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THIN GOLD LAYERS ON NIOBIUM FOR SRF CAVITIES*

S. Seddon-Stettler†, M. Liepe, T. Oseroff, N. Sitaraman
Cornell Laboratory for Accelerator-based ScienceS and Education (CLASSE),
Ithaca, New York, United States
V. Do, H. Lew-Kiedrowska, S. J. Sibener, University of Chicago Department of Chemistry
and James Franck Institute, Chicago, Illinois, United States
C. Wang, National Cheng Kung University, Tainan, Taiwan

Abstract

New materials beyond the standard bulk niobium have the potential to greatly improve the performance of Superconducting Radio Frequency (SRF) cavities. Specifically, thin coatings of non-oxidizing normal conductors such as gold have the potential to improve the key RF performance metric of quality factor. We present progress on depositing thin gold layers onto 2.6 GHz SRF cavities and testing their RF performance.

INTRODUCTION

Superconducting Radio-Frequency (SRF) cavities underlie current cutting edge accelerator technology on a variety of scales. Typically, SRF cavities are manufactured from bulk niobium, several millimeters thick, and are given a variety of chemical and thermal treatments to improve their performance [1]. Though the niobium is thick, the RF field excited in the cavity interacts with the cavity most strongly at the surface, specifically within (approximately) the first 40 nm [2]. Because of this, engineering and optimization of the surface of niobium has become a strong focus of research and development for improving SRF cavity performance [1].

When exposed to atmosphere, the surface of niobium forms a complex, multi-phased oxide [3, 4]. By volume, the oxide is composed primarily of the pentoxide, Nb_2O_5, then lower phases including NbO_2, NbO, and other lower phases. The pentoxide can be removed by thermal treatments at reasonable temperatures, but not the lower phases [5]. The electronic properties of the oxide, and therefore its interaction with RF fields, are affected in many subtle ways by different cavity treatments. The lower phases of the oxide may have some normal conducting properties [3], which may inhibit cavity performance at energies relevant to accelerator applications. However, due to the complexity and irregularity of the oxide, it is difficult to study in isolation.

Work at Cornell University and elsewhere proposed to remove the oxide entirely, then replace it with a thin layer of a non-oxidizing normal conductor such as gold [6–8]. That work showed promise for improving cavity RF performance at very thin (sub-nm) layer thicknesses of gold.

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† sgs238@cornell.edu

We have previously presented preliminary work towards developing a gold passivation technique that could be applied on a full-scale SRF cavity [9, 10]. Here we discuss progress towards a fully plated 2.6 GHz SRF cavity, including progress on the electrodeposition process and development of a suitable cavity.

ELECTRODEPOSITION OF GOLD

A major challenge of applying a thin layer of gold to an SRF cavity is the choice of deposition method. Many deposition methods common to materials science applications are not able to accommodate the large size and irregular geometry of a typical 1.3 GHz SRF cavity. Furthermore, removal of all oxide layers requires a chemical treatment of hydrofluoric acid in an inert atmosphere in order to prevent the oxide from reforming. Given these requirements, we are developing an electroplating system capable of depositing thin layers of gold on niobium substrates that can be performed entirely within an inert atmosphere glovebox [10].

Our electroplating setup uses a commercially available sodium gold sulfite electroplating solution, which has a deposition rate that scales linearly with current density. Deposition thickness in electrochemical processes also scales linearly with time. In order to deposit very thin films of gold, we have developed a custom timing circuit that can reliably deliver very low quantities of current over very short intervals of time [10]. During the process, the current is monitored using an ammeter and recorded digitally, resulting in a trace of current vs. time. An example such trace is shown in Fig. 1. This together with the geometry of the substrate receiving the deposit allows for estimation of the deposited thickness of gold.

SAMPLE CHARACTERIZATION

Optimization of an electroplating process for use on an SRF cavity requires regular characterization of the films produced by the process. There are two main tools for this: X-Ray Photoelectron Spectroscopy (XPS), which scans over binding energies to identify elements and chemical phases present on a sample, and Scanning Electron Microscopy (SEM), which allows for visual characterization of deposited films. An example XPS scan of a thinly plated niobium sample, showing the presence of gold but with very low counts per second (indicating a very thin film of gold), is shown in Fig. 2.

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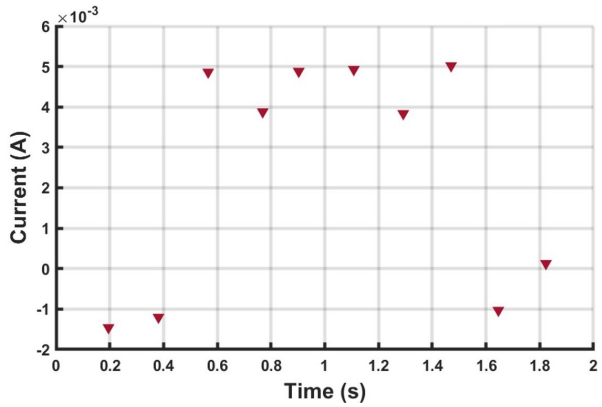


Figure 1: Readout of applied current vs. time during an electroplating procedure of a thin niobium sample.

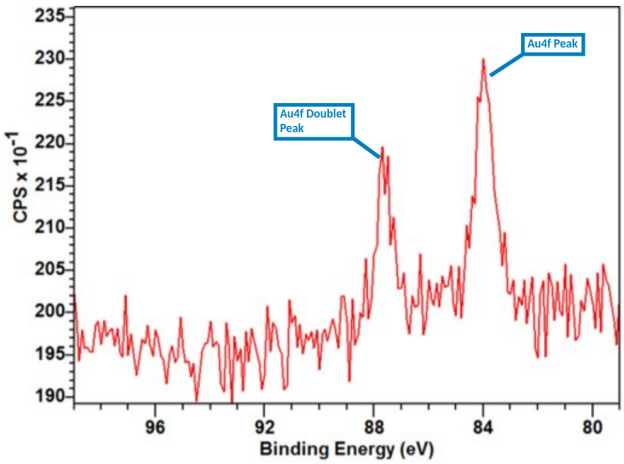


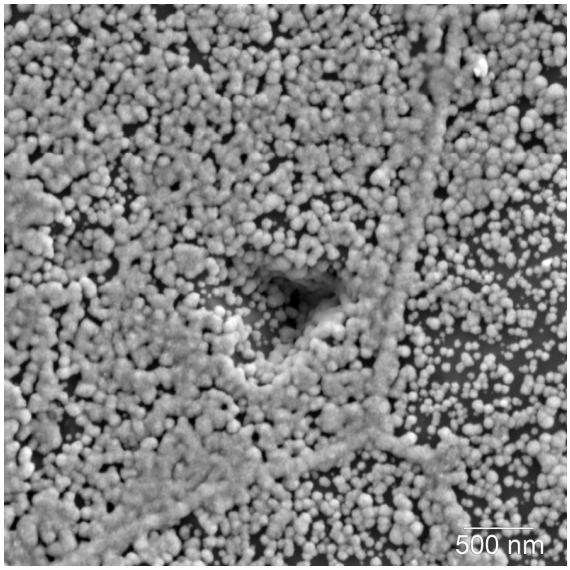
Figure 2: Au4f XPS scan of a niobium sample plated with a thin layer of gold.

Ex-situ scanning electron microscopy (SEM, Zeiss Merlin) was used to characterize two niobium samples with thin electrochemically deposited gold films. The SEM images were acquired using the Everhart Thornley secondary electron detector with a primary beam energy of 7 keV and a beam current of 2 nA. The resulting images are shown in Fig. 3. The sample shown in Fig. 3a had current applied to it for twice as long as the sample shown in Fig. 3b.

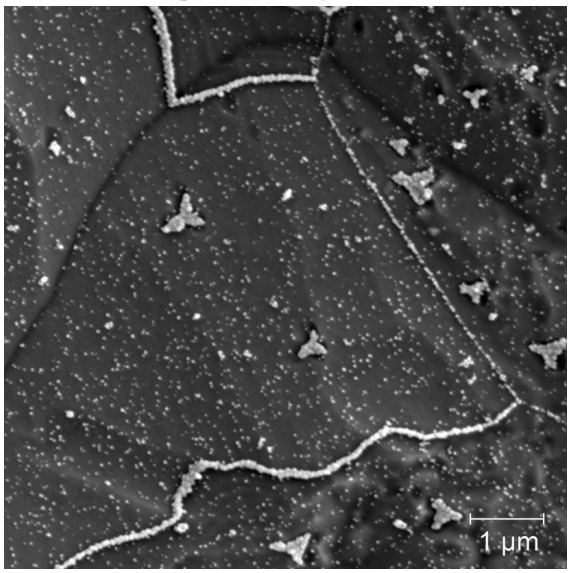
The thin layer sample shown in Fig. 3b shows gold nucleating in small triangular craters on the niobium surface, as well as along some grain boundaries of the niobium. This is likely due to the fact that current on a metallic surface concentrates more strongly on sharp corners and edges, and deposition of the gold scales proportionally to the current. The flat surface of the niobium has hardly any gold nucleating on it, and the gold that is present is sparse.

The thicker layer sample shown in Fig. 3a shows gold nucleating in a small triangular crater, along grain boundaries, and across the surface of the niobium.

These images indicate that a very smooth starting substrate is necessary to ensure a full, even coating of gold across the surface, and that while the gold plating recipe is being optimized, extensive characterization through SEM and XPS will be necessary to determine the extent to which the niobium oxide has been passivated.



(a) SEM image of a niobium sample with gold electrochemically deposited on it. This sample was given a thicker layer than the other sample in this study.



(b) SEM image of a niobium sample with gold electrochemically deposited on it. This sample was given a thinner layer than the other sample in this study.

Figure 3: SEM images of two niobium samples with gold electrochemically deposited on them.

2.6 GHZ SRF CAVITY BASELINE RF TEST

Once a fully optimized recipe for electrodeposition of thin gold layers has been developed, it will be applied to a full-scale TESLA elliptical SRF cavity. In order for this study to determine the effect of the process on the cavity performance, the cavity must be selected and its baseline RF performance (before gold plating) determined. The typical

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frequency used in accelerator applications of SRF cavities is 1.3 GHz. However, 1.3 Ghz cavities are large, and would require significant infrastructure in order to safely perform the chemical oxide removal process necessary for the study. As such, we elect to use a 2.6 GHz cavity instead. Since the interest is to determine a relative increase in performance, the specific frequency of the cavity is not relevant, and the smaller size of 2.6 GHz cavities presents a significant advantage.

We have selected a bulk niobium 2.6 GHz SRF cavity for use in this study. We have tested the initial performance of the cavity, and the plot of its quality factor vs. accelerating gradient at 2 K is shown in Fig. 4.

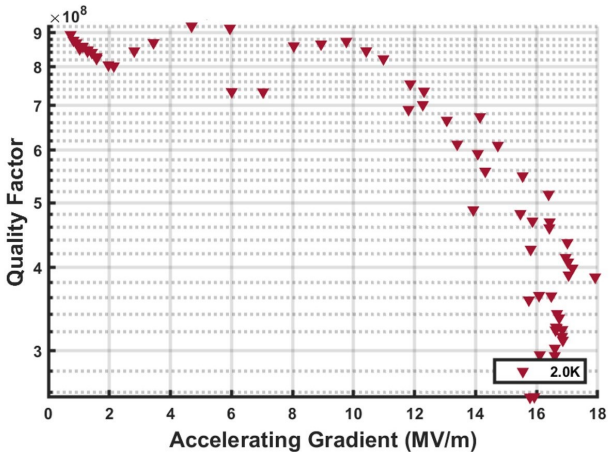

Figure 4: RF Baseline test results of the 2.6 GHz SRF cavity intended for gold selectroplating.

At low accelerating gradients, the cavity reached quality factors in the high 10^9 range, but as the accelerating gradient increases, the quality factor drops sharply. This is possibly due to a number of factors that can inhibit quality factor, and is indicative of the fact that the cavity is in need of further chemical and thermal treatments to improve its performance before it is plated with gold. Current planned treatments are a buffered chemical polish, a nitric acid treatment, and a high temperature bake.

CONCLUSION

In this work, we present significant progress on the development of an electroplating system for coating 2.6 GHz cavities with thin films of gold. We present multiple methods of surface characterization of samples with the native niobium oxide removed and a thin layer of gold electrochemically deposited. We present baseline RF characterization of the cavity intended for use in full-scale cavity testing of the gold-plating process. Next steps in the development will be to treat the cavity to improve its RF performance, and finalize a gold recipe for use in plating the cavity.

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