Superconducting Thin Film Growth, Process Development, Defects Investigation, and Device Fabrication for Radio-Frequency Accelerating Cavities

CNF Project Number: 2779-19

Principal Investigator(s): Matthias Liepe

User(s): Zeming Sun

Affiliation(s): Cornell Laboratory for Accelerator-based Sciences and Education, Cornell University

Primary Source(s) of Research Funding: the U.S. National Science Foundation under Award PHY-1549132, the Center for Bright Beams

Contact: mul2@cornell.edu, zs253@cornell.edu

Website: https://physics.cornell.edu/matthias-liepe

Primary CNF Tools Used: Thermal / E-Gun Evaporation System, Oxford FlexAL Atomic Layer Deposition System, Jelight 144AX UV Ozone Generator, Arradiance Gemstar-6 Atomic Layer Deposition System, Chemical Vapor Deposition System, Woollam Spectroscopic Ellipsometer, Zygo Optical Profilometer, P10 Profilometer

Abstract:

Superconducting radio-frequency (SRF) cavities are the key component for particle accelerators that have broad applications such as synchrotron X-ray, high-energy colliders, and extreme-UV lithography. Our research is to search for the next-generation SRF materials and surfaces beyond the industry-standard niobium (Nb). Niobium-tin (Nb_3Sn), niobium-zirconium (NbZr), Nb with a processed/designed surface, niobium titanium nitride (NbTiN), and vanadium silicate (V_3Si) are of our interest. By using facilities at the CNF, we mainly focus on SRF thin film growth, sample preparation for material characterization, post treatment to improve RF properties, and device fabrication to fundamentally understand the SRF physics. We highlight our recent success on a NbZr alloyed cavity, which is the first experimental demonstration for such cavities and shows better RF performance than a reference Nb cavity [1-3].

Summary of Research:

(1) We demonstrated a high-performance NbZr alloyed SRF cavity [1-3]. In the sample-scale study, we deposited the initial Zr films using the e-beam evaporator at CNF, and achieved different Zr surface profiles after thermal annealing. Figure 1 shows the surface morphology of the annealed samples. We found the critical temperature of these samples are improved due to the NbZr alloying. We further developed an electrochemical deposition process to scale up the alloying process to a Cornell sample test cavity, and we observed the reduction of surface resistance owing to the increased critical temperature of NbZr alloys.

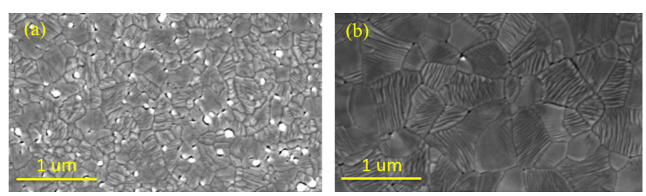

Figure 1: Surface morphology of the annealed NbZr samples with different initial Zr film thicknesses: (a) 40 nm and (b) 20 nm.

PHYSICS & NANO-STRUCTURE PHYSICS

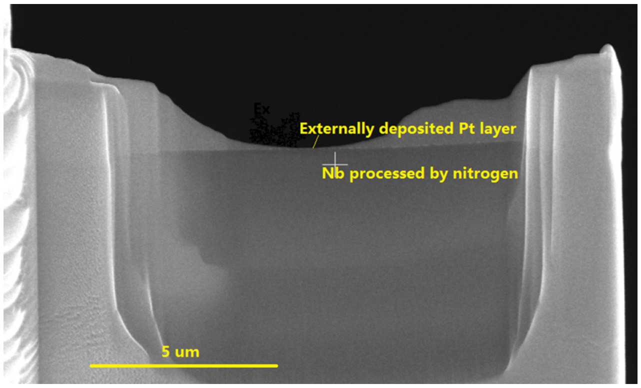

Figure 2: Cross-sectional image of a nitrogen-doped Nb specimen coated with the Pt protective layer used for scanning transmission electron microscopy.

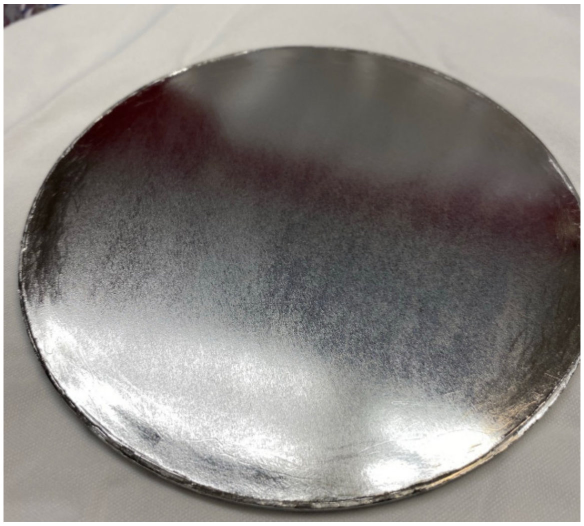

Figure 3: Picture of a Cornell sample test SRF cavity (the testing plate) with the artificially controlled surface.

(2) We demonstrated electrochemically-made Nb_3Sn thin films with extremely low surface roughness and an improved stoichiometry. Zhaslan Baraissov and Prof. David Muller's research group at Cornell Applied Physics are working on atomic analysis of these high quality Nb_3Sn films together with Nb samples processed under different treatments. To overcome the sample preparation issues before atomic imaging, we deposited an external Pt layer, at CNF, to protect the sample surface which is the most critical region for SRF applications (Figure 2).

(3) We fabricated SRF devices using the e-beam evaporator and Oxford FlexAL atomic layer deposition system at CNF to fundamentally understand the RF surface design. This year, we scaled up the artificial control process of a Nb surface to the Cornell sample test cavity. Preliminary results showed positive RF results owing to our rational surface design.

References:

[1] Z. Sun, et al., "Materials investigation and surface design of superconducting radio-frequency accelerating cavities at Cornell University", presented at the 2022 MRS Spring Meeting, Honolulu, HI, May 2022.

[2] N. S. Sitaraman, "Theory results on novel surface preparations for superconducting radio-frequency cavities", presented at the 2022 MRS Spring Meeting, Honolulu, HI, May 2022.

[3] Z. Sun, et al., "First demonstration of a ZrNb alloyed surface for superconducting radio-frequency cavities", presented at the North American Particle Accelerator Conference (NAPAC'22), Albuquerque, NM, August 2022.

PHYSICS & NANO-STRUCTURE PHYSICS