A Sapphire Loaded TE_{011} Cavity for Surface Impedance Measurements – Design, Construction, and Commissioning Status

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Introduction and Motivation

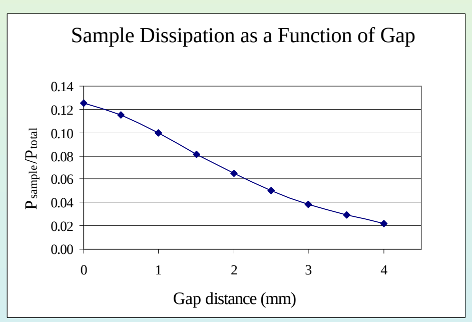
The RF surface impedance (R_s) of niobium at surface magnetic fields in the range of 90 – 180 mT is a subject of much interest. Anomalous “Q-drop” is observed to occur frequently in this region in SRF cavities. That the “drop” is often eliminated or “pushed up” by mild thermal processing suggests that it is a feature of rather mild surface chemistry. Thermometric mapping suggests that the losses are non uniform across regions with nominally uniform surface field strength. The closed geometry of SRF cavities makes detailed analysis of the relevant surface very difficult.

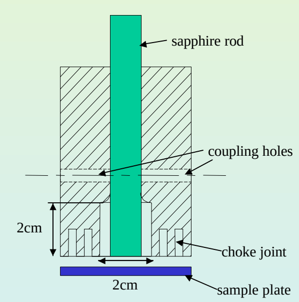
A unique RF test apparatus has been designed and constructed at JLab for the express purpose of presenting high RF magnetic fields to flat sample surfaces under controlled cryogenic conditions so as to calorimetrically measure the surface impedance and allow correlations with surface analytic measurements of the same localized surface.

The apparatus uses a sapphire-loaded cylindrical niobium TE_{011} cavity with a non-contacting endplate. Niobium coupons prepared by arbitrary techniques may be mounted and subjected to high RF fields and the thermal dissipation measured as a function of temperature. The apparatus has been constructed and is presently being commissioned.

Advantages of This Design Approach

- Sapphire has a high permittivity, high heat conductance, and low dielectric loss. It makes it possible to design a small RF cavity with a reasonably low frequency and low heat and radiation losses.
- The TE011 cavity design has no cross wall-joint RF current. With a good choke-joint design, joint loss can be minimized.
- RF losses are measured only on the flat sample plate which is easily bonded to the calorimeter and can later be detached for surface analysis.
- Demountable samples can be examined by various forms of analytical instrumentation, and treated by any surface chemistry techniques.
- Reproducible and robust measurements will allow for a more reliable correlation between RF parameters (R_s, λ, H_{c1}, H_{c2}, …) and surface properties (like morphology, purity and micro-structure).
- The calorimetric measurement technique is sensitive to the sample surface only while being insensitive to other cavity losses.
- Thin film sample measurements are possible.

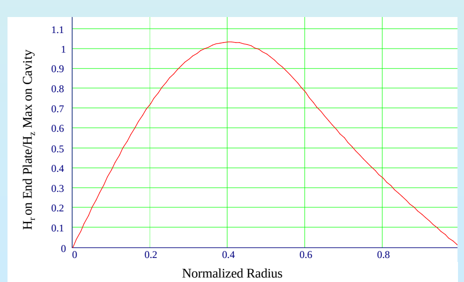




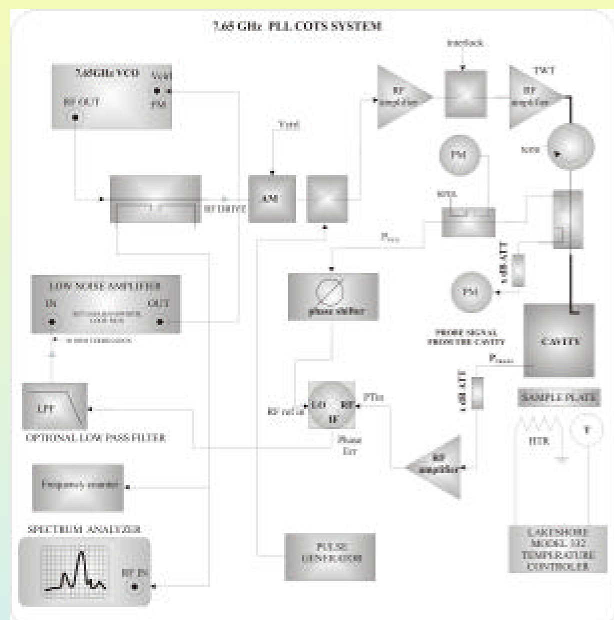
Schematic of the cavity/sapphire/sample holder geometry, used in MAFIA modeling for design optimization studies

The plot above gives the fraction of RF power dissipated in the SC sample, as a function of distance between sample and cavity, for fixed field. To the right is a plot of the radial magnetic field (scaled by the maximum magnetic field of the cavity), whose integral over the sample surface gives the total power dissipated. The specific power dissipated by the sample, in Watts, is given by:

$P_s = 3.7 \times 10^7 R_s B^2$ where R_s is in Ω, and B is in Tesla



RF System Layout

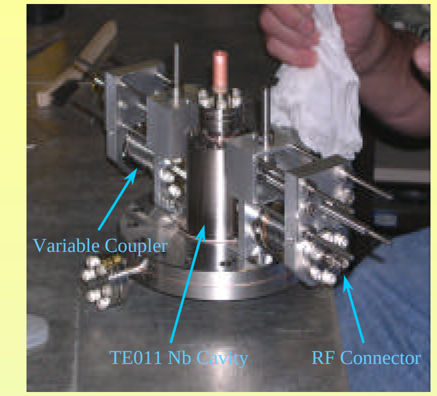


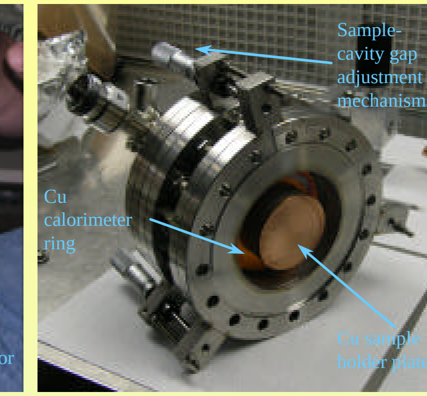
RF System Features

- Custom PLL/VCO to provide RF drive
- TWT amplifier
- Amplitude modulation used to control RF sample heating, provided by pulse generator
- Variable coupling for incident and transmitted power probes
- Full set of crystal detectors, power meters, frequency counters

Design Features

- Thermally isolated non-contacting endplate
- Independent temperature control of sample holder and cavity
- Cu sample plate and Cu ring function as calorimeter
- Cernox sensors (2 ea) on sample holder and Cu ring
  - Readout using Lakeshore Model 218 Temperature Monitor
- Heaters (25W) on sample holder and Cu ring, independently operated
  - Controlled using Lakeshore Model 332 Temperature Controller
- Sample edges not exposed to fields – no fringe field effects
- TE011 mode used to avoid multipacting on sample





Present Measurement Capabilities & Methodology

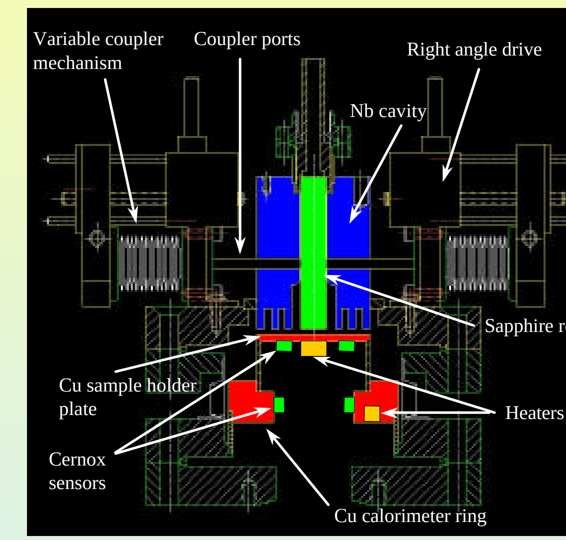
R_s as a function of T, H_{rf}

Set sample holder to desired temperature T_s using heaters on Cu calorimeter ring
Apply pulsed (square wave) RF field, of known amplitude, period, and duty cycle
- Duty cycle can be varied to keep ΔT low for a given RF amplitude

Measure T_s and Cu calorimeter ring temperature (T_r), and, calculate ΔT
Turn off RF field, and set Cu ring heater to yield identical ΔT
- Heater power is equal to RF power dissipated in sample

Penetration depth (λ) as a function of T

Set sample temperature T_s near T_{crit} of Nb
Apply small RF field
Vary T_s below and above T_{crit}, while measuring f_{cav}
Plot f_{cav} as a function of T_s/T_{crit}
- λ varies as $1/\sqrt{1-(T/T_c)^4}$
- Penetration depth sensitivity of this design is 3Å/Hz



Present Status/Future Plans

Present Status
- All cryogenic hardware has been fabricated and assembled
- Components have been leak checked
- Calorimeter section has been cooled down to 2K.
- Heater control exercised
  - Temperatures controllable to 2mK
  - Thermometer sensitivity ~ 1mK
  - Good thermal response
- All RF components in place
- Ready for cooldown of complete system after SRF workshop

Future Plans
- Begin commissioning runs
  - Cavity RF characterization
  - Continued calorimeter response investigations and calibration
  - RF system/amplitude modulation commissioning
  - Initial sample runs, sample power dissipation measurements, determination of R_s
  - Investigation/characterization of system sensitivity over RF field amplitude, RF duty cycle, and sample temperature ranges of interest
- Sample characterization program

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