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OPTIMISATION OF NIOBIUM THIN FILM DEPOSITION PARAMETERS FOR SRF CAVITIES

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INTRODUCTION

Bulk Nb to TFs

Bulk Nb SRF cavities are close to reaching their theoretical limits in terms of accelerating gradients and Q factors. As a result, there is a push to develop cavities using either TF Nb or alternative higher critical temperature (T_c) superconductors (e.g. Nb_3Sn, NbTiN, V_3Si). Given an increasing cost of LHe, electricity and accelerator infrastructure, Cu cavities coated with thin film (TF) superconductors (SC) provide sustainable alternatives to bulk Nb cavities.

Why Nb/Cu?

Compared to bulk Nb, Nb/Cu leads to a reduction in material/production costs, more easily machinable, higher thermal conductivities, less sensitivity to trapped magnetic flux, operation at 4.2 K with lower BCS resistance (R_{BCS}).

Requirement for quick optimisation studies with RF:

TF development begins on planar samples – low cost & easy to analyse. Several DC facilities exist at Daresbury Laboratory to measure RRR, T_c and field of full flux penetration (B_{fp}), but these cannot analyse behaviour under RF. TF optimisation can now be performed rapidly with a new RF facility to understand TF behaviour and any correlations with DC & surface analysis results.

THIN FILM OPTIMISATION

Optimisation on planar samples: 1 – substrate preparation, 2 – PVD deposition, 3 – RF characterisation, 4 – DC characterisation, 5 – surface analysis

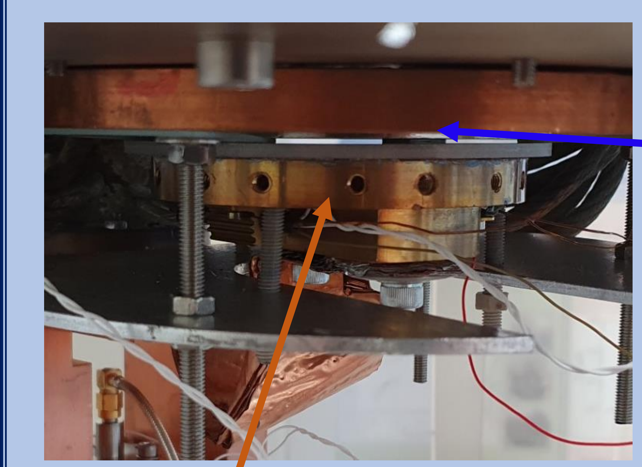
Split 6 GHz cavity

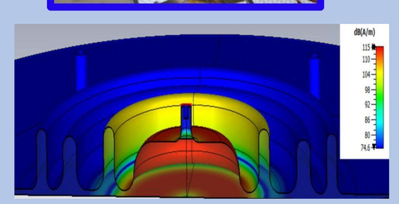
1.3 GHz cavity

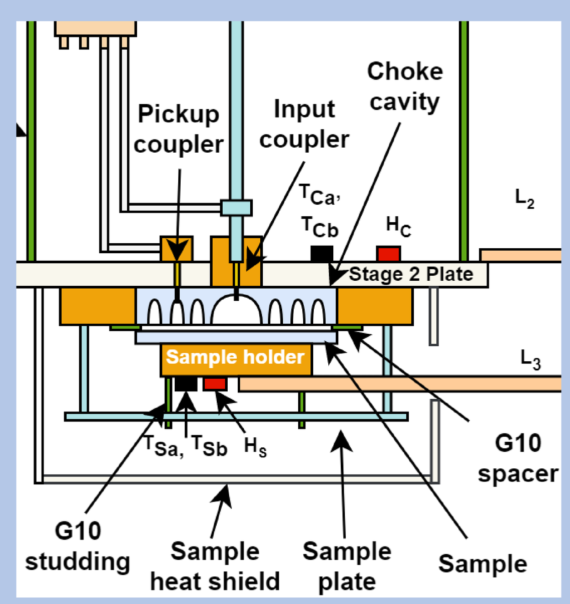
RF CHOKE CAVITY FACILITY

A recently commissioned high-throughput RF test stand allows for rapid TF sample surface resistance (R_s) **measurements every 2 days.**

Choke cavity & *H*-field.







Stage 2 of the cryogen-free system

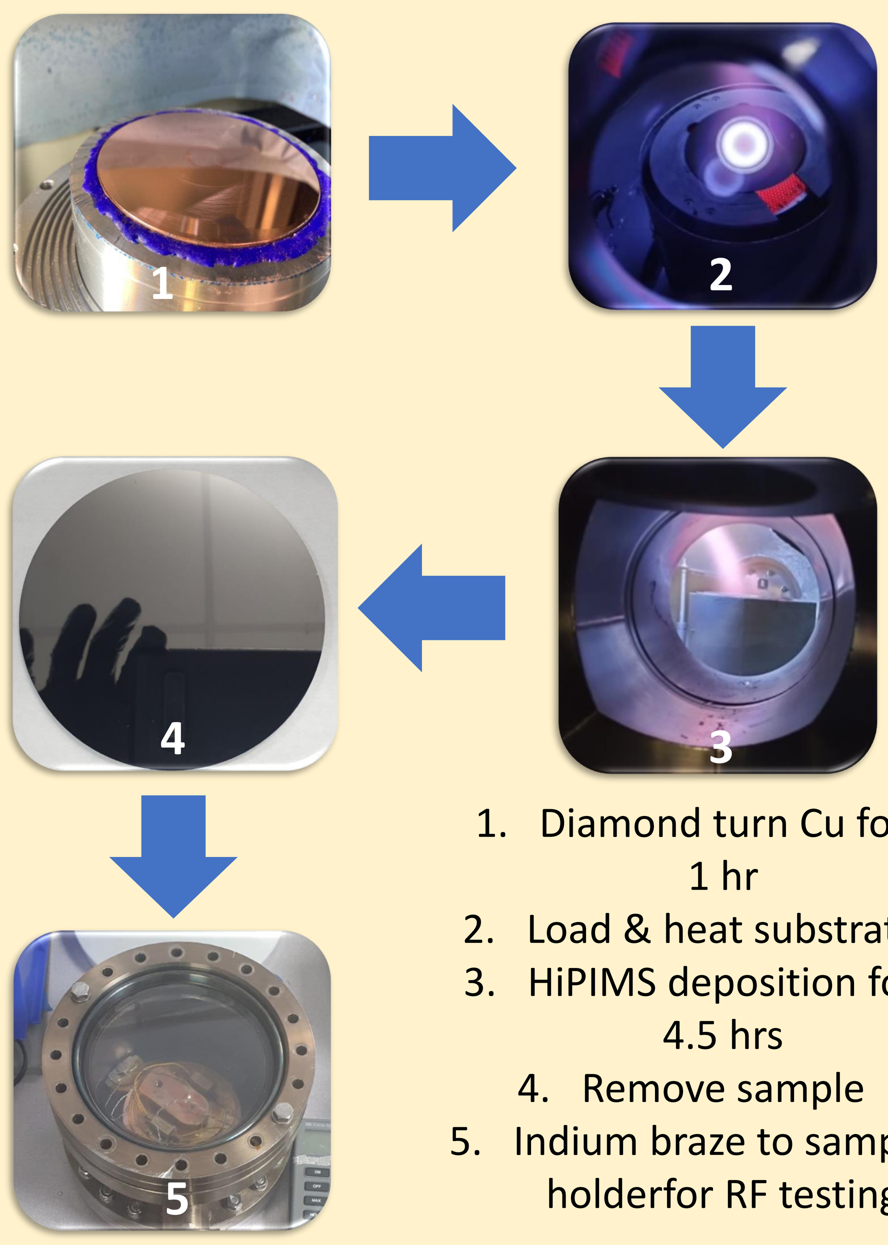
Sample – 90 to 130 mm TF/Cu.

Cavity & sample thermally & physically isolated with 1 mm gap – simple R_s measurements via RF-DC compensation.

Planar RF optimisation with choke cavity prior to QPR

Parameter	Present Choke	Upgraded Choke	QPR
Sample rate	3/week		1-2/month
Cooling	Cryocooler		LHe
$\boldsymbol{B_{sample}}$	1.2 mT	15 mT	120 mT
$\boldsymbol{T_{sample}}$	> 4 K		> 1.9 K
$\boldsymbol{f_0}$	7.8 GHz		400-1300 MHz
Capability	$R_s\,(T_{sample})$, $R_s\,(\boldsymbol{B}_{sample})$, $\Delta f\,(T_{sample})$		

SAMPLE PREPARATION

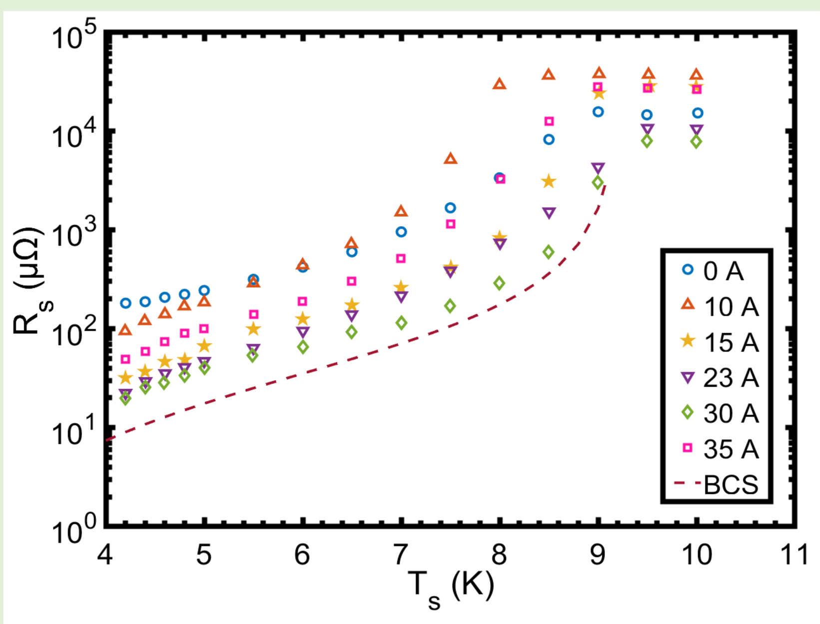


1. Diamond turn Cu for 1 hr
2. Load & heat substrate
3. HiPIMS deposition for 4.5 hrs
4. Remove sample
5. Indium braze to sample holderfor RF testing

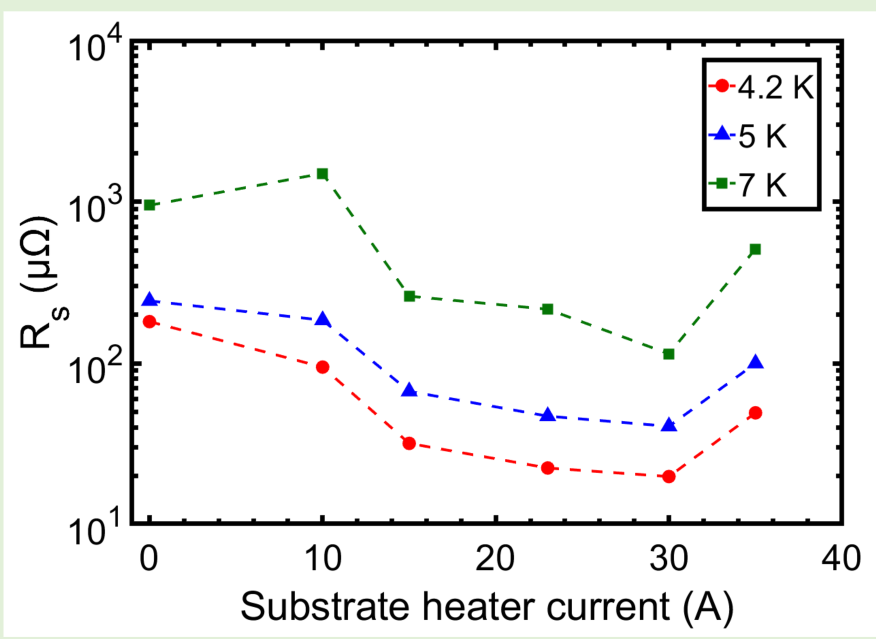
HiPIMS deposition parameters: 6 Nb/Cu samples (thickness ≈ 3 µm) deposited with planar magnetron and variable substrate heater current (temperature)

Deposition Parameter	Value
Base pressure (mbar)	10^{-9}
Initial heating time (h)	20
Initial heating current (A)	0 - 35
Pressure with heating (mbar)	10^{-7}
Average target power (W)	400
Pulse duration (µs)	80
Pulse frequency (kHz)	1
Discharge gas	Kr
Deposition pressure (mbar)	2×10^{-3}
Substrate heater current (A)	**0 - 35**
Substrate temperature (°C)	**RT to ≈ 650**
Deposition time (h)	4.5

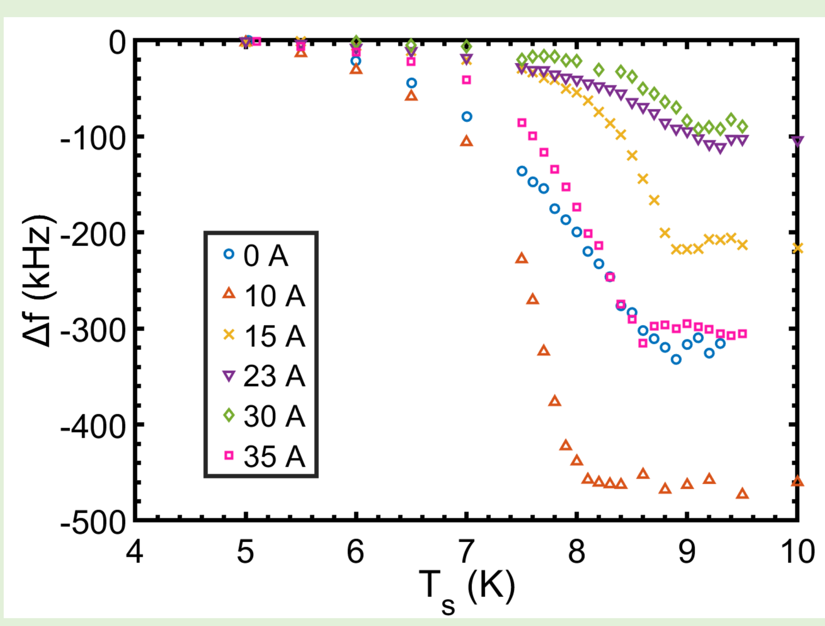
RESULTS



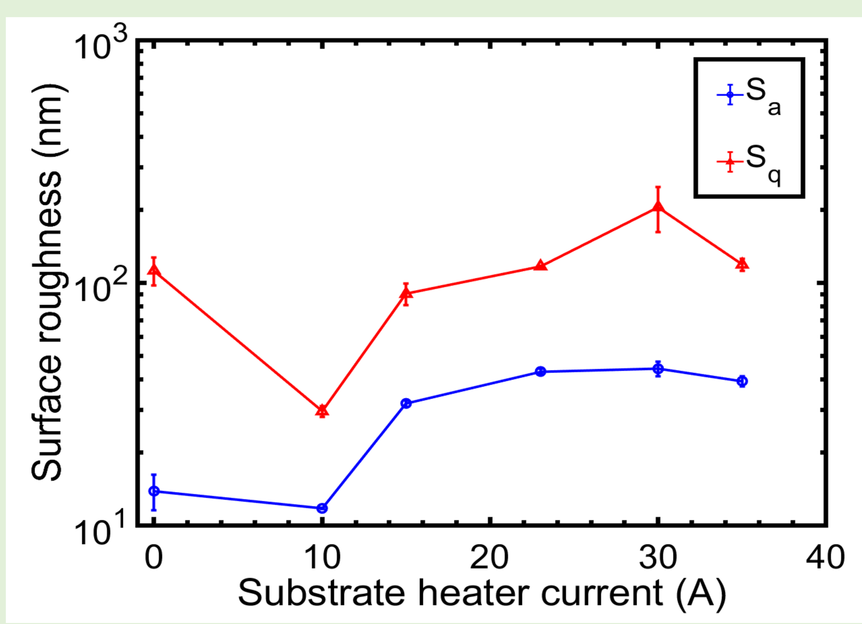
1. Surface resistance as a function of sample temperature, T_s ($\sigma_{R_s} \approx 15\%$).



2. Surface resistance as a function of substrate heater current (RT to ≈ 650 °C) - T_s = 4.2 K, 5 K and 7 K.



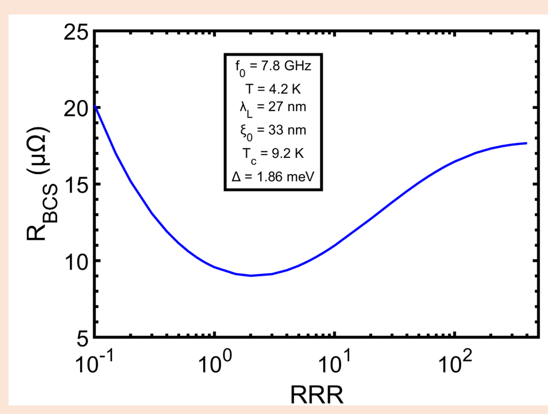
3. Resonant frequency shift (Δf) as a function of sample temperature - choke cavity temperature kept constant. Approximate T_c of samples can be inferred from where Δf levels off.



4. Surface roughness as a function of sample temperature – S_a is the mean arithmetic roughness and S_q is the root mean square roughness. Measured with a white light interferometer. S_a = 2-3 nm and S_q = 5-6 nm before deposition.

DISCUSSION

Typical R_{BCS} vs RRR for TF Nb



1. Lowest R_s = 19.9 ± 2.7 µΩ for 30 A (≈ 500 – 550 °C).
2. Decrease in R_s from 0 A (room temperature) to 30 A. Increases at 35 A (≈ 600 – 650 °C).
3. Lowest Δf for 30 A sample (T_c ≈ 9.2 K), highest Δf for 10 A sample (T_c ≈ 8.2 K).
4. Increase in surface roughness after deposition (S_a = 11.8 – 44.3 nm, S_q = 29.6 – 205.9 nm). Highest for the 30 A sample - roughness unlikely to be the dominant influence on R_s.

- Further analysis to be performed: DC magnetic field penetration, RRR, T_c, surface analysis
- Quick optimisation of deposition parameters (3 samples/week) possible, not limited to Nb.
- **Best Nb deposition parameters:**
  - QPR - higher-field measurements at three frequencies
  - Split 6 GHz cavity – cavity-like geometry with easy film inspection
  - Baseline for multilayers (e.g. Nb/AlN/NbTiN)

CONCLUSIONS

With a recently developed high throughput RF facility at Daresbury Laboratory, it is now possible for the lab to characterise thin films with the primary aim of optimising deposition parameters for peak RF performance. A study investigating the effect of substrate temperature during deposition of Nb/Cu planar samples has been performed with the focus being on low-field RF performance. The sample deposited with a heater current of 30 A (≈ 500 – 550 °C) performed best with the lowest R_s. A worn out Nb target meant that no further depositions were possible; however, more samples will be deposited with a new Nb target for comparison. All samples will be analysed further by measuring DC superconducting properties & surface properties.

ACKNOWLEDGEMENTS

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