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Investigation of profile characteristics and interface of anodized niobium superconducting films

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ABSTRACT

The profile and interface characteristics of anodized Nb (Nb-oxide) layer were investigated using atomic force microscopy (AFM) and transmission electron microscopy (TEM). The surface morphology of Nb-oxide layer shows smoother as well as the Nb grain gradually vanished with increasing anodization depth. The root mean square (RMS) roughness of Nb-oxide layer was decreased to be 0.35 nm with increasing applied voltage of anodization to 100 V. An amorphous NbO_x layer in the interface between Nb layer and Nb_2O_5 layer was confirmed by X-ray reflectometry (XRR) and transmission electron microscopy (TEM) analysis. The thickness of NbO_x layer decreases to be 1.5 nm with the increasing anodization depth for 45 nm depth Nb-oxide layers, which is comparable to the value observed on the surface of Nb films.

1. Introduction

High quality Josephson tunnel junctions based on Nb/Al–AlOx/Nb structure have received attractive attention due to its very low leakage current in the sub-gap voltage region, a sharply defined gap voltage, high current uniformity and controllability of critical current compared to other types of junctions. These advantages are highly significant for designing superconducting devices and circuits, for example, superconducting quantum interference devices (SQUIDs) [1,2], SIS mixers [3,4], superconducting single flux quantum (SFQ) circuits [5,6].

To improve the quality of Nb/Al–AlOx/Nb junctions, anodization process was widely used for covering the side-leakage current. Since Kroger et al. [7] developed the selective niobium anodization process (SNAP), a number of modifications and variations have been introduced [8–11]. However, most of the reports only focused on application or experiment changing of Nb anodization process, which is not suitable for understanding how it works in details. In the present work, we study the surface microstructure of anodized Nb (Nb-oxide) layer by atomic force microscopy (AFM) and investigate the component of such Nb-oxides by X-ray reflectometry (XRR) and transmission electron microscopy (TEM) for understanding the mechanism of Nb anodization.

2. Experimental

Nb films were deposited by DC magnetron sputtering at room temperature in 0.5 Pa Ar with 1.5A sputtering current. The substrate was silicon wafer with 300 nm-thick thermal oxidation SiO_2. The thickness of Nb films was about 300 nm. The anodization was done using standard anodization techniques. The electrolyte was a mixture of 156 g ammonium pentaborate, 1120 ml ethylene glycol, and 760 ml H_2O [7]. A platinum plate was used as a cathode, and the partially submerged Nb films prepared by DC sputtering were used as an anode. A current source with a value of 5 mA was applied between the anode and the cathode. As the Nb-oxide layer grows, the load voltage increases which can be monitored and used to determine the thickness of the Nb-oxide layer.

The step height of the Nb-oxide layer was measured by KLA-Tencor Profilers. The surface morphology of the Nb film was investigated using an AFM with scan size of 1 μm × 1 μm. XRR were used to determine the composition, thickness. A cross-section of the sample was prepared by a FEI Helios Focused Ion Beam (FIB) and the sample was subsequently observed in TEM in order to investigate the interfacial microstructure and element distribution.

3. Results and discussion

Fig. 1 shows the applied voltage dependence of a step height from the surface of the Nb film to the surface of the Nb-oxide layer.

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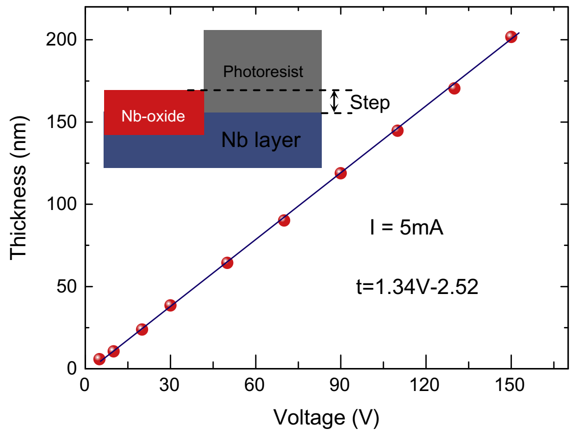

Fig. 1. Step height from original Nb surface to Nb-oxide surface depends on applied voltage. About 1.34 nm step for each volt is observed.

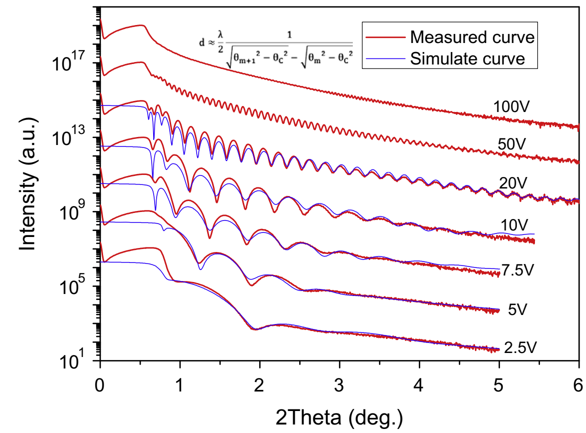

Fig. 3. X-ray reflectometry (XRR) pattern for Nb-oxide layers prepared in different applied voltages.

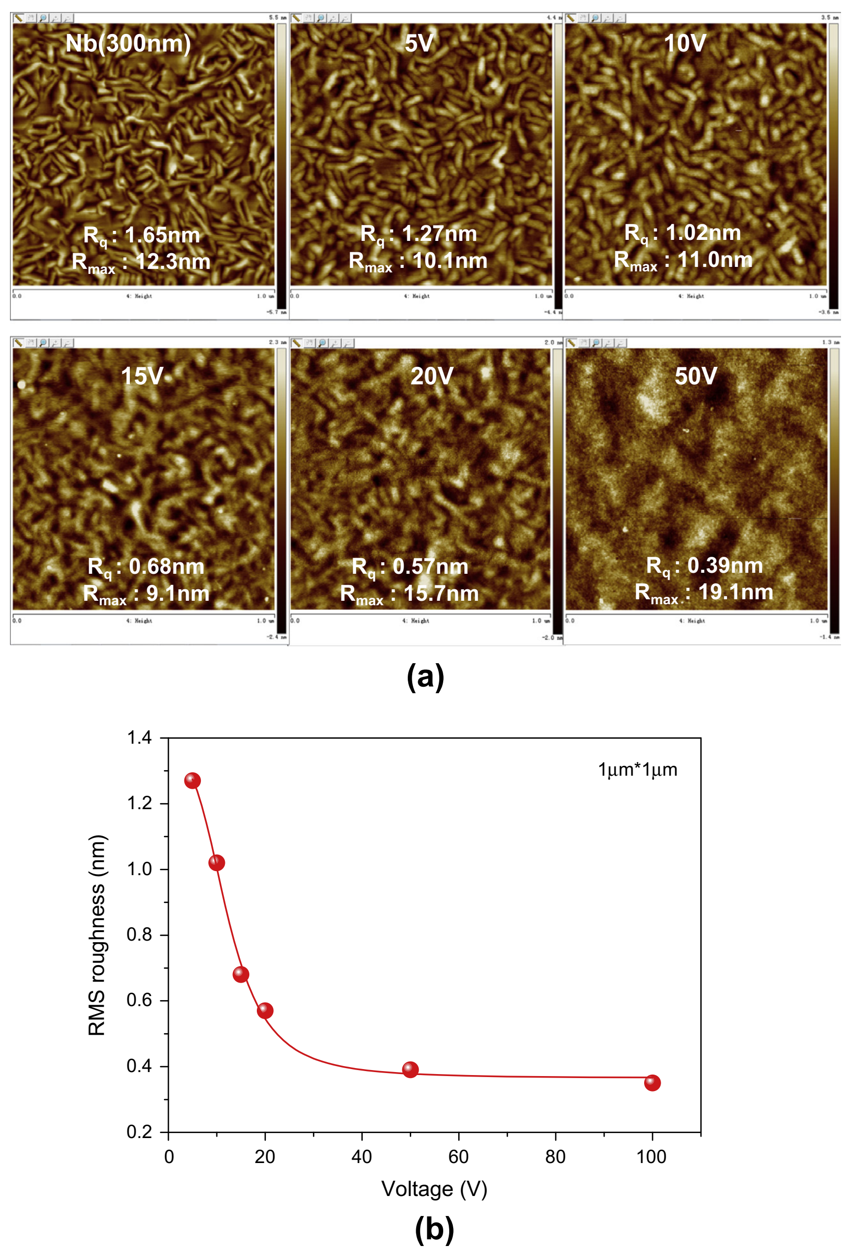

Fig. 2. AFM images for Nb-oxide layer prepared in different applied voltages. (b) shows the root mean square (RMS) roughness with different applied voltage. The solid line is guide to the eyes.