Tue-Mo-Or8-06

Bi2223 persistent current coil with superconducting joint fabricated by JIM method

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[1]Muroran Institute of Technology

[2]RIKEN

1. Introduction

JST-Mirai Program

(Grant Number JPMJMI17A2)

PM Dr. Hideaki Maeda

Social implementation of super-high field **NMR**s and DC superconducting cables for railway systems, through advancement of joint-technology between high-temperature superconducting wires

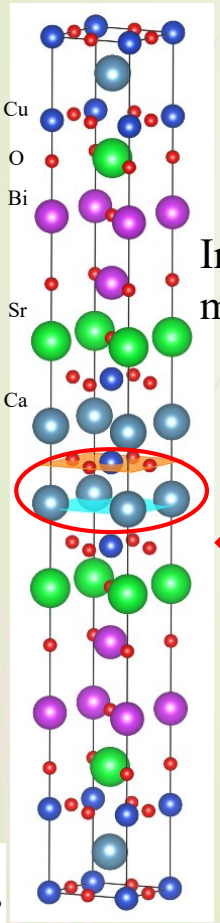
In Muroran Institute of Technology, we develop a superconducting joint and coil between two multi-filamentary Bi2223 tapes with a joint by incongruent melting (**JIM**) method [1].

This study is also supported by MEXT project of Leading Initiative for Excellent Young Researchers (LEADER, Project ID: 16810210), and JSPS KAKENHI (Grant Number JP18K04719), Japan.

[1] X. Jin, Y. Suetomi, R. Piao, Y. Matsutake, T. Yagai, H. Mochida, Y. Yanagisawa, H. Maeda, "Superconducting joint between multi-filamentary $Bi_2Sr_2Ca_2Cu_3O_{10+\delta}$ tapes based on incongruent melting," Supercond. Sci. Technol., vol. 32, 2019, Art. no. 035011.

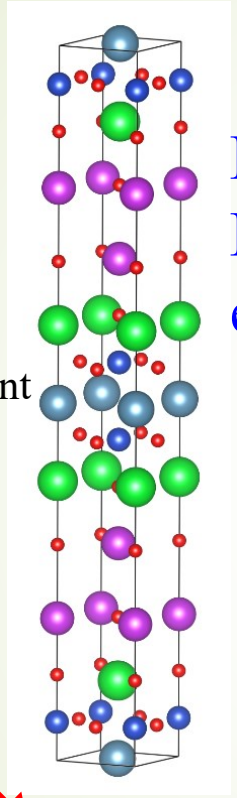
JIM method

Bi2223



Incongruent melting

Bi2212



Recovery to Bi2223 is not essential.

Small liquid ($CaCuO_2$)

Amount of liquid is insufficient to bonding.

	Melting point at 1 atm.	Tc (K)
Bi2223	~860	~110
Bi2212	~880	~90

Bi2223 → Bi2212 → Bi2201

Bi2212 → partially **Liquid** (sufficient for bonding)

Heat treatment such as **890 °C** with a short duration is necessary.

2. Heat treatment and wire structure

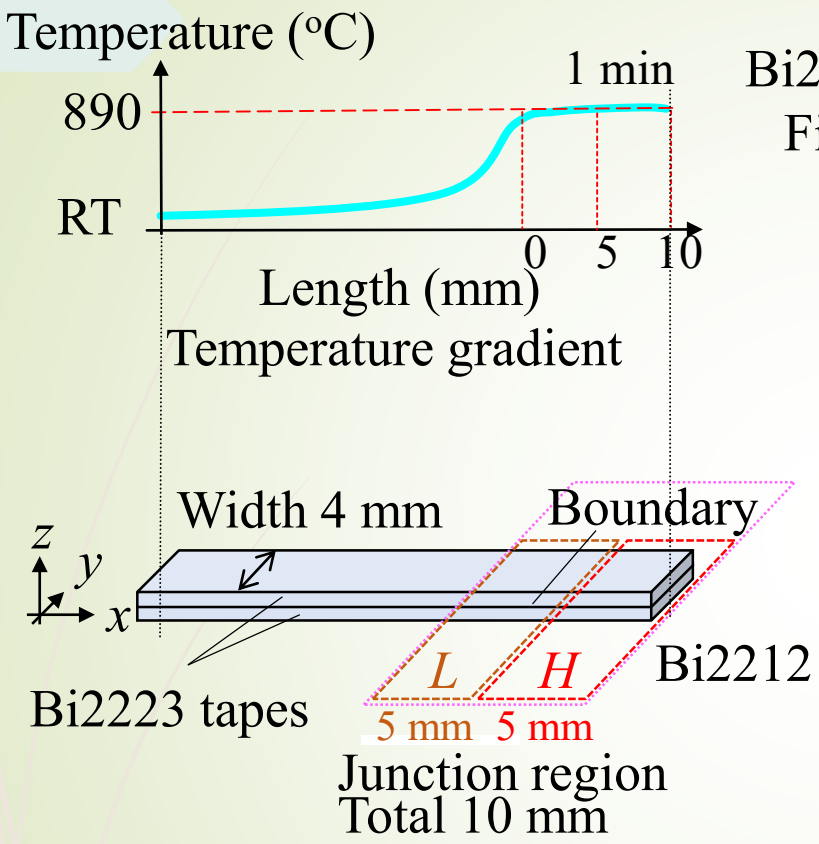
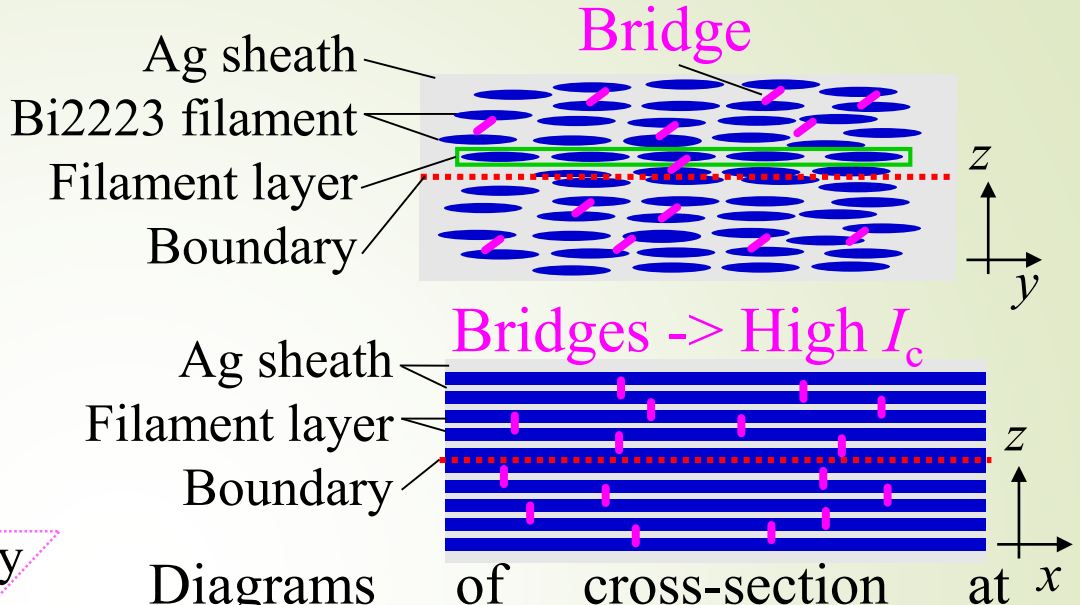


Image of joint sample having high-temperature (*H*) and low-temperature (*L*) junction regions .

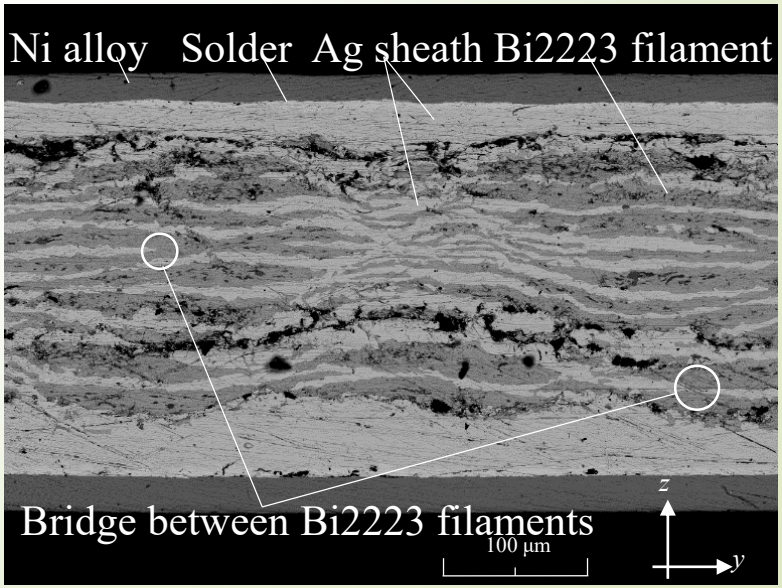
Highest tenperature

L: 860~880 °C Bi2212

H: 880 ~ 890 °C partical Bi2201



Diagrams of cross-section at junction region.



Cross-section of original tape

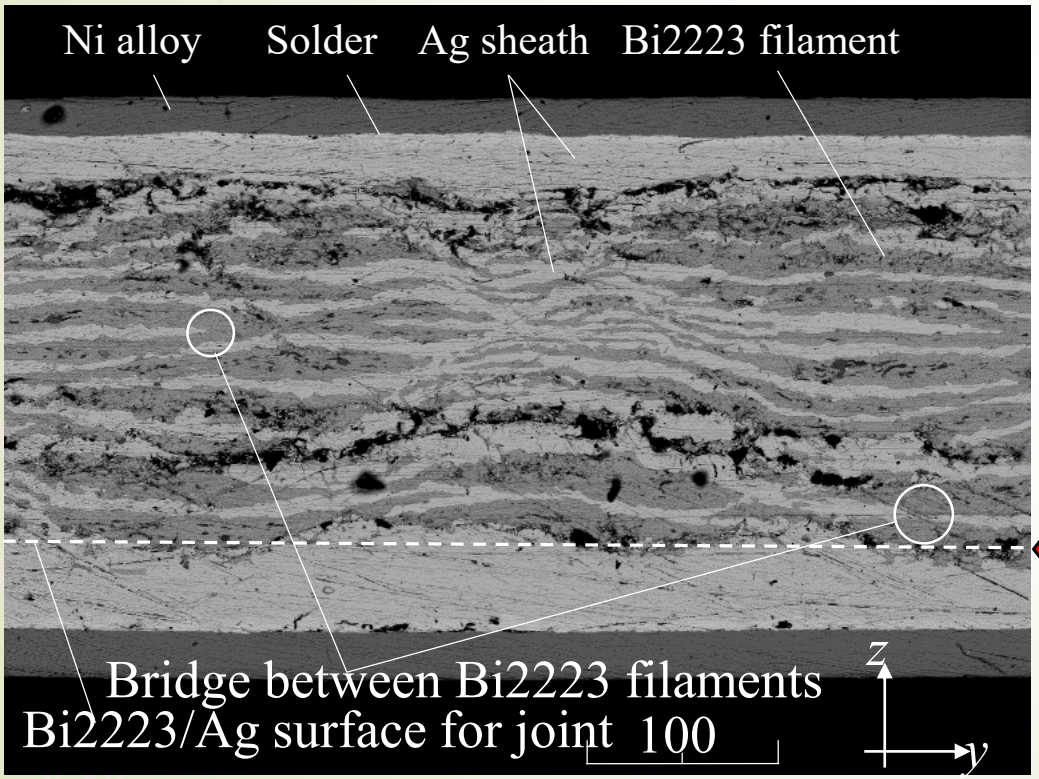
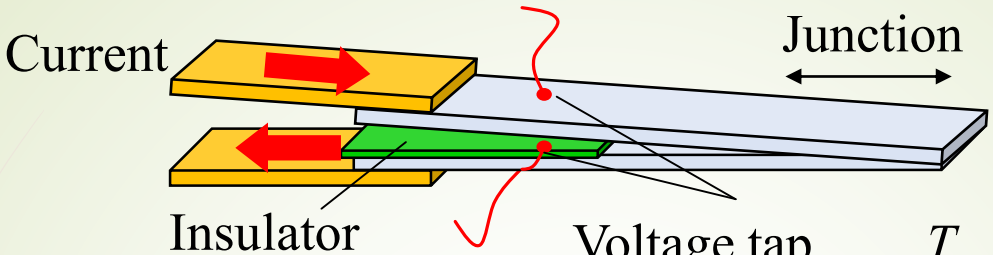


Table 1. Specifications of original Bi2223 tape.

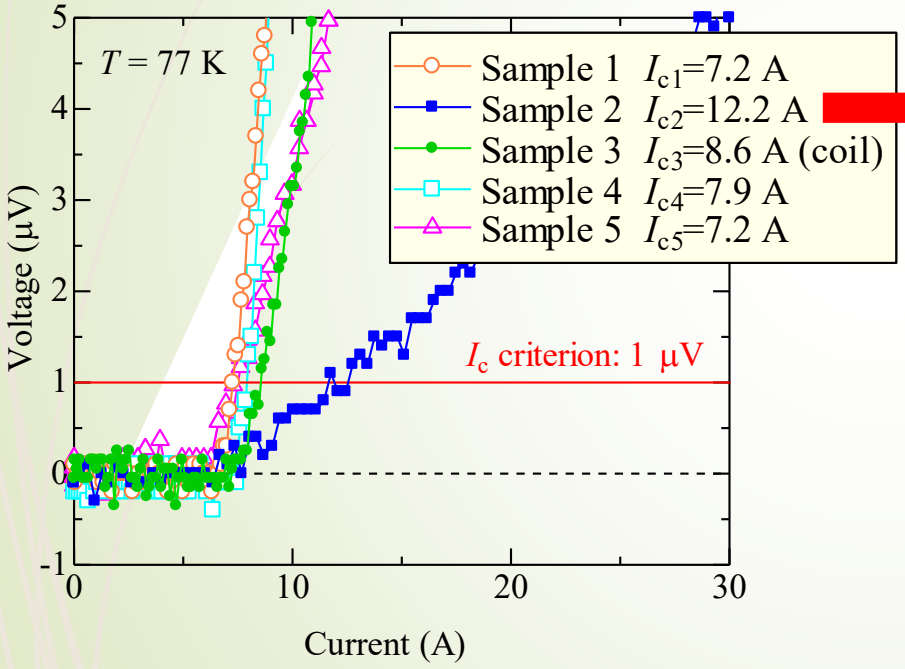
Wire type	DI-BSCCO Type HT-NX
Tape width (mm)	4.5
Tape thickness (mm)	0.31
Reinforcement	Ni-alloy
Number of filaments	121
I_c at 77 K (A)	190

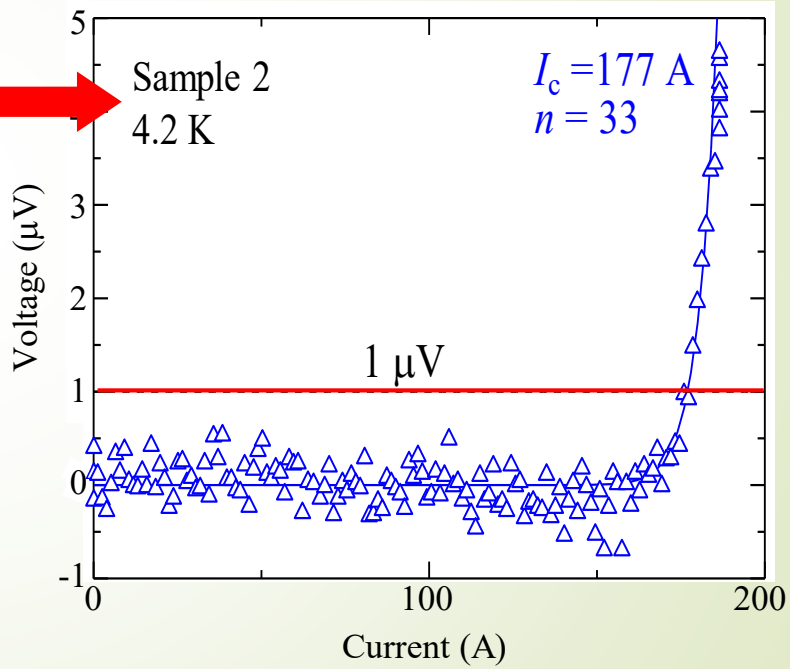
The Bi2223 surface is exposed by using sandpaper.

3. Critical current measurements



T_{max} during joint < 100 °C

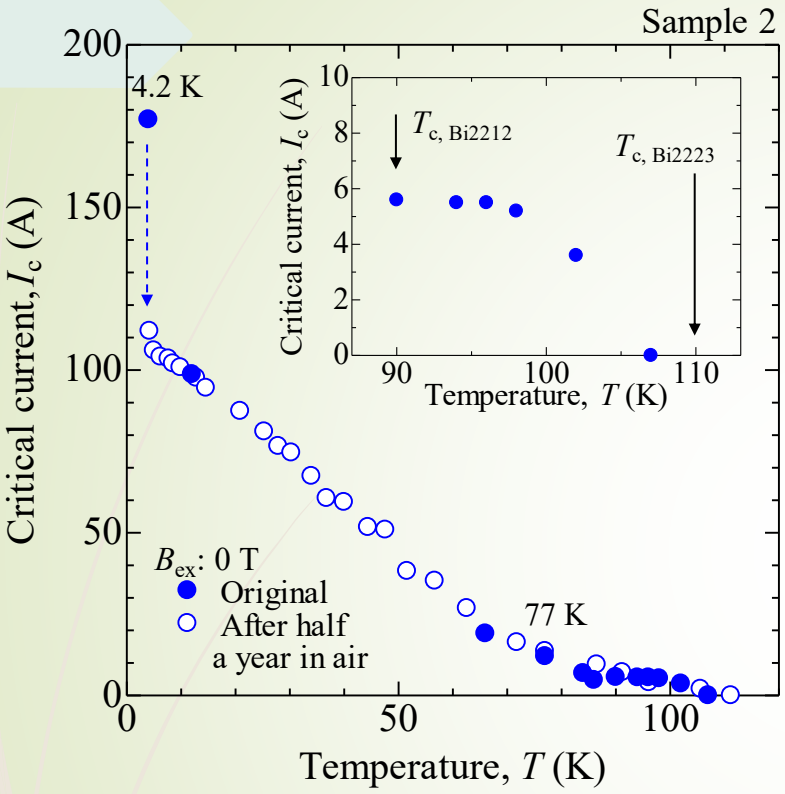




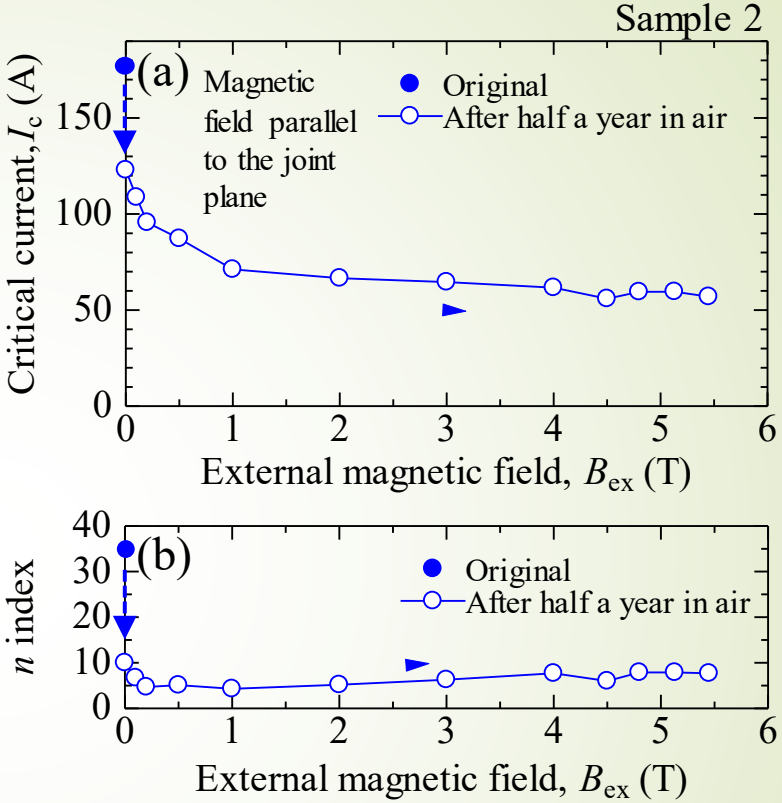
I-V properties of samples at 77 K

I-V property of sample 2 at 4.2 K [1]

[1] X. Jin, Y. Suetomi, R. Piao, Y. Matsutake, T. Yagai, H. Mochida, Y. Yanagisawa, H. Maeda, Supercond. Sci. Technol., vol. 32, 2019, Art. no. 035011.



Temperature dependence of the critical current [1]



External magnetic field dependence of the critical current [1]

[1] X. Jin, Y. Suetomi, R. Piao, Y. Matsutake, T. Yagai, H. Mochida, Y. Yanagisawa, H. Maeda, Supercond. Sci. Technol., vol. 32, 2019, Art. no. 035011.

4. XRD measurements

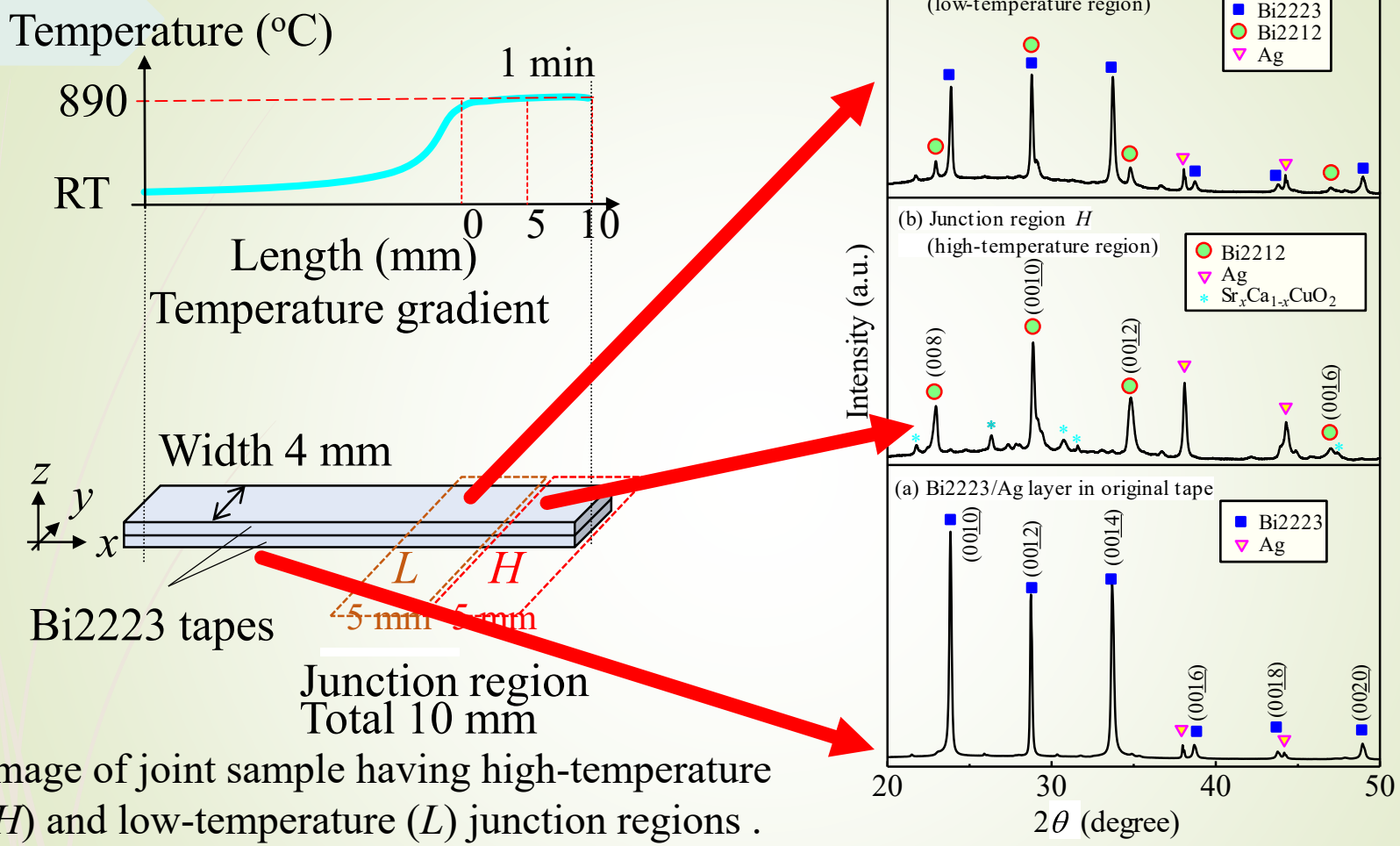


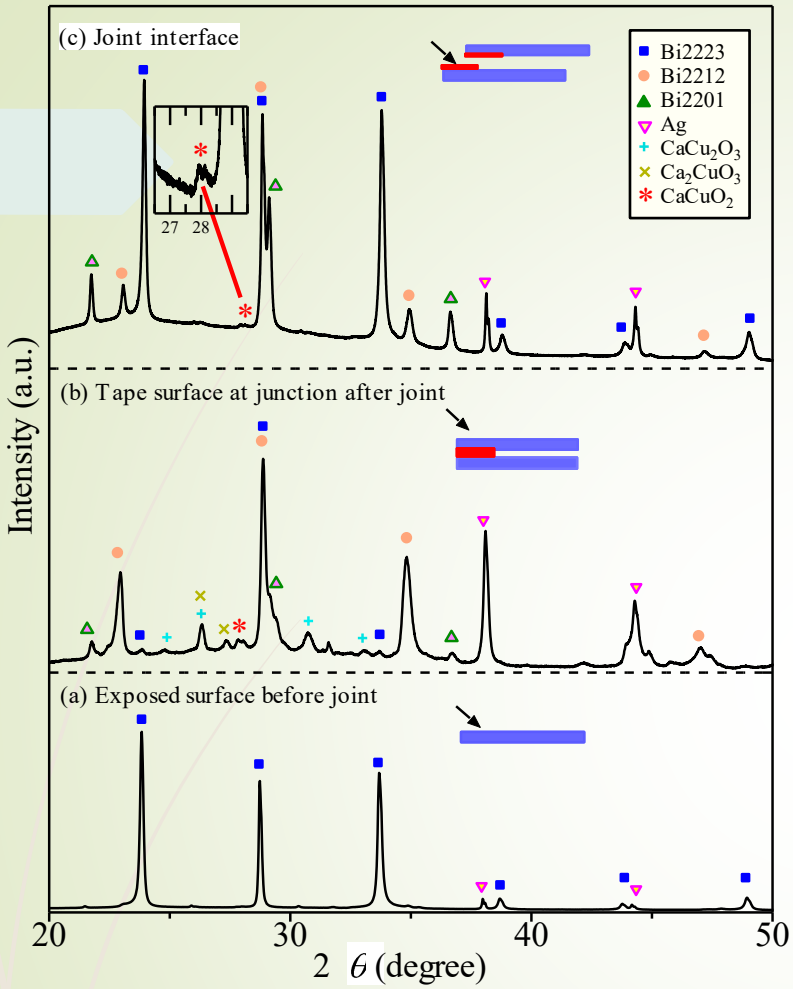
Image of joint sample having high-temperature (*H*) and low-temperature (*L*) junction regions .

Highest tenperature

L: 860~880 °C Bi2212

H: 880 ~ 890 °C partical Bi2201

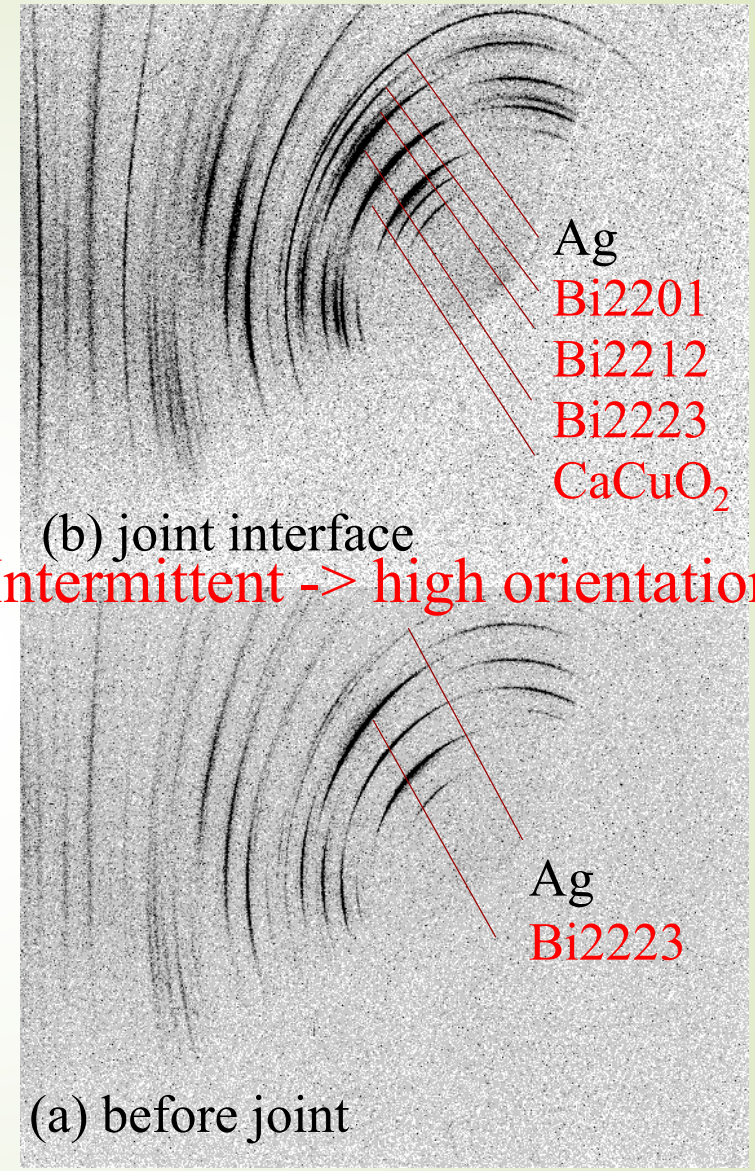
XRD patterns for the samples. (a) is for the exposed Bi2223/Ag layer in tape before joint, (b) and (c) are for joined sample at junction regions *H* and *L*, respectively.



XRD patterns for the samples. (a) is original Bi2223/Ag layer before joint, (b) and (c) are for joined samples. [2]

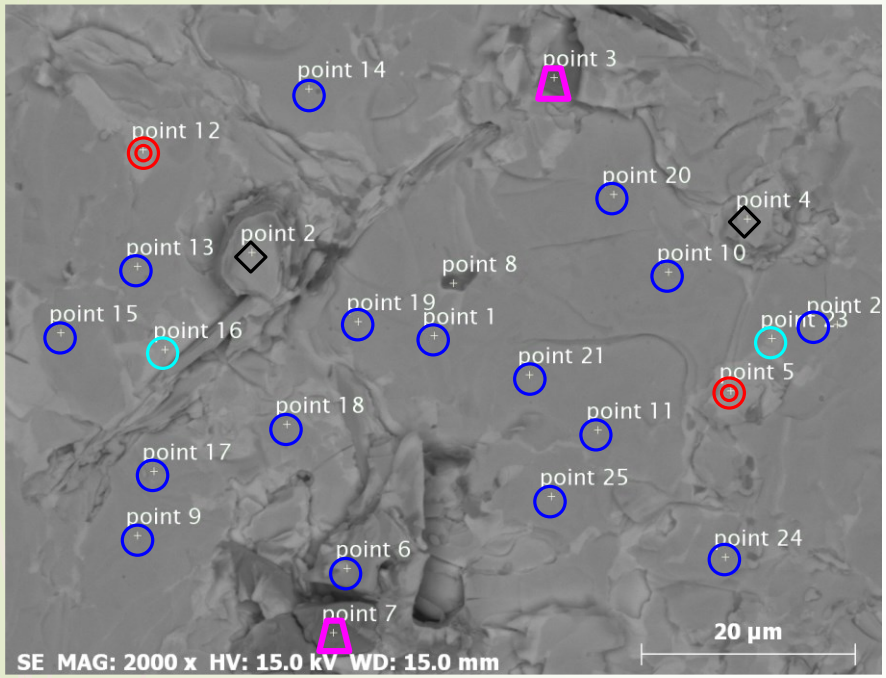
High-orientations

[2] Shintetsu Kanazawa, Yoshinori Yanagisawa, Journal of Alloys and Compounds **806**, 897-900, 2019



2D-XRD patterns for the samples. (a) is original Bi2223/Ag layer before joint, (b) is for joined sample. [2]

5. SEM/EDX analyses



○Bi2223 ○Bi2212 ◎Bi2201/Ag
⏢Sr-Ca-Cu-O ◇Ag

SEM image for a part of junction.
The 25 points were used for EDX analysis.

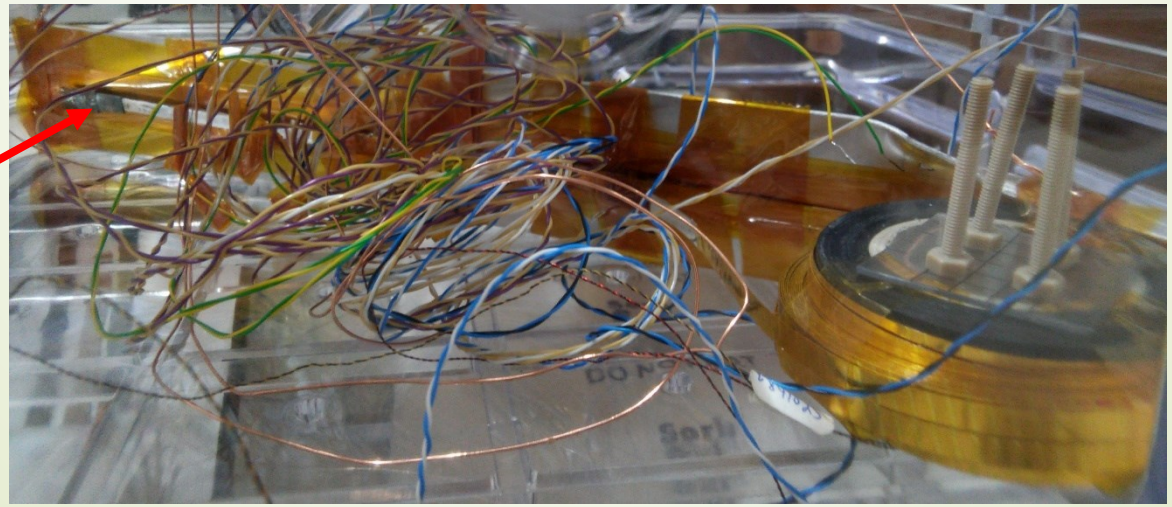
Table 2. Analysis results of main materials at the points.

Point num.	Ag	Bi	Sr	Ca	Cu	O	Main material
	(at. %)						
point 1	0	10	11	15	17	48	Bi2223
point 2	91	0	0	0	2	6	Ag
point 3	2	0	5	25	14	54	Sr-Ca-Cu-O
point 4	88	0	1	1	1	10	Ag
point 5	31	7	8	1	5	48	**Bi2201/Ag**
point 6	0	11	13	8	18	50	Bi2223
point 7	0	0	19	21	38	22	Sr-Ca-Cu-O
point 8	0	5	6	32	7	49	(Void)
point 9	0	10	11	14	17	47	Bi2223
point 10	2	10	11	12	16	49	Bi2223
point 11	0	9	11	14	17	49	Bi2223
point 12	25	12	10	1	6	46	**Bi2201/Ag**
point 13	0	11	11	14	17	48	Bi2223
point 14	12	8	9	9	13	49	Bi2223
point 15	0	10	11	14	16	48	Bi2223
point 16	0	13	14	6	17	50	Bi2212
point 17	4	9	10	11	16	50	Bi2223
point 18	0	11	13	15	20	41	Bi2223
point 19	0	9	12	14	16	49	Bi2223
point 20	0	9	11	13	17	51	Bi2223
point 21	0	9	11	13	17	49	Bi2223
point 22	1	9	12	12	17	49	Bi2223
point 23	3	13	13	8	15	48	Bi2212
point 24	0	9	12	15	16	48	Bi2223
point 25	1	9	12	14	16	47	Bi2223

6. Persistent current coil

Table 3. Specification of coil sample (sample 3)

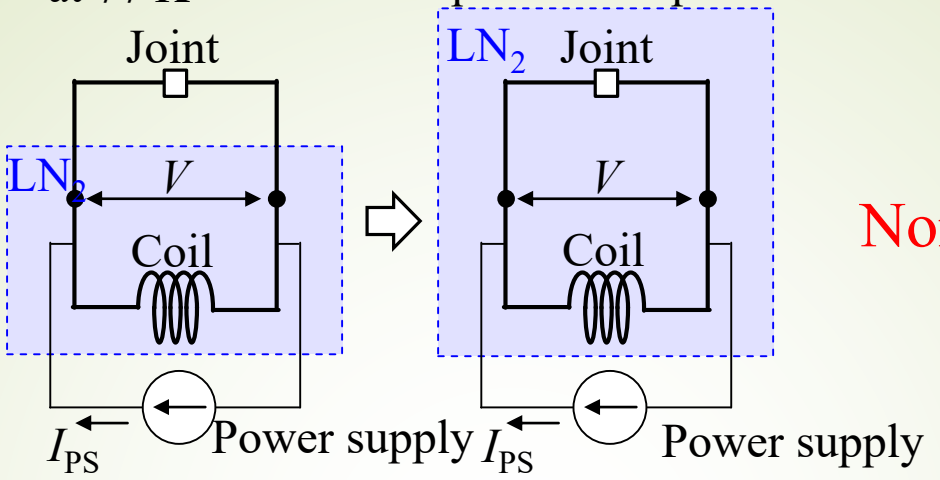
Winding method	Double pancake
Tape length (m)	8
Coil inner diameter (mm)	50
Coil outer diameter (mm)	58
Number of turns	44
Self-inductance (mH)	0.10
Insulating material	Kapton tape
Coil sample length (cm)	~30



Picture of coil sample with a joint

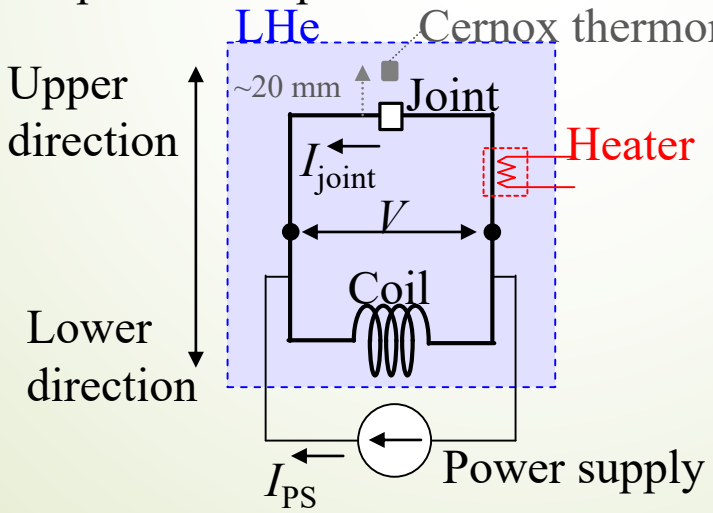
(a) Coil charging at 77 K

Power supply current reduction and persistent operation at 77 K



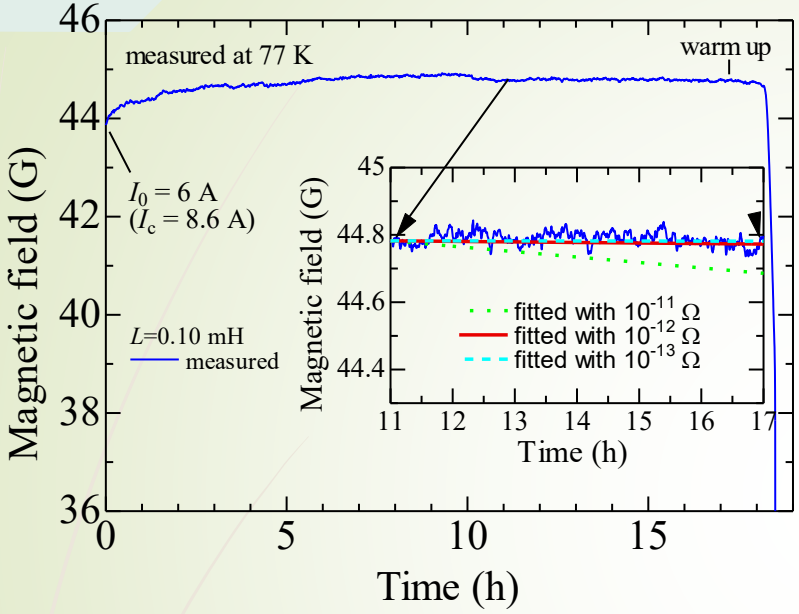
Non-additional PCS

(b) Coil charging, power supply current reduction, and persistent operation at 4.2 K

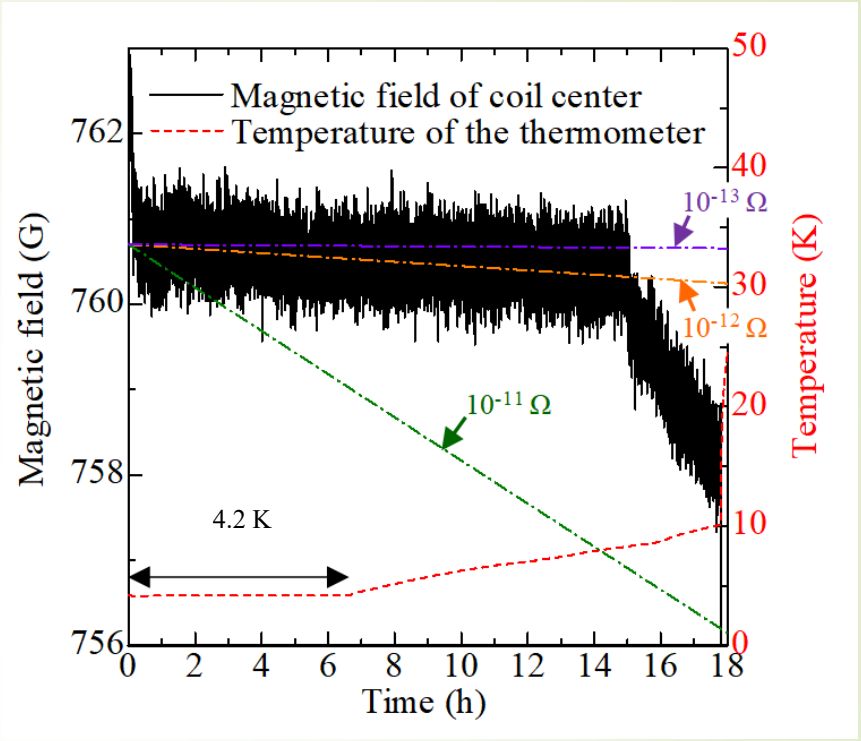


Additional PCS

Measurement methods for persistent current coil of sample 3 at (a) liquid nitrogen (LN_2) and (b) liquid helium (LHe) temperatures.



Measurements of persistent current at 77 K [1]

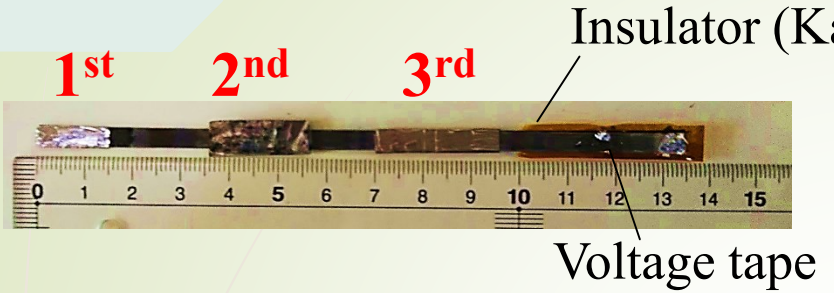


Measurements of persistent current at 4.2 K [1]

A low-resistance about 10^{-12} Ω after 12 hr

[1] X. Jin, Y. Suetomi, R. Piao, Y. Matsutake, T. Yagai, H. Mochida, Y. Yanagisawa, H. Maeda, Supercond. Sci. Technol., vol. 32, 2019, Art. no. 035011.

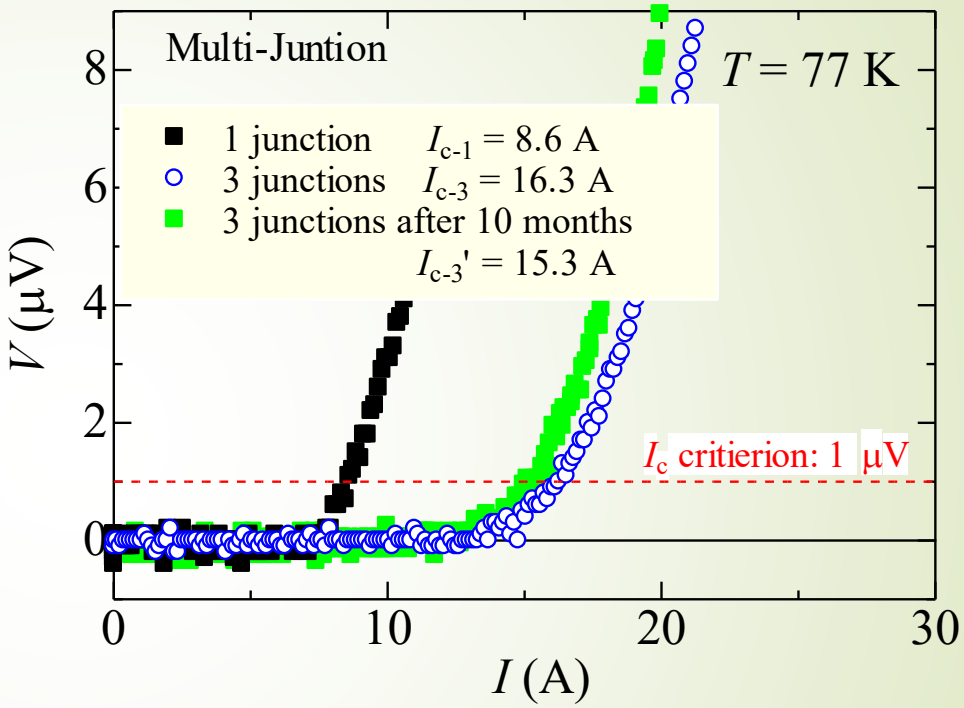
7. Improvement of critical current



Multi-junction method

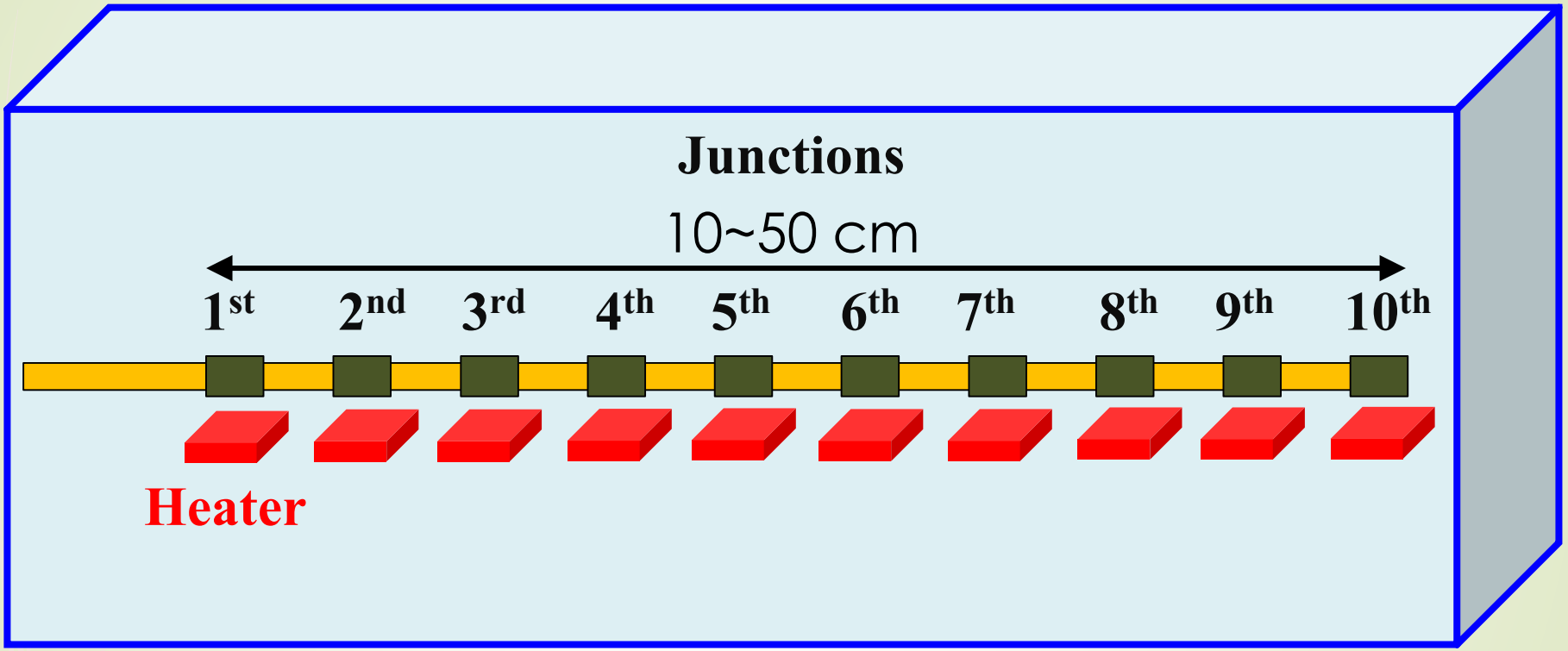
Table 4 Specifications of joint sample with multi-junction

Tape type	**DI-BSCCO HT-NX**
Original I_c(A) at 77 K	150~180
Length (mm)	135
Juntion number	3
Each length of junction (mm)	10



I_c that is 10% of original was obtained by 3 junctions. Multi-junction method is effective to increase the critical current

Development of a furnace for multi-junction



R&D goals: I_c = **50 A at 77K**

I_c = **500 A at 4.2 K**

R_{coil} = **1 pΩ at 77 and 4.2 K**

8. Results

- We prepared many joint samples between multi-filamentary Bi2223 tapes. The critical current of joint at 77 K is below 10% of original tape, and it should be increased above 5 times for application.
- This small critical current at 77 K may be due to the formation of Bi2212 and partial Bi2201 at junction, as measured by SEM/EDX, these T_c are smaller than that of Bi2223.
- However, the critical current at 4.2 K has a large value about 177 K. This may be related to high-orientation of Bi2212 and Bi2201, as measured by XRD.
- The measurement results of persistent current shows a low-resistance about 1 pΩ, which value is applicable for NMR developments.
- Multi-junction method is effective to improve the critical current, and development of a furnace for multi-junction is started.