Nb_3Sn and Cryocooler R&D

Tomohiro Yamada, CASA, KEK

Supported by

Kotaro Takahashi, Taro Konomi, Kensei Umemori, Hayato Ito, Hiroshi Sakai, Eiji Kako, Ramnarong Wanison, and more

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Towards conduction cooled SC accelerator

- Liquid helium based SC accelerator is sophisticated.

  Very uniform cooling, High electrical efficiency, etc…

  However, using liquid helium is sometimes a big obstacle for small application in company and university levels.

  A lot of helium, High pressure code, Very complex cryomodule, Liquefier's operator, etc…

- Conduction cooled SC accelerator will be a game changer. For this, we are developing following two topics in KEK:

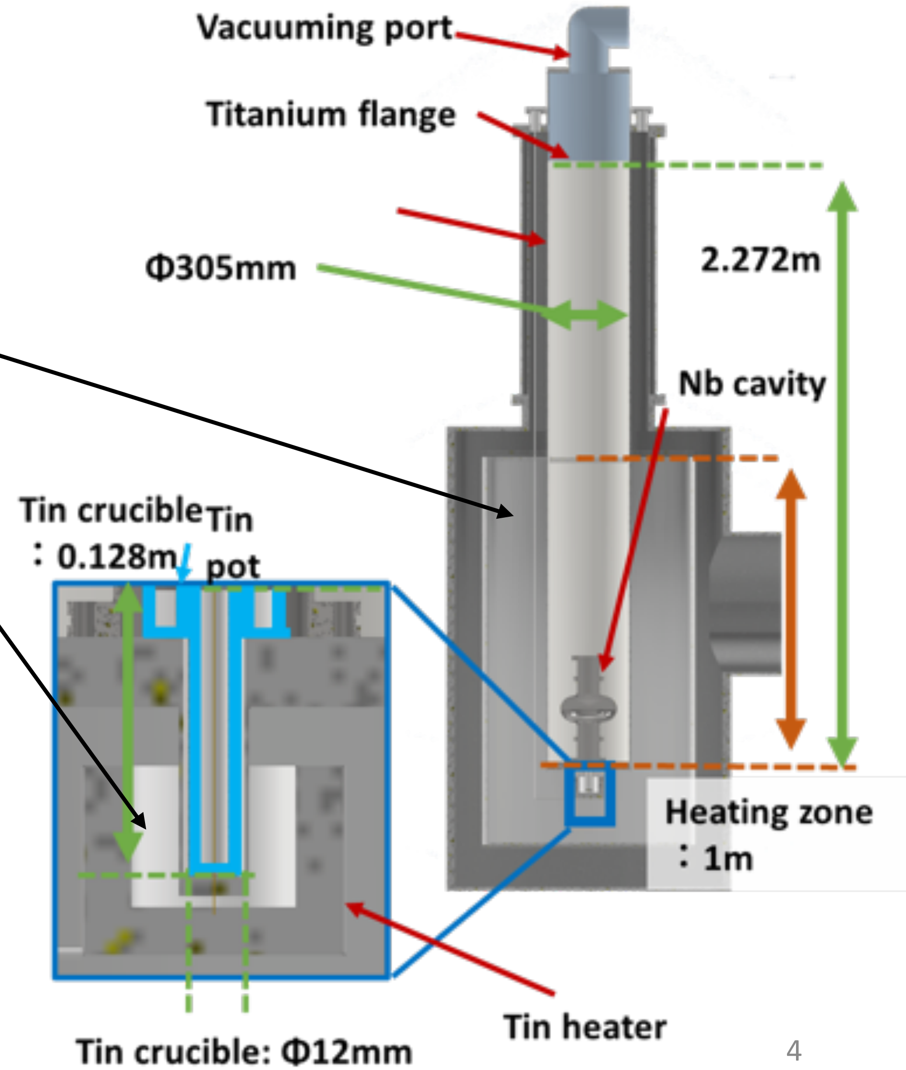
  - High quality Nb_3Sn cavity by vapor diffusion method,

  - Conduction cooling of the cavity using a mechanical cryocooler.

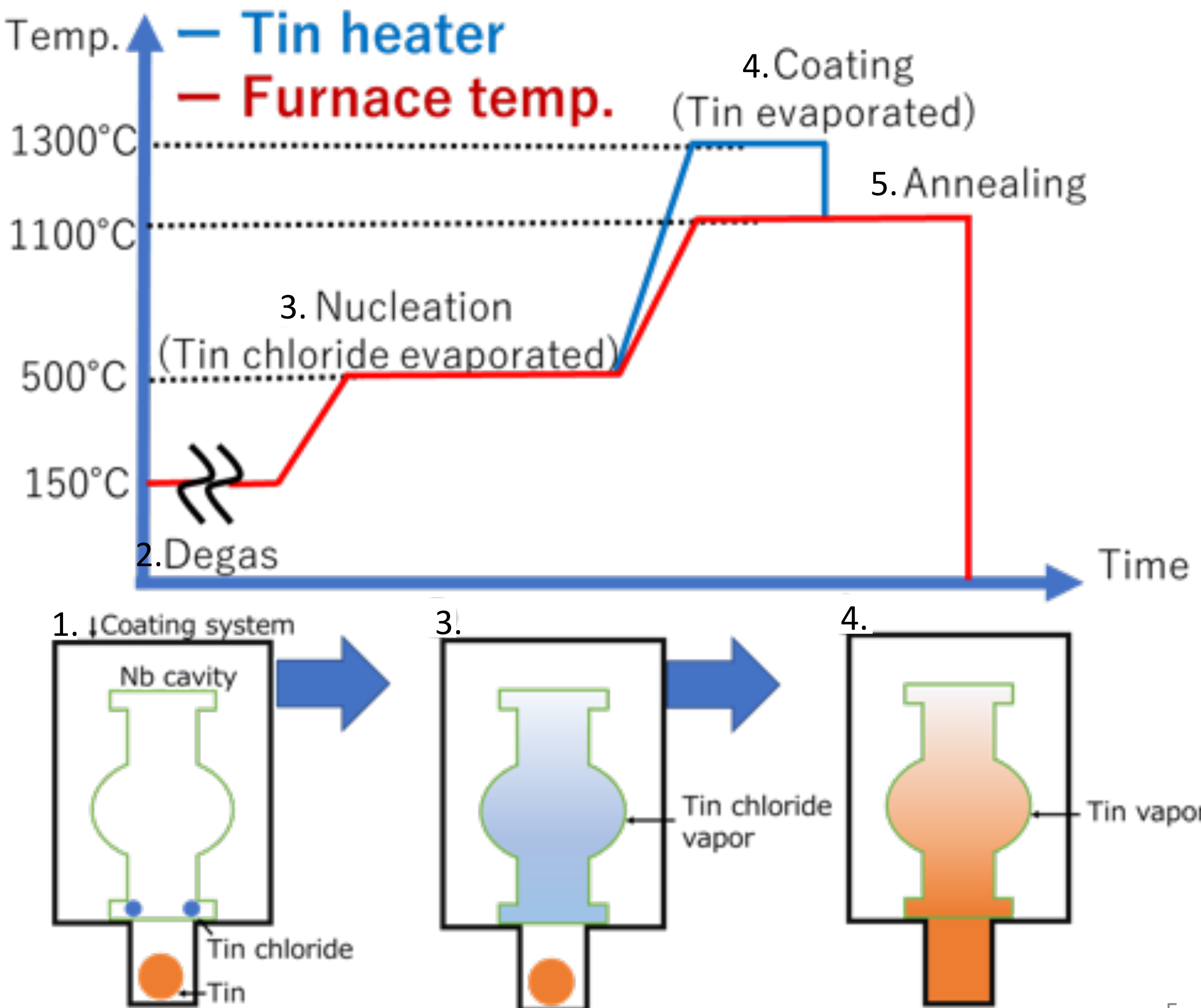
Nb_3Sn cavity R&D

Nb_3Sn coating system by vapor diffusion method

- Independent two vacuum systems
  - Inner chamber: mostly Nb body
  - Outer chamber: furnace
- Heaters
  - Furnace: Max 1200°C
  - Tin heater: Max 1500°C

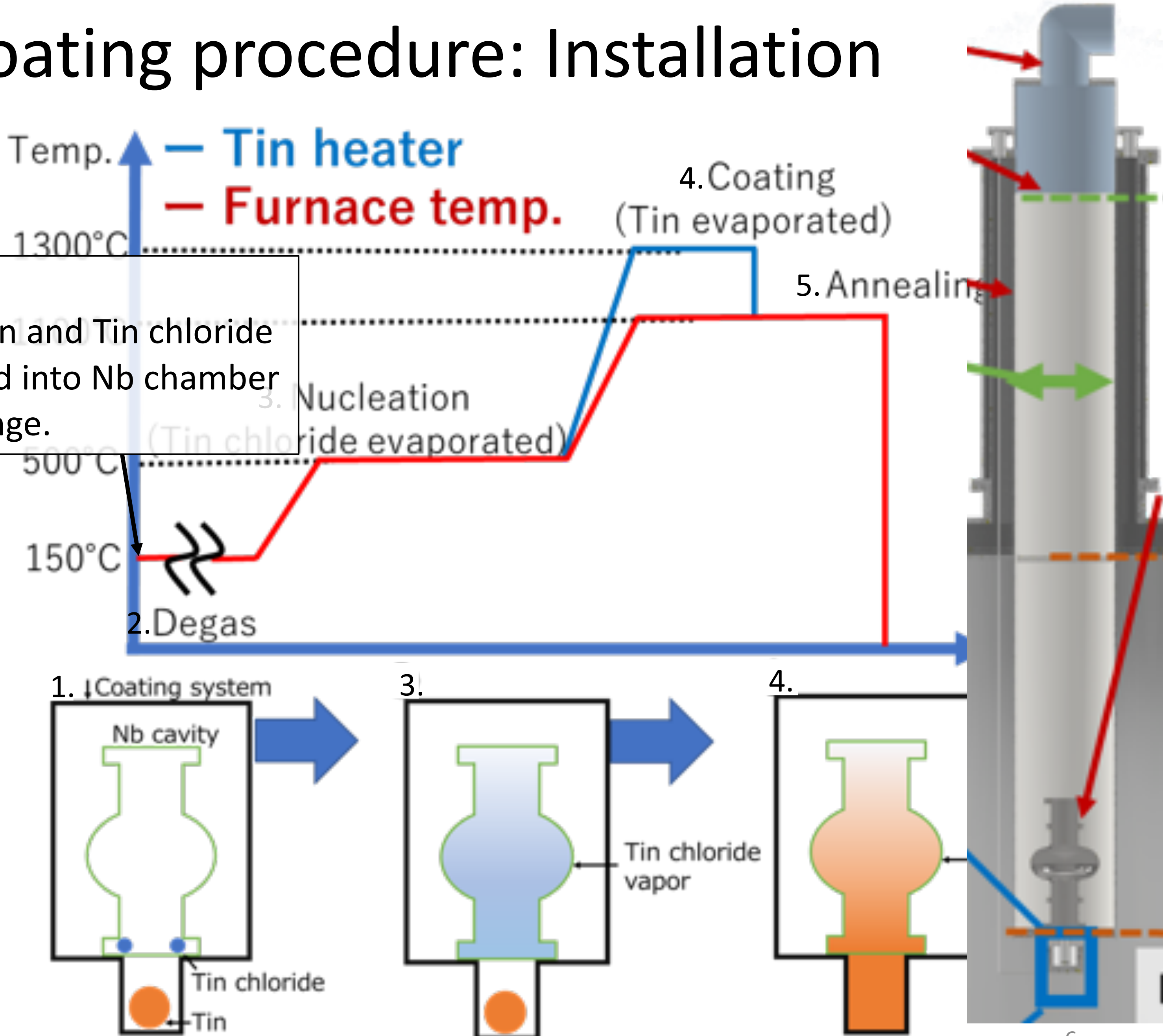


Nb_3Sn coating procedure



Nb_3Sn coating procedure: Installation

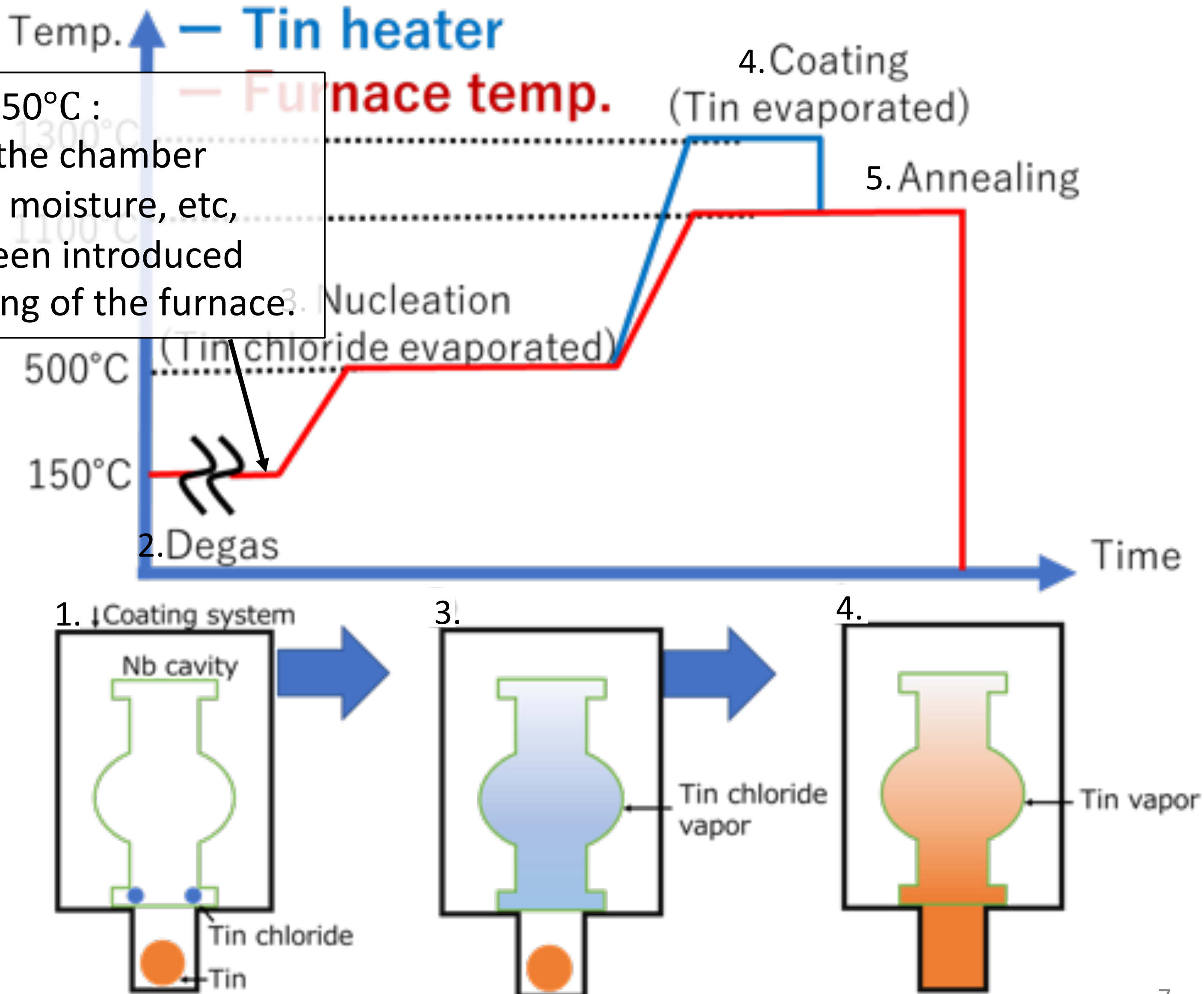
1. Installation:
Nb cavity with Tin and Tin chloride ($SnCl_2$) is inserted into Nb chamber from the top flange.



Nb_3Sn coating procedure: Degassing

2. Degassing at 150°C :
Inner surface of the chamber releases residual moisture, etc, that may have been introduced during the opening of the furnace.

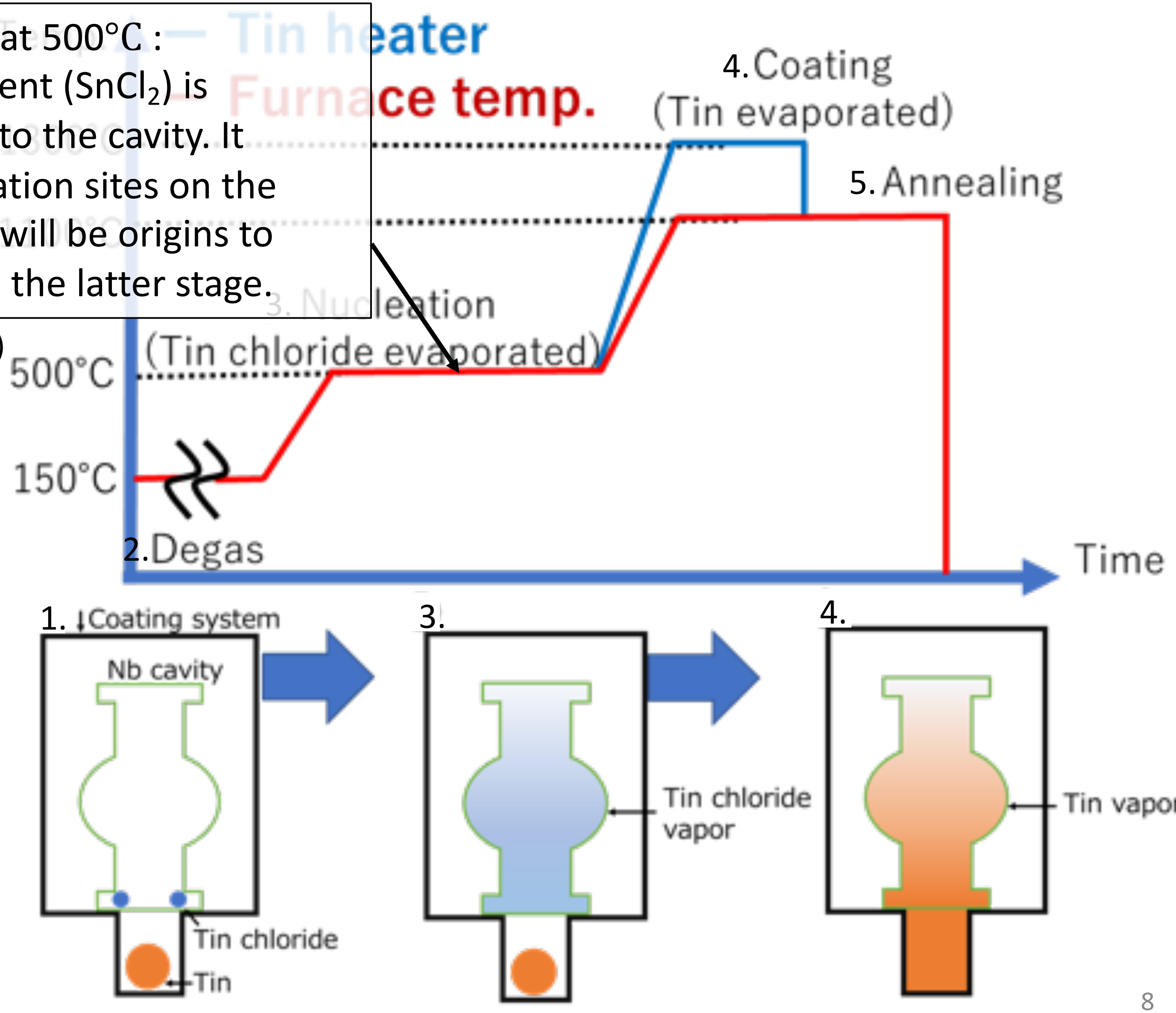
S.Posen *et al.* (2017)



Nb_3Sn coating procedure: Nucleation

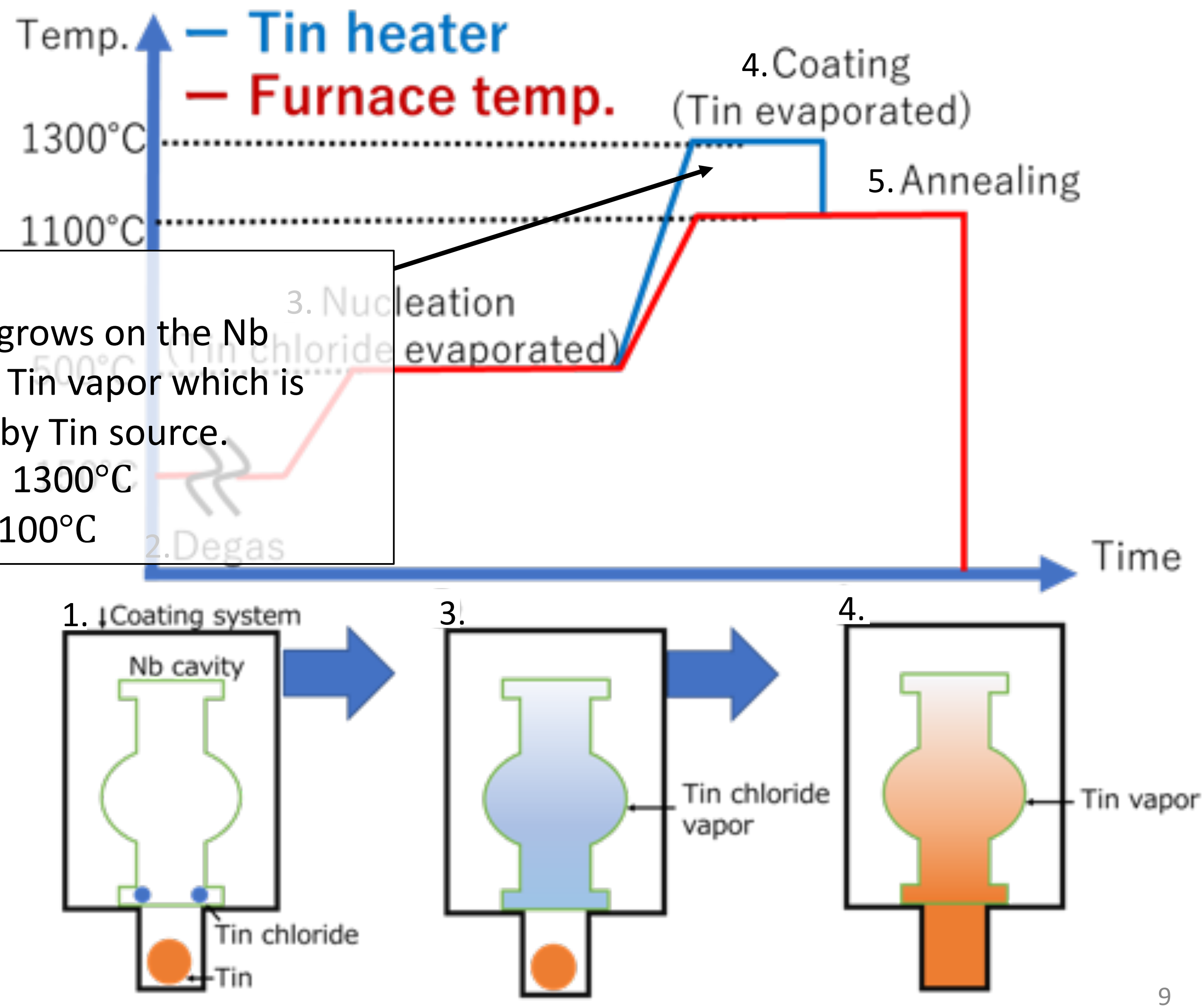
3. Nucleation at 500°C : Nucleation agent ($SnCl_2$) is evaporated into the cavity. It creates nucleation sites on the surface. They will be origins to form Nb_3Sn in the latter stage.

S.Posen *et al.* (2017)



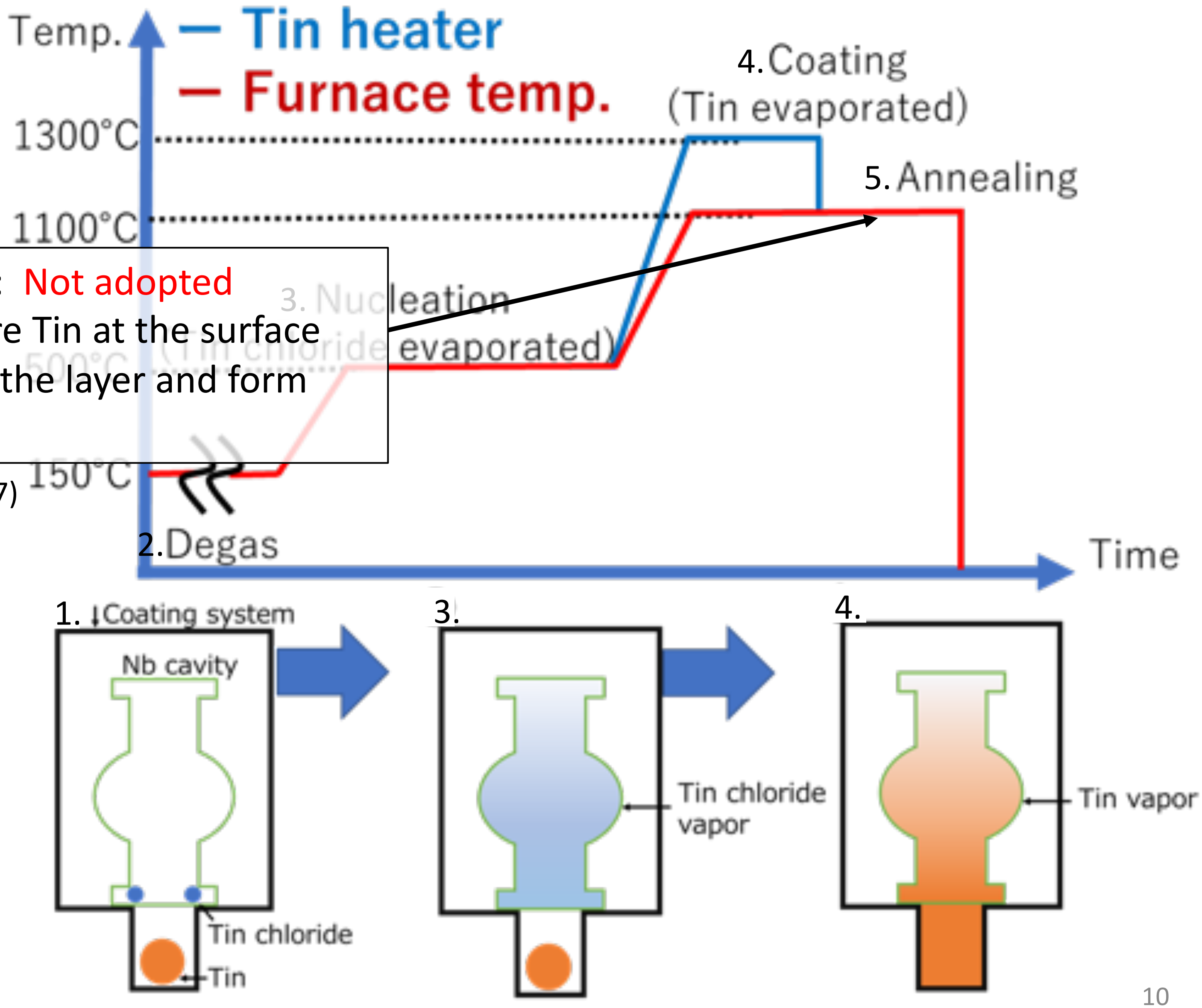
Nb_3Sn coating procedure: Coating

4. Coating:
Nb_3Sn layer grows on the Nb surface with Tin vapor which is replenished by Tin source.
Tin heater: 1300°C
Furnace: 1100°C



Nb_3Sn coating procedure: Annealing

5. Annealing: Not adopted
Excess of pure Tin at the surface diffuses into the layer and form Nb_3Sn.



S.Posen *et al.* (2017)

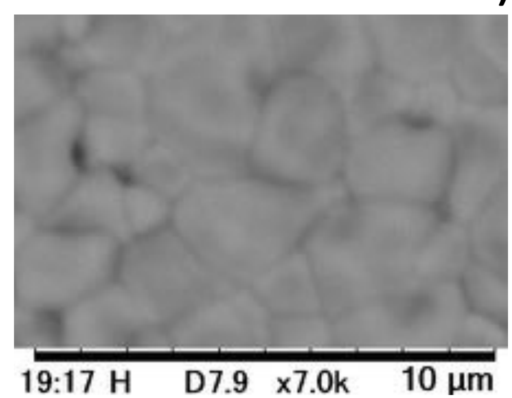
Inspection after coating

- Visual inspection

Before coating: Metallic luster was seen.

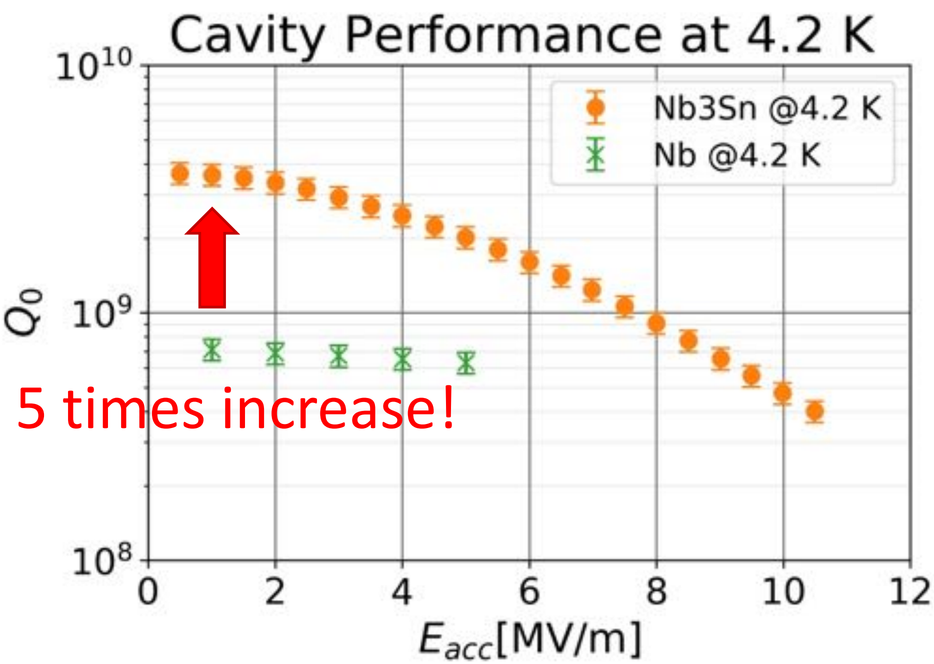
After coating: Metallic luster is lost. All of the inner surface is covered by Nb_3Sn layer.

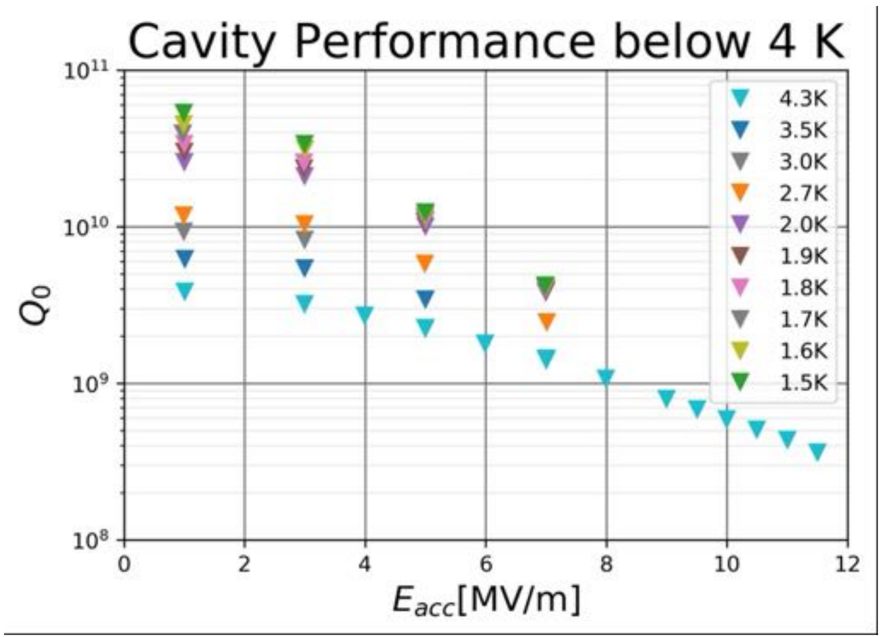
- Sample inspection (Samples are coated at the same time.)
  - Grain size: 1~3 um
  - Thickness: 1.7±0.4 um
  - Atomic Sn content: 23.1±0.4 %



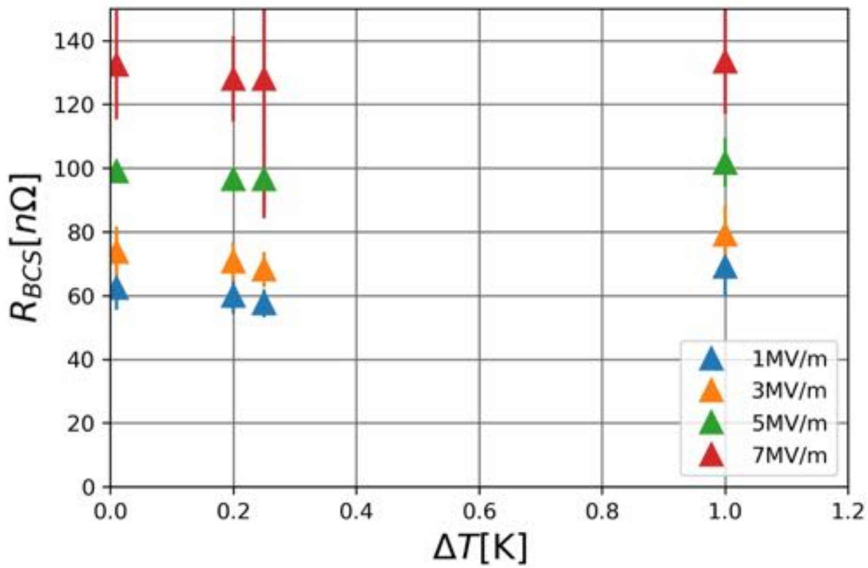
Vertical test results

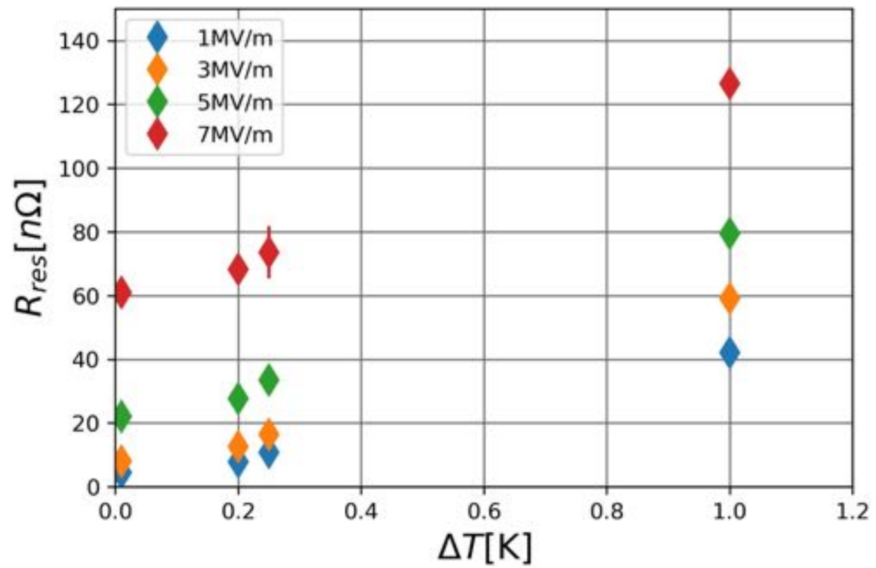
- $Q_0 = 4x10^9$ at 1MV/m
- $Eacc_{Max}$ = 11 MV/m





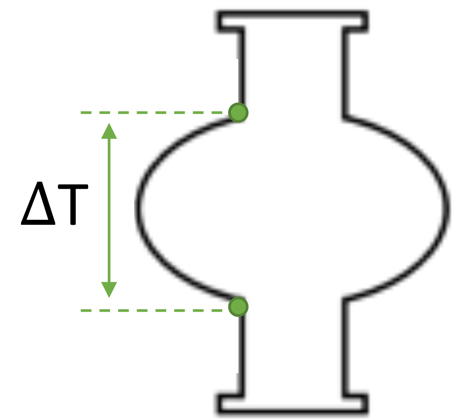
SC transition with temperature gradient





R_{BCS}

- Independent with respect to ΔT
- 60~130 nΩ ← Excess Sn? Contamination?



R_{res}

- Increase as ΔT increases
- 5~60 nΩ

↖ Trapping magnetic flux created by thermo-current??

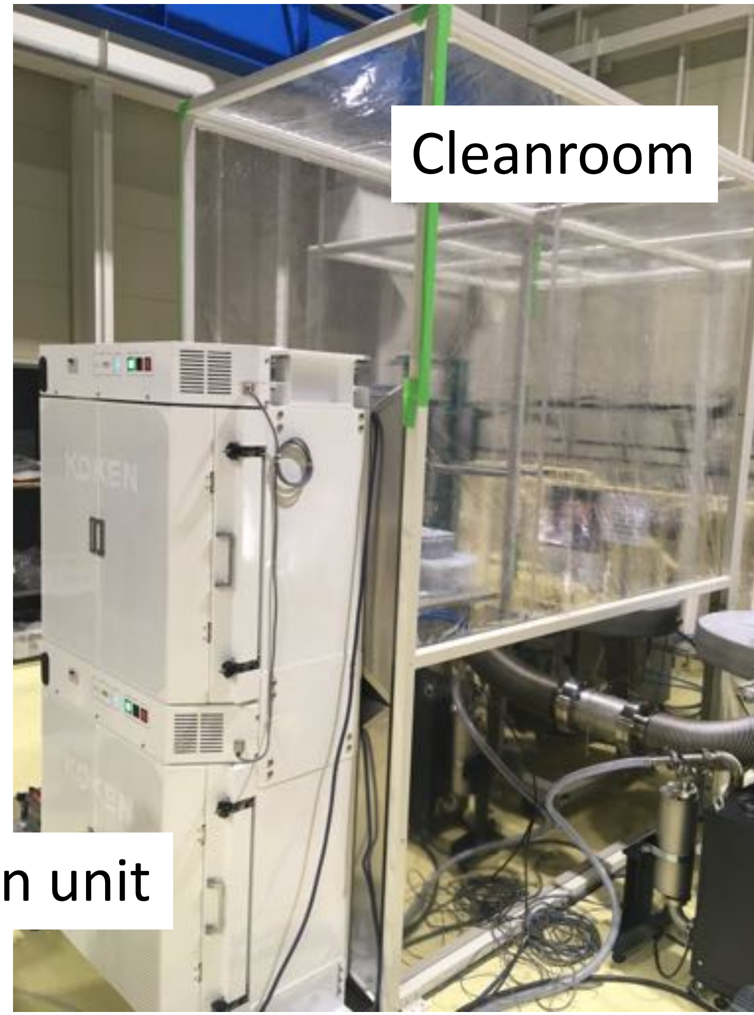
Summary and future works

- Target: High quality Nb3Sn with $Q_0 = 1 \times 10^{10}$ at 4.2 K

  ⟷ <u>4×10^9 at 4.2K</u>

- For the target:

  - Cleanroom
  - Coating parameter search
    > Nucleation time/temperature
    > Coating time/(temperature)
    > Amount of Sn and $SnCl_2$
    > etc...
  - Better diffusion technique



Cryocooler R&D

Conduction cooling of the SRF cavity

- Designing a cryostat

  Towards a cryomodule in near future, conduction cooling study for the cavity has been just started.

- Many challenges

  - Where to cool?
  - How to make contact between the cavity and the thermal conductor?
  - Cooling scheme/order?
  - How much vibration of the cryo-cooler affects cavity performance?
  - etc…

Besides this preparation, two cryogenic experiments were carried out with SHI mechanical cryocooler.

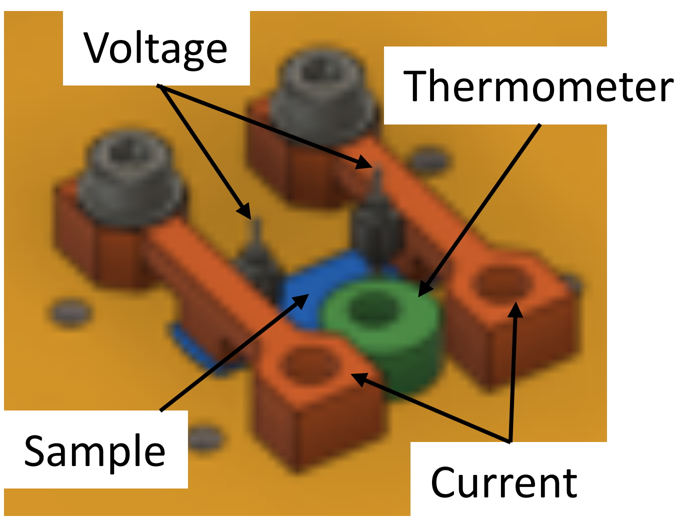
Tc measurement of Nb and Nb_3Sn

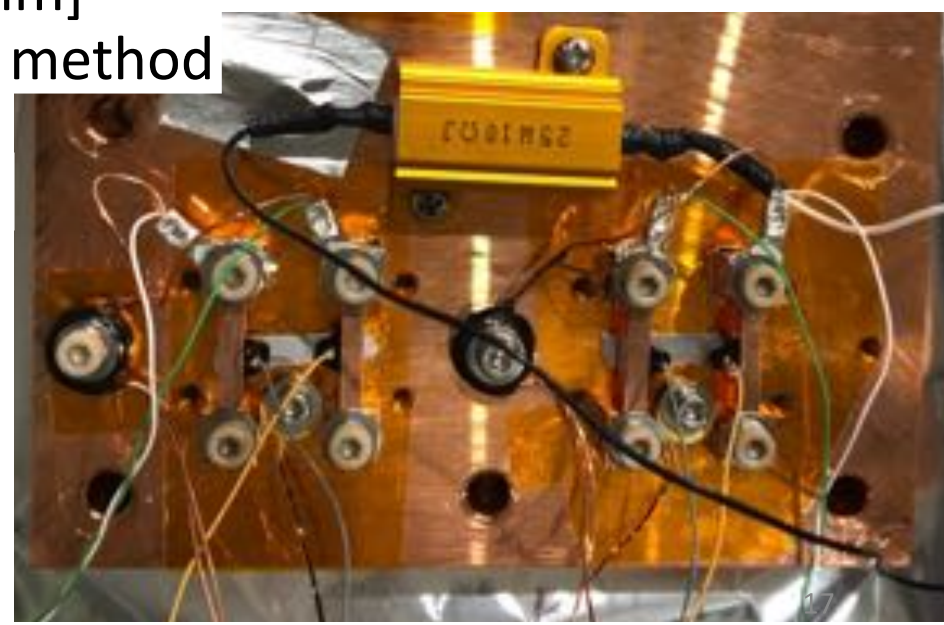
- Background

  Coupon cavity is an appropriate option to study a position dependence of the coating inside the cavity. Critical temperature (Tc) is one of the good references to know coating quality.

- Setup

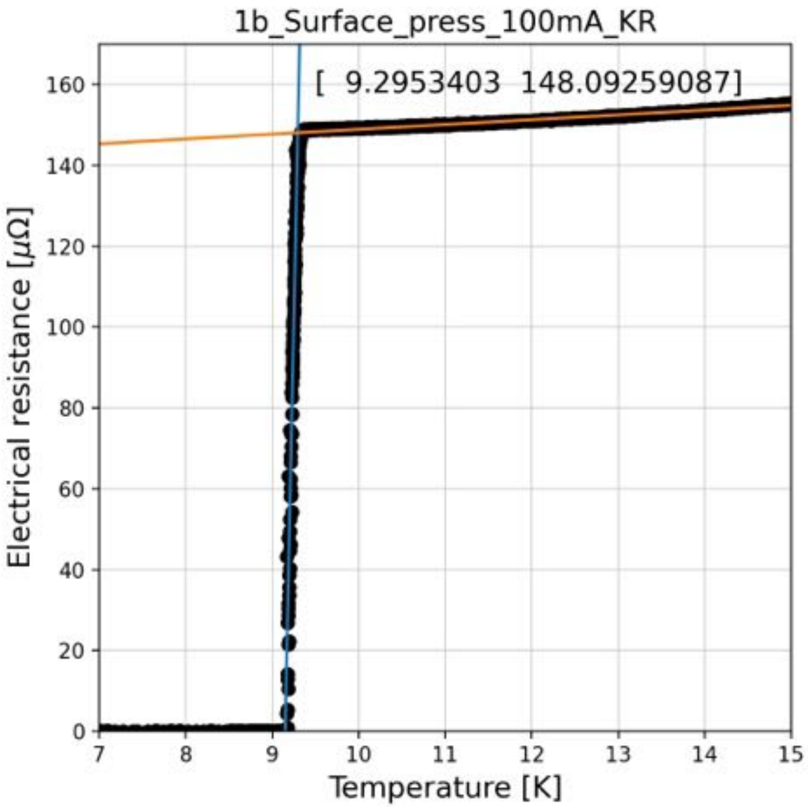
  Sample size: w6 x L20 x t0.1 [mm]
  Method: 4-wire measurement method



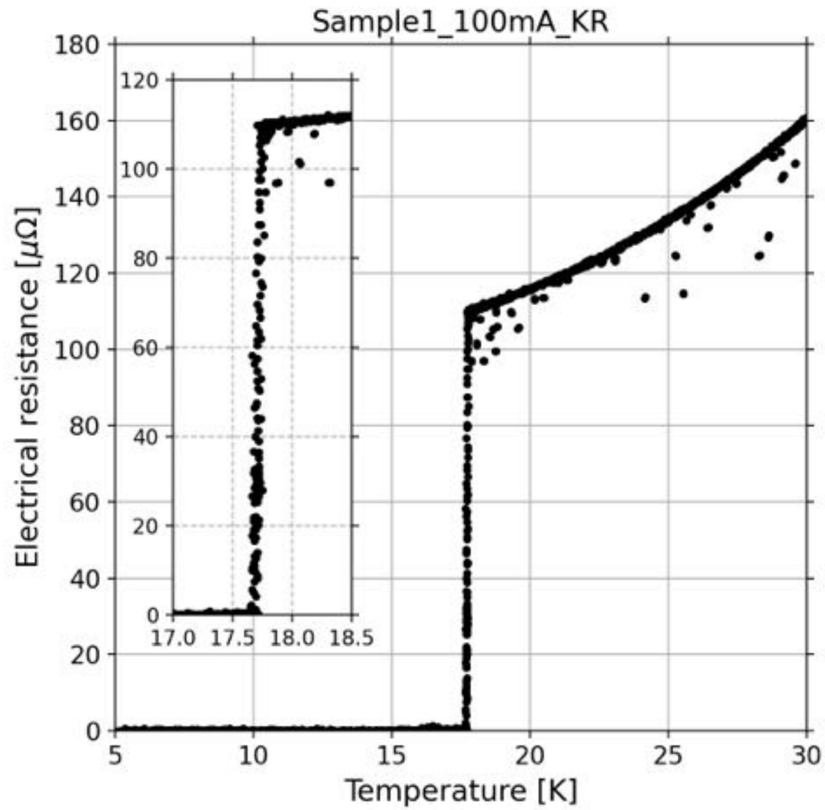


Tc measurement results

Nb: 9.3 K (Tokyodenkai)



Nb_3Sn: 17.7 K (Coated by us)



Measurement jigs and system have worked fine. Tc of 7 samples from 7 places in the coupon cavity will be quickly measured. These data will be immediately fed back to the coating parameters. This work accelerates Nb_3Sn coating study.

Searching for cheap temperature sensors

- Background

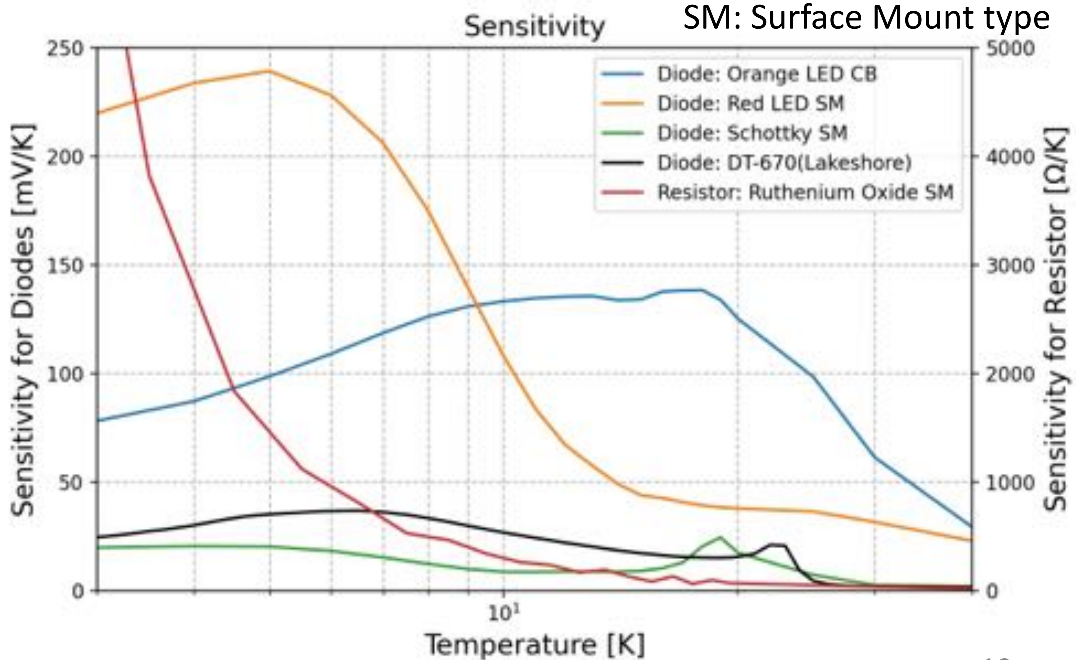
The Allen Bradley carbon resistor has been traditionally used as a cheap temperature sensor for Nb cavity temperature mapping because it is sensitive at very low temperature. Nb3Sn has Tc at 18 K, therefore, traditional carbon resistor is not a suitable option and new cheap temperature sensors were studied.

- Results

Several diodes and resistors were tested. Sensitivities were comparable or better than commercial DT-670.

Further tests are still needed.

CB: Cannon ball type
SM: Surface Mount type



Summary and future works

- Test cryostat

  Many tests for conduction cooled cavity will be started.

- Tc measurement

  Setup and system worked fine. Thanks to this system, feeding back time to the coating quality will be compressed.

- Cheap temperature sensor

  Several candidates were found. Long-term stability, repeatability, and reproducibility will be checked.

Overall summary

Nb_3Sn cavity R&D

- Firstly coated Nb_3Sn cavity showed:
  Q_0 = 4x10^9 at 1MV/m, $Eacc_{Max}$ = 11 MV/m.
  Rres might be increased by trapping magnetic flux created by thermo-current.
- Studies for better quality Nb_3Sn cavity is on-going.

Cryocooler R&D

- Many tests for conduction cooled cavity will be started with a newly designed cryostat.
- Tc measurement system has started working.
- Several candidates for the cheap temperature sensor were found. Long-term stability, repeatability, and reproducibility will be checked.