SPUTTERING OF HIGH QUALITY NIOBIUM FILMS INTO 1.5 GHZ MONOCELL CAVITIES.

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Abstract

High quality Niobium films have been produced into 1.5 GHz monocell Copper cavities in a DC Magnetron Sputtering configuration. Several magnetron configurations with different types of discharge confinement have been tested. The optimization of the coating purity and superconducting properties are compulsorily for the achievement of high RF performances.

1. INTRODUCTION

Superconducting RF cavities are traditionally made of Niobium metal sheet by welding together half-cells produced either by deep drawing or by spinning. An alternative solution to this, consists in replacing Niobium with OFHC Copper and coating all over the resonator interior with a Niobium film deposited by DC magnetron sputtering. The advantage of this solution is twofold: the higher thermal conductivity of the Copper substrate enhances the thermal stability of the whole resonator against quench; moreover a not negligible cost reduction due to the Niobium saving becomes important for large numbers of cavities.

The CERN commissioning of around 160 Nb/Cu sputtered cavities to three different European industries for the LEP200, passing from laboratory to industrial scale production, is a large scale demonstration that the sputtering technology applied to superconducting cavities is well-established [1]. In the mean time even in the field of low-beta RF structures for the acceleration of heavy ions, high quality RF performances have been achieved for Niobium sputter-coated Copper Quarter Wave Resonators [2].

Nevertheless, regardless of whether cavities are made of bulk Niobium or Niobium-coated Copper, the achievement of higher accelerating fields at low rf losses is compulsorily for the new generation of linear colliders as TESLA. Therefore great efforts have been devoted to the improvement of bulk Niobium thermal conductivity for the former approach, and to the understanding of the mechanism of Q-degradation with increasing accelerating field for coated cavities. The cost reduction in cavity manufacture is also a key parameter for the choice of the cavity production technology applicable to new colliders.

In such a context the sputtering of high quality Niobium films into 1.5 GHz Copper monocell prototypes, also already carried on by other groups [3,4], is a preliminary operation to a feasibility research on sputter-coating multicells applicable in real accelerators.

2. DC MAGNETRON SPUTTERING FOR 1.5 GHZ MONOCELLS

On the basis of the good results obtained at CERN by cylindrical magnetron sputtering for 350 MHz and 500 MHz, the most natural thing it would be the design of a sputtering configuration for 1.5 GHz recalling the classical one: a stainless tube inserted along the cavity axis, surrounded by a Niobium liner and containing an electromagnet [5]. The magnetic field lines work as an electron trap, since "they are born from the cathode and die onto the target". Such a cylindrical magnetron configuration has already widely demonstrated to be suitable for production of high quality Niobium films having values of the Residual Resistivity Ratio (RRR) up to 40.

For sputtering 1.5 GHz monocells we built a cylindrical post-magnetron . The idea under such a design was the search of high sputtering rates and high thickness uniformity of the coating sampled along the cavity profile. Higher sputtering rates respect to classical cylindrical magnetron are possible when sputtering from the whole target surface. The advantage is twofold: the fraction of impurities trapped in the film linearly decreases versus deposition rate, moreover the deposition takes shorter time.

On the other side for the classical cylindrical magnetron, when the discharge is switch on, plasma do not live simultaneously on the whole target surface, instead it is strictly confined onto the target surface portion where ionizing electrons are trapped by magnetic field lines. A large portion of target surface, the one just outside of the magnetic trap, reaches high temperatures as well, but there is not sputtering from it, unless the electromagnet is moved toward this region. On the basis of our experience on cylindrical magnetrons of such a design, we have observed that films untouched by plasma have systematically worse purity than films immersed in the discharge. This problem becomes not important for post-magnetrons, since the whole target surface is sputtered simultaneously. When designing a post-magnetron two choices were possible: a) the cathode must follow the profile of the cavity, keeping the magnetic field lines constantly parallel to the target. End losses being avoided by an electrostatic mirror outside of the cavity. In this case the shape of the target is rather complicated since to get into the narrow bore of the cut-off, it must be collapsible. b) the cathode is a straight tube and the magnetic field follows the shape of the cavity.

This second solution it looks more convenient especially if exotic materials (i.e. A15 materials) will be sputtered by this configuration and the shape of the target must be as simple as

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possible. In order to enhance the ionization only at the cavity equator level, the magnetic field is shaped by the two long coils around cut-off tubes, and it is left unconfined at the equator level (fig. 1). Indeed since the magnetic moment of a trapped electron $\mu = \frac{W_\perp}{B}$ is an adiabatic constant ($W_\perp$ is the electron kinetic energy associated to the velocity component orthogonal to the magnetic field B), the maximum of ionization takes places at the center of the plasma bottle, that corresponds to the level of the equator. Electrons in a curved magnetic field of the type we use, together with the **E** x **B** drift, experience a $\nabla B_\perp \times \mathbf{B}$ drift that is proportional to $W_\perp$. Thus conservation of energy cause electrons passing in the direction of $\nabla B_{\parallel}$ reflected by magnetic field. The highest density of ionizations is hence where magnetic field is the smallest (and is parallel to the target).

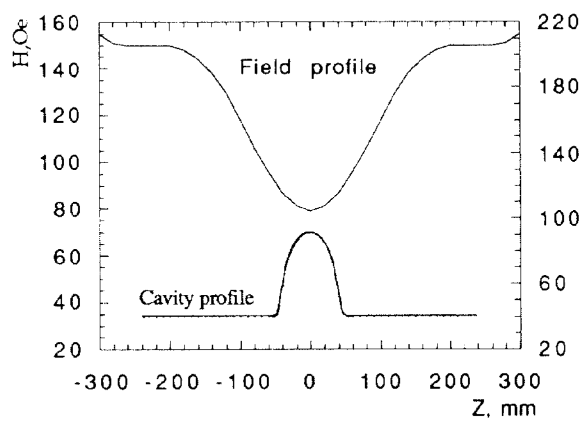

Fig. 1 Parallel component of the magnetic field profile along the cavity axis for the post-magnetron we built.

Target erosion is enhanced around this region. End losses are limited by two cathode wings for the electrostatic confinement and by two additional coils that close the bottle neck. The presence of these two additional coils allows us to reduce the wings diameter. Each one of the wings has a surrounding shield which can be polarized positively for biasing the discharge. The possibility to introduce bias is a strong advantage for increasing the RRR of Niobium films.

The I-V characteristics of the postmagnetron driven at zero bias were fitted with the $I = V^n$ law. Values of the confinement efficiency **n** around 6-7 were found.

Apart the high deposition rate two further advantages of our configuration are the following:

i) A plasma confinement following as faithfully as possible the cavity geometry at high currents and pressures will behave as an unbalanced magnetron all over the substrate, improving uniformly the quality of the coating.

ii) The post-magnetron configuration with external coils is easily adaptable to coat higher frequency cavities for which the target becomes very small and the production of a strong magnetic field by an internal electromagnet is not immediate.

The main disadvantage of our system is instead recognizable with the difficulty of centring and aligning.

In figure 2 it is displayed the sputtering rate distribution along a resonator meridian at the limited discharge power of 1.2 kW. The thickness uniformity is within a factor 1.5. The whole cavity can be coated in less than 10 minutes with a Niobium film 1 micron thick.

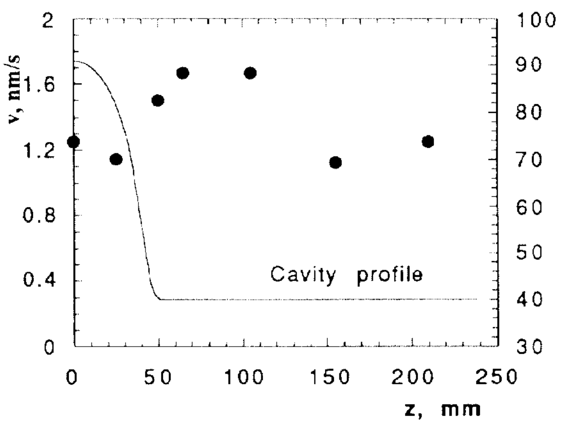

Fig. 2 Sputtering rate distribution along a meridian.

Values of Tc over 9.25 K and of RRR between 10 and 40 were achieved with little effort and high reliability. The highest values of RRR were obtained all around the iris of the resonator (where the plasma substrate interaction is stronger).

3. CONCLUSIONS

A cylindrical post-magnetron configuration with magnetic and electrostatic confinement has been conceived and built for the sputtering inside 1.5 GHz monocell resonators. Primary results show that it is worthwhile to develop this type of deposition. Biasing the substrate can lead to a significant improvement for the quality of Niobium films.

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