10thACASC/2nd Asian-ICMC/CSSJ Joint Conf., Okinawa, Jan. 6-9, 2020

National Projects on superconducting wires and their applications in Japan

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National Institute for Materials Science, Japan

I. JST(Japan Science and Technology Agency)-MIRAI program "Social implementation of super-high field NMRs and DC superconducting cables for railway systems."

II. JST-ALCA(Advanced Low Carbon Technology Research and Development) program.

III. NEDO(New Energy and Industrial Technology Development Organization) program.
Promotion of commercialization of high temperature superconductivity (HTS) .

JST-MIRAI Program (Nov. 2017~)

By considering social and industrial needs, this program will set technologically challenging goals with clear targets designed to produce beneficial economic and social impacts.

Projects relating to applied superconductivity

Small start Type

1. Superconducting computing for low carbon AI
2. Low-ac-loss and robust high temperature superconductor technology

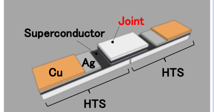
Large-scale Type

1. Social implementation of super-high field NMRs and DC superconducting cables for railway systems
2. Development of advanced hydrogen liquefaction system by using magnetic refrigeration technology.

Schedule of the development of super-high field NMR 1.3 GHz (30.5 T) NMR

Leader: H. Maeda, Riken

FY	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026



Joint technology (Shimoyama Group)

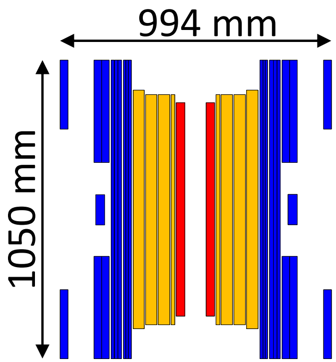
R&D:
(1) Persistent-mode HTS inner coil technology
(2) 30 T-class HTS inner coil technology
(3) Operation of a compact 1 GHz-class LTS/HTS NMR (driven-mode)
(4) Conceptual design of a persistent-mode 1.3 GHz NMR magnet

1.3 GHz inner coils

1.3 GHz magnet

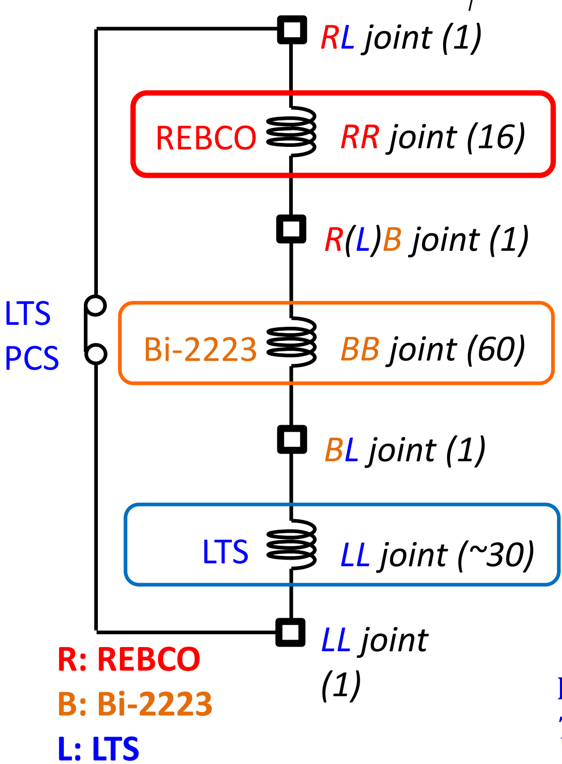
NMR evaluation (Ishii Group)

Development of Persistent-mode HTS inner coil technology



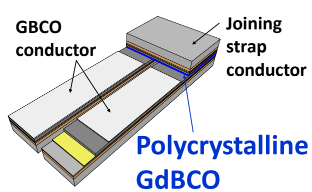
Preliminary magnet design of 1.3GHz NMR

Number of joints

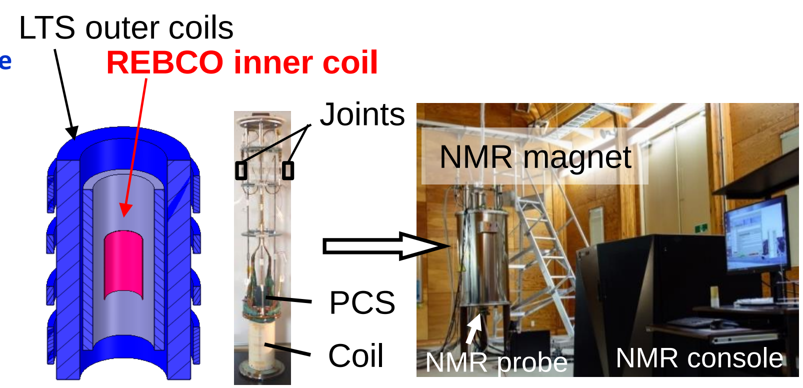


First step towards a persistent mode 1.3 GHz NMR

Partial demonstration → **400 MHz (9.39 T) LTS/REBCO NMR**



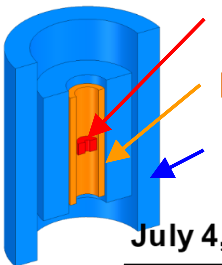
Intermediate grown superconducting (iGS) joint



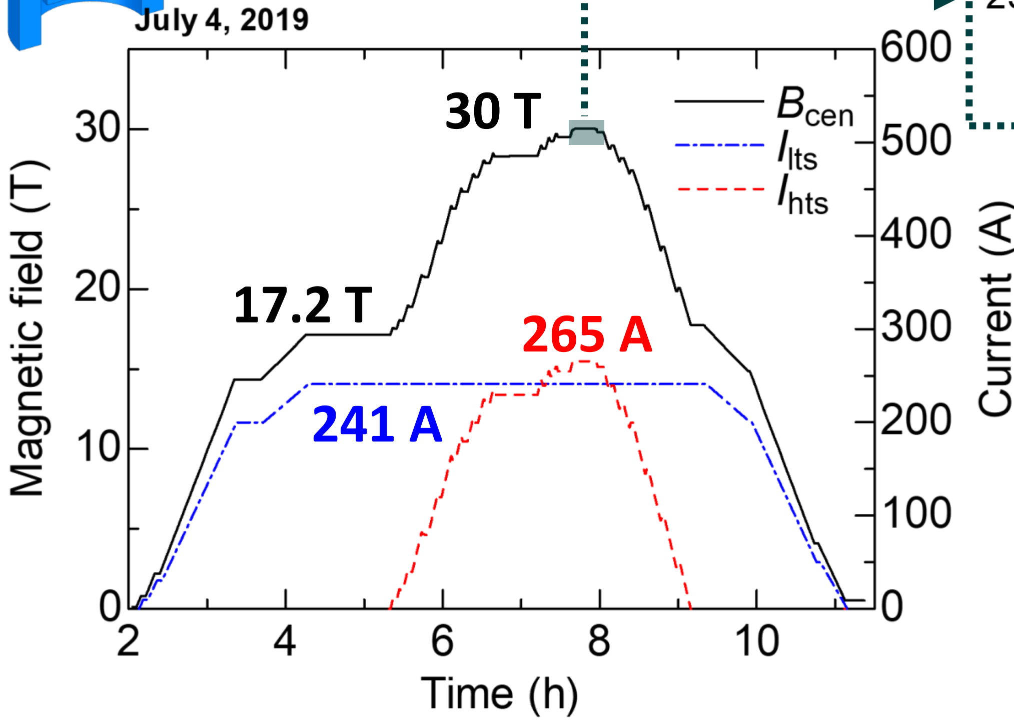
K. Ohki et al, *Supercond. Sci. Technol.* **30** (2017) 115017

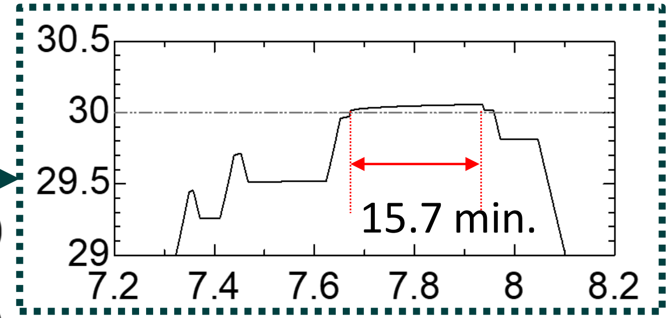
Excitation test of a 30 T model magnet

30 T-magnet (model of the 1.3 GHz NMR magnet)



REBCO coil (LNI): 9.3 T
Bi-2223 coil (insulated): 4.0 T
LTS coil (17 T magnet in NIMS)





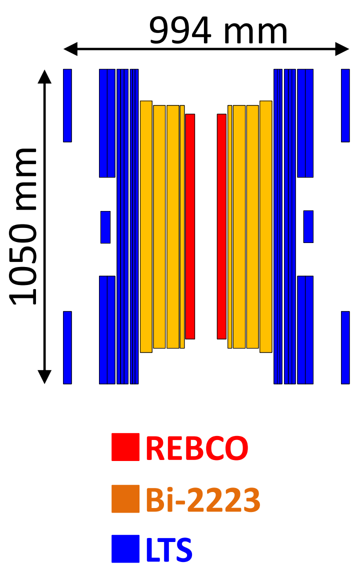
Max. BJR : **462 MPa**
Max. σ_z : **10.3 MPa**

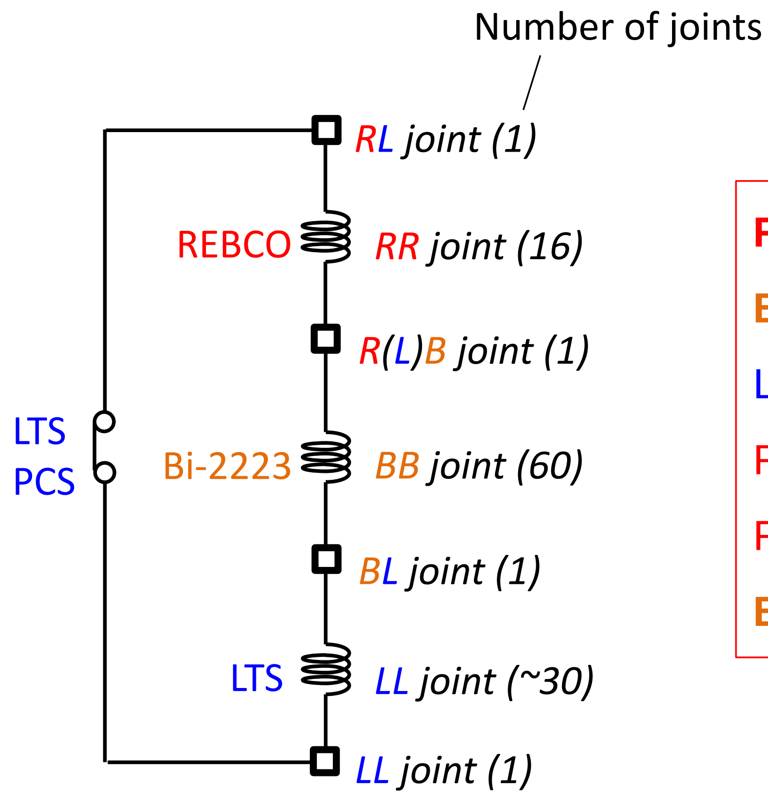
Y. Suetomi et al, MT26, Fri-Mo-Or27-02, Vancouver, Sep. 22-27, 2019

- **30 T generation without normal voltage on the REBCO coil**
- **The REBCO coil survived from a 31 T quench.**

Development of Superconducting joints

Magnet design





RR joint (16)

BB joint (60)

LL joint (~30)

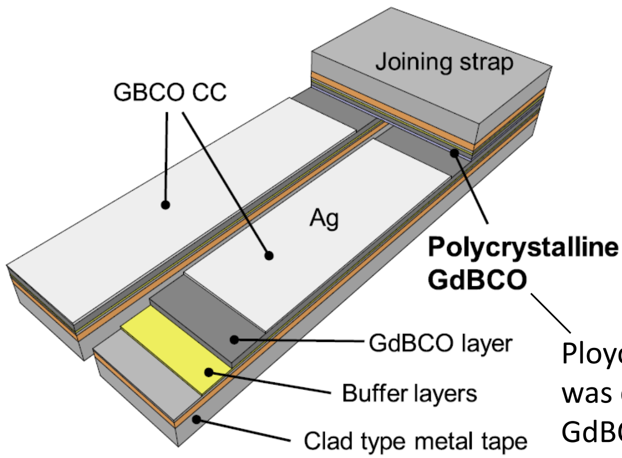
RL joint (1)

R(L)B joint (1)

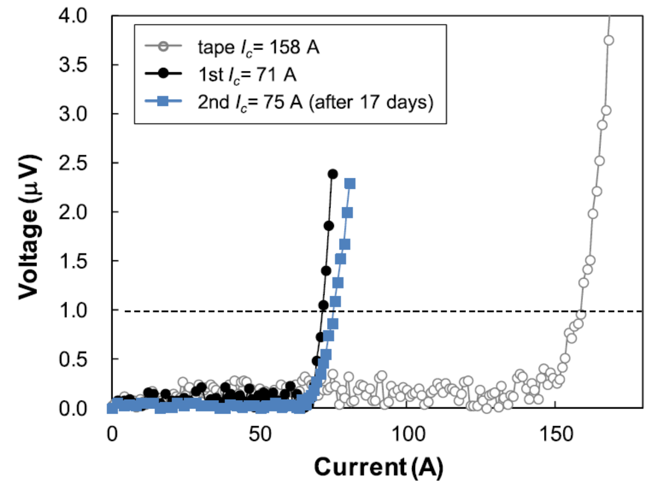
BL joint (1)

R: REBCO
B: Bi-2223
L: LTS

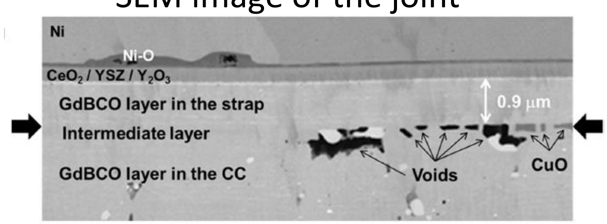
Development of REBCO-REBCO joint

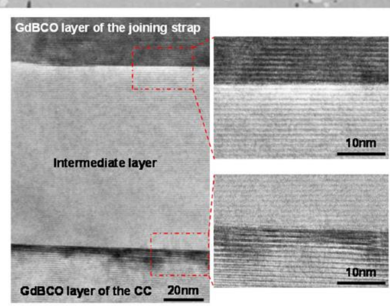


Ploycrystalline GdBCO was deposited on the GdBCO layer of the joining strap by spin coating.



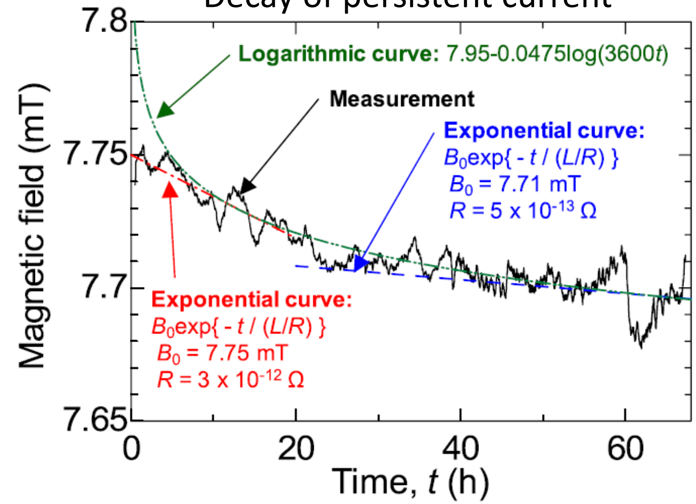
SEM image of the joint





TEM image of the joint

Decay of persistent current

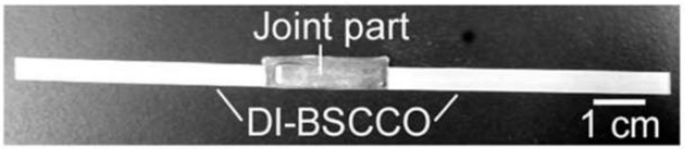


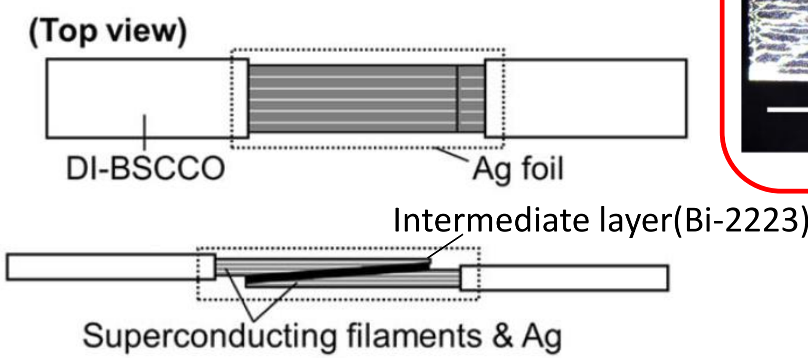
K. Ohki et al., SUST 30(2017)115017.

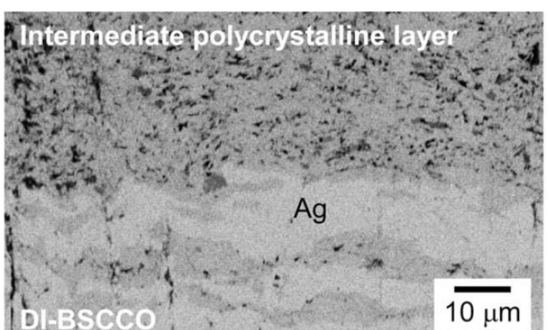
Development of BSCCO-BSCCO joint
Superconducting Joints Connecting DI-BSCCO® Tapes Via Bi-2223 Thick Film Layer

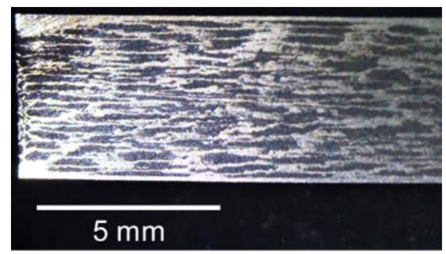
J. Shimoyama et al., Aoyama Gakuin Univ.

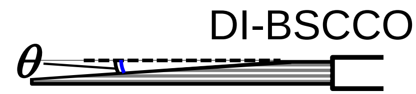
Straight Joint











Low angle polishing ($\theta < 0.6^o$) to expose ~100 filaments is effective for enhance joint I_c.

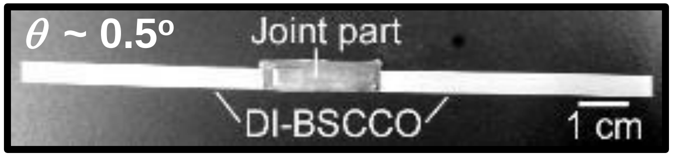
Termination Joint

***Joint Area* ~ 70 mm²**

Y. Takeda, et al., Appl. Phys. Express 12(2019)023003.

Superconducting Joints Connecting DI-BSCCO® Tapes Via Bi2223 Thick Film Layer

Straight Joint

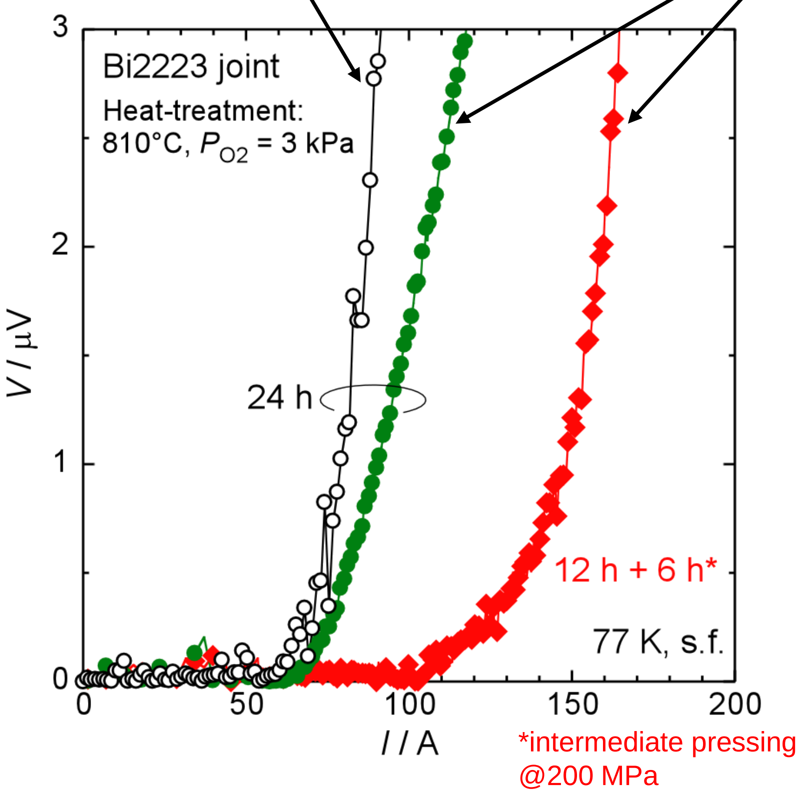


***Joint Area* ~ 100 mm²**

Y. Takeda *et al.*, *Appl. Phys. Express* **12** (2019) 023003

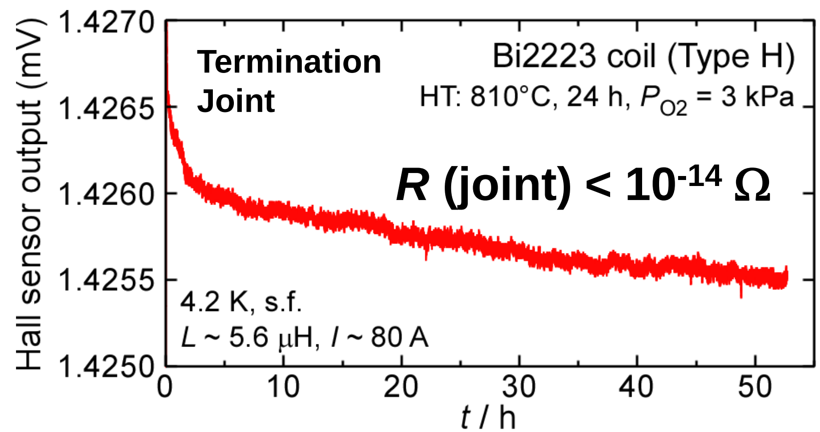
Termination Joint

***Joint Area* ~ 70 mm²**



Joint I_c (10^{-9} W)
~ 100 A (77 K, s.f)
300 A (4.2 K, 1 T)

I_c(conductor)
~180A (77 K, s.f)



JST ALCA Program

(Advanced Low Carbon Technology Research and Development) Programs.
[Five projects are in progress]

- **Development of Low-Cost REBCO Coated Conductors**
  T. Doi, Kyoto University
- **System of Superconducting Rotating Machines for Transport Equipment that Supports Low Carbon Society**
  T. Nakamura, Kyoto University
- **Removing Iron Oxide Particles from Boiler Feed-Water of Thermal Power Plants**
  S. Nishijima, Fukui University of Technology
- **Development of REBCO Fully Superconducting Rotary Machines**
  M. Iwakuma, Kyushu University
- **Development of High Performance MgB_2 Long Conductors**
  H. Kumakura, National Inst. Material Science

Development of low-cost $YBa_2Cu_3O_7$ tape conductors

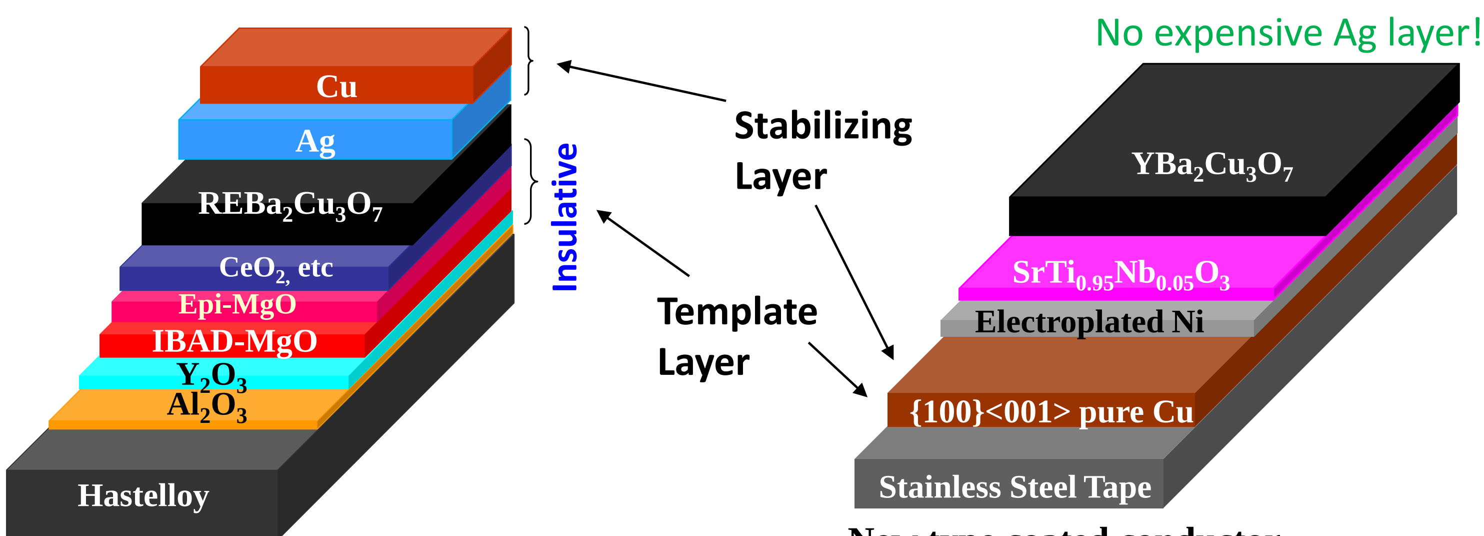
T. Doi et al., Kyoto Univ.

Conventional coated conductor
Template is insulative → Stabilizing Ag and Cu layer is required on REBCO.

Concept

By using {100}<001> textured pure Cu tape as the template of in-plane aligned REBCO and using conductive Ni and Nb-doped $SrTiO_3$ as a buffer layers, the textured Cu tape can also work as a stabilizer layer.

→ The new structure does not require the expensive Ag.



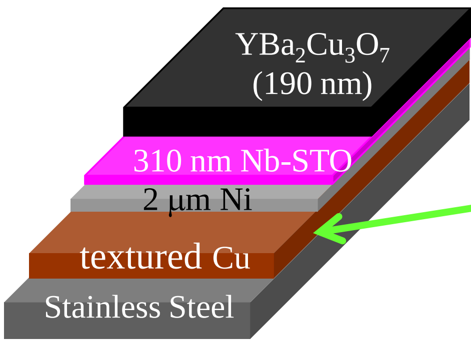
Conventional coated conductor(IBAD)

New type coated conductor

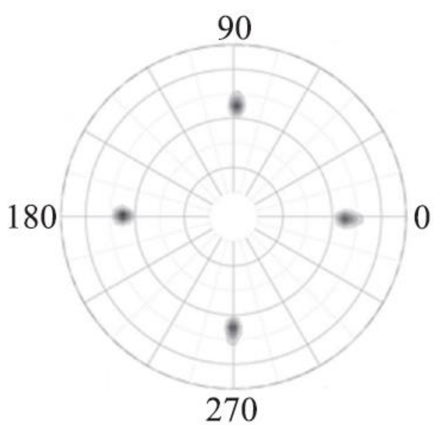
T. Doi et al., Mater. Trans. 58(2017)1493.

Fabrication method of new type coated conductor

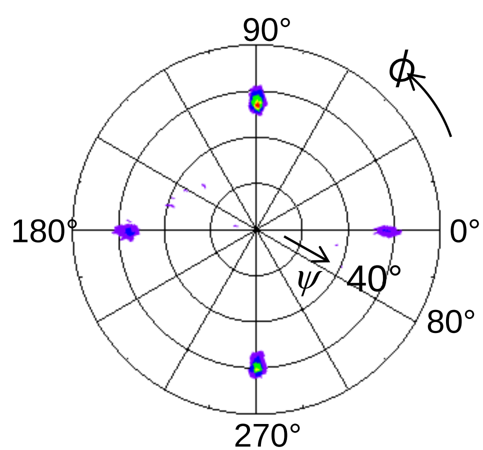
	Ni	Nb-doped $SrTiO_3$	$YBa_2Cu_3O_7$
Substrate	{100}<001> textured pure Cu / SS316 lamination tape		
Deposition Method	electroplating	PLD (Pulse Laser Deposition)	



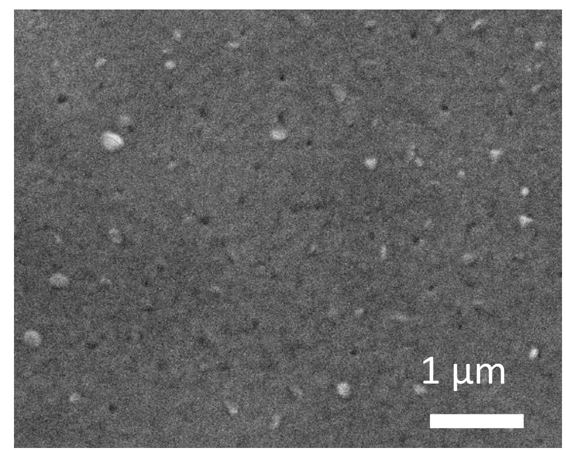
{001}<100> textured Cu layer can be obtained by cold rolling and heat treatment(recrystalization).



$(110)_{Nb\text{-}STO}$ pole figure



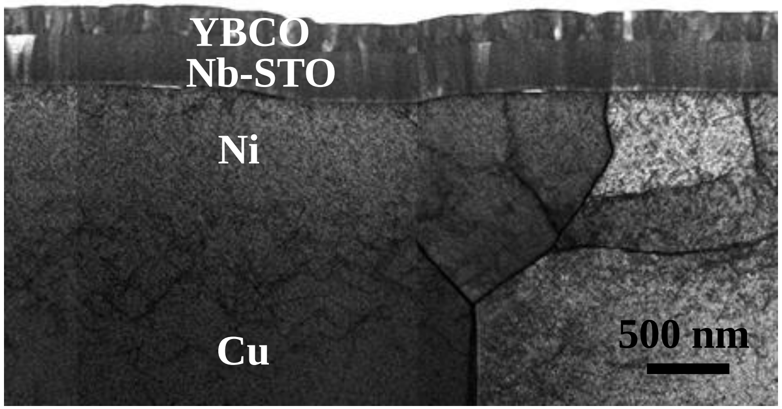
$(102)_{YBCO}$ pole figure



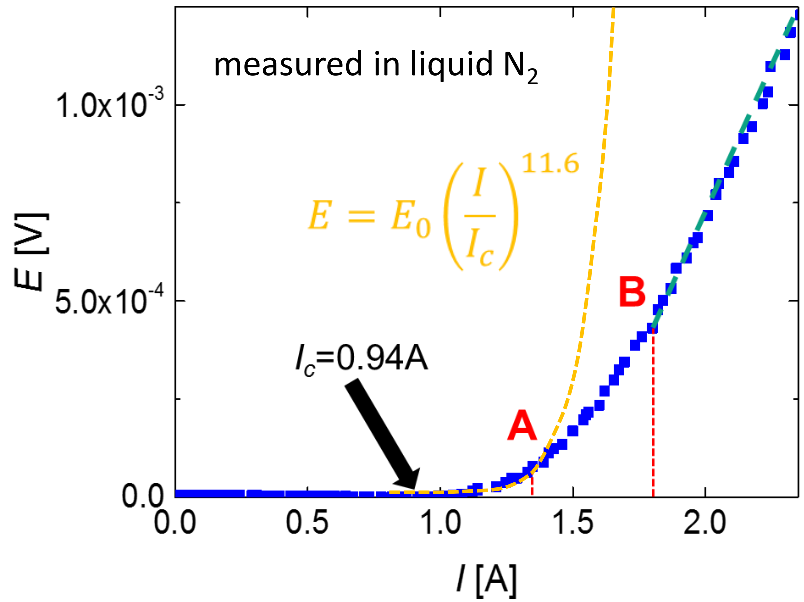
SEM micrograph of the YBCO surface of the sample

I -*V* characteristic of the YBCO/Nb-STO/Ni/Cu/SS316 tape

STEM image of the cross section



Nb-STO/Ni and YBCO/Nb-STO interfaces are clean and sharp over a wide area .



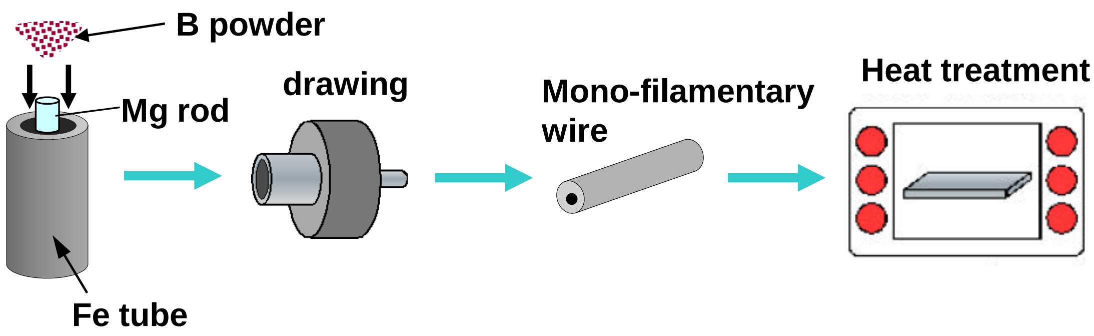
J_c=2.5 MA/cm^2 at 77 K, in self field

The measured voltages of the sample were lower than those of the calculated values by *n*-value model in normal state region ($I > I_c$).

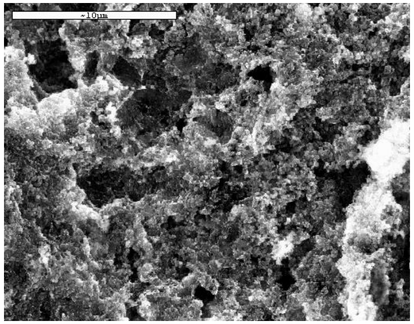
Some current flew into the Cu tape through the conductive Nb-STO and Ni buffer layers.

Development of high performance MgB_2 wires

Fabrication of MgB_2 wires by the Internal Mg diffusion(IMD) method

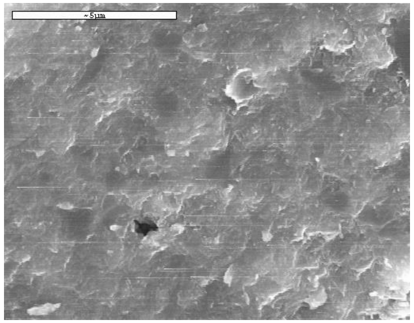


PIT

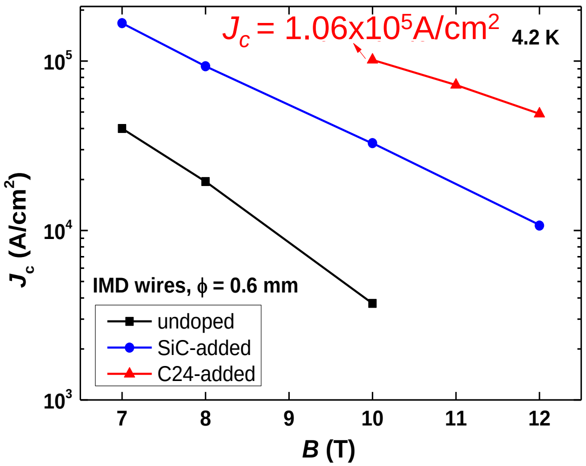


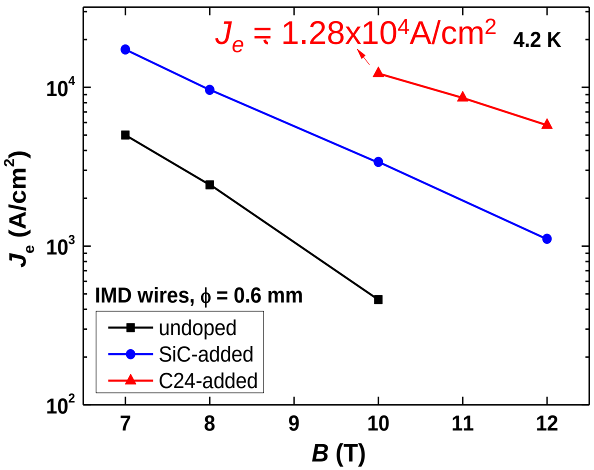
Density: ~50%

IMD



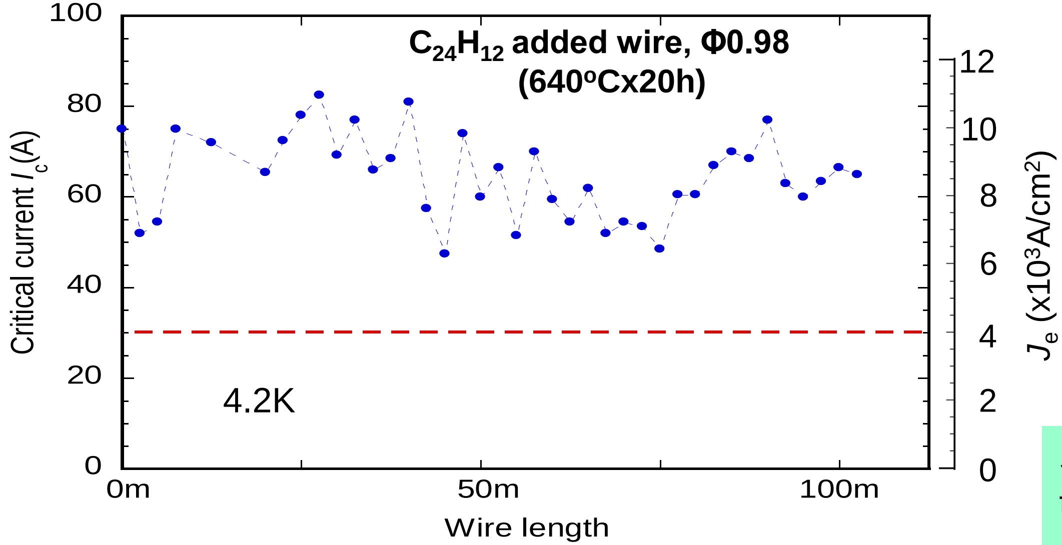
Density: ~80%



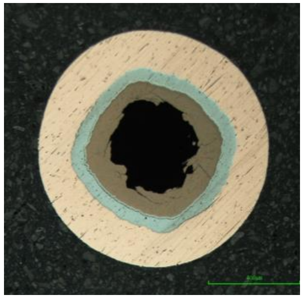


$C_{24}H_{12}$ was added as carbon source.

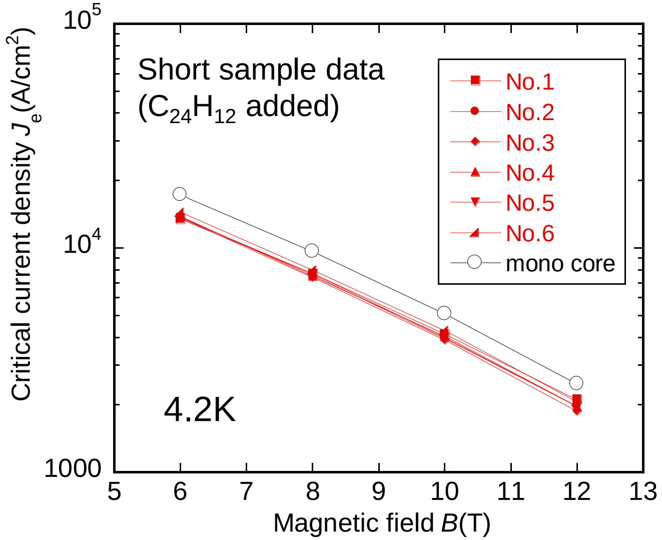
100m-class mono- and 7-filamentary IMD MgB_2 wires



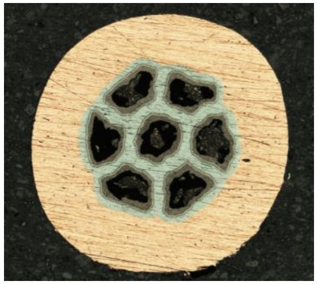
Mono-filamentary MgB_2 wire



Scattering of I_c is mostly due to the scattering of MgB_2 cross sectional area.

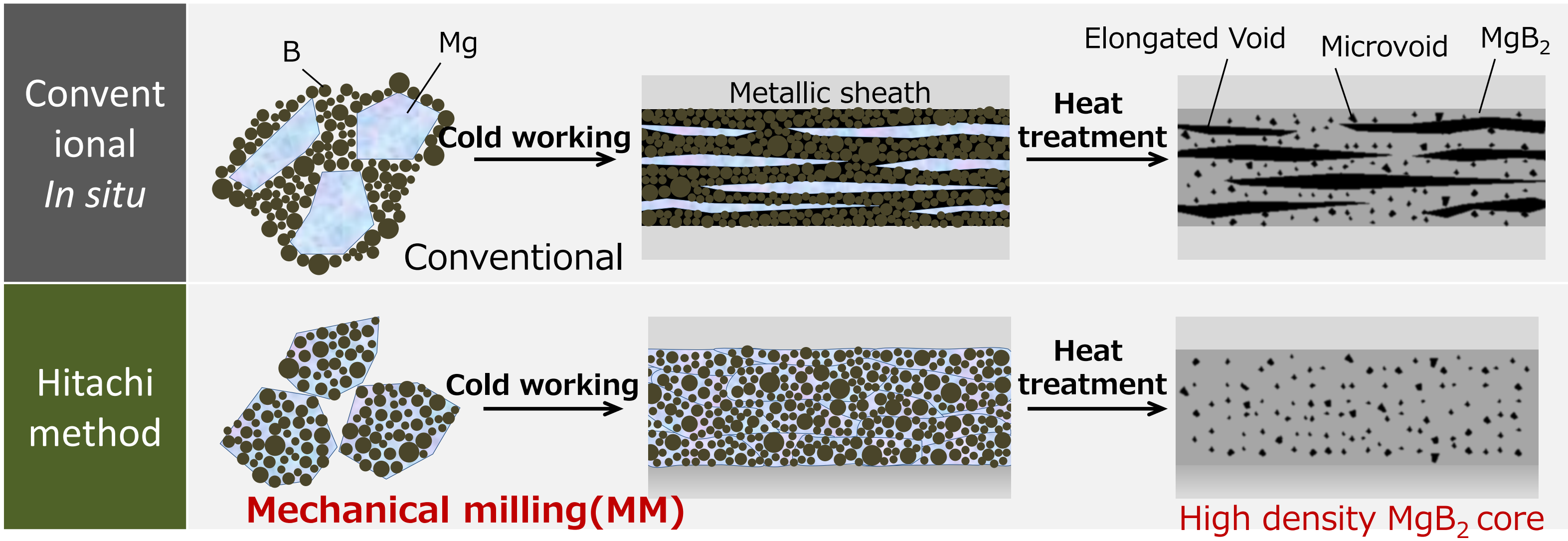


7-filamentary MgB_2 wire(~70m)



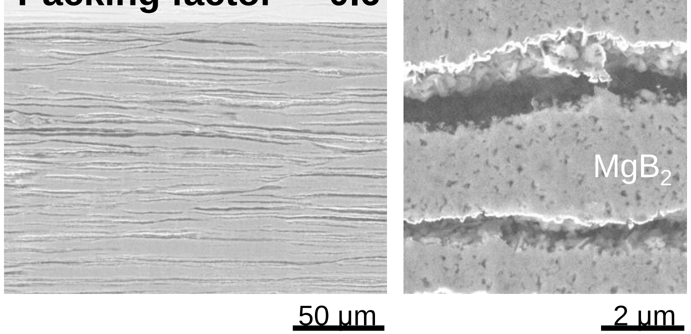
Development of high density PIT MgB_2 wires

HITACHI
Inspire the Next



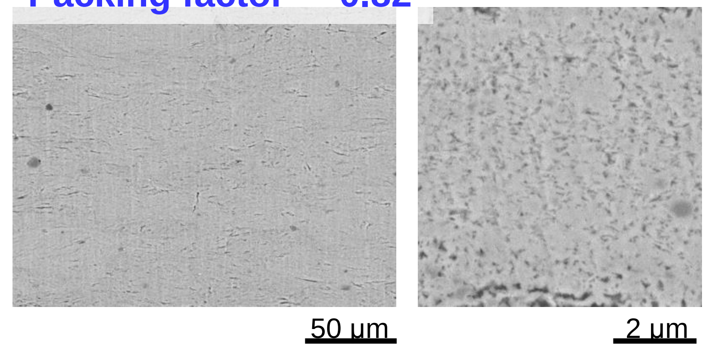
Conventional

Packing factor ~ 0.6



Mechanical milling

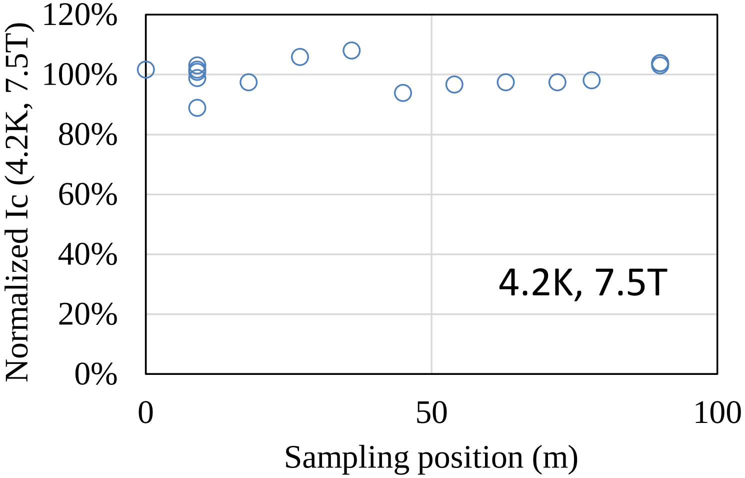
Packing factor ~ 0.82

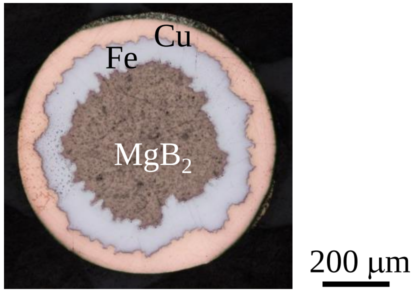


Fabrication and evaluation of 100m-1km class MgB_2 wire

HITACHI
Inspire the Next

I_c distribution of 100m long MM processed MgB_2 wire



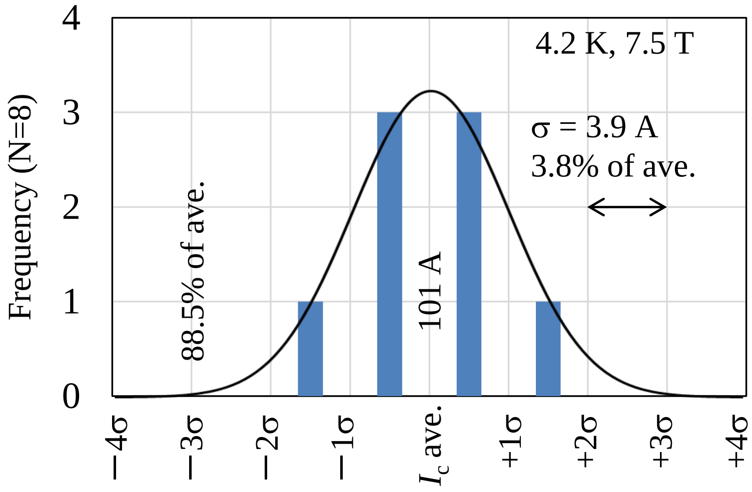


MM processed MgB_2 wire(φ0.77mm)
[$C_{24}H_{12}$ was added as carbon source]

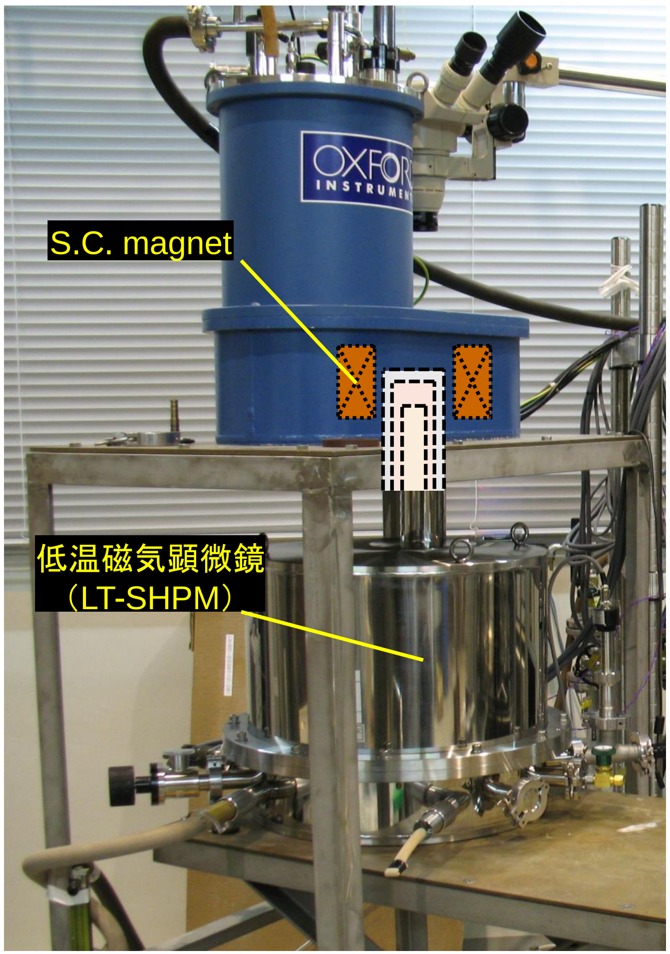
1.2km long MgB_2 wire

I_c(uniformity)
$= (I_{c,ave} - I_{c,min})/I_{c,ave}$
= 11.5% < target(15%)
$(I_{c,min} = I_{c,ave} - 3\sigma)$
σ :standard deviation

Evaluation of I_c distribution from the short samples



New evaluation technique of MgB_2 wires



Hybrid method of visualization of 3-dimentional microstructure and I_c distribution
[with X-ray micro CT and scanning Hall probe microscope] (T. Kiss et al, Kyusyu Univ.)

Wire fabrication process
Improvement of microstructure and I_c

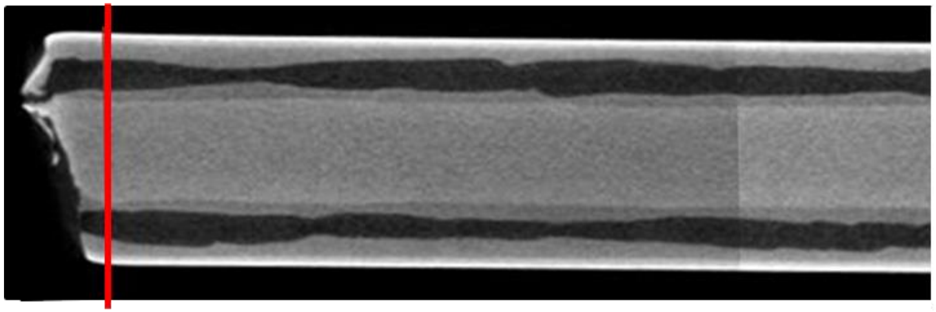
X-ray micro CT
⇒local distribution of microstructure

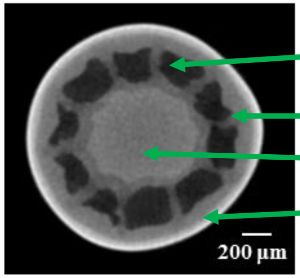
Scanning Hall probe microscopy
⇒local I_c distribution

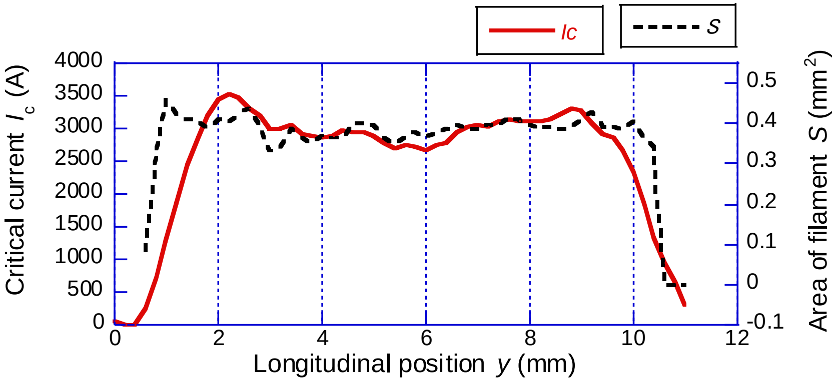
Analyses of 10-filamentary PIT MgB_2 wire(Hitachi Ltd.)

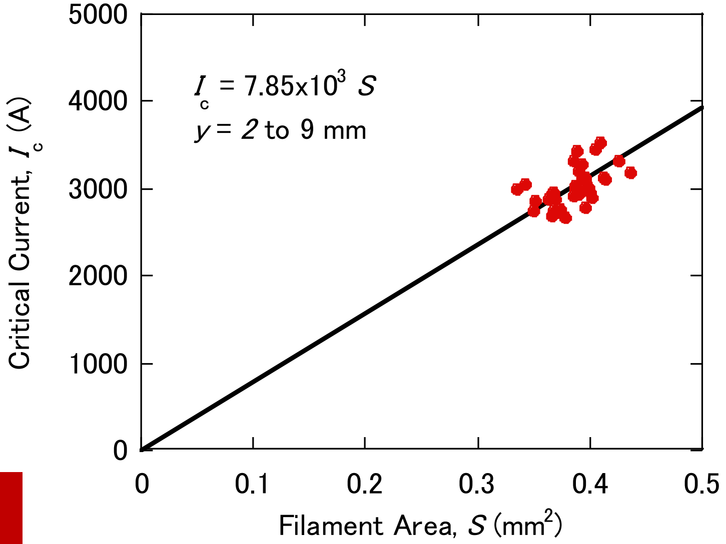
Image of X-ray micro CT

Non destructive visualization of 3-dimentional structure of MgB_2 wire









- Good correlation between I_c and S.
- I_c scattering is mostly comes from the scattering of cross sectional area.

NEDO Identified Four Areas for Technology Development to Promote Commercialization of High-Temperature Superconductivity

ー Promotion of Commercialization through Comprehensive Implementation of Fundamental and Demonstration Technology Development ー

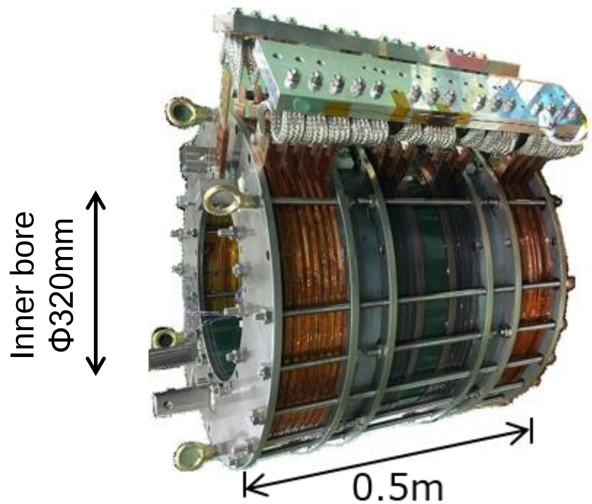
(Fiscal year:2016~2020)

1. R&D for the practical use of superconductivity cable systems (In the field of electric power)
2. Demonstrations of superconductivity DC power transmission system (In the field of transportation)
3. The application of HTS to magnetic resonance imaging (MRI) (In the field of industrial technology)
4. The technology development of HTS wire to improve the magnetic field characteristics and to reduce the cost with the aim of promoting rapid commercialization.

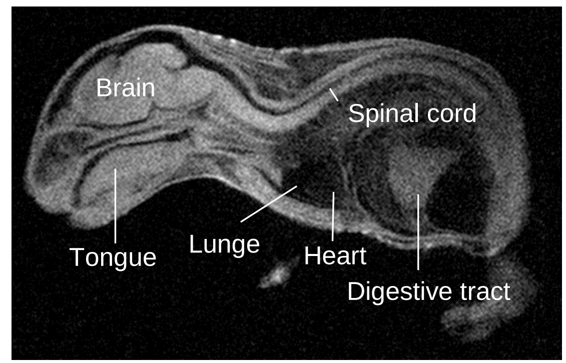
The application of HTS to MRI

MITSUBISHI ELECTRIC
Changes for the Better

1/3 scale 3T REBCO He-free MRI (2016)

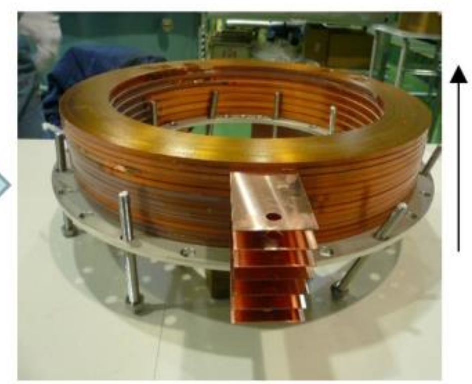


High resolution Imaging of mouse baby
Length: ~25mm



Conductors:
REBCO IBAD
C.C. (Fujikura)

Pancake coil

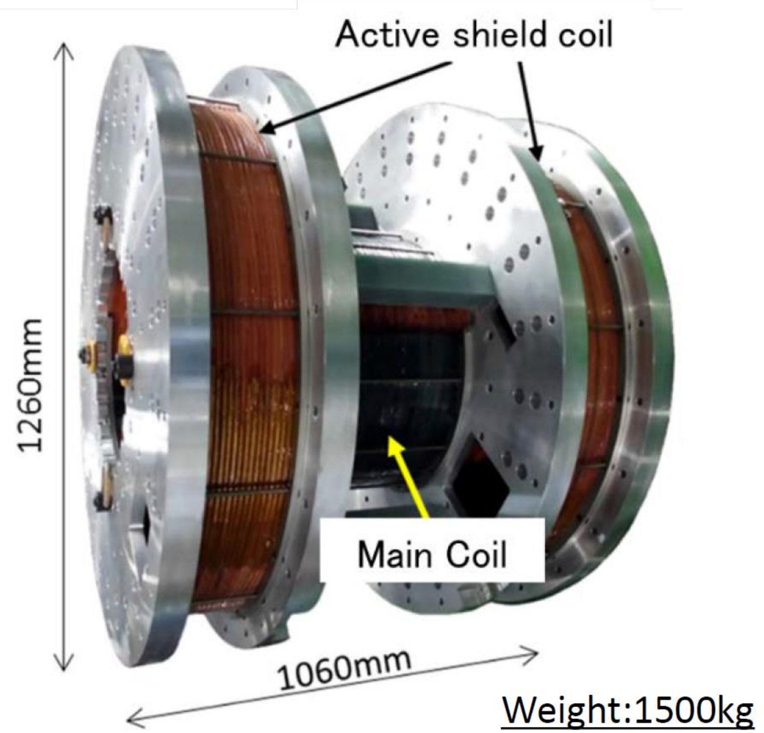


Development of half size He-free 3T HTS(REBCO) MRI

Specification of the half size 3T HTS Coil

Inner diameter	580mm
Maximum outer diameter	1200mm
Axial length	980mm
Operating central field	**2.9T**
Maximum field	Bzmax=4.2T,Brmax=2.9T
Current density of coil	121A/mm2
Inductance	145H
Stored energy at operation	1.6MJ
REBCO wire Total Length	70km
Field uniformity on design	**1.7ppm/250mmDSV**
Leak magnetic field area	2.5mX3.4m (0.5mT)

They fabricated 272 pancake coils and used 220 of them for the construction.



Photograph of the half-size active shield-type 3T coil

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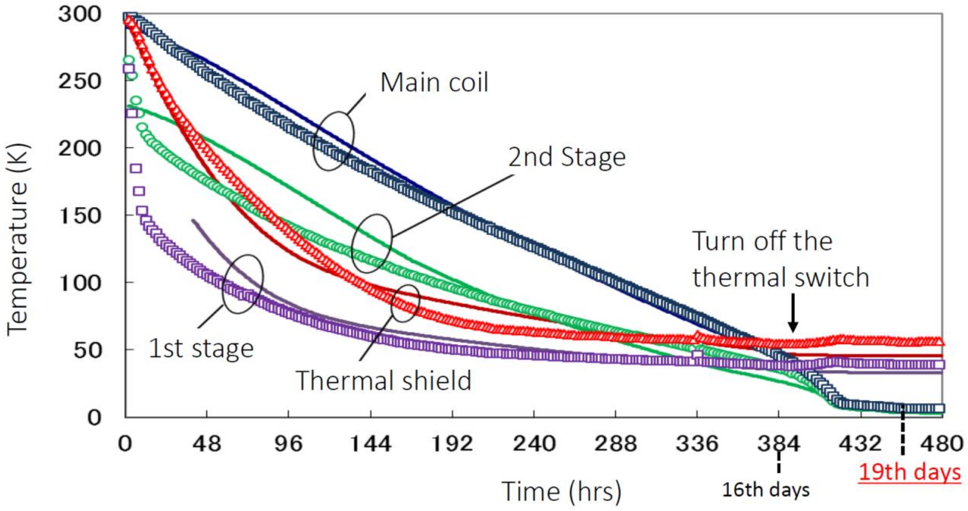
Cooling and excitation of half size 3T magnet

Photograph of a Cryostat
(Max：W1881-Z1672-H1790)

Initial cooling properties of half-size 3T magnet



Excitation test of the coil

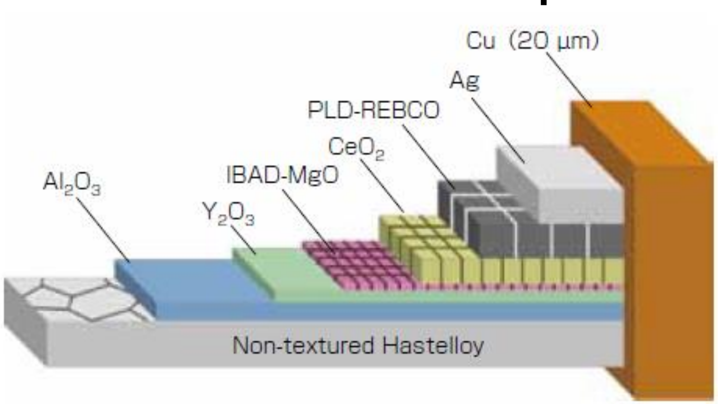
- Temperature <6K
- Voltage of 25mV was generated at the joints due to the shear stress.
- They will change the joint structure and carry out an excitation test again.

Program to promote rapid commercialization of HTS
- Development of long length Eu-123 coated conductors having artificial pinning centers -

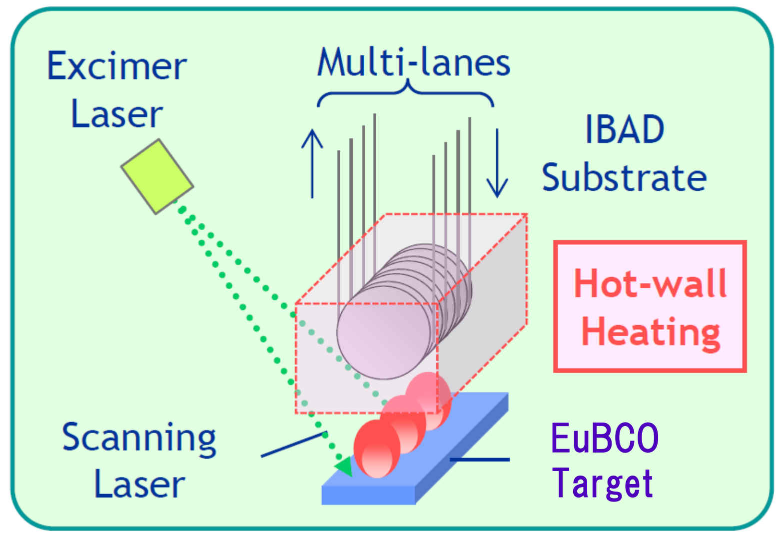
Fujikura

Eu-123 layer was deposited with PLD method.

IBAD substrate tape



Hot wall heating is applied to obtain stable temperature during PLD.



Artificial pinning centers: $BaHfO_3$
(Target material: $EuBa_2Cu_3O_{7-\delta}$+$BaHfO_3$)

http://www.fujikura.co.jp/products/newbusiness/superconductors/01/superconductor.pdf
http://www.fujikura.co.jp/rd/gihou/backnumber/pages/__icsFiles/afieldfile/2019/08/02/132_R6.pdf

Microstructure and I_c of Eu-123 coated conductors with artificial pinning centers

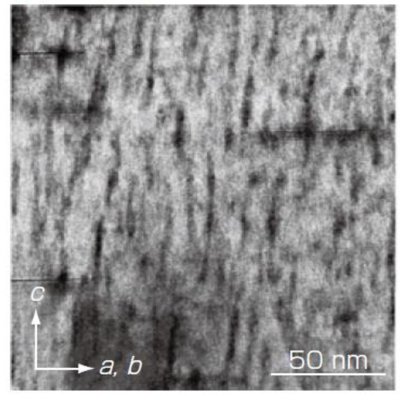
Fujikura

Two types of PLD deposition

Table 1. Specifications of the samples used for evaluation of the in-field characteristics.

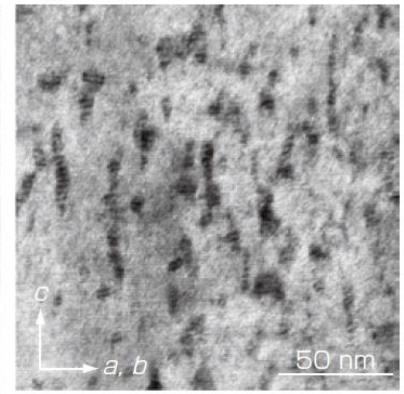
Sample Index	REBCO layer	Deposition rate [nm/sec]	REBCO thickness [μm]	I_c (77.3 K, s. f.) [A/cm-w]	T_c [K]
FAST	EuBCO-BHO	20-30	2.2	387	91.2
SLOW	EuBCO-BHO	5-15	1.1	250	91.8
Pure	GdBCO	10-20	1.9	575	93.1

depo. cond. SLOW

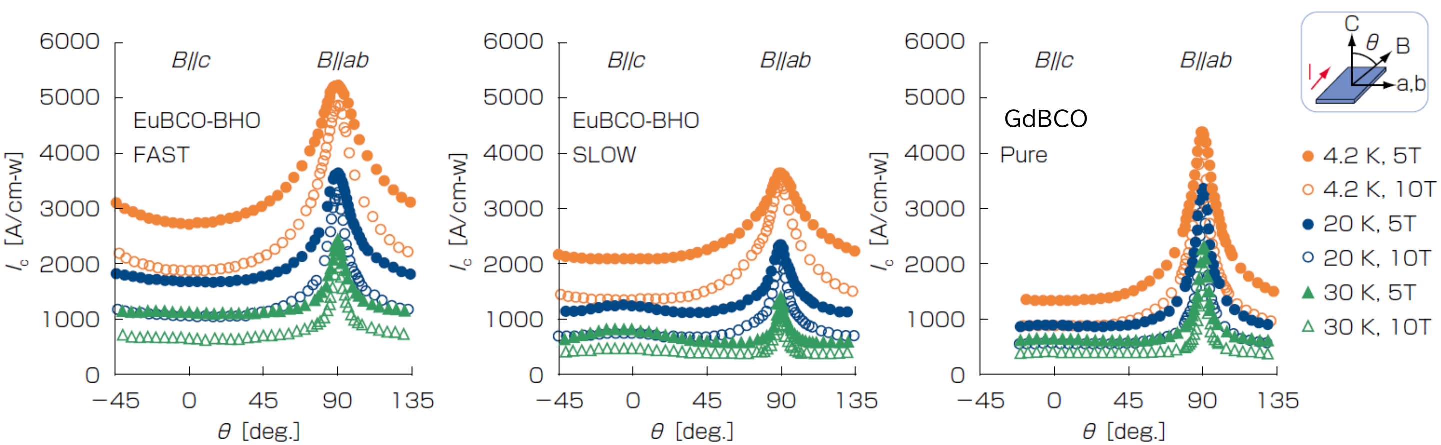


BHO nano rods // c-axis

depo. cond. FAST



BHO short nano rods



Magnetic field orientation

I_c homogeneity of Eu-123 coated conductor with artificial pinning centers

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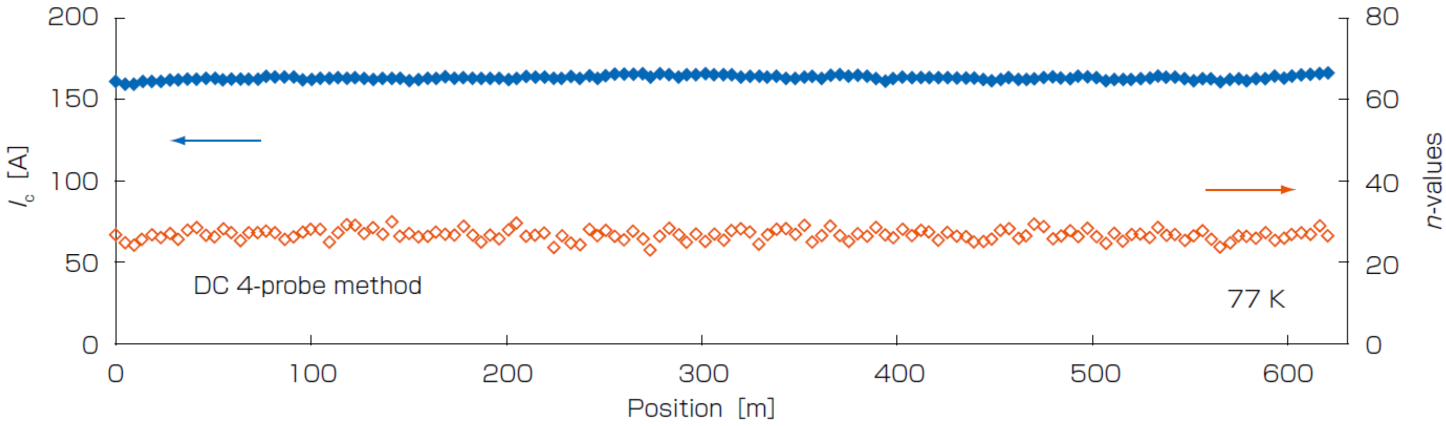
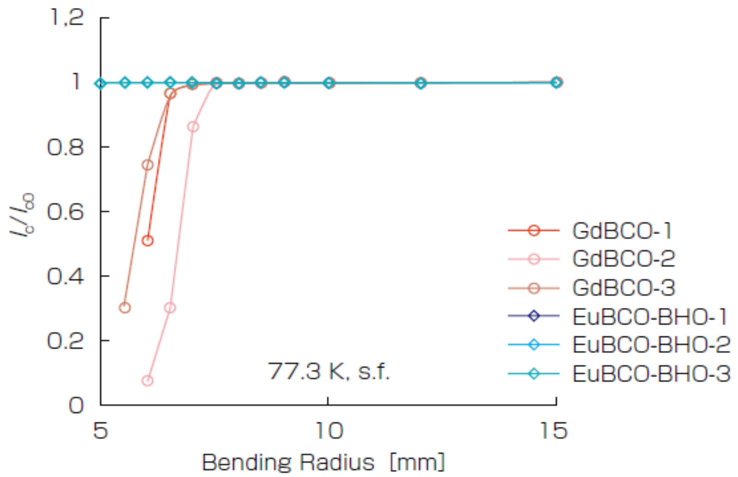


I_c tolerance to bending strain



Scattering of I_c in the 5 tapes