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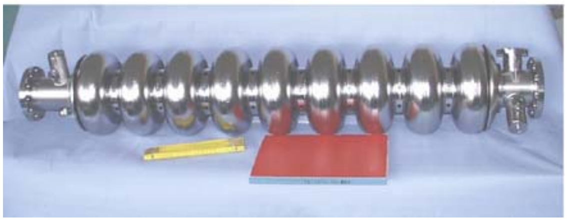

WP4.2 – Thin film cavity production

Deliverable 4.2.2.4
First multicell coating with planar arc cathode

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Abstract

Superconducting cavities can be produced from Niobium sheet material. An alternative fabrication method is to coat copper cavities with a thin Niobium film. At low frequencies cavities are large so that considerable cost can be saved with the reduced amount of expensive Niobium. The sputter coating technology has been developed by CERN. At moderate gradient Niobium coated copper cavities showed low loss, i.e. high quality factor. But with increasing gradient the quality factor drops down. Vacuum arc coating is a well known alternative coating method but was never tried out with RF cavities. There is a hope that the high impact energy of arc produced ions might create a "better" Niobium film without reduced Q-drop. In this R&D activity cavities have been coated by vacuum arc technology. The Niobium films show reasonable superconducting properties. But sever adhesion problems of the coating could not be solved within the time frame of the project.

Acknowledgements

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1. Introduction

The main aim of Work Package 4 was to develop a new method of thin-film coating by means of arc discharges under ultra-high vacuum (UHV) conditions, in view of applying it to superconducting RF cavities. CERN pioneered copper cavities, magnetron sputtered inside with a thin Nb-layer, could in fact become an alternative also to the present, high voltage, bulk-Nb ones if their present electric field limit could be overcome. Our new approach was based on the idea of using cathode-arc discharge plasmas, generated in ultra high vacuum (UHV) environments, to produce ultra–high purity metallic film coatings with excellent adhesion for applications in superconductivity.

Cathode-arc discharges operating under relatively high (HV) gas pressure environments were known and employed in different countries, e.g. USA and Russia for various different purposes but, for our purpose they had to be developed to comply with UHV standards. Two different arc configurations were considered: Planar and Linear.

The main institutions engaged in WP4 were: the Andrzej Soltan Institute for Nuclear Studies (IPJ), Poland, responsible for task WP4.1 (Linear-Arc Cathode Coating) and the INFN-Roma2, Italy, responsible for task WP4.2 (Planar-Arc Cathode Coating). The tasks used different experimental facilities but explored the same principle and using identical measuring techniques. Both tasks were thus carried out in a framework of the full scientific collaboration. Valuable support has been received by: CERN (EU), Cornell University (USA), DESY (Germany), HCEI Tomsk (Russia), INFM Naples (Italy), INFN-ROMA2 (Italy), INFN Milano (Italy), INFN-LNF, JLAB (USA) and CEA/Saclay (France).

2. WP4.2

This report presents the most important results obtained by WP4.2 activities in the period from January 2004 to December 2008.

Task WP4.2 was focused on the development of the Ultra High Vacuum Cathodic Arc (UHVCA) technique in planar-cathode geometry, best suited to coating single-cell RF cavities.

3. Experimental setup development

3.1 *Prototype apparatus*

The basic design configuration of our prototype system to arc-coat samples is shown in Figure1. The solenoids are needed to guide the arc plasma to the sample.

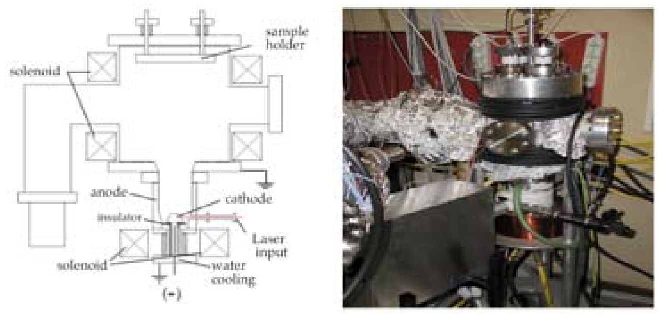

***Fig.1**. Schematics of the first prototype apparatus designed for UHV planar cathode arc coating.*

The sample holder is biased to a negative constant voltage to avoid excessive substrate heating by the large plasma electron current. The chamber is pumped down to 10^{-11} hPa with an oil-free pumping system consisting of a two-stage piston pump as a fore-line of a turbo molecular pump. All vacuum chamber components and accessories, as well as all vacuum connections, have been manufactured using only high purity materials: stainless-steel, OFHC copper and high-quality ceramics (shielded from the arc). The cathode and all parts accessible to the arc have been made of pure Nb with RRR $\geq$ 250. The reliable triggering (ignition) of arc discharges is often a serious problem, even in the industrial arc-based devices. In HV systems, thin layers of gasses and impurities formed upon the surface of electrodes, are beneficial in that sense that they facilitate the starting of an arc discharge.

Under UHV conditions the high-temperature baking of the vacuum chamber removes almost totally such layers. The described effects, as well as requirements that all other sources of impurities must be effectively eliminated, make ignition more difficult. After testing many known triggering methods from the point of view of the operational reliability and cleanness, we have finally built an ignition system based on a Nd: YAG (50-100mJ, 10ns, 10 Hz rep.rate) laser, the laser beam being focused upon the cathode surface through an appropriate vacuum-tight quartz window. The arc discharge is triggered extremely reliably without introducing any additional impurity whatsoever. The mastering of the laser ignition technique has been decisive for achieving the desired purity of the deposited superconducting films.

3.2 Micro-particle filters

One undesired feature of the arc process is the emission of up to μm size molten droplets (micro-particles) of the cathode material that solidify in flight. Micro-particles can be filtered out by bending the plasma flux in a magnetic channel so that the heavy particles, traveling in a straight line, can not reach the sample. Appropriate geometries and magnetic field configurations have been designed and tested: two different shape filters are shown in Figure 2. The coil arrangement is designed to force electrons to follow magnetic field lines with orbit radii smaller than the inner radius of the bent vacuum chamber. The Figure also shows the elbow filter 2D computed magnetic field configuration.

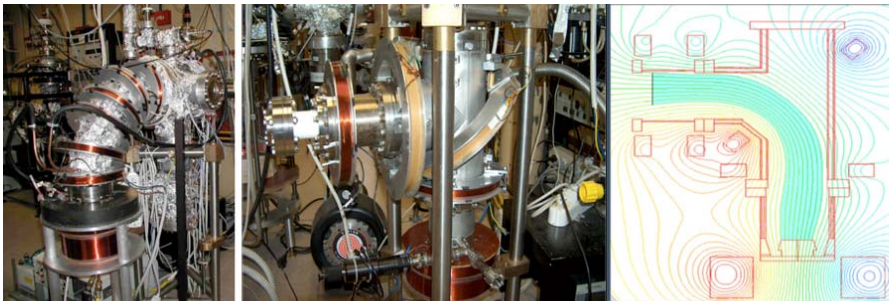

Fig.2. *a) Curved filter, b) Elbow filter, c) Elbow filter_magnetic field configuration.*

3.3 Single cell cavity coating system

A first unfiltered apparatus to coat single cell cavities was equipped with a single cathode arc and a dummy stainless steel cell, splittable in two in halves, carrying a number of sample holders to measure the film thickness distribution on the cell inner surface and the corresponding arc current values. It was chosen, in order speed the early cavity production, to start without micro-particle filtering. The apparatus was mainly used study and optimize the focusing magnetic field configuration; a rather complicated one, including fields rotating around the cavity axis, was needed in order to obtain an adequate uniformity of film thickness on (one half of) the cavity. The apparatus is shown in Figure 3.

It required interrupting the process after coating one half-cell, breaking vacuum and physically reversing the cavity to expose the other half-cell.

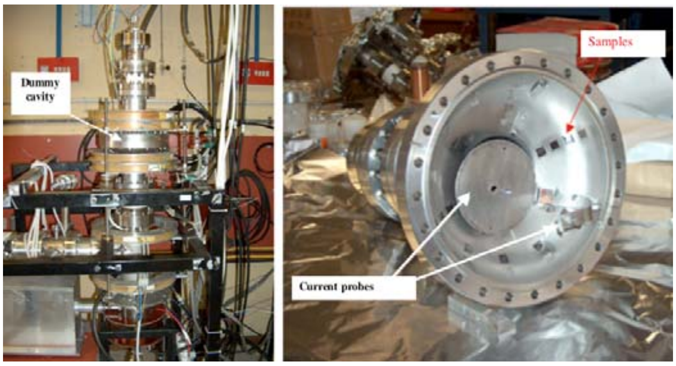

Fig. 3. *Single arc source apparatus carrying the dummy cavity.*

A significantly modified system was built in 2007-2008, equipped with two planar arc plasma sources so that coating could be performed without breaking vacuum. Among others, dust shields and a quasi-laminar vertical flow chamber were added to prevent contamination during assembly.

The double arc sources equipped, unfiltered apparatus is shown in Figure 4.

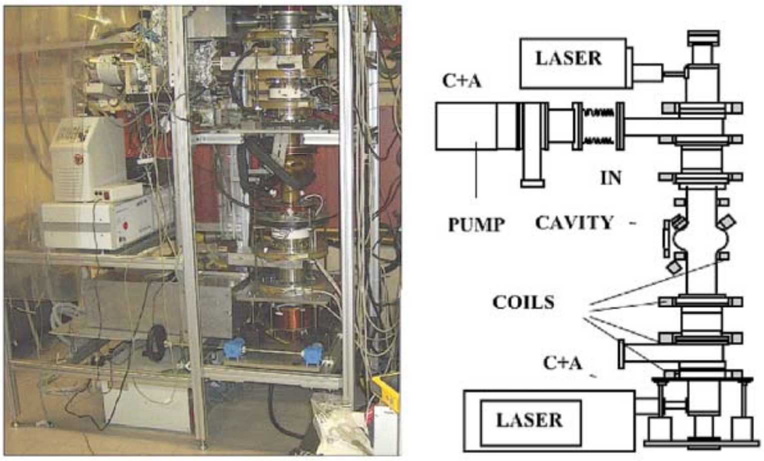

***Fig. 4**. Double arc plasma sources Single cell cavity coating device. C+A: Cathode+anode assembly; IN : Insulator*

Figure 5 finally shows the design of a double-arc source, horizontally laid out version of the one in Figure 4, including two elbow-type micro-particle filters.

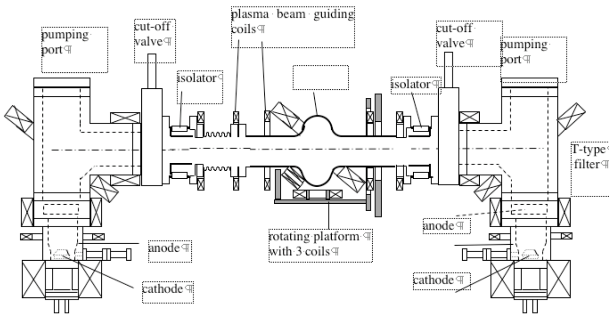

***Fig 5** Design of filtered single cell coating system*

4. Progress in single cell cavity coating.

Two copper cavities (kindly delivered by Saclay) were Nb coated in 2007 in the single arc plasma system.

After the first coating of a previously chemical etched and electro-polished single cell cavity, high pressure rinsing (HPR) at a water pressure of 100 *bar* showed that the surface layer adhesion to the copper substrate was too week. The film was stripped-off over substantial areas, close to the equator and to the inner cut-off pipe. The layer damage resulting from HPR was substantially reduced on a second Nb-coated copper cavity, prepared by chemical etching only (no electro-polishing) and reducing the water pressure during HPR down to 40 Bar. Only a small area (of the order of tenths of mm^2) was damaged by rinsing, close to the end of the cut-off pipe.

A third RF test at 4.2*K* on a bulk-Nb cell, Nb coated and not HPR rinsed, showed a sharp Q drop at an accelerating field value as low as 2-3 MV/m. This was traced to accidental contamination of the surface by the In-Ga mixture used to ensure good thermal contact between the Nb cathode and its Cu support.

A fourth copper single-cell cavity (delivered by CERN) has been Nb coated in Oct. 2008 using the double arc source and pulsed cavity bias (amplitude of -60V, frequency of 10 kHz and duty factor of 30%). The total deposition time amounted to 90 min. The total residual gas pressure (dominated by H_2) during deposition dropped down to $5 \cdot 10^{-8}$ mbar, 4 times lower compared to our earlier depositions performed using a single planar arc. The final cell surface layer looked satisfactory to visual inspection, showing no significant signs of peeling or non-uniformity (Fig. 6). The cavity has been shipped to Jefferson Laboratory (Newport News, VA, USA) for RF testing. Results still pending.

Fig. 6. *Nb coated inner surface of the fourth, 1.3 GHz copper cavity, awaiting measuring in Jlab.*

5 Report on the Quality of Niobium thin films on samples

Extensive measurements were performed on UHV films arc deposited on Sapphire and Cu sample substrates, to characterize their superconducting properties.

5.1 Adhesion

When a film is grown on a substrate the first question to be addressed is the adhesion between film and substrate. This is particularly true for Nb films deposited on the inner surface of a copper cavity, since after deposition, the films are cleaned using De-Ionized (DI) water at 100 bar (HPWR), to remove any dust particle collected during handling of the coated cavity. HPWR can peel off the film at places with poor adhesion or to internal stresses (in ~ ≥10μm thick) films. Adhesion on our carefully cleaned samples, including the large ones measured in Cornell (see par.5.4), has always proven satisfactory. Peeling episodes on cavities are attributed to local contamination. Superior adhesion and lower stress of UHVCA Nb films is confirmed by results from Nb films as thick as 40μm (par. 5.5).

5.2 Film Residual resistive ratio (RRR)

The Residual Resistivity Ratio of SC Nb films is defined as

$$RRR = \frac{R_{300K}}{R_{10K}} = \frac{\rho(300K)}{\rho(10K)} \approx \frac{\rho_{phonons}(300K) + \rho_{defects}}{\rho_{phonons}(10K) + \rho_{defects}}, \qquad (1)$$

where $\rho(T)$ is the electrical resistivity at temperature T.

RRR is a good indicator of the purity of the film since it is sensitive to the presence of defects (scattering centres), even if not on the nature of the contaminant. The T_c of Nb films is very sensitive to impurity and stresses; in fact small amounts of impurities can lower the film T_c whereas compressive stresses can raise it.

RRR values measured on our UHVCA deposited films on sapphire (deposition rate of $300 \div 500$ *nm/min*) were consistently in the 26 – 50 range.

For comparison, RRR values of Nb films deposited on glassy quartz and on copper substrates, held a temperature of 150 °C, by magnetron sputtering, a technique developed at CERN and proven on LEP, typically range from 5 to 30, depending on the discharge gas used and the voltage applied to the cathode.

5.3 Film critical temperature

Our measured T_c values, close to those of bulk Nb, indicate that stresses in UHVCA films are relatively low while the narrow transition widths (<0.02 K) indicate that they are uniform and clean.

The critical temperature (T_c), transition widths (ΔT_c) and surface current density (J_c) values of our best film samples are also close to those of bulk Nb, i.e.:

$T_c = (9.26 \pm 0.03)$ K, $\Delta T_c \approx 0.02$ K and $J_c = 3x10^7$ A/cm^2.

The example in Fig. 7, shows that values indistinguishable, within the errors, from those of bulk Nb can be obtained.

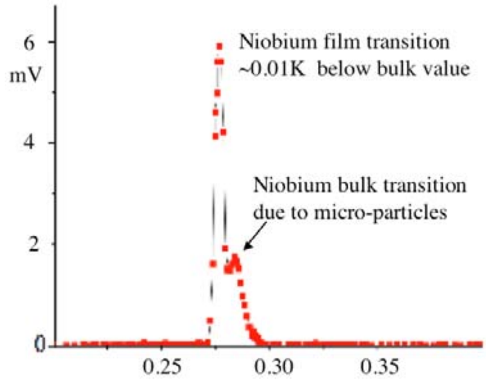

***Fig.7**. Measurement of the critical temperature T_c of the Nb-coated sample*

5.4 Film elemental analysis

Our UHVCA Nb film samples are deposited using high purity Nb cathodes, samples and single cell cavities being part of the vacuum chamber; as a consequence contamination from undesired elements is very unlikely. Nevertheless, when developing a new technique spurious, uncontrolled effects may contaminate the film; elemental analysis has therefore been utilized to help understand the origin of the contamination, if any.

Results of X-Ray spectroscopy performed on the first Nb coated samples produced by UHVCA showed (Fig. 8, lowest curve) the presence of Stainless Steel (Nickel and Iron) and Copper contaminants. After improving the deposition system by better confining the plasma and avoiding erosion of regions close to the cathode, contaminants did drop below the ~1% detection limit of the technique (upper curve of Fig.8).

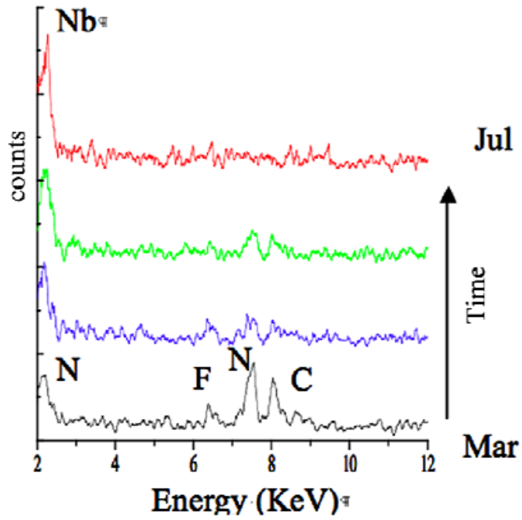

***Figure 8** - Nb film showing strong Cu and stainless steel contamination (lowest curve). After system optimisation, contaminants were below the detection limits (uppermost curve).*[1]

SIMS analyses also show that when depositing by UHVCA undesired contaminants other than residual gases present in the UHV chamber, mainly consisting of hydrogen, and ones coming from the cathode material are practically absent.

5.5 Film morphology

UHVCA has the advantage that, because the deposition is via ions, by negatively biasing the substrate the ions incidence angle on the substrate can be made almost normal to the substrate itself independently from the angle under which the latter is seen from the cathode. UHVCA produced films

[1] Courtesy of Dr. V. Merlo, Università di Roma “Tor Vergata”

have in fact consistently shown low roughness, almost independent from the cathode-to-substrate angle. Transport and superconducting properties of such films, deposited at room temperature on sapphire, are also almost independent from the incidence angle up to 60 *deg* with RRR values of ~ 40 ~ 40, decreasing to ~20 and ~15 at angles of 75 and 90 *deg* respectively.

The results show that when the incidence angle is ~ $<60^0$, a uniform layer is obtained (except for unfiltered micro-droplets, e.g. in Fig 9c)) whereas at angles ~ $\geq 75^0$ increased roughness of the layer surface, with texture, is visible. The latter type of microstructure is typical of sputtered Nb films inside cut-off tubes of RF resonators but does not cause field emission due to the low field level in that area.

SEM images of Nb films deposited using the UHVCA techniques are shown in Figures 9[2]. and 10.

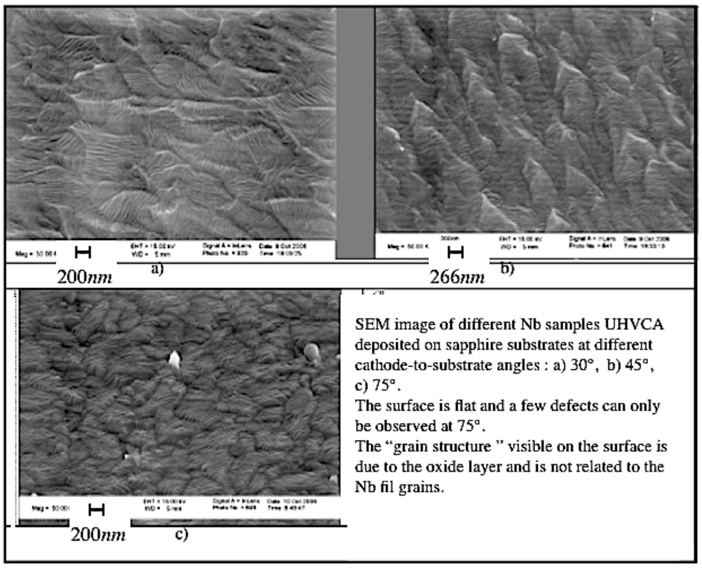

Fig. 9. *SEM image of different UHVCA depositNb ed samples on sapphire*

Similar studies were performed on niobium layers on sapphire and glass substrates under pulsed, -40V to -80 *V* bias, 1 to 40*kHz* frequency, and 30% or 50% duty factor ranges. The total average deposition rate was higher compared to the dc bias case, reaching 600-*900nm/min* with RRR values mostly in between 50 and 80. Tests indicate that applying a pulsed bias better morphological and structural properties of Nb films can be obtained. The pulsed bias deposited Nb films show larger grains (up to microns) with less defects and flat surface.

On thicker films larger grains can be obtained as show in the example of figure 10 c).

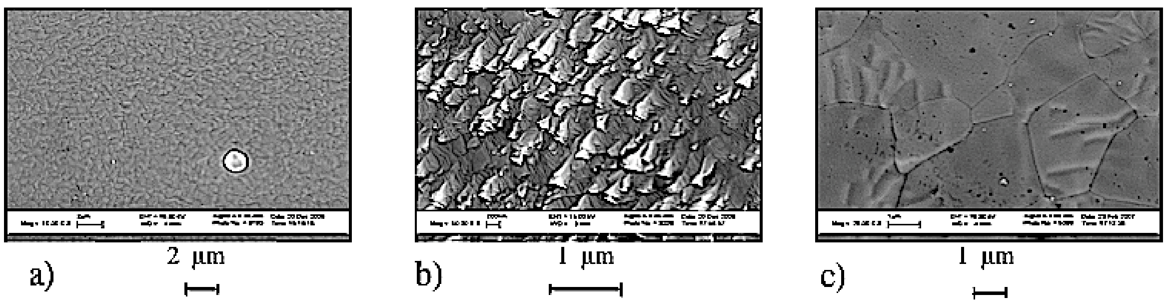

Fig. 10 *- . SEM micrographs of Nb films on sapphire substrates, UHVCA deposited at DC voltage bias of -40V: (a) 90° w.r. to the arc plasma propagation direction, (b) 15° to arc direction, (c) 90° to arc direction, pulsed deposition; 10 kHz repetition rate and 30% duty cycle: grain dimension in this 10µm thick sample reached up to 5 µm.*

[2] The film density and therefore its surface fraction permeable to He could unfortunately not be measured since the instrument is no longer in operation in CERN.

X-ray spectra show that grains are randomly oriented, i.e. no epitaxy between film and substrate is present. The superior adhesion and lower stress of UHVCA Nb films is confirmed by the good adhesion of Nb films as thick as 40μm.
SEM and XRD studies of selected samples revealed smooth surface layers consisting of unusually big grains (up to 5 *μm*, their size growing with the layer thickness (Fig.10 c), high purity, very low stress level and lattice parameter of ~0.3304 *nm* - practically identical to that of bulk Nb.

6. *Micro-droplets (MD)*

The possible problem with UHVCA is increased film roughness due to the presence of micro-droplets. The number and size distribution of the latter have been studied: it is found to depend on the coating conditions and the particular geometry used, whether using a planar cathode or a cylindrical one. A typical droplet size distribution is shown in Fig.11.

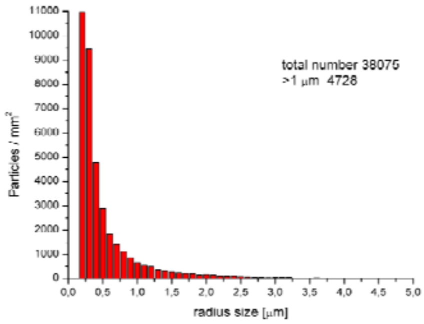

Fig.11 - *Unfiltered micro-droplet population on a UHV linear arc coated sapphire sample.*

Detailed 3D-profilometry on unfiltered and filtered UHVCA Nb film samples on sapphire has been performed in the framework of collaboration with Jefferson Laboratory, USA, to study the efficiency of our present magnetic filters.
The result of Fig. 12 shows that while on the unfiltered, 0.04mm^2 sample one counts ≈ 10 large signals over the explored area, clearly to be attributed to Nb droplets, on the filtered sample only a few weak signals – to be better classified - are seen. It can be concluded, within present statistics, that large (*μm* size) micro-particles are removed by the filter. As for smaller ones, it is not known at the moment whether possible residual MDs will limit the RF cavity voltage performance, due to either field emission, RF field enhancement and/or creation of voids in the film.

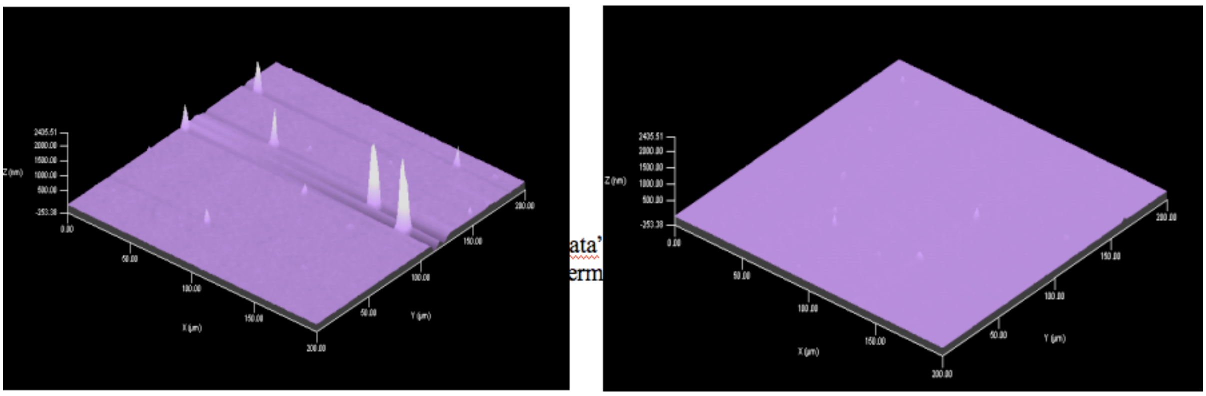

Figure.12 - *Profile-diagrams of unfiltered- and filters-samples 200 μm x 200 μm in size. The vertical scale (0-2.5μm) is the same in both pictures* [3].

[3] *Courtesy of A. Wu, Jefferson Lab, USA*

Recent results obtained at Wuppertal University suggest that pure Nb spherical micro-particles resting on the film surface should not be expected to field-emit at least up to RF fields of ~40MV/m. Other effects on the RF cavity response, such as the presence of voids left in the film due to (large) micro-particle shadows, still need further investigation.

7. Structural properties

X-ray diffraction is the best technique to study the structure of films deposited on substrates. It is based on the reflection of X-ray beams by the material crystallographic planes, according to the well–known Bragg relation $2d\sin\vartheta = n\lambda$ where d is the distance between lattice planes, ϑ the X-ray beam incidence angle, λ the X-rays wavelength, and n the order of the reflection.

The position of the peak of the reflected radiation line provides the value of the distance between planes; the line width and shape contain information on grain size and micro–strain whereas the line intensity is related to the presence of texture.

Contrary to what reported in literature about Nb films, deposited by sputtering at relatively low partial pressures, typically said to experience intrinsic compressive stresses, UHVCA deposited films, continuously bombarded by much higher energy ions, have recently been shown to be very little stressed.

Figure 13 compares the width of the diffraction peak as function of the tangent of the angle of incidence on the substrate of a sputtered film to that of a UHVCA deposited one.

The intercept on the y axis is too close to zero to extract the grain size but its been close to zero confirms that the width of the diffracted peak is related to micro-strain more than to grain size.

The smaller slope of UHVCA deposited films also indicates that they are less strained than sputtered ones.

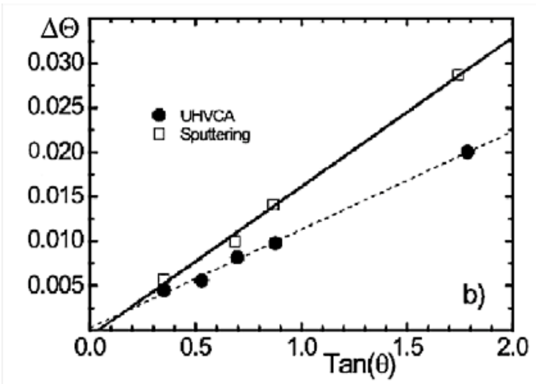

Figure 13 *- a) Width of the diffracted peak as a function of the tangent of its position of: sputtered film (squares) and a UHVCA deposited one (circles).*

8. **Film superconducting Properties**

The low field RF properties of the Nb-coated samples also started being investigated by our collaborators at INFN-Napoli: RF measurements were performed on (small) sapphire coated samples.

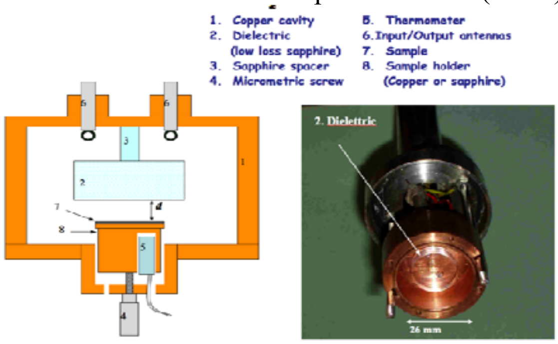

Fig.14 *- "Puck" dielectric 20 GHz cavity used for Sample RF measurement*

Early low field RF measurements as a function of temperature are shown in Fig. 15.
They prove that UHVCA Nb-coated samples can be produced that show the same behaviour as bulk Nb, and that the quality of the film improves with MP-filtering.

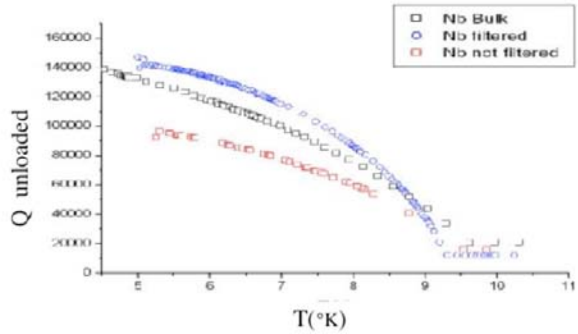

Fig.15 - *Comparison between the quality factors of bulk Nb and UHVCA deposited Nb film samples.*

Other information on the RF properties was obtained by the studying the intermodulation product (see Fig 16). Calling f_1 and f_2 two frequencies slightly displaced, symmetrically, with respect to the resonator centre frequency f_o, at $T << T_c$ the power P in a good RF superconductor should obey the relation $2f_2 - f_1\ (or\ 2f_1 - f_2) \propto P_{circ}^3$.

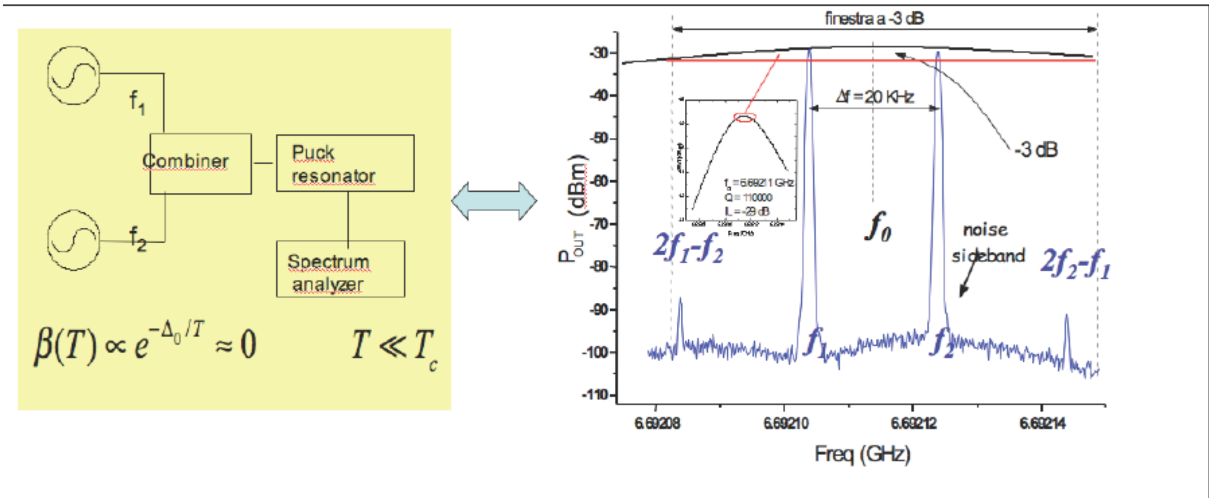

Fig.16 - *Intermodulation measurement principle.*

The results of inter-modulation measurements shown in Fig 17 prove that, within the explored range in parameter space, - UHVCA filtered films behave better than sputtered films.

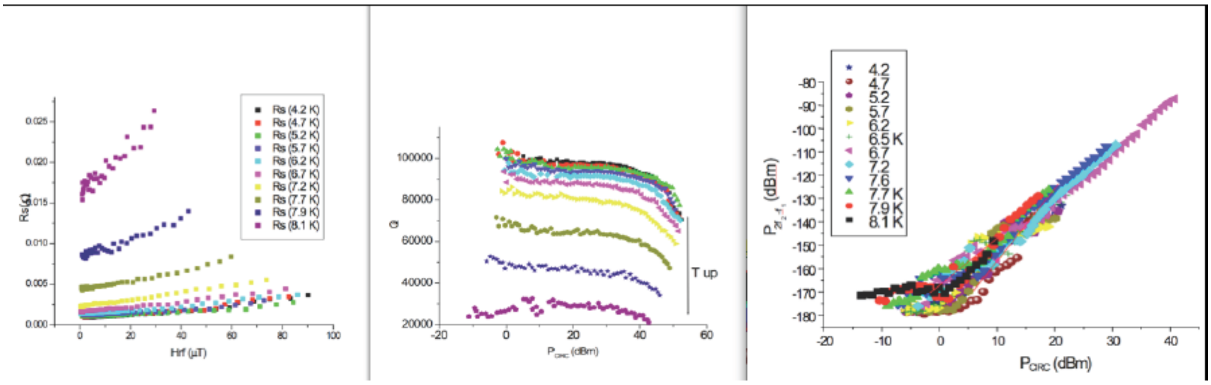

Fig. 17 – Residual resistance, Q, and inter-modulation measurements as functions of temperature

Characterization of Nb films on copper samples was performed through collaboration with researchers at Cornell University, USA, who carried out high field measurements on a number of large, ~10*cm* diameter, copper samples we deposited samples.

The first high-field RF measurements of filtered Nb-coated, large Cu-samples were performed at 6 GHz, and the results were reported by A. Romanenko and H. Padamsee at SRF-2005. The quality factor (Q) of the best sample, which sustained a magnetic field of 300 Oe, corresponding to ~ 10 *MV/m*, possibly limited by the host cavity quench, was comparable within the errors to the limit value ($\approx 3 \times 10^8$) of the host cavity.(Fig. 18)

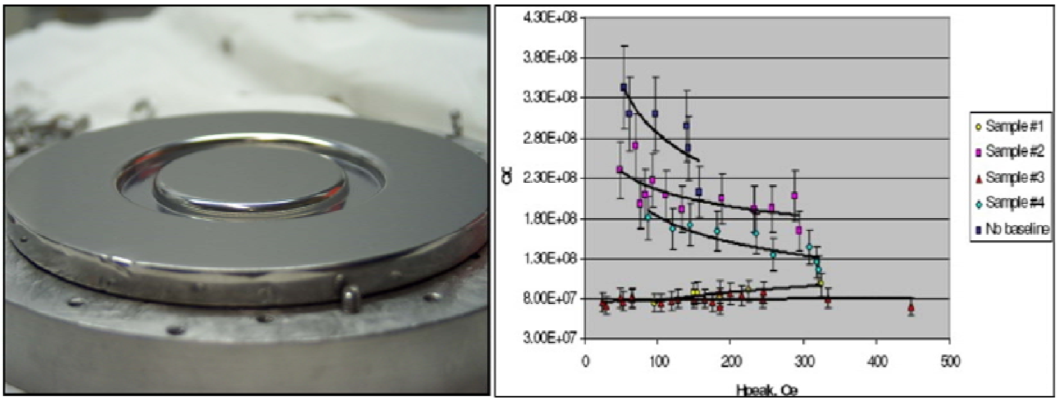

Fig.18 *- a) One of our ≈10 cm diameter Nb coated Cu samples measured in Cornell; b) Residual resistance and Q values of the investigated samples as a function of temperature.*

Conclusions

While the correlation between properties of films deposited on sample substrates (by either sputtering or UHVCA) and the overall RF cavity performance are not completely understood, UHVCA deposited large samples have shown better quality with respect to sputter deposited ones, due to the absence of contaminants, such a the noble gases required for magnetron sputtering, in the film.

UHVCA deposited films are also less stressed and show RRR values, lattice parameter and superconducting critical temperature very close to those of pure bulk material. First measurements on large Cu samples have therefore been very encouraging.

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9. Status of nitrides deposition by UHV cathodic arc

The Cathodic Arc in high vacuum (HV) is a well-known technique, mainly used to produce hard nitrides coatings on cutting tools having complex shapes. The very high energy of ions arriving on the substrate (up to several hundreds volts) is believed to be the origin of the excellent adhesion and the good quality of the treated materials.

On the other hand, to our knowledge, there was no literature on the production of nitrides for superconducting applications. One of the main reasons for it, is possibly that, in HV, contamination of the cathode originating from residual gases would deteriorate the purity and the superconducting transport properties of the deposited material while the UHV arc deposition technique we developed would preserve the purity of the deposited cathode material.

We therefore also investigated the production of nitrides for superconducting application using the UHVCA arc technique.

Figure 19 shows the phase diagram of Nb. The grey area indicates the narrow region where the superconducting delta phase can be obtained without the presence of other phases. The delta-cubic phase is thermodynamically stable only at temperature higher than 1280C and in a narrow range of nitrogen concentration. The film deposition techniques are not at the thermodynamical equilibrium and they must therefore provide the energy necessary to form the cubic phase.

We expected, in analogy to what reported in literature on nitrides deposition by sputtering, the important parameters to be the ratio between the Nb deposition rate and the flux of nitrogen atoms at the surface of the growing film and the substrate temperature. It was conjectured that lower substrate temperatures could be used since the thermal energy needed would be replaced by the kinetic and potential energy of ions arriving on a suitably negatively biased substrate. It was also conjectured that good superconducting films could be produced at lower nitrogen pressure, over a larger range of deposition parameters, a condition necessary to allow obtaining a uniform coating over the whole surface of a cavity cell.

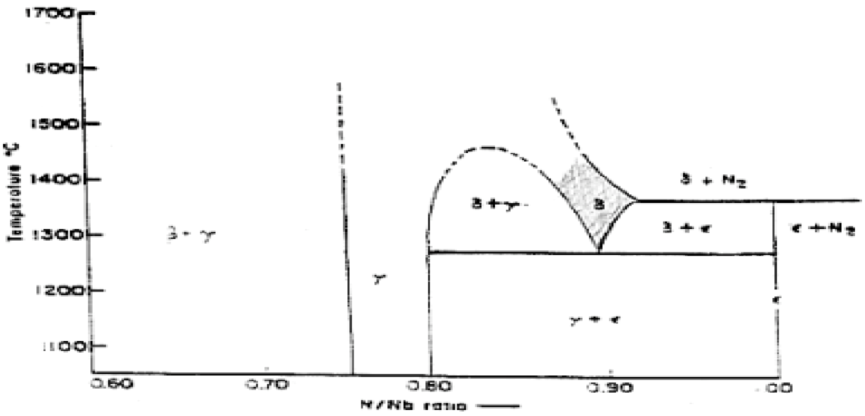


Fig. 19*- Phase diagram of NbN at nitrogen atmospheric pressure:*

Our conjectures were supported by our first deposition when a few sapphire samples were UHV arc coated in nitrogen atmosphere, at different N partial pressures, using a UHVCA quality, very simple, not yet optimized apparatus.

The R(T) of the best coated sample (Fig.20) showing a ~5K wide transition to the SC state starting at about 15K, was a clear indication that the cubic phase was formed.

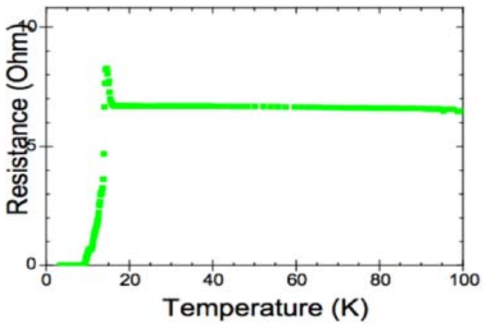


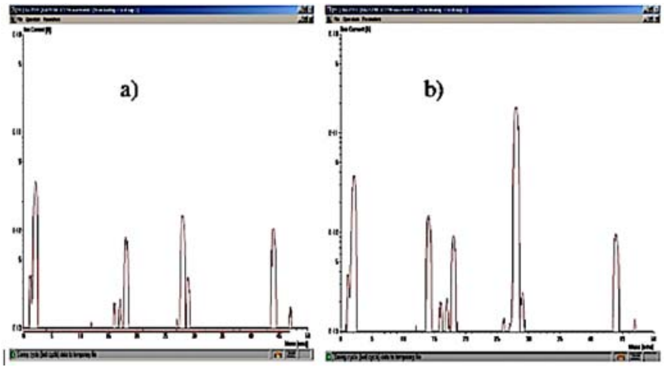
Figure 20*-Transition to the superconducting state of one of the first UHV arc deposited NbN samples.*

Despite the fact that the result was not totally satisfactory since the relatively large transition width indicated that several phases were present, in particular beta and gamma ones with low nitrogen content, it was believed that it would be possible to improve the film superconducting properties by further optimizing the deposition parameters.

The apparatus was therefore upgraded in terms of arc ignition reliability, plasma transport, arc stability and thermal stability according to the experience acquired in setting up the Nb film deposition systems. A new vacuum system was built equipped with a N injection line and a mass-flow meter in order to control the nitrogen flux. Extra coils were also added to control the plasma transport magnetic configuration in order to optimize the Nb ion flux reaching the substrate.

Fig.21 shows spectra of the residual gas composition after bake-out to a pressure of ~2x10^{-10}mbar (a) and after injection of small amount of nitrogen (b): the only injected masses are 14 and 28, corresponding to atomic and molecular nitrogen respectively.

But despite having coated a number of sapphire samples under different conditions, ranging from room temperature to 200C, from 0V to -120V bias and with a nitrogen pressure from 1x10^{-4}*mbar* to 1x10^{-1}*mbar*, no results better than those of Fig.1 were obtained
In addition, adhesion problems were experienced inside the vacuum system, as evidenced in figure 17. Peeling was present on all grounded parts of the vacuum system while good adhesion was only obtained on the negative biased surface of the sample holder. Because for safety reasons the major part of the vacuum system was grounded, peeling was a severe problem because of metallic fragments falling into the cathode region would short-circuit the cathode to the anode.



a) b)

***Fig. 21**– Residual gas composition after bake-out*

The results indicated that the nitrogen pressure should be further increased, but the arc started becoming unstable as the pressure was increased above ~10^{-2} *mbar*. The instability was traced to an inversion in the sign of the current on the biased sample holder. Changing the arc current range and the magnetic coil configuration so as to reduce the niobium ion flux on the sample, did not help.

A much finer scan of the nitrogen pressure and possibly of the bias values would have been needed but it was concluded that it would be too time consuming in view of the other higher priority tasks and, most of all, because it was felt that the extreme criticality of parameters would make it very difficult to obtain the desired phase (see Fig.19) everywhere on the cavity cell complex geometry surface. In addition it was further argued that the Nb ion energy distribution in the arc may be too large to obtain a single-phase film (a large difference in ion energy is equivalent to a different temperature). To deposit single-phase films one should develop techniques that allow making the ion energy distributions more uniform. Even if theoretically achievable, this was argued to be difficult to apply given the complex cavity shape.

Furthermore, SEM images showed the presence of aggregates on the nitride film surface: in addition to the usual macro–particles ejected from the cathode, there were several particles with micrometer dimension and complex shapes, as shown in Fig.22. Such aggregates are believed to be formed in flight, from cathode to substrate, and cannot therefore be easily eliminated by the 90*deg* macro-particle filters.

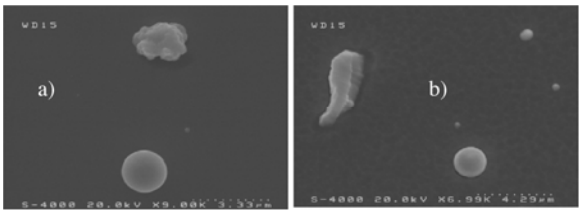


***Fig. 22** - SEM images of nitride film surfaces: spherical niobium macro-droplets are present together with aggregates of different shapes probably formed from the reaction of niobium and nitrogen in flight from the cathode and the substrate.*

Conclusion

Several samples have been coated using a Nb cathode UHV arc in a nitrogen atmosphere. Nitrogen pressure, arc current and voltage bias were varied trying to obtain nitride films with good superconducting properties. Despite the effort the maximum obtained T_c was ~15K with a large transition width. The films were not uniform and aggregates of irregular shape, presumably formed in flight, were present on their surface. While further work would have been needed to optimize the deposition parameters in our UHV planar arc configuration it was concluded that, due to the extreme criticality of parameters, it would have be very difficult to obtain the desired nitride cubic phase everywhere on the complex geometry surface of a DESY-like RF cavity cell.