# Superconducting DC and RF Properties of Ingot Niobium Used in SRF Cavity Fabrication*

Pashupati Dhakal,# Gianluigi Ciovati, and Ganapati Rao Myneni
*Jefferson Lab, Newport News, VA 23606, USA*
# *Email: dhakal@jlab.org*

**Abstract.** Superconducting radio frequency cavities fabricated from ingot niobium have become a viable alternative to standard high-purity fine-grain niobium for the fabrication of high-performing SRF cavities with the possibility of significant cost reduction. In this contribution, we present the results of superconducting properties of ingot niobium subjected to several heat and chemical treatments. In addition, we present the high power RF testing results on the cavity fabricated from ingot niobium.

**Keywords:** Ingot Niobium, Superconducting cavities
**PACS:** 74.70.-b, 29.20.Ej

## INTRODUCTION

The current state-of-art superconducting radio frequency (SRF) technology is relying on high-purity (residual resistivity ratio, RRR > 300), fine-grain (ASTM 5) bulk niobium (Nb). In recent years, large grain ingots Nb become an alternate to the fine grain Nb for the fabrication of high performance SRF cavities. Simpler fabrication procedures, potential cost reduction, higher thermal stability at 2K, as well as reproducibility in the performance of cavities has attracted the SRF community towards the fabrication of SRF cavities with ingot Nb for future accelerators [1,2]. The study of the superconducting properties of this material is important to optimize the chemical and heat treatment procedure during the fabrication of SRF cavities to achieve high values of the quality factor, $Q_0$, at 2 K and accelerating gradients of ~ 20-25 MV/m for future accelerators. Recently [3-5], the DC and low frequency magnetic and thermal properties of large-grain ingot niobium samples subjected to different chemical and heat treatment were reported. In this contribution, we report on a similar study of the cylindrical hollow rods fabricated from four new niobium ingots (labelled F, G, H and I), manufactured by CBMM, Brazil, and subjected to the chemical and heat treatment used in cavity fabrication. The RRR obtained from the thermal conductivity of the samples at 4 K is ~ 200 and the Ta content is ~ 700-1300 wt.ppm., as determined by chemical analysis

* This manuscript has been authored by Jefferson Science Associates, LLC under U.S. DOE Contract No. DE-AC05-06OR23177. 

by the manufacturer. In addition, single-cell cavities are being fabricated from the same ingot material and initial results on one of them showed high $Q_0$-values at 2 K up to peak surface magnetic fields of about 110 mT. Residual resistance values below 5 nΩ have been consistently achieved on this cavity. A new induction furnace was commissioned for the heat treatment of these single-cells, which allows avoiding subsequent chemical etching of the cavity surface.

## SUPERCONDUCTING DC PROPERTIES

### *Thermal Conductivity*

The thermal conductivity of ingot niobium is measured using Fourier's law where the constant power is supplied to the one end of the sample (source) and other end is in thermal contact with helium bath (sink). The temperature dependence of the thermal conductivity measured for one of the samples is shown in Fig. 1. The "as machined" sample didn't show any enhancement of thermal conductivity around 2K, however an enhancement of $\kappa_{2K}$ by a factor of ~3 and ~ 6 was measured after the 800 °C heat treatment for 3 hours and 1000 °C for 6 hrs, respectively. As mentioned, the cavity made of large grain Nb operating around 2K may have better thermal stability due to the enhancement of thermal conductivity around 2 K (so-called "phonon peak").

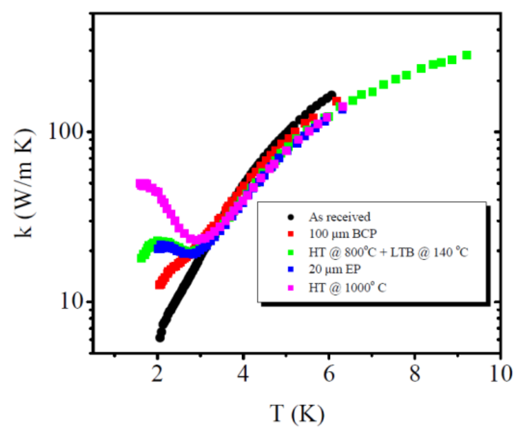


**FIGURE. 1** The temperature dependence of thermal conductivity of sample-I after various surface and heat treatments.

### *Penetration Depth and DC Magnetization*

Figure 2 (a) shows the magnetization measurements carried out in the temperature range 2-8 K of sample-I after several treatments. The hysteresis (irreversible magnetization) in magnetization curve is observed for all temperature ranges. In case of pristine, as machined sample, the flux starts to enter the sample at 2K at an applied field ~0.4T and suddenly penetrates into the sample as seen by the sudden jump in magnetization. After surface treatments both the hysteresis area and the first flux penetration field ($H_{ffp}$) are reduced, indicating the reduction of bulk and surface pinning by these processes.

The change in penetration depth was measured by the Schawlow-Devlin method [6]. Figure 2 (b) shows the change in penetration depth as a function of external applied DC magnetic field at 2 K for sample–I. When the external magnetic field is ramped up, no flux is penetrating so that there is no change in the penetration depth. Once the external field $H>H_{ffp}$, the flux starts to penetrate in the form of flux lines. The Lorentz force of the induced RF screening current causes the vortices near the surface of the sample to oscillate and the oscillations are transmitted deep into the sample, increasing the effective penetration depth. At $H_{c2}$, the bulk sample becomes stable in its normal state, whereas the surface superconductivity still exists up to the $H_{c3}$.

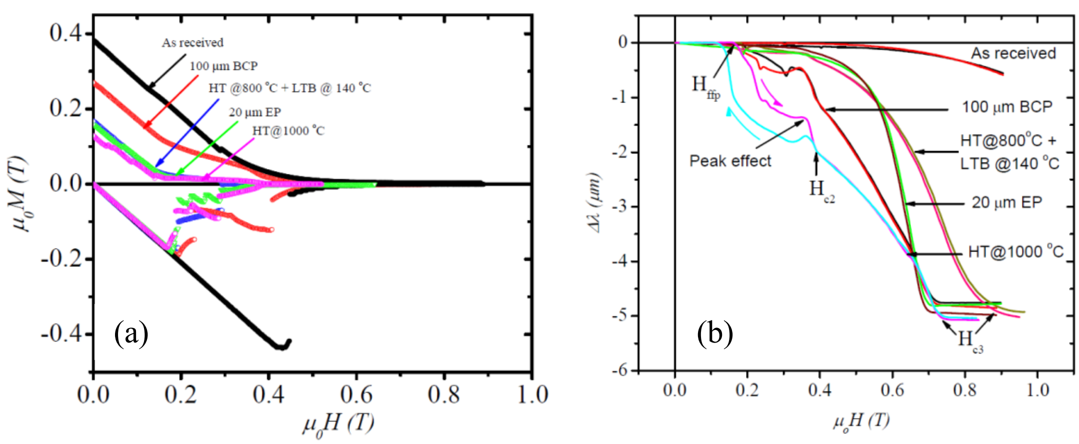


**FIGURE 2.** (a) The magnetization measurement at 2K for sample-I subjected to several surface and heat treatments. (b)The change in penetration depth as a function of applied external magnetic field in sample-I subjected to various treatments at 2K. The critical field $H_{c3}$ increases after the low temperature baking.

### ***Single Cell Cavity Test***

A single cell 1.47 GHz CEBAF shape cavity was fabricated from ingot G (~1375 wt.ppm. Ta content). The cavity was subjected to 73 μm material removal by centrifugal barrel polishing and 65 μm buffered chemical polishing (BCP 1:1:1). The cavity was then heat treated (HT) at 800 °C for 3 h, followed by 20 μm BCP and high-pressure rinse (HPR) with DI water for the baseline RF measurement at 2.0 K. After that the cavity was HT in clean UHV furnace at 1200 °C for 6 hours, degreased and HPR. Another RF test was done at 2.0 K and 1.5 K. Then the cavity was baked *in situ* at 120 °C for 12 hours (LTB). The cavity was re-tested at 2.0 K

Figure 3 shows the results of the $Q_0$ vs $B_p$ before and after the heat treatments. The $Q_0$(2 K, 90 mT) increased by ~19% after the HT and ~ 6% after the LTB. The residual resistance after HT is ~ 1.6 nΩ and $Q_0$(1.5 K) >$10^{11}$. These tests were limited by multipacting induced quenched around $B_p$ ~ 95 mT.

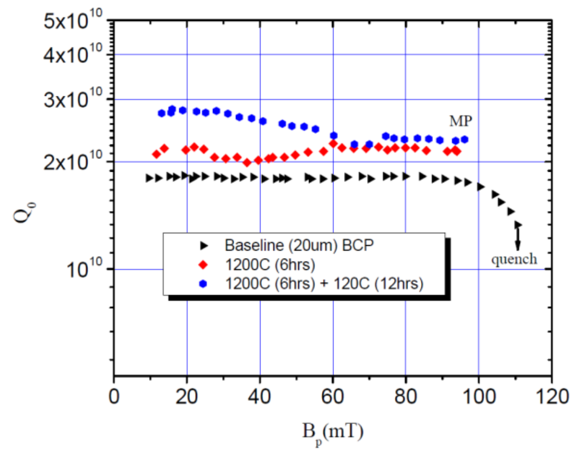


**FIGURE 3.** Summary of $Q_0$ ($B_p$) measurements at 2K.

## CONCLUSION

We have presented initial results of superconducting properties on Nb rods machined from ingot niobium with medium purity and different Ta content, provided by CBMM, Brazil. The rods have been subjected to different treatments typically applied to SRF cavities. In addition, initial results on one single cell cavity fabricated from ingot Nb showed the highest $Q_0$-values at 2 K, 1.5 GHz, up to peak surface magnetic fields of about 100 mT. Residual resistance $R_{res}$<2 nΩ was measured with the $Q_0$ >$10^{11}$ at 1.5K. Further optimization of high temperature heat treatments and surface treatments procedures are currently being investigated for the further reduction of surface resistance and hence the improvement of $Q_0$ for future accelerator technology.

## REFERENCES


[1] P. Kneisel, *Proc. of SRF 2007*, Peking University, Beijing, China, paper TH102.

[2] G. Ciovati, P. Kneisel, and G. R. Myneni, *Symp. Supercond. Sci. and Tech. of Ingot Niobium*, AIP Conf. Proc. **1352**, 25-37 (2011).

[3] J. Mondal, K.C. Mittal, G. Ciovati, P. Kneisel, and G. R. Myneni, *Proc. of SRF 2009*, Berlin, Germany, paper THOAAU01.

[4] A. Dhavale, G. Ciovati, and G. R. Myneni, *Symp. Supercond. Sci. and Tech. of Ingot Niobium,* AIP Conf. Proc. **1352**, 119-130 (2011).

[5] P. Dhakal, G. Ciovati, P. Kneisel, and G. R. Myneni, *Proc. of SRF2011*, Chicago, paper THO057.

[6] A. L. Schawlow, and G. E. Devlin, *Phys. Rev*. **113**, 120 (1959).