Examining the effects of the surface oxide layer on Nb and Ta superconducting films for quantum devices

K. McCauley[1,2] , A. Cano[2], A. Murthy[2], G. Eremeev[2], J. Lee[2]

[1]Illinois Valley Community College, Oglesby, Illinois, 61348, USA; [2]Fermi National Accelerator Laboratory, Batavia, Illinois, 60510, USA

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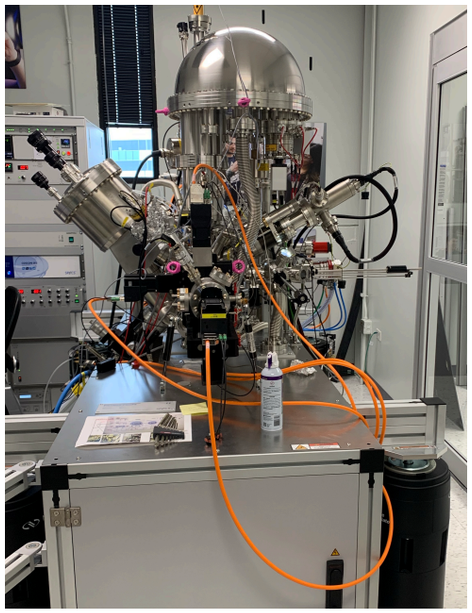
Introduction

The scientific motivation is to optimize the nano-fabrication of superconducting niobium and tantalum thin films for quantum devices. The formation of metal oxides on the topical layer of the film causes microwave loss or decoherence in quantum devices. By studying the characteristics of the oxide layer, we can better understand microwave loss and propose new methods to mitigate these losses.

Experimental



X-ray photoelectron spectroscopy (XPS) was the technique used in this experiment. It is a non-destructive technique, that implements the photoelectric effect to characterize the sample's surface. Angle-resolved XPS was used to quantify the thickness of the oxide layer.

The samples being tested are 155 nm Nb deposited on a Si substrate and Ta deposited on Al2O3 substrate

X-ray photoelectron spectrometer with an Al K-alpha x-ray source of 1486.6 eV

$$d_{ox} = L_{ox}\, cos\Theta\left(1 + \frac{I_{ox}}{R_{ox}\, I_{ele}}\right)$$

The equation from the International Standard of surface chemical analysis was used to calculate the oxide layer thickness.

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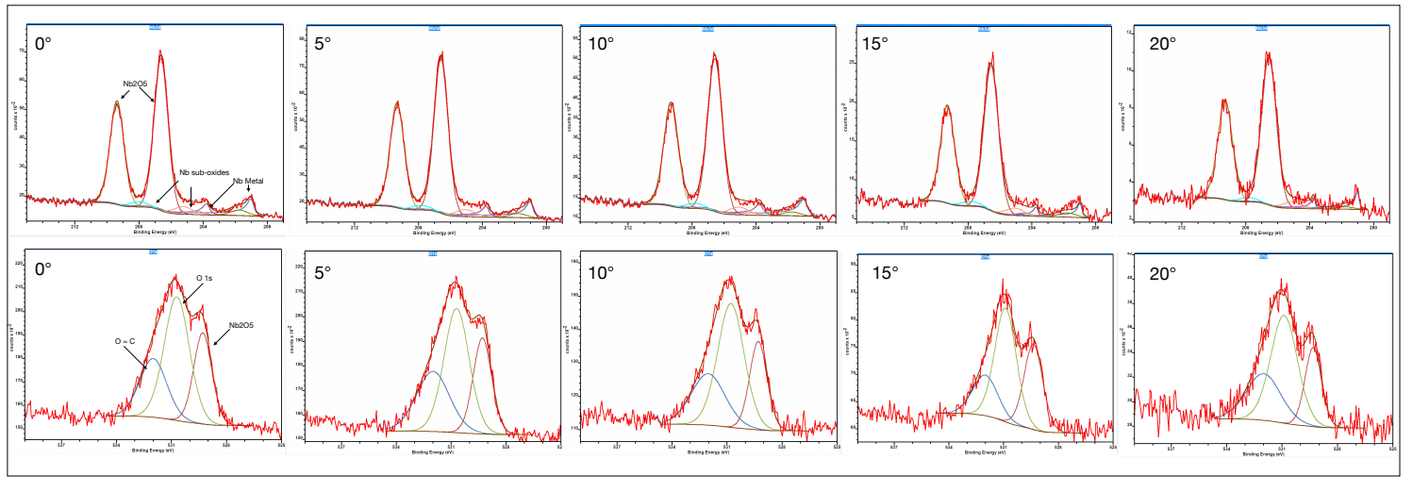
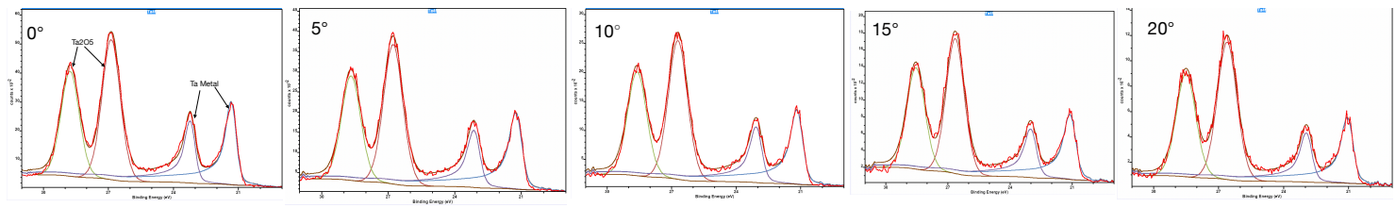
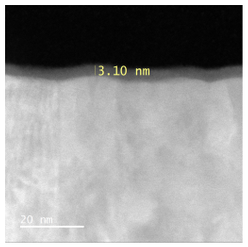
Results/Discussion



Data from the 155 nm Nb/Si. Top row: Peak-fittings of Nb oxides and metal as they relate to increasing surface sensitivity. Bottom row: Peak-fittings of the O 1s spectra with increasing surface sensitivity

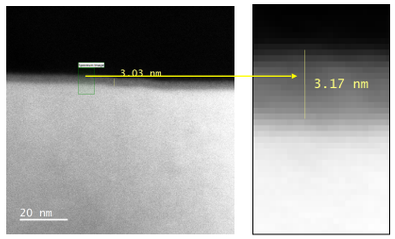


Peak-fittings of Ta2O5 and Ta metal with increasing surface sensitivity



Oxide layer thickness of Nb oxides = 3.9 nm

Data provide by Jae-Yel Lee



Oxide layer thickness of Ta oxides = 3.0 nm

Data provide by Jae-Yel Lee

Future Steps

The data suggests there is a significant amount of Nb and Ta oxide on the surface of the superconducting thin films, which will cause microwave loss within quantum devices. Some ways to mitigate the formation of oxide layers on the surface include: baking the film and improving the etching process. Baking the film is a technique which one would heat the film to high temperatures to dissolve the oxide layer. Some current etching chemicals can react with the surface layer producing a thicker oxide layer or other impurities, so optimizing the etchant formula can also mitigate loss.