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# An Intermediate Grown Superconducting (iGS) Joint between REBCO Coated Conductors

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# Presentation Outline

1. **Motivation**
2. **Experimental**
   - **Structure of a REBCO coated conductor**
   - **Configuration of joint**
   - **Polycrystalline SC layer**
3. **Experimental results**
   - **Cross-sectional observation of a joined interface**
   - ***V-I* characteristics (77 K, 4.2 K)**
   - **The reproducibility of the iGS joint technique**
   - **Persistent current measurement**
4. **Summary and future plans**

# Motivation

## 1. Early studies

- **Park Y et al 2014 NPG Asia Mater. 6 e98**
- **Jin X et al 2015 *Supercond. Sci. Technol.* 28 75010**
- **Furukawa Electric website: https://furukawa.co.jp/release/2016/kenkai_160427.html**

## 2. Technical issues

- **Long processing time (Particularly, the oxidation processing time)**

## 3. This study

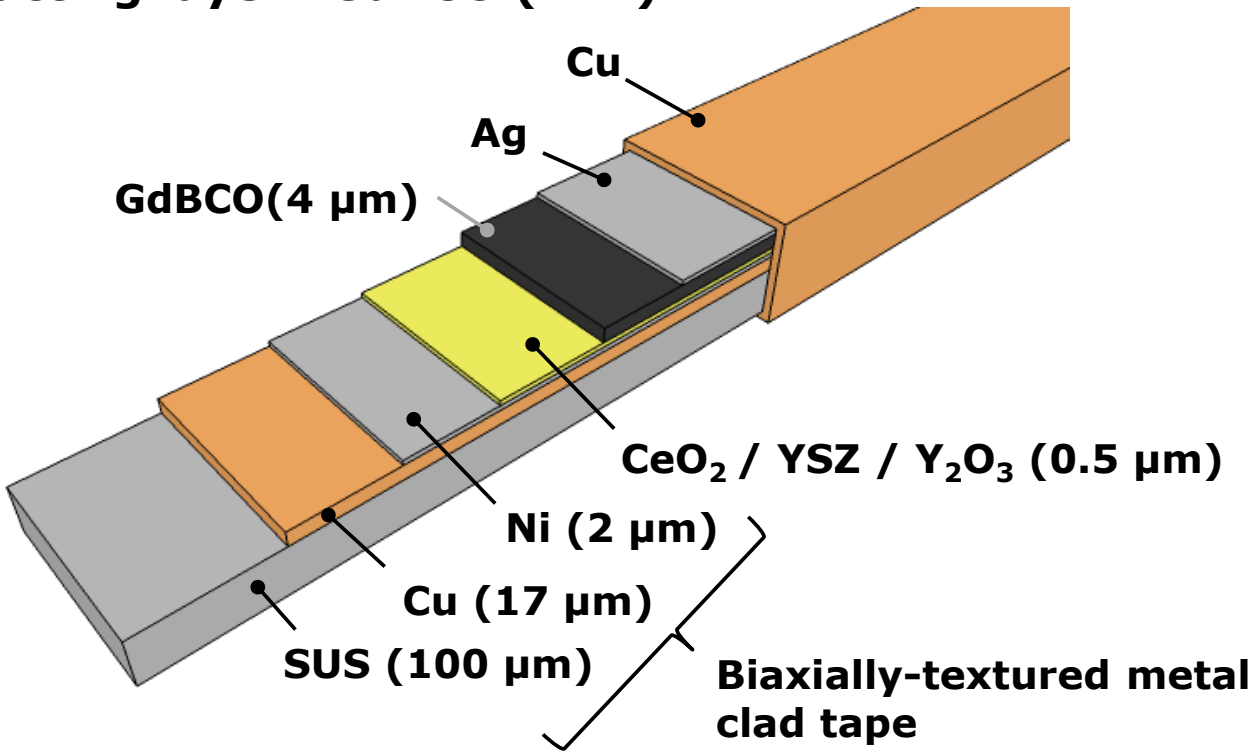
- **We developed a practical superconducting joint technique for CCs with a short process time.**

# Structure of REBCO coated conductor

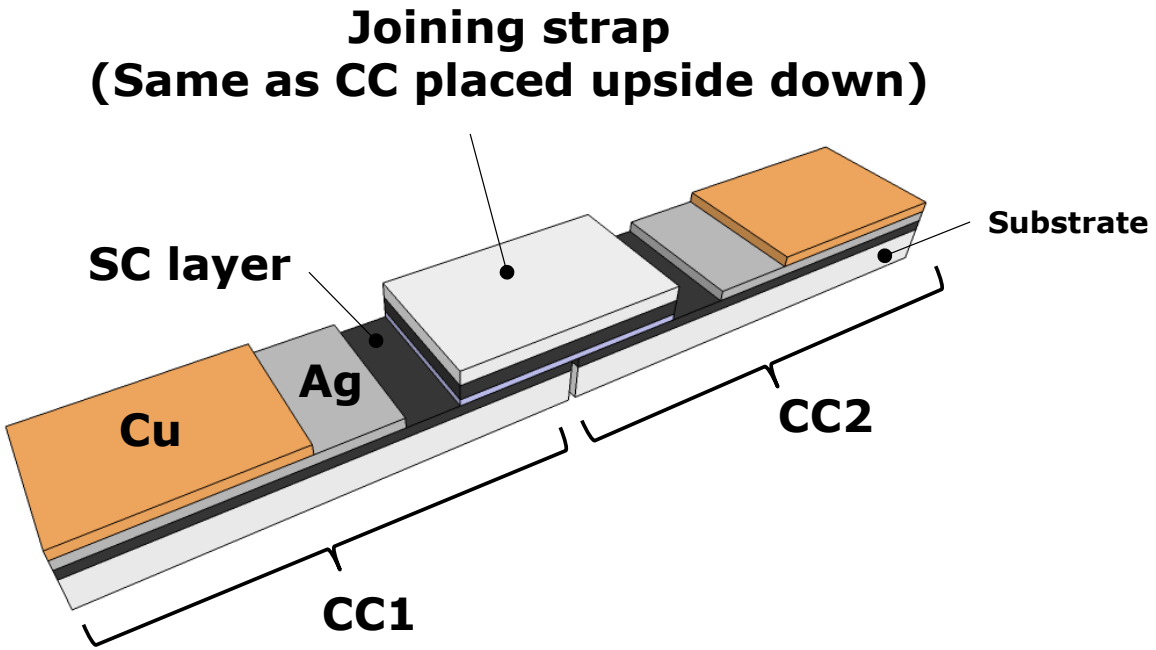
**Substrate : Biaxially-textured metal clad tape (Ni / Cu / SUS)**

**Buffer layer: $CeO_2$ / YSZ / $Y_2O_3$**

**Superconducting layer : GdBCO (PLD)**

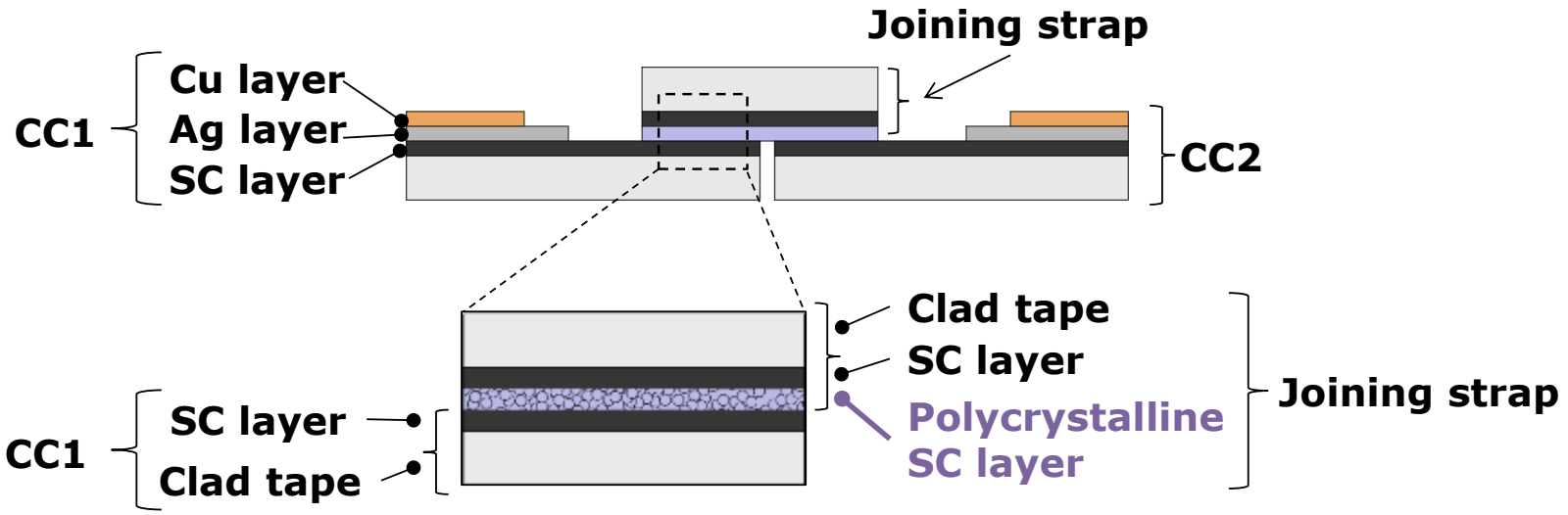


# Configuration of a joint



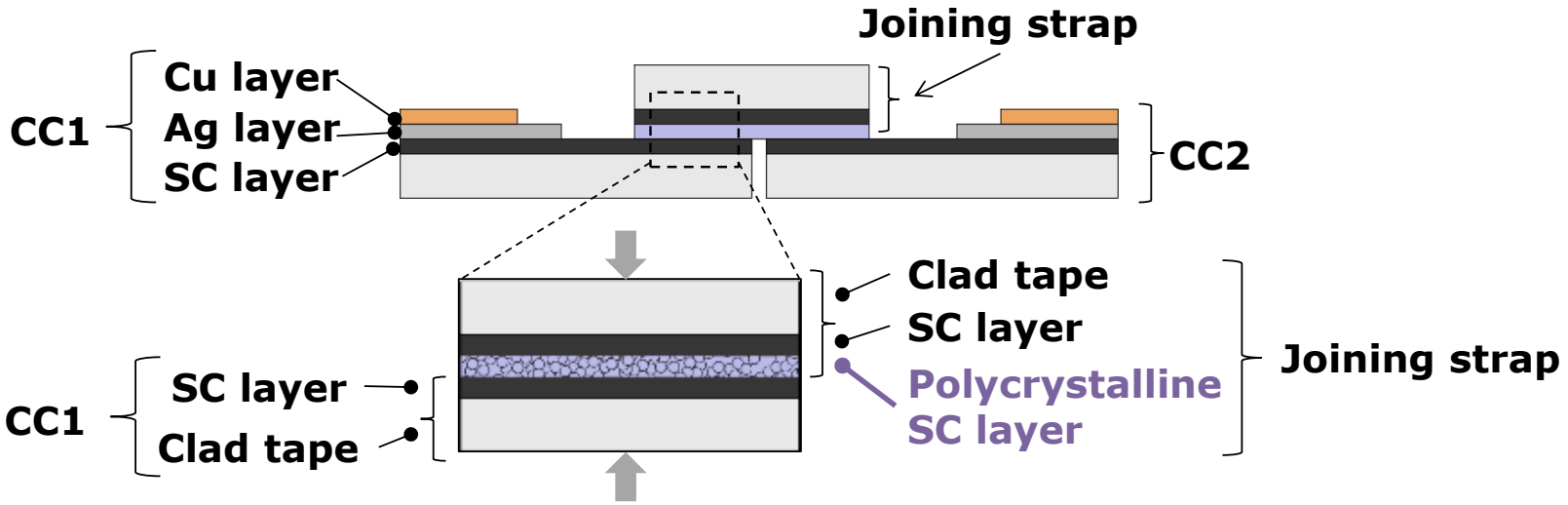
# How to make a joint

**The main point of our joining technique is the polycrystalline SC layer.**



# How to make a joint

1. **The joining strap and the GdBCO CCs are pressed together.**
2. **Heat treatment at 800 °C in an atmosphere of <u>100 ppm oxygen</u> -> The polycrystalline GdBCO layer is grown epitaxially.**
3. **Oxidation annealing in an oxygen flow at 500 °C for <u>6 h</u>**



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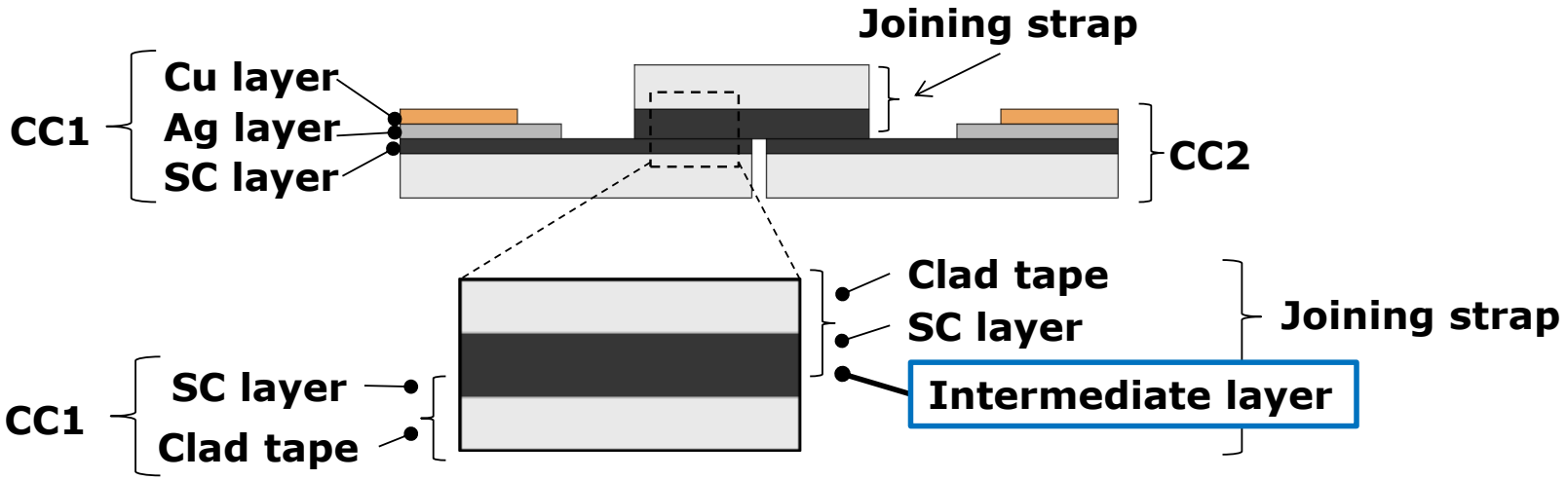
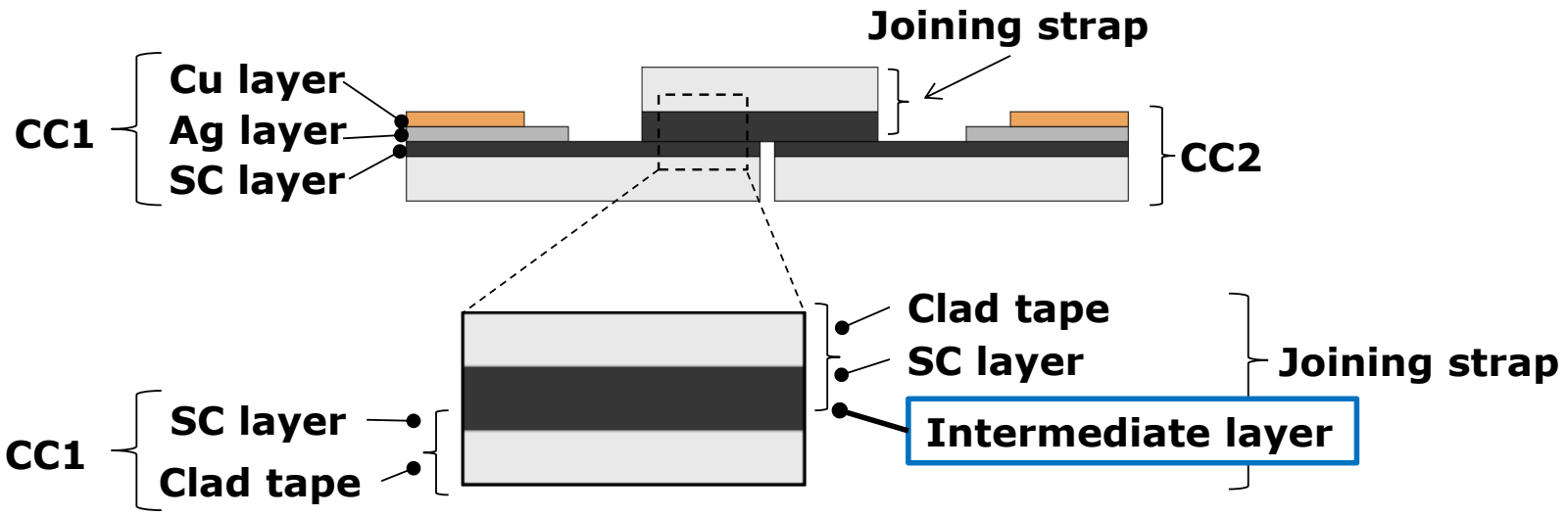


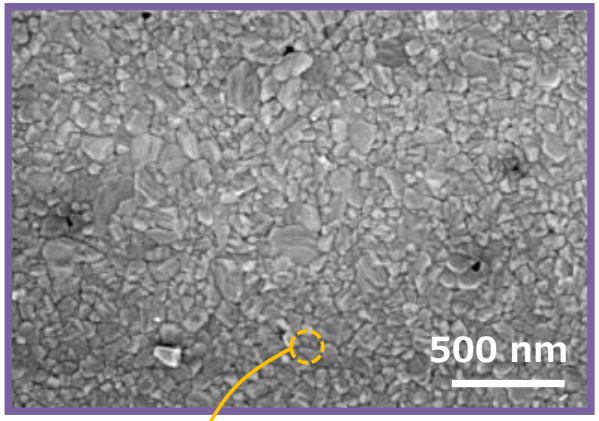
# iGS joint

**iGS (intermediate Grown Superconducting) joint**

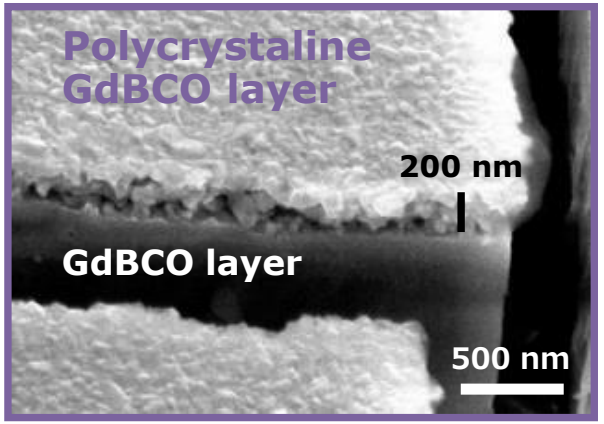


# Polycrystalline GdBCO layer


**SEM image**




**Cross-sectional SEM image**




**The grain-size of the polycrystalline is in the range of 20 nm to 200 nm**

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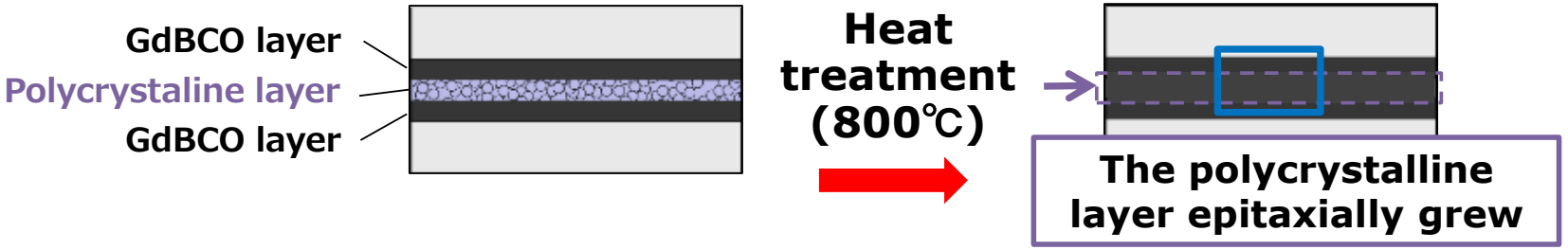
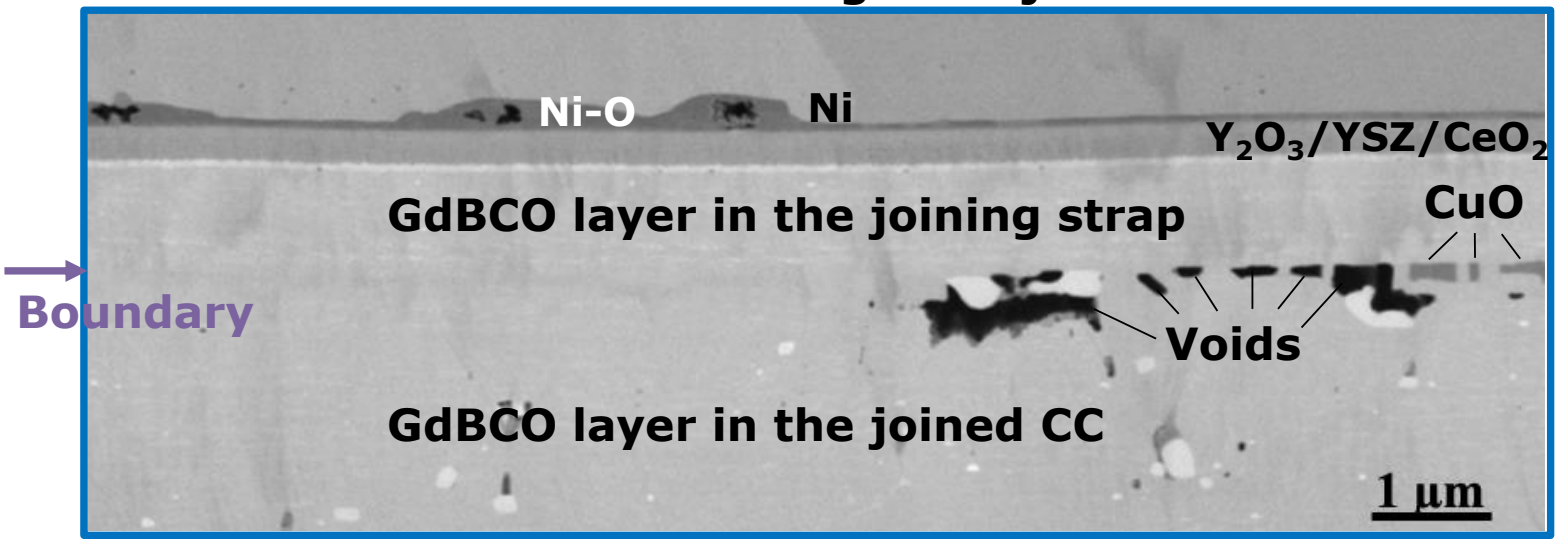
   - **A reproducibility of the iGS joint technique**
   - **Persistent current measurement**
4. Summary and future plans

# Cross-sectional SEM image of a joined interface

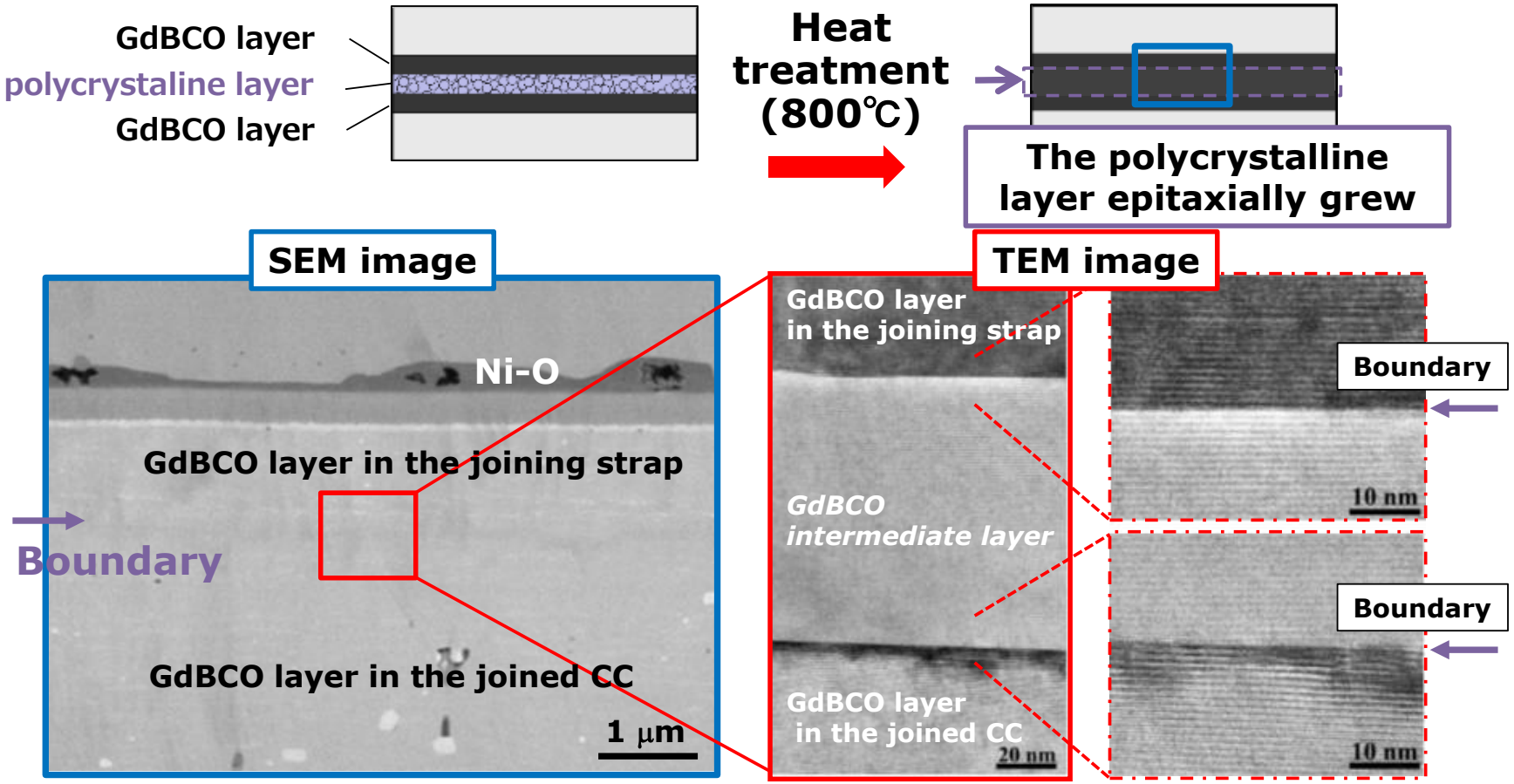



## Cross-sectional SEM image of a joined interface




- There were voids and CuO inclusions at the boundary.
- GdBCO layers were directly joined.

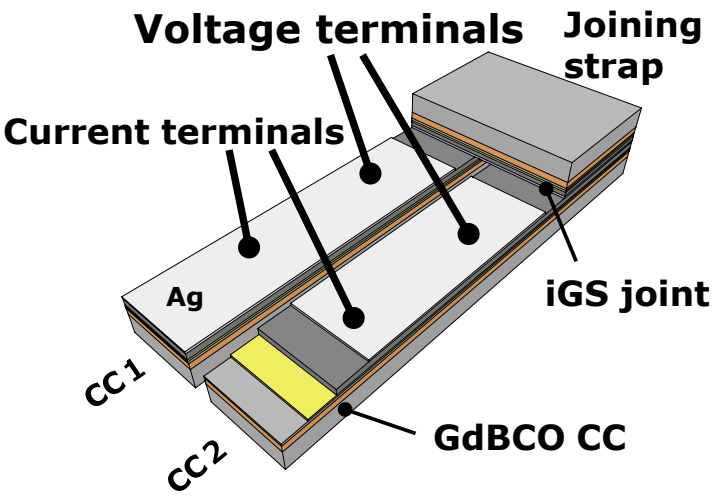
# Cross-sectional TEM image of a joint region

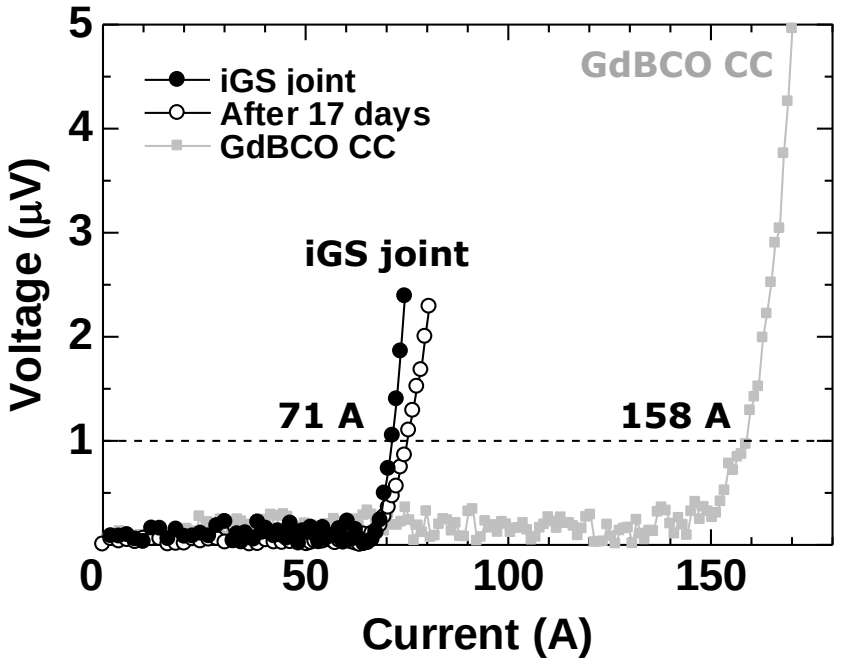



- **The polycrystalline layer epitaxially grew.**
- **The GdBCO layers were atomically joined.**

# *V-I* characteristics of a iGS joint

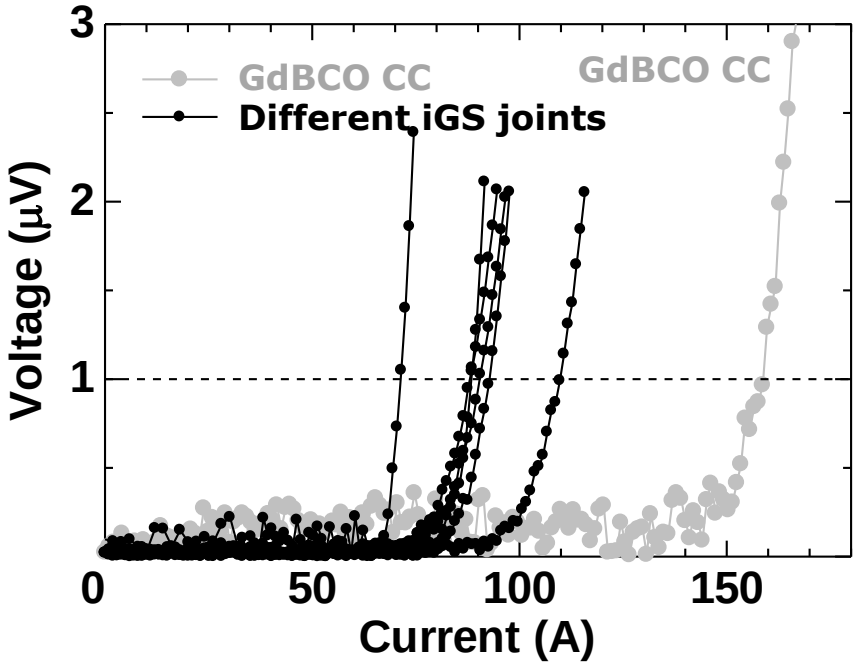
- **Joint $I_c$ = 71 A (GdBCO CC $I_c$ = 158 A )**
- **After 17 days from first measurement, no significant degradation was observed.**



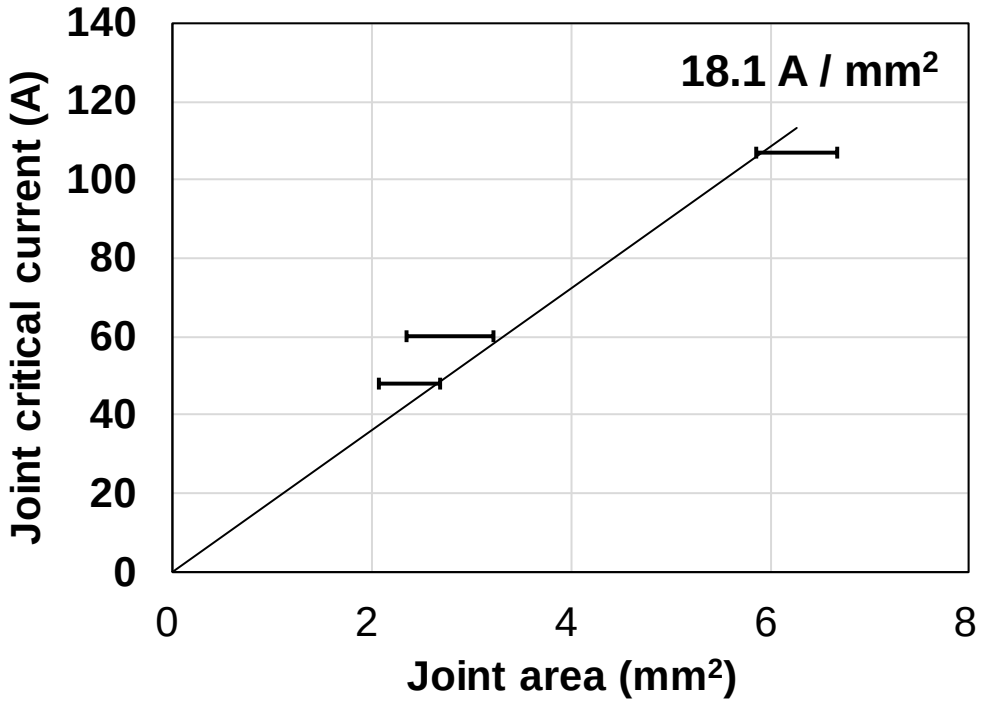
# The reproducibility of the iGS joint technique

- **In order to confirm the reproducibility of the iGS joint technique, 6 joint samples were prepared.**
- **The $I_c$ of these samples were between the range of 70 to 110 A.**
- **The iGS joint technique has reproducibility.**



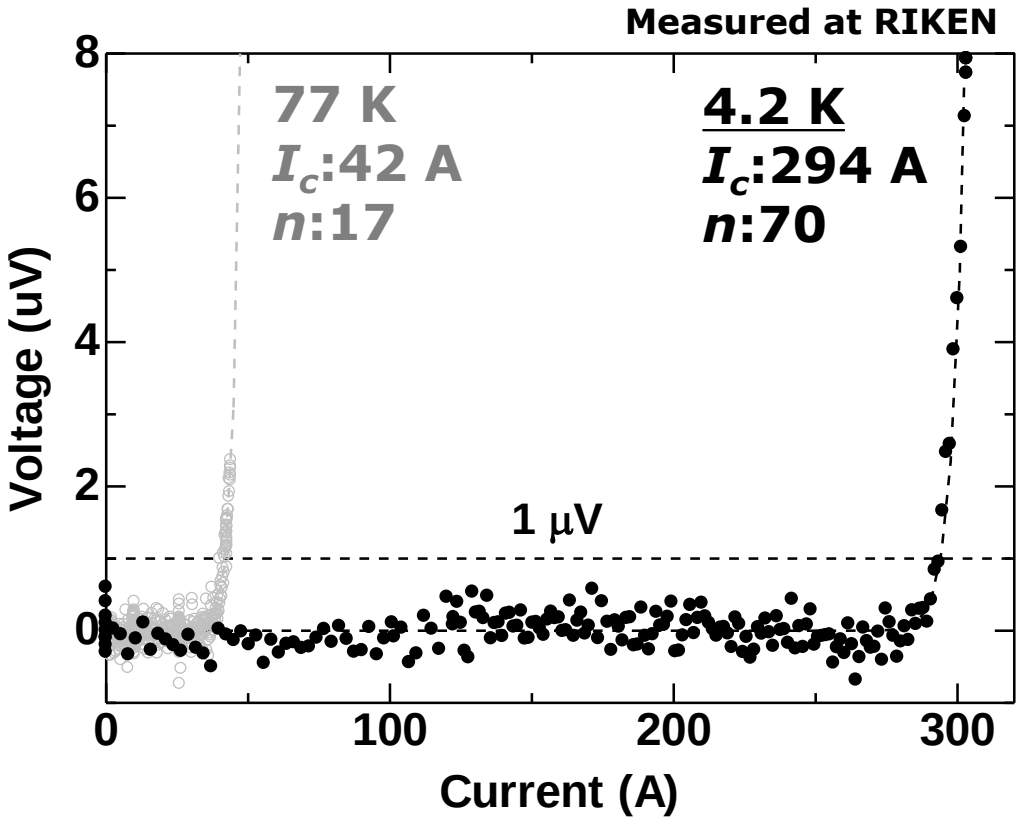
# Joint area dependence of joint $I_c$

- **The joint $I_c$ was increased with the joint area.**
  **→ Our joint is a "superconducting" joint.**



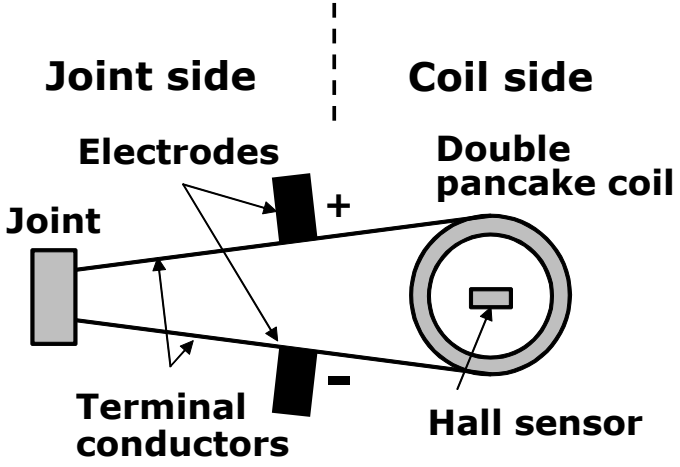
# *V-I* characteristics at 4.2 K in self-fields

- **The joint $I_c$ which was 42 A at 77 K increased to 294 A at 4.2 K**

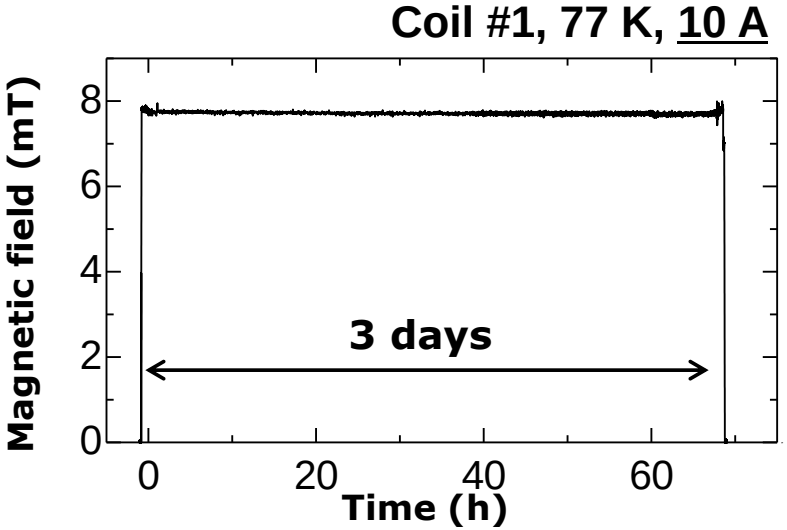


# Persistent current mode operation

**Measured at RIKEN**



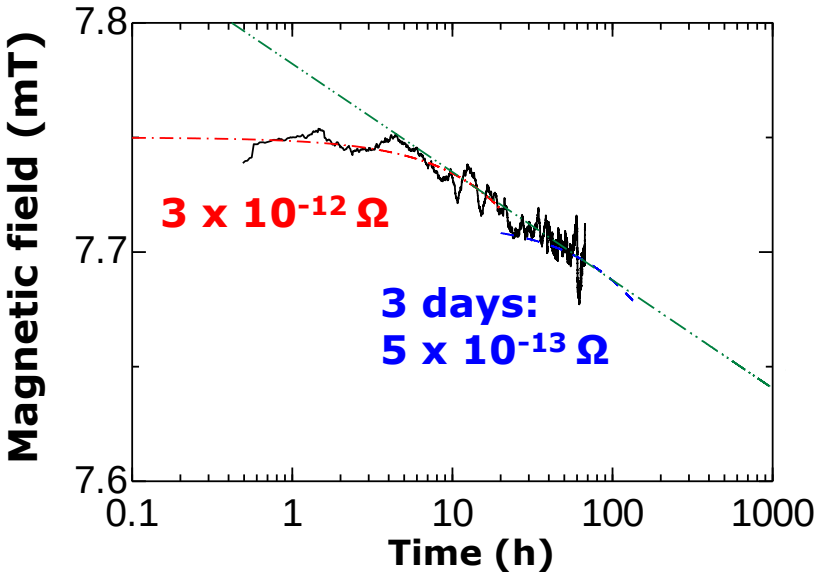

| Parameters of the coil | |
|---|---|
| Inner diameter | 40 mm |
| Number of turns | 30 (15 x 2) |
| Coil $I_c$ at 77 K | 77 A |
| Joint $I_c$ at 77 K | 140 A |



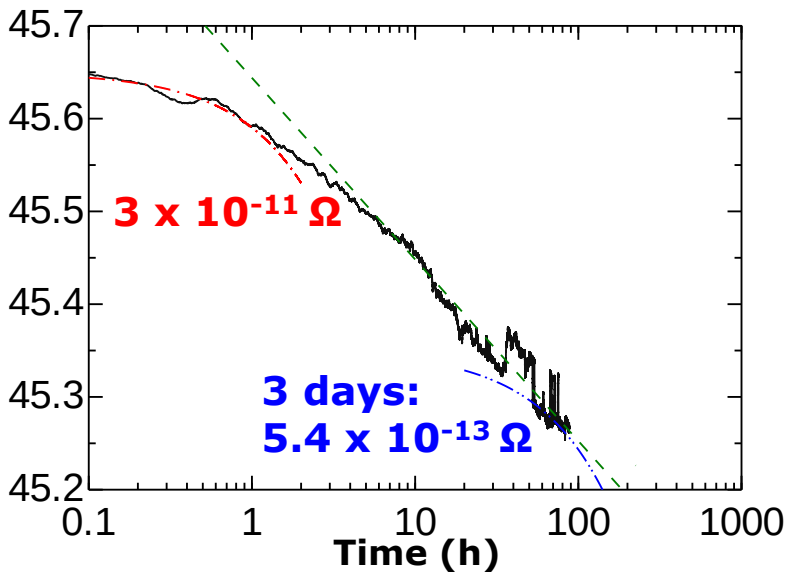
# Persistent current measurement

**Measured at RIKEN**

## Coil #1, 77 K, 10 A




## Coil #2, 77 K, 45 A




- **The joint resistance: <3x10$^{-11}$ Ω - <5x10$^{-13}$ Ω**

# Summary and future plans

## ■ Summary

- **iGS joints using the intermediate growth technique achieved a reproducible joint $I_c$ of more than 70A.**
- **Processing time of the iGS joint is less than one day.**
- **Microscopic observation showed GdBCO layers were atomically joined.**
- **Joint resistance measured by the persistent current method at 77 K is in the order of $10^{-11}$ - $10^{-13}$ Ω.**

## ■ Future plans

- **Development of the persistent current 400 MHz (9.39 T) LTS/REBCO NMR with iGS joints is underway.**