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First measurements of HiPIMS Nb film-coated 3D cavity at 1.3 GHz down to 40 mK

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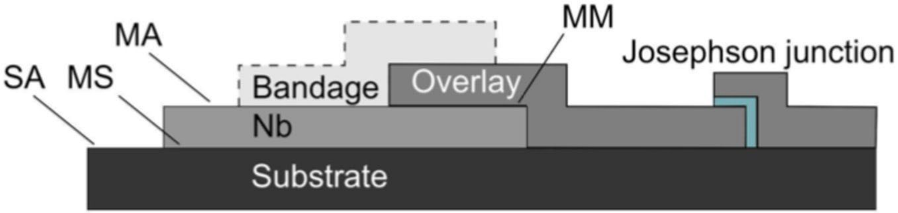
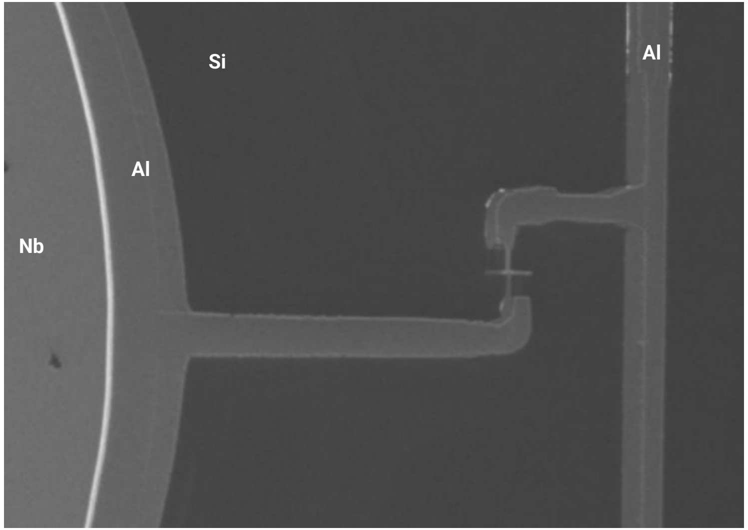
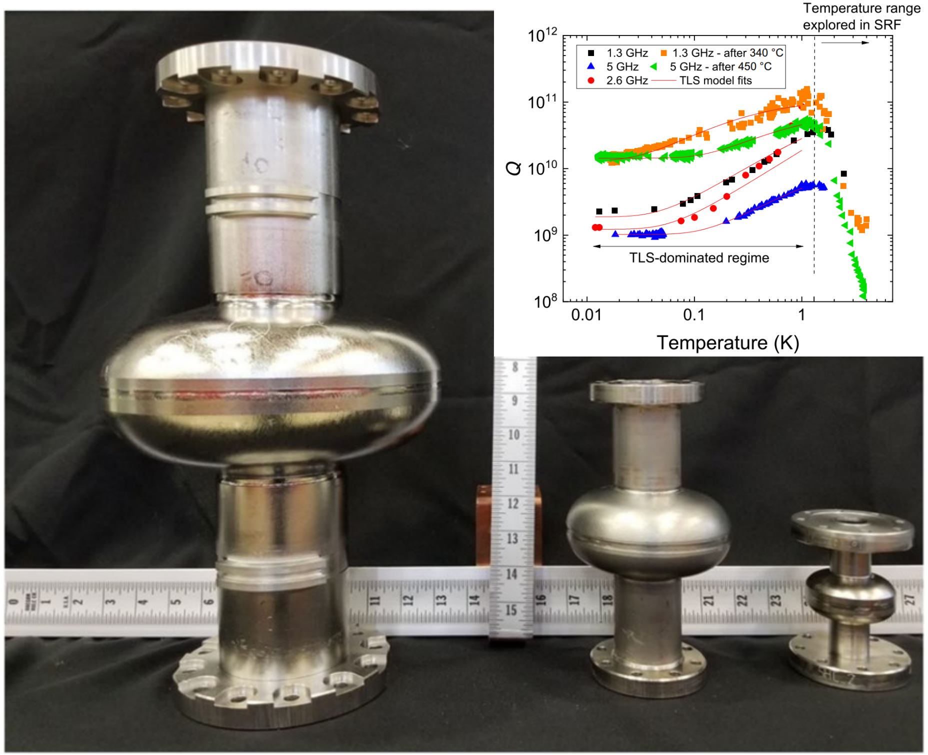
The motivation of this study is to isolate one loss channel

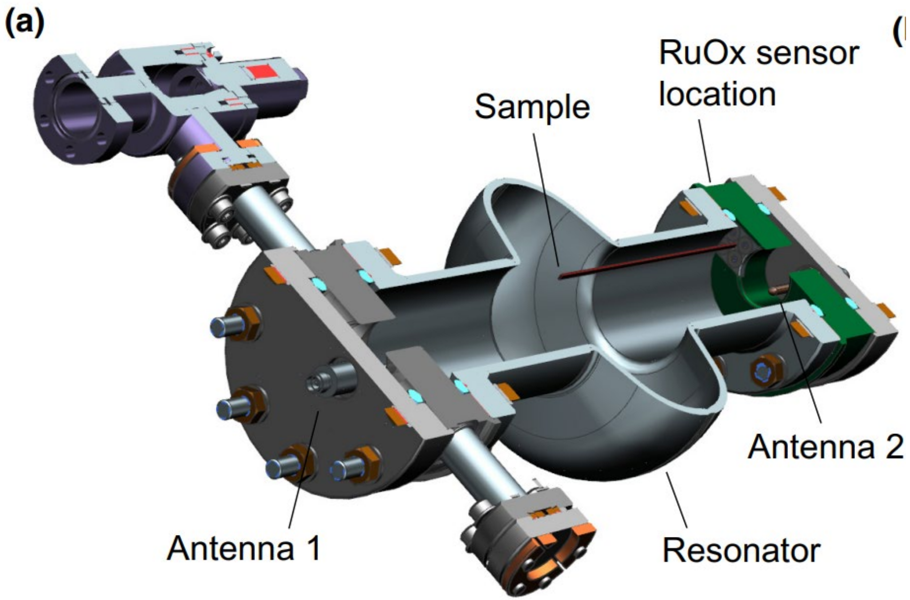




- Superconducting qubits comprise a number of materials
- Coherence time is one of the key figures of merit for superconducting qubits
- It is difficult to evaluate contributions of different loss mechanisms from the performance of qubits
- We would like to isolate different materials, so that we can study and quantify each loss mechanism

3D cavities can be used to isolate different loss mechanisms

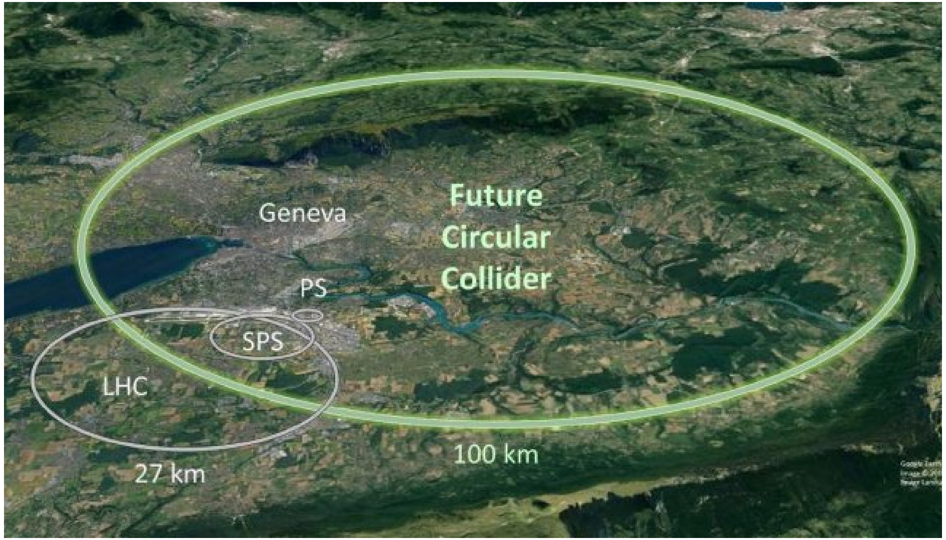




Romanenko et al., Phys. Rev. Applied **13**, 034032

Checchin et al., Phys. Rev. Applied **18**, 034013

Niobium film developments for FCC

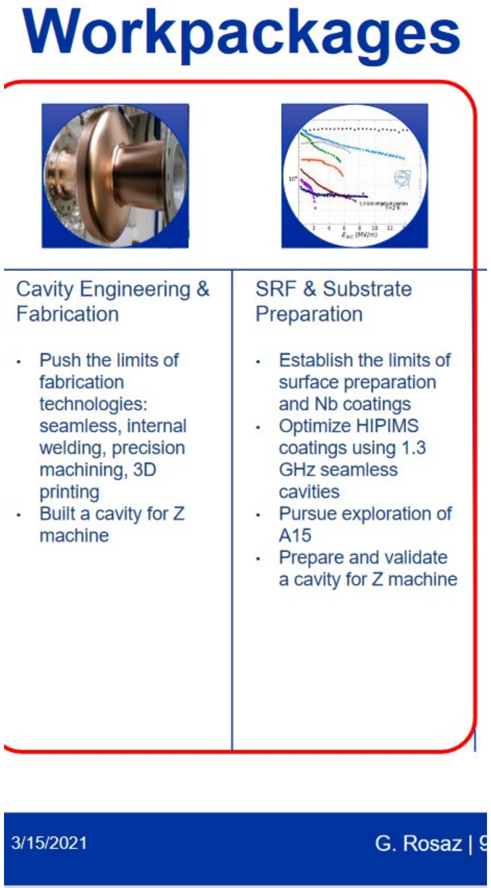


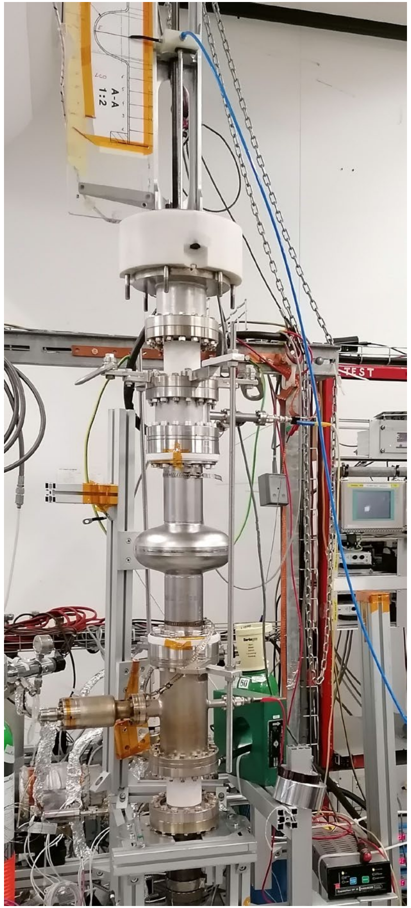
LHC Nb film:

- $Q_0 > 2 \cdot 10^9$ @ $E_{acc} = 5$ MV/m @ 4.5 K

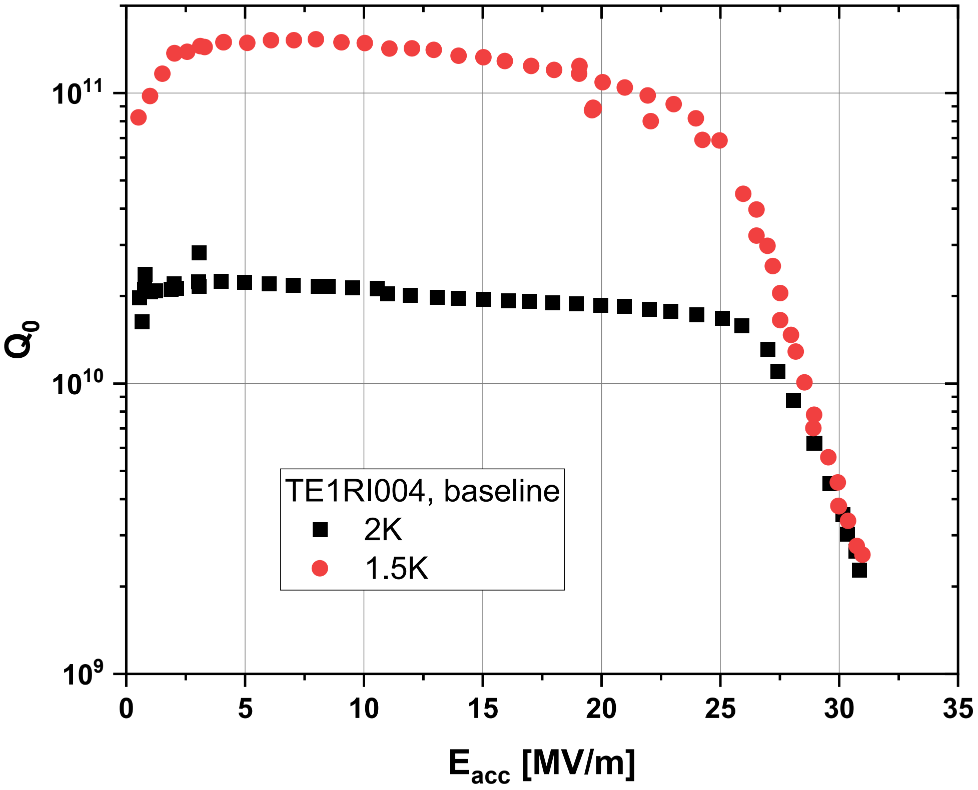
FCC Nb film target:

- $Q_0 > 3 \cdot 10^9$ @ $E_{acc} = 12$ MV/m @ 4.5 K



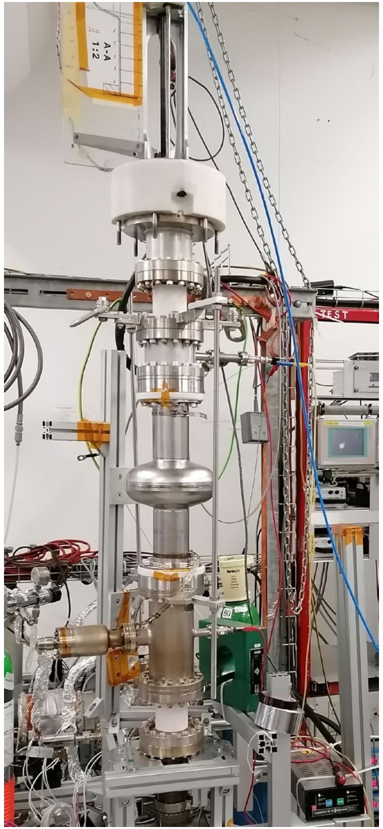


Qualification of a 1.3 GHz niobium cavity for film studies



- Electropolishing treatment for a welded bulk niobium cavity
- A typical behavior of an SRF cavity after electropolishing
- Limited by the high field Q-slope at high fields
- Residual resistance is ~ 1 nΩ

Cavity coating with HiPIMS niobium film @ CERN

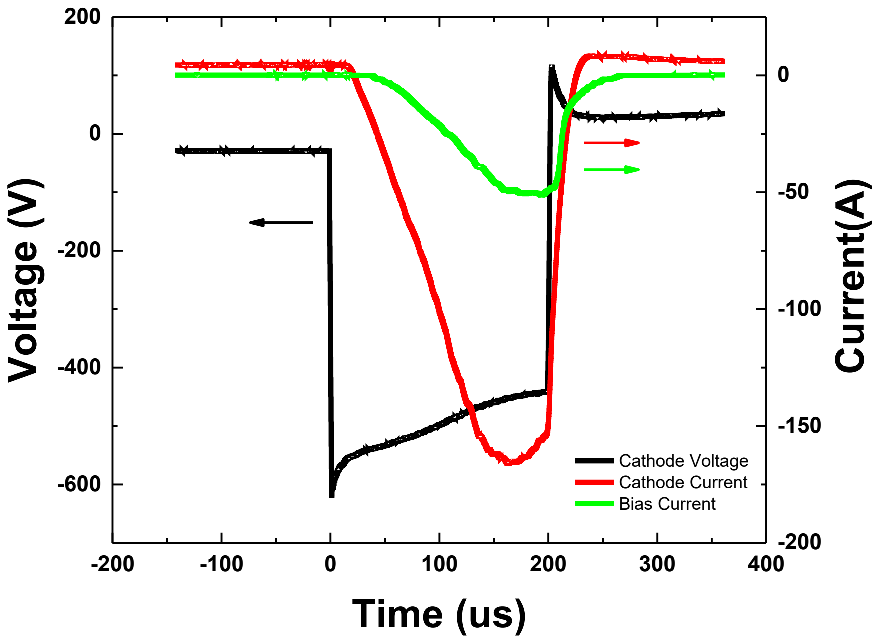


Cell coating:

Thickness: 6µm

Coating technique: Biased-HiPIMS

- Main pulse duration: 200us
- Bias voltage: -75V
- Peak current: ~170A
- Bias current: ~51A
- Power: ~1.2kW
- Gas Kr
- Pressure: 3 · 10^{-3} mbar
- Coating duration: 6 hours
- Target: Nb RRR300
- Magnetron: standard cylindrical magnet (50mm long, 30mm diameter)



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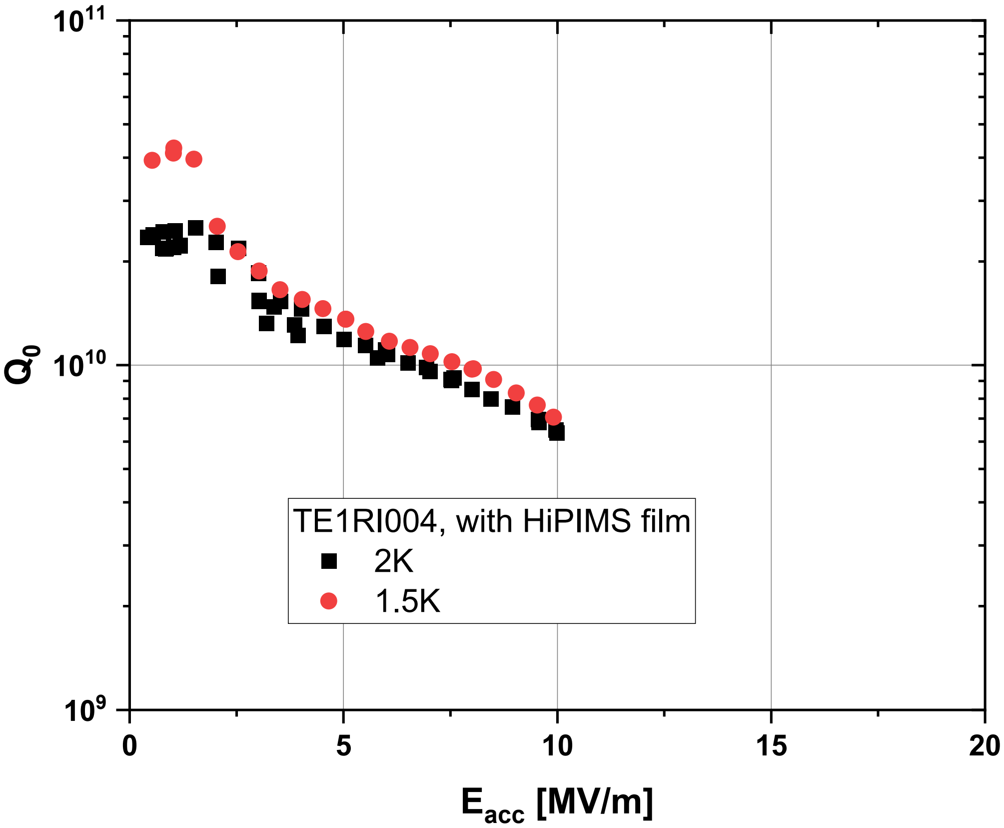
HiPIMS niobium film measurements in "accelerator" regime



- After thin film deposition, performance is representative of niobium thin film
- Strongly field-dependent residual resistance
- Limited by a thermal breakdown
- Residual resistance is ~ 10 nΩ

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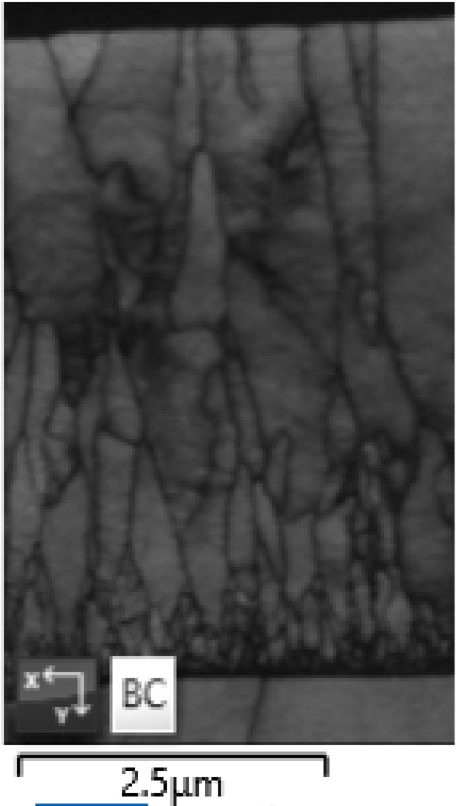
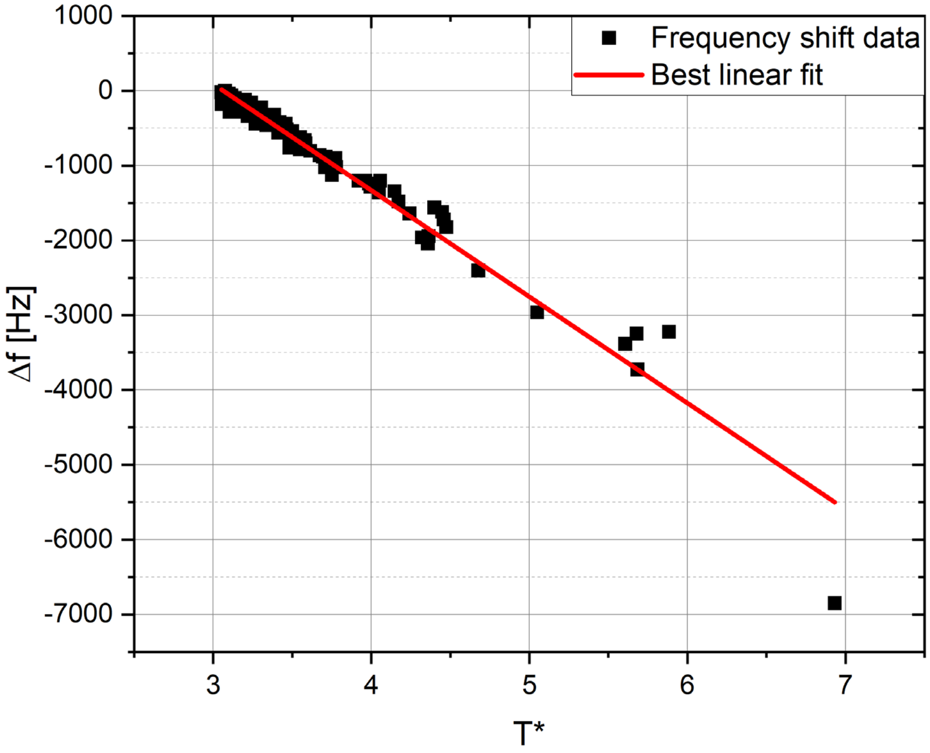
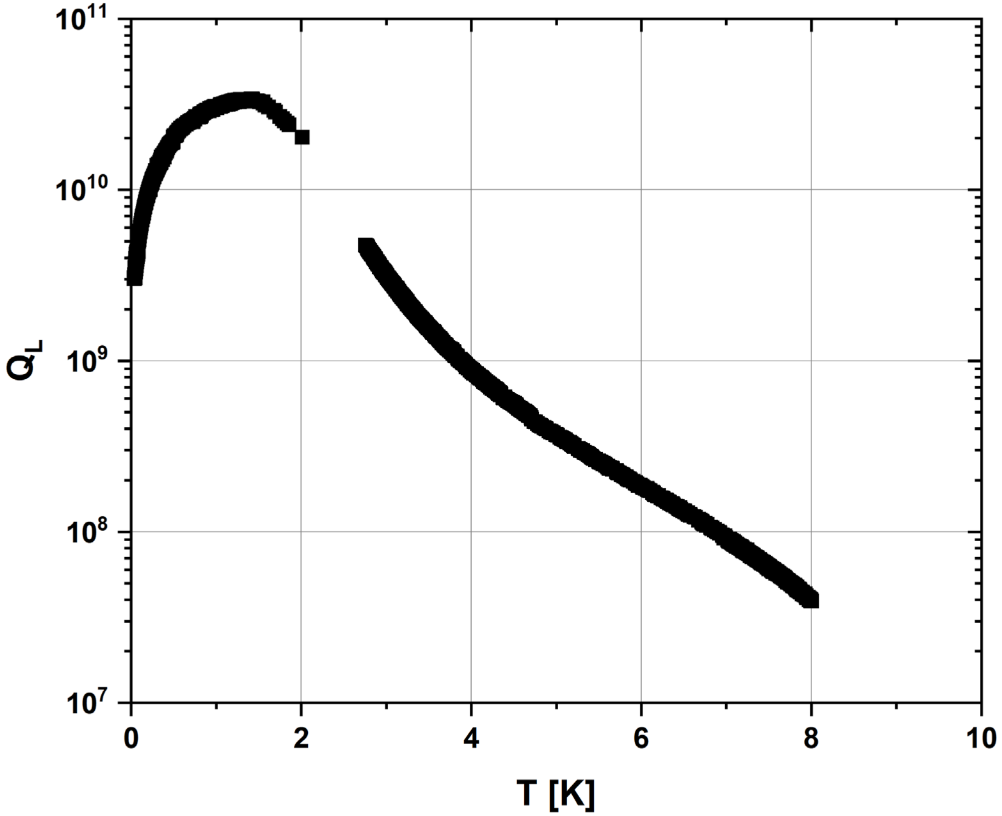
HiPIMS film structure and composition





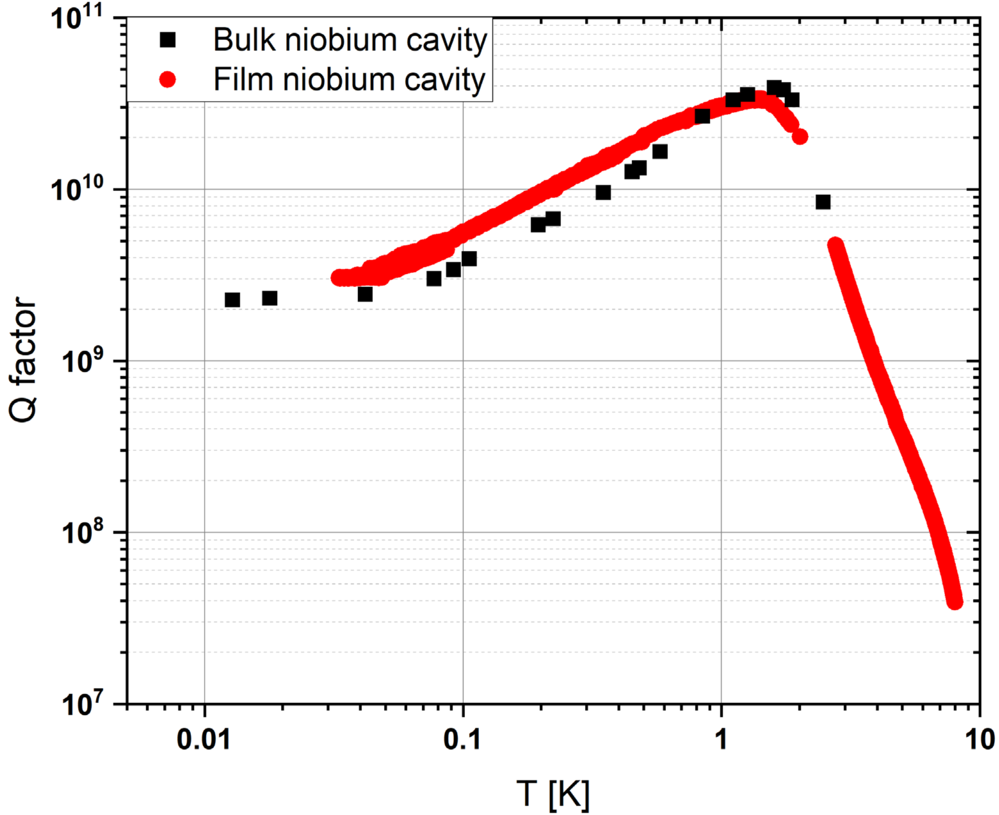
- 6 μm thick niobium film
- 1 μm grain size on the surface
- ~ four orders of magnitude more grains than bulk niobium
- RRR ~ 30 vs RRR ~ 300 for bulk niobium

HiPIMS niobium film results down to mK temperatures



- Surface resistance is BCS dominated above 1.5 K
- Anomalous loss below 1.5K
- It was difficult to control DR temperature between 2 K and 3 K
- Because of the fixed couplers, the transmission becomes too weak above 8 K to collect reliable data

HiPIMS niobium film comparison with bulk niobium



- Similar temperature dependence of the surface resistance between bulk niobium and film niobium
- Surface resistance decrease with temperature below 1.5 K
- Surface resistance is ~ 100 nΩ at 40 mK in film cavity, corresponding to τ ~ 100 msec

Bulk niobium results from Romanenko et al., Phys. Rev. Applied **13**, 034032

Conclusion

- 3D cavity at 1.3 GHz is used to isolate and evaluate microwave loss of HiPIMS niobium film down to 40 mK
- Microwave loss of HiPIMS film exhibited temperature dependence similar to bulk niobium at low temperatures
- Surface resistance of HiPIMS film was measured at about 100 nΩ at 40 mK, corresponding to $\boldsymbol{\tau}$ ~ 100 msec, significantly longer than the typical coherence times of 2D superconducting qubits
- Studies continue to evaluate how microwave losses change after different surface treatments

Thank you!

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