Nb_3Sn cavity R&D at IHEP

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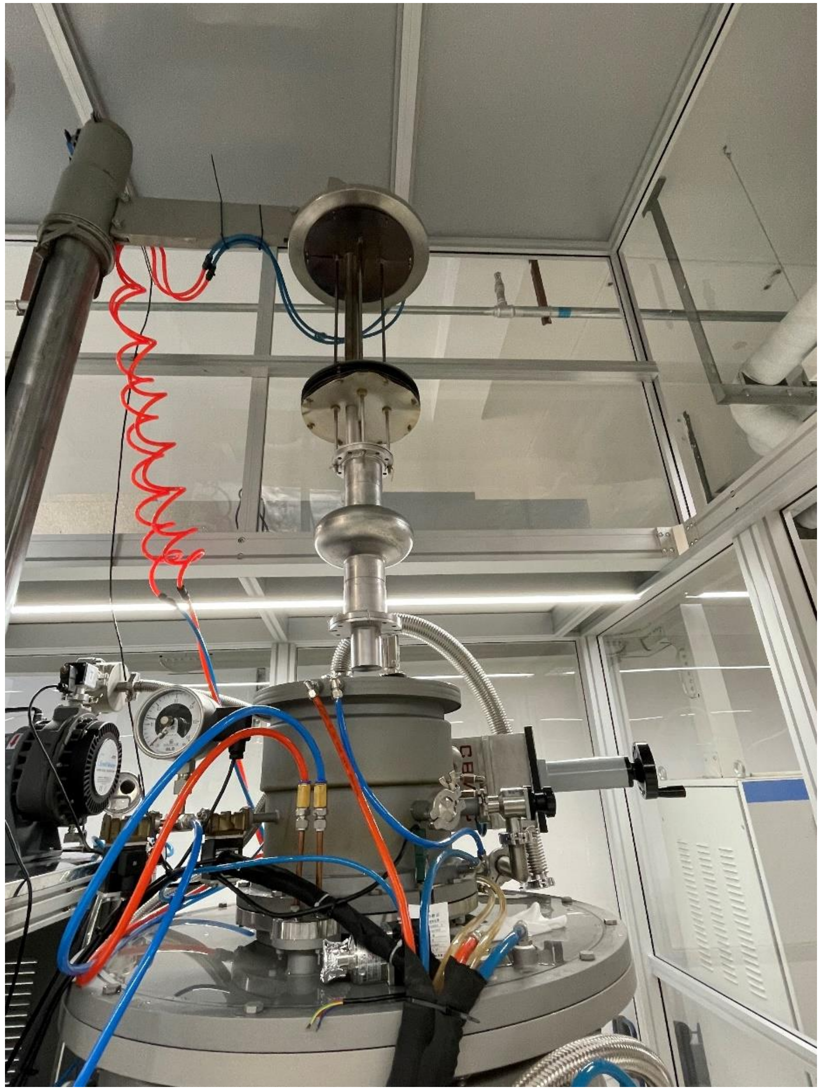
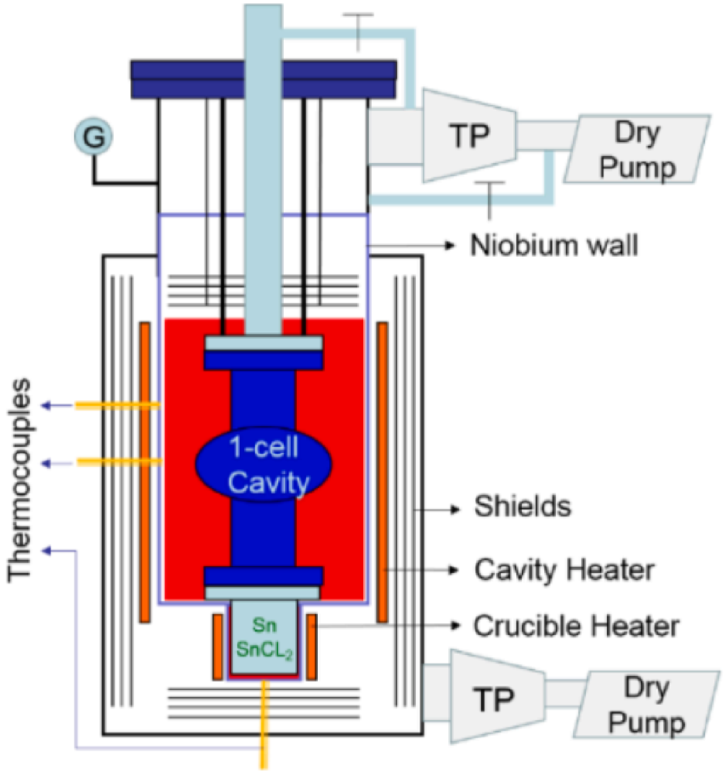
Furnace



Setup of the furnace



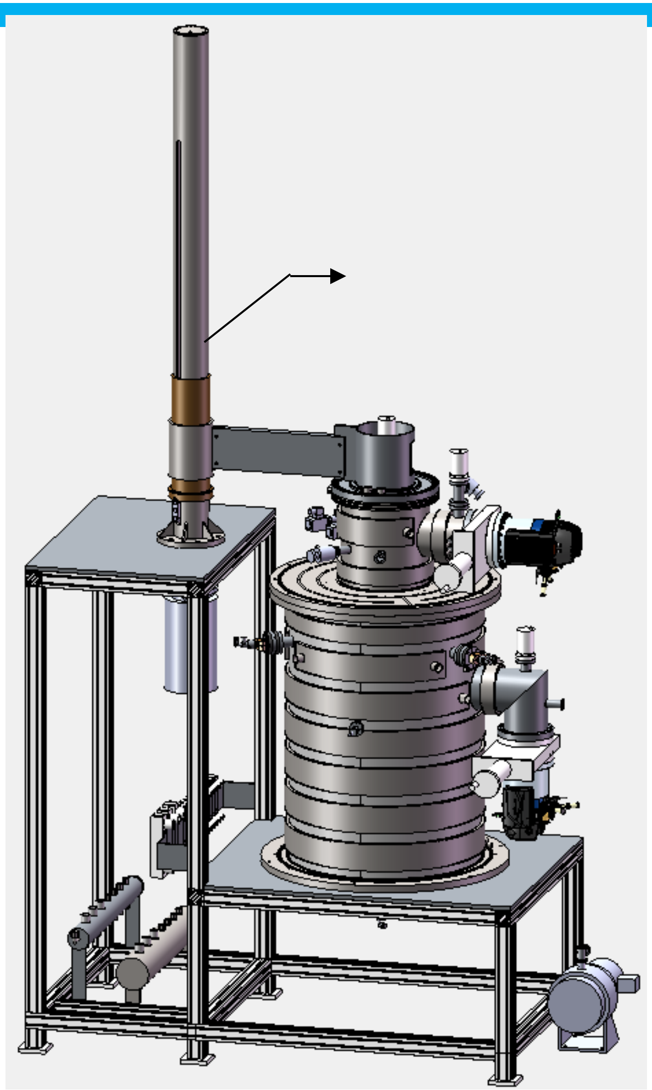
1. Type: vertical double vacuum furnace.

2.Effective Uniform Temperature Zone
The diameter is not less than 300mm, with a height of 500mm.

The inner wall material of the high-temperature zone furnace is niobium.

3. Vacuum System
Ultimate vacuum: ≤ 5.0×10^{-5} Pa (empty furnace, room temperature, fully degassed)
Working vacuum: ≤ 9.0×10^{-4} Pa (1300°C, empty furnace, fully degassed)

Vacuum pumps: oil-free molecular pump unit.
4. Temperature Control System
Maximum furnace temperature: 1200°C
Maximum crucible temperature: 1300°C
Temperature uniformity: Better than ±4°C



- *Physica C: Superconductivity and its applications* 600 (2022) 1354107

Calibration of the temperature

- The actual furnace temperatures are approximately 30C lower than the measured value
- The actual crucible temperature is 65-80C lower than the measured value.
- Hence, 1290C (1220C actual) was adopted by the crucible, 1130C (1100C actual) was adopted by the furnace.

Furnace (℃)			Crucible(℃)		
measured	actual	△T	measured	actual	△T
510	--	--	600	513.0	87
609	567.3	41.7	701	616.3	84.7
807	771.2	35.8	901	823.4	77.6
905	870.3	34.7	1001	924.1	76.9
1005	972.1	32.9	1100	1027.3	72.7
1104	1072.8	31.2	1201	1131.3	69.7
1202	1173.0	29	1300	1232.5	67.5
1203	1175.4	27.6	1320	1243.3	76.7

Typical procedure of coating

Degas: 150℃ 17h

↓

Nucleation temperature & time
Crucible/Furnace: 850C/540C 5h

↓

Ramp-up: ~1h

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Coating temperature & time
Crucible/Furnace: 1290℃/1130℃ 1-3h

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Annealing temperature & time
Crucible/Furnace: None

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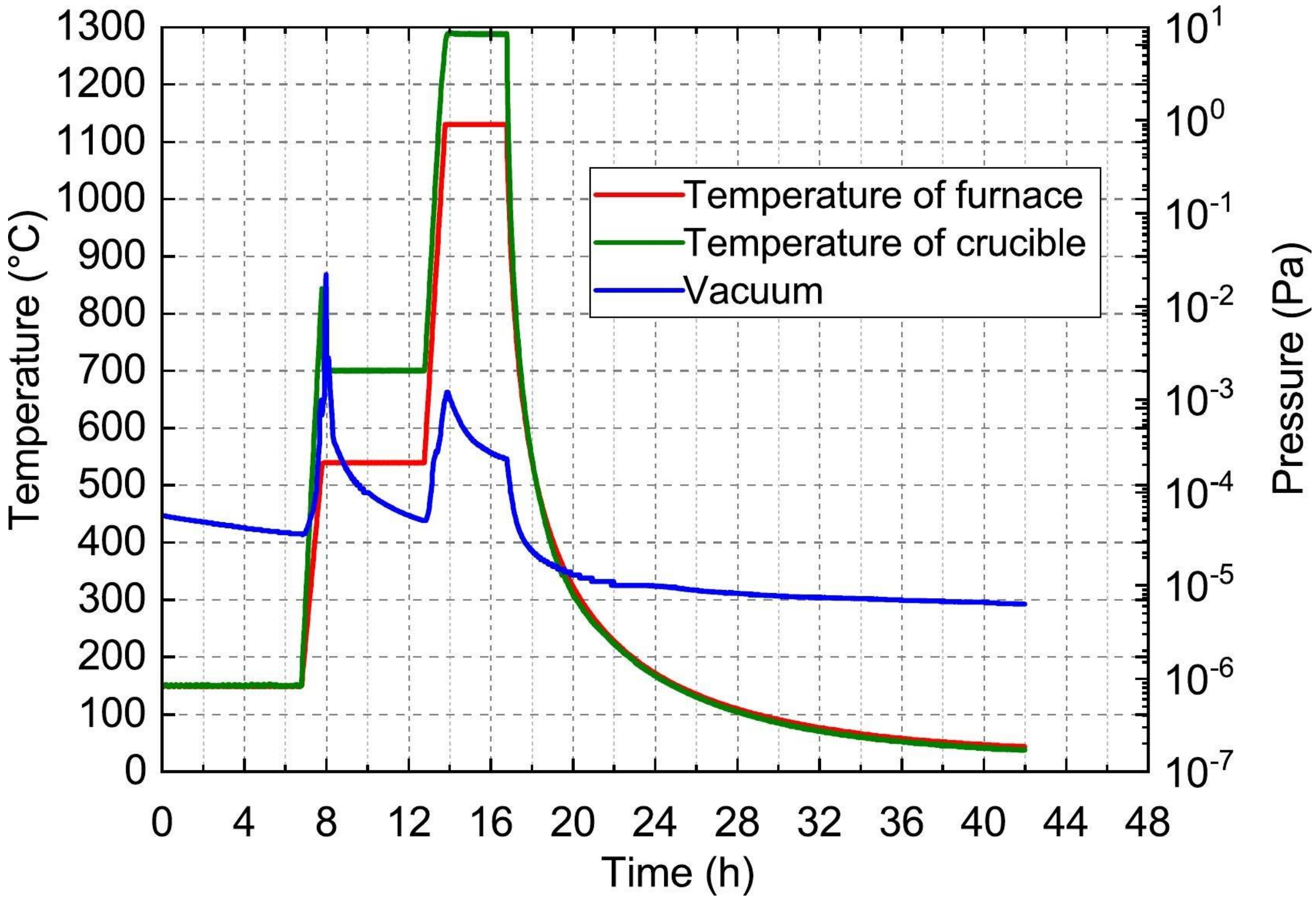
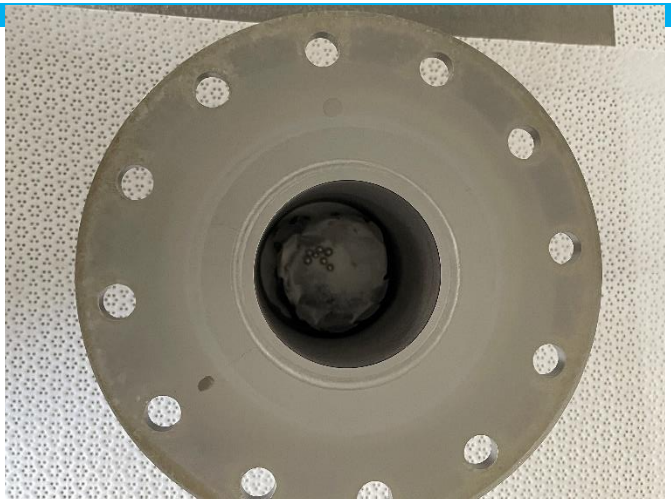
Ramp-down to 40C: ~25h

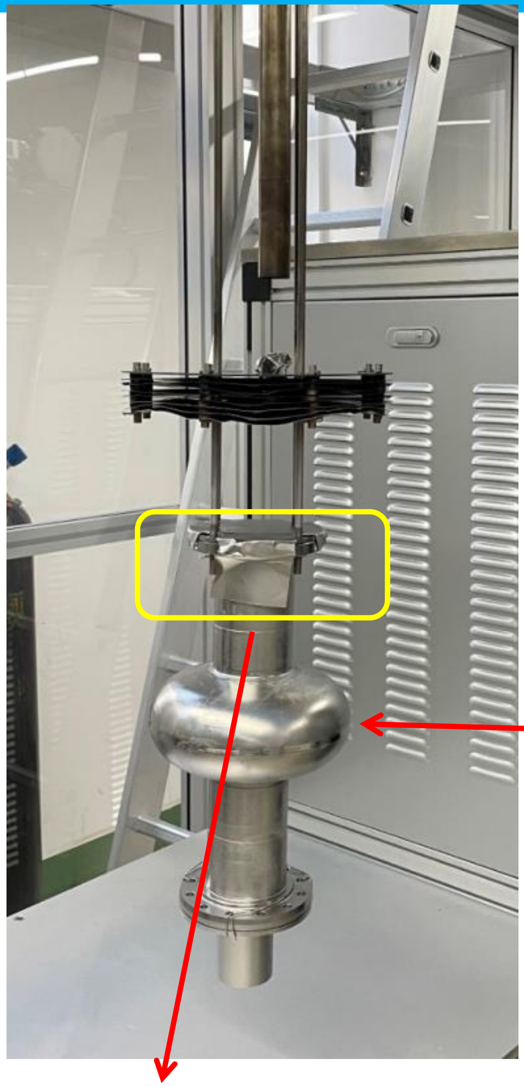


Typical procedure of coating



The Sn and $SnCl_2$ in the crucible

The niobium crucible with a lid on top

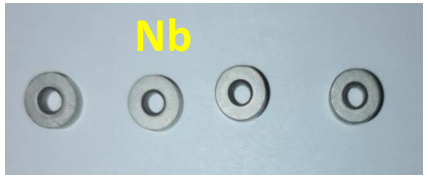


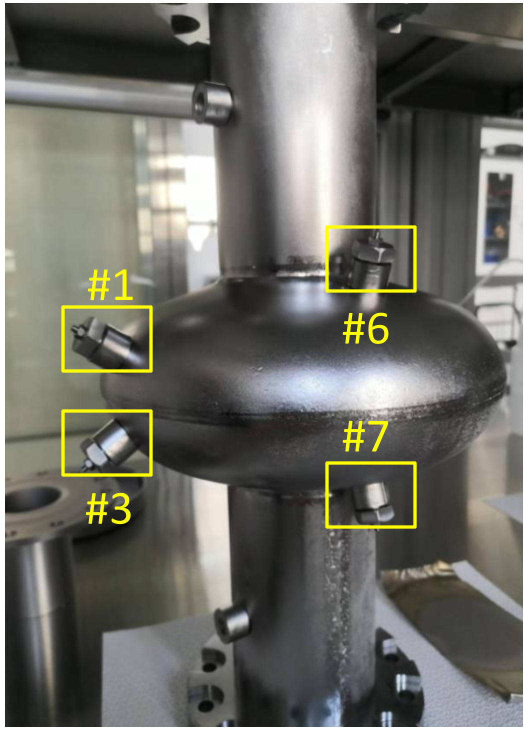
The top flange of the cavity was covered with niobium foil.

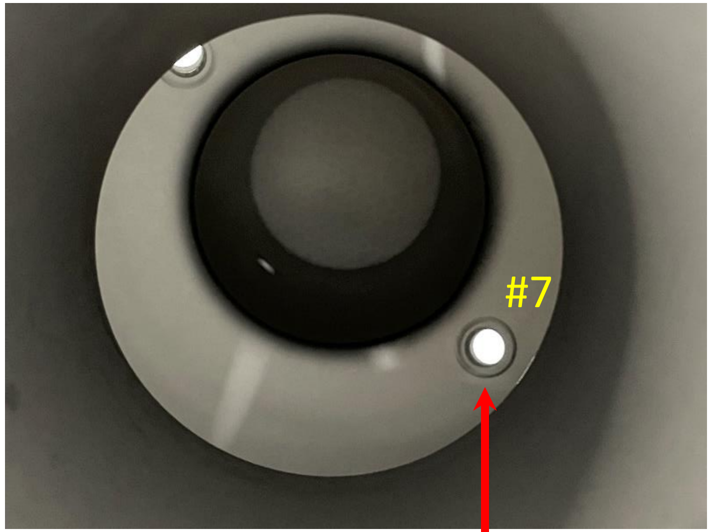
The second Sn source was put in the middle of the cavity.

Sample cavity

- A sample cavity made of Nb was used for the coating experiments.







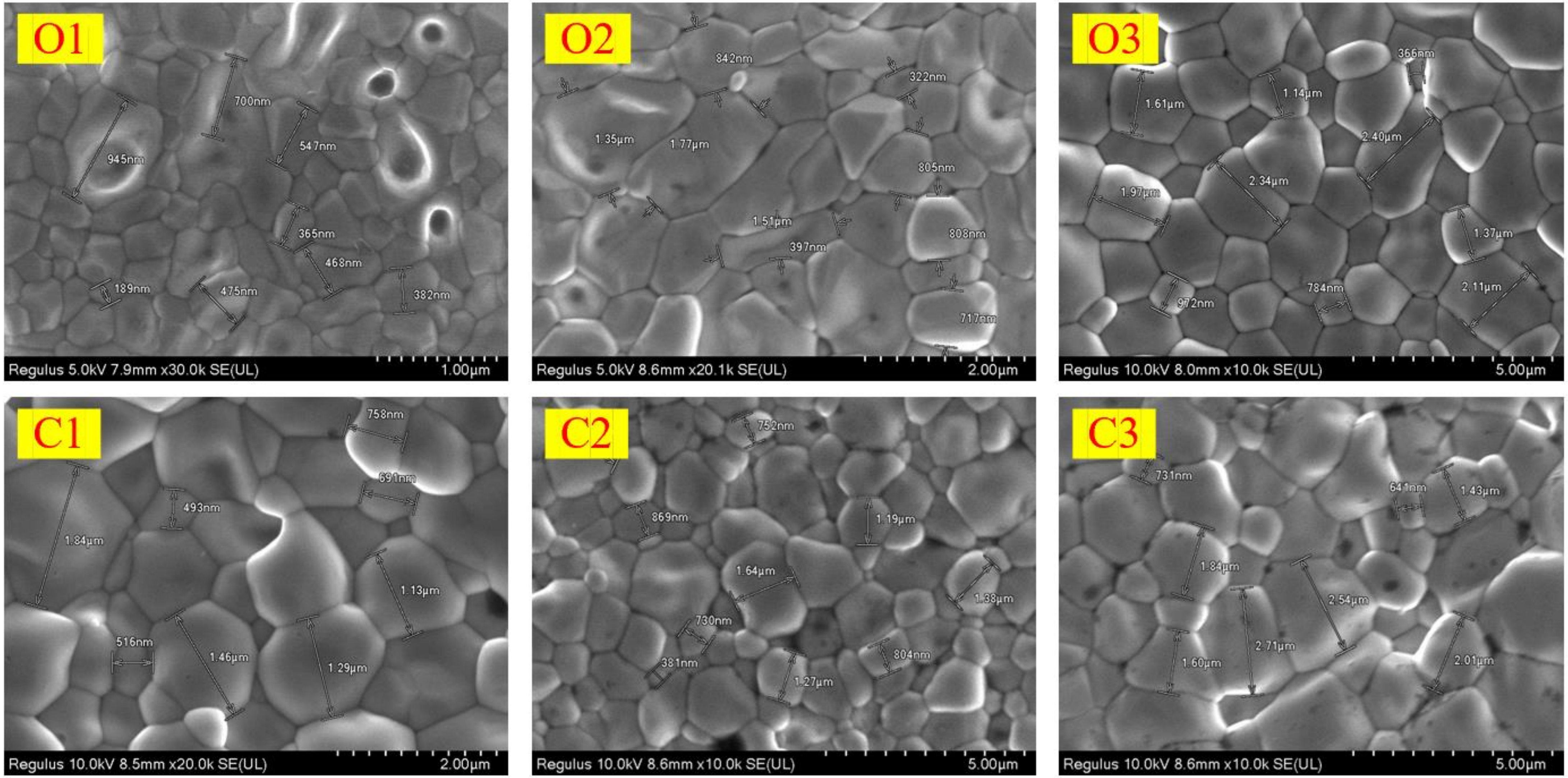
Coating of sample cavity

- The ratio of Nb/Sn was adjusted through the time duration of coating.
- The gate valve of the furnace was always open during the coating of the three cavities (O1, O2 and O3). For comparison, it was closed during the coating of the other three cavities (C1, C2 and C3), in order to increase the vapor pressure of Sn and $SnCl_2$. Hence, the Sn content increased.
- Note: Nb/Sn was measured with wavelength dispersive spectrometer (WDS) on EPMA-1720.

No.	Degas Temperature & time	Nucleation Temperature& time Crucible/Furnace	Coating Temperature& time Crucible/Furnace	Annealing	Sn (g)	SnCl2 (g)	Nb/Sn
O1	150C 17h	Max：850/540℃ 5h	1290C / 1130 1h	None	0.6+0.36	0.32	3.82
O2	150C 17h	Max：850/540℃ 5h	1290C / 1130 2h	None	0.61+0.4	0.4	3.48
O3	150C 17h	Max：850/540℃ 5h	1290C / 1130 3h	None	0.65+0.42	0.41	3.16
C1	150C 17h	Max：850/540℃ 5h valve closed	1290C / 1130 1h valve closed	None	0.65+0.42	0.41	3.19
C2	150C 17h	Max：850/540℃ 5h valve closed	1290C / 1130 2h valve closed	None	0.65+0.44	0.4	2.91
C3	150C 17h	Max：850/540℃ 5h valve closed	1290C / 1130 3h valve closed	None	0.65+0.41	0.53	2.87

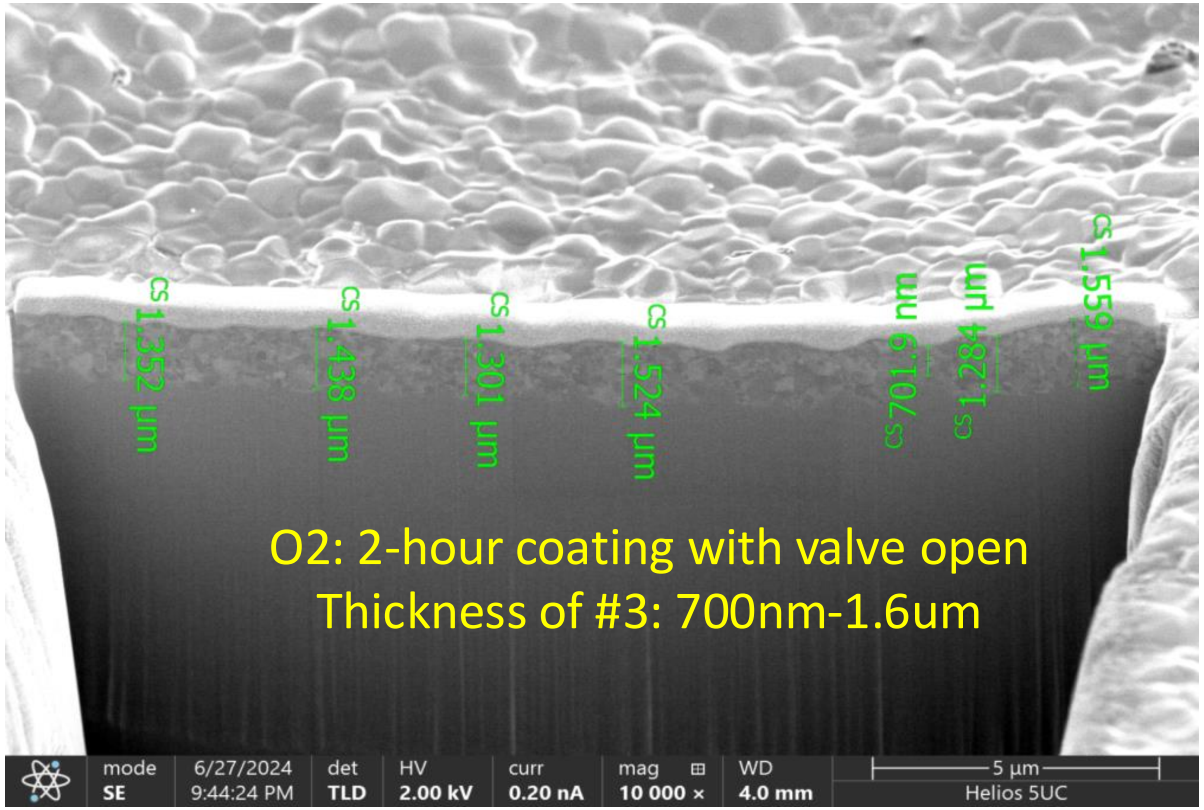
SEM

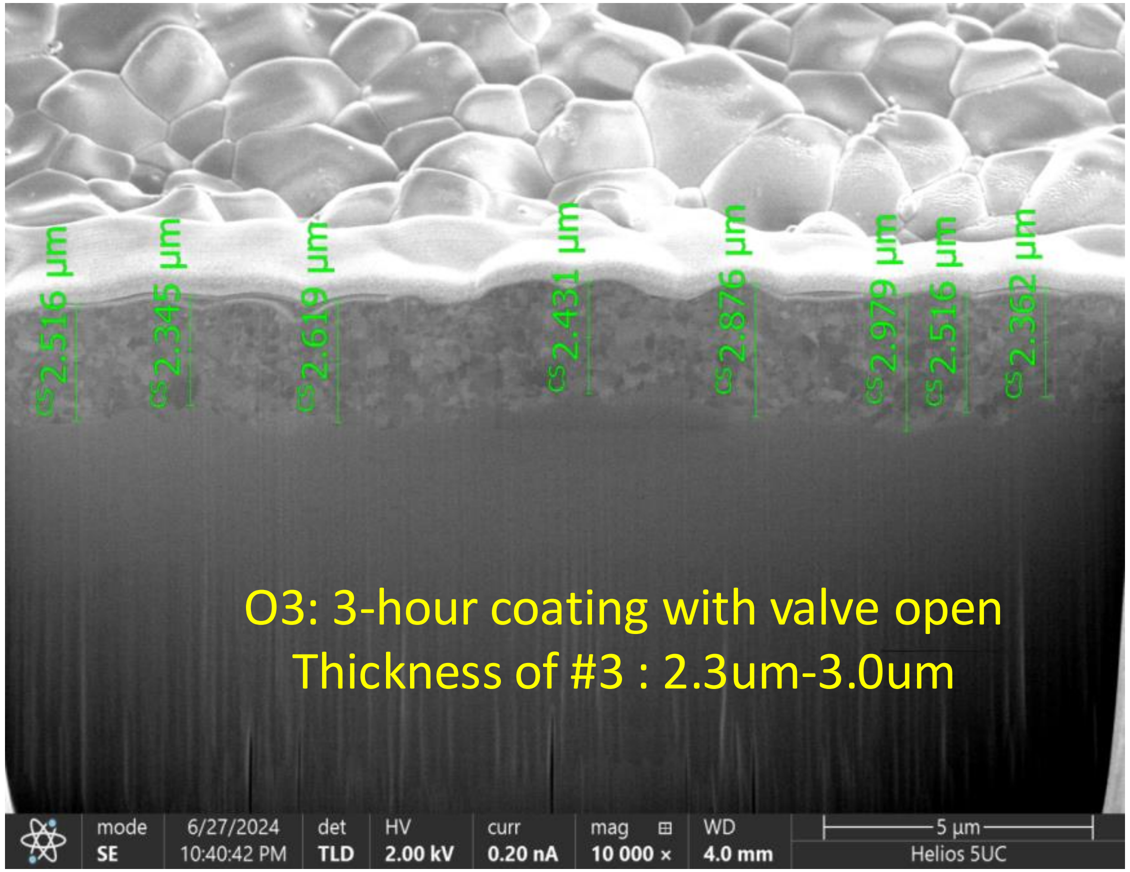
- The grain size was not uniform and there were patchy areas (Hitachi SU5000/8000).



Thickness of Nb_3Sn film

- Thickness is proportional to the time duration of coating.



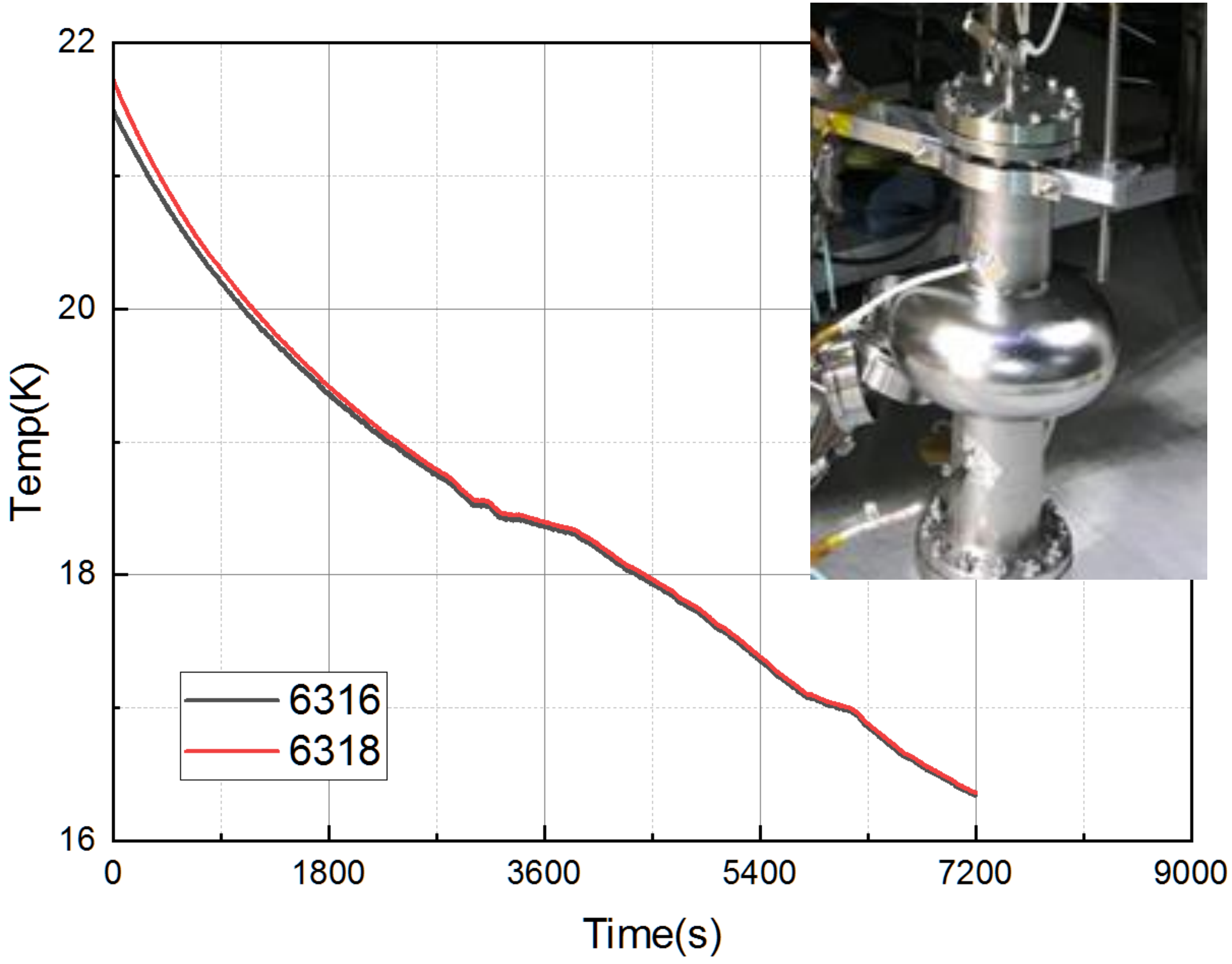


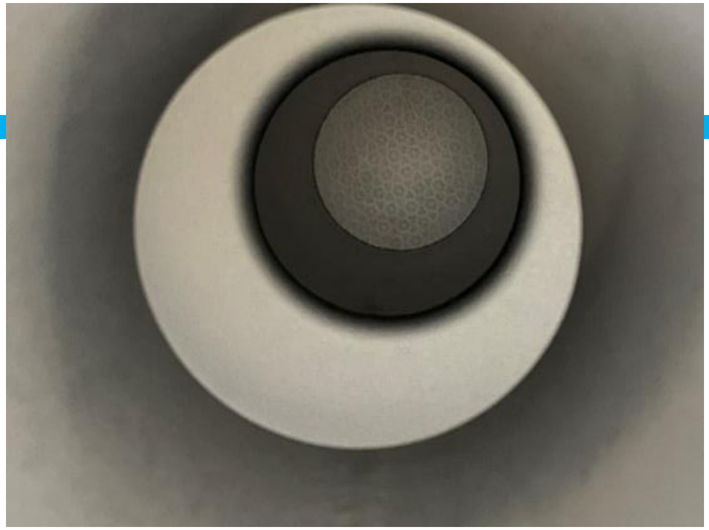
Coating of 1.3 GHz 1-cell cavity

- The same recipe of sample cavity were adopted.

Coating Date+ Cavity No.	Degas Temperature & time	Nucleation Temperature& time Crucible/Furnace	Coating Temperature& time Crucible/Furnace	Annealing	Sn (g)	SnCl2 (g)
O1	150C 17h	Max：850/540℃ 5h	1290 / 1130 ℃ 1h	None	0.66 + 0.34	0.38
O2	150C 17h	Max：850/540℃ 5h	1290 / 1130℃ 2h	None	0.64 + 0.42	0.4
O3	150C 17h	Max：850/540℃ 5h	1290 / 1130℃ 3h	None	0.65 + 0.42	0.41
C1	150C 17h	Max：850/540℃ 5h valve closed	1290 / 1130℃ 1h valve closed	None	0.67 + 0.43	0.4
C2	150C 17h	Max：850/540℃ 5h valve closed	1290 / 1130℃ 2h valve closed	None	0.68 + 0.38	0.5
C3	150C 17h	Max：850/540℃ 5h valve closed	1290 / 1130℃ 3h valve closed	None	0.66 + 0.34	0.49

Cool down





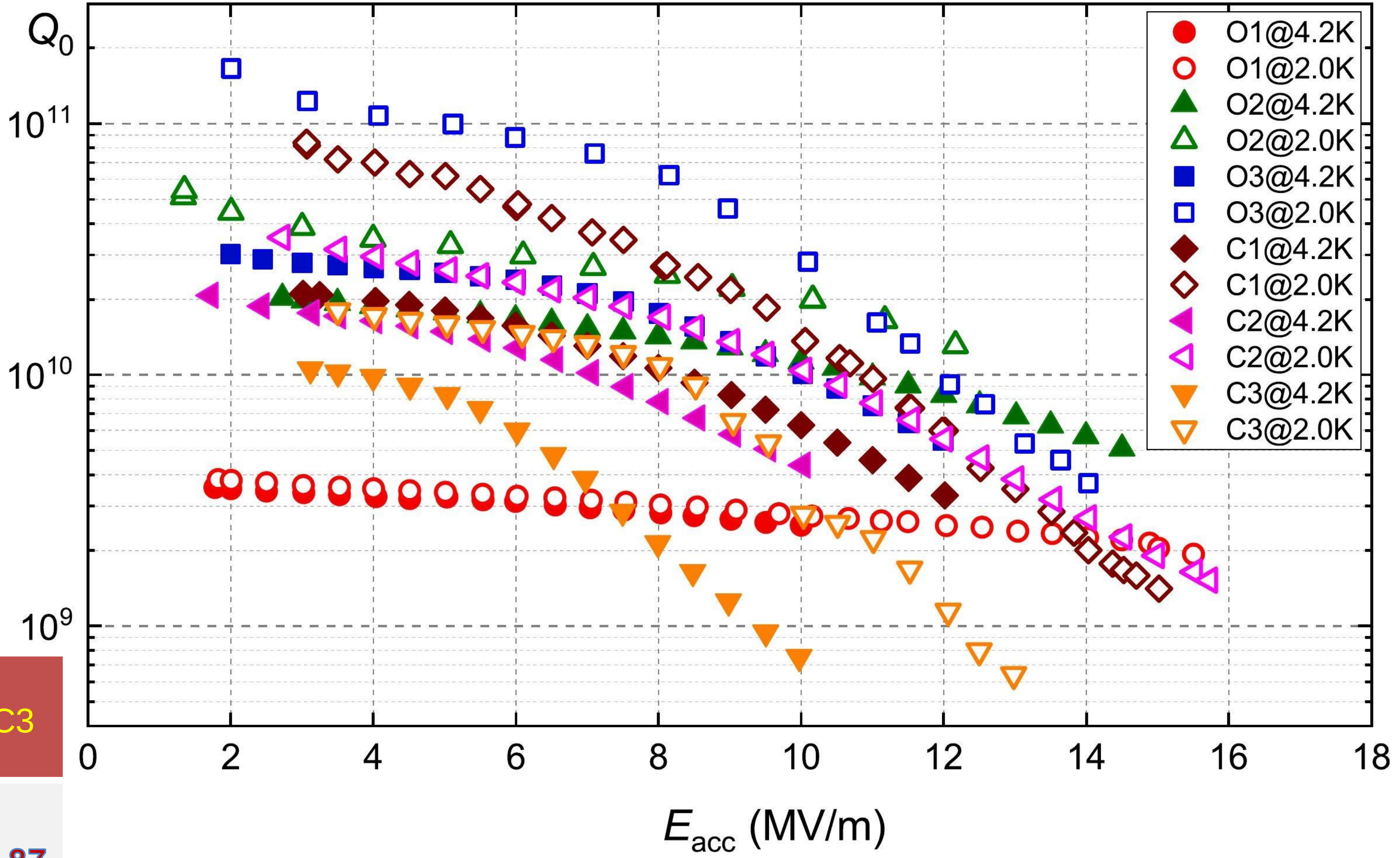
Inner surface of Nb3Sn cavity

- During the cooling process, the temperature gap between the upper and lower beamtubes (TI6318, TI6316) on the 1.3 GHz 1-cell Nb_3Sn cavity is less than 0.02K, which indicated uniform cooldown.

Vertical test result

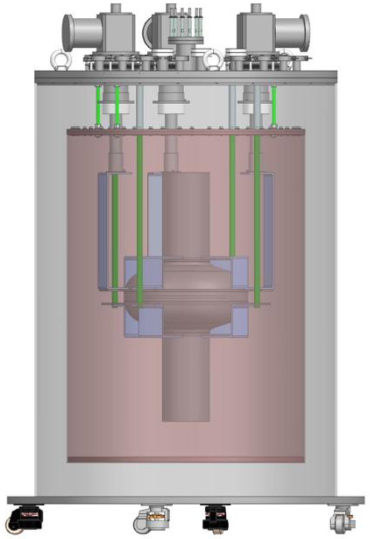
- In General, the performance of O2, O3 and C1 was better.
- When the ratio of Nb/Sn was slightly > 3, the best performance achieved.
- Max Q: 3E10@2MV/m, 1.1E10@10.5MV/m at 4.2K; 1E11@5MV/m at 2K.
- C2 and C3: Sn excess.
- O1: Sn deficiency.

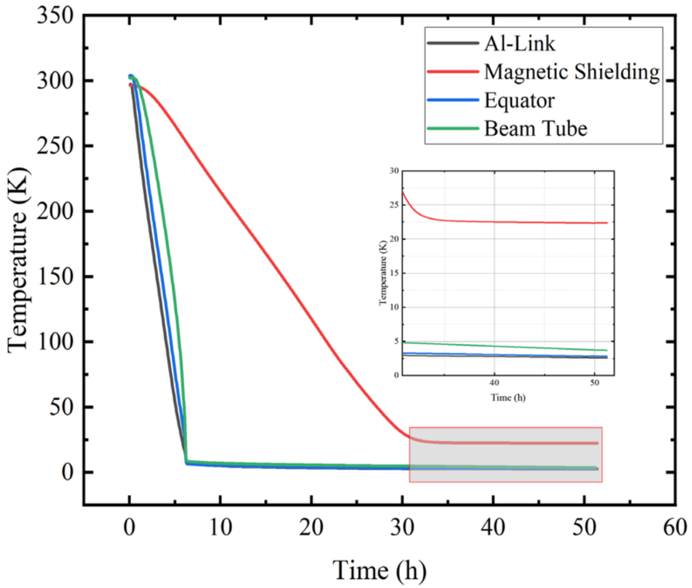
No.	O1	O2	O3	C1	C2	C3
Nb/ Sn	3.82	3.48	3.16	3.19	2.91	2.87



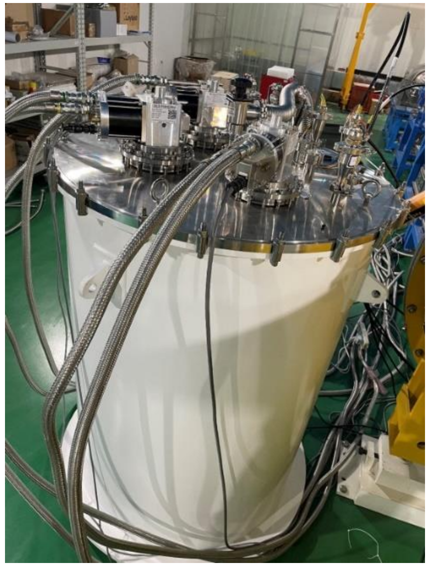
- *Materials letters* 379 (2025) 137710

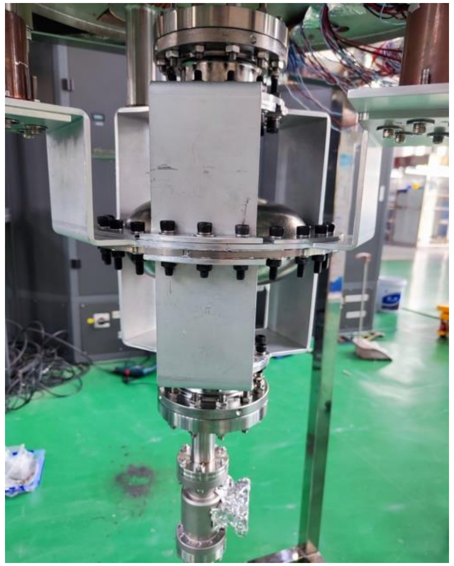
Conduction cooling of Nb cavity

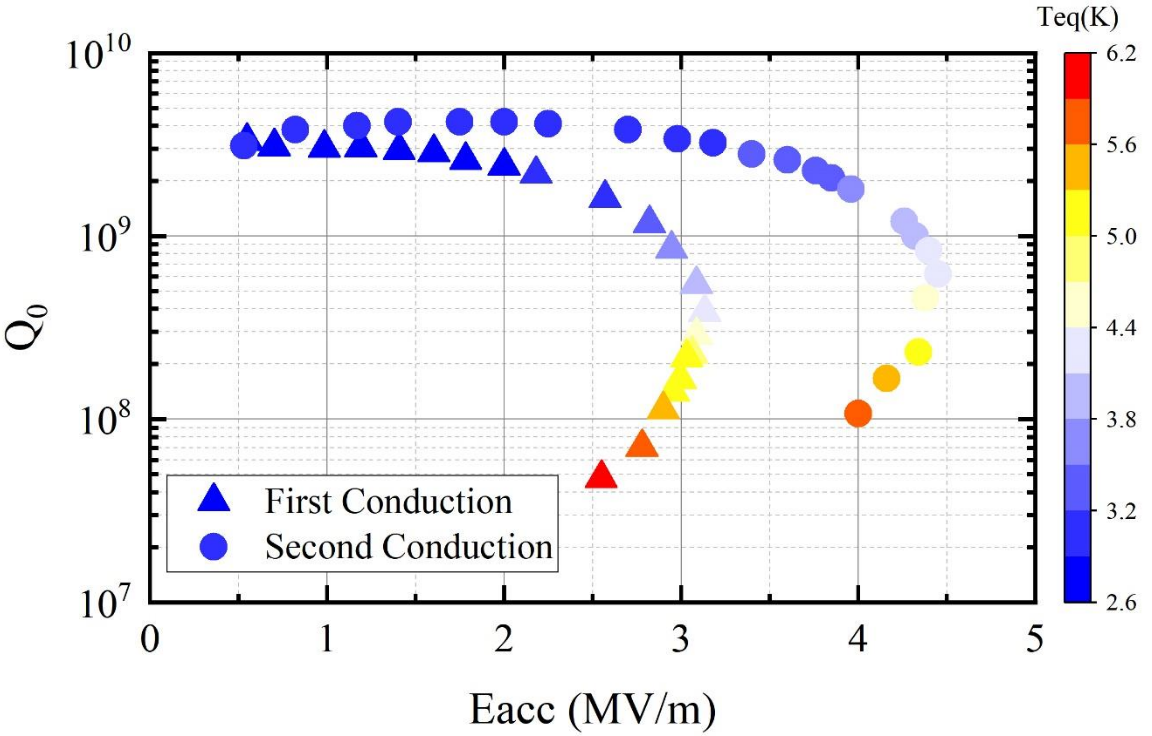




- Three GM refrigerators are adopted.
- Firstly, 1.3 GHz 1-cell Nb cavity was adopted for the conduction cooling test.
- Then, the cavity was coated with Nb3Sn film.

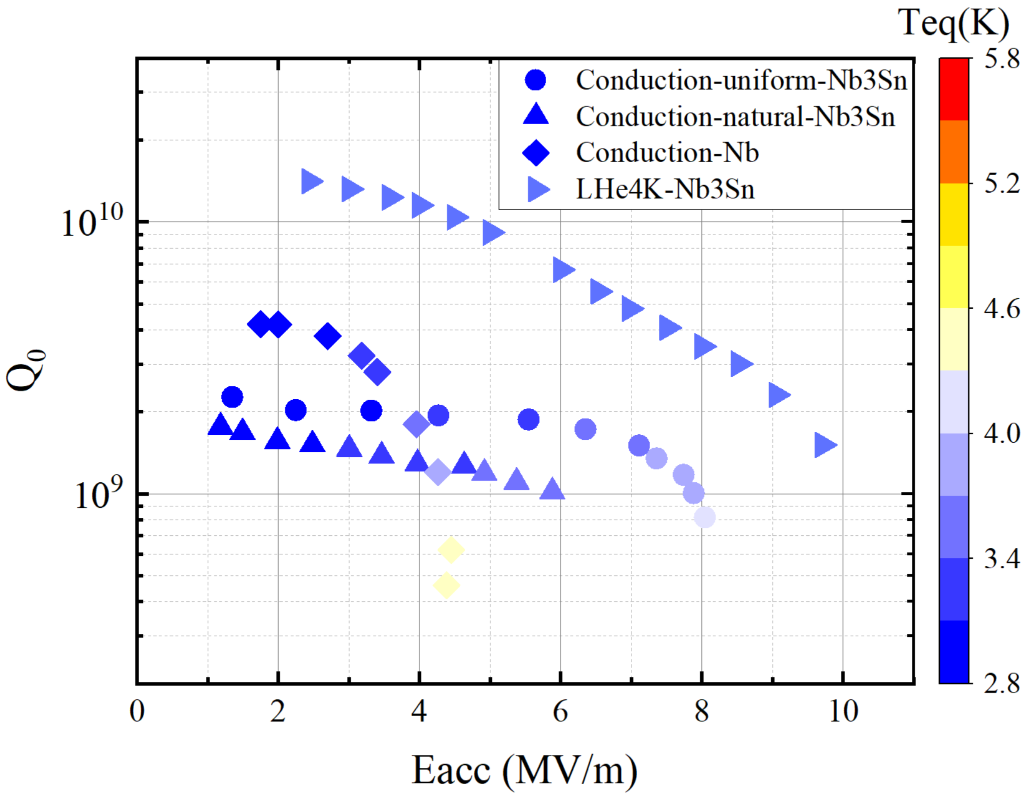


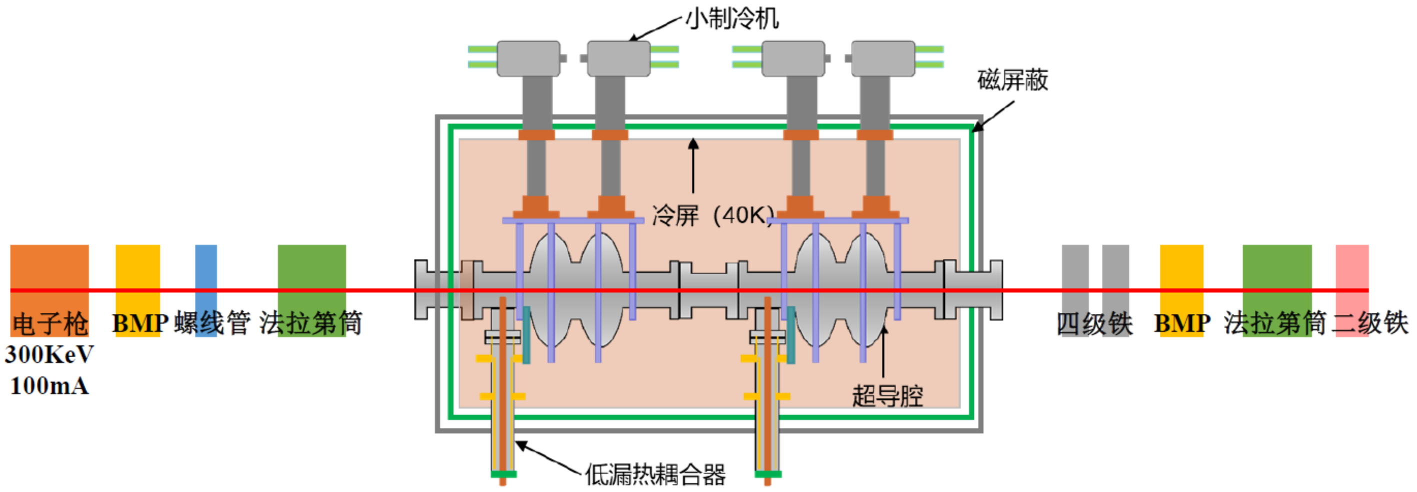




Conduction cooling of Nb3Sn cavity

- Natural cooling as Nb cavity.
- Uniform cooling: 0.038K/min between 22~14K.
- The third cooling is undergoing, which is slower and more uniform.





Schematic of Nb3Sn SRF accelerator, which include two 1.3 GHz 2-cell cavity.

Summary

- Improve the coating process, in order to enhance Q and Eacc.
- Start to coating at 650 MHz cavity, which will be conducted at a new big furnace.
- Develop the Nb_3Sn SRF accelerator, which is under design.

Thanks for your attention!