Thin-Film Deposition for Surface Characterization Studies for Superconducting Radio Frequency Cavity Application

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Primary CNF Tools Used: CVC SC4500, AJA Sputter Deposition 1 & 2

Abstract:

Superconducting radio-frequency (SRF) cavities are a key component of particle accelerators (with applications ranging from fundamental physics research to synchrotron X-ray sources, to e-beam microscopy and lithography) and are also being developed for applications in dark matter detection and quantum computing. We are developing next-generation surface treatments to enhance the performance of niobium superconducting surfaces. By using facilities at the CNF, we investigate the effect of metallic doping on the niobium surface. We highlight our recent success in altering the niobium native oxide by zirconium doping and by gold doping.

Summary of Research:

We used CNF's AJA sputter deposition tools to deposit zirconium on niobium sample plates for RF testing. This builds on our earlier development of a zirconium oxide capping layer recipe using the same CNF tool on small coupon samples. Prior to deposition, sample plates received a 60-micron electropolish followed by a 5-hour 800°C vacuum bake and a baseline RF performance test.

The first sample then received an acid wash and high pressure rinsing prior to zirconium deposition at CNF, followed by another 5-hour 800°C vacuum bake. The RF performance of this sample was poor, which post-analysis linked to contamination during transport between CNF and the vacuum furnace.

The second sample similarly received an acid wash and high pressure rinsing, then used a specialized sample holder for clean transport to and from CNF for zirconium deposition. The sample then received an additional high pressure rinse and was delivered to the furnace in the clean-transport holder. This sample will undergo RF testing shortly.

We also used CNF's CVC SC4500 evaporation deposition system to deposit 5-10 nm gold layers on small niobium coupon samples. These samples received short 800°C vacuum bakes, and XPS analysis showed that the resulting surface had greatly reduced niobium oxide concentrations.

Conclusions and Future Steps:

We have now developed two methods to eliminate the niobium pentoxide from a niobium superconducting surface. We expect that this method may be applicable to niobium superconducting devices and niobium-zirconium alloy surfaces, as well as possibly other niobium-based superconducting surfaces which typically form a niobium-rich oxide. We plan to do further RF testing on zirconium-oxide-capped and gold-passivated niobium surfaces in the near future. We will also attempt to apply this method to the Nb_3Sn surface, and we will investigate other passive oxide layers such as hafnium, aluminum, and silicon oxide for SRF applications. We are also using the AJA sputter deposition tool to conduct preliminary investigations of Nb_3Al growth and oxide properties; coupon samples have received aluminum deposition and vacuum baking recipes are currently being finalized for testing.

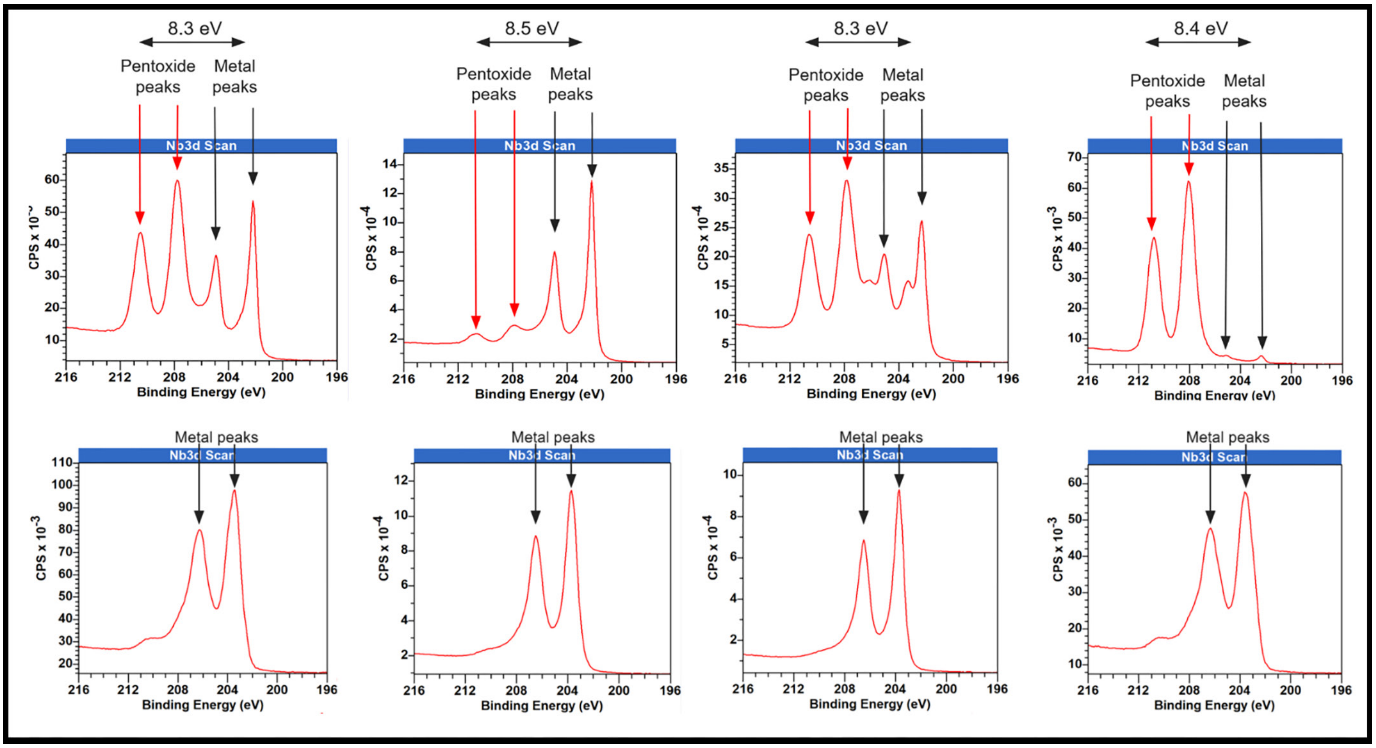

Figure 1: Top row, XPS data from niobium samples of various preparations without gold passivation. Niobium pentoxide peaks are consistently detected at a constant energy shift relative to the niobium metals peaks. Bottom row, XPS data from niobium samples after receiving different gold passivation recipes, none of which have peaks at the expected position for the pentoxide.

References:

[1] Sitaraman, N.S., Sun, Z., Francis, B.L., Hire, A.C., Oseroff, T., Baraissov, Z., Arias, T.A., Hennig, R.G., Liepe, M.U., Muller, D.A. and Transtrum, M.K., 2023. Enhanced Surface Superconductivity of Niobium by Zirconium Doping. Physical Review Applied, 20(1), p.014064.

[2] Seddon-Stettler, S., Liepe, M., Oseroff, T., and Sitaraman, N. Novel materials for beam acceleration. Proc. IPAC'24, 2680-2682.