NEW METHODS FOR THIN FILM DEPOSITION AND FIRST INVESTIGATIONS OF THE USE OF HIGH TEMPERATURE SUPERCONDUCTORS FOR THIN FILM CAVITIES*

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Abstract

Niobium thin film cavities have shown good and reliable performance for LEP and LHC, although there are limitations to overcome if this technique should be used for new accelerators such as the ILC. New coating techniques like High Power Impulse Magnetron Sputtering (HiPIMS) has shown very promising results and we will report on its possible improvements for Nb thin film cavity performance. Current materials used in accelerator Superconducting Radio Frequency (SRF) technologies operate at temperatures below 4 K, which require complex cryogenic systems. Researchers have investigated the use of High Temperature Superconductors (HTS) to form RF cavities, with limited success [1]. We propose a new approach to achieve a high-temperature SRF cavity based on the superconducting 'proximity effect' [2]. The superconducting proximity effect is the effect through which a superconducting material in close proximity to a non-superconducting material induces a superconducting condensate in the latter. Using this effect we hope to overcome the problems that have prevented the use of HTS for accelerating structures so far. We will report the preliminary studies of magnetron sputtered thin films of Cu on Nb.

INTRODUCTION

The thin film cavities have several advantages towards cavities made of bulk material, among them cost advantages. Nb thin film cavities are in use at LEP and LHC at CERN with good results. Currently Nb thin film quarter wave resonators for HIE-ISOLDE are in production [3]. One problem that Nb thin film cavities experience is that the Q-factor drops significantly with increasing accelerating fields, and thus inhibits the use of Nb thin film cavities e.g. for the ILC. There is strong evidence that film properties such as micro structure, grain size and granularity influences the rf performance. The influence of the new coating technique is highly interesting, where high power pulses instead of a dc potential is used to produce the plasma needed for sputtering. Nb films have been deposited with HiPIMS, but its superconducting rf properties have not been addressed yet.

Another path of using thin films for cavities is to make use of the proximity effect, which implies that a superconducting material can induce superconductivity into a normal conducting thin film which is in good contact with the superconducting film by diffusion of Cooper pairs into the normal metal.

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PROXIMITY EFFECT

The proximity effect has already been shown for Cu/Nb bilayer films produced by dc magnetron sputtering [4]. With the aim to produce SC cavities operating above LH2-temperature the proximity effect for HTS in close contact with a NC, such as Nb and Cu, will be investigated.

Experiments

Samples of different thin film materials and substrates have been produced for different purposes. In Tab. 1 details for the different samples are listed. The first tests have been performed in order to verify the quality of the very thin films which are required for the proximity effect to occur.

The samples have been investigated with the AFM/UFM system at Lancaster University, UK [5], see also Fig. 1. With a UFM it is possible to not only measure the topography of the sample, but also its elastic properties. By this method grain boundaries or islands of different materials can be detected. In Fig. 2 the UFM images of an uncoated Si sample and a sample with a 2 nm thick Nb coating is shown. First investigations show that the surface is continuous and the grain size of the films is in the expected range. Residual Resistivity Ratio (RRR) measurements have been performed with a satisfying RRR of 9.4 on a Nb-film of 840 nm.

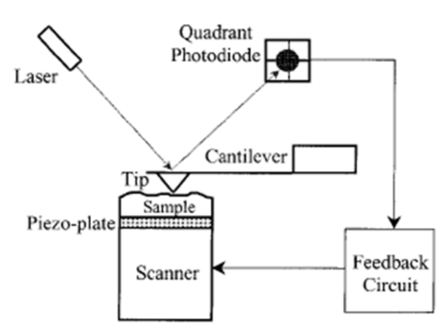

Figure 1: Schematic view of an AFM with added UFM function [5]. In addition to a standard AFM setup the sample can be vibrated. The force change on the tip gives information about the elasticity of the sample.

Table 1: Specification of produced samples for the various experiments.

Coating	Substrate	Thickness	Purpose
Nb	Monocrystalline, polished Si	2-50 nm	Very thin film samples for test of continuity of the film and grain size.
Nb	Monocrystalline, polished Si	840 nm	Reference sample
Nb	Polycrystalline unpolished Si	4 nm	Samples for diffusion measurements
Nb/Cu bilayer	Mono crystalline Si	300 nm Nb and 10-70 nm Cu	Proximity effect studies

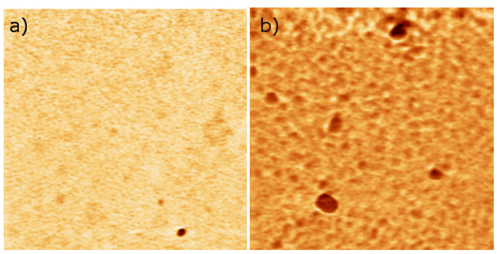

Figure 2: UFM images, a) shows an uncoated Si sample; b) shows the surface of a 2 nm Nb layer on top of a Si sample.

An important factor for the proximity effect is the influence of the interface between the SC and the NC. This interface has to be well defined to allow for the Cooper pairs to tunnel. Thus a good sample preparation is of great importance, but also parameters like diffusion of the thin film material into the substrate. Measuring the resistivity across the interface with a four-point probe gave no change of the resistivity before and after the coating.

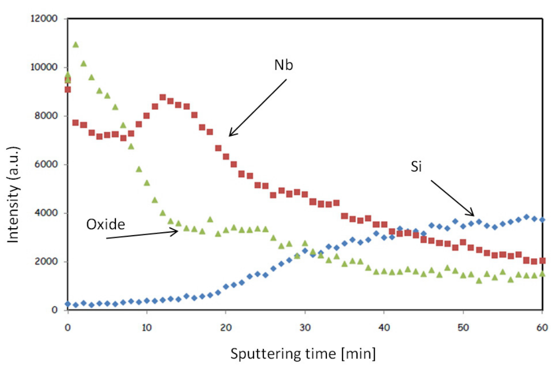

Figure 3: Depth profile of the XPS measurement. One can clearly see the Nb oxide layer at the surface, while the oxygen content decreases with deepness. Looking at the raw data it can clearly be seen that there is an oxygen peak appearing at the interface between the Nb thin film and the substrate.

The depth profile of Nb on Si have been investigated with an XPS by sputtering away layer by layer and investigating its composition, see Fig. 3. The results show that there is an oxide barrier still left between the coating and the substrate, such that a diffusion can be hindered.

The rf performance of the produced samples will be tested in a copper resonator designed for the purpose, such that it is possible to attach small samples. It will operate at 12 GHz. Furthermore samples will be produced for measurements of the surface resistance at 400 MHz with a quadrupole resonator at CERN [6].

HIPIMS

High Power Impulse Magnetron Sputtering is a recent technique for thin film deposition [7], which has already found its way into industry for making hard and endurable coatings [8]. Figure 4 shows a planar magnetron configuration. By applying very high power pulses not only the coating gas is ionized but also the sputtered target material. The low duty cycle gives an average power which is comparable to dc Magnetron Sputtering (dcMS), see Fig. 5.

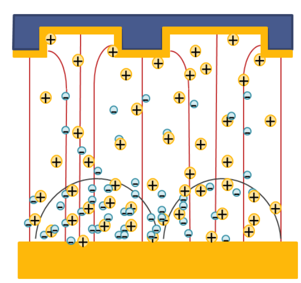

Figure 4: Schematic view of the HiPIMS system. If the substrate is biased the angle of incidence of the target ions will be perpendicular to the surface.

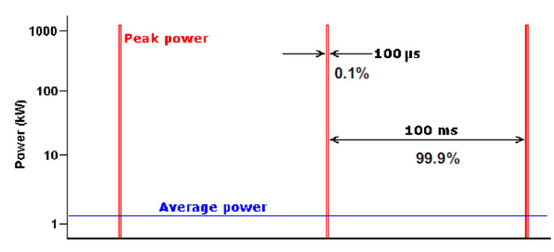

Figure 5: An example of a HiPIMS cycle. The average power is comparable to dcMS although the peak powers are exceeding the values of dcMS by orders of magnitude.

From the point of view of accelerator techniques, coatings produced with HiPIMS are highly interesting as it has been proven that the film properties are enhanced. One can expect better adhesion [11], a better (normal) conductivity, less defects in the crystal, as well as dense and smooth films [9, 10] as can be seen in Fig. 6. This results from the fact that the target material is partly ionized such that the ions will reach the target with a higher energy and, in case of an applied bias voltage to the substrate, always perpendicular to the surface. The result is a homogeneous coating even on non-flat surfaces.
Previous investigations of dcMS Nb films on Cu cavities have shown that the RF performance is strongly depending on the film quality [12]. Thus the use of HiPIMS for the production Nb thin film cavities can possibly push the limitations towards a better performance.

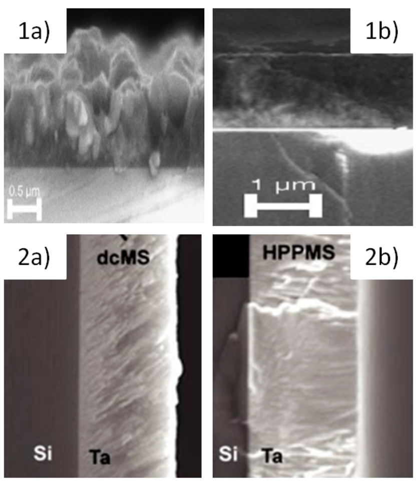

Figure 6: HiPIMS vs dcMS sputtered films. For dcMS the film is rough (1a), less dense and the grains grow with the angle of incidence (2a). While the HiPIMS produced films show both a smoother surface (2a) and in case of an applied bias voltage on the substrate a film growth perpendicular to the surface (2b). Pictures taken from [9] and [10]

OUTLOOK

The chosen power supply is Huettinger TruPlasma Highpulse 4006 and gives a maximum peak power of 6 MW with a peak current of 3 kA. It has recently been taken into operation and the first tests will focus on the characterization of the current and voltage characteristics for different coating gas pressures. The coating gas of use will be Kr. It is of interest to try to operate in the self sputtering regime with Nb. This has up to now only been shown for Cu [13]. The first tests will be performed on a planar magnetron configuration with a target diameter of 150 mm. Furthermore samples for the quadrupole resonator [6] will be produced for rf characterization of the films. In a later step we will try to use HiPIMS for elliptical cavities or for the HIE-ISOLDE cavity coating system [3], which is a large, cylindrical cathode.

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