Superconducting Thin Film Growth, Post-Treatments, and Defects Investigation

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Primary CNF Tools Used: Chemical vapor deposition system, Oxford FlexAL ALD, Arradiance Gemstar-6 atomic layer deposition system, Thermal/ E-gun evaporation system, Woollam spectroscopic ellipsometer, Zygo optical profilometer, P10 profilometer

Abstract:

Superconducting radio frequency (SRF) cavities are important in accelerating charged particle beams that have broad applications such as colliders, neutron sources, and light sources. Niobium tin (Nb_3Sn), vanadium silicate (V_3Si), and magnesium diboride (MgB_2) are the most promising superconductor candidates for the next generation SRF cavities. However, their thin film growth is still challenging due to surface roughness, defect generation, grain boundaries, and surface oxidation. Thus, this project investigates the growth mechanisms of superconducting films deposited via electroplating, sputtering, chemical vapor deposition approaches, and explores post-processing techniques, such as electropolishing, surface passivation, and laser annealing, to mitigate the crystal defects, surface roughness, and oxidation. Moreover, this project studies the impact of defects on the SRF performance through studying the performance of artificial structures that are fabricated at the Cornell NanoScale Science and Technology Facility (CNF).

Summary of Research:

(1) We demonstrated ultra-low surface roughness Nb_3Sn superconductors (detailed in Reference [1]). This is achieved by thermal conversion of a pre-deposited Sn film that is uniform, smooth, dendrite-free, and has strong adhesion. Electroplating, as an excellent method for coating intricate SRF cavity surface, is used to enable the deposition process of a high-quality Sn film. The resultant Nb_3Sn shows an extremely low surface roughness of 65 nm as shown in the atomic force microscopy image (Figure 1).

(2) Alternative deposition approaches such as sputtering, chemical vapor deposition, and chemical methods are explored to deposit Nb_3Sn and V_3Si. For example, a fast-ion transport reaction is demonstrated for generating Nb_xSn (detailed in Reference [2]). X-ray photoelectron spectroscopy (XPS) depth profiling provides direct evidence of film stoichiometry (Figure 2). Another success is sputtering of Nb_3Sn and V_3Si have been enabled on Nb and Cu substrates (Figure 3). The optimization of film quality is ongoing.

(3) Post treatments such as electropolishing and laser annealing are explored to improve the superconductor film quality. For example, the chemical vapor deposited Nb film is greatly smoothed via electropolishing with the surface roughness reduced by half (detailed in Reference [3]). Moreover, the laser annealing technique has been studied to reduce film surface roughness. A titanium nitride film was deposited via atomic layer deposition to improve the laser light absorption. The deposition condition is optimized for desired film thickness and refractive index (Figure 4). With this critical absorption layer, the laser is able to melt the Nb_3Sn surface and remove the sharp surface pits.

(4) MgB_2 superconducting thin film is easily oxidized in air which hinders its wider application. An aluminum nitride film is deposited on the film using plasma-enhanced atomic layer deposition to passivate the surface. The interface is being analyzed using XPS.

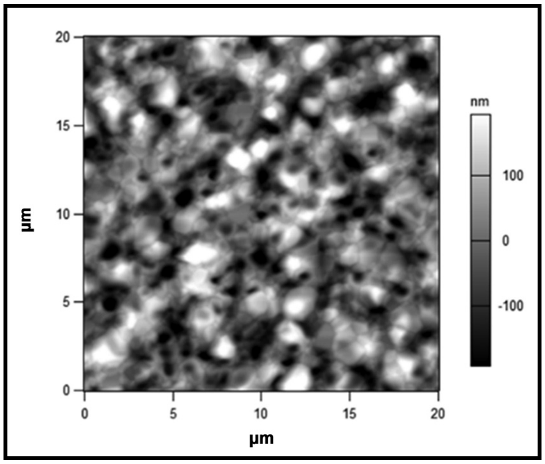

Figure 1: Atomic force microscopy of thermally converted Nb_3Sn from electroplated Sn films, showing an extreme low surface roughness.

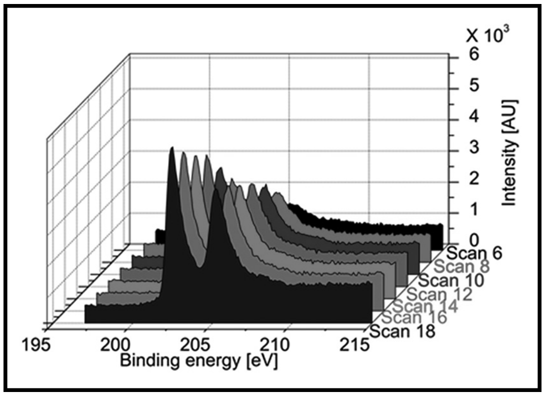

Figure 2: X-ray photoelectron spectroscopy depth profiling of fast-transported Nb_xSn film showing Nb 3d intensity approaching stoichiometry of Nb_3Sn.

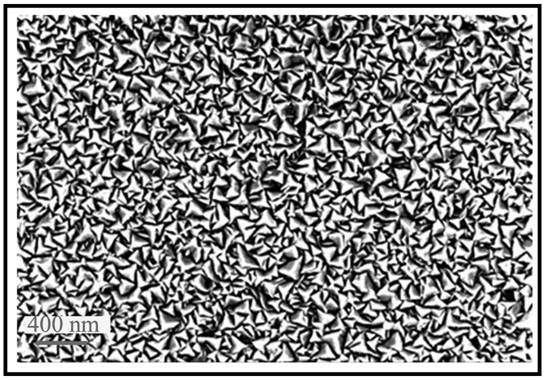

Figure 3: SEM of the sputtered Nb_3Sn films.

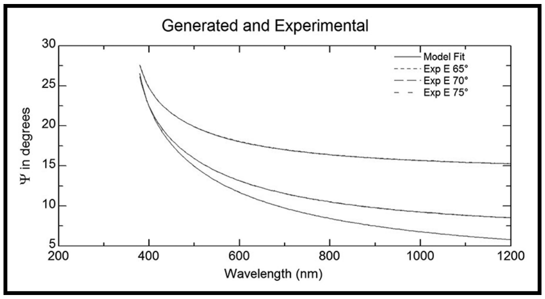

Figure 4: Ellipsometry modeling for optimizing titanium nitride deposition by thermal atomic layer deposition.

References:

[1] Z. Sun, M. Liepe, T. Oseroff, R.D. Porter, T. Arias, N. Sitaraman, A. Connolly, J. Scholtz, M.O. Thompson, Electroplating of Sn film on Nb substrate for generating Nb-Sn thin films and post laser annealing, Proceeding of SRF'19, Dresden, Germany, 2019.

[2] Z. Sun, M. Liepe, J.T. Maniscalco, T. Oseroff, R.D. Porter, D. Zhang, X. Deng, Fast Sn-ion transport on Nb surface for generating NbxSn, Proceeding of NAPAC'19, Michigan, 2019.

[3] Z. Sun, M. Ge, K. Howard, M. Liepe, J. Maniscalco, T. Oseroff, R. Porter, V. Arrieta, S. McNeal, TESLA Technology Collaboration workshop, Geneva, Switzerland, February, 2020.