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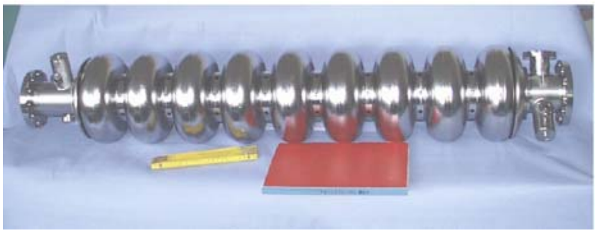

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Abstract

A new deposition technology has been developed, based on a cathodic arc system working under UHV conditions, to produce metallic thin films. The technique presents several advantages compared to standard sputtering, mainly: ionized state of the evaporated material, absence of gases to sustain the discharge, higher energy of atoms reaching the substrate surface, possibility to apply bias to the substrate and to guide the arc plasma using magnetic fields. Recent results on superconducting Niobium films deposited under several conditions and on sapphire substrate are reported. A cavity deposition system has been developed and the plasma transport to the cavity cell studied

INTRODUCTION

Copper RF cavities coated with thin Niobium(Nb) films are an interesting possible alternative to bulk-Nb ones because copper is cheaper than Nb, has higher thermal conductivity and better mechanical properties. The observed degradation of the quality factor (Q) with increasing RF field shown by Nb sputtered cavities makes them unsuitable for future very high energy linear accelerators needing gradients higher than 15MV/m. We are therefore developing an alternate deposition technology, based on a cathodic arc system working in UHV conditions. Its main advantages compared to standard sputtering are the ionized state of the evaporated material, the absence of gases to sustain the discharge, the higher energy of atoms reaching the substrate surface and, possibly, higher deposition rates.

The schematic drawing of the UHV arc systems can be found in [1]. It is pumped down by an oil-free pumping system consisting of a membrane pump on the foreline of a turbo molecular drag pump, and reaches a base pressure of 10^{-8} Pa after a 12 h bake-out at 150 C. Ignition of the arc at such a low pressure is not only more critical than for a standard arc device, but the triggering system must also be absolutely clean so as not to contaminate the plasma.

A common triggering method that uses high voltage discharge across the surface of an insulator had to be discarded because traces of elements evaporated from the insulator were found in the films, particularly when several ignitions were needed during a single deposition. After testing several other methods [2] a laser triggering system has been finally adopted. A compact 50 mJ Nd.YAG laser focused on the cathode is sufficient to most reliably ignite the arc under the cleanest possible conditions. To prevent contamination due to memory effect when the same system is used to deposit different materials [3] we have only used high purity niobium cathodes.

The main disadvantage of the arc technique is the production of microdroplets (or macroparticles) with typical dimensions in the range from 0.1 to 10 μm, emitted from the region of the arc spot and consisting of molten cathode material. Microdroplets become charged with electrons during their passage trough the plasma region near the cathode and accelerated to high energy. They solidify during their flight to the anode and can become embedded in the growing film. While not contaminating the film, the droplets may create voids, increase the surface roughness and become possible sources of field emission. They should therefore be filtered out.

The deposition of a particular geometry such as the inner wall of a RF cavity, may rise additional problems, such as the uniformity of the deposited layer, and differences in the morphological and superconducting properties of niobium film due to different arriving angles of the Niobium atoms. The effect of the low angle was demonstrated to be the major problem in deposition of low beta cavities using the sputtering technique [4].

The role of the bias must be investigated to find its influence on the niobium film properties. In [5] was pointed out that, ones fixed the maximum voltage bias, using a pulsed bias and changing the duty cycle was possible to cover particular geometry with large aspect ratio.

For these reason we concentrated our effort in three directions: a) to study the effect of voltage bias on the RRR when the samples face the cathode and under different angles between the substrate and the cathode surface. b) to develop a new compact filter arc to filter out the macrodroplets and to improve the deposition rate, c) to commission the first prototype of a cavity system to study the plasma transport in the cavity in order to deposit a single cell of RF cavity.

The study of the influence of a pulsed bias, and the optimization of the magnetic field inside the cavity will be the next steps of our research.

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NEW FILTER ARC

We've already run a knee-type magnetic filter with a long (about 70 cm) 90 degrees elbow showing that the transport of plasma on such long distance in not a problem and a film free of macroparticles can be obtained [6]. However in order to reduce the system dimensions and to improve the transport efficiency we designed and put in to operation a new filter. The new filter has a T-type geometry (see fig. 1). It was fabricated using a modified T shaped vacuum chamber with CF 100 flanges resulting in a compact structure. An outer jacket for water cooling was also realized to improve the cooling and to avoid overheating. Several thermocouples are placed in the inner vacuum wall to measure the chamber temperature. The magnetic field simulation and first experimental investigation carried out in Swierk [7] have shown that the plasma hit the corner resulting in plasma transport losses and corner overheating. For these reasons, respect to a standard T shape connection, the corner of the T between the cathode and the sample holder was smoothed.

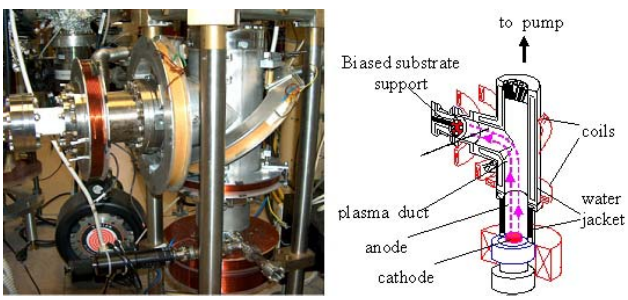

Figure 1: Left: picture of the realized system: magnetic coils used to guide the plasma are well visible. Right: a schematic drawing of the new compact T-type filter: cathode is at the bottom and plasma is guided by the magnetic coils to the sample-holder placed at 90 degree out of sight from the cathode.

Distributions of magnetic field lines within the considered filter were computed by means of a Maxwell R 2D-v10 code available as a share-ware program on the Internet [8]. It is based on the finite element method, and it gives good approximation for axially symmetrical windings. Detailed numerical computations were performed to find the best configuration.

The average value of the magnetic field near the cathode surface is 16 mT, while that value inside the magnetic channel is about 13 mT. Such values of the magnetic field enabled effective guiding of electrons to be achieved, but more important was uniformity (smoothness) of magnetic field lines and the elimination of so-called deformed lines (touching and penetrating walls of the vacuum channels).

The average deposition rate was found about 120 nm/minute on the whole surface, ranging from a maximum of about 200nm/min near the center of the outdoor CF100 exit flange, to a minimum of about 60nm/min near the chamber wall. These results are a factor 2.5 higher than the previous elbow filter and also higher then the previous reported results using the T-type filter [7], mainly due to the smoothing of the T corner between cathode and samples. The number of the droplets also was very low, only hundreds for square millimeter, a factor 10 less than usual planar arc and in the same order than previous elbow filter, i.e. the improved plasma transparency doesn't affect the macroparticle filtering efficiency.

BIAS AND GEOMETRY

A systematic study of the bias voltage dependence of the deposition rate and the film quality have been performed on samples deposited facing the cathode. During the same run have been also deposited substrate placed at different angles respect to the cathode in order to study the influence of the deposition angle on the film properties. The niobium film were deposited during the same run on copper and sapphire substrates placed on 3 sample holders similar to that described in [4]. It should be pointed out that in the sputtering case the angle between substrate and cathode also determine the angle of incidence of niobium atoms on the growing film. When the arriving angle is low respect to the substrate surface, the growing film shows a rough surface and it becomes porous. However, in the arc case evaporated niobium is fully ionized and, if a bias is applied, the ions are accelerated in the sheath region trough the substrate and they reach the surface almost with a normal incident angle (angle of incidence depending on the voltage bias). For this reason the film quality is not expected to be affected by the angle between substrate and cathode, whereas large variation in thickness cannot be excluded.

Bias (V)	**min thick.(μm)**	**max thick.(μm)**	**RRR**
-23	0.9	1.1	26
-40	0.9	2.8	40
-60	1.0	1.7	30
-80	0.7	1.5	50

Table 1: Results on niobium films deposited on sapphire substrate as function of the bias voltage

In table 1 we report the result of thickness and RRR measurements performed on niobium films deposited on sapphire substrate as function of the voltage bias. The maximum and minimum thickness depend on the deposition angle, ranging from 0 degrees to 90 degrees respect to the plasma direction. The RRR (all at 0 degrees) results does not show a clear dependence from the voltage bias, all values being high quality, whereas the thickness decrease increasing voltage bias due to self sputtering of the growing film [9]. The dependence of the film thickness from the angle is less than expected, and it reduced when the bias voltage is increased (less then a factor 3 in -40V and less than a factor 2 at -80V) A systematic study of the surface morphology, the crystal structure and the RRR dependence from the deposition angle is in progress and it will be reported in a future publication.

CAVITY SYSTEM

The device for vacuum arc Nb surface coating of RF cavities is composed of a cathode-anode tandem with a standard CF-100 vacuum t-junction which serves as a vertical plasma duct and enables pumping of the system by a 180 l/s turbo-pump unit . A schematic view of the system is shown in Figure2 On the top of the T-junction a ceramic isolator is installed which supports a vacuum chamber shaped as a 1.3 GHz TESLA cavity . Another cylindrical isolator mounted on the top of the system supports a flange equipped with a low-voltage feedthrough. An isolated, horizontal, 7 cm diam stainless steel disc is connected to one of the feedthrough pins and is suspended at the top of the cavity. The disc served as a plasma ions collector to optimise the plasma transport in the cavity cell. The magnetic field to guide the plasma is generated by six dc-current fed coils: - a coil ”0” which consists of 1600 windings of 1.5 copper wire, wound in 27 layers with the inner diameter of 133 mm, and height of 83 mm. The coil surrounds the cone-shaped niobium cathode in order to stabilize the position of cathode spots, - five other identical coils (numbered from ”1” to ”5”) with 350 windings each, with inner diameter of 226 mm and height of 26.5 mm. The positions of the coils is shown in Figure2.

A series of tests have been performed in order to optimize niobium plasma transmission in the system using different combination of dc currents which fed the coils.

The total ion current collected by the biased cavity during these tests was typically 2 A and was weakly dependent on the bias. We have realized several collectors to be placed in different regions of the cavity cell to study the dependence of the ion current from the frequency and duty cycle of the pulsed bias that we intend to use in the cavity deposition, and to check how the current is distributed in the cavity

CONCLUSION

We designed, realized and put in operation a new filter arc, T-type, with a plasma transport efficiency much larger than previous elbow filter. The improved plasma transparency doesn’t affect the macroparticle filtering efficiency.

We deposited several samples with different bias and angles in respect to the plasma direction. The complete characterization of the samples is undergoing, but we have already observed that there is no dependence of the RRR from the bias potential, and only weak dependence of the thickness from the angle.

We are also commissioning a system to deposit a single cell RF cavity, demonstrating that it is possible to obtain large ion current on the cavity. The magnetic field distribution and the use of pulsed bias are under investigation to optimise the deposition on the inner surface of the cavity in term of uniformity of thickness and coating quality.

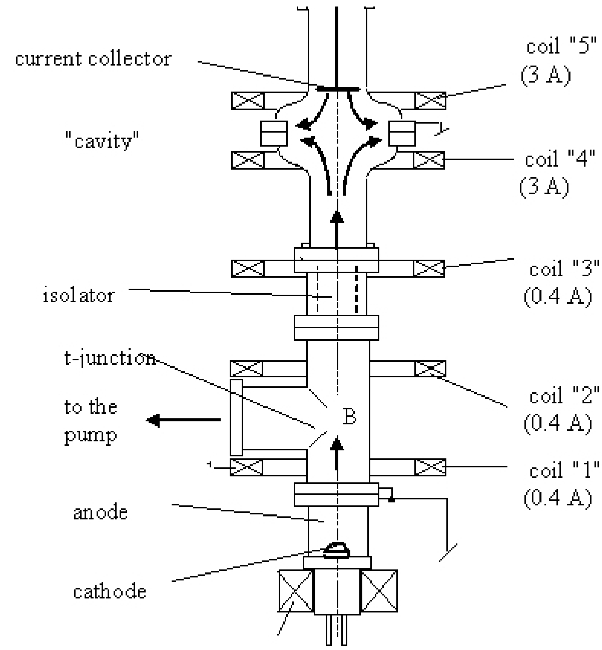

Figure 2: Schematic draw of the system for cavity deposition. The coil currents indicated in the figure correspond to about 1.5mT uniform magnetic field and represent one possible configuration for cavity deposition in the cusp geometry.

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