First Test of a 1.5 GHz Single Cell Accelerating Cavity Obtained by Magnetron Sputtering of Niobium

G.C.Gualco, A.Matrone, S.Rizzo, F.Rosatelli
ANSALDO RICERCHE
Corso F.Perrone 25
16156 Genova Italy

R.Parodi, P.Fabbricatore, G.Gemme, R.Musenich
Bi Zhang
INFN-Genova
Via Dodecaneso 33
16146 Genova Italy

Abstract

The first results of RF tests on a single cell copper niobium cavity operating at 1.5 GHz are presented .[1]

The cavity was obtained by spinning an OFHC copper sheet in half cups and tubes.

The cavity's components are welded together under vacuum; the so obtained cavity was niobium coated by using a scaled version (to our dimension) of the magnetron sputtering system developed at CERN for S/C cavities operating at 350 and 500 MHz.

The results of our first tests on two cavities, together with the ancillarry measurements performed on several Niobium samples are presented.

INTRODUCTION

Since 1986 ANSALDO RICERCHE started an R&D program on superconducting cavities to assess the industrial feasibility of a Superconducting accelerators;

For that reason we started the developement of 1.5 GHz single cell accelerating Copper Niobium cavities .

The deposition by Magnetron sputtering of a Layer of Niobium on the copper cavity seems at the moment the most promising (albeit the most challenging) way to build low losses high field superconducting accelerating structures.[1]

The sputtering deposition will allow, in the future, the deposition of composite materials like Nitrides, or eventually Carbides, and a wide choice of out of thermodynamical equilibrium Superconducting composites with high critical temperature T_c and even higher critical RF magnetic field.

These composites should provide great benefits in low loss high gradient accelerating structures compared with the "standard" niobium and niobium on copper technology.

DEPOSITION TECHNIQUE

The deposition Technique we used is based on the cylindrical magnetron technique developed at CERN by C. Benvenuti and coworkers to coat the LEP cavities [2].

Due to the different frequency, 1.5 GHz in our case and 350 MHZ for the CERN, some modifications in the sputering setup are mandatory.

To produce the 200 Gauss magnetic field needed for the confinement of the argon discharge , we used a stack of Nd-Fe-B permanent magnets.

We carefully checked the field distribution and strength of different magnet configurations by several runs of the 2D magnetostatic solver PE2D.[2]

The magnet was housed inside a AISI 304L tube and cooled by flowing demineralized water; in that configuration the temperature of the permanent magnets never ecceeds 120 Celsius.

The vacuum tigth stainless steel tube is used to fasten the Niobium cathode obtained by rolling an high purity (RRR=200) Niobium sheet one millimeter thick.

Before starting the deposition the Niobium cathiode was deeply cleaned by using the standard (HF,HNO_3, H_3PO_4 1:1:1) [4] chemical treatement for the niobium.

After the chemical polishing the cathode was further cleaned by removing several microns of niobium via the sputtering of a dummy cavity.

This process allowed us for state the rigth working point in the current pressure plane to obtain a good film growing at a reasonable rate.

QUALITY OF THE NIOBIUM FILM

The niobium films produced by our sputtering system were carefully investigated to have a check of the efficiency of our process via the measurement of the critical parameters of the superconducting film.

First we measured the transition temperature of a film, deposited on an alumina substratum , by the usual resistive method.

With the best choice of sputtering parameters the samples showed a critical temperature Tc of 9.2 $\pm$0.2 K, a

---

[1]This work was supported by CNR under the Progetto FinalizzatoTecnologie Superconduttive e Criogenia

0-7803-0135-8/91$03.00 ©IEEE

transition width of 0.1 K and a Reduced Resistivity Ratio (RRR) of 7±0.3.

We cross checked our resistive measurements by measuring the AC magnetic susceptibility on the same samples.

The AC measurements showed a Tc of 9.1±0.2 K and a sharp, single phase transition without any evidence of low Tc phases due to contamination or oxidation of the niobium.

After the check of the niobium film quality we started the deposition of niobium films on copper substrata housed in different positionds inside a dummy cavity;

The composite Nb-Cu samples were used to check whether the sticking properties of the Nb film on the copper are depending on the surface treatement of the substrata, the polishing procedure, and the sputtering position in the dummy cavity.

After some trial run we succeeded to get a strong correlation among the baking temperature of the copper substratum, the sticking properties of the niobium film and the production of blisters.

Due to the low resistivity of the copper we were unable to measure the transition temperature of the Nb-Cu composite.

We only checked for heavy distorsion of the Nb La ttice by X-Ray Diffraction.

The results obtained showed no significant changes in the lattice of Niobium on copper films compared to the lattice of high purity high RRR Niobium.

The crystals of the Niobium films were found preferentially oriented (95%) along the [110] crystallographic axis.

ANCILLARY RF TESTS

The quality of our Niobium on copper films was also checked by measuring the RF surface resistance of a flat round disk 54mm in diameter.

The sample produced in our sputtering system by using the standard technique developed in our lab, was used as bottom flange of a demountable RF cavity operating at 8 GHz in the lowest TE monopolar mode.

Due to the fairly high local geometric factor of the flange, (G=10400) against a total geometric factor of the cavity of 770, this method gives us only a feeling of the relative value of the surface resistance of the niobium film compared to the value of the surface resistance of a bulk Niobium flange.

The surface resistance of the reference full niobium TE cavity was limited by a fairly high value of 100 nΩ due to a residual surface resistance , temperature independent up to 1.5 K.

This surface resistance gives a Q value of 7×10^9 for the TE cavity ·

Measurements on the same cavity after substitution of the bottom flange with the niobium on copper films resulted in exactelly same value for the Q_0 when the right sputtering process was found.

From these measurements we concluded that our sputtering process was able to produce, on a well polished and outgassed flat copper matrix , niobium films having an RF surface resistance lower than 500 nΩ .

That value of surface resistance for the bottom flange results in a 30% lower Q_0 for the composite cavity, well within the sensitivity of our measurements.

Because that value of residual resistance will result in an accelerating cavity with a Q_0 value of 6×10^8 , we decided that any further improvement of our sputtering process was to be implemented on the final set up, trying to produce a full scale 1.5 GHz accelerating cavity with the right surface resistance (lower than 200 nΩ) , sustaining accelerating fields up to 5 MV/m at least.

1.5 GHz CAVITY PRODUCTION

According to our construction process a 1.5 GHz cavity was built by vacuum brazing together two half cups obtained by spinning and machining to the final shape two copper sheets 4mm thick.

The beam tubes brazed to standard 100 mm Conflat flanges were added .

The cavity was first mechanically and chemically polished before the assembling procedure in order to remove the layers of copper damaged during the forming steps.

After the final assembling the cavity was once more deeply chemically polished , rinsed with high purity demineralized water to remove chemical contaminants and assembled in the UHV system forming the sputtering set up.

The upper flange of the cavity holds via a high voltage insulator, the niobium cathode and the high voltage high curent feedtroogh ; the pump down of the cavity starts typically in less than one hour from the final rinsing.

All the sputtering system was heated up to 250-300 C for 24 hours to reach an ultimate vacuum, after the baking, of 3- 4 10^{-10} torr.

Once the sputtering sustem ready a suitable pressure of high purity Argon gas (99.9995 per cent) is admitted in the cavity via an in-line liquid nitrogen cooled trap was used in order to remove further contaminants, typically water, from the gas.

The contaminants in the vacuum system are checked during the sputtering process by a standard residual gas analyzer system.

The permanent magnet is inserted inside the cathode holder and the gas discharge started.

Due to the large difference in diameter of the equator and the irises of the cavity, a tree step sputtering process is needed.

We plated first the equator of the cavity, then the magnet are moved to a new position to plate the upper iris and cut of tube; finally the lower iris is plated.

The sputtering process completed, the cavity is again evacuated to 10^{-10} torr to completely remove the argon gas;

After thatthe vacuum system is vented by admitting high purity (3ppm H_2O and 2ppm O_2 max) nitrogen.

The cavity is removed from the sputtering set up and , in less than one hour mounted in the test criostat and pumped down to 10^{-7} torr .

Subsequently the cavity is connected to a 60 l/sec Jon pump and inserted in a standard parallel cryostat for the cryogenic tests.

The cavity is cooled to the LHe temperature when a pressure of 10^{-8} was reached.

EXPERIMENTAL RESULTS

Despite the care used for producing the Nb-Cu composite cavities, the results obtained till now are less than encouraging.

At the first run of the 1.5 GHz cavity a Q_0 value of $3x10^5$ was measured.

The change in penetration depth after the transition, measured as the eigenfrequency shift,was as large as 5μm.

This value is roughly ten times the total thickness of our film, and is a strong hint for insufficient thickness of the niobium film in some cavity region, leading to additional losses in the copper.

This our feeling was confirmed by careful measurements of the film thickness in the flat region midway between the equator and the irises.

In this region the film thickness was measured to be 200 nm.

We coated a new cavity increasing the deposition rate by a factor of five. The Q_0 increased up to a factor of 100; the measured change in penetration depth was now less than 100 nm showing a complete screening of the normal metal by the superconductor.

The surface resistance was limited by a very high value of surface resistance 10 μΩ of residual surface resistance due possibly to some contamination of the niobium film.

Visual inspection of the cavity showed some shadow on the flat region between the irises and the equator and a substantial blistering of the film in the same region.

This fact is probably due to a not so good removing of the chemical polishing solution in that region during the rinsing.

CONCLUSIONS

Our first attempt to produce a good 1.5 GHz cavity by sputtering ogf niobium on a copper matrix was frustrated by some drawbacks in the film deposition process on the copper cavity.

Despite a good film quality on allumina substrata, T_c= 9.2 K , ΔT= 0.1 K , RRR=7and good RF properties on a flat copper matrix ($R_S \leq$ 500 nΩ at 8 GHz) low Q_0 values were obtained in the first two prototipes we measured.

Nevertheless from our first tests we learnt a lot about the influence of the geometry on the process.

We discovered first that (at least in our cavity) is very difficult to cover with a niobium film, thick enough to completelly shield the normal metal , the flat region midway between the equator and the irises.

To try to circumvent this flaw in our deposition process ve changed the deposition time , improving our results, but obtaining always Q_0 values by a factor of 100 lower than our goal; this problem seems to be happened to other groups at trying to cover by a niobium layer 1.5GHz copper cavities[5].

In our opinion nevertheless a lot of improvements are possible , because at the moment we have changed only the deposition time.

We plann in the next year to check carefully any step of our deposition process in order to improve our technique and to gather from the experience and experimental results the knowledge of the sputtering process needed to master the complex task of producing high field and low dissipation Nb-Cu composite cavities.

AKNOWLEDGMENTS

We are deepful indebted to V.Palmieri of INFN-LNL for the help he provided us in some fruitful discussion at the beginning of our work.

We thanks the CERN S/C-RF Group for showing us teh CERN facilities for S/C cavity production and testing during a visit at CERN at the very beginning time of our research.

REFERENCES

[1] Ph. Bernard et al " Status Report on Superconducting Nb Cavities for LEP". in *Proceedings of the 4th WORKSHOP on RF SUPERCONDUCTIVITY* " KEK , TSUKUBA, Japan 1989 ,pag.19-36

[2] PE2D is a Bidimernsional Magnetostatic solver distributed by VECTOR FIELDS inc. UK.

[3] C;Benvenuti , et al "Status Report on CERN Activities Aiming at the Production of Sputter Coated Copper Superconducting RF cavities for LEP" in *Proceedings of the 4th WORKSHOP on RF SUPERCONDUCTIVITY* " KEK , TSUKUBA, Japan 1989 ,pag.869-884.

[4] P.Kneissel " Surface Preparation of Niobium" *Proceedings of the First WORKSHOP on RF SUPERCONDUCTIVITY* " KFK -KARSRUHE Federal Republic of Germany, 1980. Pag.27-40

[5] Arnolds-Mayer et al. " On Niobium Sputter Coated Cavities" *Proceedings of EPAC 88 Conference* Rome, Italy 1988 Pag. 1187-1189.