Progress in Research on Deposition of Thin Superconducting Films by Means of Ultra-High Vacuum Arc Discharges

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Outline

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4. Summary

Introduction

In a comparison with other techniques (e.g. the PVD), **vacuum arc discharges can produce ions of higher kinetic energies (from about 15 eV to about 150 eV).**

S. Anders et al., *Surf. Coat. Tech*. 156 (2002) 3.

In R&D programs concerning the construction of large linear accelerators, special efforts were devoted to the deposition of thin super-conducting layers upon internal surfaces of RF cavities.

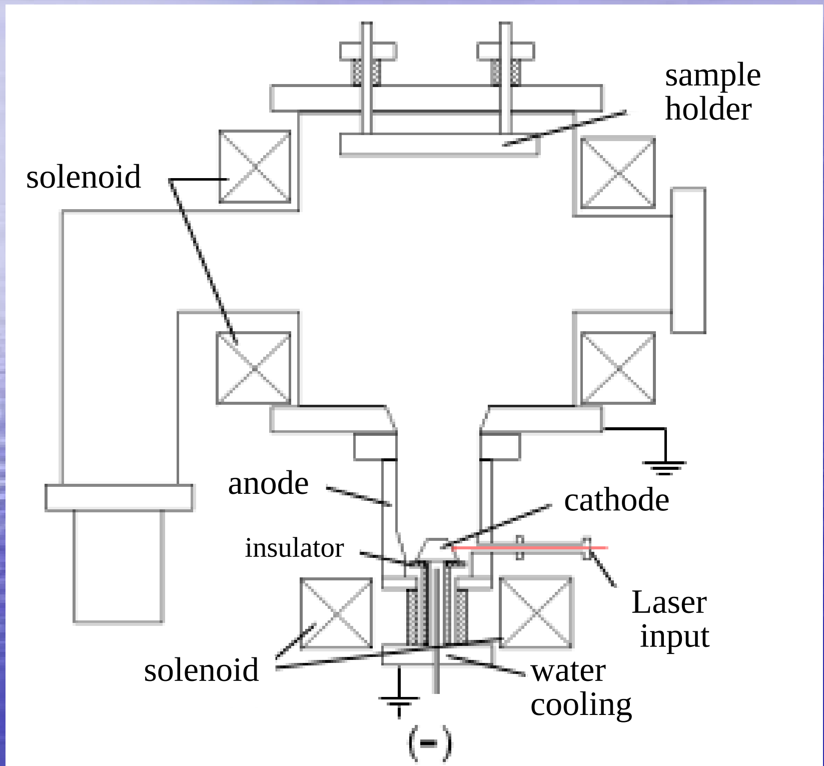
The adhesion of magnetron-deposited layers to accelerator cavities appeared to be not very strong. **Therefore, a new concept of the deposition of thin super-conducting layers by arc discharges under Ultra-High Vacuum conditions was proposed several years ago.**

J. Langner, M.J. Sadowski, et al., *Proc. IC PLASMA-2003,* Poland.
J. Langner, M.J. Sadowski, et al., *Czech. J. Phys*. 54 (2004) C914.

Due to higher energies of ions the UHV arc technology makes possible to produce denser films, to reduce surface defects (such as voids and columnar growth) and to improve adhesion.

Experimental facilities

UHV arc devices with a "planar" cathode contain a truncated cone electrode fixed upon a cooled support inside a vacuum chamber.

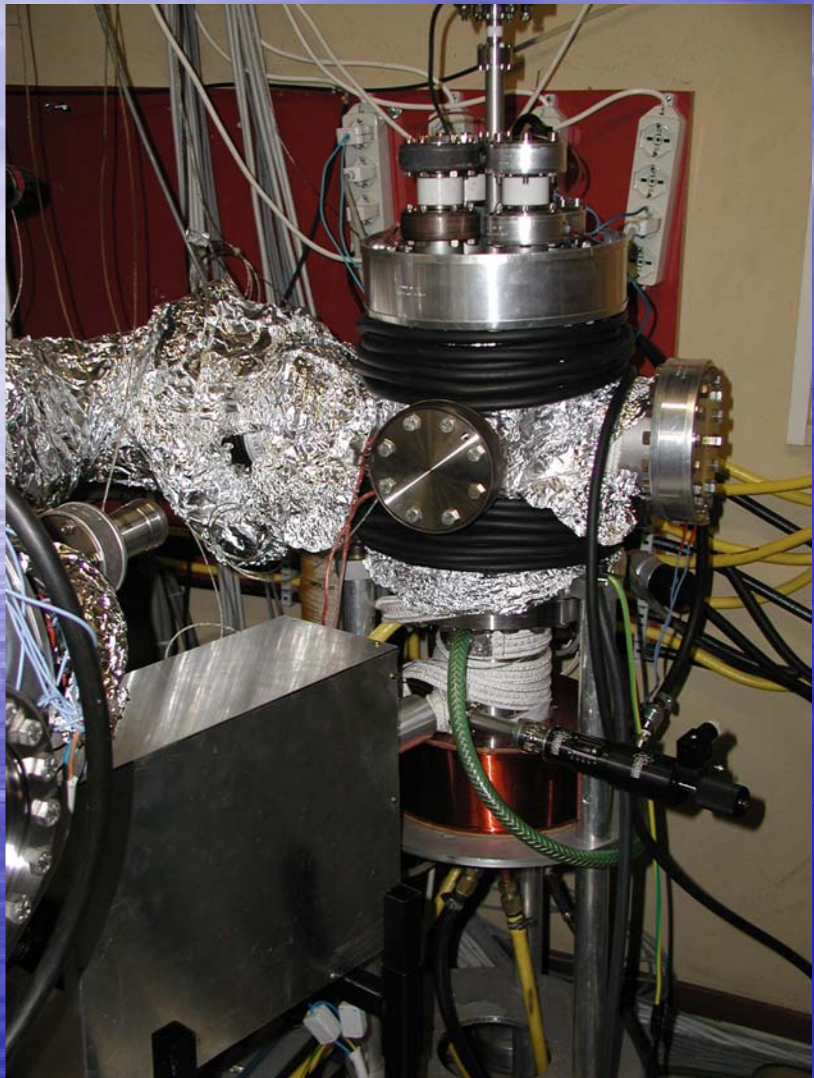


Scheme of the UHV system with a truncated-cone cathode.

Several samples of sapphire and Cu-substrates can be mounted upon a holder consisting of a Cu-flange and kept at a constant temperature.

The holder is electrically insulated from walls of the vacuum chamber, and a bias of 20-100 V (both in DC and kHz pulse regime) can be applied to the coated substrates.

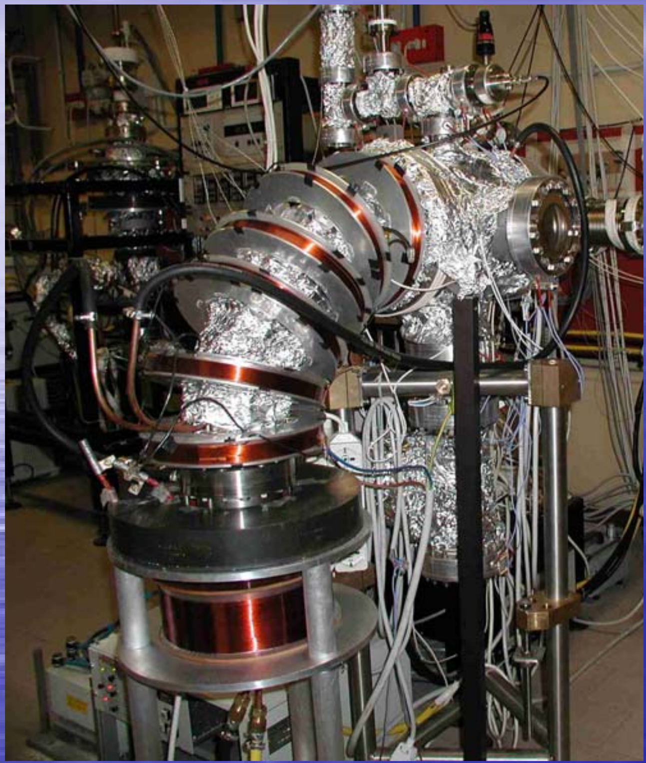
The planar-arc facility constructed in Tor Vergata lab, Rome, in 2005

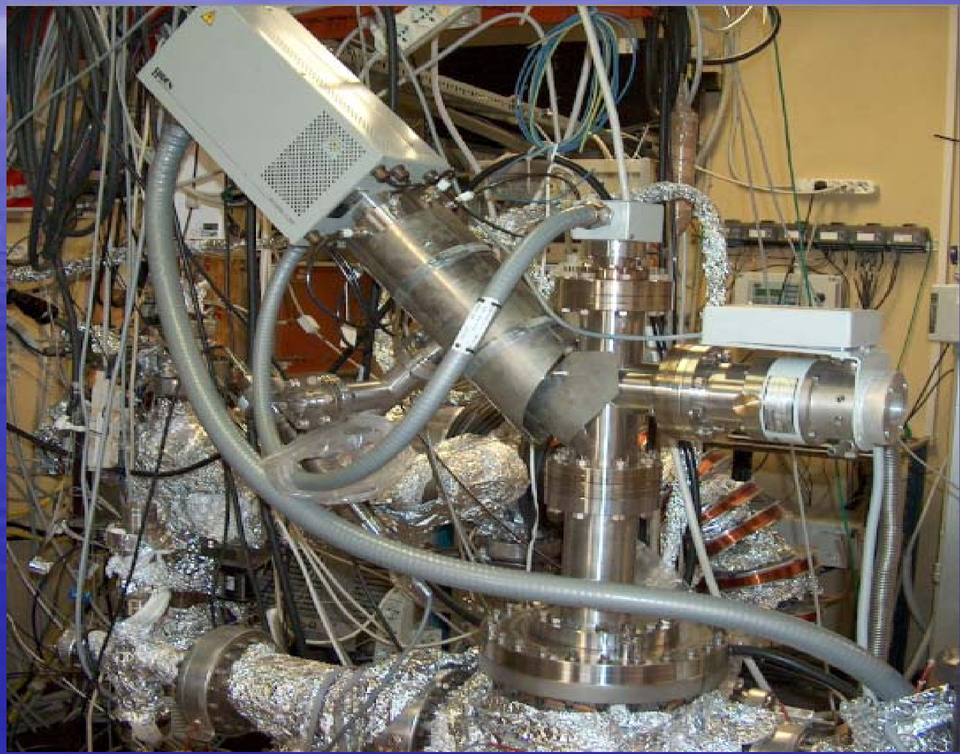


The main drawback of such vacuum arc discharges is the production of micro-droplets, which can be embedded in a film and increase its roughness.

To eliminate the micro-droplets from vacuum-arc plasmas, one can apply appropriate filters.

To reduce an amount of micro-droplets one can use a magnetic filter deflecting a plasma-ion stream and separating micro-droplets.





Magnetic filter (on the left) and ion energy analyzer (on the right), as installed upon the second planar-arc facility in Tor Vergata University in 2005.

UHV planar-arc sources constructed at IPJ (Poland)

A new filtered planar-arc system operated at the Dept. of Plasma Physics & Technology.

The detailed description of the UHV arc facilities and their operational characteristics can be found in our previous papers.

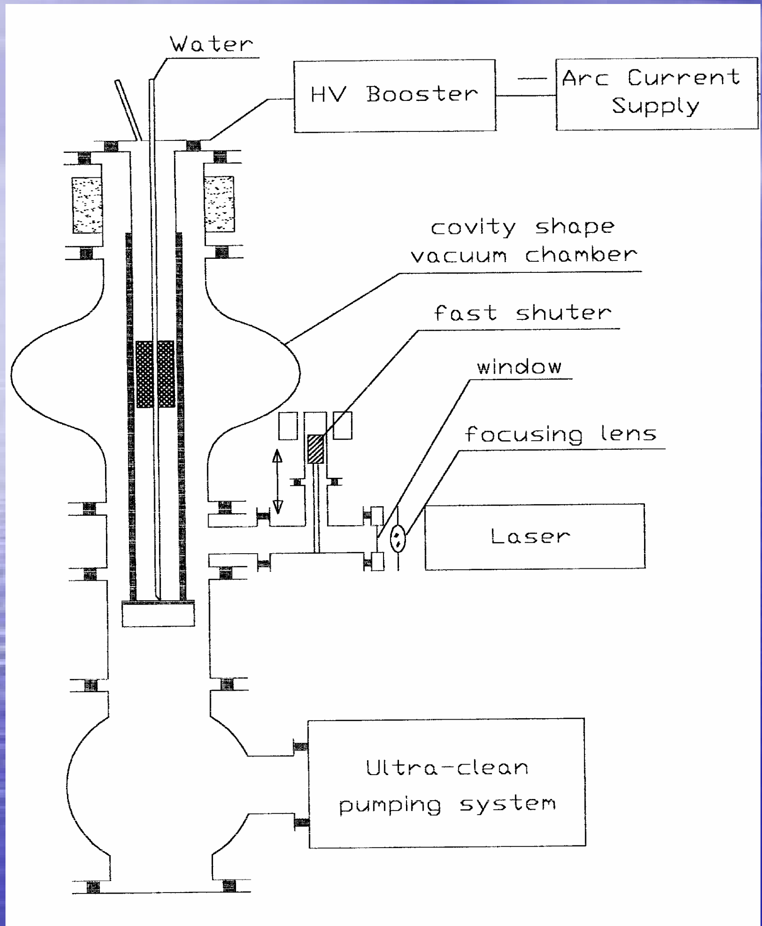
J. Langner, M.J. Sadowski, et al., *Czech. J. Phys*. 54 (2004) C914.

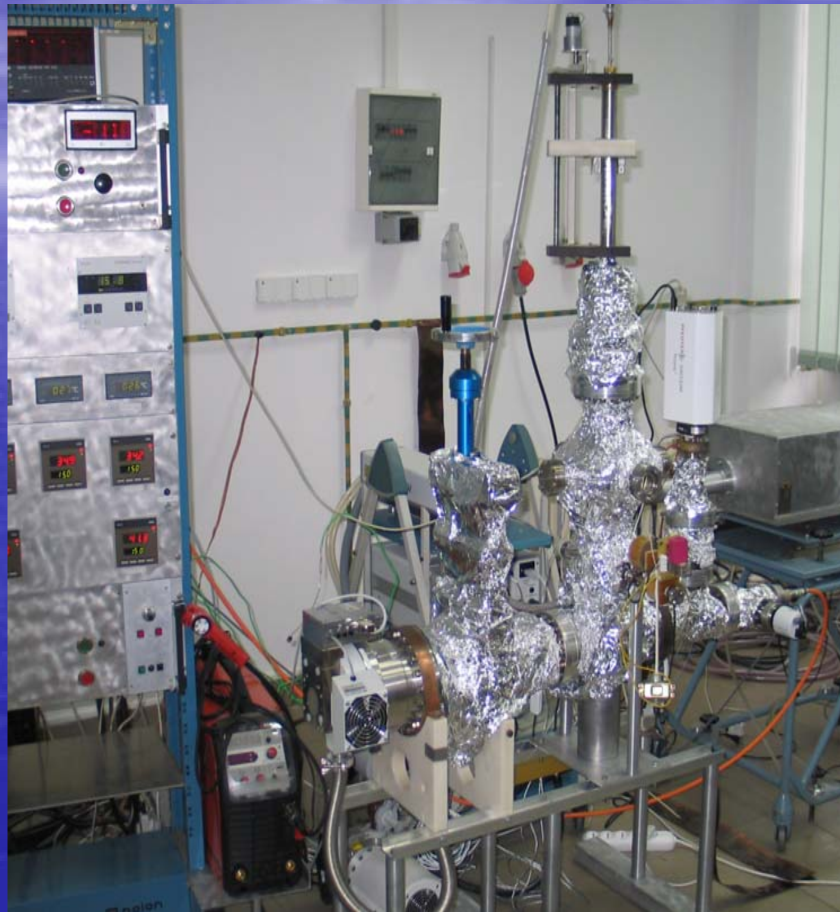
R. Russo, L. Catani, et al., *Supercond. Sci. Tech*. 18 (2005) L41.

P. Strzyzewski, J. Langner, et al., *Physica Scripta* T123 (2006) 135.

P. Strzyzewski, L. Catani, et al., *AIP CP* 812 (2006) 485.

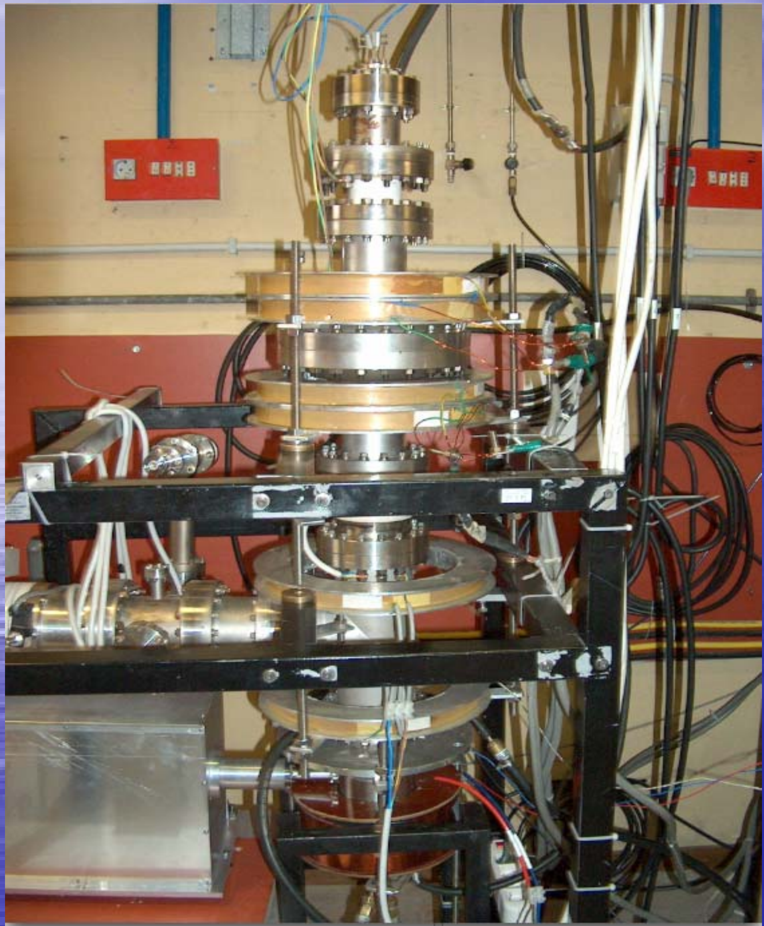
UHV arc systems with a linear cathode





Scheme of the UHV system with a linear (cylindrical) arc and the first linear-arc facility constructed at IPJ in Swierk, Poland, in 2005.

Investigation of films deposited by UHV arc-discharges



General view of a new unfiltered planar arc facility at the Tor Vergata lab (2006).

The lowest possible arc current for the stable operation in the DC mode is about 60 A for Nb and only 23 A for Pb. The cooling system of the anode has the upper limit equal to about 140 A.

The residual pressure is usually set within the 10^{-10} hPa range. It rises to about 10^{-7} hPa when the discharge starts and it remains almost stable during the deposition process.

The pressure rise is caused mainly by hydrogen, which partial pressure is more than 3 orders of magnitude higher than other contaminants.

R. Russo, et al., *Supercond. Sci. Techn*. 18 (2005) L41.

Modified UHV planar-arc facility at Tor Vergata lab (2006)

The inner surface of the upper half-cell with sample holders.

The deposition rate achievable with the system operated with arc currents of 80-100 A was equal to about 1 nm/s.

Most samples have been deposited at temperatures close to the room temperature, and only a few samples have been investigated at higher temperatures (100-200 ^{o}C).

Studies of samples coated within the modified facility will be presented in the next talk by R. Russo.

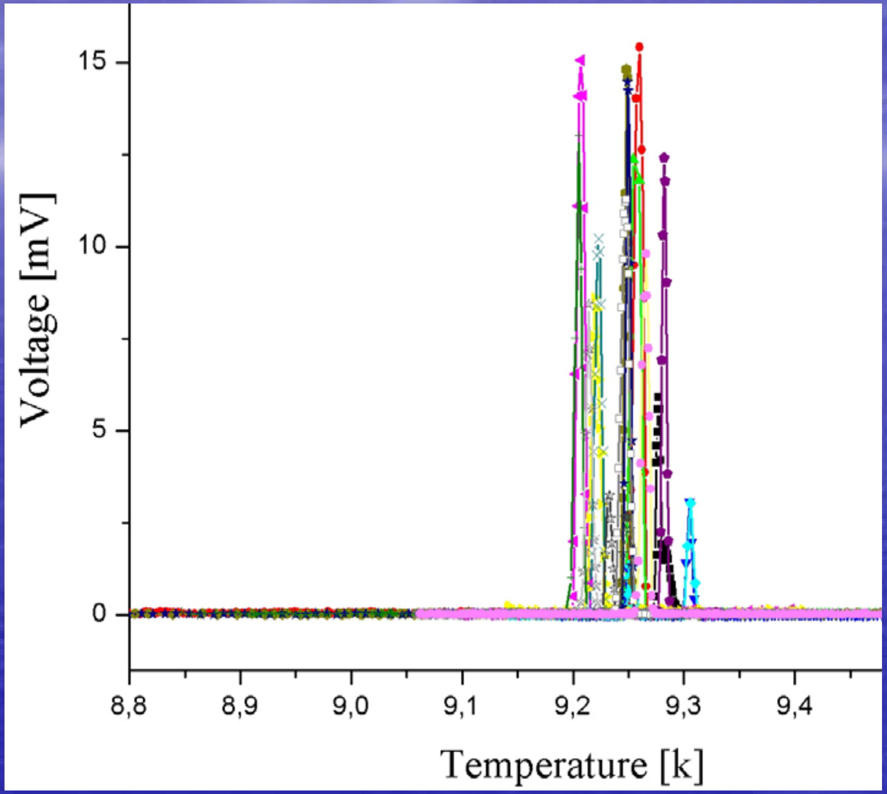
Characteristics of arc-deposited Nb-films

The UHV arc-deposited Nb-layers have been characterized by measuring their critical temperature T_c and RRR, defined as the ratio of the resistivity at a room temperature to that at 10 K.

These parameters are sensitive to impurities, e.g. small amounts of oxygen can lower T_c value strongly.

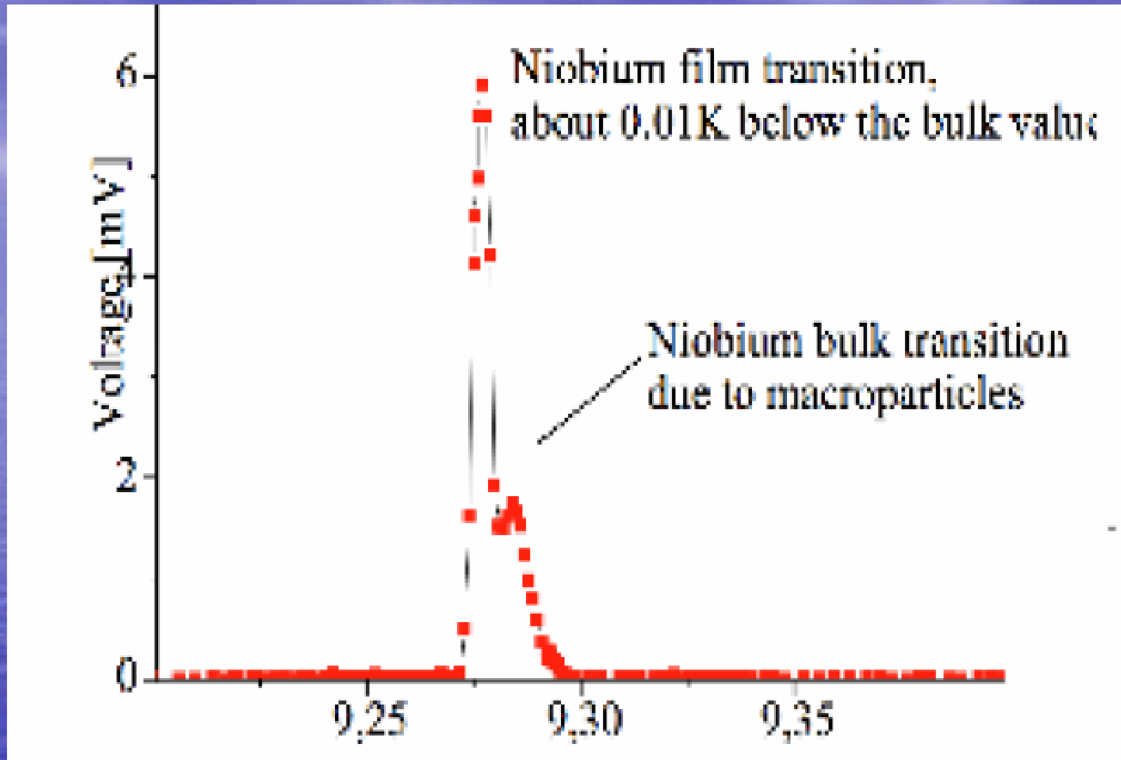
RRR values of our 1.5-µm Nb-films, deposited upon sapphire substrates at a room temperature under UHV conditions, ranged from 20 up to 50.

The record value of RRR = 80 was obtained by heating up the substrate to the temperature of 150 ^{0}C.



Narrow transition width (<0.02 K) indicate that the deposited Nb-films were uniform and clean. T_c values showed that stresses were low.

Critical temperature of the best arc-deposited Nb-sample



The critical temperature (T_c), transition width (ΔT_c) and surface current density (J_c) of our best film samples have shown values close to those of te bulk Nb, i.e. T_c = (9.26 ± 0.03) K, $\Delta T_c \approx$ 0.02 K and J_c = 3x10^7 A/cm^2.

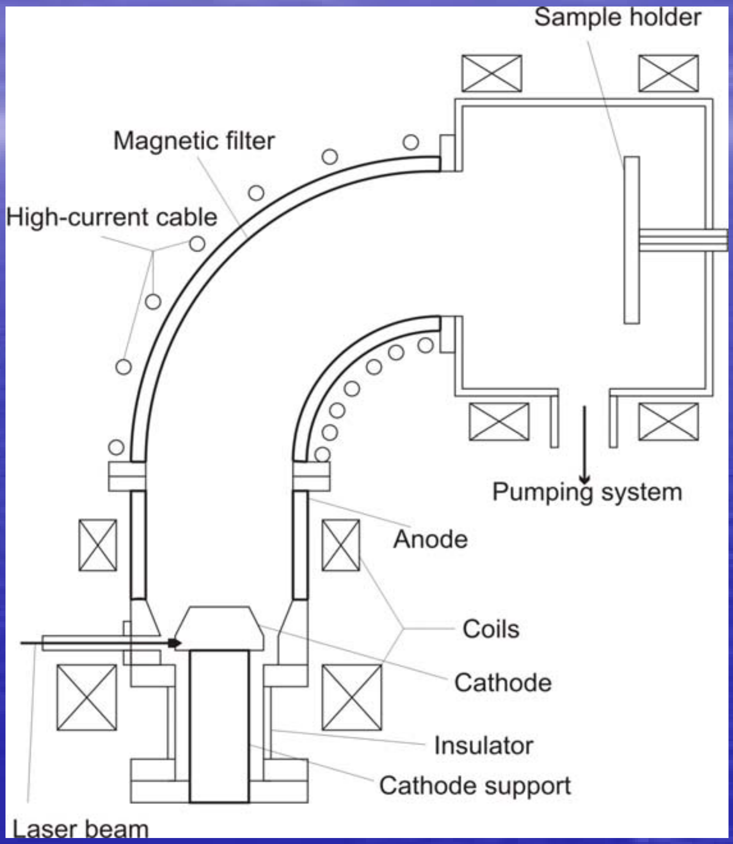
R. Russo, L. Catani, et al., *Supercond. Sci. Technol.* 18 (2005) L41.

To eliminate micro-droplets one must apply an appropriate filter

The main idea of a micro-droplet filter is to separate a plasma stream (e.g. by means of a magnetic field) and to eliminate micro-droplets, which move from the cathode along almost straight lines.

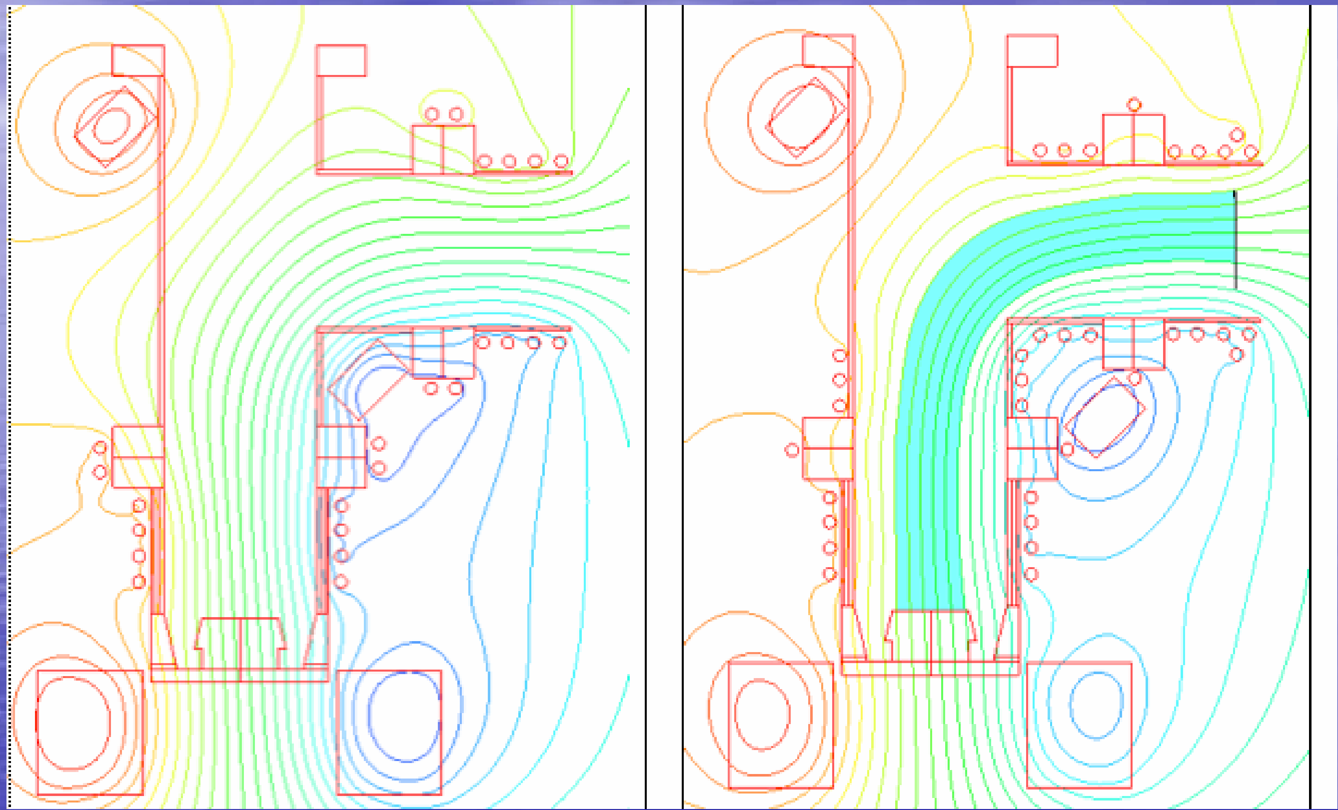
Concepts of different magnetic filters suited for UHV conditions have been developed and investigated both in the Tor Vergata lab (Rome) and in IPJ (Swierk).

P. Strzyżewski, et al., *Phys. Scri.* T123 (2006) 135.



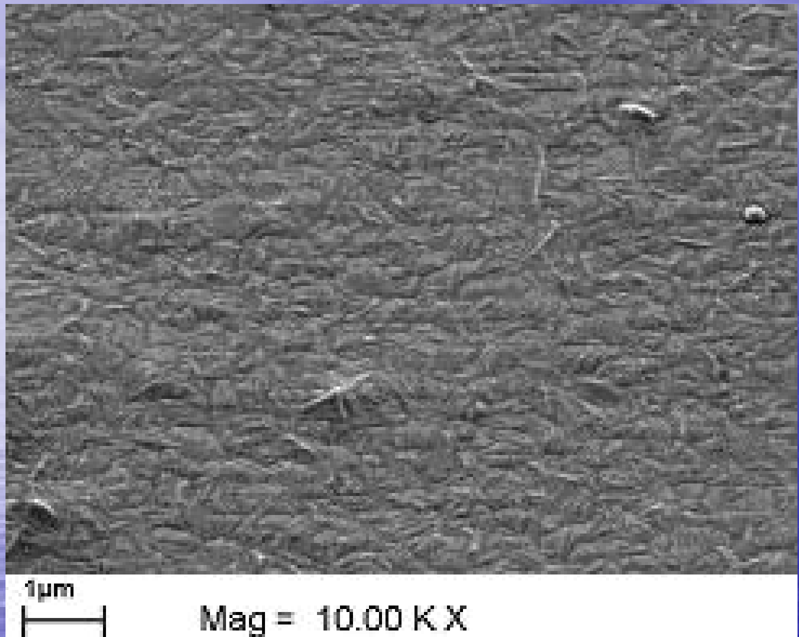
Schematic drawing of an UHV arc facility with a planar cathode and a knee-type filter.

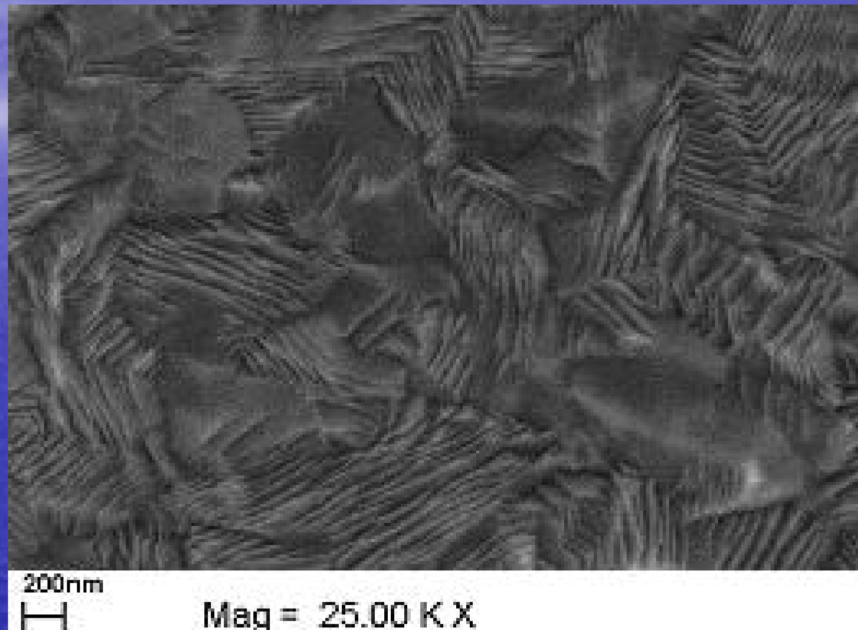
Optimization of magnetic filters



Distributions of magnetic filed lines within the filter channel depend strongly on the configuration of coils and values of magnetizing currents.

Scanning Electron Microscopy (SEM) is a useful tool to perform the surface quality inspection and to look at the surface structure.





SEM pictures of the surface of a niobium film, which show that the deposited layer was homogenous and dense. One can see the longitudinal shape of surface grains. The roughness of the Nb-layer was of the order of a few tenth of a nanometer.

A lack of micro-droplets is the confirmation of good plasma filtering.

Preliminary RF measurements of arc-coated samples

Large Nb-coated Cu sample prepared for RF measurements at Cornell .

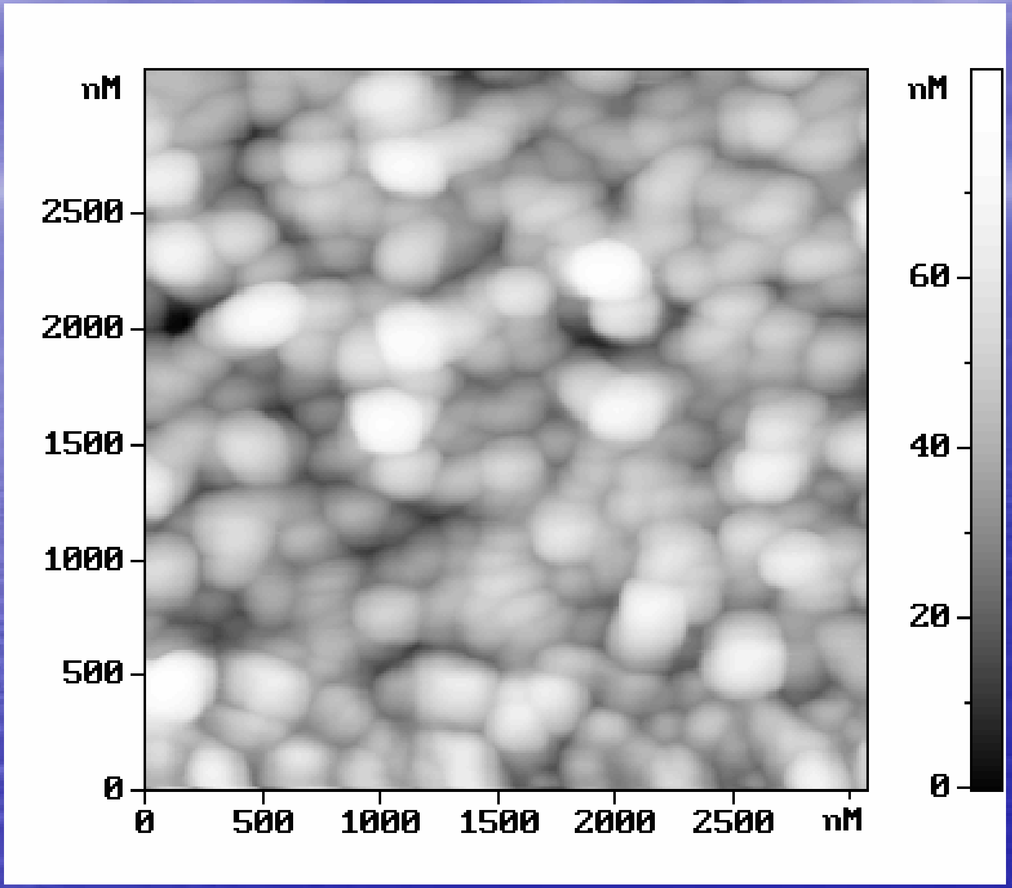
Results of a comparison of the filtered Nb-coated samples with bulk Nb ones were presented at SRF2005 Workshop.

see A. Romanenko and H. Padamsee, Proc. SRF2005, Cornell, USA, 2005.

The quality factor (Q) of the best sample was comparable with the present limit value of the host cavity (equal to $\approx 3 \times 10^8$).

The sample sustained a magnetic field value of 300 Oe, possibly limited by the cavity quench.

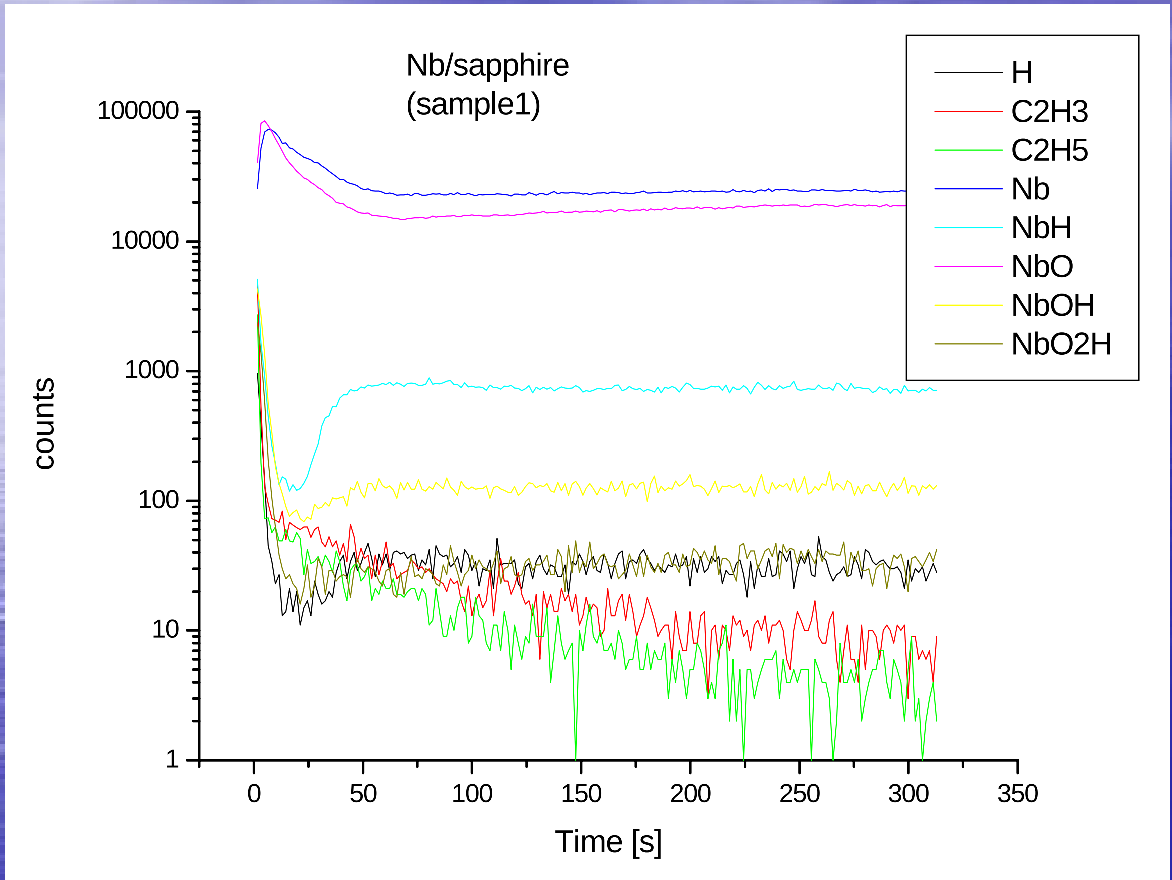
Investigation of the filtered Nb film quality



AFM image of a niobium film deposited on sapphire (at I_{arc} = 120 A, V_{bias} = - 40V); the Nb layer was 2 μm in thickness, the average Nb-grain dimension was 200 nm.

R. Russo et al., *Proc. ICMCTF06, San Diego, USA, Session B2-1-8, P.132.*

Information about the surface chemical composition and depth profile were obtained by means of a SIMS technique



Results of SIMS measurements of the Nb-layer deposited with a filtered planar-arc source at IPJ in Swierk (2006).

The instrument was equipped with an O^{2+} ion gun and a high-resolution ToF mass analyzer.

During the analysis the sample surface was irradiated with pulses of 1-keV ions, and an average ion current was 40 nA.

Secondary ions emitted from the bombarded surface were mass-separated and counted with a ToF analyzer.

Another diagnostic method applied to determine the purity of the UHV-arc deposited films was a Glow Discharge – Optical Emission Spectroscopy (GD-OES) technique .

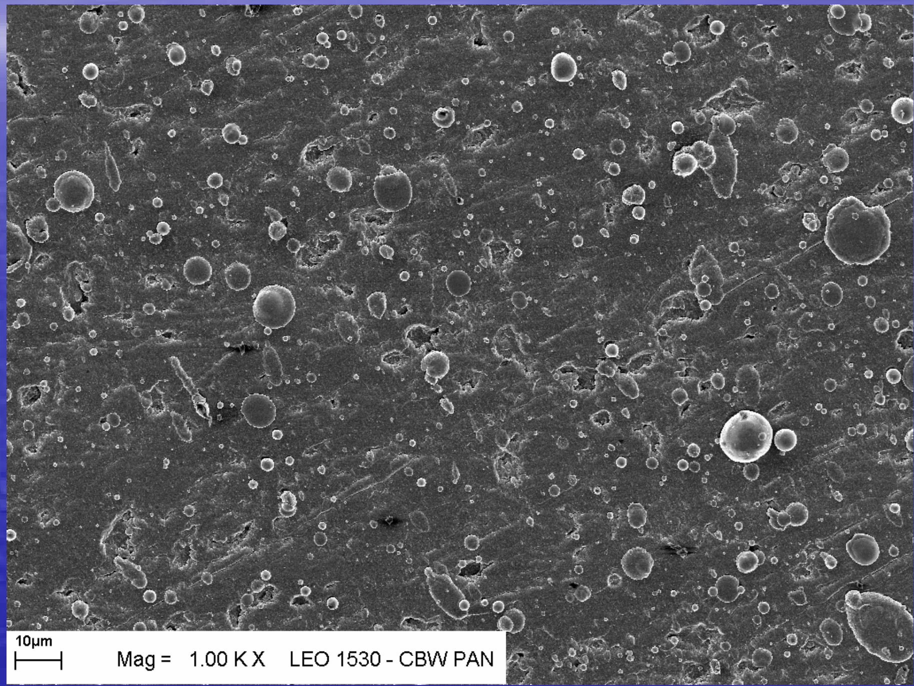
It has been used during recent experimental studies, which concerned the UHV-arc deposition of superconducting films of pure lead (Pb) to be applied as photo-cathodes in electron injectors.

another presentation by P. Strzyzewski et al.

Modified UHV linear-arc facility constructed at IPJ in Swierk, Poland

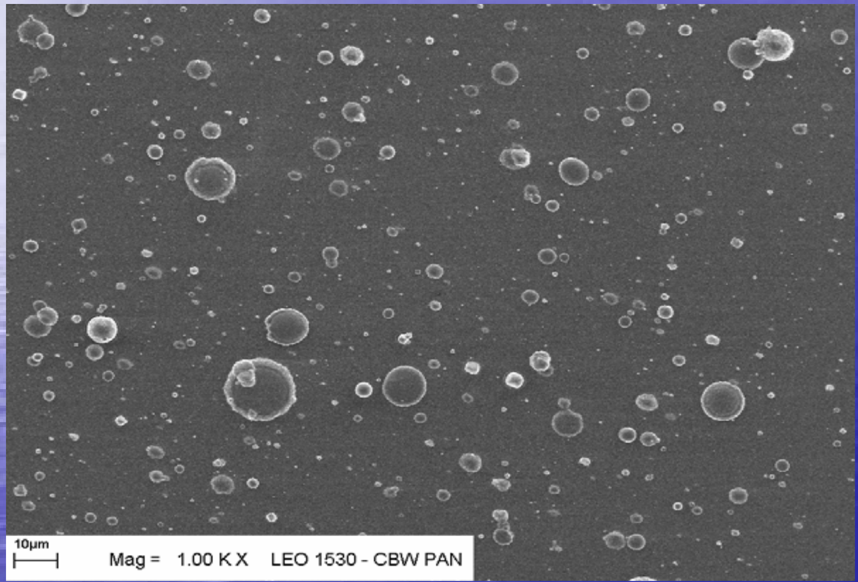
The facility was designed for the deposition of superconducting Nb-layers upon internal surfaces of RF cavities.

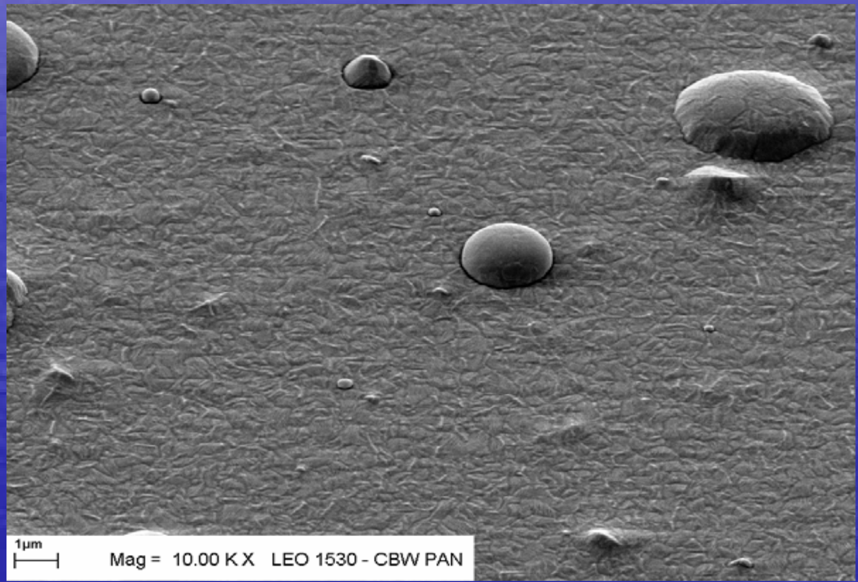
Results of preliminary coating of a single RF cell within UHV linear arc facility without a micro-droplet filter



Axial cut of the RF cell with the inner surface coated with a pure Nb-layer (left) and a SEM picture showing the deposited micro-droplets.

SEM analysis of Nb-layers deposited within UHV linear arc facility without a micro-droplet filter



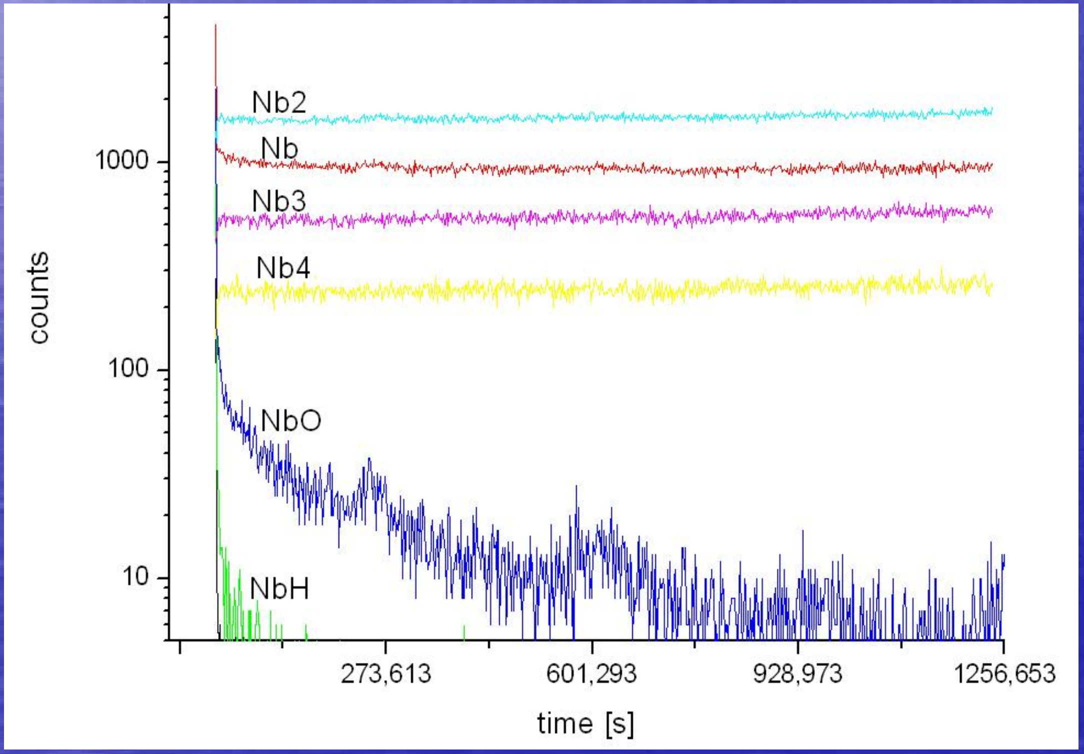


SEM pictures of a Nb-coated sapphire sample, showing the micro-droplets (left), and the structure of the Nb-layer and micro-droplets (right, larger magnification).

Recent studies of un-filtered Nb-layers deposited within the UHV linear arc facility

RRR value measured for an un-biased sample was equal to 25, while that determined for the biased (–70V) one amounted to 48.

SIMS analysis (performed with Ar-ions) showed that the NbO concentration was reduced by 2 orders of magnitude (2006).

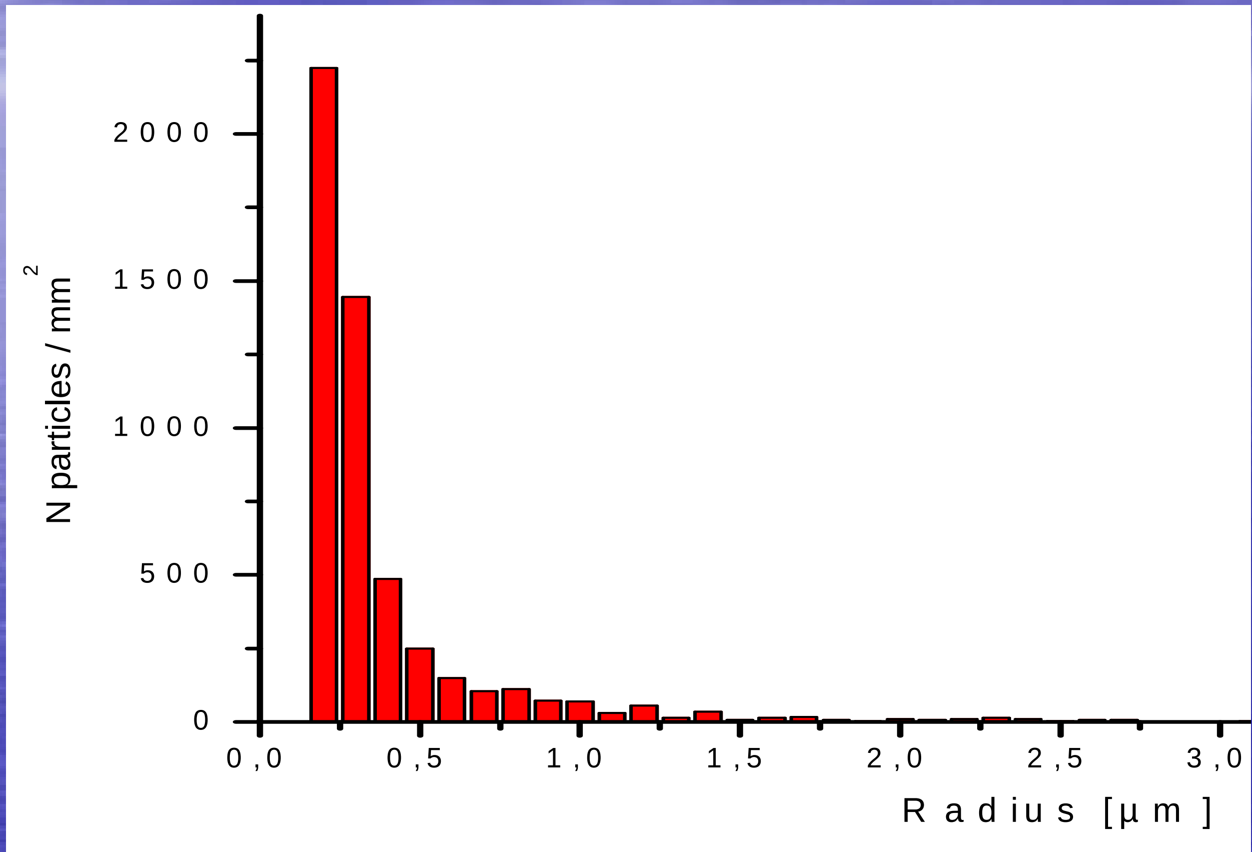


To eliminate micro-droplets (macro-particles) or at least to reduce their amount in the UHV linear-arc facility - special cylindrical filters have been considered.

Two different versions of such filters have been designed: a passive Venetian-type filter and an active cylindrical filter (supplied by a magnetizing current and producing an additional magnetic field).

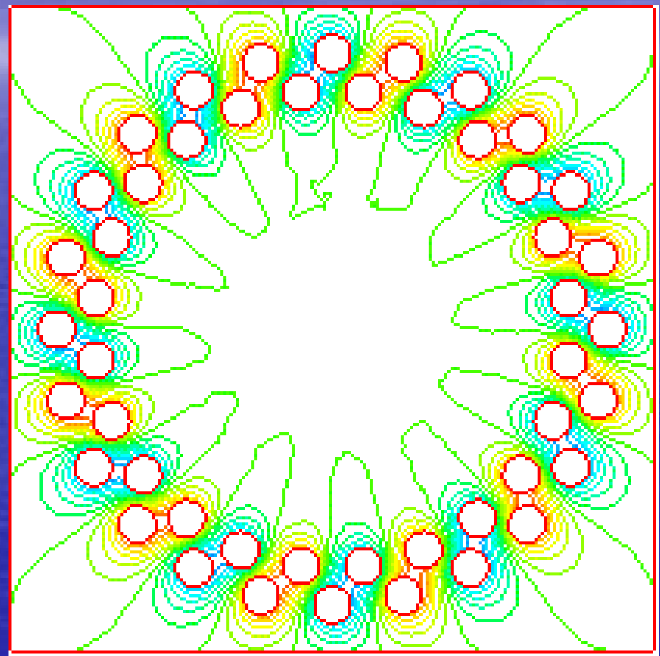
Prototype of a cylindrical Venetian-blind filter.

Recent studies of filtered Nb-layers deposited within the UHV linear arc facility (2006)



Distribution of micro-droplets upon the Nb-layer deposited within the UHV linear arc facility, which was equipped with a Venetian-filter.

New cylindrical filters for elimination of micro-droplets



A cylindrical magnetic filter consisting of current-carrying tubes (left) and the distribution of magnetic field lines in its cross-section (right).

Summary and conclusion

New experimental facilities based on arc discharges under ultra-high vacuum (UHV) have been developed and investigated.

It has been shown that the deposition processes, which are realized by means of UHV arc discharges, can guarantee a very low level of unwanted impurities within the deposited films.

It has been confirmed by good superconducting properties and results of the purity measurements of the arc-deposited Nb-layers.

Test coatings of the original single RF-cavity of the Tesla-type have not been performed because it has not been delivered by our partners. In spite of that an evident progress has been achieved in the mastering and optimization of the UHV-arc deposition technology.

The described UHV arc technology is a new road to many applications where dense, high-quality and pure metallic-films are needed, e.g. in micro-electronics, nanotechnology, medicine etc.

Acknowledgement

The support of the European Community-Research Infrastructure Activity under the FP6 "Structuring the European Research Area" program (CARE contract RII3-CT-2003-506395) is kindly acknowledged.