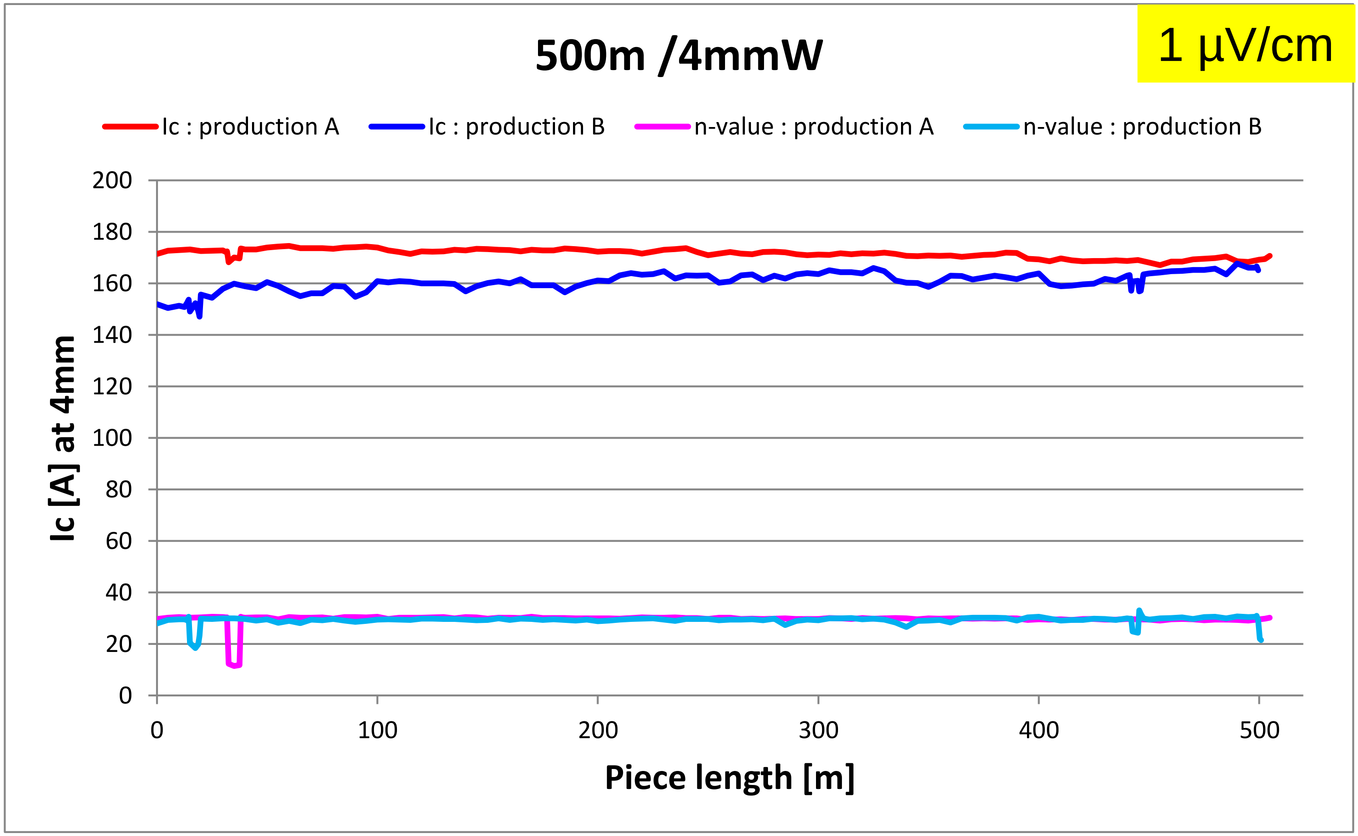
Ic performance of production enhanced A.P. wire at 77K/s.f



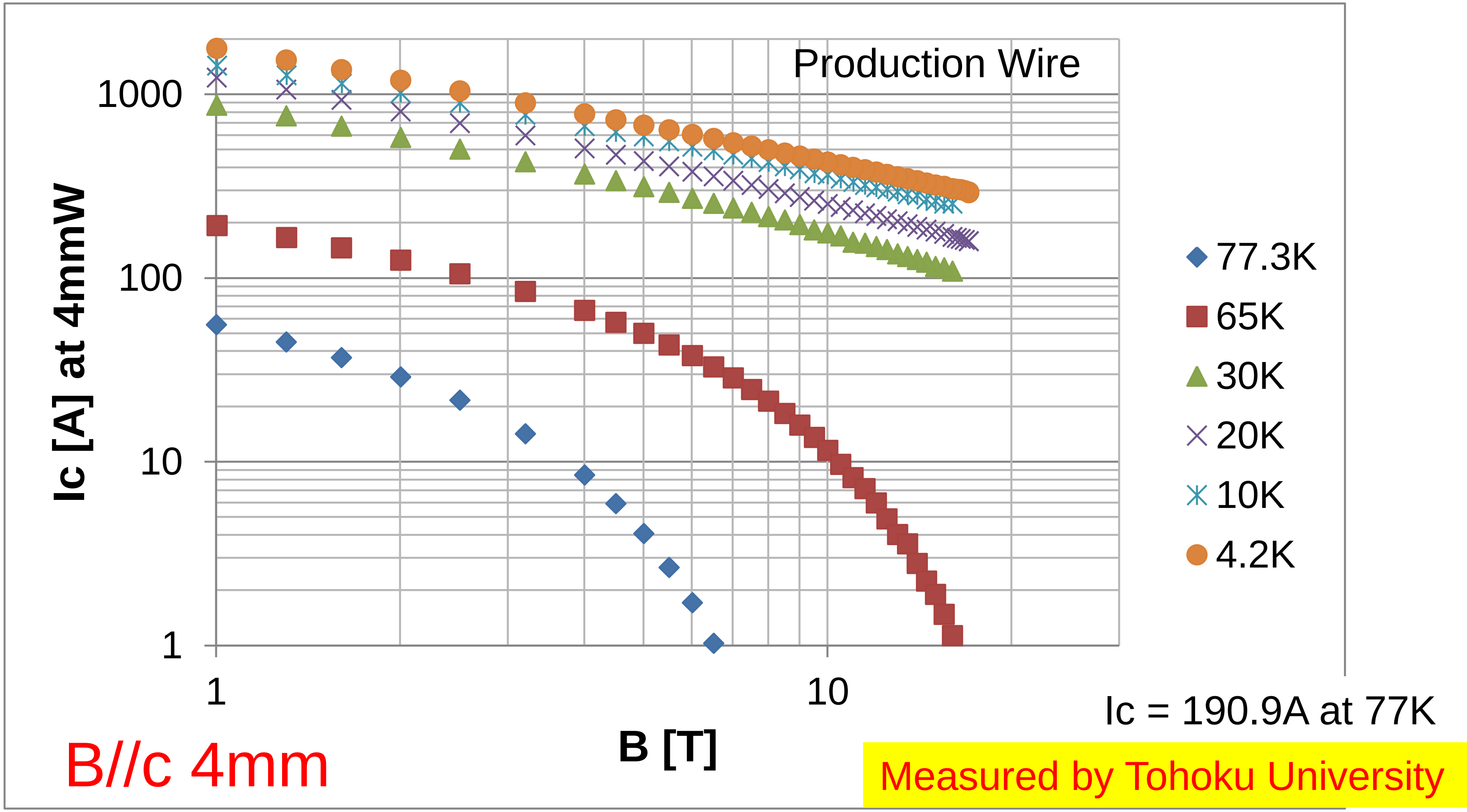
- Magnetic, non-contact measurement
- High special resolution, high speed, reel-to-reel
- Monitoring I_c at multiple production points after MOCVD
- Capable of quantitative 2D uniformity inspection

Ic performance of enhanced A.P wire at 77K/s.f



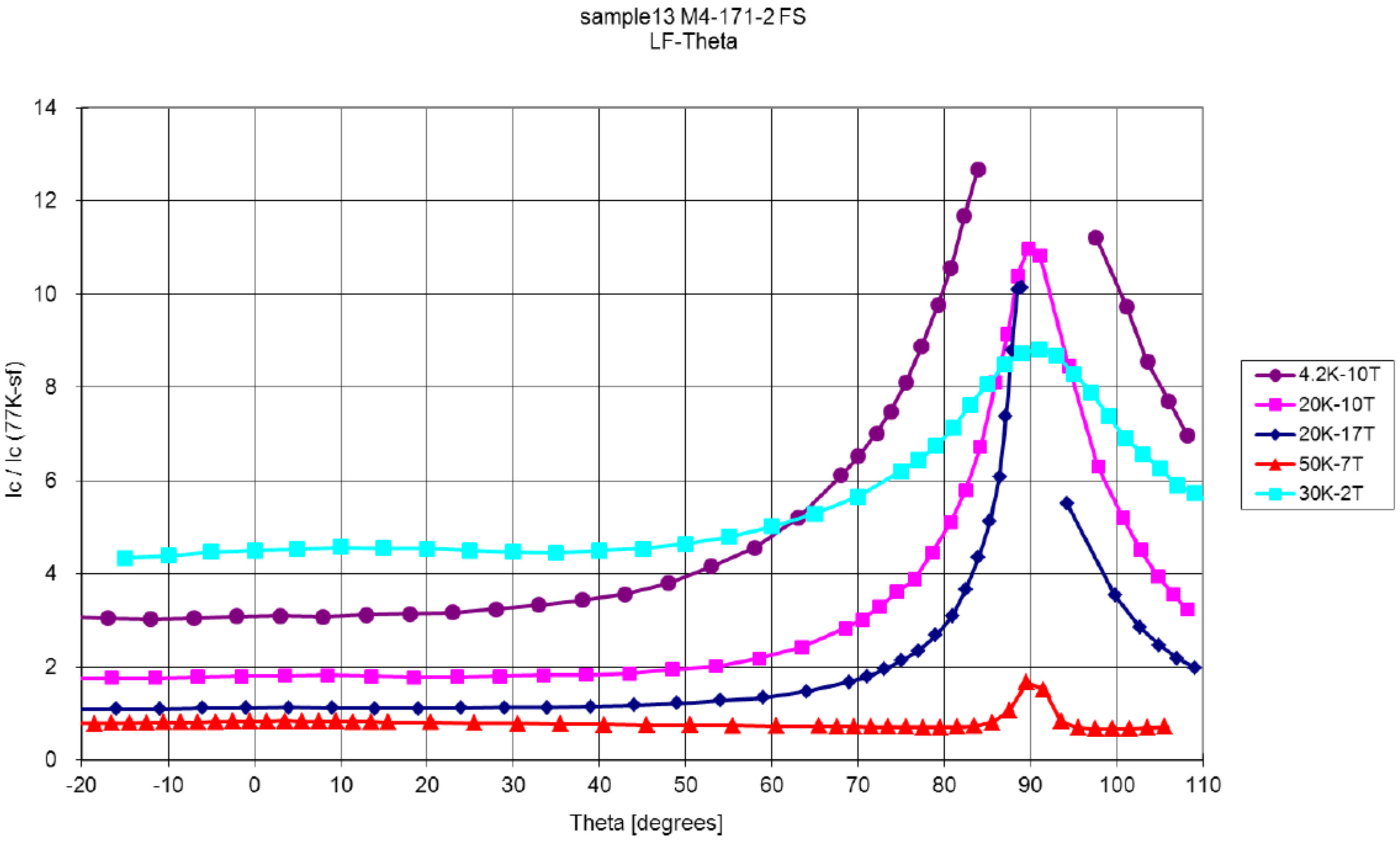
- Transport measurement by every 5m, with 40μm copper.
- Extend the piece length up to 500m

Performance of enhanced A.P wire (7.5% Zr)



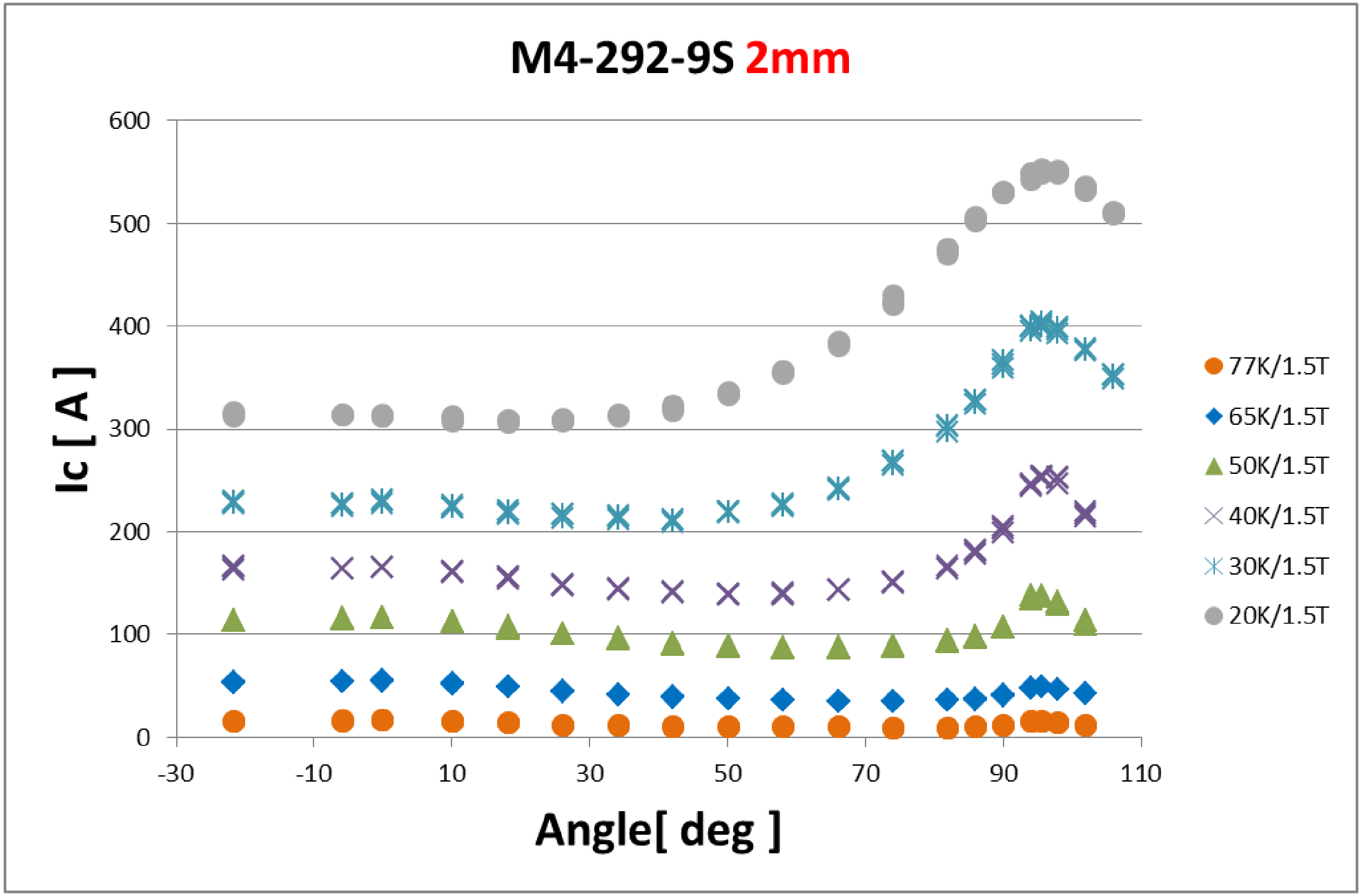
- Enhanced A.P wire shows high in-field performance

High field IcBT data on 7.5% Zr doped sample



Measured at Tohoku Univ

IcBT typical data – enhanced AP

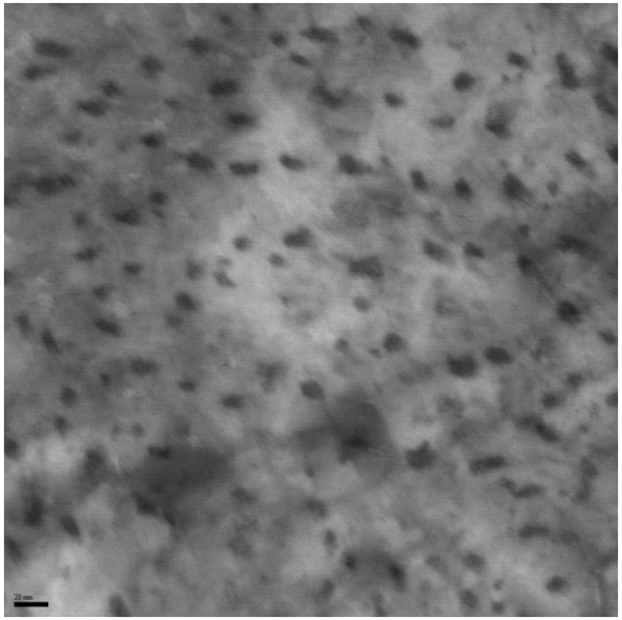


2G HTS Tape R&D

- Pinning
- Thick film
- Thinner substrates

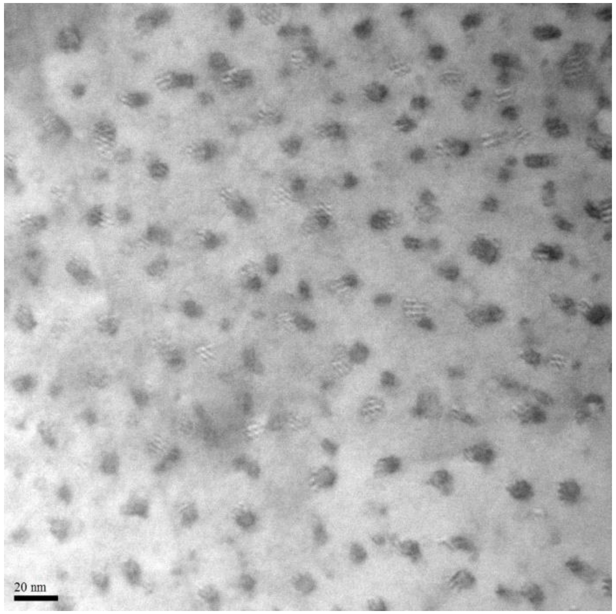
TEM analysis for enhanced Zr doping

Zr = 7.5%



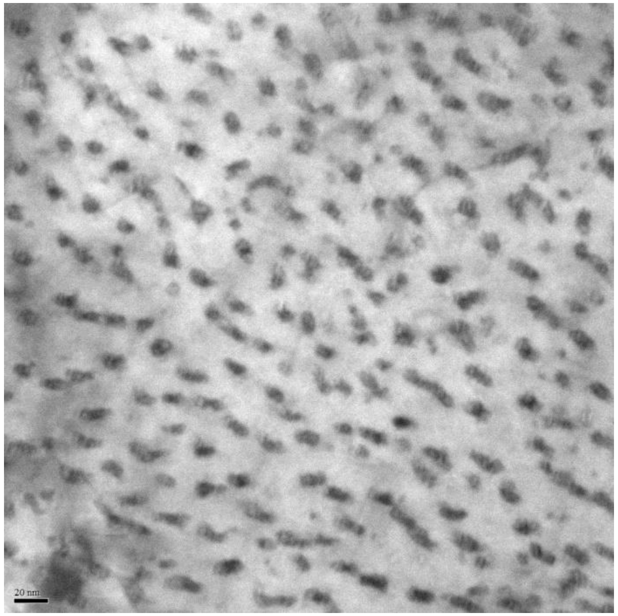
Size : 4.4~6.2nm
Distance : 20.8~26.8nm

Zr = 11.5%



Size : 4.4~5.6nm
Distance : 16~20.7nm

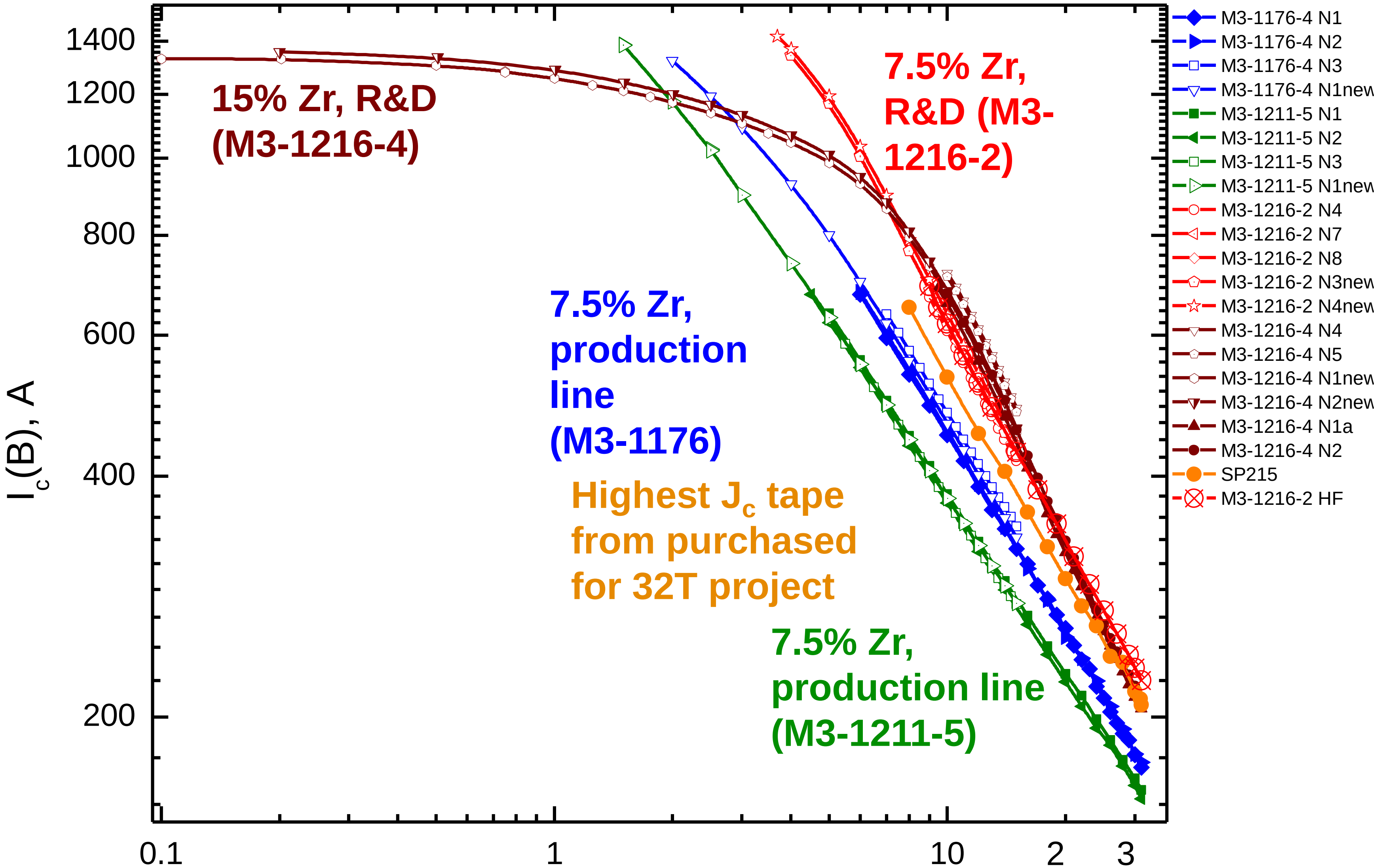
Zr = 15%



Size : 4.4~5.6nm
Distance : 12.8~18.3nm

Combination of I_c(B,4K) measured in resistive and superconducting magnets

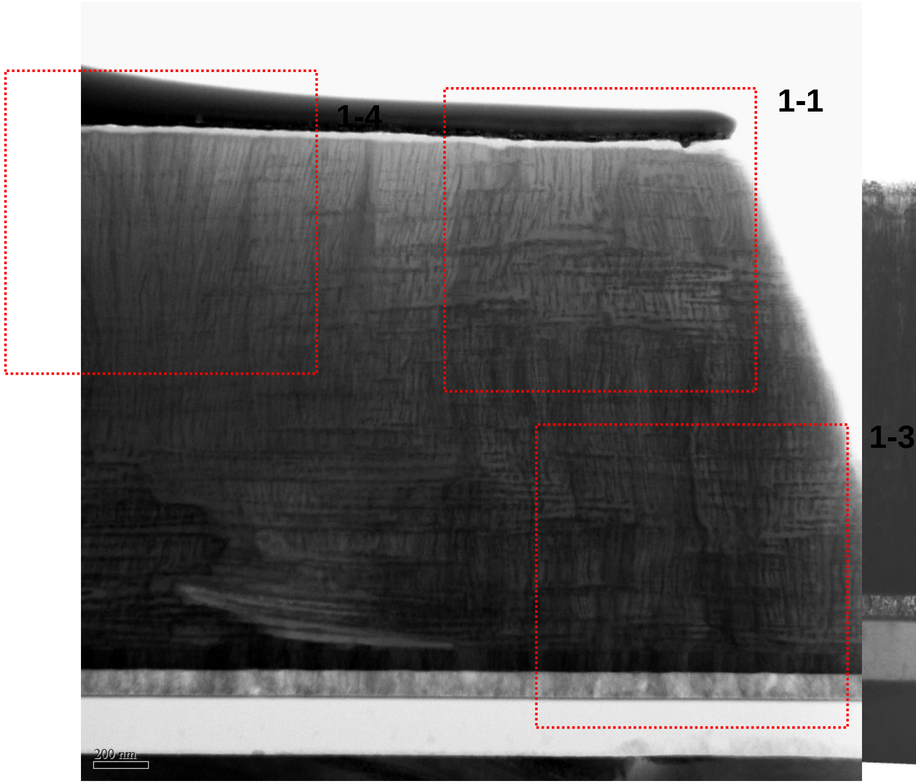
Below ≈2T 15% Zr tape has lower I_c than 7.5% Zr production line tape

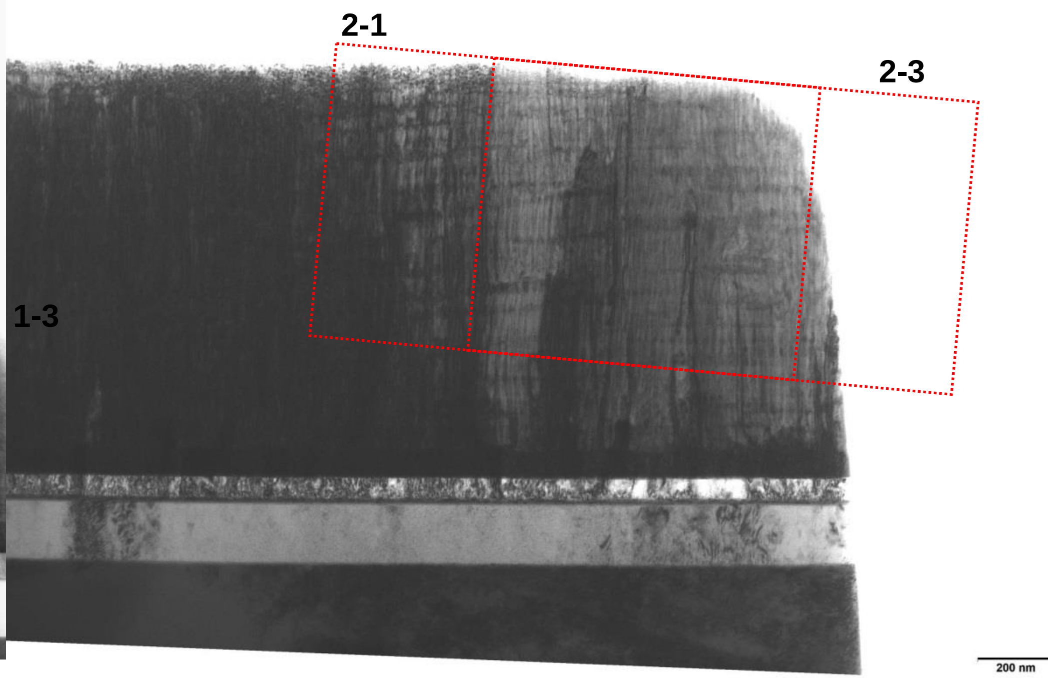


R&D tapes with Zr=15%

M3-1166-10
A.P. type with 15%

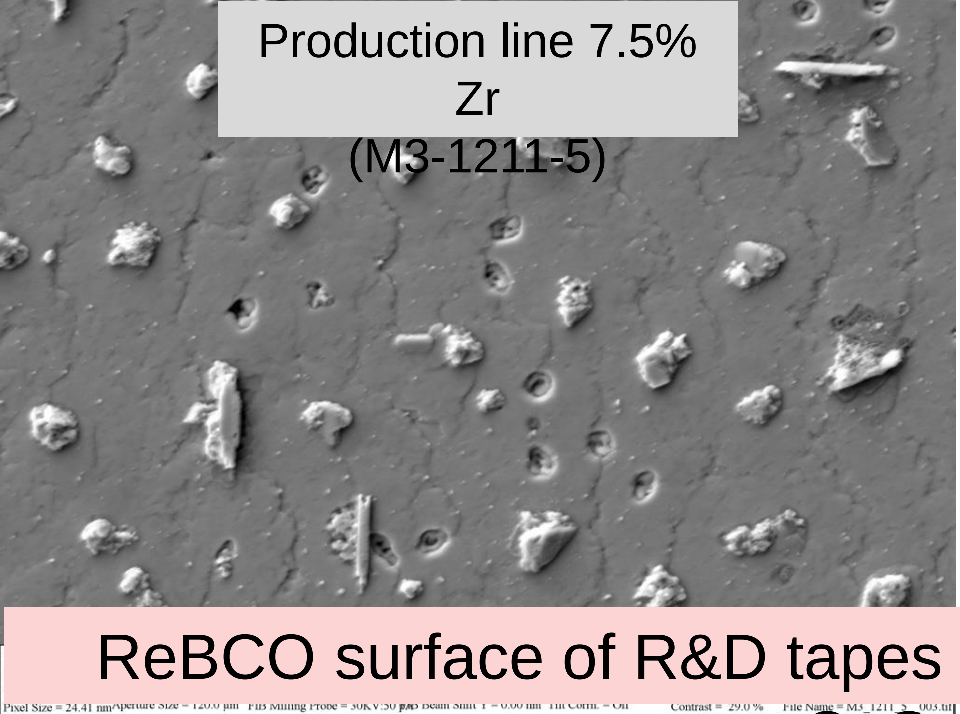
M3-1216-4
High-mag type with 15%

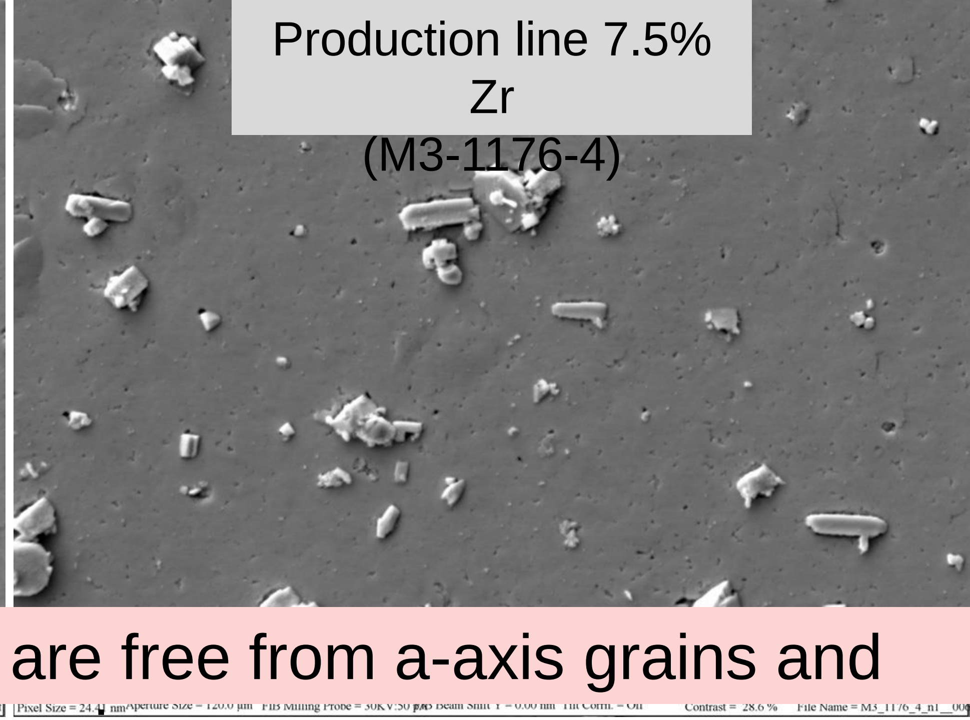


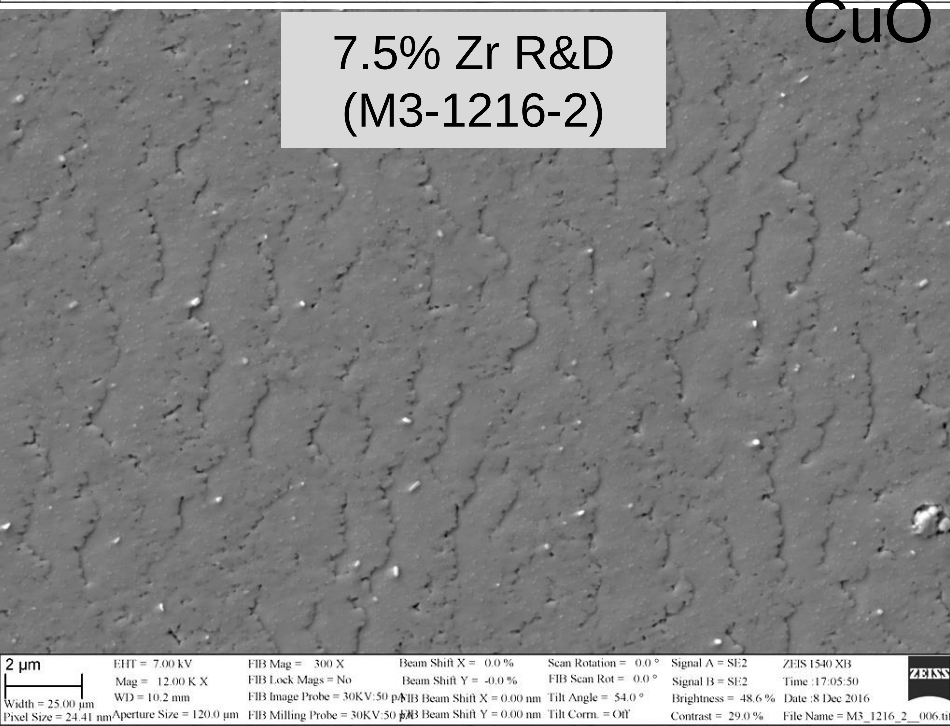


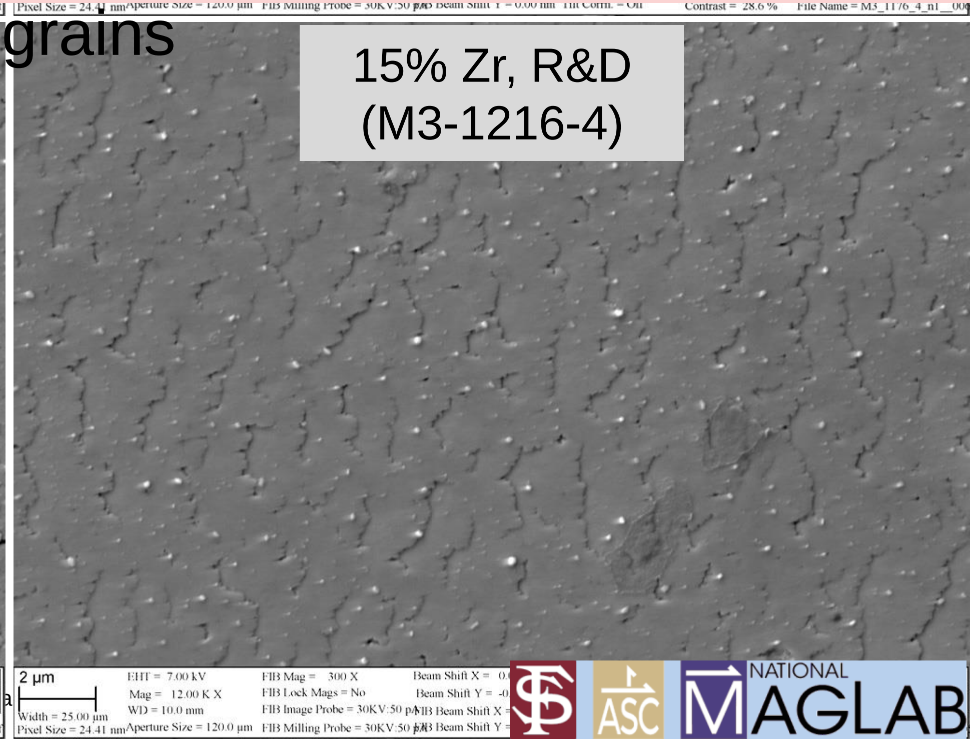
Vertical BZO nano-rods with additional horizontal REOx growths

ReBCO surface of R&D tapes are free from a-axis grains and CuO grains



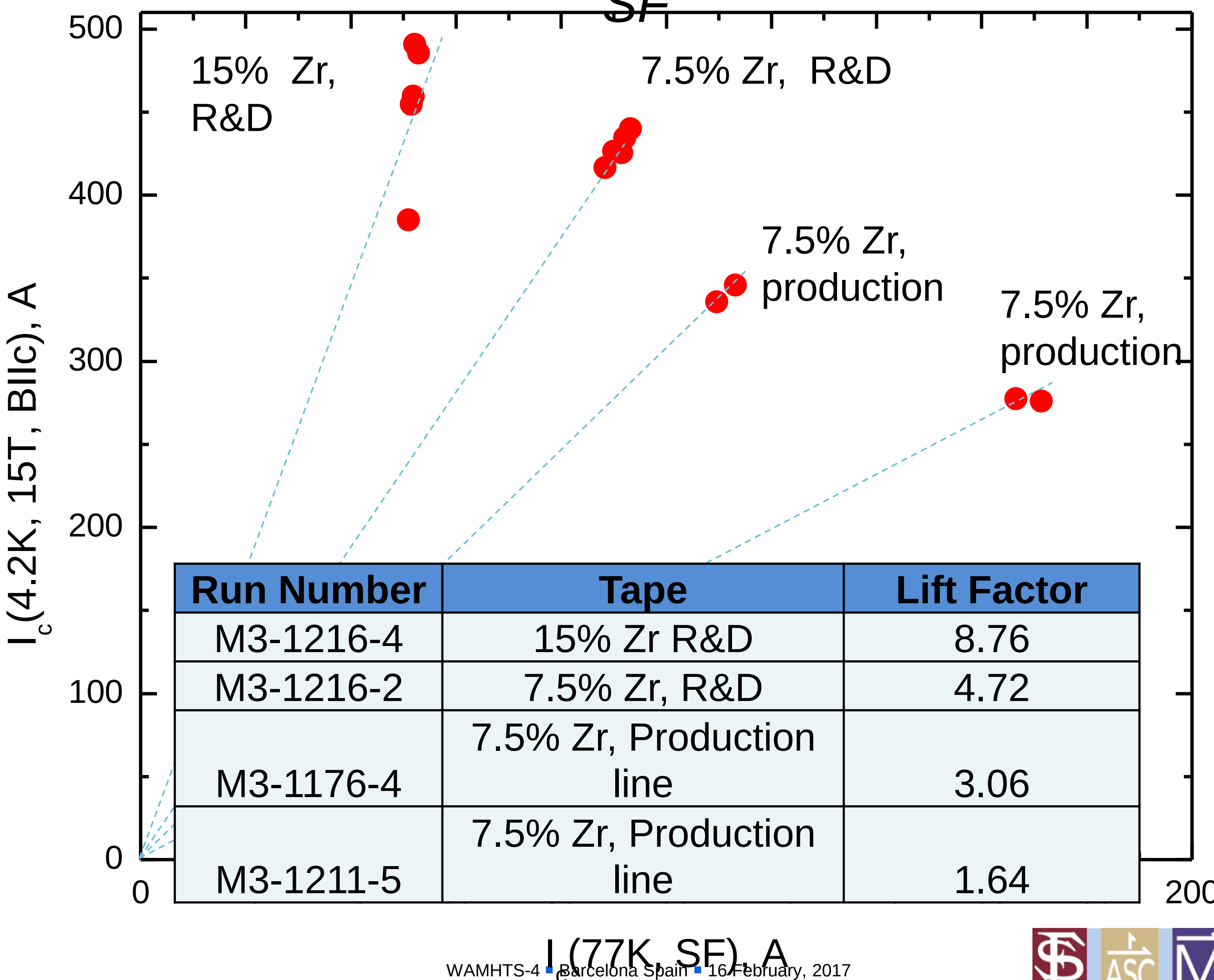






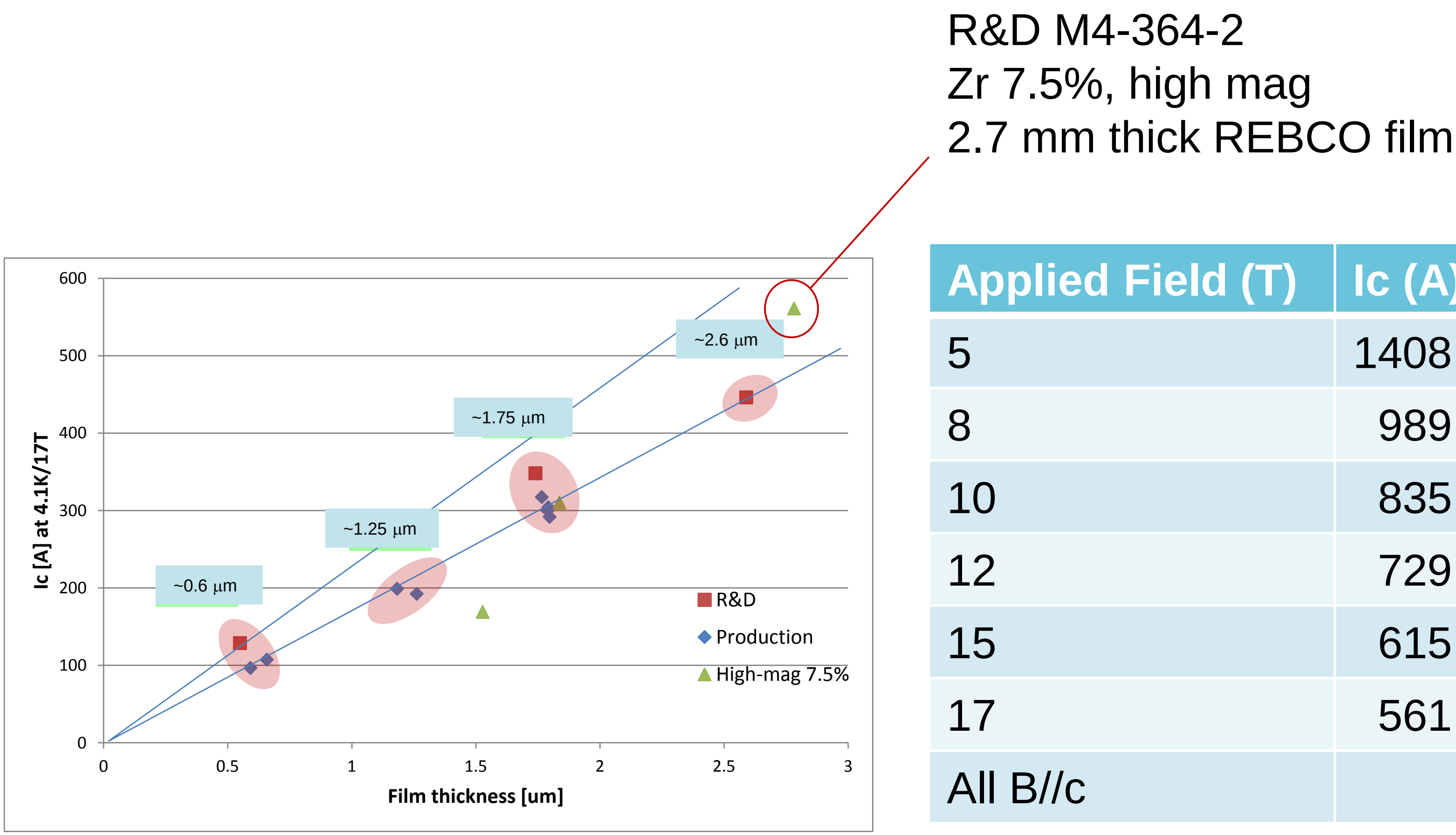
Very different lift factors for compared tapes

Interpretation: Additional pinning centers are not effective at 77K, SF



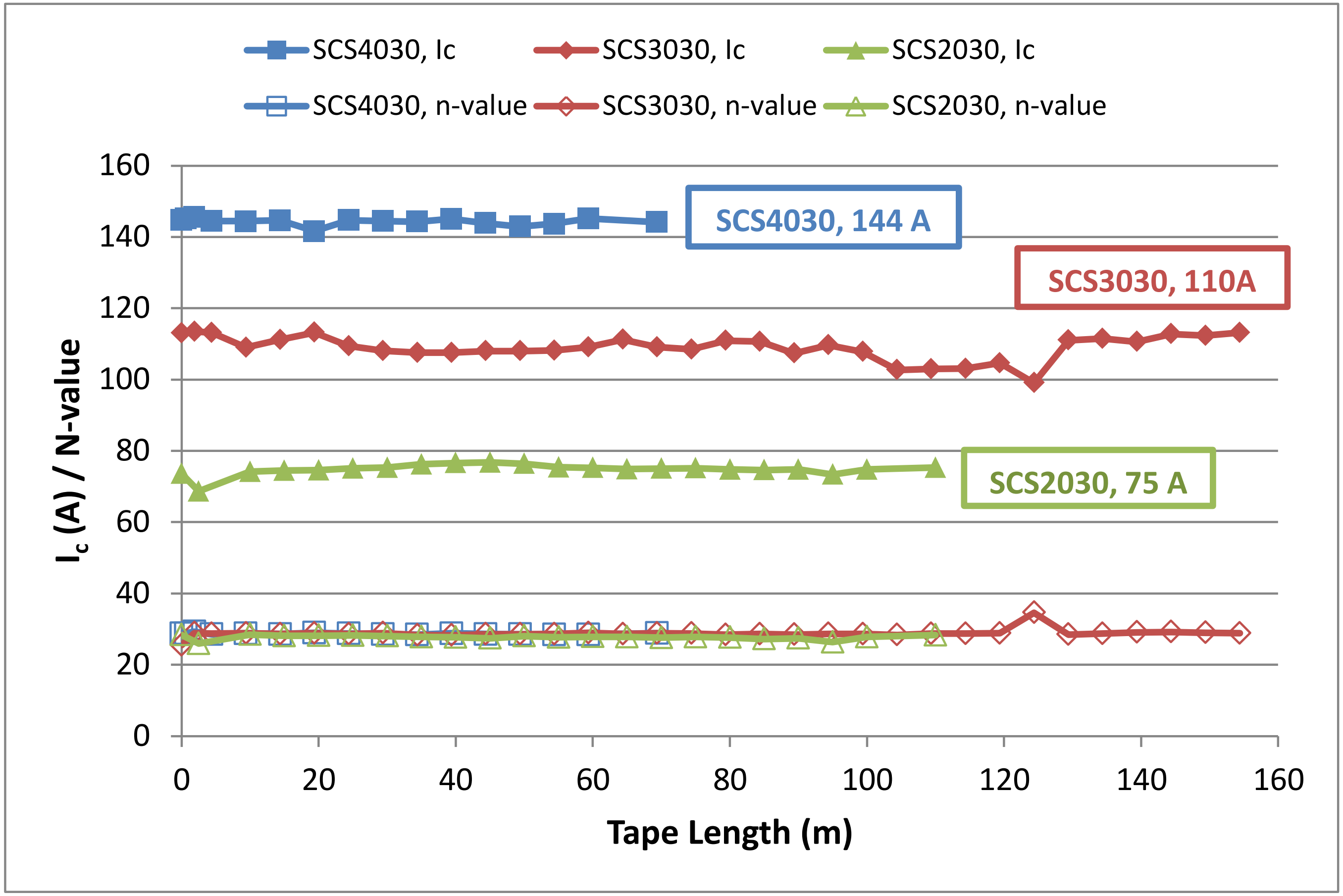
Run Number	Tape	Lift Factor
M3-1216-4	15% Zr R&D	8.76
M3-1216-2	7.5% Zr, R&D	4.72
M3-1176-4	7.5% Zr, Production line	3.06
M3-1211-5	7.5% Zr, Production line	1.64

Thick film development progressing



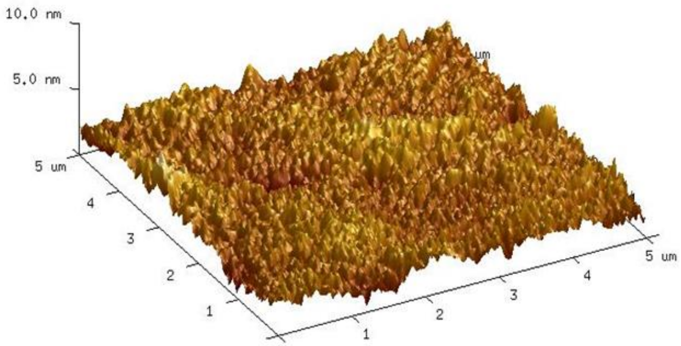
Applied Field (T)	Ic (A) – 4 mmW
5	1408
8	989
10	835
12	729
15	615
17	561
All B//c	

Development progress of 30µm substrate

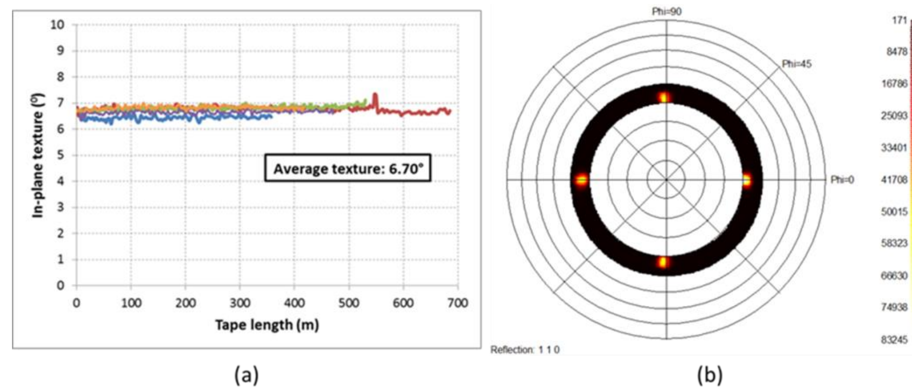


- Base performance of 30µm substrates are comparable to 50µm.

Electropolishing, buffer and MOCVD deposition parameters of 30 μm Hastelloy C276 substrate developed

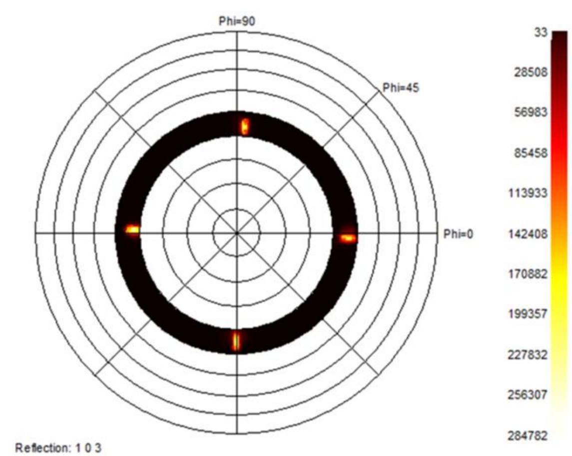


AFM 5 x 5 um scan obtained from 30 um thick electropolished Hastelloy C-276.



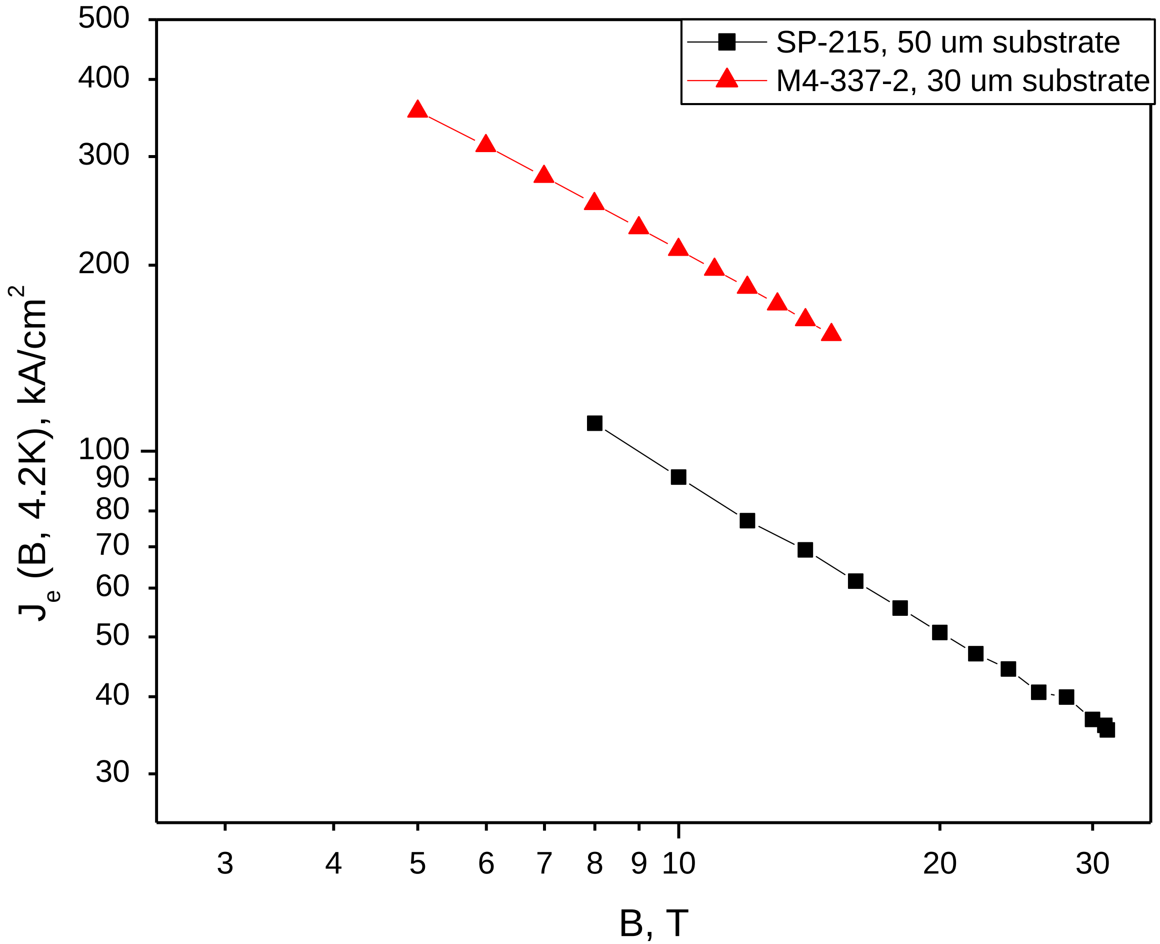
(a) In-plane texture and (b) (110) pole figure of LMO buffered IBAD MgO template on 30 um substrate.

(103) Pole figure of REBCO film with 7.5% Zr deposited on IBAD MgO template on 30 μm substrate.



Improved Je demonstrated with 30 μm tapes

Engineering current density at 4.2 K vs. applied field for 30 um and 50 um ReBCO tapes with 7.5% Zr

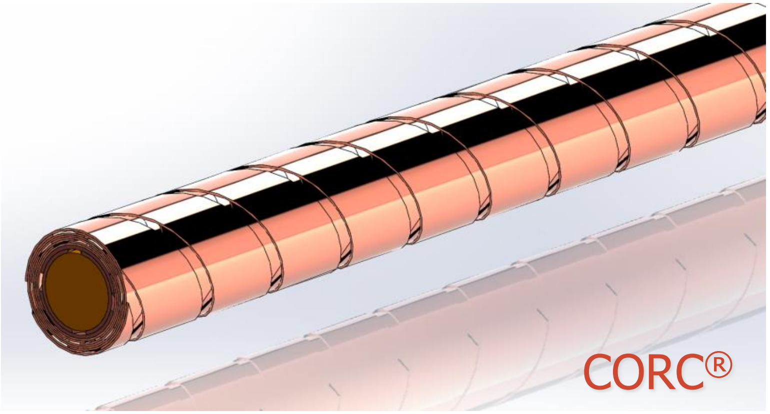


Measured at NHMFL

CORC® wires using SuperPower tapes

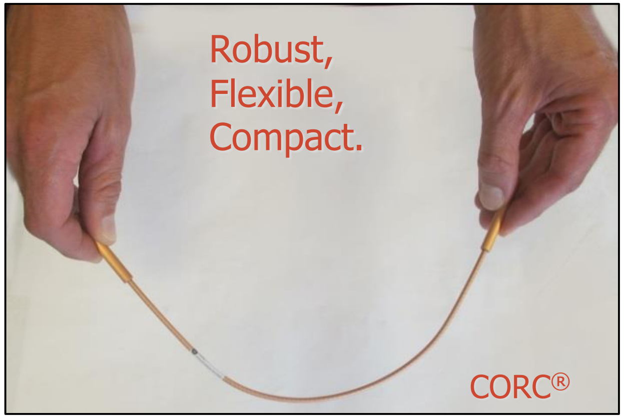
16 superpower tapes wound helically

- Copper core: 2.2 mm diameter
- 2 mm wide tapes with 30 μm substrate
- 6 mm twist pitch with partially transposed tapes for low AC loss
- Wire outer diameter: 3 mm
- Terminal diameter: 6.35 mm
- Nominal wire I_c: > 1,000 A (77 K)

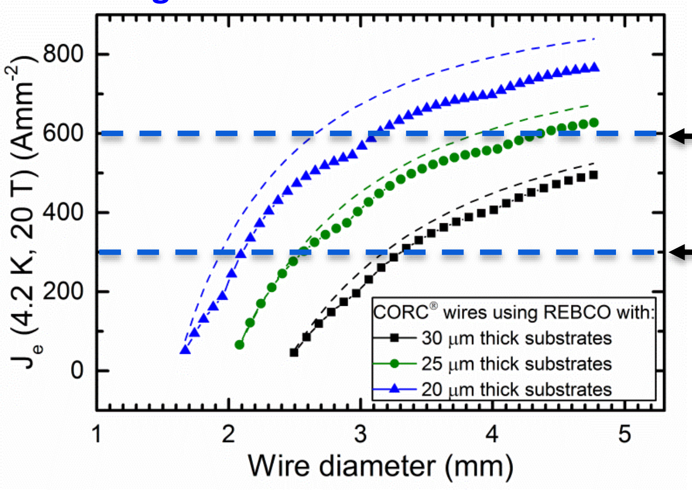


Applications

- High field magnets
- Accelerator magnets
- Fusion magnets
- High power density transmission



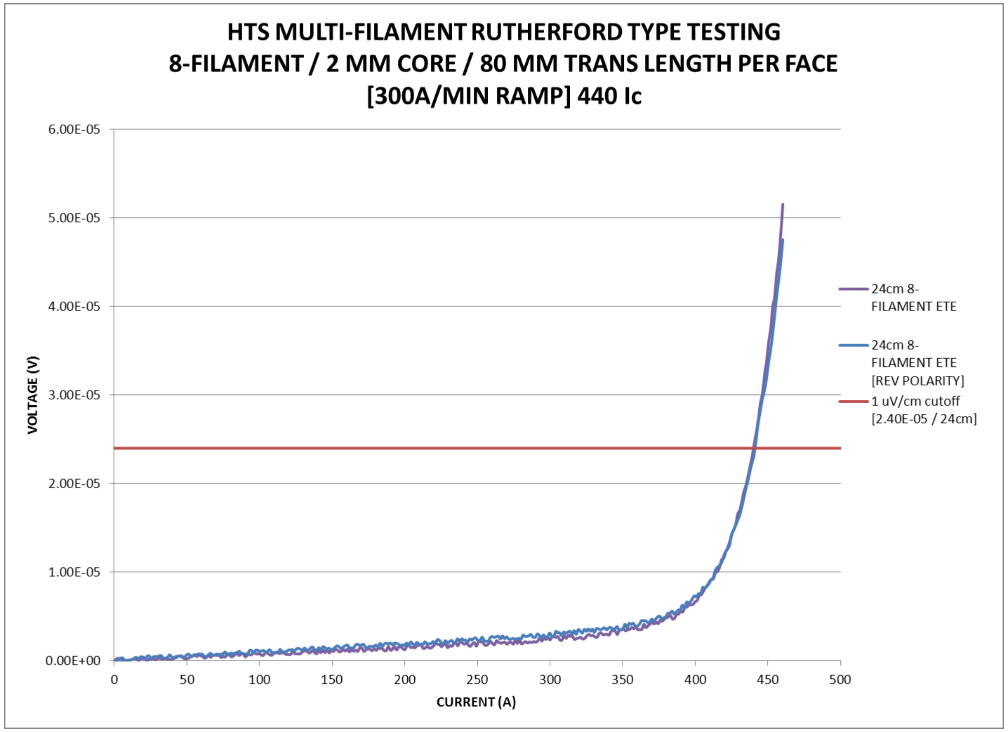
High magnetic field critical current density obtainable by increasing wire diameter and decreasing substrate thickness



Value desired for accelerator magnets such as CCT dipoles

Value desired for high-field research magnets

Prototyping of quasi-Rutherford style cable



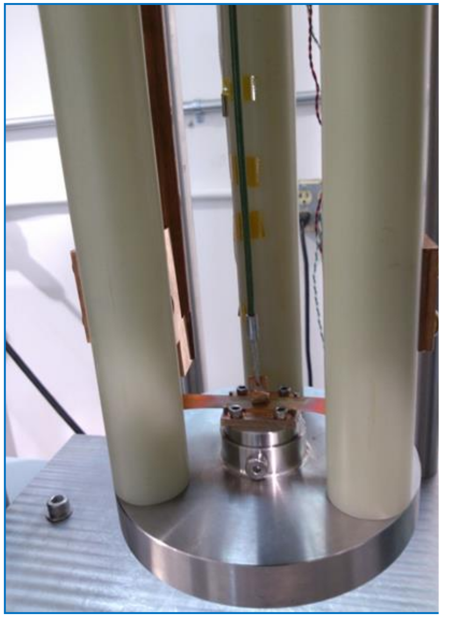
- 8x 30 μm substrate x 2mm wide tapes wrapped around 14 mm x 2 mm core (1 mm radius) without Ic degradation.
- Thinner substrates and narrower tapes will enable smaller, more flexible core.

2G HTS Tape electromechanical characterization

Studies on mechanical/electromechanical properties

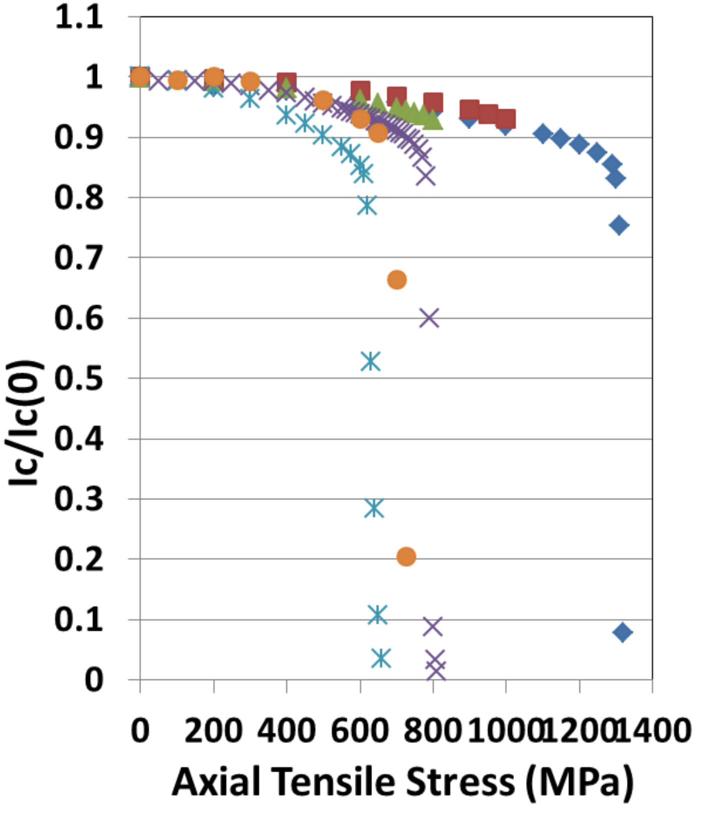
- Mechanical behaviors under various stress conditions at RT and/or 77K
- Electromechanical testing for stress (strain) dependence of I_c at 77K
- Electromechanical strength determined by critical stress with 95% I_c retention

Axial tensile
RT or 77K w/ I_c



Transverse tensile
Stud method
RT or 77K w/ I_c

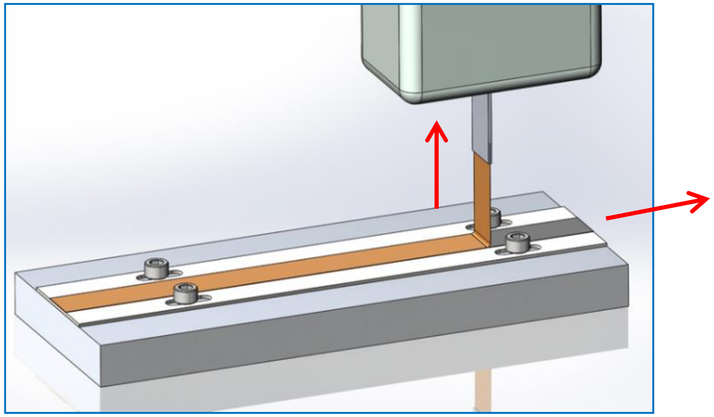
Fixture for mechanical/electromechanical testing



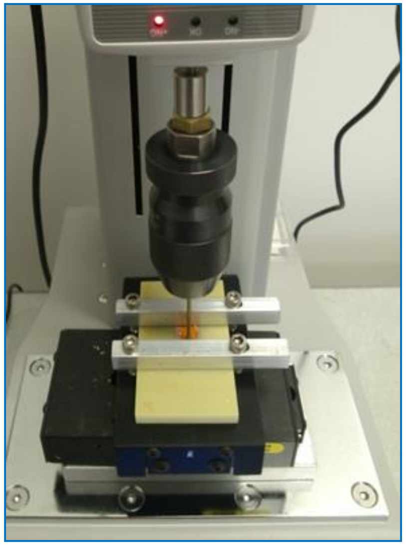
Normalized I_c vs. axial tensile stress for

SF12100, SF12050, SCS12050-20, SCS12050-40, SCS12050-100, FtF-Bonded

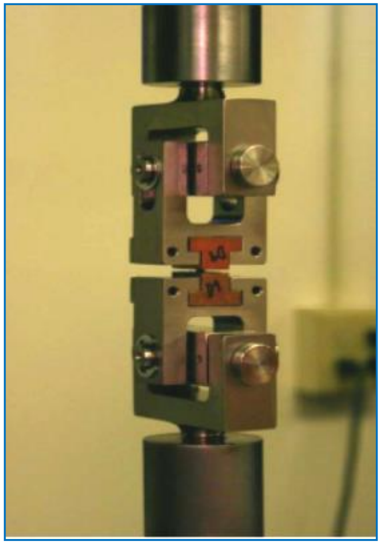
Studies on mechanical/electromechanical properties



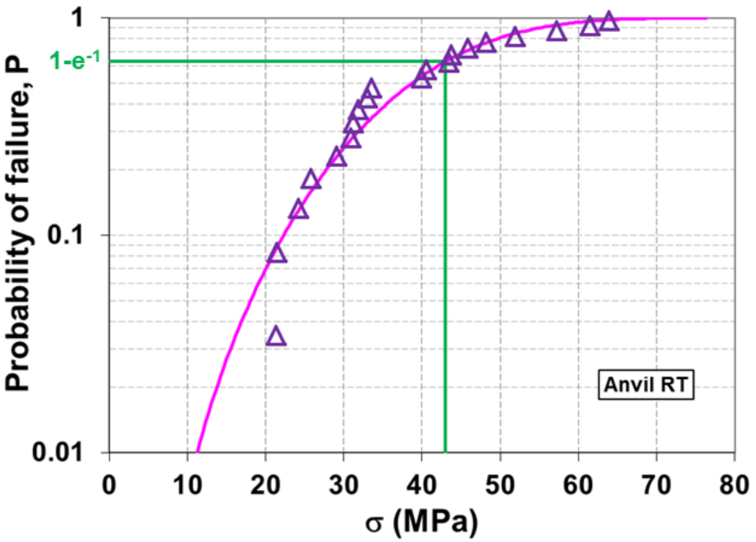
90° Peel test, RT

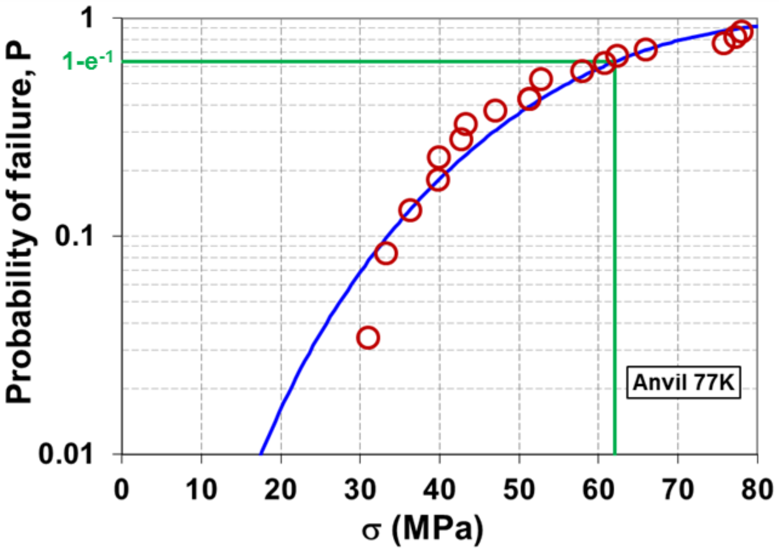


Transverse tensile
Pin-pull method
RT



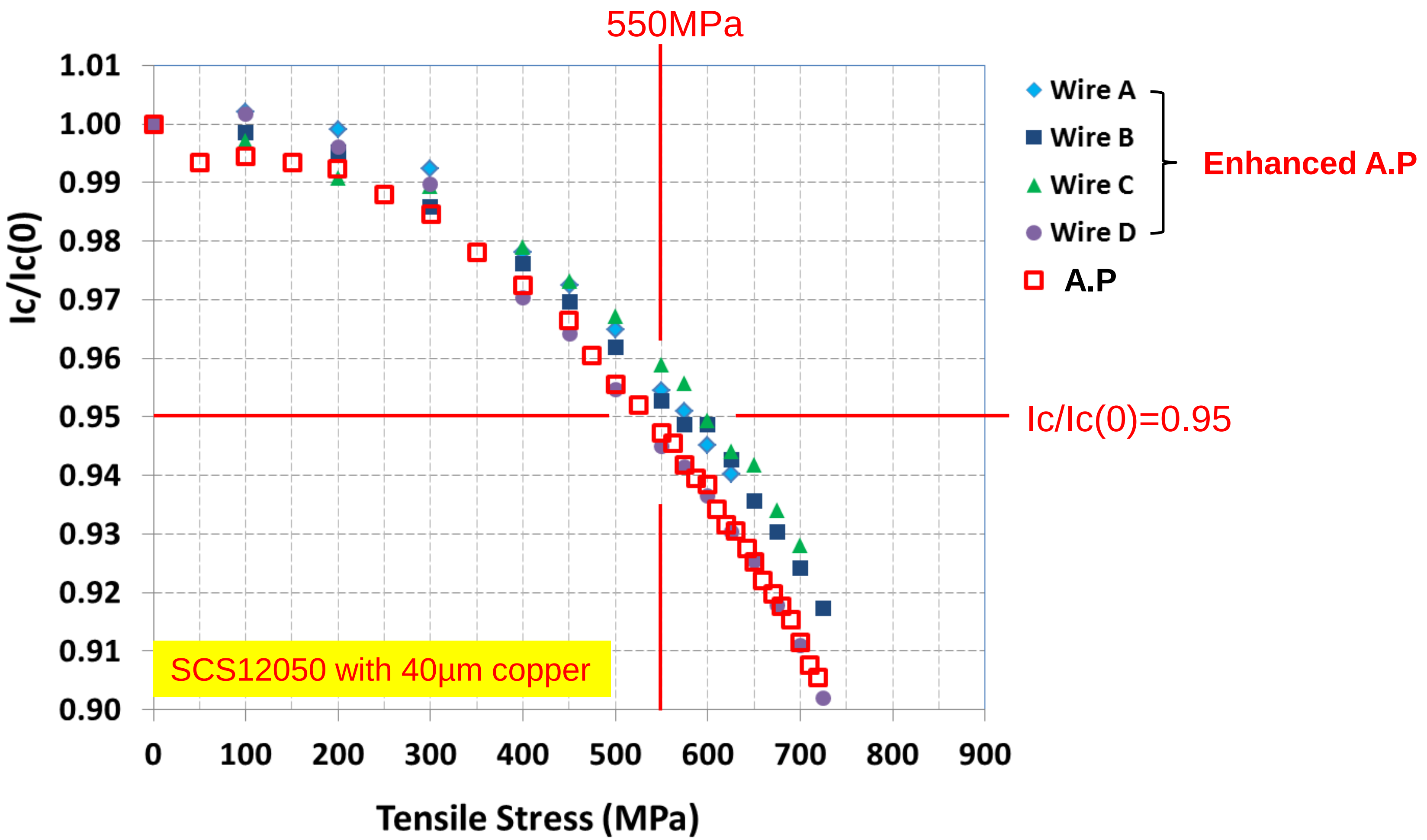
Transverse tensile
Anvil method
RT or 77K

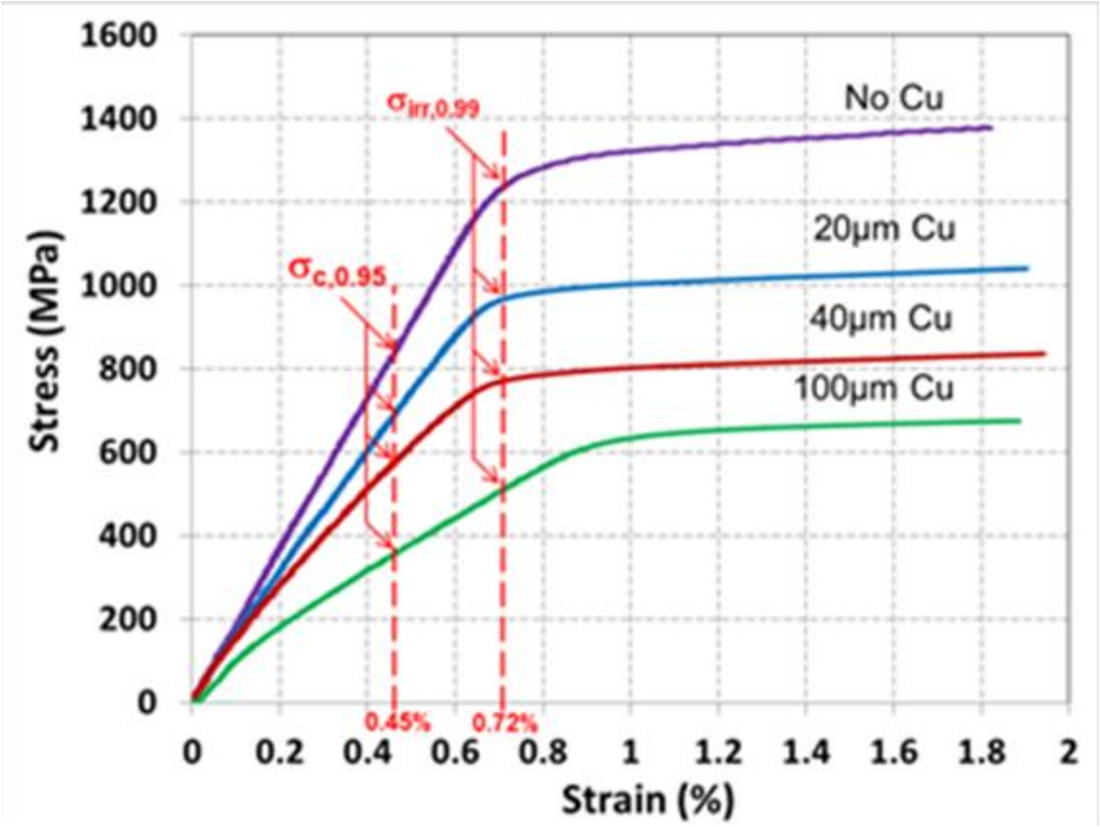




Weibull analysis results – anvil test

Electromechanical property - Ic under tension at 77K





Stress-strain relationship curves of four different SCS4050 wires. The critical strain and irreversible strain as well as the corresponding critical stress and irreversible stress illustrate the dependence and independence of these properties on the Cu stabilizer thickness.

Summary

- Strong focus on processing to improve uniformity, repeatability, piece lengths and yield.
- Maximize current capacity while developing next generation equipment
  - When is the time to pull the trigger?
- Enhance performance parameters for developing operating spaces
  - Thinner substrates
  - Thicker films
  - Optimized pinning
- Continue to improve mechanical properties
  - Delamination mitigation
  - Ic (ε)

Thank you for your attention

superior performance. powerful technology.

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