Growth and Properties of Vapor Diffused Nb₃Sn Coating for Superconducting Radiofrequency Accelerator Cavity Applications

Uttar Pudasaini

College of William & Mary, Department of Applied Science, 2019
Field: Interface/Thin Film/Surface Science
Degree: Ph.D.

Advisor: Michael Kelley, Professor of Applied Science

Abstract

The desire to reduce construction and operating costs of future SRF accelerators motivates the search for higher-performing alternative materials. Nb₃Sn (Tc ~ 18.3 K and Hsh ~ 425 mT) is the front runner. The tin vapor diffusion process is currently the technique of choice to produce promising Nb₃Sn-coated cavities. Understanding Nb₃Sn nucleation and growth in this process is essential to progress. Samples representing different stages of Nb₃Sn formation have been produced and studied to elucidate the effects of nucleation, growth, process conditions, and impurities. Nb₃Sn films with thickness from a few hundred nm up to ~15 µm were grown and characterized. The microscopic examination of samples suggests the mechanisms of thin film nucleation and growth. Broadly, nucleation deposits tin as a thin surface phase and, under some conditions, a few hundred nanometersized particles as well. Conditions that impair nucleation promote the formation of defects, such as “patches”, in subsequent coating growth. Analysis of coated samples is consistent with the model of Nb₃Sn grown in which tin diffuses via grain boundaries to Nb₃Sn-Nb interface, where the growth of Nb₃Sn into the niobium bulk takes place. Similar scaling laws are found for grain growth and layer thickness. Non-parabolic layer growth is consistent with significant grain growth, which reduces the number of Sn-transport channels. Examination of patchy regions in Nb₃Sn coating revealed it to be large single crystalline grains, pointing to impeded Nb₃Sn layer growth due to low grain boundary density, resulting in a significantly thin coating in those areas. Examination of RF loss regions from a coated cavity, identified with a thermometry mapping system showed patchy regions and carbonus defects were associated with strong local field-dependent surface resistance. RF measurements of coated cavities were combined with material characterization of witness samples and coated-cavity cutouts to improve the coating process. Understanding obtained and applied to cavity coatings, resulted in single-cell Nb₃Sn cavities with a quality factor of ~3 ×10¹⁰ up to 15 MV/m accelerating gradient at 4 K, without "Wuppertal" Q-slope. We have also produced Nb₃Sn-coated CEBAF 5-cell cavities with accelerating gradients useful for accelerator cryomodules. We will discuss the genesis of the Nb₃Sn coating in a typical tin vapor diffusion process, effects of different process parameters, and its consequences to the coating of single-cell and multi-cell SRF accelerator cavities.