Evaluation of SRF thin film properties using a microstrip disk resonator

Daniel Bowring

Lawrence Berkeley National Laboratory

July 19, 2012

Motivation

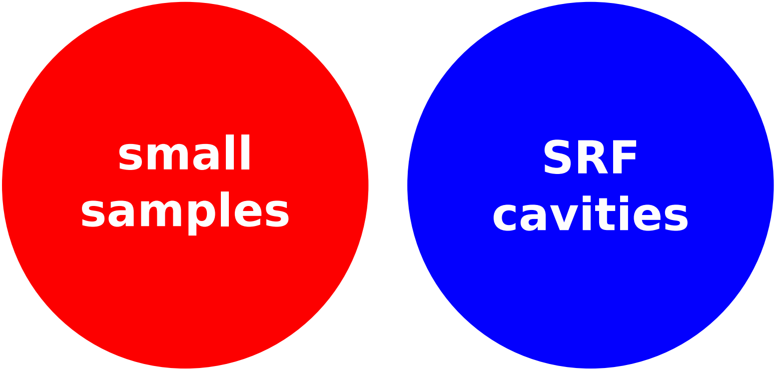
Disk resonator

Preliminary results

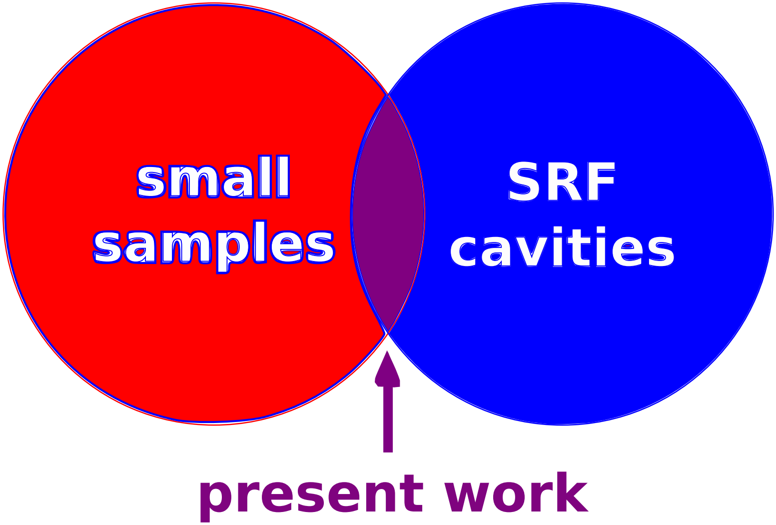
Future aspirations

NbTiN postscript

Overview



Overview



Overview

1. Motivation: Evaluating multilayer films
2. **Disk resonator:** operating principle, experimental design
3. Preliminary results
4. Future aspirations
5. Postscript: A note on NbTiN

We want a method to evaluate multilayer thin films.

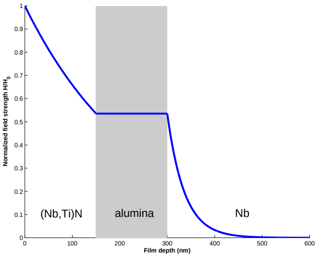


Figure: Thin films screen the magnetic field from the bulk layer.

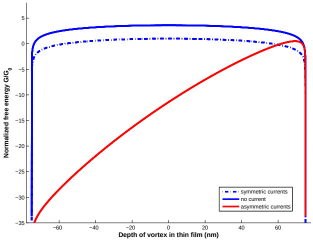
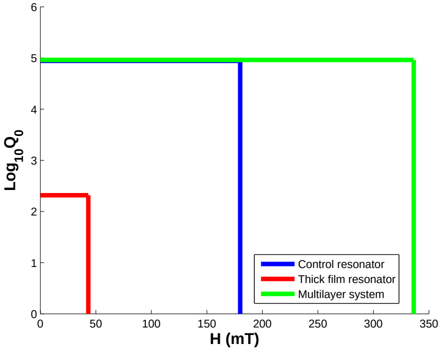


Figure: This is why it works: asymmetric currents tilt the free energy profile of a flux vortex.

$$G/L = \frac{\phi_0^2}{4\pi\mu_0\lambda^2} \ln\left[\frac{d}{1.07\xi}\cos\frac{\pi u}{d}\right] - \phi_0 \int_u^{d/2} J(z)dz$$

Test this using NbTiN films.



NbTiN has **low** H_{c1}. This simplifies testing, leaves basic physics unchanged. We didn't try to exceed 180 mT right away. **Walk before you run.**

What has been done?

- Theory
- Modeling
- Design and fabrication
- Process development: reactive magnetron sputtering in JLab's UHV system.
- Preliminary cryo/RF testing
- Material analysis

Inconveniently-timed capital development at JLab $\rightarrow$ No clean multilayer films for testing. Yet.

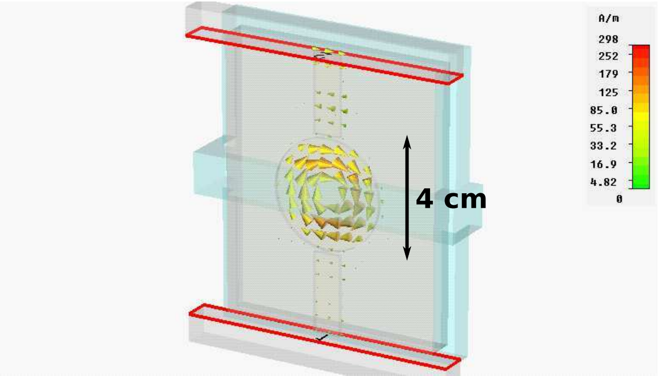
Our experimental facility can evaluate multilayer thin films under cryogenic, RF conditions.

Experimental design goals:

- Reduce parameter space: evaluate multilayer physics using small, flat samples.
- Highest magnetic field must be on sample → sample is performance-limiting feature.
- Suppress multipacting, field emission as much as possible.
- Modular, easily-demountable samples → quick experimental turnaround. In the VTA, can get 2 measurements per day if you push.
- Small flat samples → easier & quicker post-facto surface analysis.

A microstrip disk resonator satisfies the above requirements.

Pillbox-like TM_{01} fields supported between a circular disk (which sets frequency) and a superconducting ground plane.

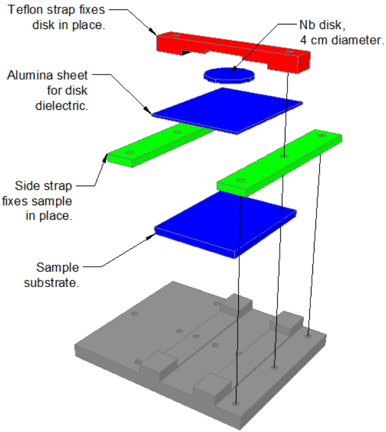


$f = 2.8$ GHz, $Q_0 \approx 10^5$ (very low U). Capacitive coupling.
Simulations via CST Microwave Studio.

Other configurations are possible.

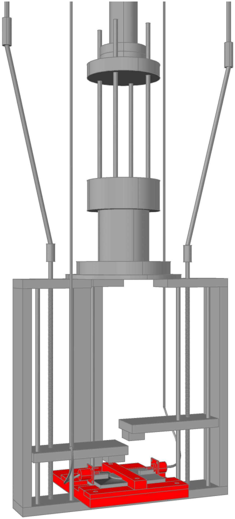
- “Active” sample size set by frequency requirements. (1 cm radius $\rightarrow$ 6 GHz.)
- Rectangular ground plane not required. Can operate with circular samples (and minimal hardware changes).

Resonator assembly



Currently, minimum sample size is 4 cm diameter.

Dewar insert for operation in JLab's VTA



Preliminary results

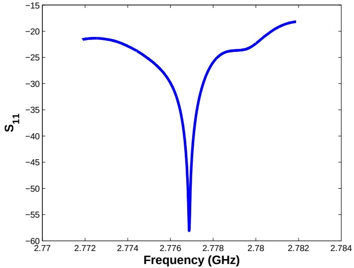


Figure: $f = 2.78$ GHz, $Q_0 \approx 10^3$.

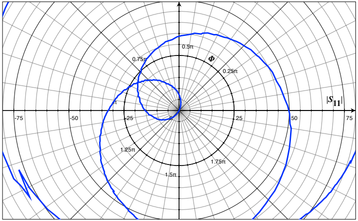


Figure: Tuners permit critical coupling.

Coupler upgrade, full system characterization must wait until TEDF is online.

Future aspirations

- Several people at this workshop have indicated a desire to evaluate SRF properties of small samples.
- Upgrade couplers, amplifier.
- Add thermometry capabilities.
- This system is not only useful for multilayer films. **Can also explore SRF films on various substrates; bulk properties from grain size, surface treatments; build large statistical database.**
- $R_s = \frac{A\omega^2}{T} e^{-\Delta/kT} + R_0 \rightarrow$ at low temperatures, measure R_0 directly.

In the future, use this system in Texas A&M's cluster tool.

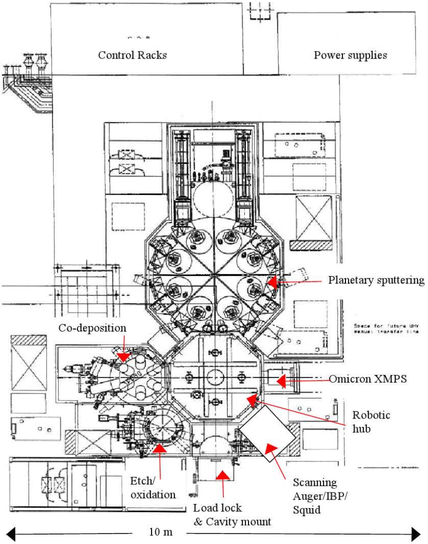
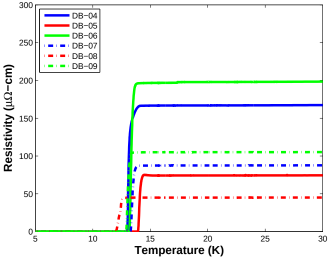


Figure 1. Ulvac MS-6000 system for surface modification and characterization.

A brief epilogue re: NbTiN



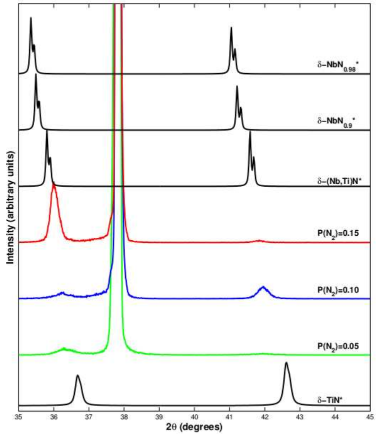
- $T_c = 13.2 \pm 0.4$ K
- RRR$= 1.46 \pm 0.58$ (but this was during commissioning)

What is NbTiN?

Typically, literature mentions T_c with no further analysis. Everybody writes it in a different way:

- NbTiN
- (Nb,Ti)N
- δ-NbTiN
- $Nb_{1-x}Ti_xN$
- Nb-Ti-N

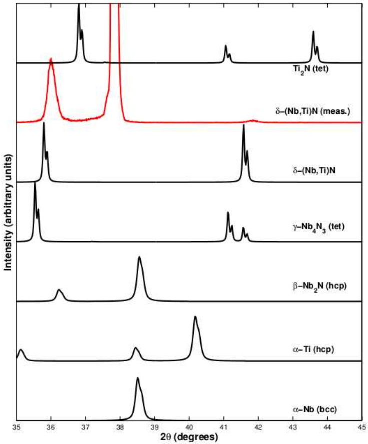
XRD comparisons to PDF



XRD measurements of JLab-made films with various $P(N_2)$, compared with PDF.

- Powder Diffraction File, edited by S. Kabekkodu (International Centre for Diffraction Data, Newton Square, PA, USA, 2011).

XRD comparisons to PDF



Comparison of JLab-made film with other possible phases of the Nb-Ti-N system.

- Powder Diffraction File, edited by S. Kabekkodu (International Centre for Diffraction Data, Newton Square, PA, USA, 2011).

δ−(Nb,Ti)N

- Substitutional solid solution.
- B1 structure similar to NbN.
- Ti stabilizes the δ-phase.

Acknowledgements

L. Phillips, J. Spradlin, A.-M. Valente-Feliciano, X. Zhao