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

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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 essential component for accelerating charged particle beams that have broad applications such as high-energy colliders, high-intensity X-ray sources, high-precision photolithography, and quantum computing. Niobium tin (Nb_3Sn), conventional niobium (Nb) with a processed/designed surface, niobium titanium nitride (NbTiN), and vanadium silicate (V_3Si) are the most promising superconductor candidates for the next-generation SRF cavities. Here, with the capabilities at the Cornell NanoScale Science and Technology Facility (CNF), we mainly focus on SRF thin film growth development, materials characterization together with sample preparation, post-treatment development to improve RF superconducting properties, and SRF device fabrication to fundamentally understand some SRF physics theories.

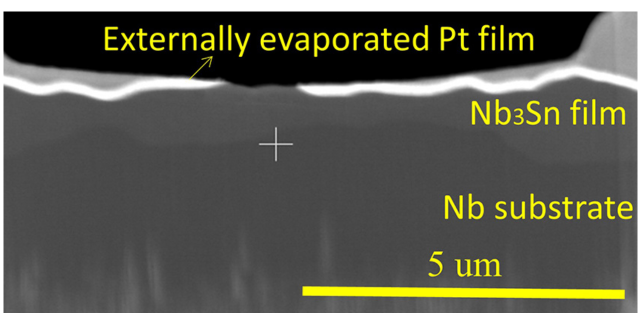

Figure 1: Cross-sectional image of STEM specimens that yield high-resolution atomic imaging.

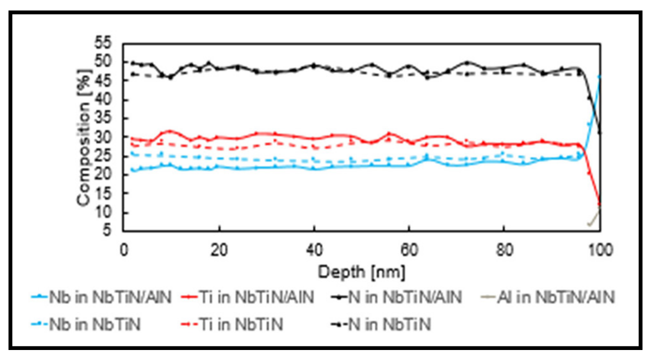

Figure 2: Composition depth profiles of Nb, Ti, N, and Al for atomic-layer-deposited NbTiN/AlN and NbTiN-only films on Nb substrates [5].

Summary of Research:

(1) We demonstrated stoichiometric Nb_3Sn thin films with extremely low surface roughness from electrochemical deposition [1-3]. Reduction of surface roughness and retention of stoichiometry are critical to improving the RF performance of accelerating cavities. We are further investigating the growth mechanism of this Nb_3Sn film using scanning transmission electron microscopy (STEM) through collaborating with Zhaslan Baraissov and Prof. David Muller's research group at Cornell Applied Physics.

High-resolution atomic imaging requires a thin specimen below ~ 10 nm. However, the sample preparation via focused ion beam (FIB) was difficult due to the lack of a proper protection layer for the film surface. We have resolved this issue by depositing an external Pt layer using the e-beam evaporator at CNF (Figure 1), and achieved high-resolution composition and strain mappings [4].

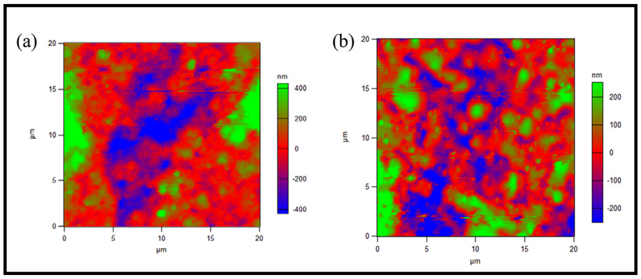

Figure 3: Atomic force microscopy images of Nb_3Sn (a) before and (b) after laser annealing [8].

(2) Alternative deposition approaches such as sputtering, chemical vapor deposition, and atomic layer deposition are being explored to deposit Nb_3Sn, NbTiN, and V_3Si films [2,5-7]. We observed a composition gradient in the atomic-layer-deposited NbTiN films in presence of an hcp-structured aluminum nitride (AlN) layer for the superconductor-insulator-superconductor (SIS) structures (Figure 2) [5]. Moreover, thermal annealing of the sputtered Nb_3Sn and V_3Si films has been systematically investigated on Nb and Cu substrates [6]. In addition, the chemical-vapor-deposition system and process are being developed [7].

(3) Post processes such as ozone treatment, laser annealing, and electropolishing are explored to improve the superconducting film quality. We demonstrated that laser annealing is viable to remove the sharp features on the Nb_3Sn film surface that is coated with a laser absorption layer via an Arradiance Gemstar-6 atomic layer deposition system at CNF (Figure 3) [8]. Also, we successfully electropolished the chemical-vapor-deposited Nb film and reduced the surface roughness by half [9]. Furthermore, we are exploring the Nb surface modification using the Jelight 144AX UV ozone generator at CNF [10].

(4) SRF devices are fabricated using the e-beam evaporator and Oxford FlexAL atomic layer deposition system at CNF, and these devices are being tested to fundamentally understand some SRF theories prior to application of these theories on the large, complex-shaped SRF cavities.

References:

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