SuperPower Inc.
A Furukawa Company

superior performance. powerful technology.

Progress of 2G HTS (RE)BCO Conductor Development for Magnet Applications

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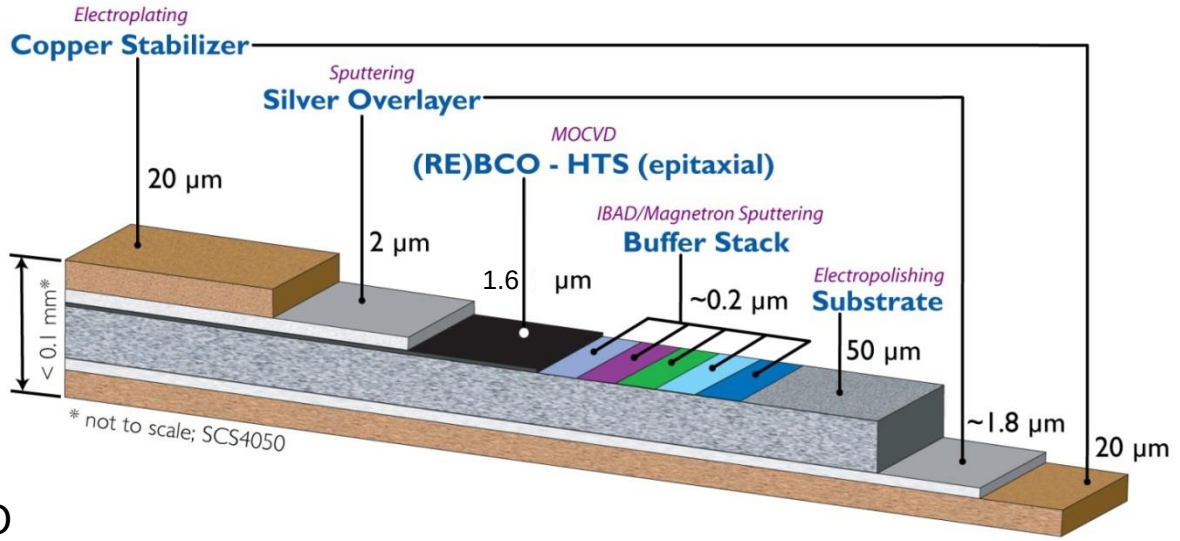
FURUKAWA ELECTRIC GROUP

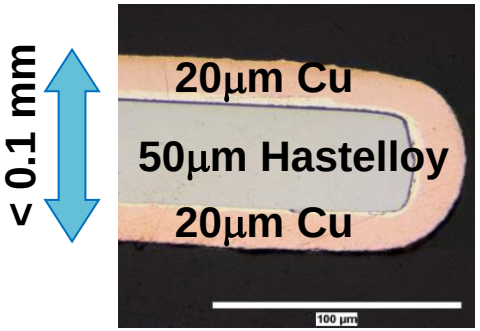
SuperPower Inc. is a subsidiary of Furukawa Electric Co. Ltd.

MT 26 International Conference on Magnet Technology
Vancouver, Canada | 2019

SuperPower's (RE)BCO superconductor with artificial pinning structure provides a solution for demanding magnet applications



- Hastelloy® C276 substrate
  - high strength
  - high resistance
  - non-magnetic
- Buffer layers with IBAD-MgO
  - Diffusion barrier to metal substrate
  - Ideal lattice matching from substrate through REBCO
- MOCVD grown (RE)BCO layer with BZO nanorods
  - Flux pinning sites for high in-field I_c
- Silver and copper stabilization



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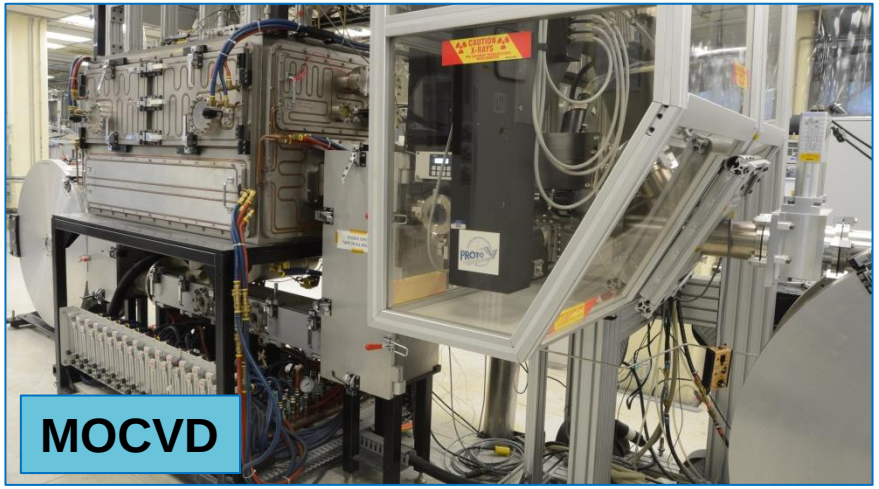
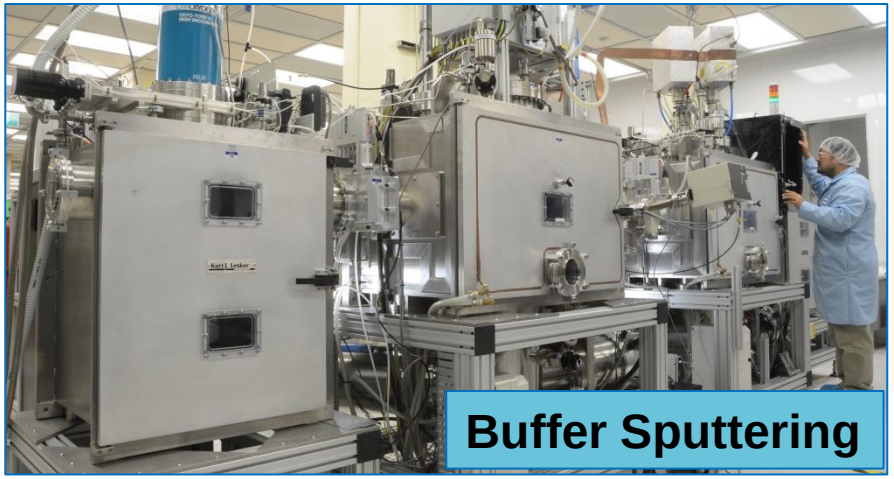
2G HTS wire has been produced with continuous upgrades at the manufacturing facility since 2006

Substrate Electropolishing

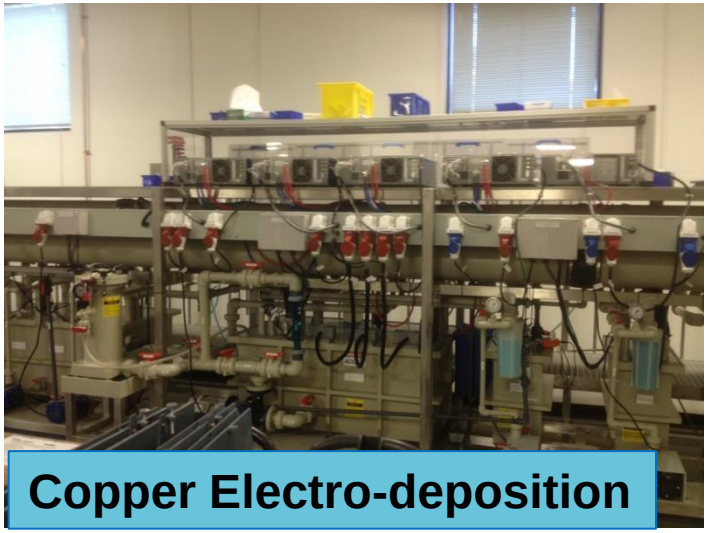

MOCVD

IBAD


Buffer Sputtering

Additional production equipment

Ag sputtering



Copper Electro-deposition

Tape Slitting

Solder Electro-deposition*

* Under construction

Some of the quality control tools utilized….

Reel-to-reel XRD

Reel-to-reel TapeStar Ic measurement

Reel-to-reel transport Ic

In order to meet skyrocketing demand, our efforts are focused on…

1. Stable wire production especially for In-field performance
2. Longer piece length with homogeneous quality
    - up to 1000+ m charge lengths for MOCVD runs are now being routinely run
3. Achieve larger production capacity and lower cost by
    - stabilizing the whole process
    - and bringing all processes in house
    - while adding new equipment
4. R&D work for improved wire performance
    - Film optimization for target operating range
    - Higher current density by thinner substrate (30 μm std)
    - Higher current density by thicker film
    - Investigation for improved post processing techniques

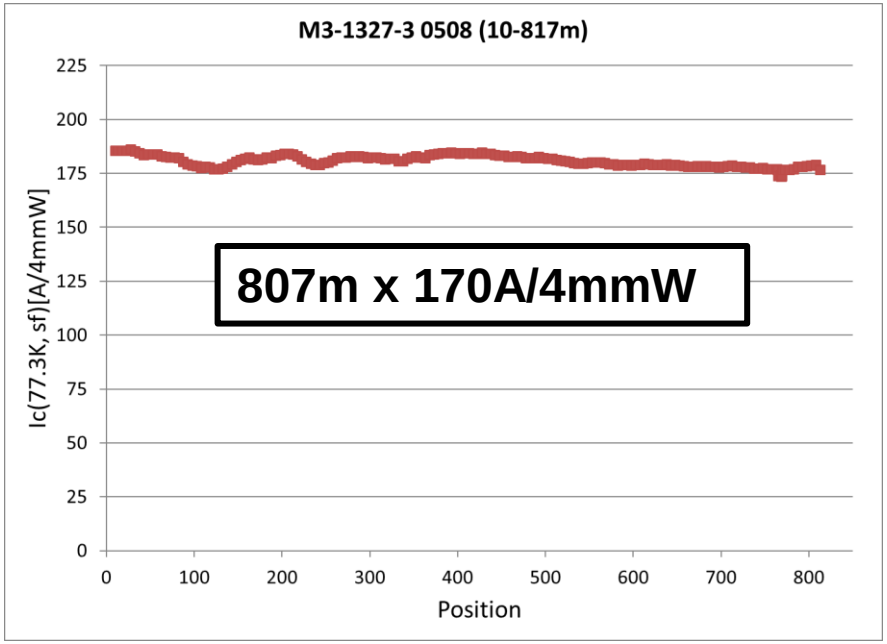
Recent production run of ~770m with 546A avg. Ic

12 mm wide
50 μm substrate
Charge length ~800m before archival samples removed

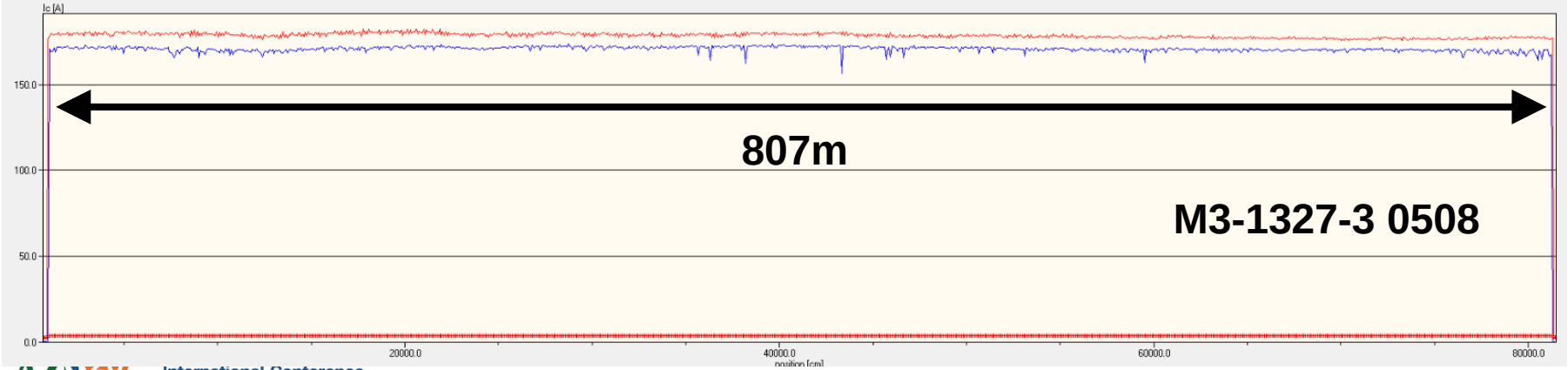
Ongoing production progress

807m piece of insulated 4mmW 2G-HTS wire

Transport measurement

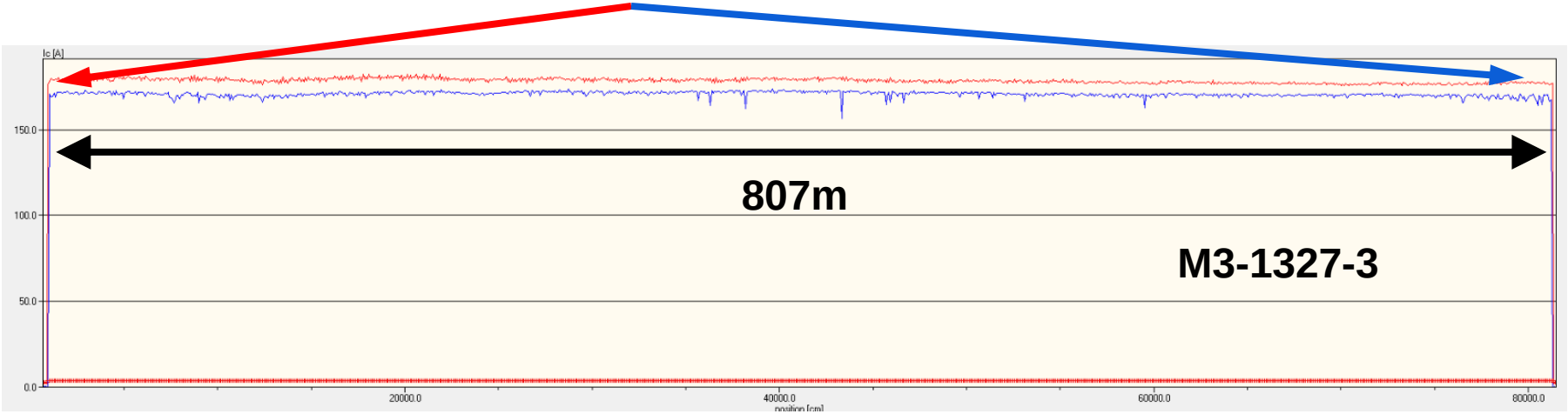


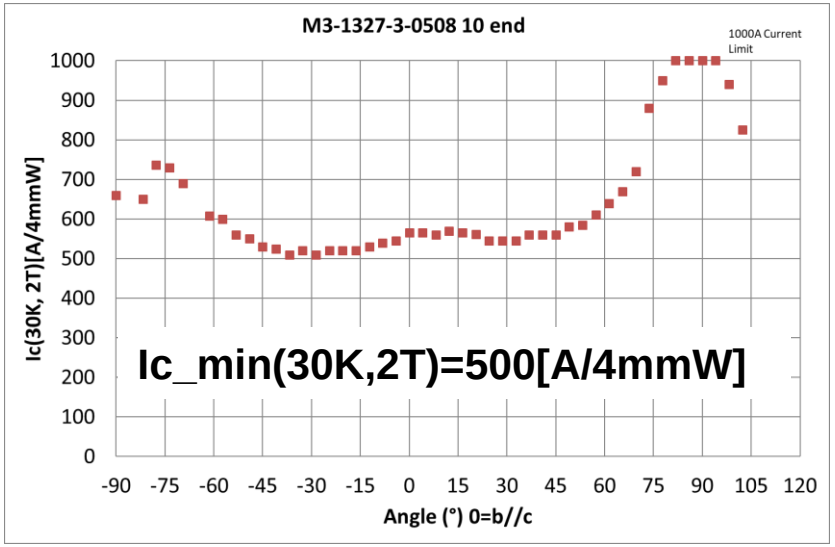
THEVA Tapestar measurement after Insulation

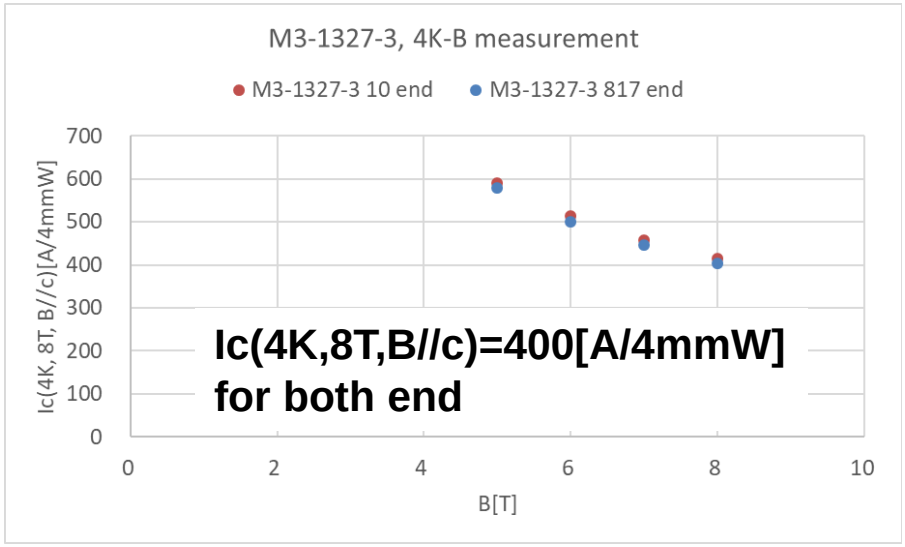


Ongoing production achievement

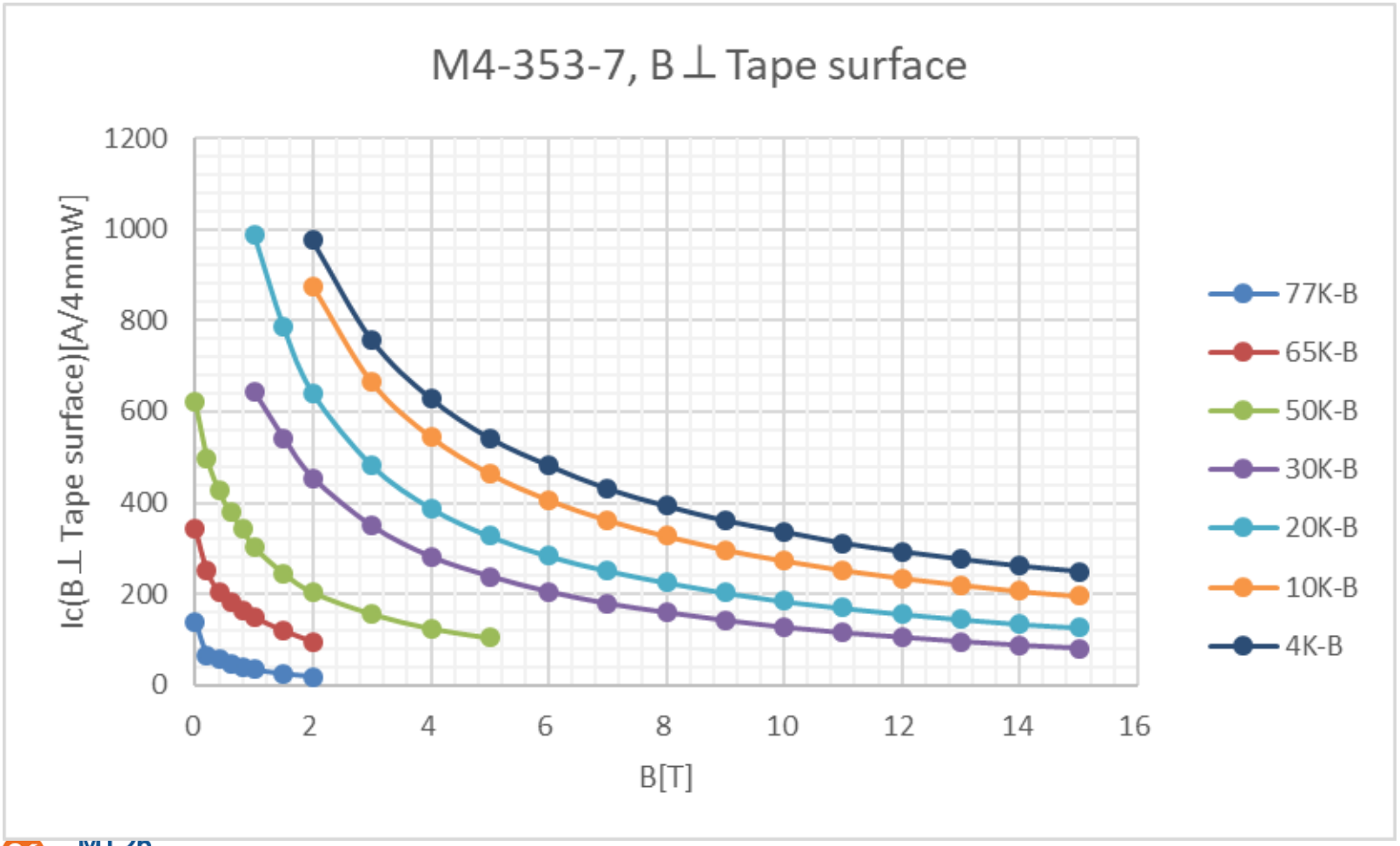
Consistent and as designed In-field performance has been confirmed.







SCS4050-A.P. (M4-353-7)



All measurements are done at Tohoku Univ.

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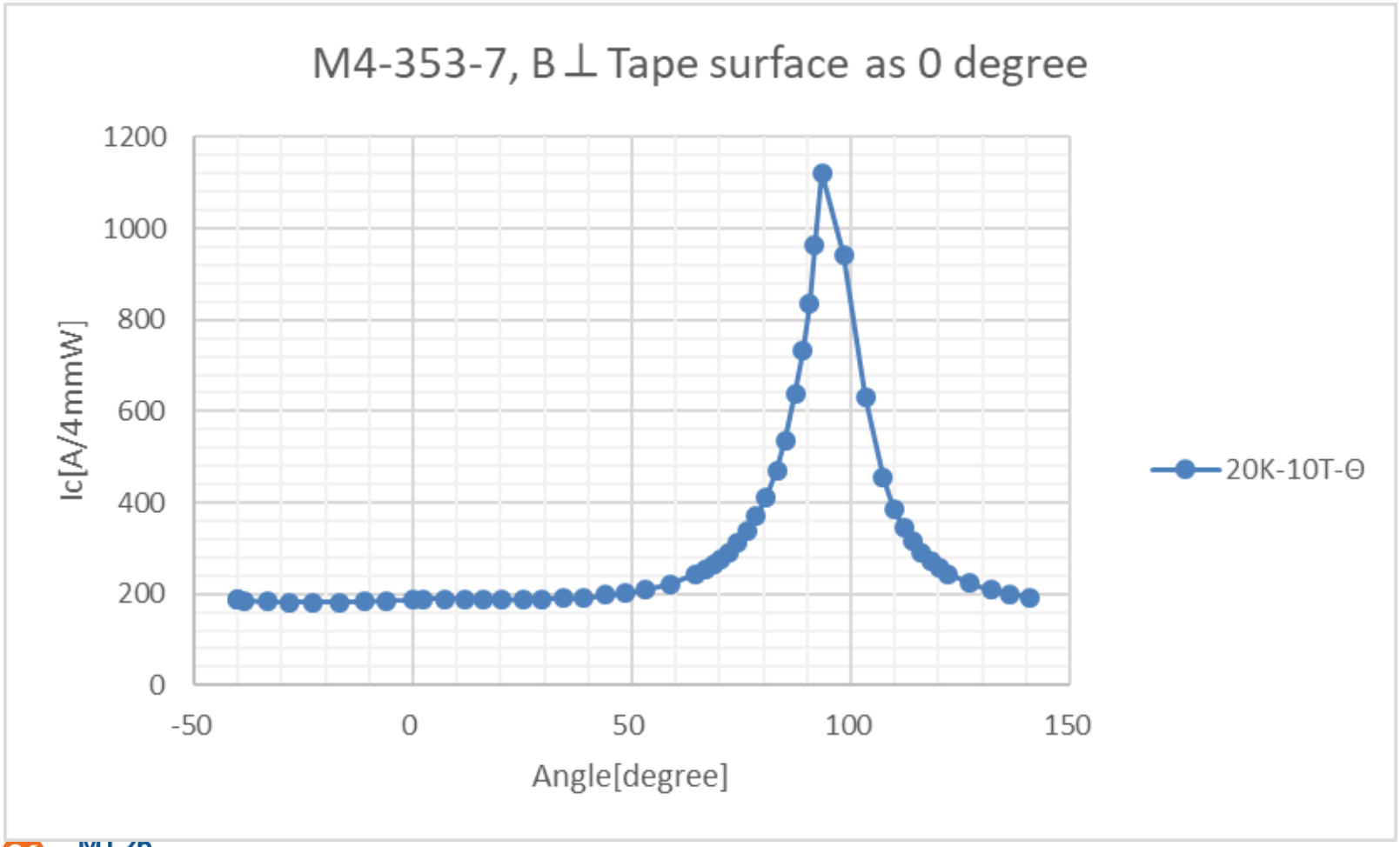

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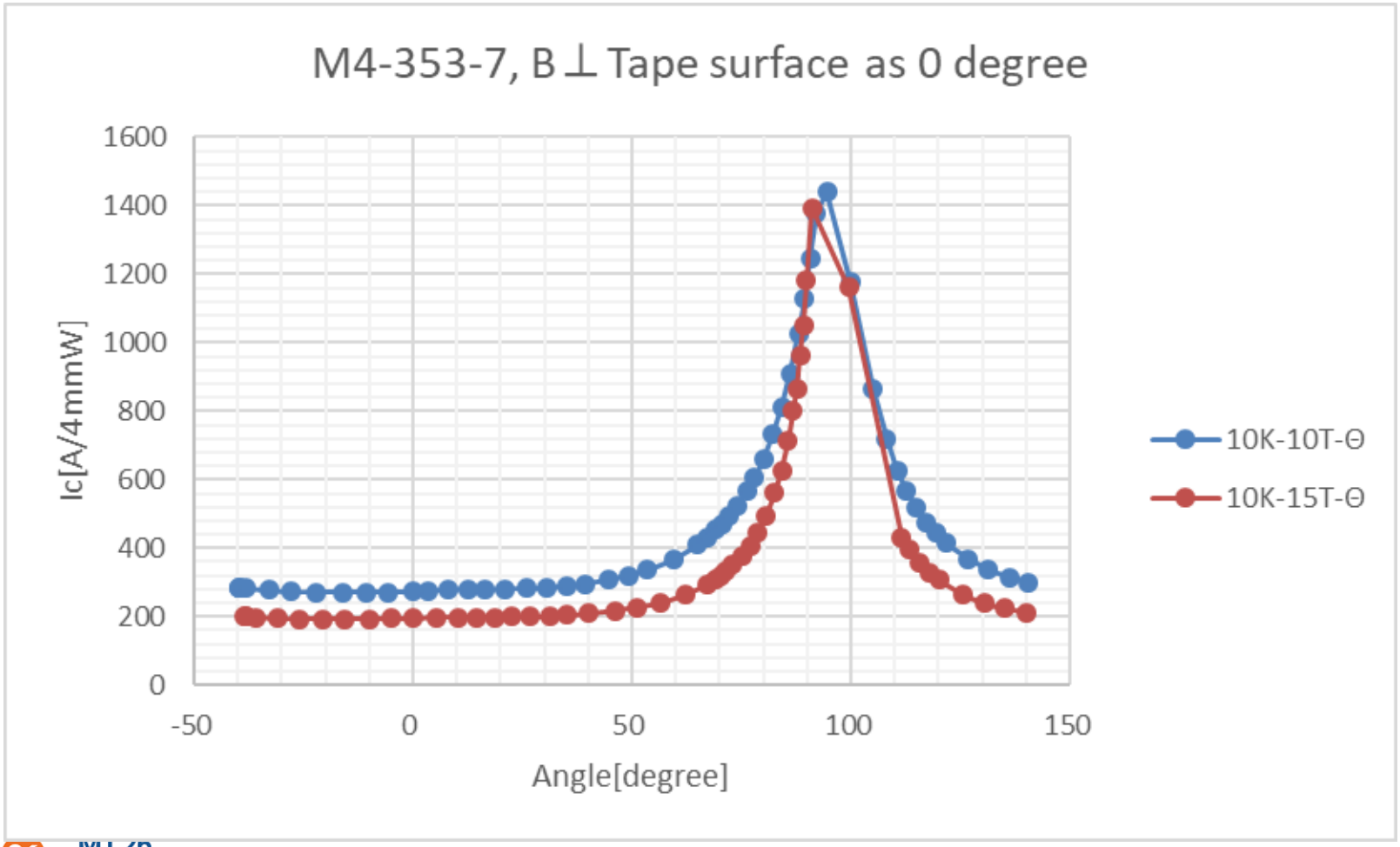
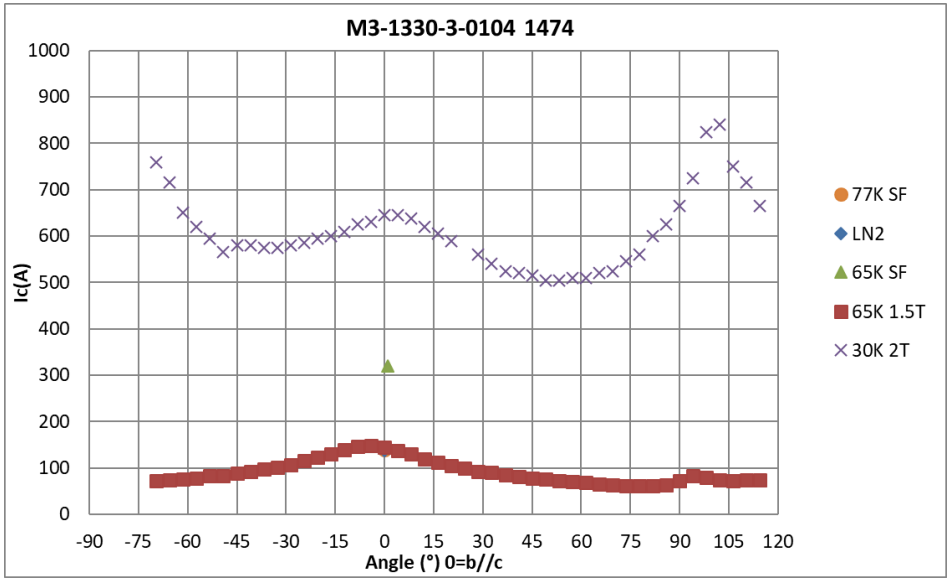


Measurements done at Tohoku Univ.

Ic-B-T-Θ measurement systems available to SuperPower

System at SuperPower Inc. (Ic-B-T-Θ)

- Cryo-cooled
- Operating condition is down to 30K
- Field strength is up to 2.5T
- Field angle can be rotated 180 degrees
- ~1000A can be applied to a sample

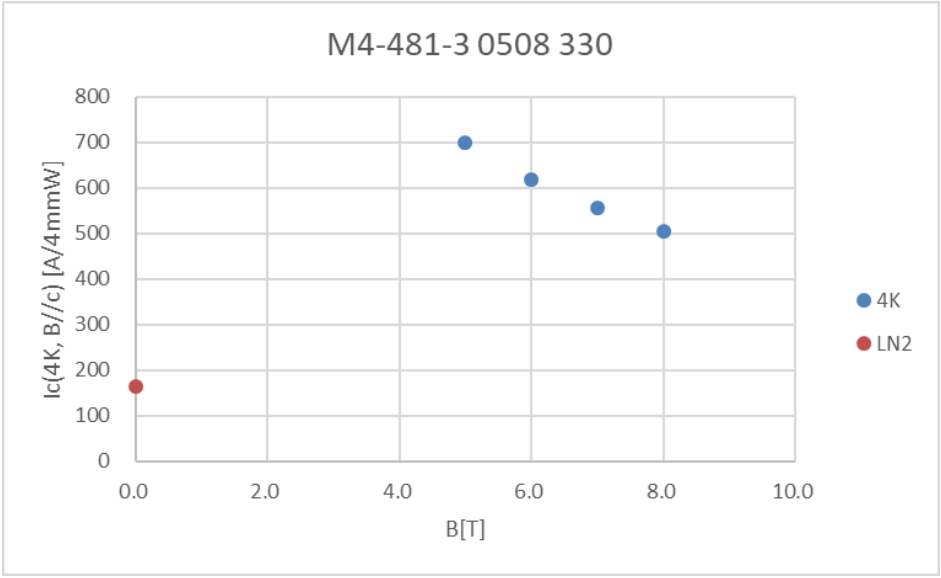


- 2T- 77K reel-to-reel transport Ic measurement system under development

Ic-B-T-Θ measurement systems available to SuperPower

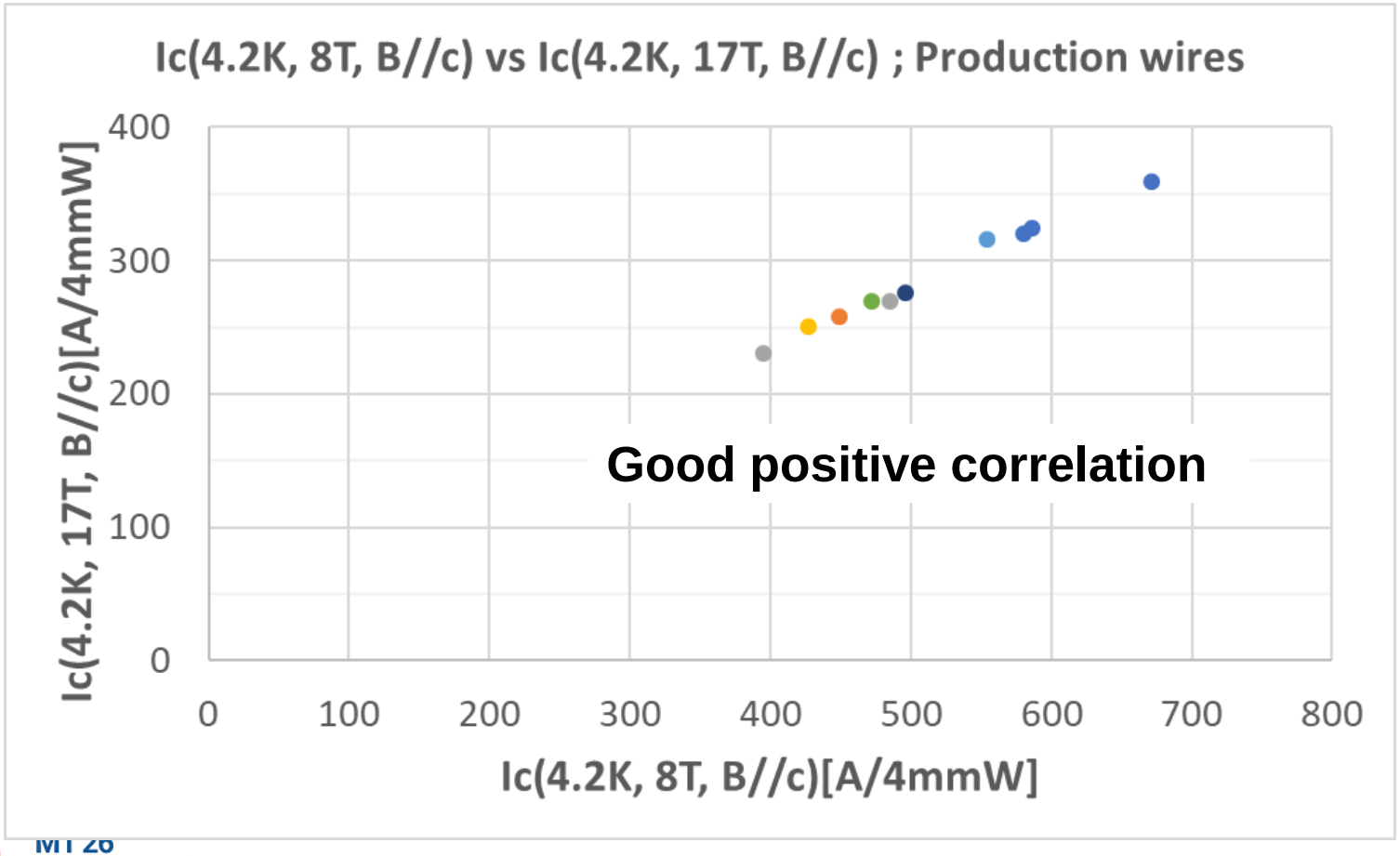
System at Furukawa Electric Co.,Ltd. (NIKKO)(4K-B)

- LHe cooled
- Field strength is up to 8T or 17T (depending on test magnet types)
- Field direction is fixed (B⊥Tape surface)
- ~1000A can be applied to a sample



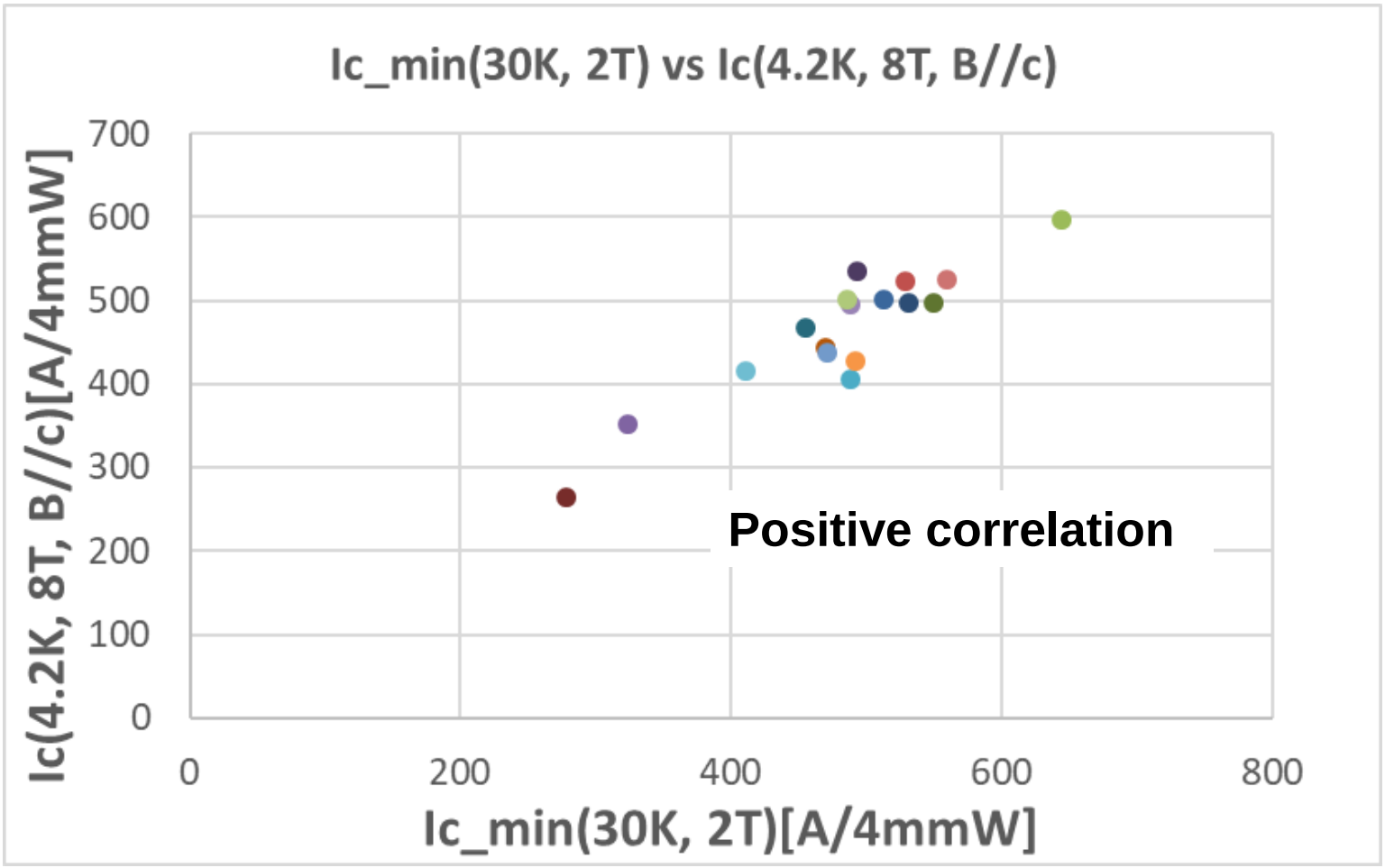
Measurement conditions to evaluate production wires

Currently we are choosing 30K-2T-Θ and 4K-8T(B//c) as representative measurement conditions to confirm the wire performances.



Measurement conditions to evaluate production wires

Correlation between Ic_min(30K,2T) and Ic(4K,8T, B⊥Tape surface)



Comprehensive testing capabilities for mechanical and electromechanical properties

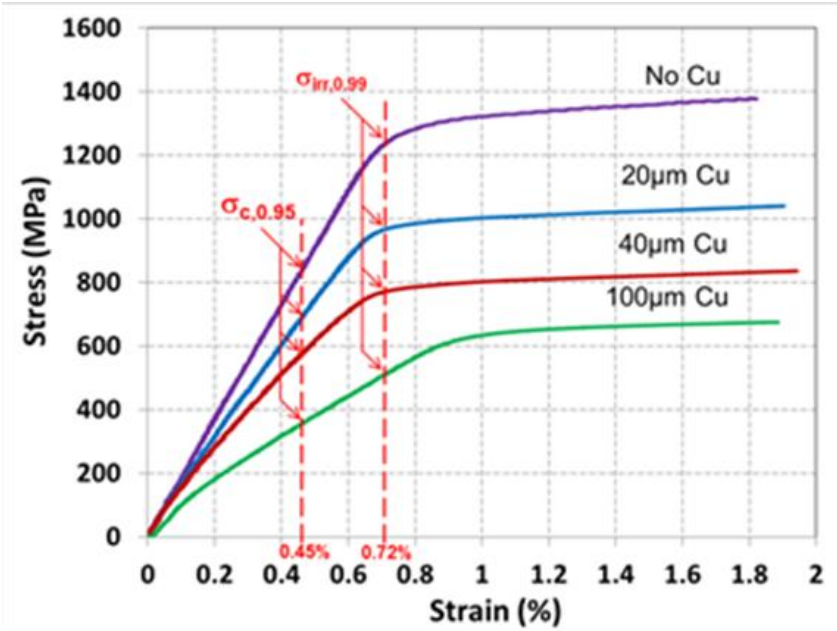
- Axial tensile test at room temperature or at 77K (with I_c)
  - Measurement of elastic modulus and yield stress
  - Determination of critical stress and irreversible stress (strain)
- Measurement of delamination strength – various testing methods
  - Peel test: at room temperature and with varying peeling angle
  - Pin-pull (c-axis tensile) test: at room temperature
  - Anvil (c-axis tensile) test: at room temperature or at 77K (with I_c)
- Transverse (c-axis) compressive test at 77K (with I_c)
  - Measurement of critical compressive stress
- Torsion-tension test at 77K (with I_c)
  - Measurement of critical tensile stress under twist
- Fatigue testing of conductor under development

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

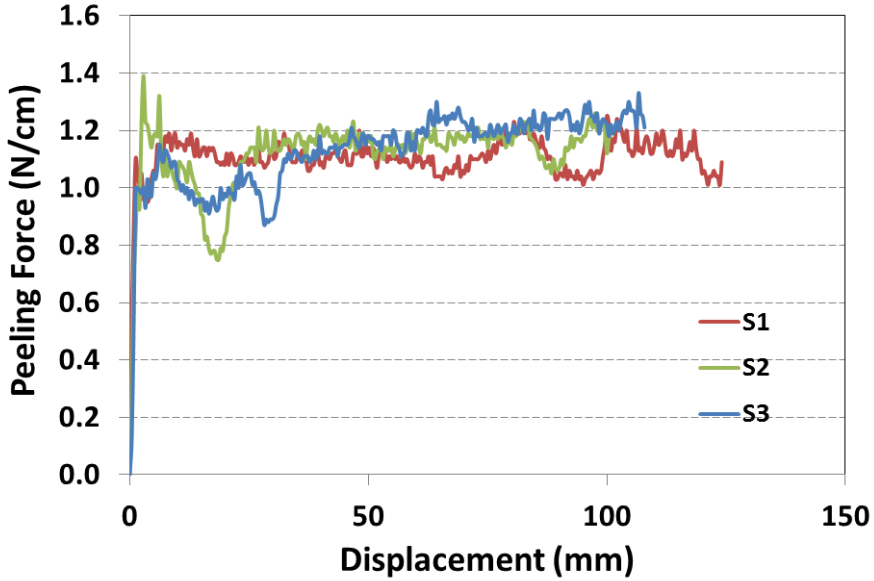


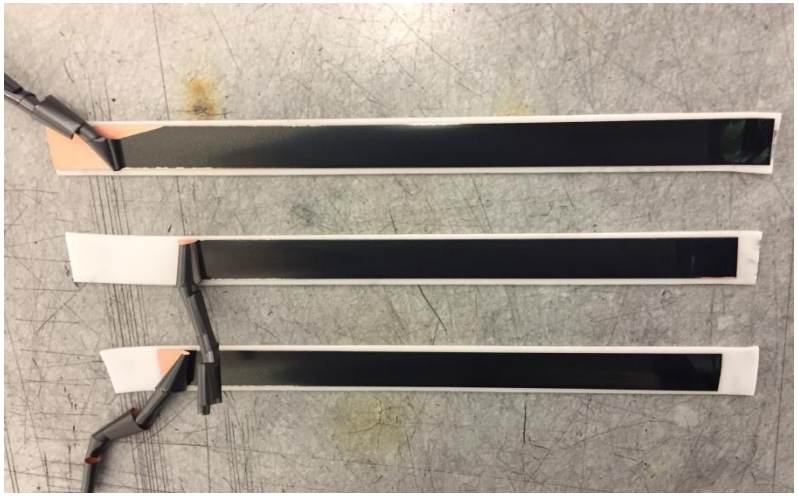
Stress-strain relationship curves of four different SCS4050 wires

Fixture for mechanical/electromechanical testing

Peel test result of M3-1337-3

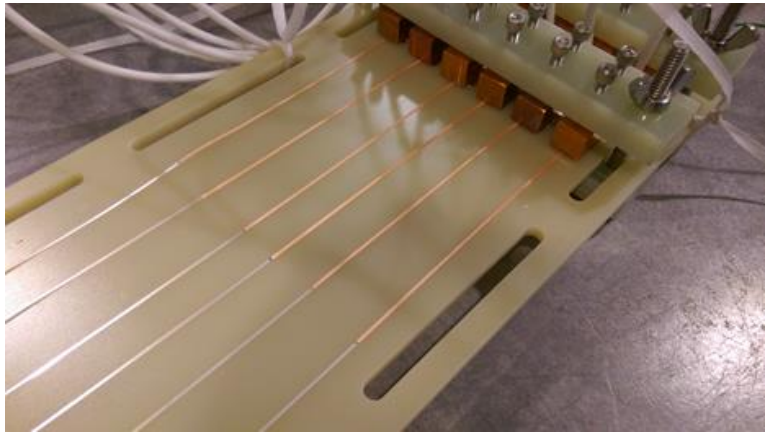
- Production manual peel test result: Passed.
- Observation: the qualitative manual peel test showed a normal peeling. behavior of the sample tape, peeling within REBCO. No bubbling observed.
- R&D instrumented peel test result: average peel strength = 1.13 N/cm (minimum peeling force = 0.75 N/cm).
- Three samples were prepared from this section and tested at the 90° peeling configuration.
- Peeling force vs. displacement curves shown below. Normal peeling behavior, good peel strength, peeling within REBCO, and clean edges.



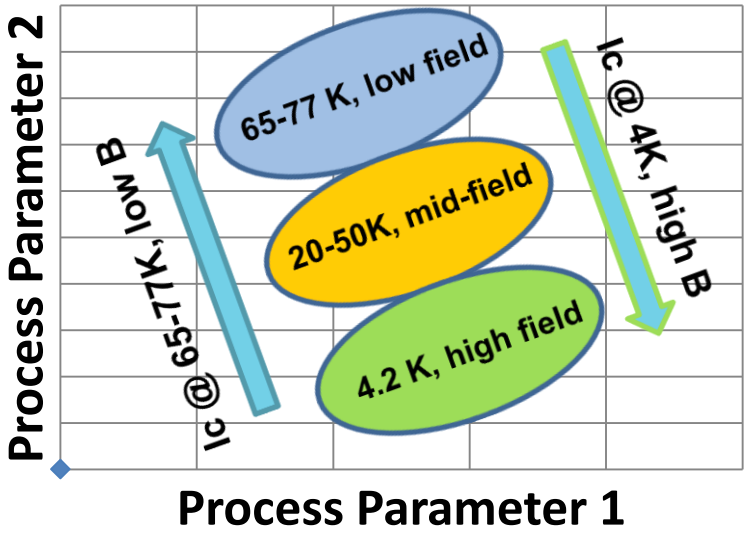


Ongoing research initiatives

- Thinner substrates demonstrated
  - 25 μm process development demonstrated thru all production cells
- Narrower tapes (1.0, 1.5 mm) under development
  - More development work to do on slitting, tape handling and Ic measurement
- Different process optimization windows for different operating conditions
  - High Ic at 77K, sf does not necessarily translate into high Ic at 4K, high field
- Thicker films
- Solder coated tapes available
- Studying joint resistances – Ag:REBCO interface resistance dominates

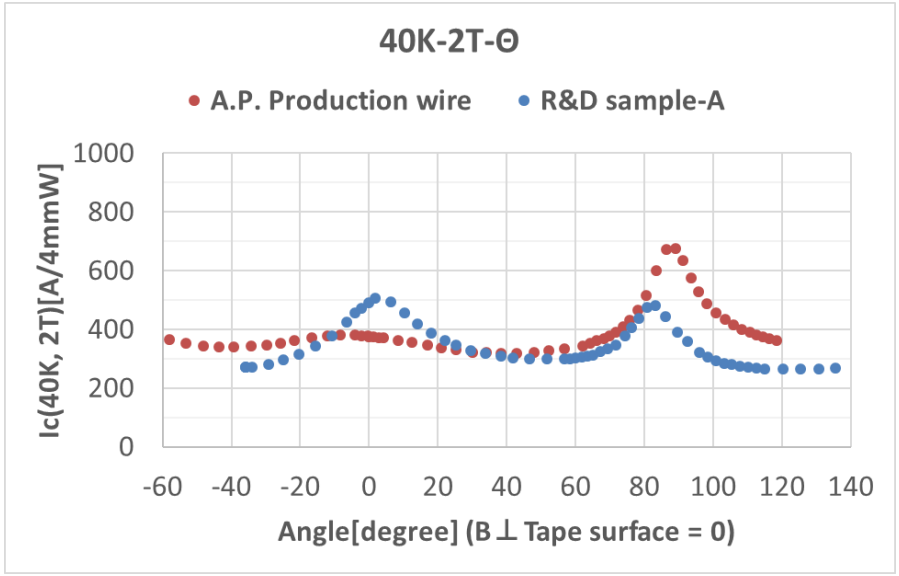


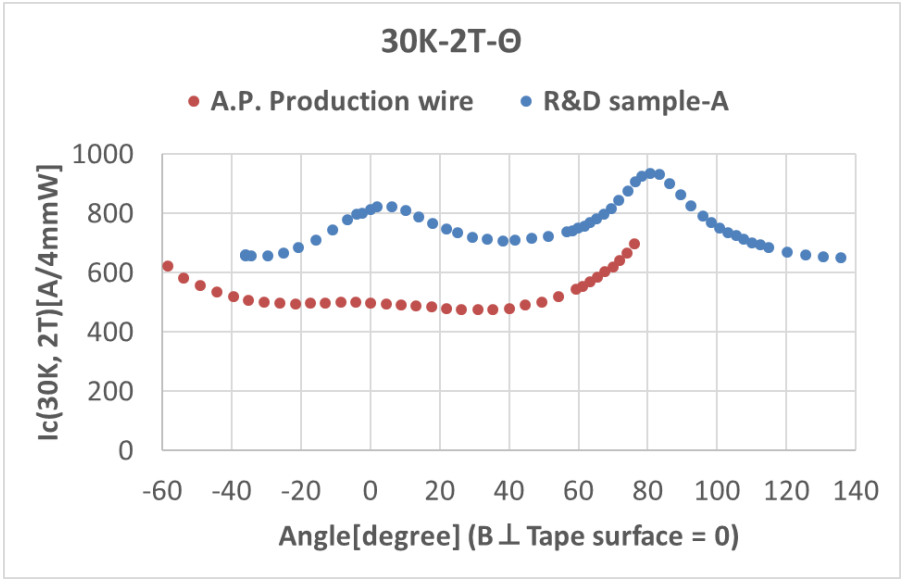
Selective Cu plated 1mm tapes under Ic test

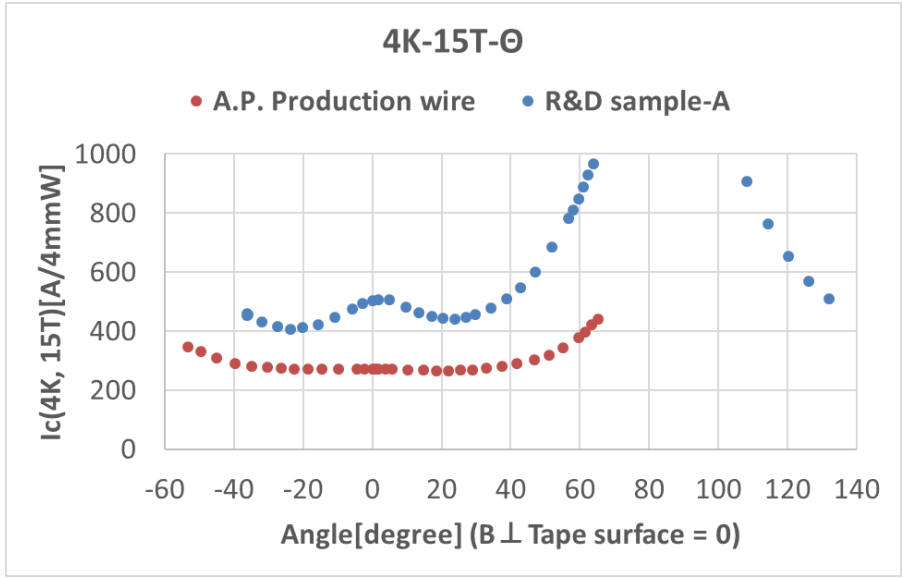


Recent R&D ; Optimization for Low-temp and High-field

	Ic_min[A/4mmW] Film thickness ≈1.6um for both samples	
	A.P. wire	R&D sample A
77.3K−sf	193	107
50K−2T	198	107
40K−2T	317	264
30K−2T	492	652
30K−5T	239	320
20K−10T	193	278
10K−10T	288	536
4.2K−15T	266	406







All measurements in this slide were done at Tohoku Univ.

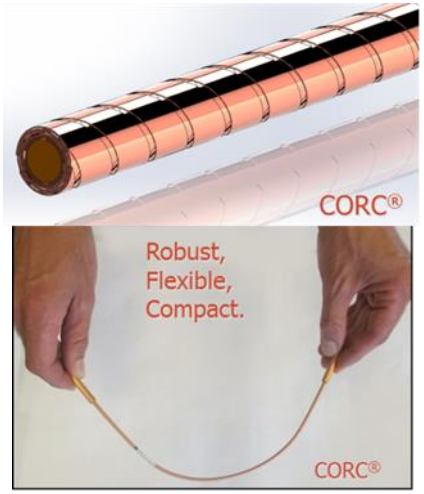
New Facility Under Construction

- New facility to be located adjacent to Schenectady County Airport, Glenville NY
  - ~ 48,000 sq ft (1st phase)
- Workforce will continue to expand as needed
- All manufacturing and standard product testing will continue to be done in house
- Full manufacturing in new facility starting in Q2 / 2020

Summary

- Strong focus on processing to improve uniformity, repeatability, piece lengths (currently up to 1 km) and yield.
- Maximize current capacity while implementing next generation equipment
  - Hardware and processing upgrades yielding benefits
  - Capacity upgrade underway
- R&D to enhance performance parameters for developing operating spaces
  - Thinner substrates
  - Narrower tapes
  - Optimized pinning

Ideal for cables such as CORC



- Further improve mechanical properties
  - Delamination mitigation
  - Ic (ε) with reinforcement
- Diverse market pull
  - Low temperature, high field
    - (Fusion, HEP, HF magnets)
  - Higher temperature, moderate field
    - Motors/generators
      - EERE NGEM (65K, 2-3 T)
    - Maglev
  - LN2 low field (Utility market)

Thank you for your attention