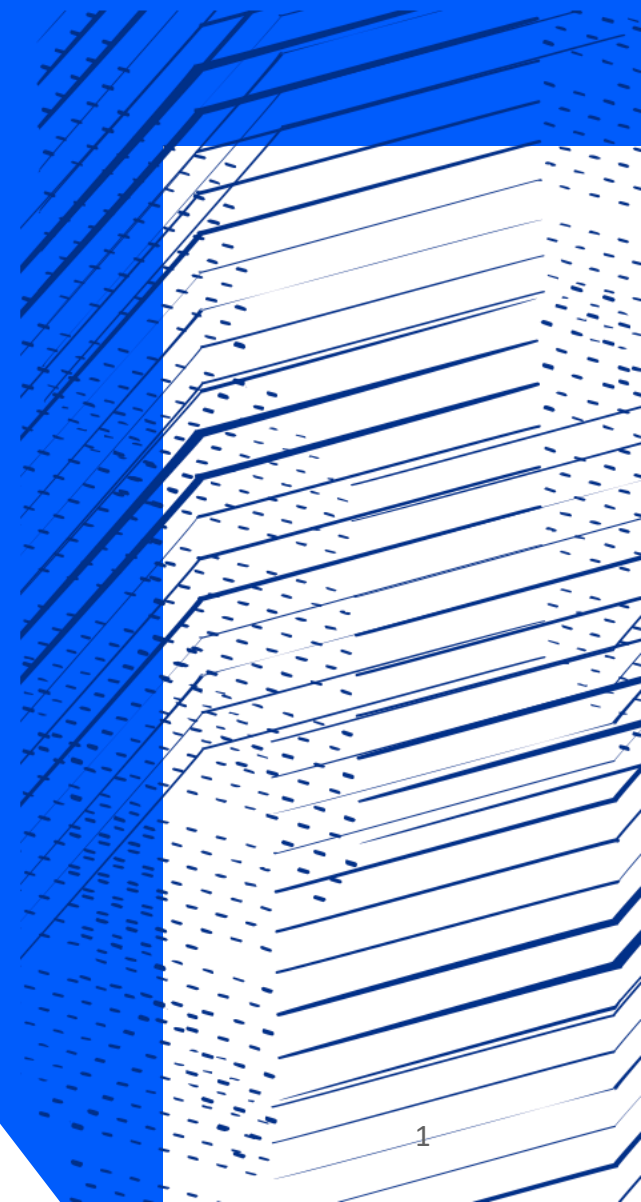




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Calibration and deposition of 1.3 GHz Nb cavity coated with Nb₃Sn thin film by PVD planar magnetron sputtering

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Oleg Malyshev, Dan Seal, James Conlon , Afshan Ashraf (STFC),
Dan Turner, Graeme Burt (Lancaster University)



Outline

- Objectives & Strategy
- Thin Film Testing & Validation
- Cavity Deposition
- Summary





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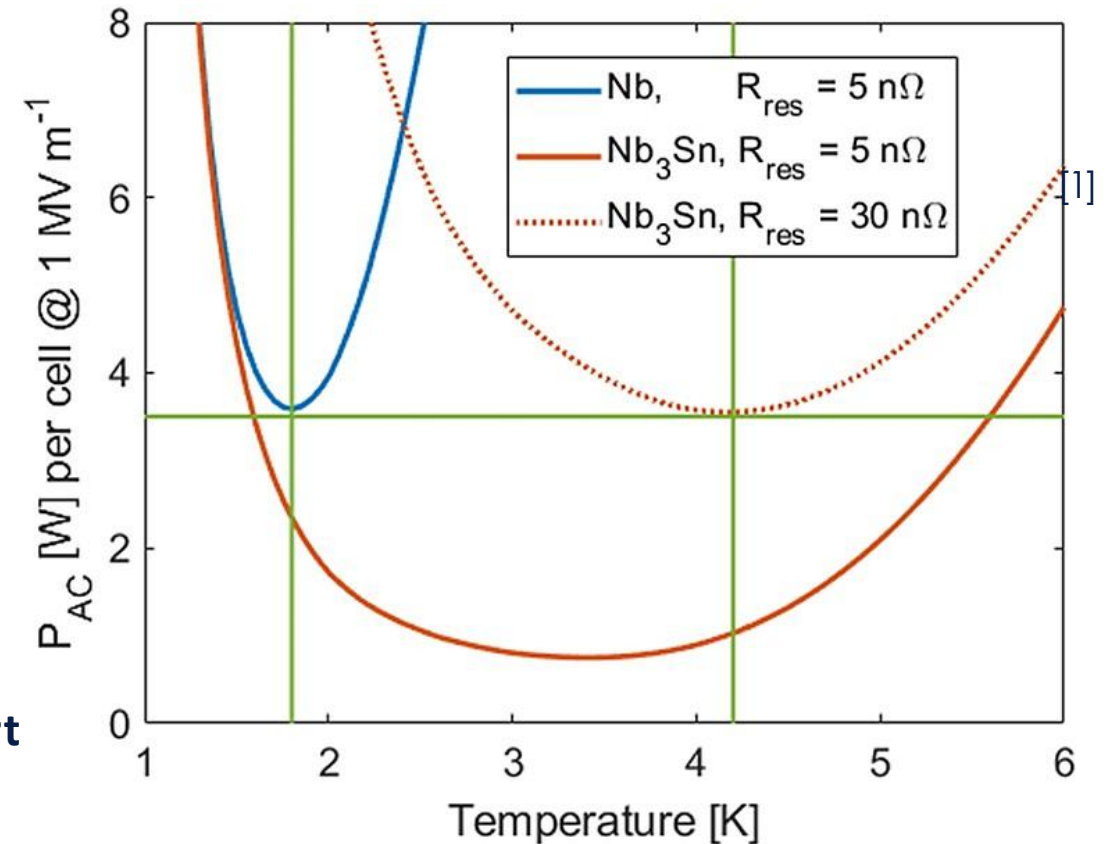
SRF Thin Film Objectives

Aims & Objectives

- To develop and validate a novel class of SRF cavities based on Nb₃Sn and NbTiN thin films:
 - improve accelerator performance and efficiency through higher accelerating fields,
 - better stability,
 - reduced material costs,
 - lower operational costs compared to traditional bulk niobium cavities
- Development of in-house skills and capabilities to deposit, measure and test thin film cavities
- Thin film cavity of high T_c tested in cryomodule with beam

Nb₃Sn for SRF – Potential

- $T_c(\text{Nb}) = 9.2 \text{ K}$ $\square$ $T_c(\text{Nb}_3\text{Sn}) = 18.3 \text{ K}$
- results in lower R_{BCS} at a given temperature
 - operation at 4.5 K
 - reduce grid power to run cryo plant **by factor of 3**
- potential demonstrated by **VTD cavities (state of the art**



$Q_0 \sim 2 \times 10^{10}$ at 20 MV/m (4.4 K, 1.3 GHz) [2]



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Thin Film Testing & Validation

RF Test With Choke Cavity

3 tests per week!

Most importantly, how does the thin film perform under RF conditions?

7.8 GHz Choke Cavity

Low field measurements:

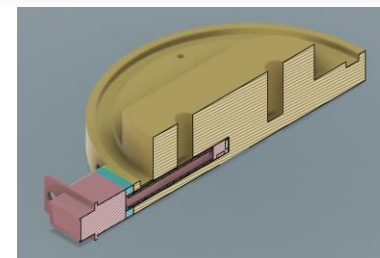
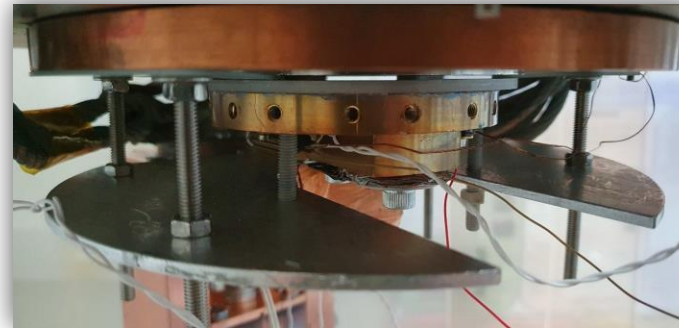
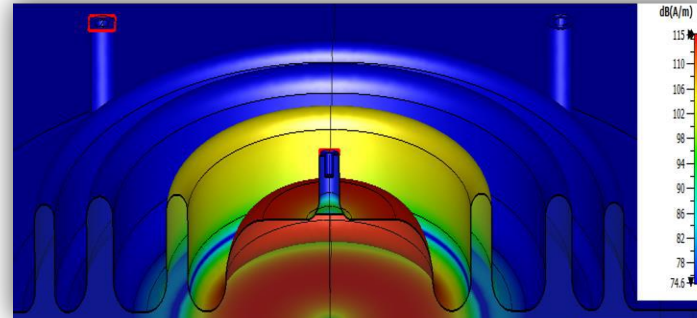
- R_s vs $B_{s, pk}$
- R_s vs T_s
- Penetration depth vs T_s

Mass parameter optimisation prior to:

- High field/low frequency tests with QPR
- Cavity tests

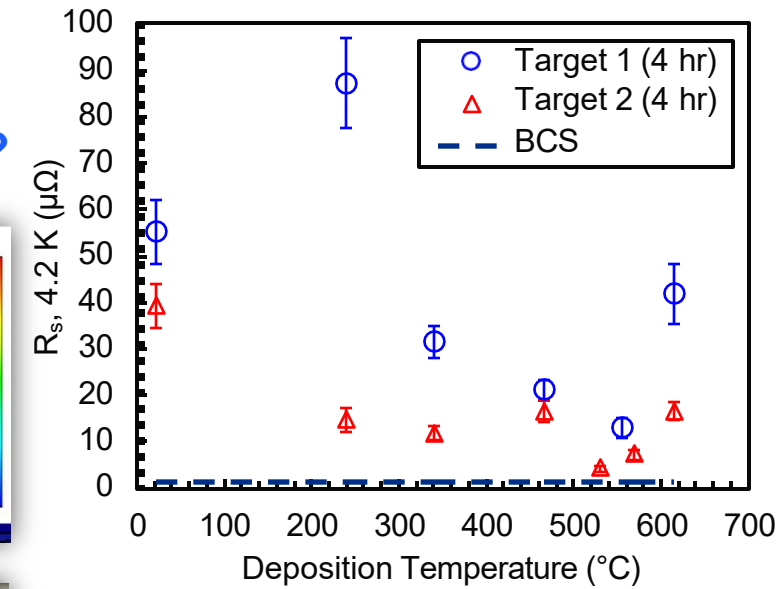
Upgrades to increase $B_{s, pk}$:

- Hall sensors for residual magnetisation studies
- Magnetic shields
- TF coated Cu cavities
- CI bunker

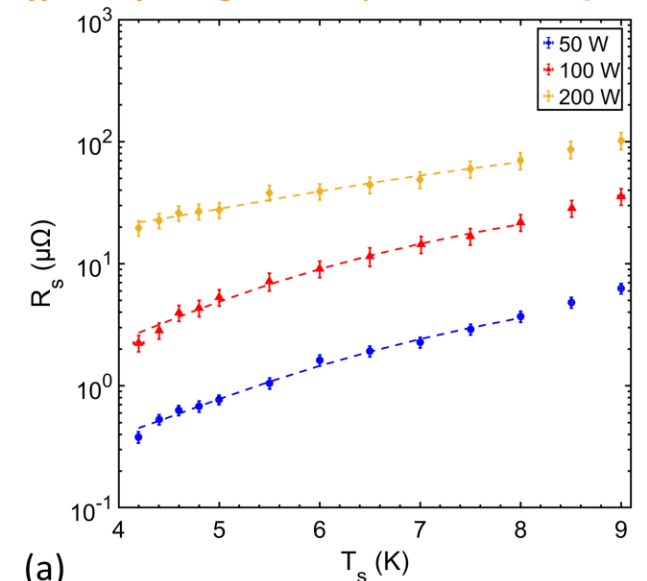


Courtesy of P. McGuinness (ASTeC)

Effect of deposition temperature on Nb/Cu

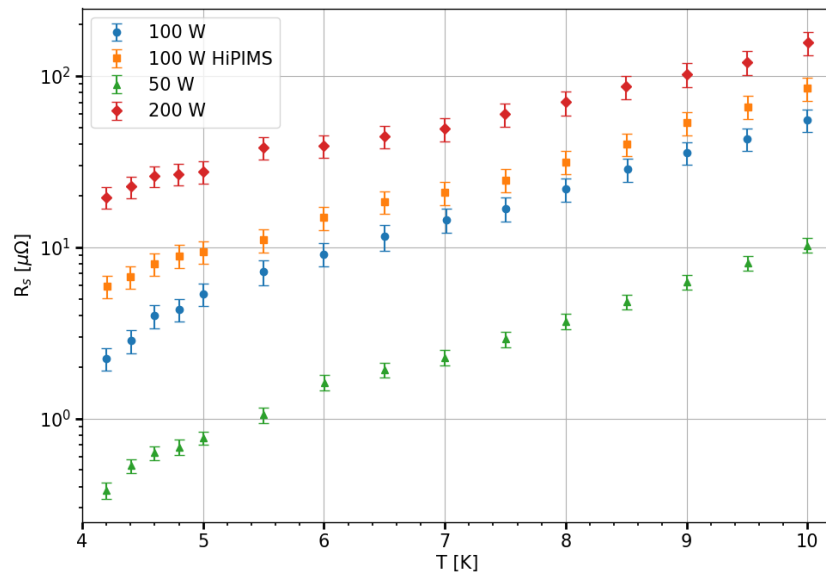


Effect of magnetron power on Nb₃Sn/Cu

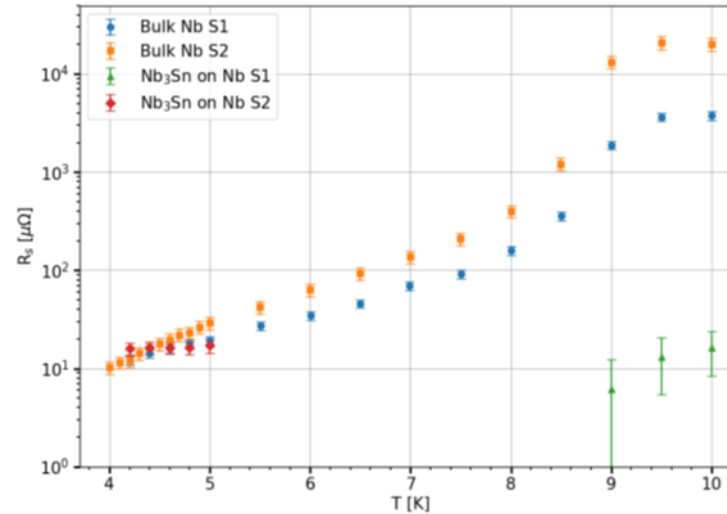


(a)

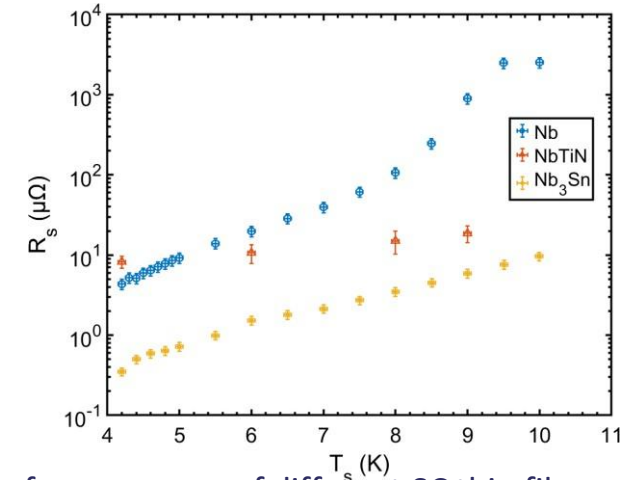
Optimisation of deposition parameters using choke cavity



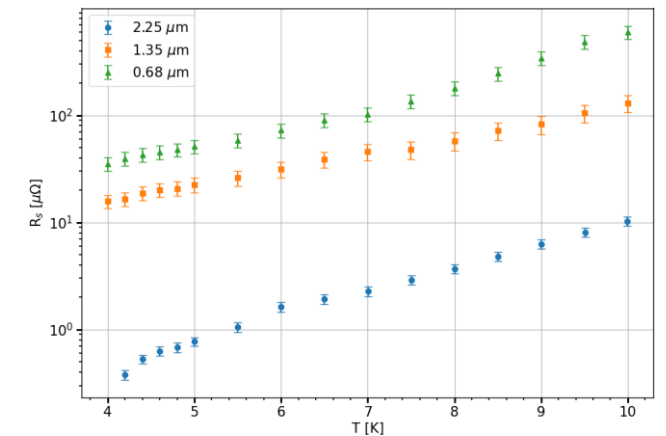
Optimisation of deposition power for Nb_3Sn on Cu



Surface resistance on Nb with different surface roughness surface preparation



Surface resistance of different SC thin film on Cu



Surface resistance of different thickness on Cu

- Optimum deposition power for Nb_3Sn is established at 50 W DC power
- Film Thickness dependence of Nb_3Sn on Cu
- Best surface resistance so far is achieved on Nb substrate
- For high T_c , Nb_3Sn seems to be more suitable candidate for 4 K operation having lower R_s than NbTiN.



Low Power Cavity Test Facility

First tests in
2025!

Cryocooler based facility

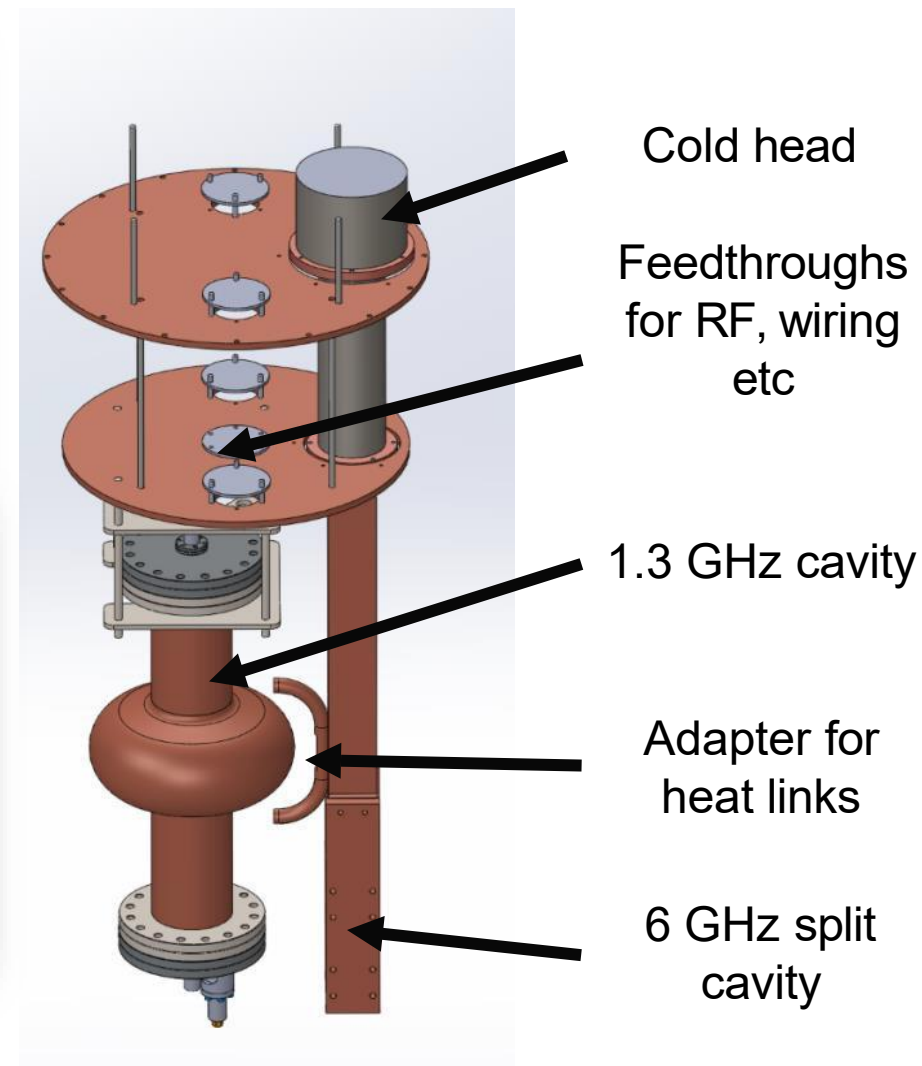
- $P < 2.5 \text{ W}$, $T > 4 \text{ K}$ (est.)
- Quick first cavity test
- Good cavities will have high power test in LHe

4 types of cavity

- 1.3 GHz closed
- 1.3 GHz split
- 6 GHz closed
- 6 GHz split



*Cavity facility alongside Choke
Cavity facility*



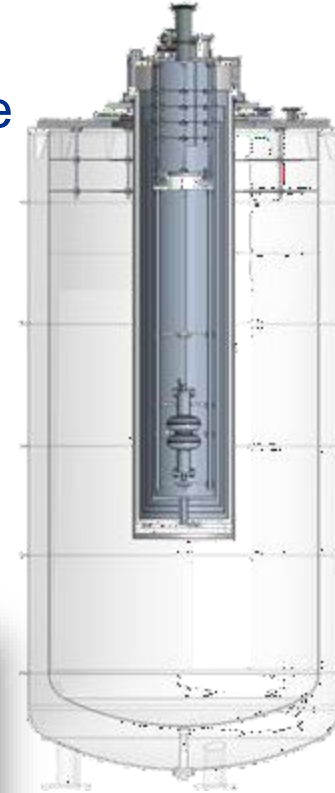
Courtesy of O. Poynton & J. Rigby



High Power Cavity Testing

Commissioning in 2025!

- Full Q_0 vs E_{acc} test with LHe
- Testing with existing STFC/DL LHe infrastructure mainly used for ESS & PIP-II cavity tests
- **Upgrades now allow for:**
 - For thin film SRF programme
 - A RF single system for 650 and 700 MHz, and 1.3 GHz
 - $P \leq 200$ W, $T = 2$ & 4.2 K
 - Capability for 9-cell tests



Courtesy of T. Sian & C. Hill

However, very limited number and durations for free timeslots, i.e. only good cavities should be characterised



Science and Technology Facilities Council
Existing SRF Test Facilities in SuRF Lab at Daresbury Laboratory

Coordinated by T. Sian (ASTeC)



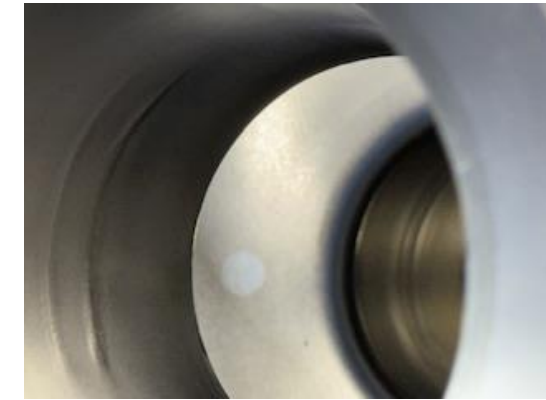
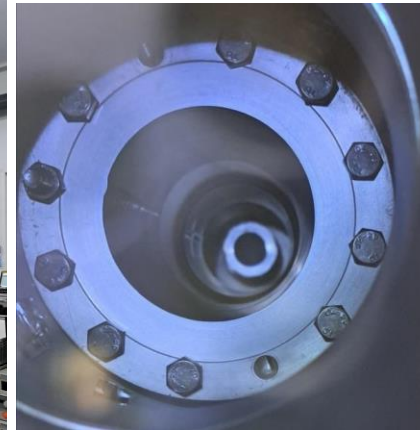
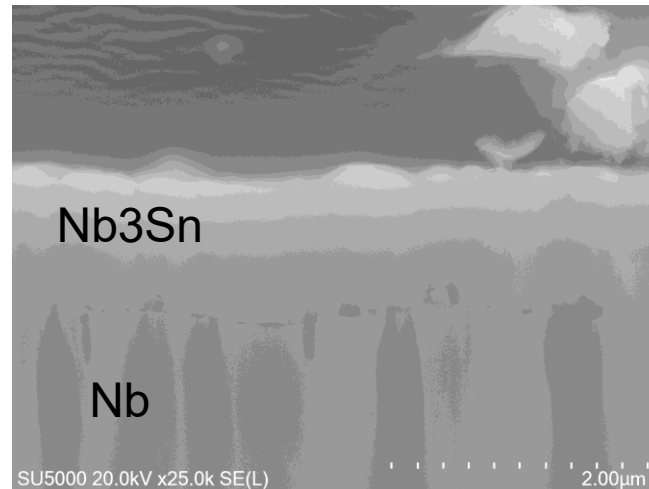
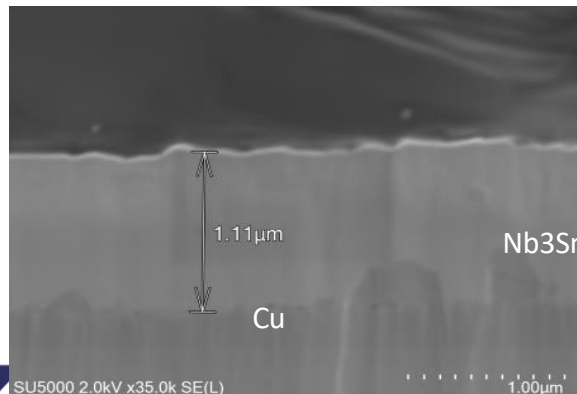
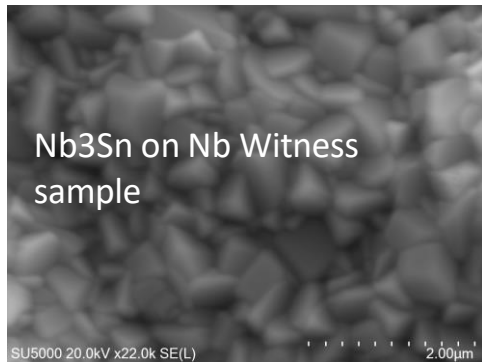
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1.3 GHz Cavity Deposition

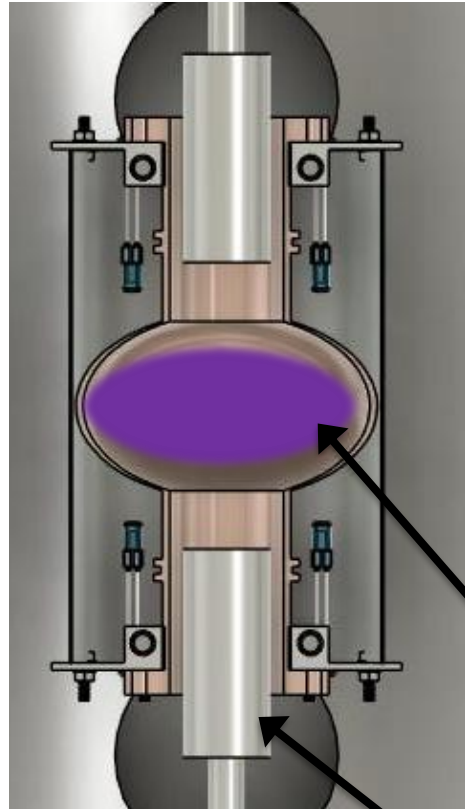
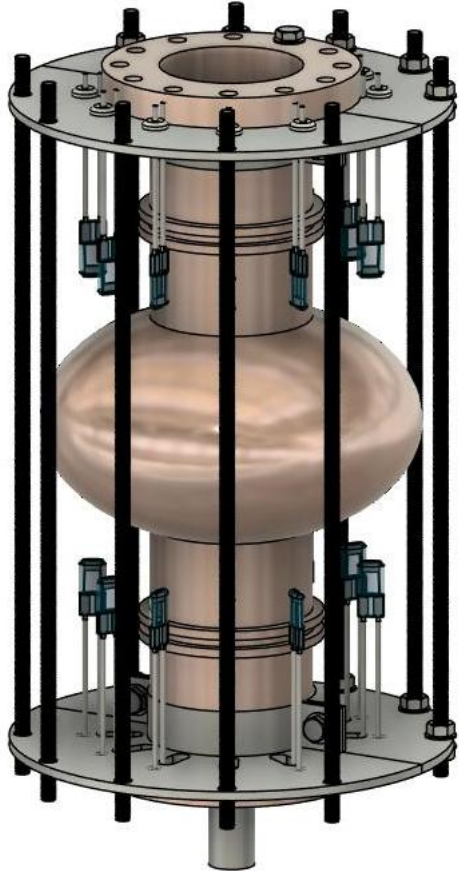
First Nb₃Sn calibration on 1.3 GHz Nb Cavity

- First trial run of Nb₃Sn deposition of 1.3 GHz Nb cavity with deposition parameters established on planar samples.
- The trial run proved to be successful.



First 1.3 GHz Nb cavity deposited with Nb₃Sn

Cavity heating stage



- Cavity is deposited using magnetron sputtering (PVD).
- Deposition inside a UHV system.
- Deposition at 600 °C
- Custom in-house magnetron designed and tested can be positioned inside the cavity.
- Two magnetron opposite each other was moved in and out during deposition total 30 hours.

Sputtered material
(Plasma)

Magnetron



First Nb₃Sn on Nb cavity at STFC.

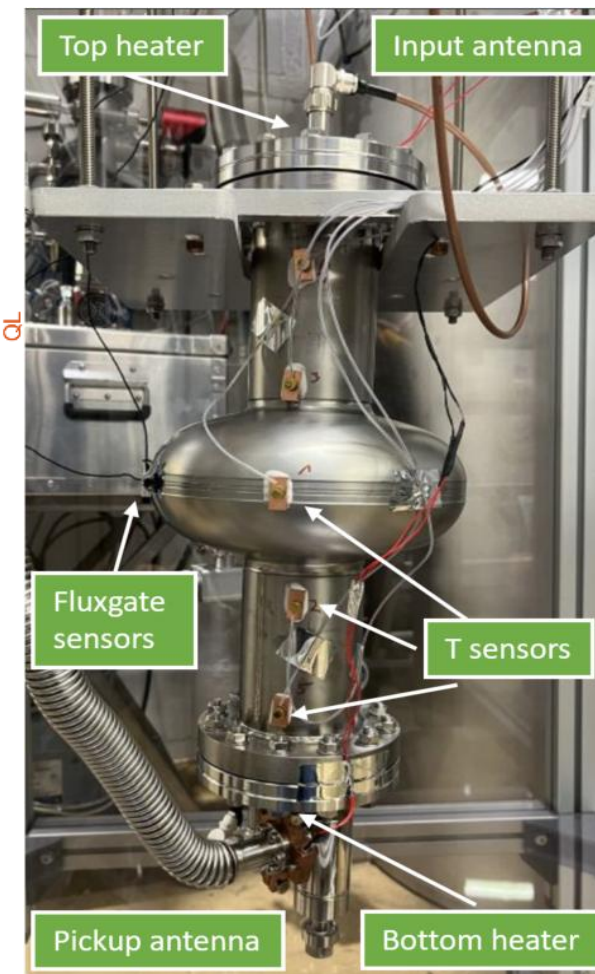
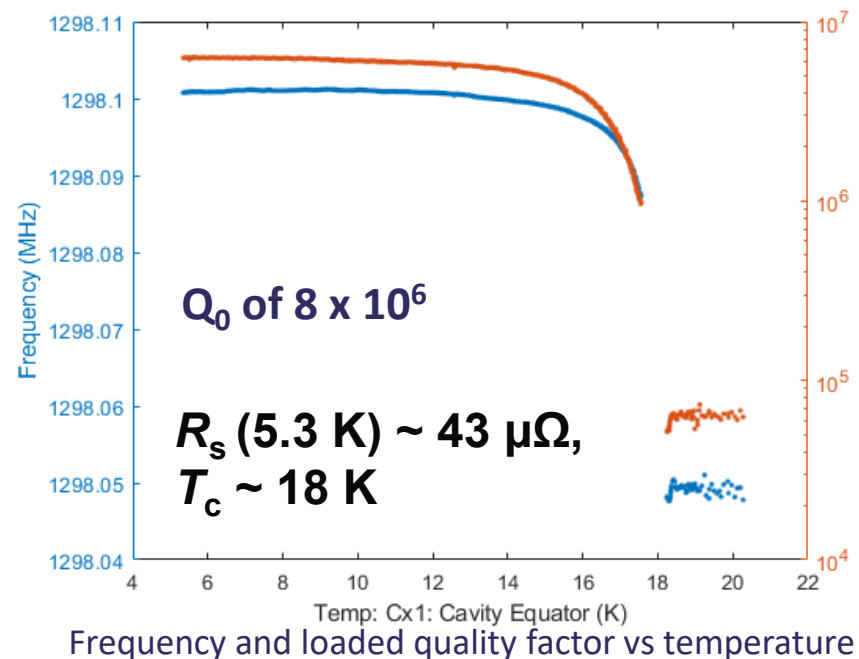
Inside the cavity after deposition

- After some test depositions the first 1.3 GHz Nb has been coated with Nb₃Sn.
- After visual inspection, the cavity was prepared for testing in an ISO 4 cleanroom environment.
- The cavity transported to HZB for testing.

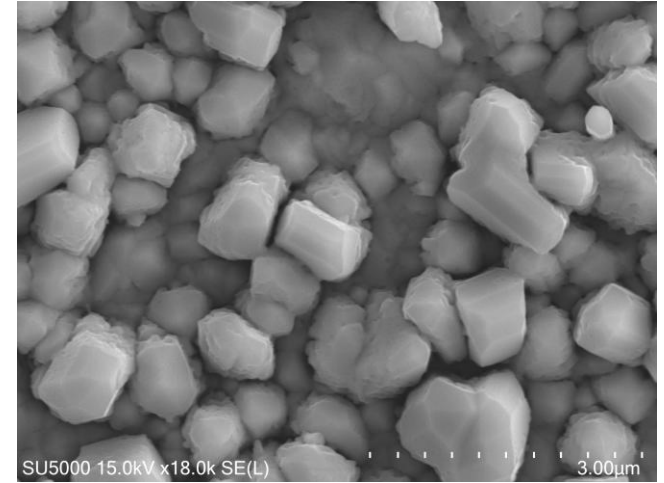
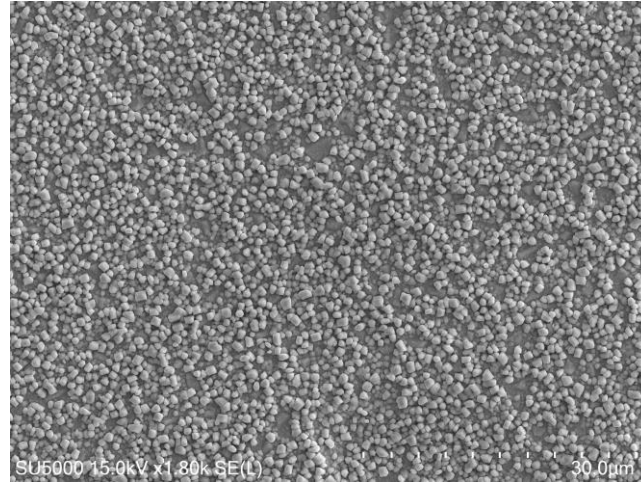


RF Test At HZB

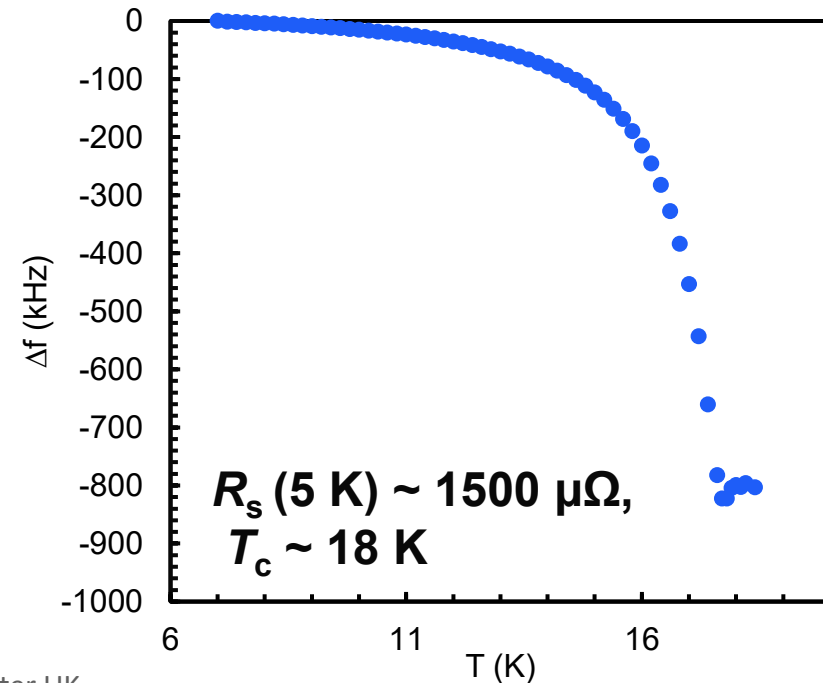
- No thermo-currents were recorded with the azimuthally placed sensors.
- While the T_c was at 18.1 K it only achieved a Q_0 of 8×10^6
- No T_c of Nb was detected: Possibly cavity fully coated.
- Poor Q factor:
 - Cu contamination at surface layer due to diminishing target
 - Present of other normal conducting material due to poor cavity handling.
 - Or other reasons to be determined.
 - No HPR after Deposition



Nb Disk deposition inside segmented Nb Cavity C

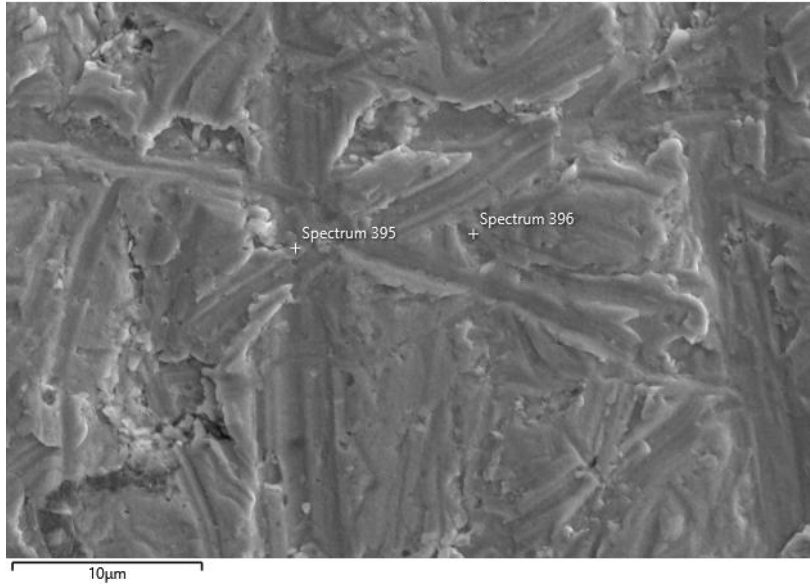


- Unfortunately, this resulted in mixed composition and non superconducting phase (high Sn content) gave
- May be caused:
- By low temperature deposition below 600 C
- Or target non homogeneity

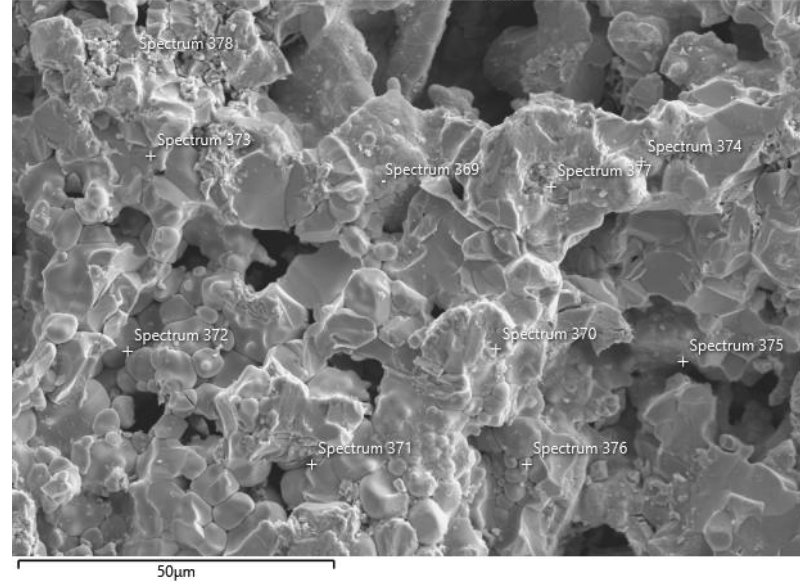


Pre and post Annealed targets

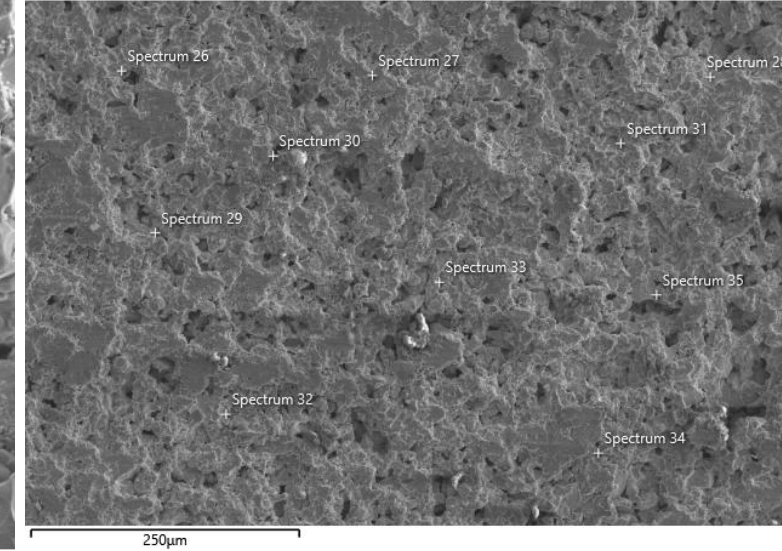
Electron Image 45 (SE)



Electron Image 42 (SE)



Electron Image 6 (SE)



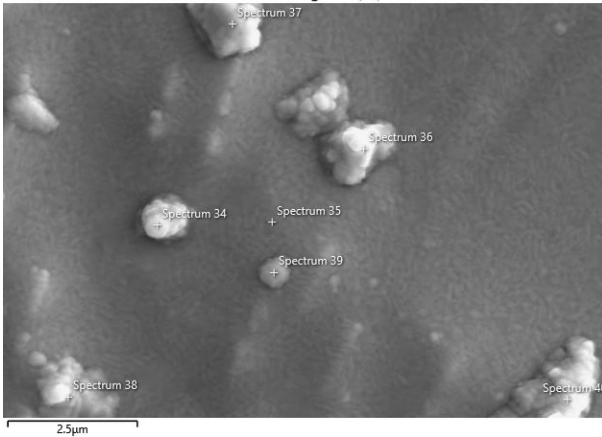
Pre annealed (Name)	Average Nb At%	Average Sn At %	No. of spectra
Site 4	70.13	29.87	10
Site 9	70.38	29.62	9
Post Annealed			
Site 1	68.98	30.02	10
Site 2	66.82	33.18	9
Site 3	63.61	36.39	7
Nb 100 mm Holder			
Center (Light spot)	95.88	4.12	2
Edge (Dark)	99.85	0.15	2

Comparison of Nb₃Sn deposition from two different targets two different magnetron outside cavity

New target/HM magnetron

Old target/Com magnetron

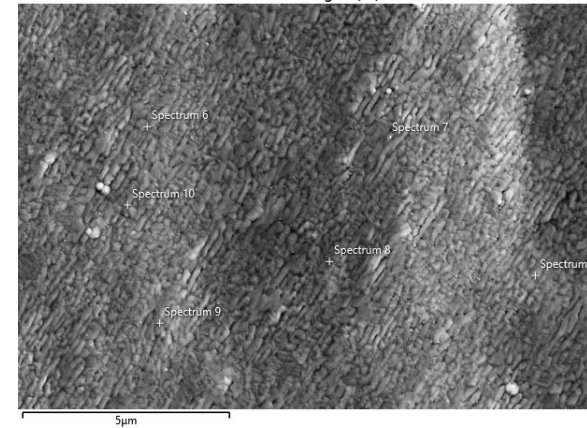
Electron Image 182 (SE)



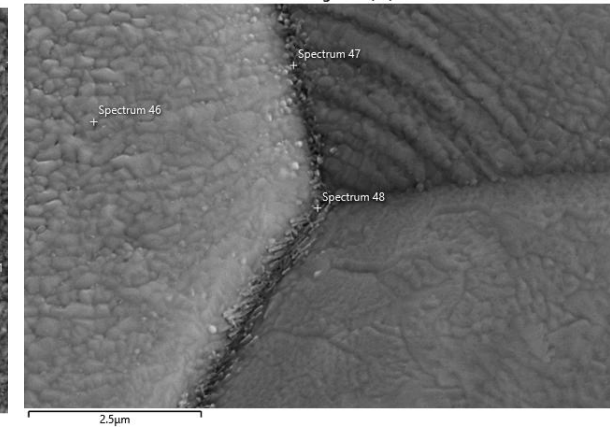
Electron Image 5 (SE)



Electron Image 2 (SE)



Electron Image 220 (SE)



Statistic	Nb	Sn
Max	76.43	26.83
Min	73.17	23.57
Average	75.38	24.62
Standard Deviation		

0.76

0.76

Statistic	Nb	Sn
Max	78.05	24.11
Min	75.89	21.95
Average	76.93	23.07
Standard Deviation		

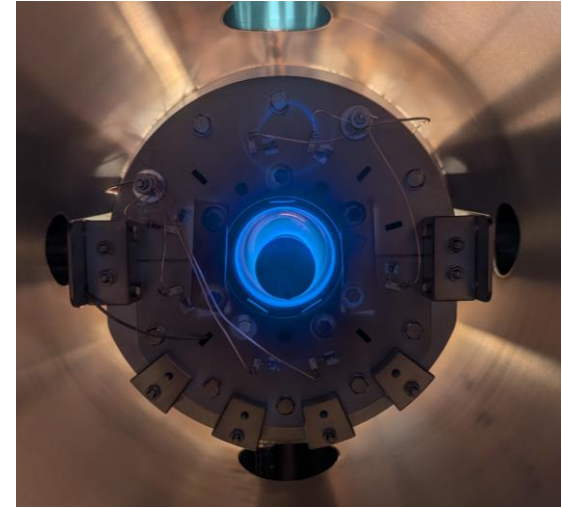
0.72

0.72

Copper Cavity deposition facility

The new deposition facility currently being commissioned at Daresbury Laboratory. It will be a dedicated facility for the deposition of 1.3 GHz cavities (Both single and two-cell).

The facility will be situated in an ISO 6 cleanroom environment. Initial deposition tests are being conducted using a Nb cylindrical target and mock Cu cavity components. Integrating the heating stage.



21/09/2026

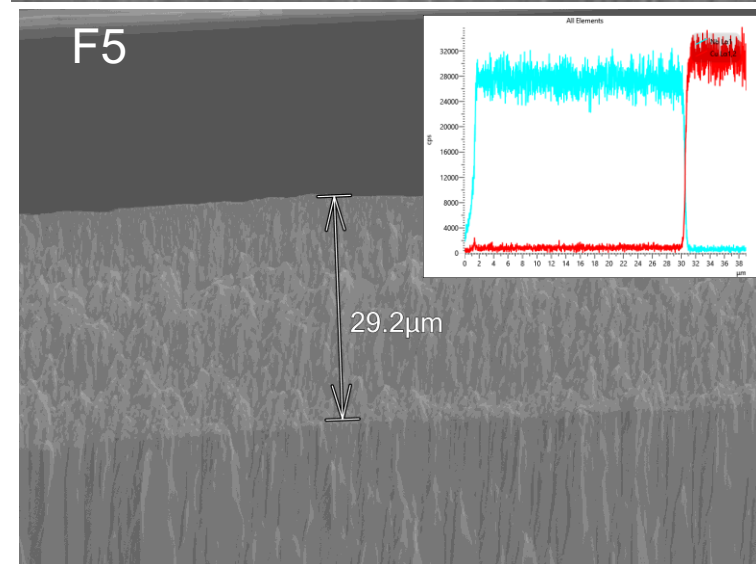
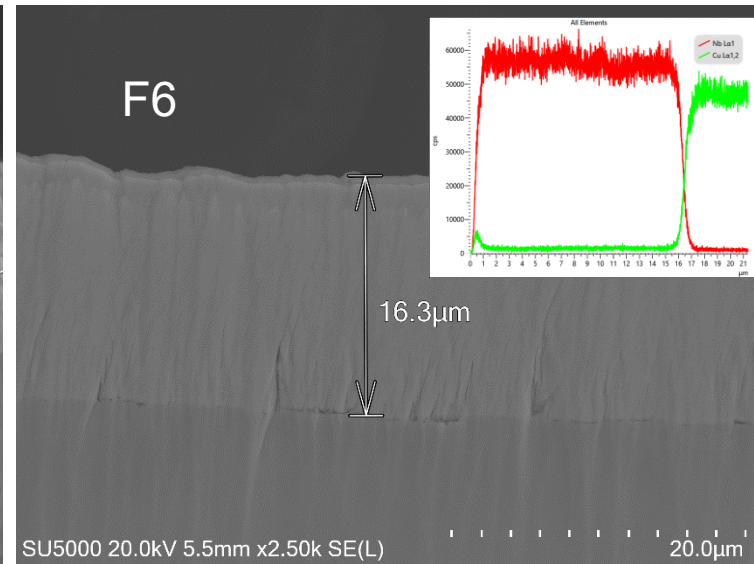
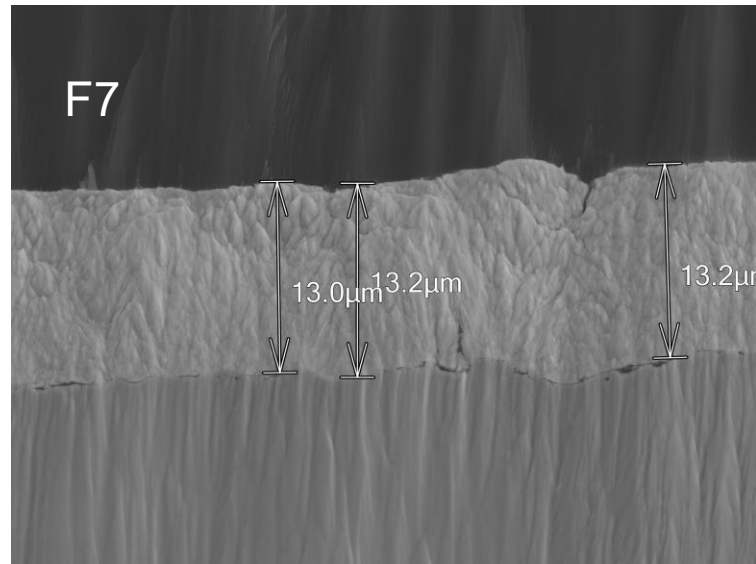
Cu mock cavity segments

Nb Cylindrical Magnetron



TESRE 2026 Workshop Chester UK

HIPIMS Nb deposition at 400 C 24 Hours



- The deposition is done with fixed magnetron position with four magnet segments.
- Two segments in elliptical part and two middle of each tube section,
- The cavity is laser welded at Electra.
- Another cavity with the same parameters is deposited for 48 Hours and sent to HZB for bronze route deposition for first trial.

Summary

- ❑ First 1.3 GHz Nb cavity was produced by magnetron sputtering, the major deliverable for IFAST and progression of ISAS.
- ❑ Although full coverage and high T_c was achieved, it resulted in low Q_0 of 8×10^6 and R_s (5.3 K) $\sim 43 \mu\Omega$, $T_c \sim 18$ K
- ❑ After optimising deposition parameters on flat samples further optimization is needed for cavity deposition
- ❑ Additional processing may be needed to remove non-superconducting phase growth to achieve low surface resistance:
 - ❑ Post thermal annealing
 - ❑ Mechanical or chemical polishing
 - ❑ Laser or plasma processing
- ❑ The ultimate goal is to deposit Nb_3Sn on copper cavity:
 - ❑ Do we need suitable buffer layer
 - ❑ Do we need further optimisation from Nb to Cu cavity?
 - ❑ Lack of cylindrical target further complicates the process.