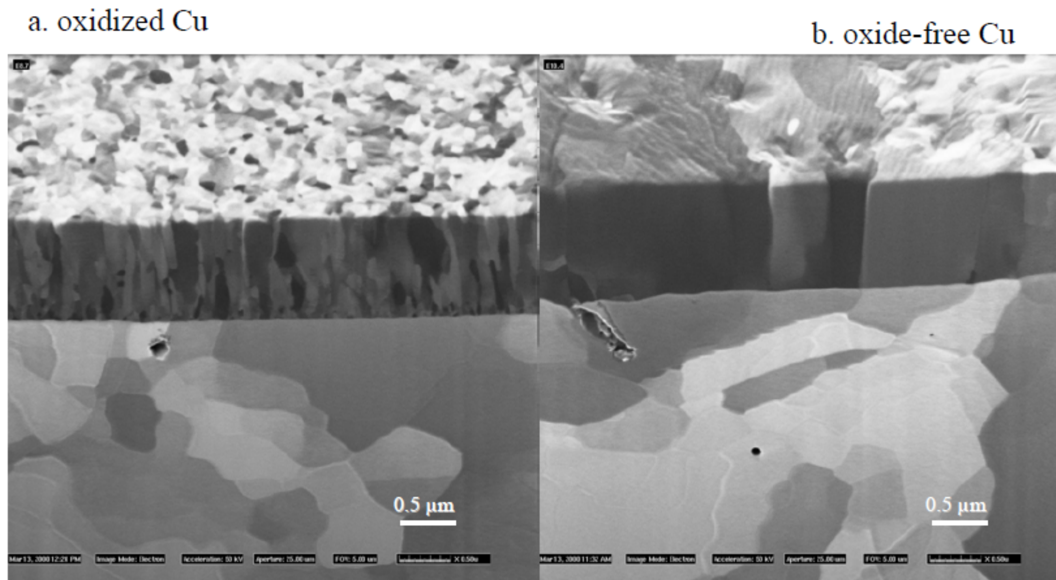
A LOCAL MEASUREMENT OF THE ELECTRONIC MEAN FREE PATH OF NIOBIUM AT 10 K

Daniel Bowring and Larry Phillips

THE PROBLEM

It is essential to know the electron mean free path, L_e, within the superconducting penetration depth.

- L_e must be high enough to avoid lowering H_{c1}.
- For thin films, L_e varies strongly with film depth x.



Courtesy: P. Jacob – EMPA & S.

Figure 1: FIB micrographs of Nb films deposited on 1.5GHz Cu cavities by magnetron sputtering at CERN

THE PROBLEM (cont.)

- Measurements of RRR are an average over the film thickness.
- Knowing $L_e(x)$ indicates defect density variation due to **film structure evolution** and **deposition energy**.
- Defect density will decrease with distance from the substrate for, e.g. sputtered films.

METHOD

- 10 K measurement of R_s at various frequencies ω_i.
- But: each measured $R_s(x,\omega_i)$ is integrated over a skin depth $\delta(\omega_i)$.
- Infer $L_e(x)$ by comparing thin films with control samples in which L_e = constant.
- Measurements of R_s at various frequencies allows a tomographic reconstruction of $L_e(x)$.

METHOD (cont.)

- **Caution: this approach is only straightforward when *j*=σ*E*** (normal RF skin depth). Real part of the surface impedance given by

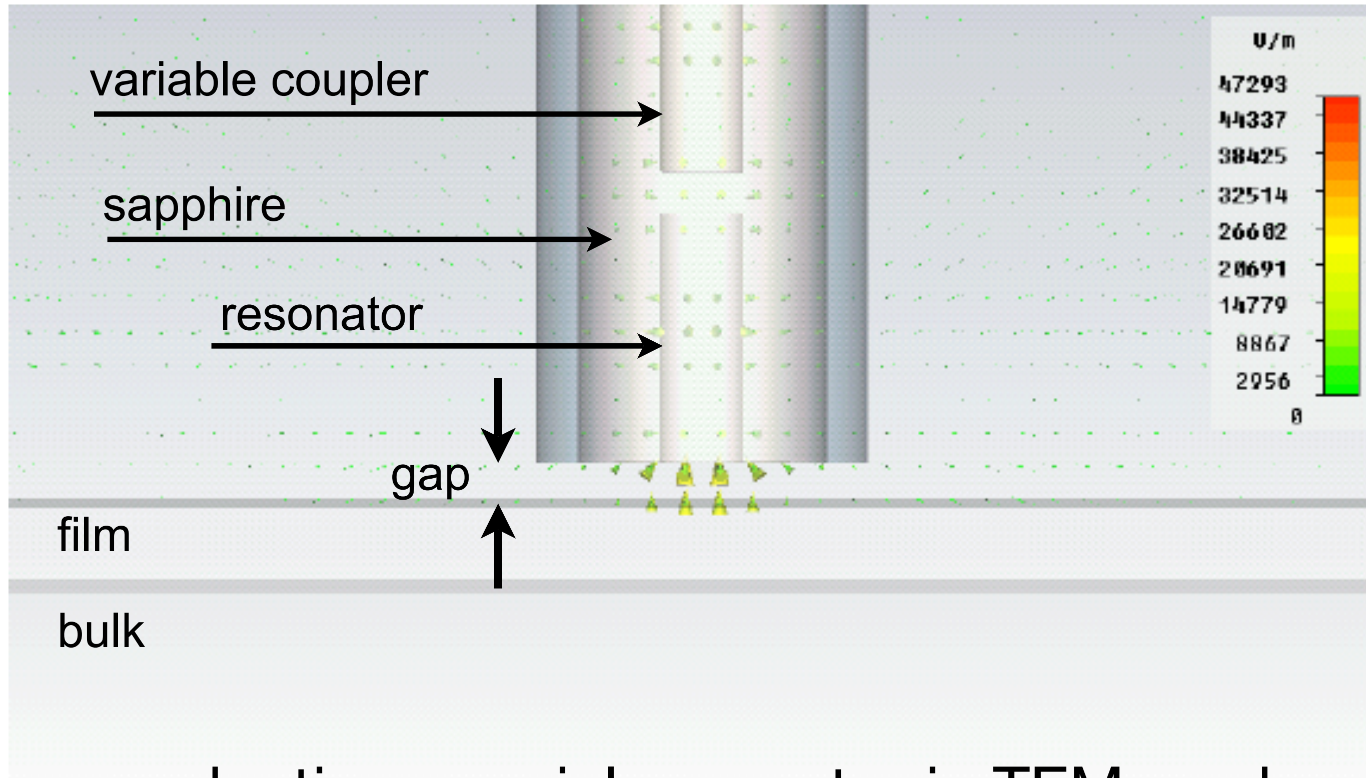
$$R_{\mathrm{s}} = \frac{\mu\omega}{2\sigma} = \frac{1}{\sigma\delta}$$

- When L_e >> δ the **anomalous skin effect** applies:

$$R_{\mathrm{s}}(L_e) = \left[\frac{\sqrt{3}\pi L_e}{\sigma}\left(\frac{\mu_0\omega}{4\pi}\right)^2\right]^{1/3}$$

and R_s becomes increasingly insensitive to L_e as L_e increases.

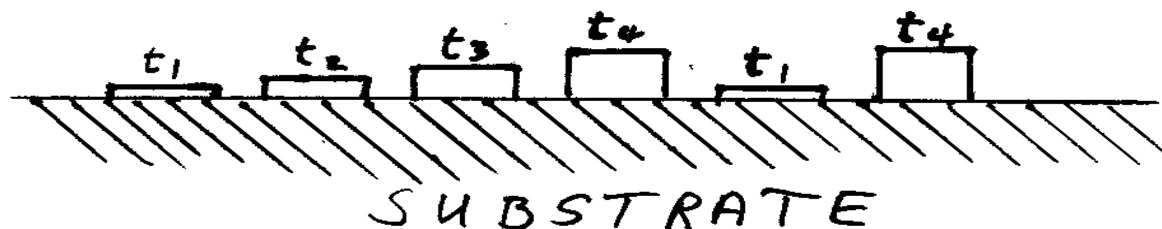
EXPERIMENTAL SETUP



- Superconducting coaxial resonator in TEM modes.
- Resonator and variable coupler are S.C. Nb with sapphire dielectric and are conduction cooled in vacuum to 2K.
- (Preliminary) finite element simulation using CST Microwave Studio shows electric field at ~28 GHz.

APPLICATION TO THIN FILMS

- In one continuous deposition, prepare by selective shuttering N samples of differing thickness, t_n.



- Coat all samples in situ with a dielectric diffusion barrier.
- Measure R_1 through R_n at 2 K and 10 K. For all frequencies, $R_n(2K) << R_n(10K)$ and for all samples we require $L_e \leq \delta$.

POSSIBLE APPLICATION TO DEFECT SCANNING IN NB SHEET MATERIAL

- Possible application to defect scanning in Nb sheet. (For 300K Nb the normal skin effect applies.)
- Any sufficiently high-*Q* resonator material can be used instead of 2 K Nb.
- Not as good as magnetometer for ferromagnetic defects.
- Simultaneous multiple frequencies provide better sensitivity.