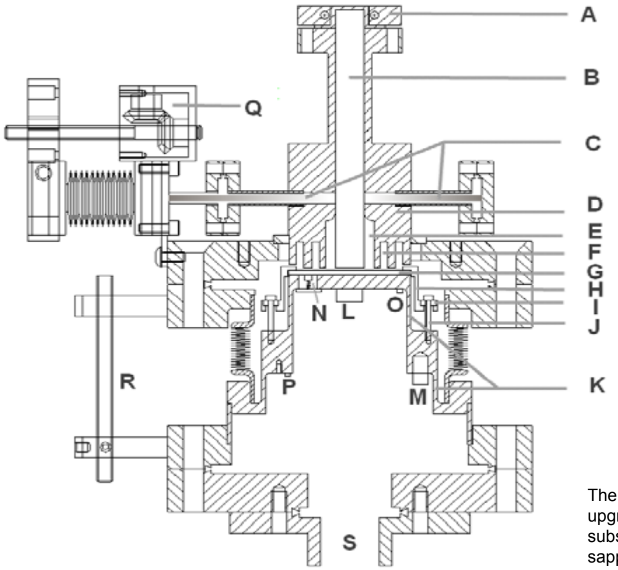
RF Surface Impedance of MgB_2 Thin Films AT 7.5 GHz

B. P. Xiao[1,2], M. J. Kelley[1,2], H. L. Phillips[2], C. E. Reece[2], T. Tajima[3]
[1]Jefferson Lab, Newport News, VA 23606
[2]College of William and Mary, Williamsburg, VA 23187
[3]Los Alamos National Lab, Los Alamos, NM 87545

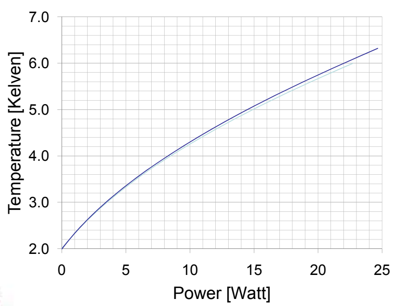
THPO048

Abstract:
The Surface Impedance Characterization (SIC) system in Jefferson Lab can presently make direct calorimetric RF surface impedance measurements on the central 80 mm² area of 50 mm diameter disk samples from 2 to 40 K exposed to RF magnetic fields up to 14 mT at 7.5 GHz. MgB_2 thin films from STI/LANL were deposited on 50 mm diameter Nb disks using reactive evaporation technique. We will report the results of measurements on these samples using the SIC system. The data will be interpreted based on BCS theory as the temperature-dependant properties suggest evaluation of the T_c, energy gap, penetration depth, mean free path and coherence length.



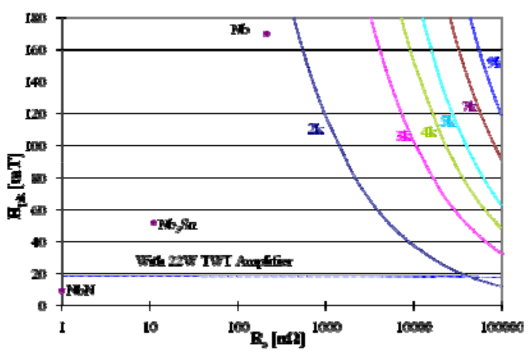
SIC system overview.
A.Cap for sapphire rod
B.Sapphire rod
C.RF coupler
D.Nb cavity body
E.TE_{011} cavity
F.Double choke joints
G.Sample on copper support plate
H.Stainless steel sample clamp
I.G-10 washer (x6)
J.Aluminium bolt (x6)
K.Stainless steel (or copper) thermal insulator
L.Heater
M.Heater
N.Thermal sensor mounted on spring
O.Thermal sensor
P.Thermal sensor
Q.Coupler tuning mechanism
R.Distance tuning mechanism (x3)
S.Port for vacuum and wires.
(Vacuum port of the cavity is not shown)

The calorimetry of the SIC system has been upgraded to accommodate different substrates such as aluminium, copper, sapphire, magnesium oxide, Nb, silicon, etc.



Temperature vs power for heater "L" (upper line) and for heater on sample (lower line). The accuracy of heat replacement measurement has been ensured to be within 3%.

Measuring capability of the SIC system



Solid lines: the limitation of copper thermal insulator under equilibrium temperature with CW RF power.

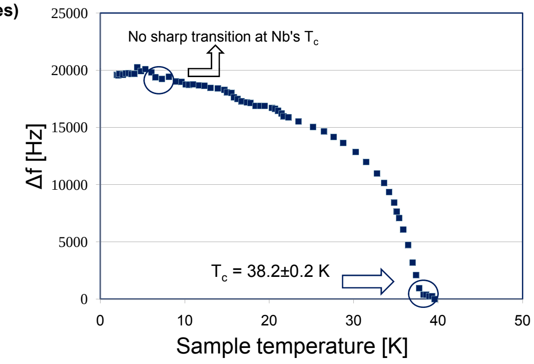
Dash line: current RF system limitation

Dots: BCS resistance and lower critical field of Nb, Nb_3Sn and NbN at 2 K and 7.5 GHz.

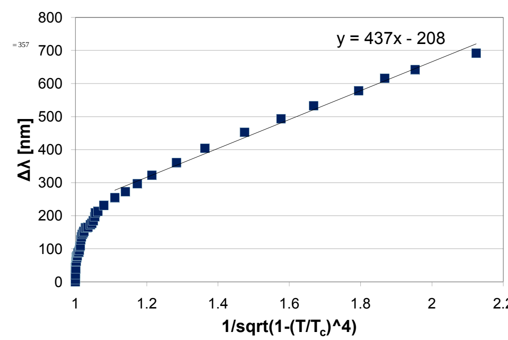
Surface Impedance $Z_s=\frac{P_{rf}}{kH_{pk}^{2}}+i\omega\mu_0\left(\lambda_{ref}+\frac{f-f_{ref}}{M}\right)$ with $k=3.70\times10^{7}\left[\frac{W}{\Omega T^2}\right]$ M=-20.5 Hz/nm $\frac{H_{pk}}{\sqrt{U}}=0.354\left[\frac{T}{\sqrt{J}}\right]$

Comparision of properties between MgB_2 and Nb (typical values)

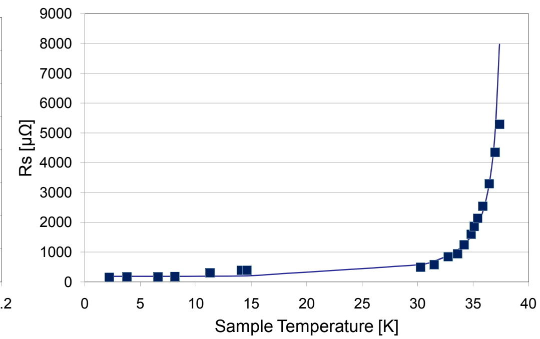
	MgB_2	Nb
T_c [K]	39	9.25
Energy gap [meV]	π-band: 2.3 σ-band: 7.1	1.5
Coherence length [nm]	5	40
Ginzburg-Landau parameter	40	1
H_{c1} [mT]	40	170
H_{c2} [mT]	30000	400
H_{sh} [mT]	1000	200



Penetration depth change with sample temperature



Surface resistance with sample temperature



$$\lambda(T)=\lambda_L\cdot\sqrt{1+\frac{\xi}{l}}\cdot\frac{1}{\sqrt{1-\left(\frac{T}{T_c}\right)^4}}-\lambda(2K)$$

with λ_L = 357 nm, $\lambda(2K)$ = 208 nm and ξ/l = 1/2

■ Measured R_s
— Theoretical value with Δ/kT_c = 2.14, T_c = 38.2 K, London penetration depth = 357 nm, Coherence length = 5 nm, Mean free path = 10 nm and Residual resistance = 181 μΩ

Summary:
The Surface Impedance Characterization (SIC) system in Jefferson Lab has been modified to adapt thin films on top of different substrates. Two calorimetry systems have been adopted to either precisely measure μW power produced on sample or measure Watts power with less accuracy. Thermal substitution technique has been qualified in both calorimetry systems within 3% error.
A 200 nm MgB_2 on top of 300 nm Al_2O_3 with Nb substrate S-I-S structure thin film has been measured using SIC system. The surface resistance at 2.2 K is 156 μΩ and critical temperature is 38.2±0.2 K. No sharp transition nearby critical temperature of Nb has been found in the surface impedance. Fitting the surface impedance data suggests parameters, London penetration depth = 357 nm, Coherence length = 5 nm, Mean free path = 10 nm. The surface resistance is dominated by the larger energy gap Δ/kT_c = 2.14.

ACKNOWLEDGEMENT :
This research was conducted at Thomas Jefferson National Accelerator Facility for the Department of Energy under grants DE-AC05-06OR23177.
Thanks to P. Kushnick , S. Dutton, M. Morrone and J. Spradlin for their support.

Jefferson Lab