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Microscopic Understanding of the Effects of Impurities in Low RRR SRF Cavities

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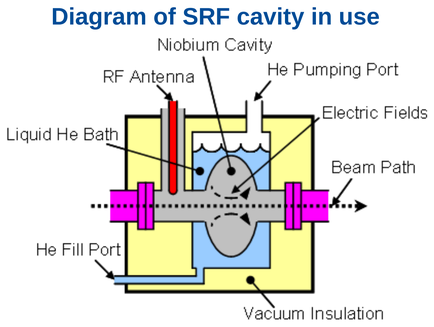
SRF = Superconducting Radio-Frequency

- SRF cavities are resonant structures made from niobium that generate the electric field along the beamline
- Goal of SRF studies is to design surface profile to increase quality factor (Q_0) and accelerating gradient

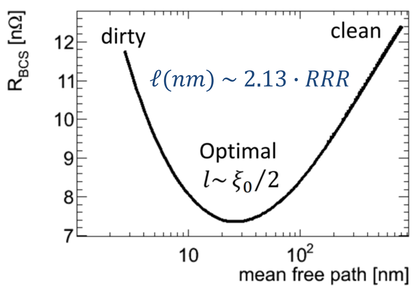
Motivation

- Many SRF studies follow a "clean bulk dirty surface" technique to optimize the BCS resistance by adding extrinsic impurities
- What role do intrinsic impurities serve?
  - Might perform similar functions as extrinsic impurities which have been shown to improve performance
- Understanding of intrinsic impurities will enable **future** high Q_0/high gradient **surface treatments**

Diagram of SRF cavity in use



Optimization of BCS resistance versus mean free path



RRR = Residual Resistance Ratio

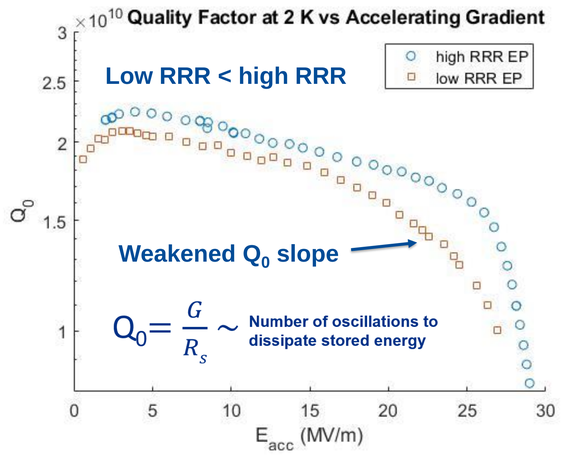
$$RRR = \frac{\rho(300\ K)}{\rho(10\ K)}$$

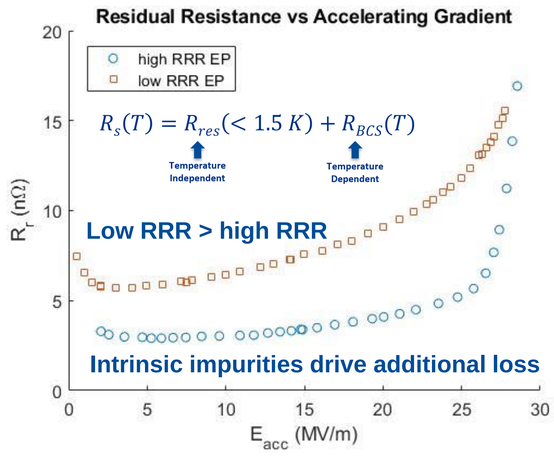
- RRR is lowered by impurities in the Nb
- High RRR for SRF is ~300

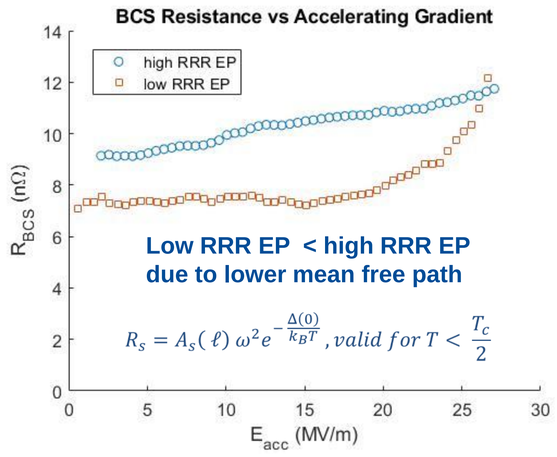
Experiment

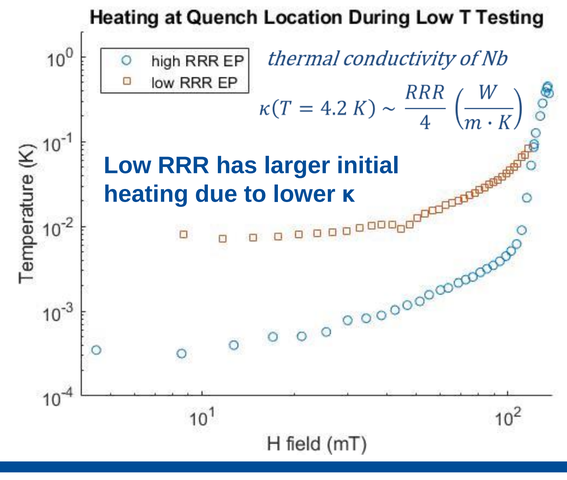
- RF testing on 1.3 GHz single-cell TESLA-shaped low RRR cavity in electropolished (EP) condition
  - Quality factor vs accelerating gradient
  - Temperature mapping
- Sample study on low RRR material
  - **RRR measurement = 35.11** → mfp ~ 75 nm
  - Secondary ion mass spectrometry (SIMS)
  - Electron backscatter diffraction (EBSD)

Cavity RF Testing Results: worse performance in general but **low BCS resistance**



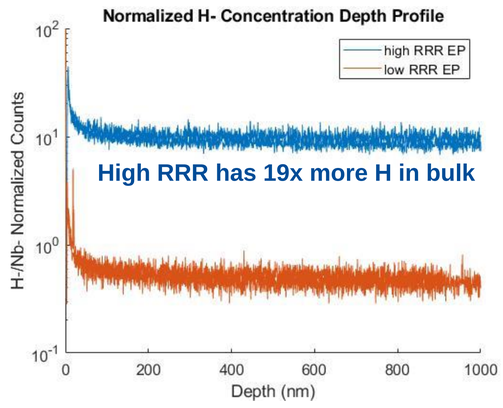


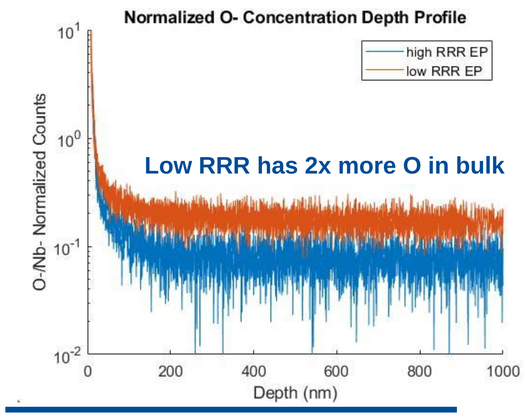




Impurity Profiles

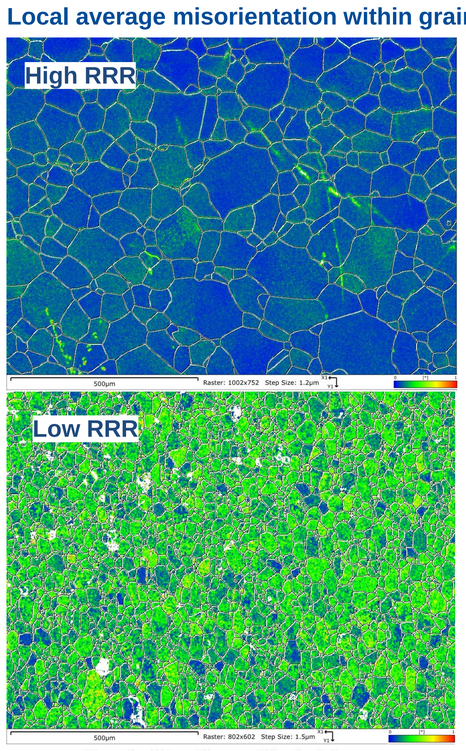
- RRR is a bulk property so we only care about deep in bulk
- **Impurity concentration is not primary reason for low RRR**



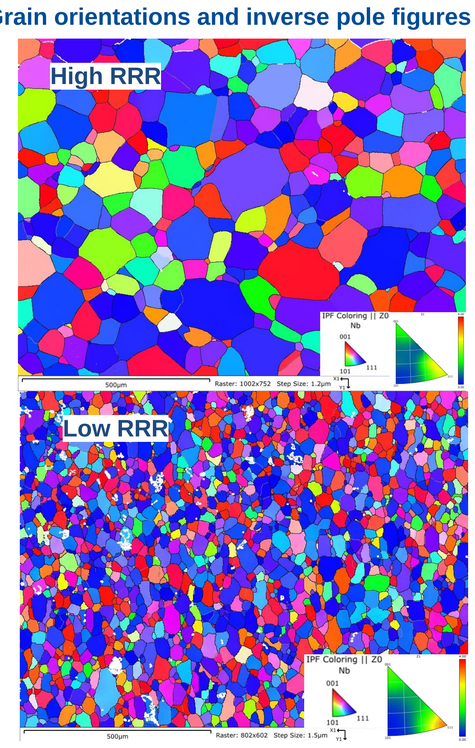


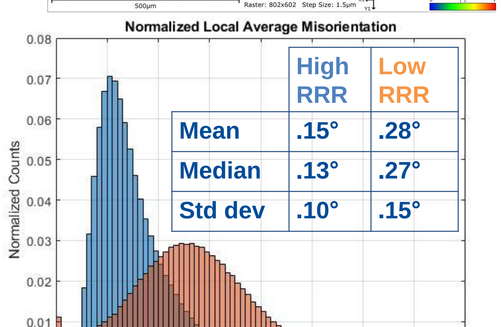
Grain Structure: small grains with high misorientation

Local average misorientation within grains

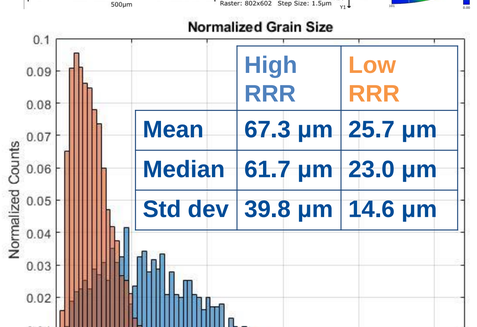


Grain orientations and inverse pole figures





	High RRR	Low RRR
Mean	.15°	.28°
Median	.13°	.27°
Std dev	.10°	.15°



	High RRR	Low RRR
Mean	67.3 μm	25.7 μm
Median	61.7 μm	23.0 μm
Std dev	39.8 μm	14.6 μm

Conclusions

- Low RRR cavity has:
  - Mitigated HFQS
  - High residual resistance
  - Low BCS resistance
  - Increased heating at quench location
- Low RRR material has:
  - Less hydrogen in bulk
  - No "key" impurity in bulk
  - **High misorientation within grains**
  - **Small grains**
- The low RRR is caused by misorientation of Nb lattice itself, not from impurities
  - Does high misorientation mitigate grain growth?
  - Are high misorientation/small grains synonymous with low mean free path?

Next Steps

- Measure strain in lattice via X-ray diffraction
- Repeat sample measurements after high temperature anneal to promote grain growth

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