TUE-OR1-602-01

MT27, Fukuoka, Japan, 16 November, 2021

Recent progress of RE-based high temperature superconductors at Fujikura

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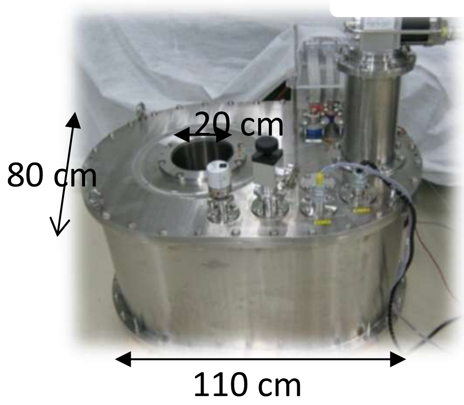
Outline

- Introduction
- Recent progress of RE-based HTS tapes at Fujikura
- Mechanical properties of RE-based HTS tapes
- Summary

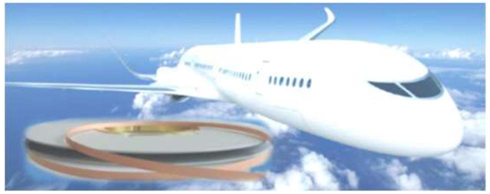
Recent shipment of Fujikura's RE-based HTS tapes

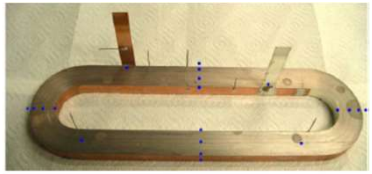
■ 5T cryocooled magnet by Fujikura(2012)



■ NEDO MRI program (2016-2018)

■ TELOS Project (2016-2019)

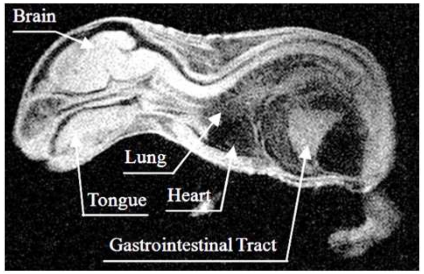


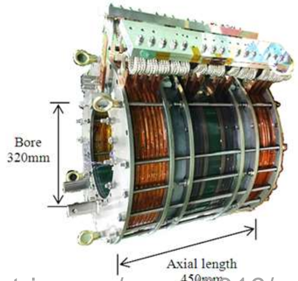


Presented at EUCAS 2019

Airbus, KIT, Siemens

■ Worlds 1st 3T MRI by Mitsubishi Electric (2015)

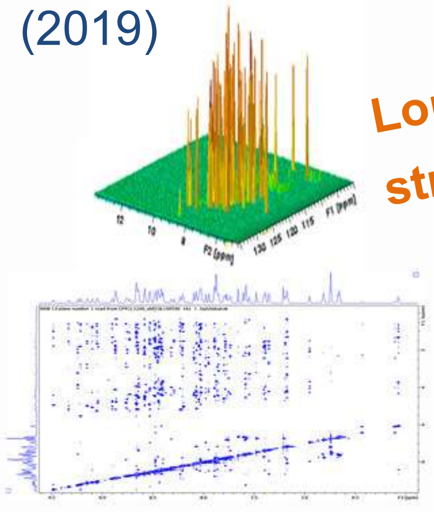




1/3 demo of
drive mode
3T class MR

http://www.mitsubishielectric.com/news/2016/pdf/0524.pdf
http://www.nedo.go.jp/english/news/AA5en_100071.html

■ Bruker 1.2 GHz high field **NMR** system (2019)



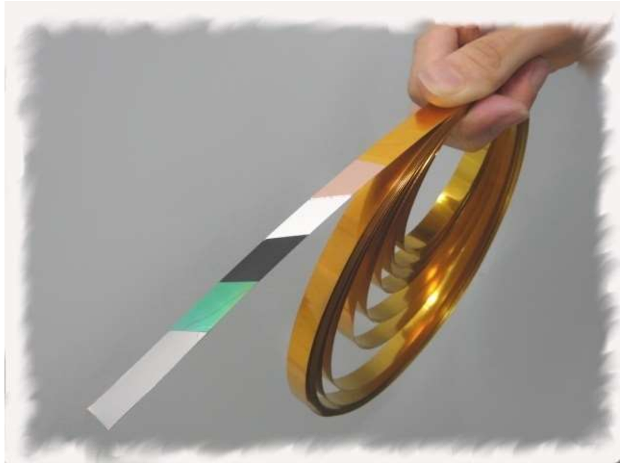
Longitudinal uniformity strongly required

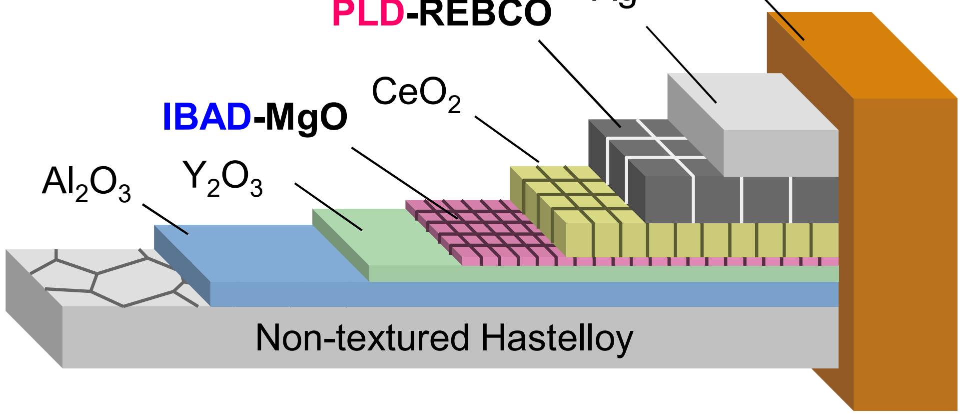
Worlds 1st 1.2 GHz NMR

28.2 T magnet
with 54 mm bore
RE-based HTS

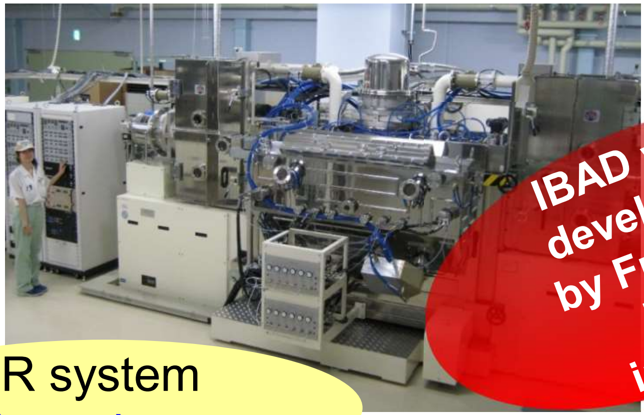
https://ir.bruker.com/press-releases/press-release-details/2019/Bruker-Announces-Worlds-First-12-GHz-High-Resolution-Protein-NMR-Data/default.aspx

Fujikura's RE-based HTS tape (IBAD / PLD)





Ion Beam Assisted Deposition (IBAD)



IBAD was developed by Fujikura Ltd. in 1991

R-to-R system
with large ion source

Pulsed Laser Deposition (PLD)

R-to-R system
with hot-wall heating

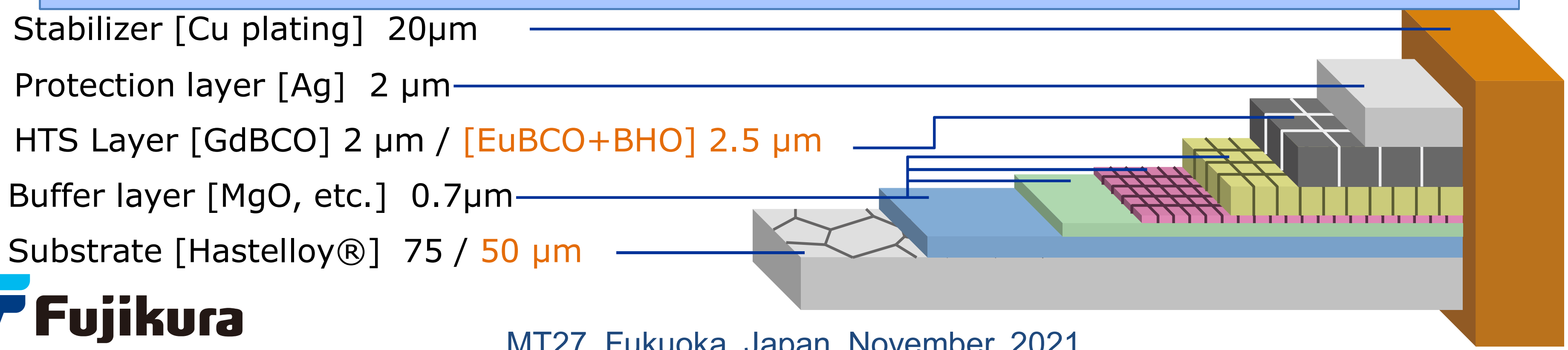
Fujikura

Typical Specifications of RE-based HTS tape at Fujikura

Products	Width [mm]	Thickness [mm]	Substrate [μm]	Stabilizer [μm]	Critical Current [A]	
					77K, S.F.	20K, 5T *3
FYSC-SCH04	4	0.13	75	20	≥ 165	368
FYSC-SCH12	12	0.13	75	20	≥ 550	1,104
FYSC-S12 *1	12	0.08	75	—	≥ 550	—
FESC-SCH02 *2	2	0.11	50	20	TBD	(257)
FESC-SCH03 *2	3	0.11	50	20	≥ 63	497
FESC-SCH04 *2	4	0.11	50	20	≥ 85	663
FESC-SCH12 *2	12	0.11	50	20	≥ 250	1,990
FESC-S12 *1,2	12	0.06	50	—	≥ 250	1,990

*1 Non-copper stabilizer specification is available in only 12mm-wide for current lead or low thermal conducting applications.
*2 Artificial pinning specification is mainly for use in magnet applications at low temperature and high magnetic field.
*3 Ic@20K, 5T is a reference value and no guarantee of the actual performance.
*4 If requested, an option customizing copper plating thickness is also available. (e.g., 5μm, 10μm or 40μm)

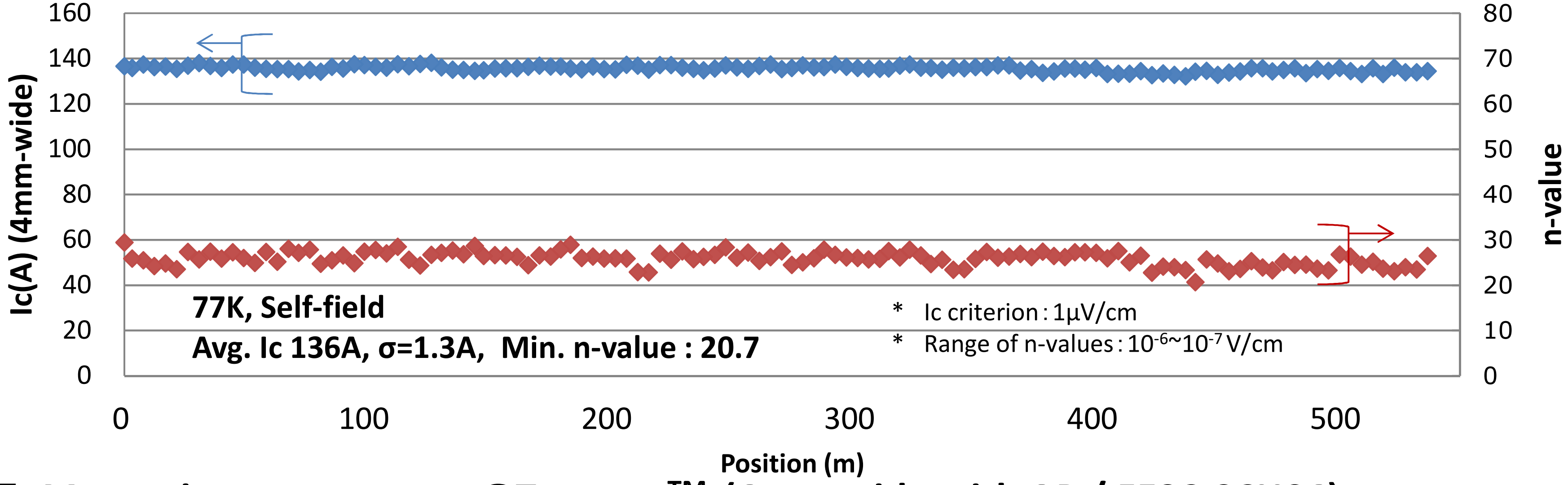
FYSC(Non-AP) is recommendable for use at relatively higher temperature.
FESC(AP) is recommendable for use in magnet applications at lower temp. and higher field.



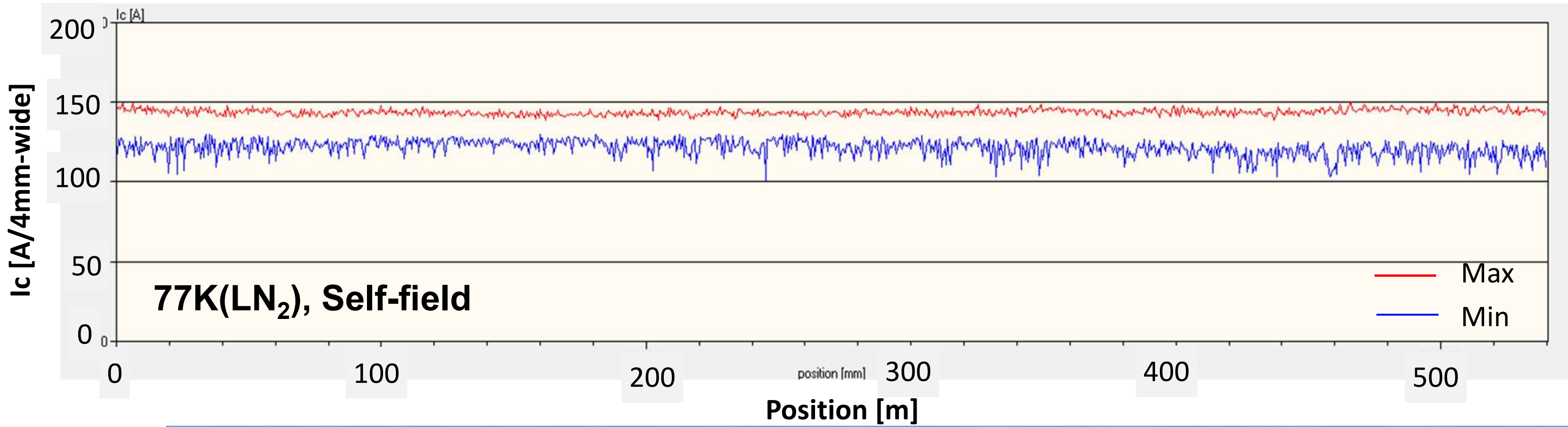
Fujikura

Example data of longitudinal I_c distribution of 4mm-wide tape

■ **Current conduction measurement (4mm-wide with AP / FESC-SCH04)**



■ **Magnetic measurement @Tapestar™ (4mm-wide with AP / FESC-SCH04)**

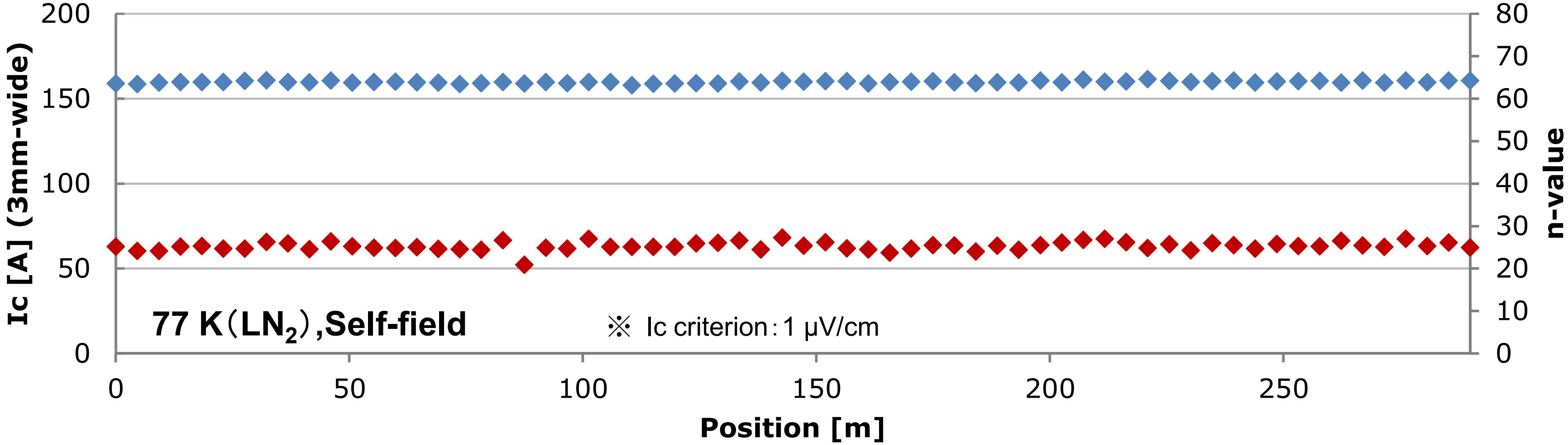


For 4mm long-tape, uniform I_c with artificial pinning tape are obtained

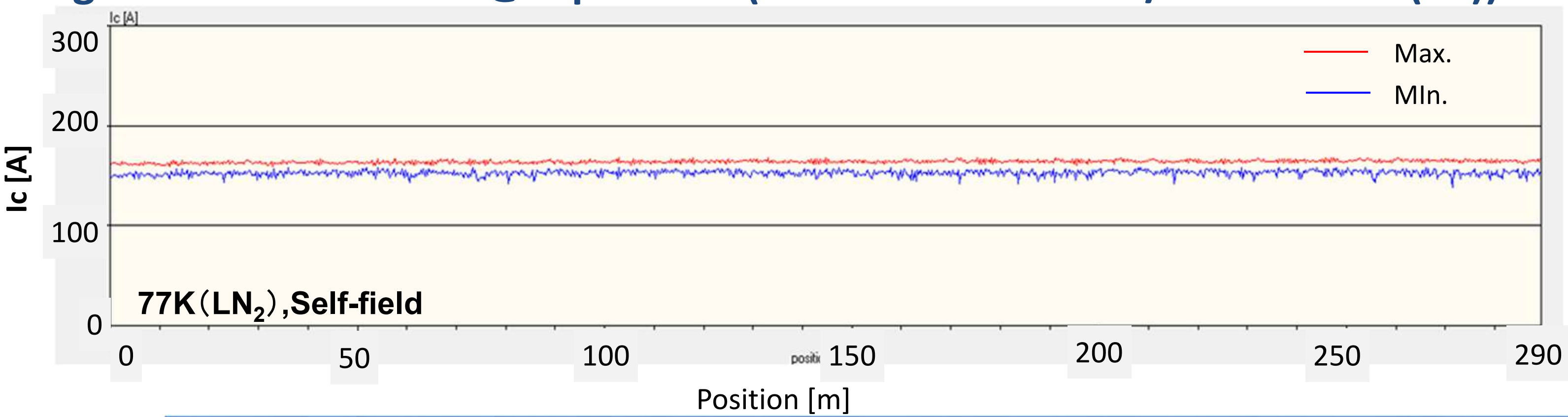
Example data of longitudinal I_c distribution of 3mm-wide tape

3 mm-wide tape: FESC-SCH03

■ 4-terminal method current conduction measurement at every 4.7 m



■ Magnetic measurement @Tapestar™ (3mm-wide with AP / FESC-SCH03(40))

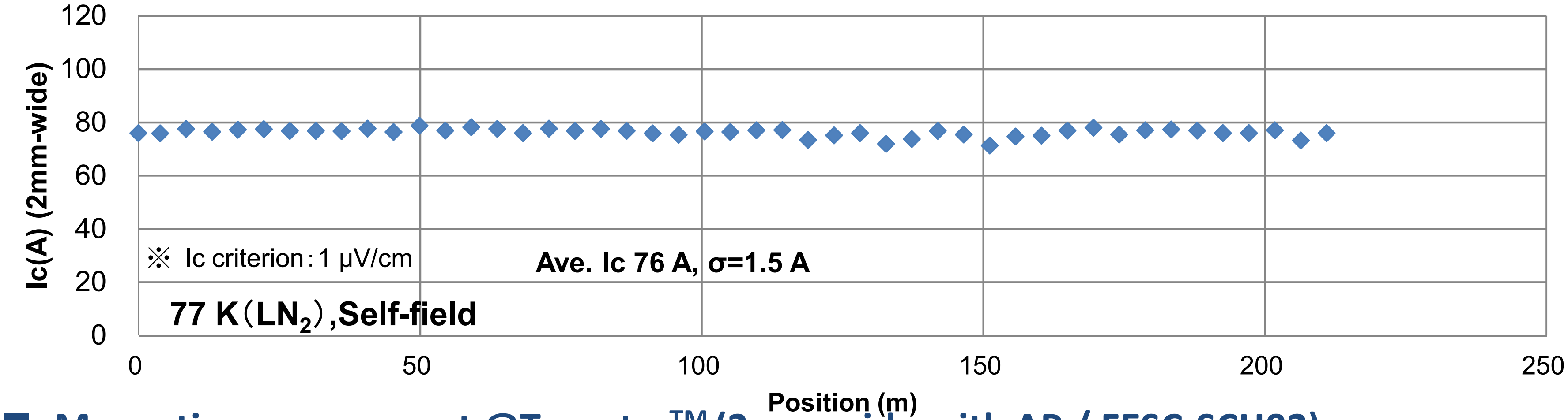


For 3mm long-tape, uniform I_c with artificial pinning tape are obtained

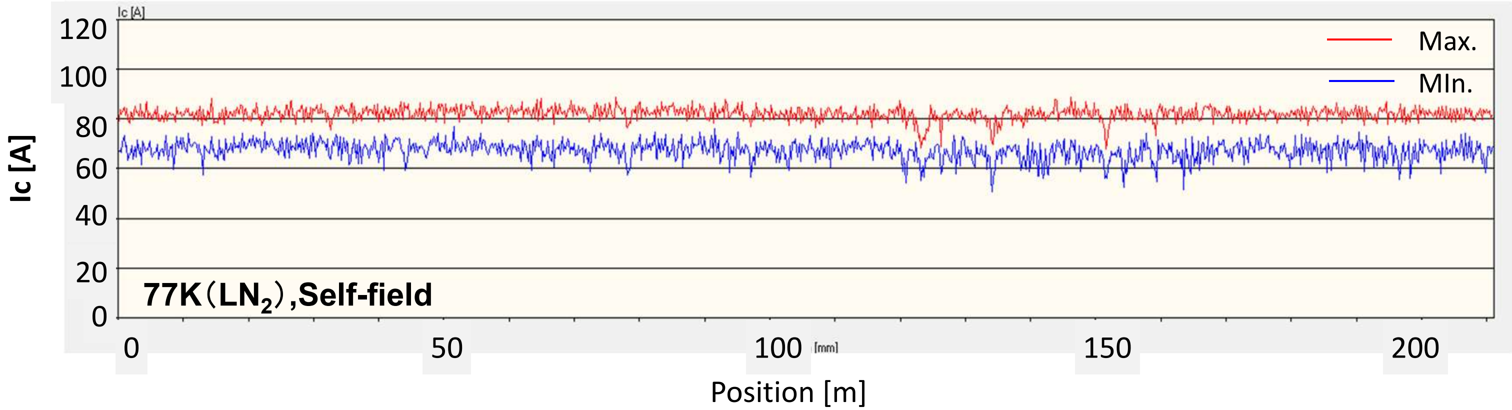
Example data of longitudinal I_c distribution of 2mm-wide tape

2 mm-wide tape: FESC-SCH02

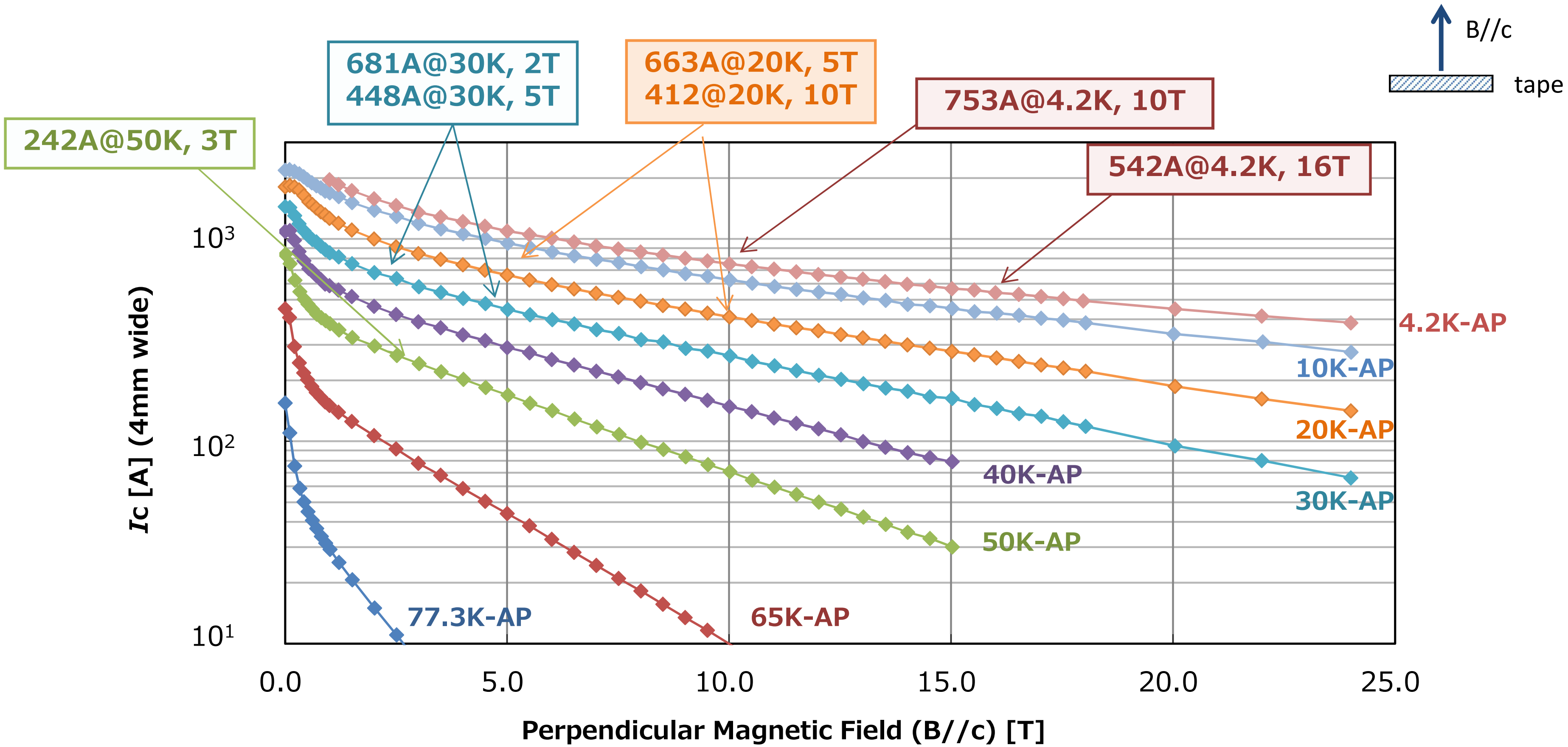
- 4-terminal method current conduction measurement at every 4.7 m



- Magnetic measurement @Tapestar™ (2mm-wide with AP / FESC-SCH02)

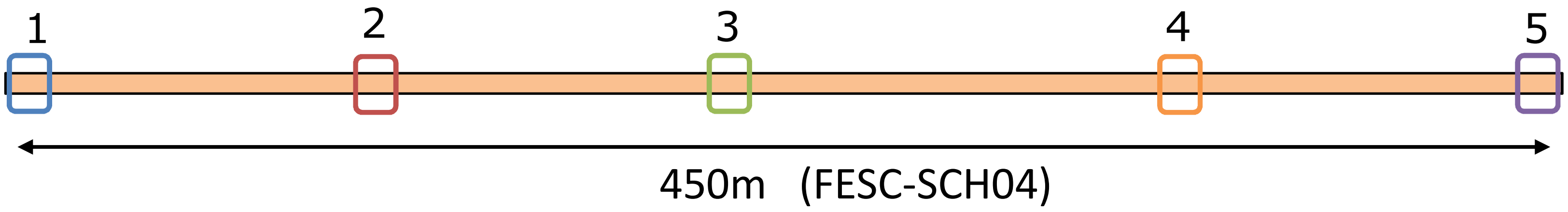


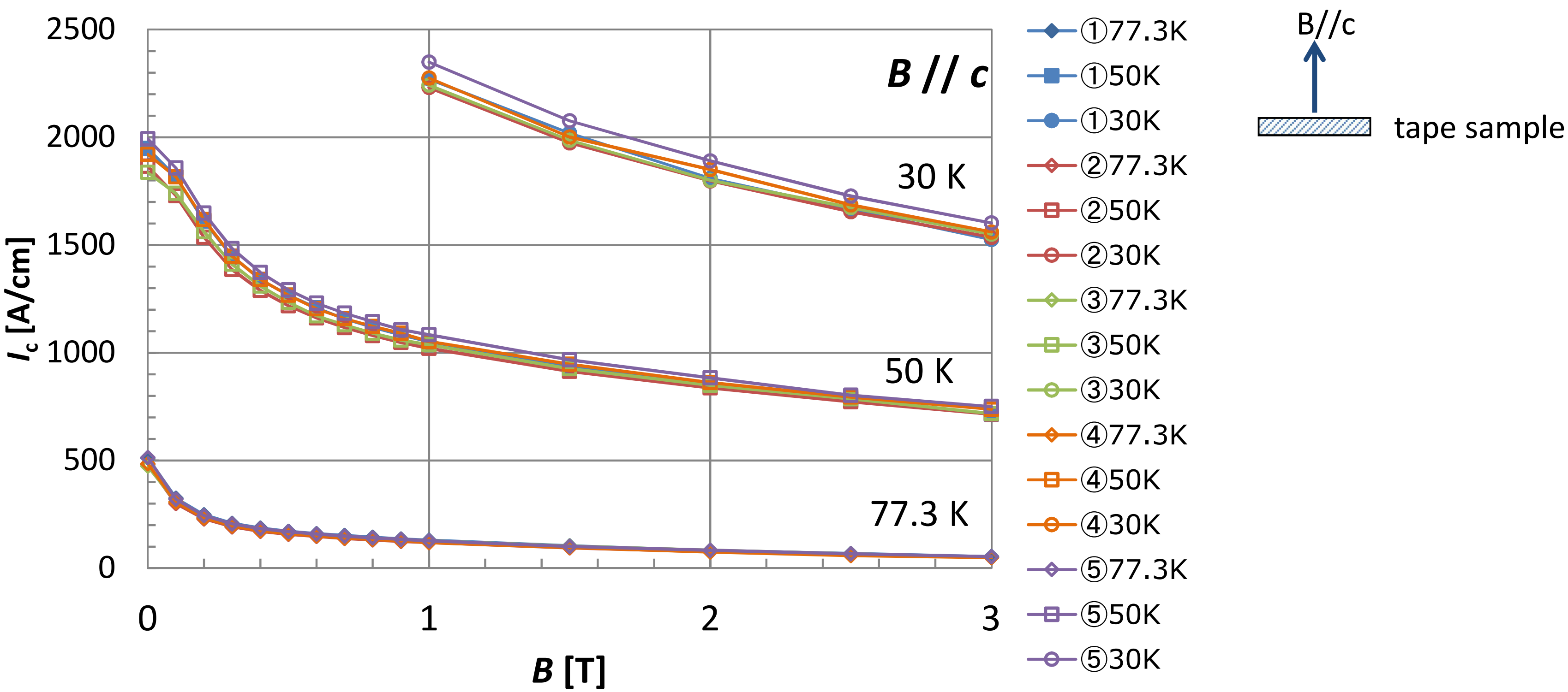
In-field *I*c Performance – FESC type – (AP)



AP specification is recommendable for use in magnet applications at lower temperature and higher magnetic field.

In-field I_c distribution in a 450m long sample (30, 50, 77 K, 3T)





difference of Max. and Min. in-field Ic at 30K 1T ≦ 5%

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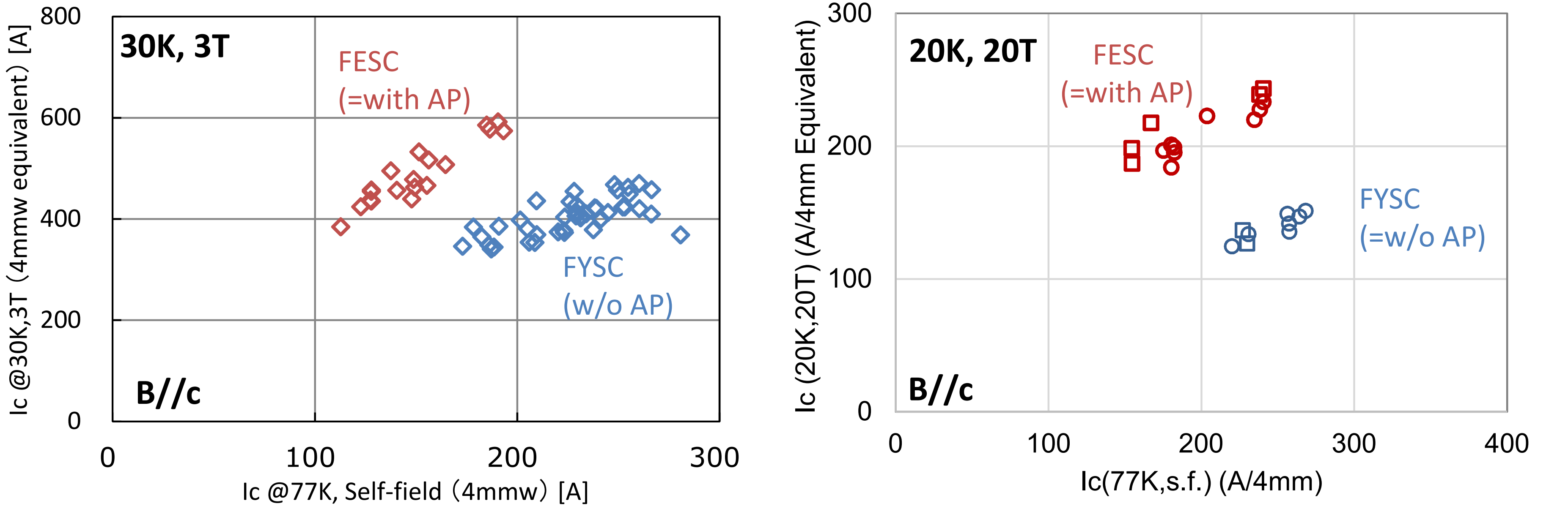
Evaluation of lot-to-lot variation of in-field Ic

Evaluation results between Ic at 77K, self-field and in-field Ic, compared with conventional(w/o AP) tapes



Fujikura's tapes show very good correlation

◇ measured at Fujikura, and exploited values with Ic
□ in-field Ic measured at Tohoku university

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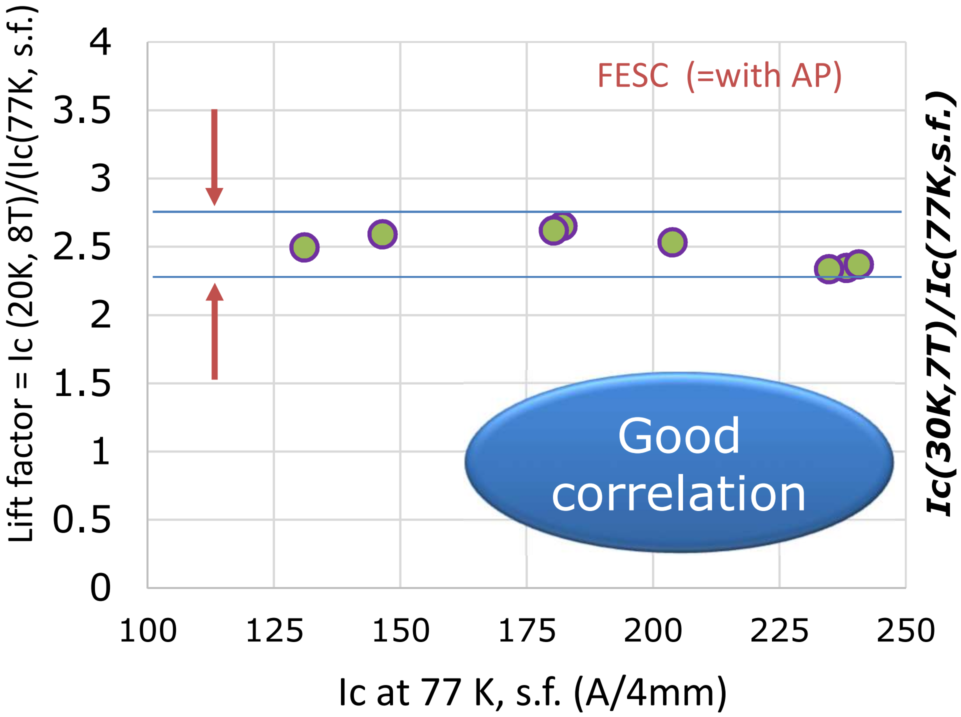
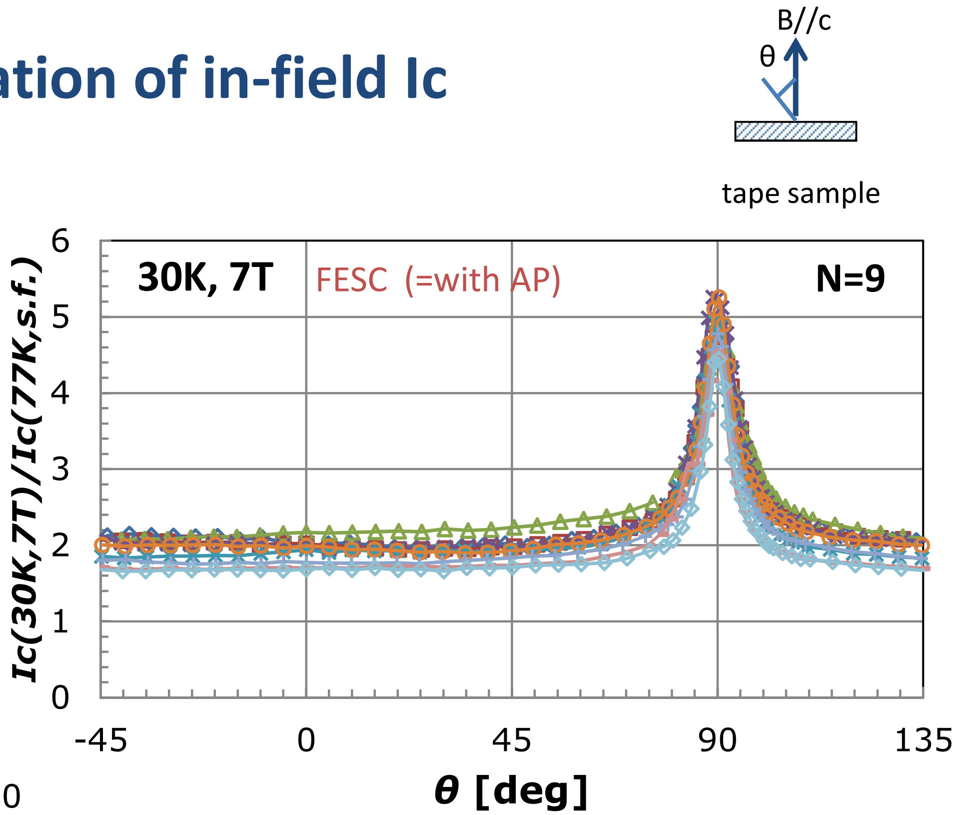
Evaluation of lot-to-lot variation of in-field Ic

Narrow width indicates small variation of in-field Ic



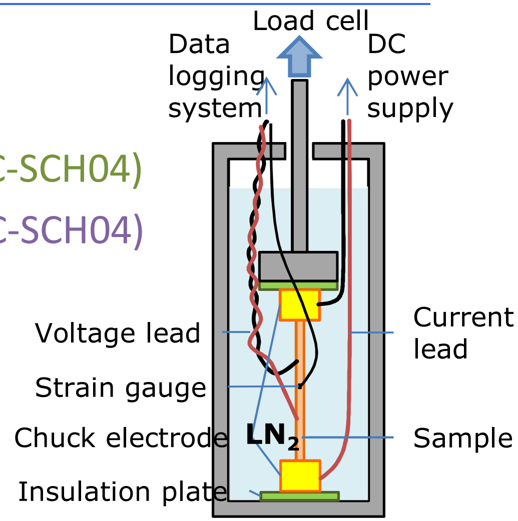


Fujikura's tapes perform very good reproducibility

Tensile Stress evaluation

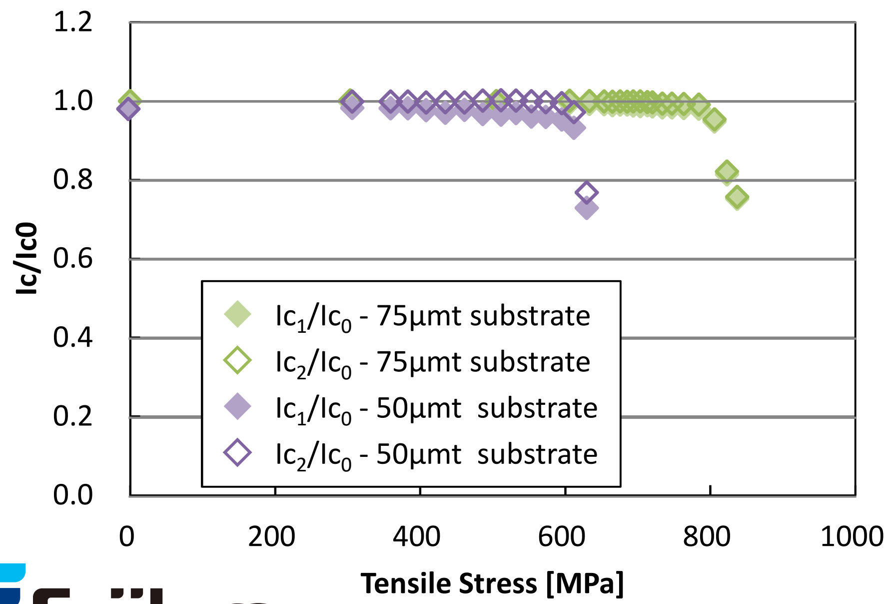
■ Tensile stress evaluation at LN_2 temperature (Reference)

- Sample : 4mm-wide, 75 µm-thick Hastelloy + 20 µm-thick Cu plating (FYSC-SCH04)
  4mm-wide, 50 µm-thick Hastelloy + 20 µm-thick Cu plating (FESC-SCH04)
- Measurement method :
  1. Ic measurement without load in LN_2 (Ic_0)
  2. Ic measurement with applying tensile strain in LN_2 (Ic_1)
  3. Ic measurement without load (Ic_2) after applying tensile strain in LN_2

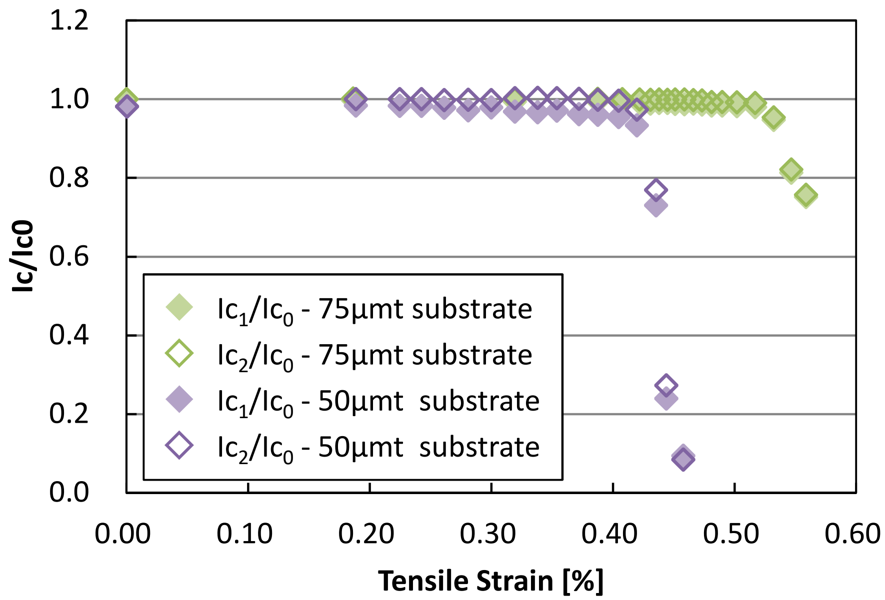


Schematic of tensile test

Ic/Ic_0 versus tensile stress



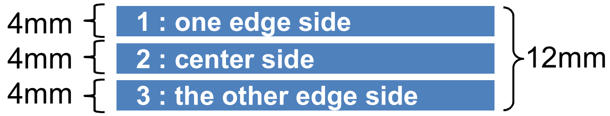
Ic/Ic_0 versus tensile strain

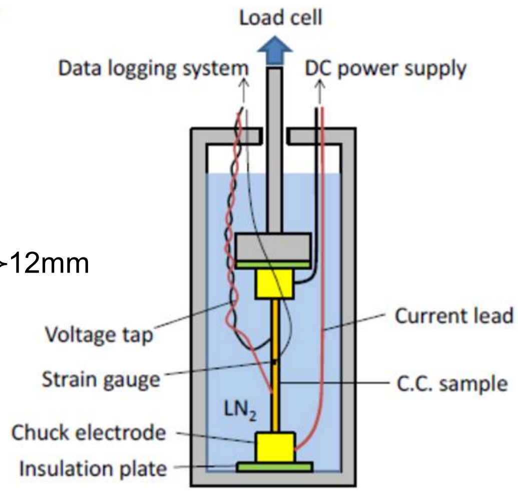


Evaluation of tensile properties of divided 4 mm-wide

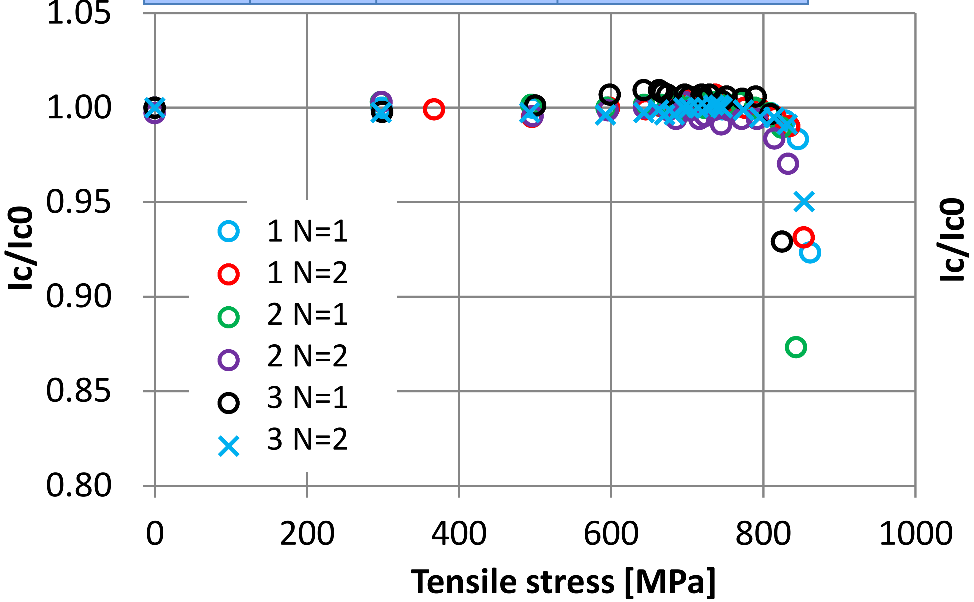
Tensile properties of 3 parts of 4 mm-wide tapes divided from 12 mm-wide coated conductor in LN2

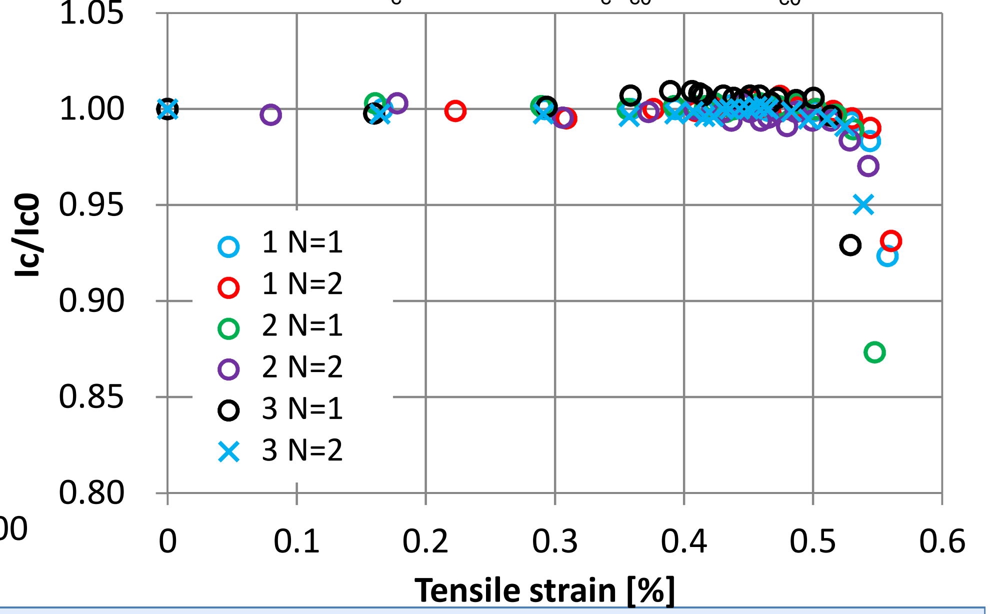
Samples (FYSC)		reversible I_c Strain [%]	reversible I_c Stress[MPa]
1	N=1	0.523	820
	N=2	0.513	817
2	N=1	0.521	813
	N=2	0.497	768
3	N=1	0.514	810
	N=2	0.496	795





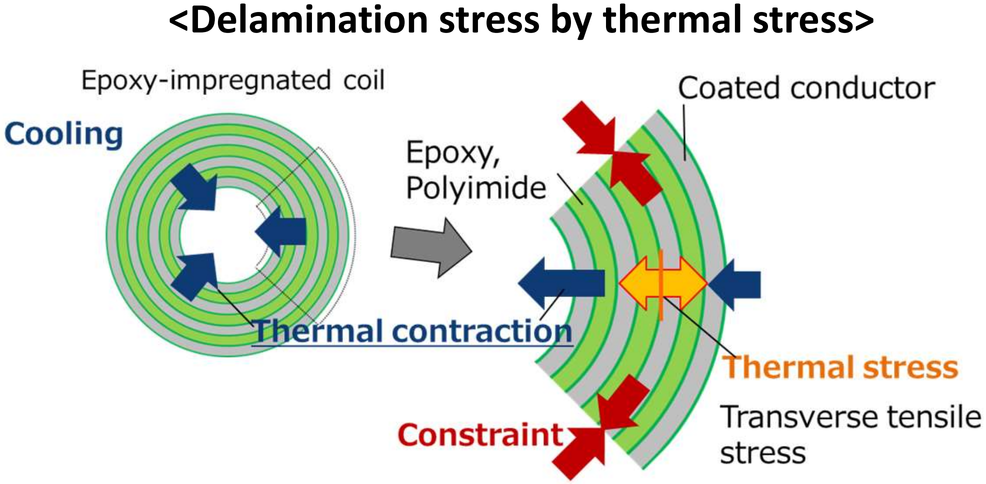
* Reversible I_c is defined at I_c/I_{c0} > 0.99 I_{c0} : Initial Ic

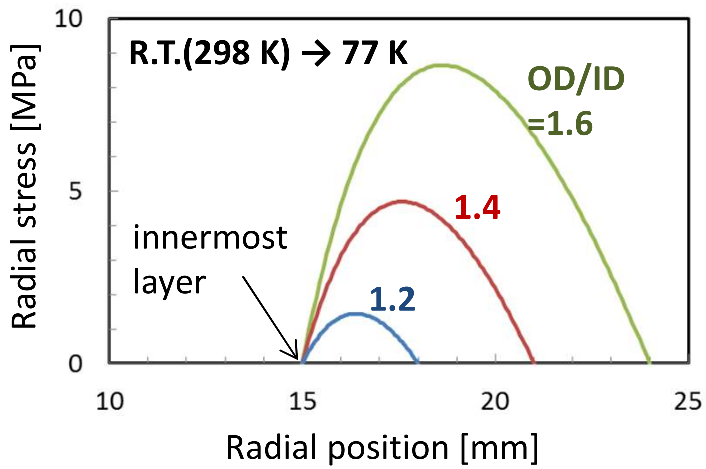


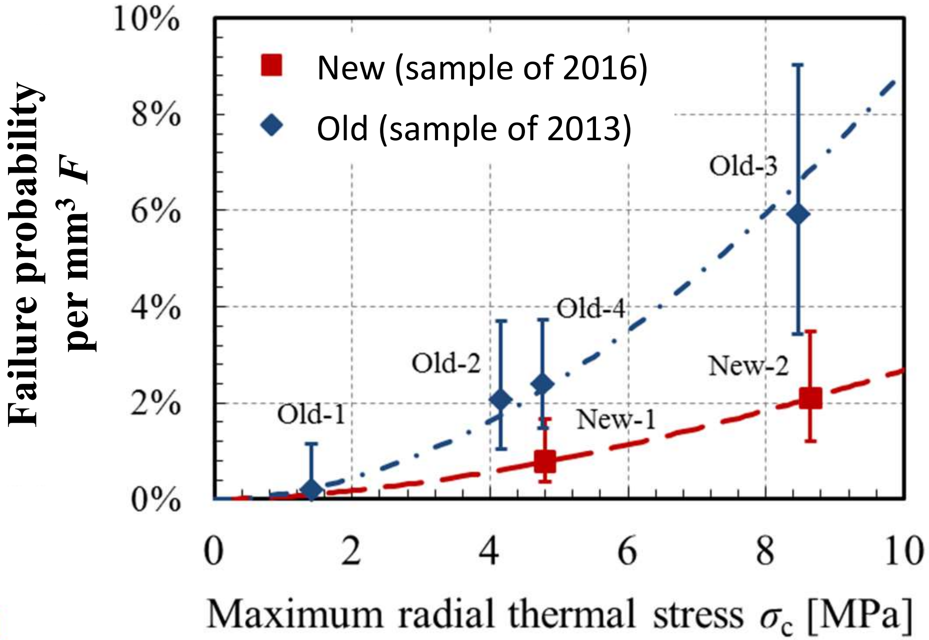


Each divided 4 mm-wide HTS tapes by laser slitting have shown equivalent tensile properties.

Evaluation of failure probability of delamination







$$F(\sigma_c, V) = 1 - \exp\left[-V_{\mathrm{E}}(m, V)\left(\frac{\sigma_c}{\sigma_0}\right)^m\right]$$

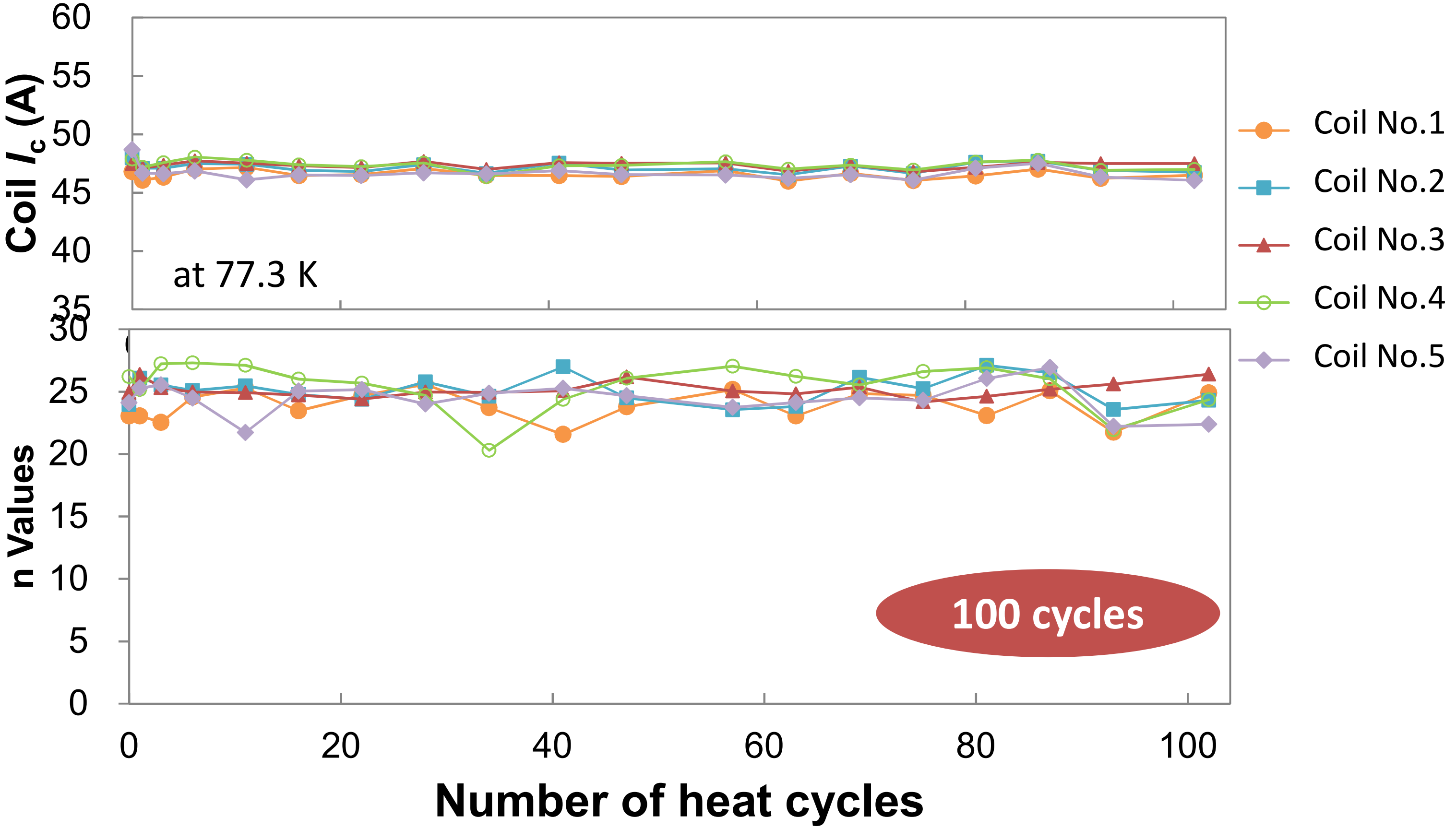
$$V_{\mathrm{E}}(m, V) = \int_V \left(\frac{\sigma(\vec{x})}{\sigma_c}\right)^m \frac{dV}{V_0}$$

Average delamination stress of RE-based HTS tapes have improved

S. Muto, et al.,IEEE Trans. Appl. Supercond. 28-4 (2018) 6601004

Heat cycle test of small epoxy-impregnated coils

Sample : FESC-SCH04 (4mm-w, 50μm-thick substrate + 20μm-thick copper), Length :11m/coil
Inner diameter:30mm, Outer diameter:54mm, **OD/ID=1.8, Epoxy-impregnation**
Delamination stress : 9.6 MPa(calculated), RT ⇔ LN2



No degradation at 100 heat cycles

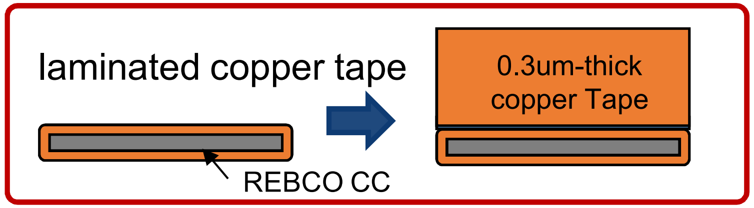
Summary

■ Strengths of Fujikura's RE-based HTS tapes

- Fujikura has focused on manufacturing uniform RE-based HTS tapes
- We recently start to ship 2mm and 3mm-wide tapes
- We have investigated various mechanical properties of the RE-based HTS tapes for the applications.

→ **THU-Or4-704-04 S. Muto et. al.,**

Quench protection study of a large scale REBCO magnet with additional copper tapes



Thank you for your attention !

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