







ENHANCING FLUX EXPULSION THROUGH MICROSTRUCTURAL CONTROL IN SUPERCONDUCTING RADIO FREQUENCY CAVITIES MADE FROM COLD-WORKED NIOBIUM

B. D. Khanal¹, S. Balachandran^{3,4}, S. Chetri³, P. J. Lee³, P. Dhakal¹,² and, G. Ciovati^{1,2}

¹Dept. of Physics, Old Dominion University, Norfolk, USA. ²Thomas Jefferson National Accelerator Facility, Newport News, USA. ³Applied Superconductivity Center, NHMFL-FSU, Tallahassee, USA. ⁴Dept. Materials Science Engineering, FSU, Tallahassee, USA.

Abstract

A well-known source of RF losses that lowers the performance of superconducting radio frequency cavities is the residual magnetic flux trapped during cool-down. In this presentation, we demonstrate how manipulating the niobium microstructure by changing the strain state of the initial Nb sheet for an elliptical cavity geometry can improve the flux expulsion behavior. In this study, we compare the use of a traditional annealed poly-crystalline Nb sheet with a sheet from the same origin but without the anneal and therefore retaining cold work strain from the sheet rolling process. We find that an 800°C heat treatment of the formed traditional sheet leads to a bi-modal microstructure that relates to flux trapping and inefficient flux expulsion. This non-uniform microstructure is related to varying strain profiles along the cavity shape. However, a more uniform microstructure after 800°C annealing is achieved when using a cold-worked Nb sheet, resulting in better flux expulsion, without the need to perform the annealing at a higher temperature.

Introduction

- Major performance degradation issue: Residual magnetic flux trapping during cavity cooldown due to incomplete Meissner effect
 - Causes RF power dissipation due to the oscillation of trapped vortices
- Favorable sites for flux trapping: Dislocations, segregation of impurities, surface roughness, grain boundaries
- Main mechanism to reduce the defects: High temperature (HT) heat treatment to fully recrystallize + grain growth for better flux expulsion

Experimental Setup

- Cavity Fabrication: TESLA shaped 1.3 GHz
- Two single cell high purity Nb cavities:
 - 1. Cavity from conventional SRF grade Nb
 - 2. Cavity from cold-worked (C-W) Nb sheet
- Recipe: 25 μm EP followed by 800°C/3 hr. HPR with de-ionized water and assembly.
- Installation: Flux gate magnetometer (FGM) and Tsensors



Cold-Worked Sheet HT Coupon Studies



• Fig. 4b: Pinning force (F_p) decreased and shifted to a lower value of *B*, with HT indicating the reduction of nanoscale pinning sites

- Thermal cycle with 10 mG to measure $B_{\rm sc}/B_{\rm n}$
- Cool down with residual *B*-field ($B_n < 2 \text{ mG}$)
- $R_{\rm s}$ vs 1/T at (4.34 –1.6) K and Q_0 vs $E_{\rm acc}$ at 2.0 K
- Coupon sample study with different final HTs



Fig 1: Set up for RF Test

• Fig. 4c: Hardness vs HT temperature for C-W sheet. 800°C is the minimum full recrystallization temperature



0.8

Fig. 4: (a) Magnetization (H), (b) $F_{p}(B/B_{c2})$ & (c) $HV_{0.3}(T)$ for cold-worked sample

Improved Flux Expulsion Using C-W Sheets



Fig. 2: a) B (T)- during cool down, b) Comparison of flux expulsion ratio

- At $\Delta T=3.28$ K, $B_{sc}/B_n = 1.55 \pm 0.03$
- Significantly better flux expulsion on cold-worked compared to SRFgrade Nb cavity after 800°C/3h
- Similar ratio (B_{sc}/B_n) after 900°C/3h & 1000°C/3h

Cross-Sectional Microstructure- Traditional versus this work

- Existence of bimodal grain distributions containing fine $(50-100 \,\mu\text{m})$ and large $(>100 \ \mu m)$ grains
- 800°C HT leads to a bimodal microstructure in a traditional cavity that is related to flux trapping and inefficient flux expulsion
- Forming cavities with coldworked Nb sheet leads to a more uniform microstructure

New results are pending:



- SRF cavities fabricated from Nb sheets with different levels of cold work
- Comparison of cross-sectional analyses



We thank the technical staff at Jefferson Lab for their support in cavity manufacturing, processing, cryogenic, and RF testing. The work is partially supported by the U.S. Department of Energy, Office of Science, Office of High Energy Physics under the Award No. DE-SC 0009960. This is authored by Jefferson Science Associates, LLC under U.S. DOE Contract No. DE-AC-06OR23177. A portion of this work was performed at the National High Magnetic Field Laboratory, which is supported by National Science Foundation Cooperative Agreement No. NSF-DMR-2128556 and the State of Florida.

