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

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 coupons. Prior to deposition, coupons received a standard pre-preparation consisting of a 60-micron electropolish, a 5-hour 800°C vacuum bake, and a 2-micron electropolish. The sputter deposition tool first removed the niobium native oxide by argon plasma sputtering, and then deposited approximately 2, 3.75, 7.5, and 10 nm of zirconium on four different samples. The deposition rate was based on the rate for similar metals and has not yet been directly calibrated. The samples then received another 800°C vacuum bake in order to fully dissolve any remaining niobium oxide and establish a uniform interface between the niobium metal and the protective zirconium oxide layer.

For increasing zirconium deposition thickness in the range of 0-3.75 nm, we find that the oxide rapidly becomes more zirconium-rich; in particular, by 3.75 nm thickness, there is no detectable niobium component in the primary oxide. Additionally, the combined intensity of the niobium and zirconium suboxide peaks decreases slightly relative to the intensity of the niobium metal peak, suggesting that the suboxide layer in the 2 nm and 3.75 nm samples is very thin. For increasing zirconium deposition thickness in the range 3.75-10 nm, however, both the primary ZrO_2 oxide and the suboxide become thicker.

We also used CNF's CVC SC4500 evaporation deposition system to deposit thin (1-2nm) layers of gold on niobium samples (prepared according to the standard pre-preparation in the earlier paragraph). This work recreated work done by a previous user from the group, Zeming Sun [1]. This work removed the oxide chemically with dilute hydrofluoric acid rather than argon plasma sputtering (as was used for zirconium deposition). We found substantial oxide still present, indicating opportunities for improvement of the process. However, we found some modification of the oxide, indicating that gold layers are promising towards oxide passivation.
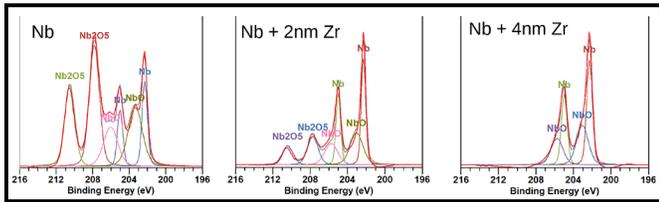
Figure 1: Peak fitting of niobium XPS data. The overall niobium oxide intensity decreases monotonically with increasing zirconium deposition thickness, and the pentoxide intensity in particular becomes undetectable by 3.75 nm zirconium deposition thickness. XPS sample analysis was performed at CCMR.
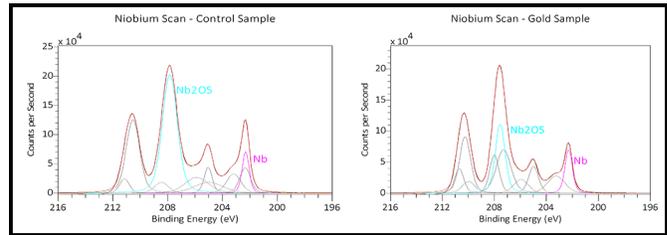

Figure 2: Preliminary peak fitting of niobium-gold XPS data. Control sample is bare niobium that has been exposed to atmosphere, gold sample has 1 nm of gold deposited on niobium. The oxide is still present, but has changed structure slightly. XPS sample analysis was performed at CCMR.

Conclusions and Future Steps:

We have demonstrated a method 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 investigate the effect of replacing niobium pentoxide with zirconium dioxide on SRF performance. 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 have also completed preliminary studies with thin-film depositions of gold, and will continue to investigate deposition methods to optimize the procedure for oxide passivation.

References:

[1]   T. Oseroff, Z. Sun, and M. Liepe, "Measurements of the amplitude-dependent microwave surface resistance of a proximity-coupled Au/Nb bilayer," arXiv, 2023. doi:10.48550/arXiv.2305.12035.