High quality Niobium films produced by Ultra High Vacuum Cathodic Arc

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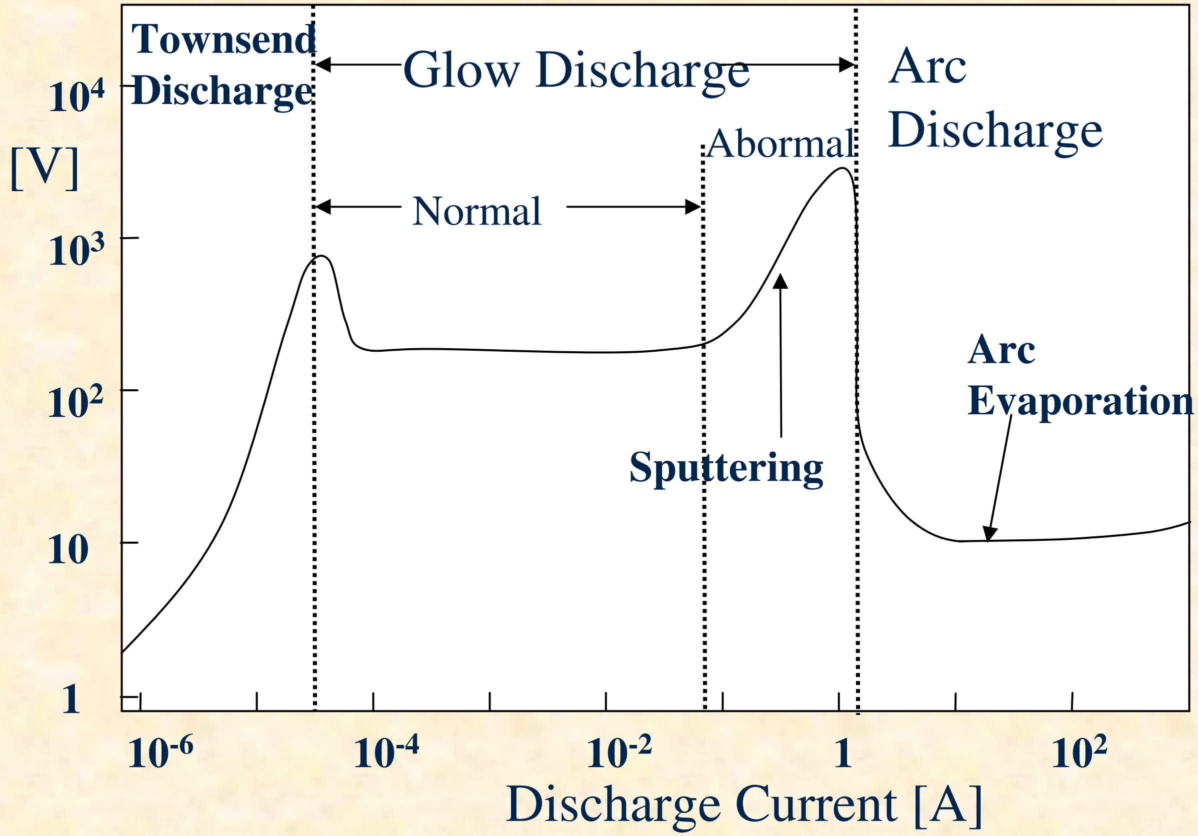
Outline

- The arc discharge vs Magnetron Sputtering
- UHV planar arc
- Magnetic Filter and cylindrical arc sources
- Summary and future plans

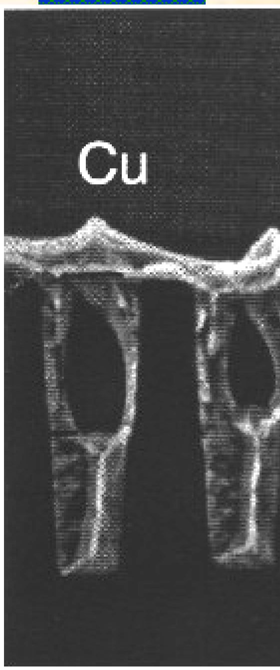
I-V of low pressure discharge

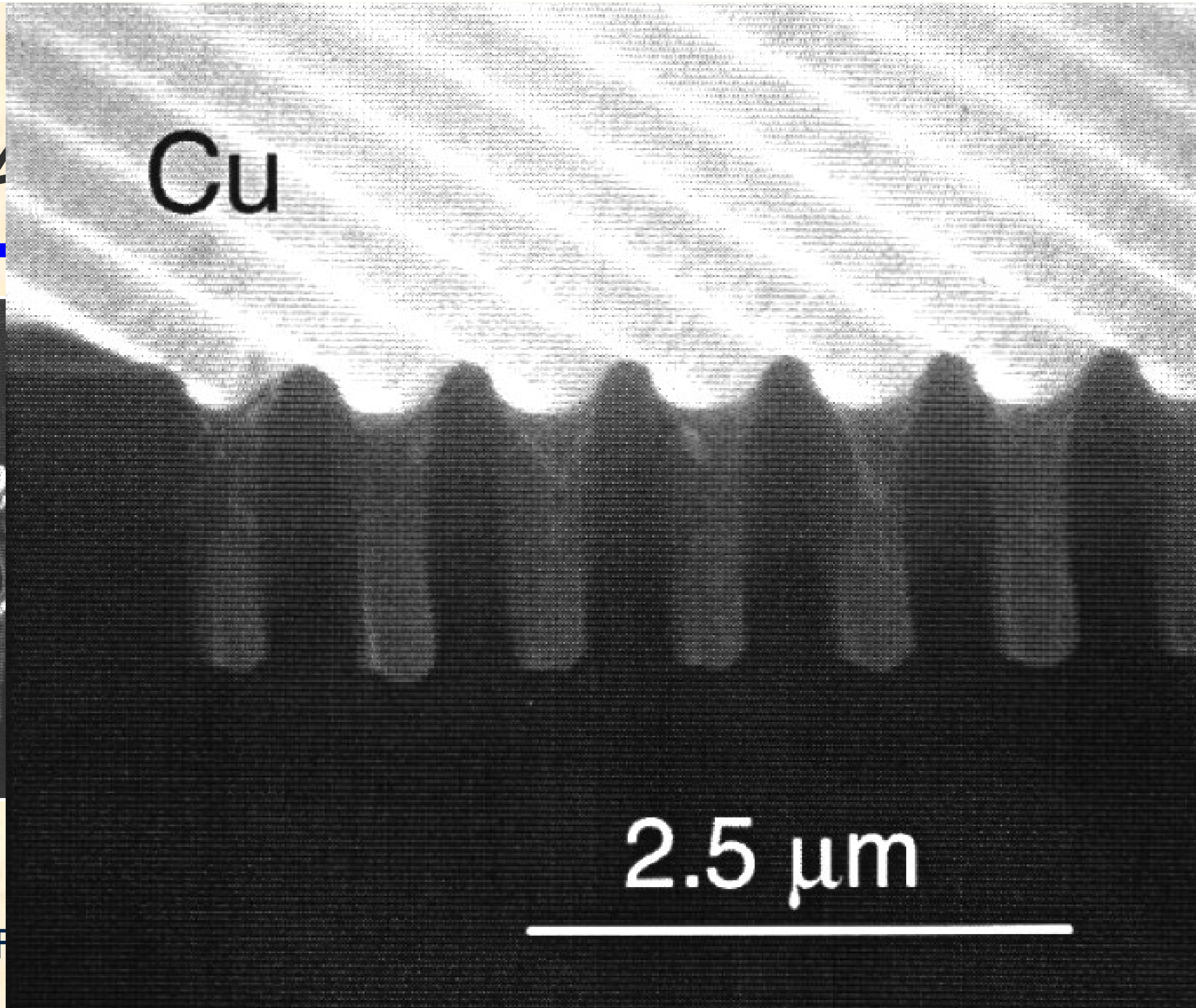


From Handbook of Thin Film Process Technology (IoP 1995)

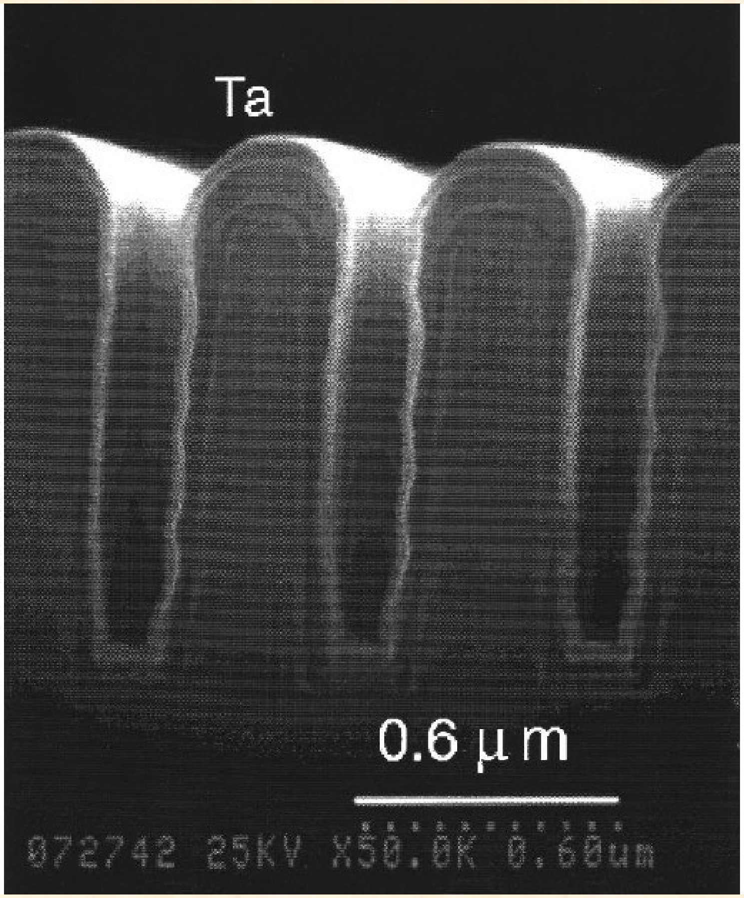
Why cathodic arc?

- no working gas (UHV)
- ionized niobium
- high ion energy (10-200eV)
- excellent adhesion
- high purity
- possible to apply bias and magnetic field

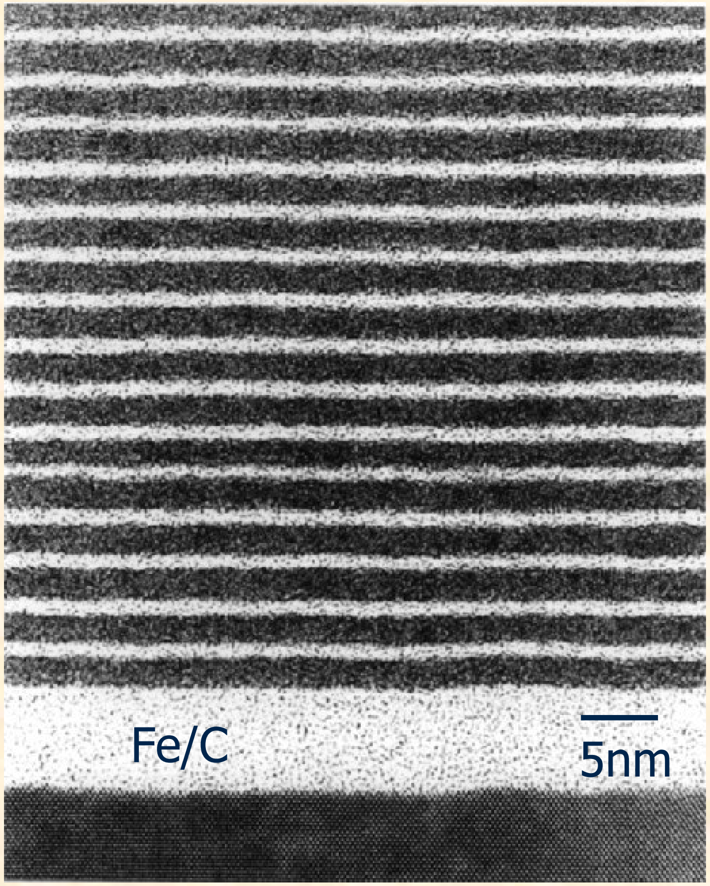

Cu


Cu
2.5 µm

Very Thin films deposition



20nm Tantalum on Silicon



P.J.Martin Thin Solid Film 394(2001)1

Vacuum arc discharge

- low voltage (Nb 30-40V),
- high current (50-200A up to several kA)
- The discharge (hot spot) is sustained in the vapor of the cathode material (no working gas)
- High degree of ionization (100% for Niobium)
- Average energy of Niobium ions >100eV (tunable with bias and magnetic field)
- multiply charged ions +2,+3,+4 (mean value for Nb +3)
- High density plasma (10^{11}-10^{12} ions/cm^3)
- High discharge current density (10^6-10^8 A/cm^2)
- Hot spot speed on the cathode (1-100m/s)

Arc spots motion

Photo t =0.1s

Nb Cathode during arc discharge

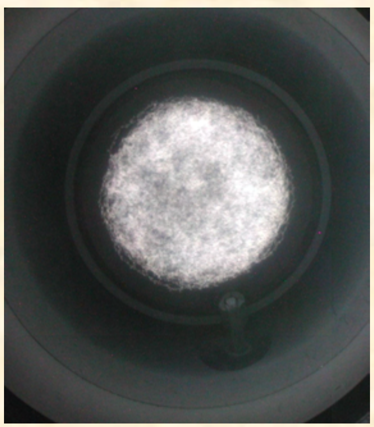
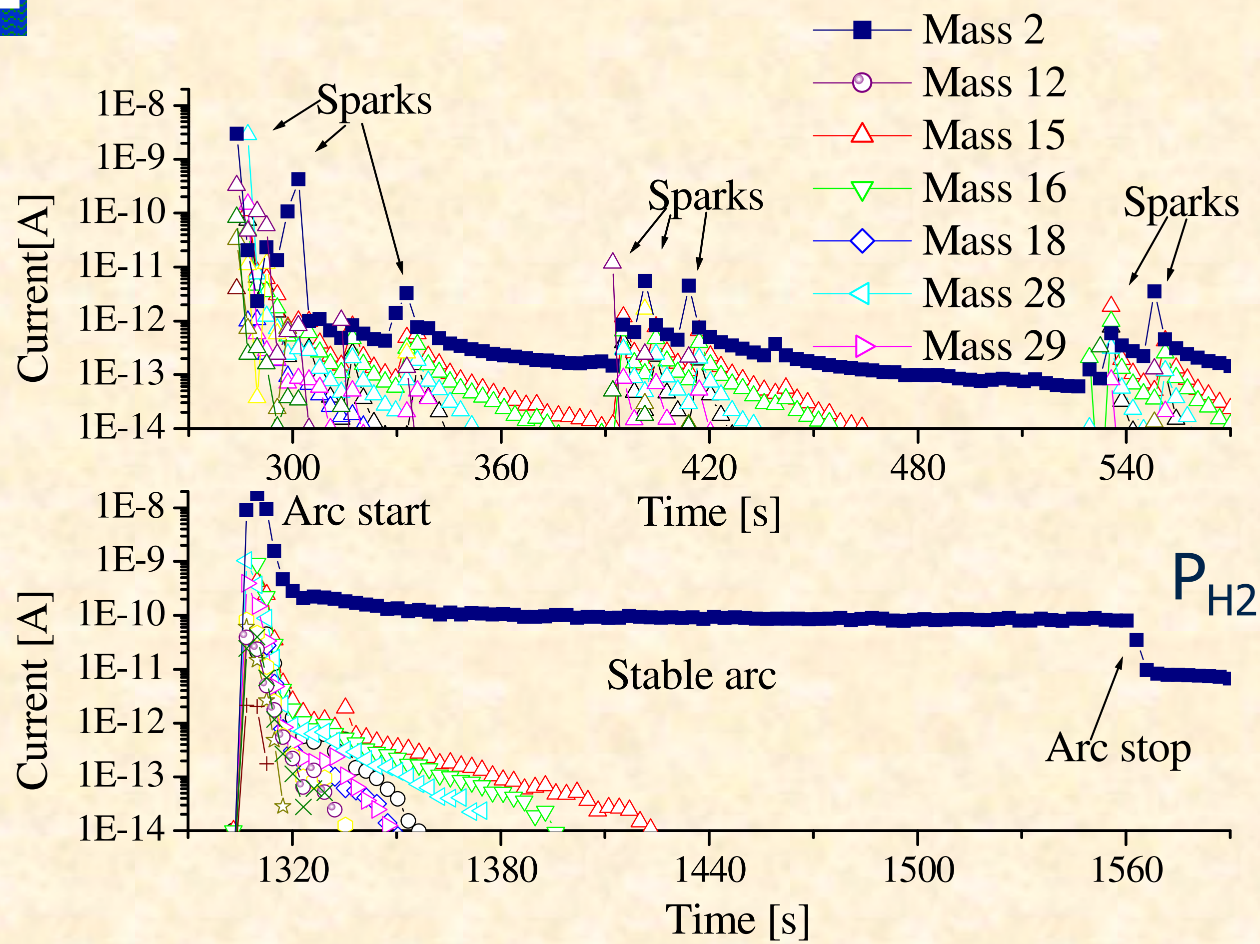


Photo t =1s

- Arc spot moves on the Nb cathode at about 10m/s
- Arc Current is 100-200A
- Cathode voltage is ≈ 35V
- Ion current ranges from 0.2 to 3A on sample-holder (1-15mA/cm^2)
- Base vacuum ≈ 10^{-10} mbar
- Main gas during discharge is Hydrogen (≈ 10^{-7} mbar)
- Voltage Bias on samples 20-100V

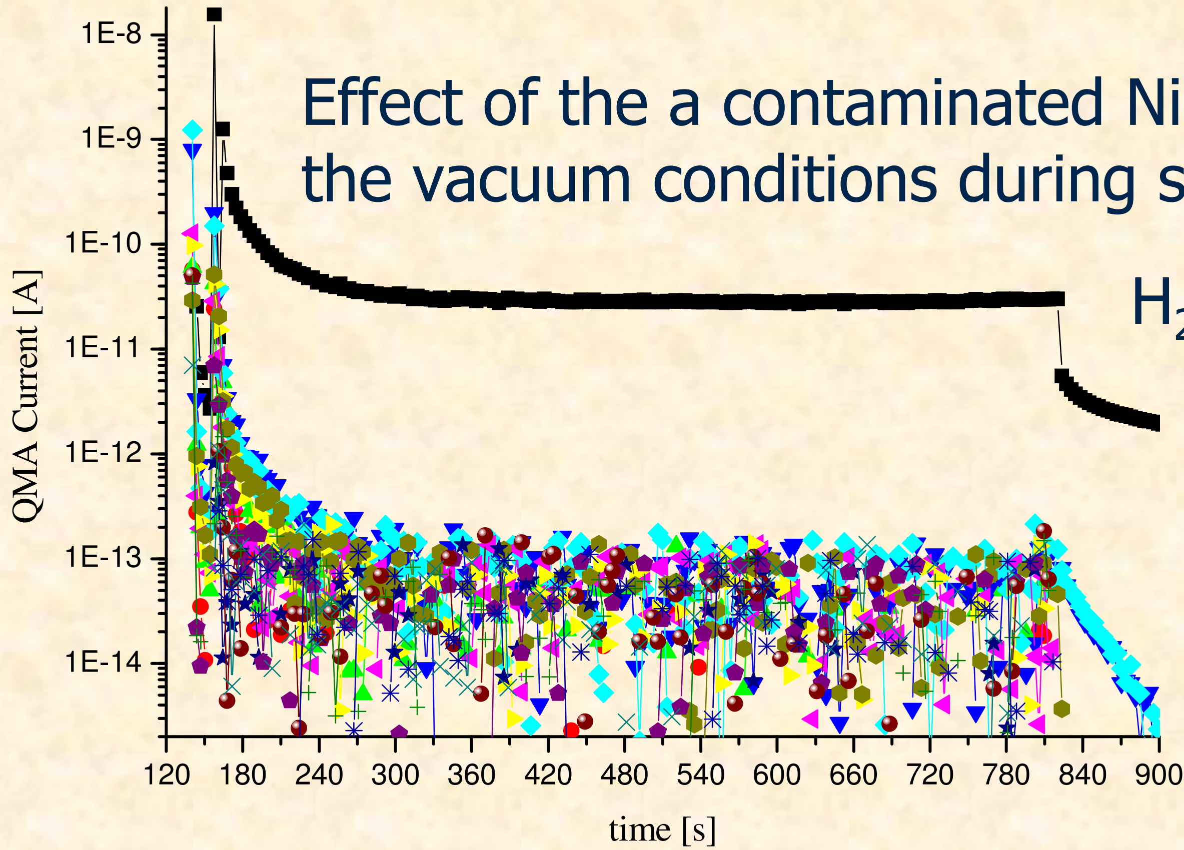
Vacuum during arc discharge I



Only sparks are present Arc doesn't start

$P_{H2} \approx 2x10^{-6}$mbar

Vacuum during arc discharge II

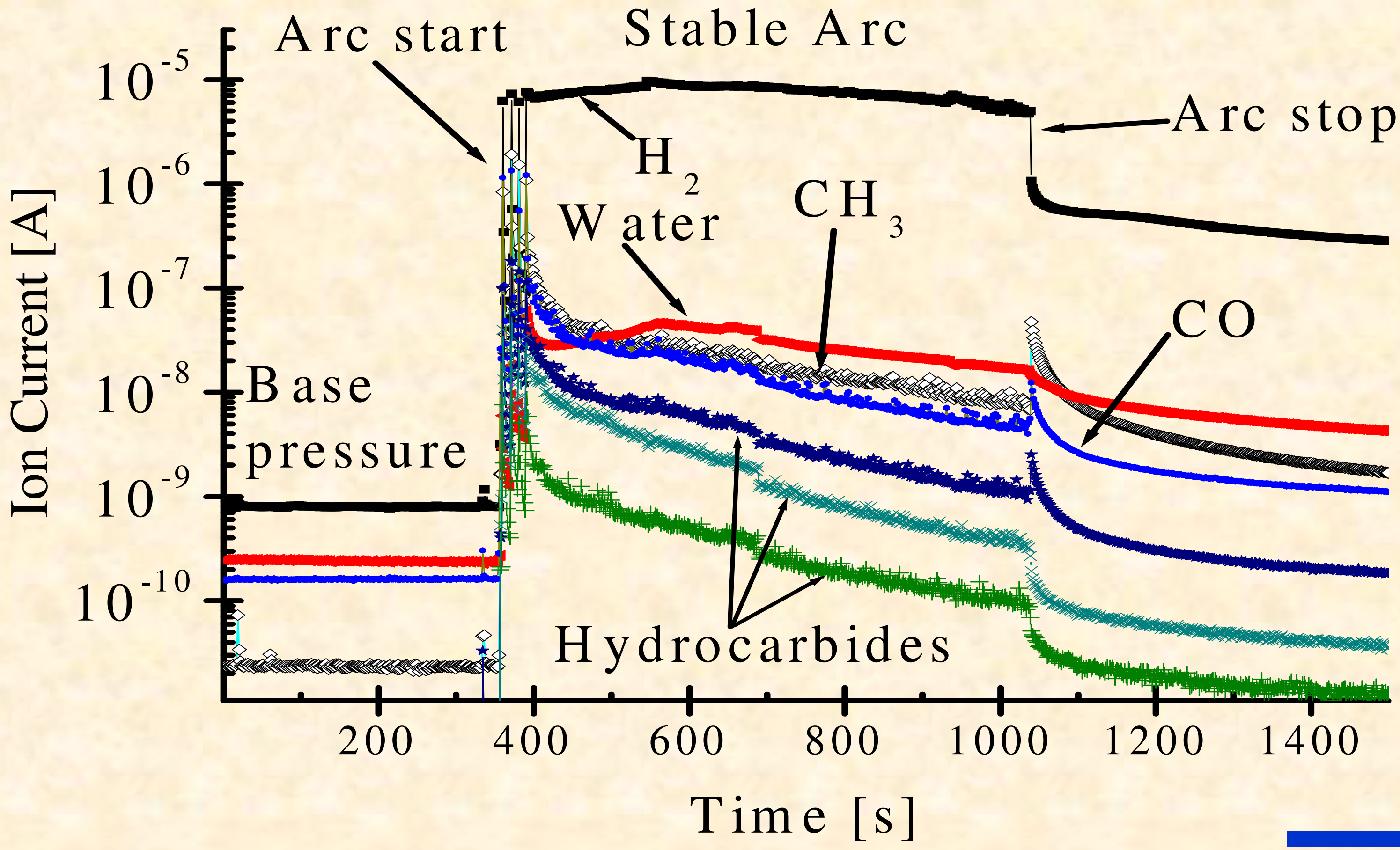


Effect of the a contaminated Niobium cathode on the vacuum conditions during stable arc operation

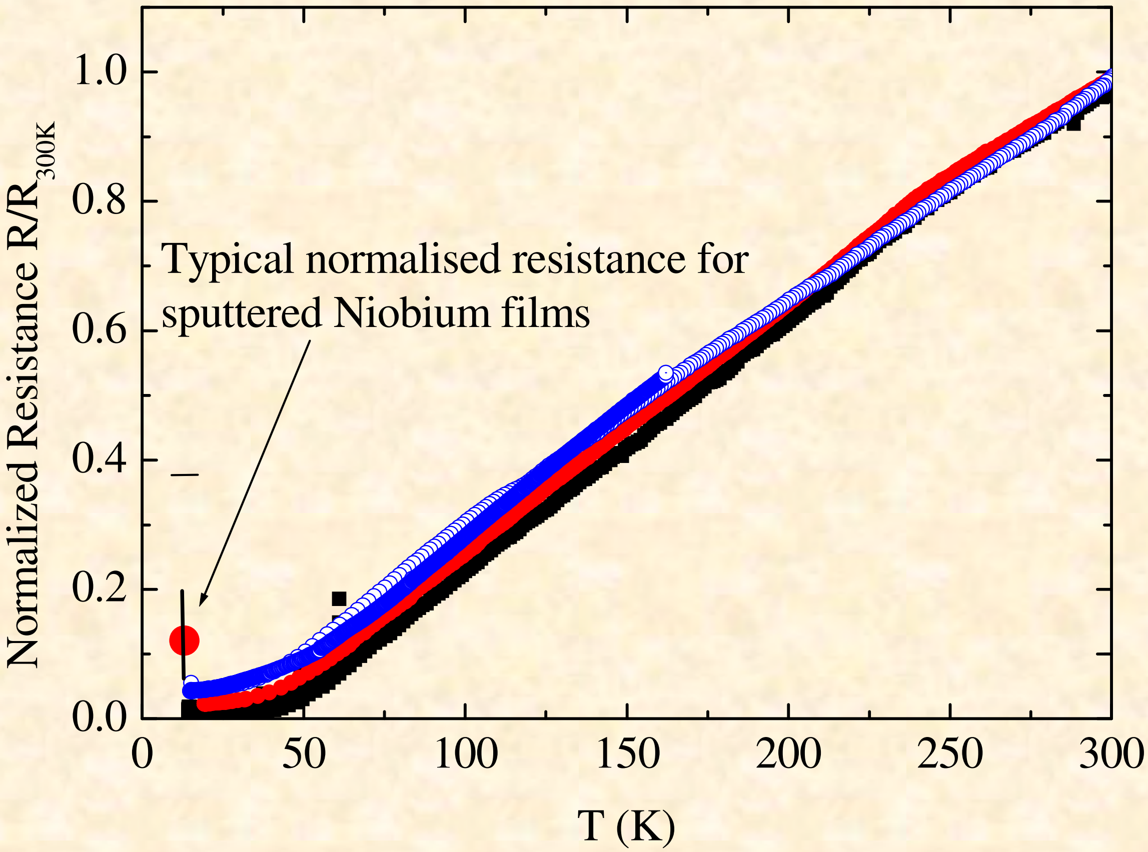
H_2 $P=5x10^{-7}$ mbar

Contaminants

Data from Residual Gas analyzer



RRR measurements

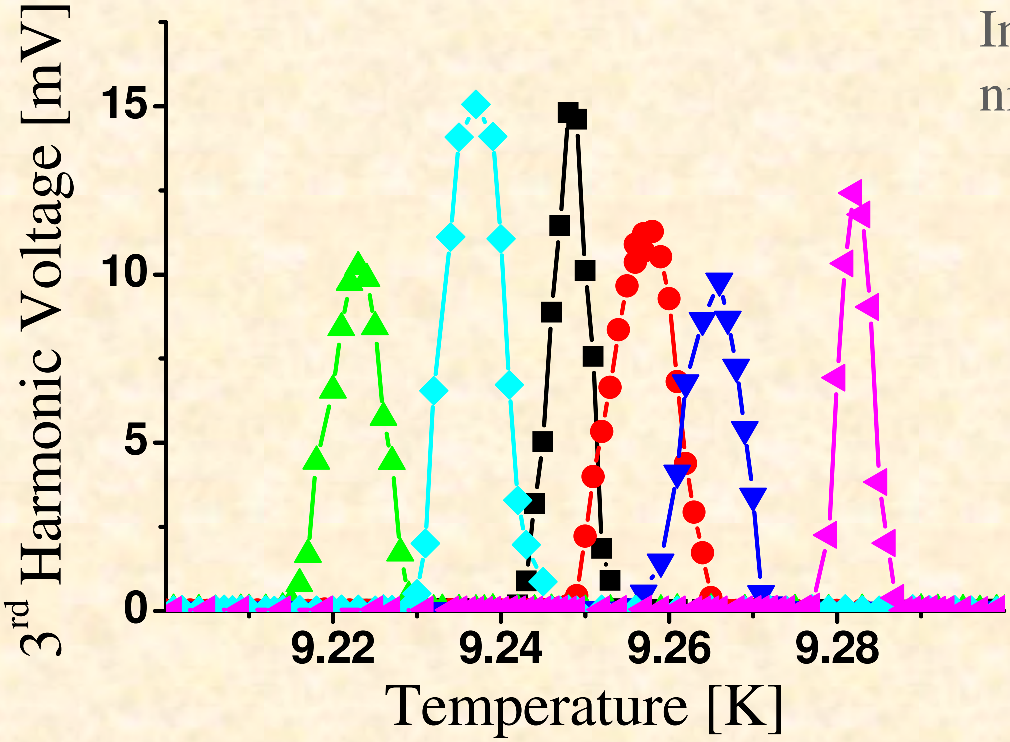


RRR values from 20 to 100 were obtained

Deposition temperature below 100°C

Thickness 100-2000nm

Inductive T_c-J_c Measurement



Inductive measurement of T_c for some niobium samples deposited by UHV arc

Nb Thickness from 40 to 1000 nm

Our standard results after discharge stabilitation

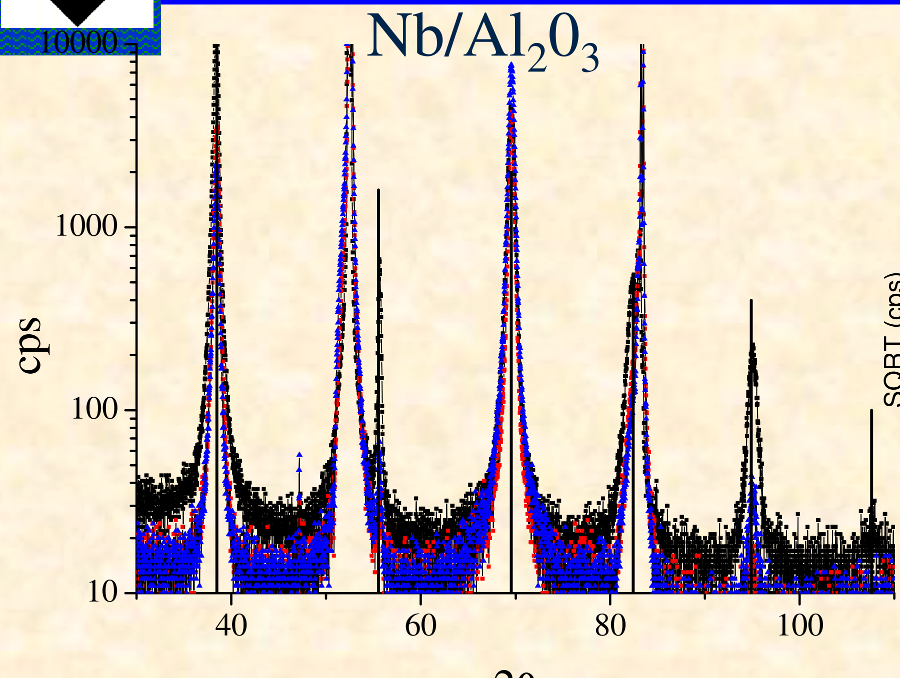
$9.1K < T_c < 9.4K$

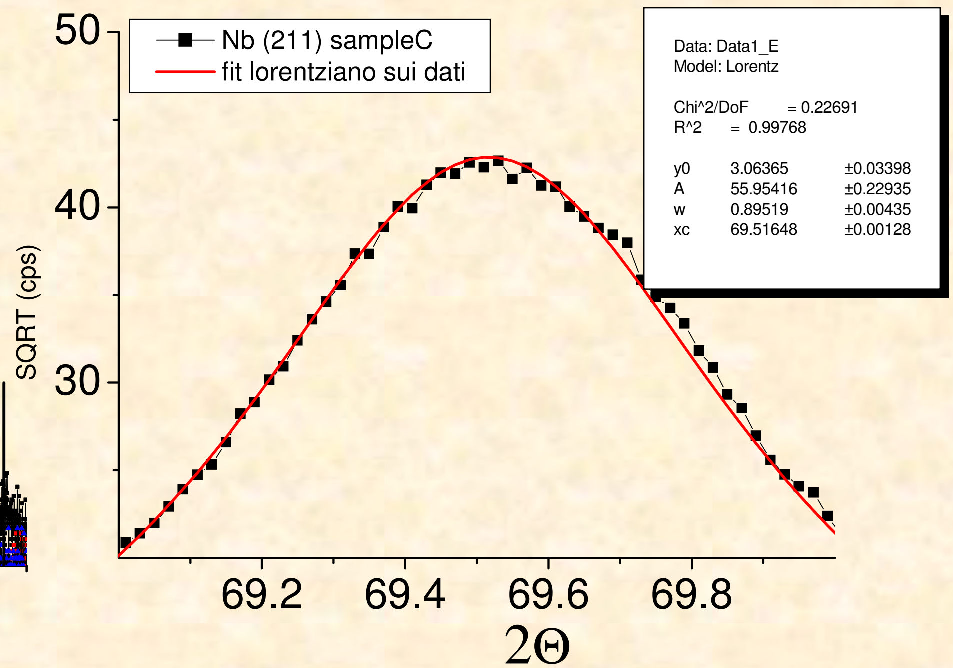
$\Delta Tc < 0.02K$

Very similar to bulk values

$J_c \approx 4x10^7 A/m^2$

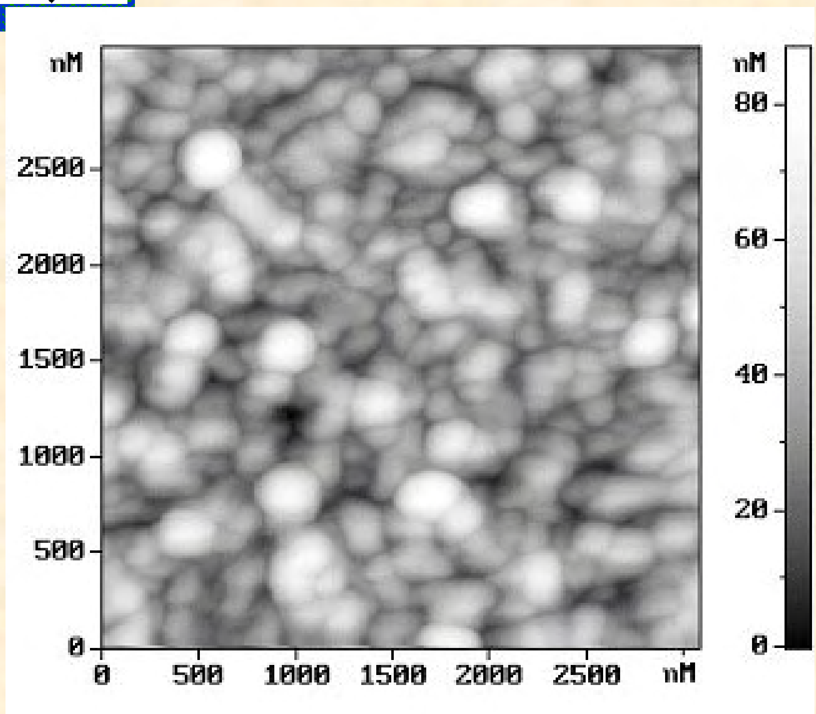
X-Ray diffraction pattern in Θ/2Θ

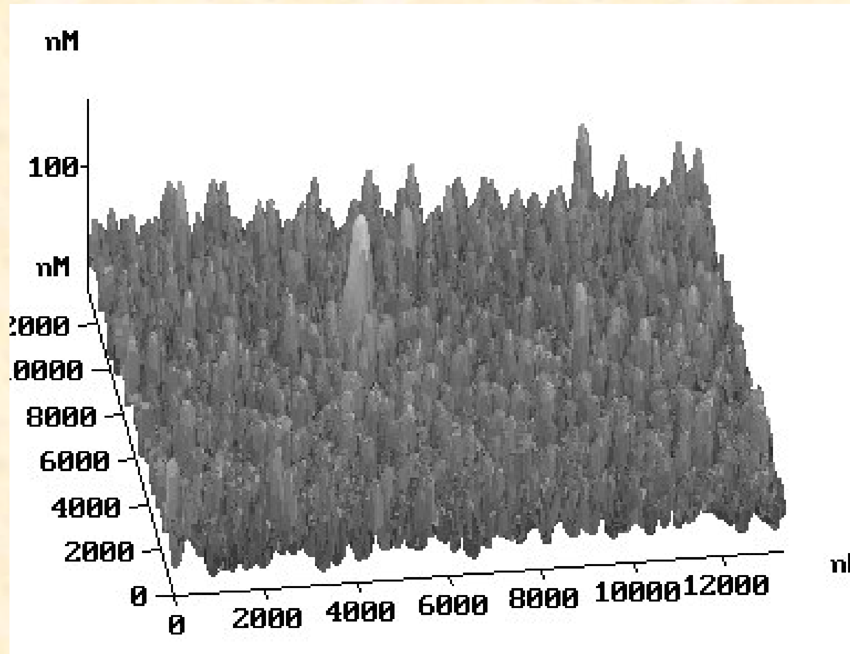




The best fit using all peaks gives a lattice parameter between 0.3308nm and 0.3318nm. These values are similar to the bulk 0.3303nm and in agreement with T_c measurement. The niobium films produced by arc deposition are less stressed than in the sputtering case and they do not present preferential orientations (almost random oriented)

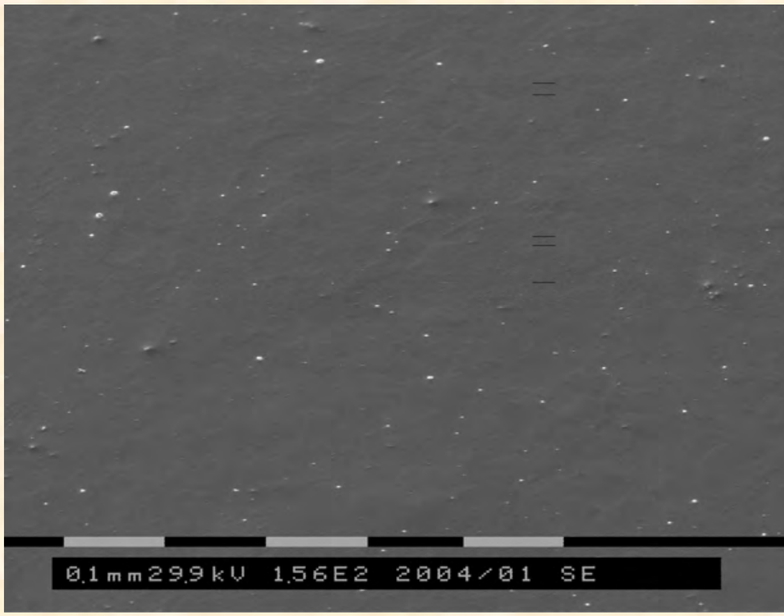
AFM Analysis



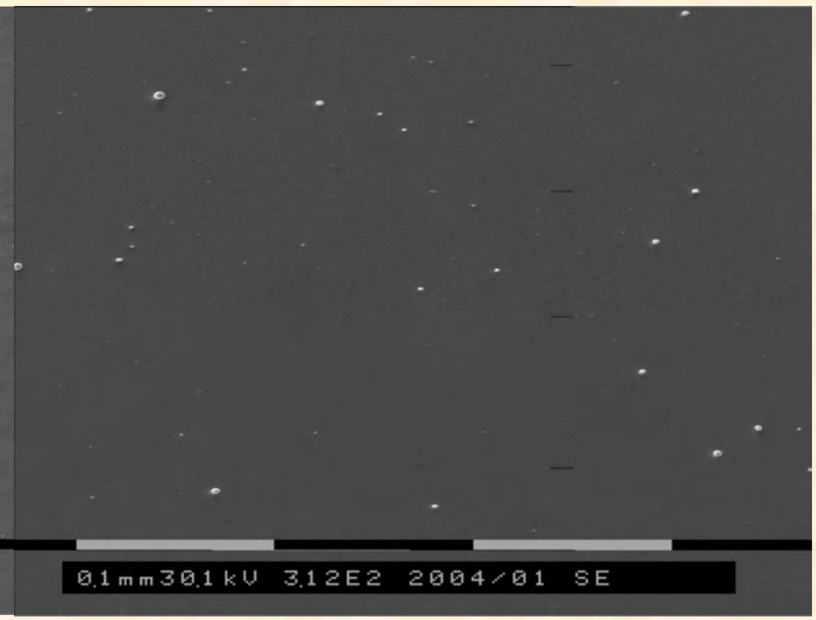


The grain size measured by AFM is about 30nm, a factor 2-3 larger then "standard" Nb sputtered films (no oxide-free).

Influence of the substrate



Copper substrate



Sapphire substrate

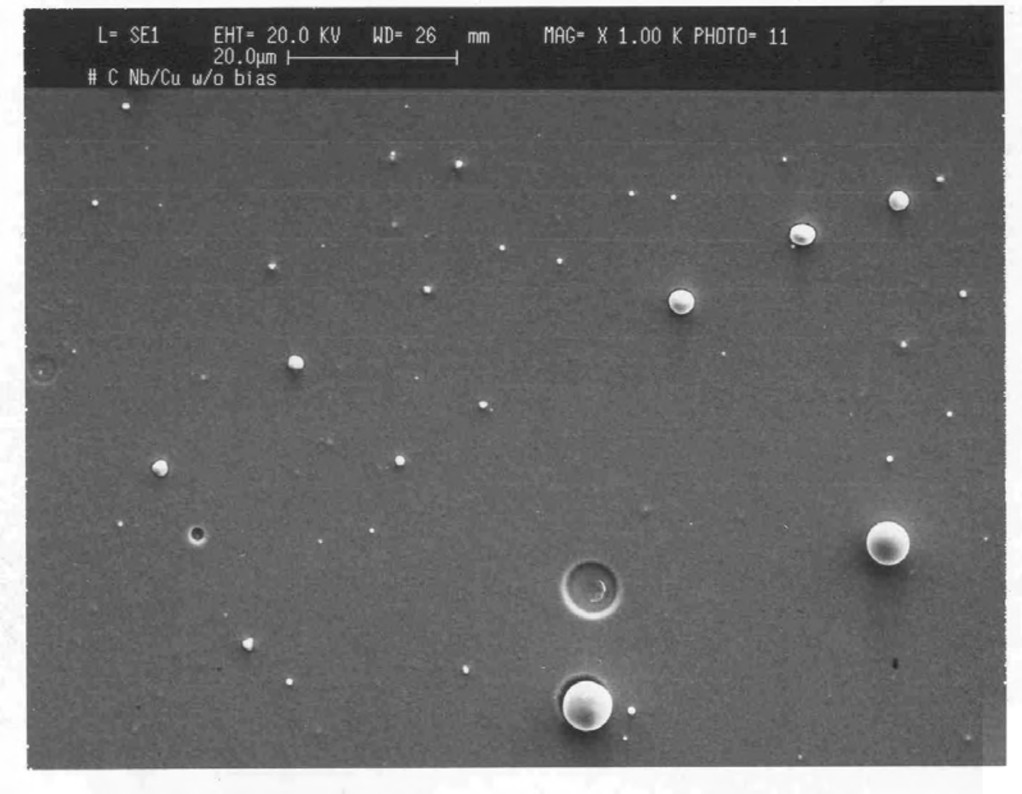
1,5micron Niobium film deposited in the planar arc system (no filter)

I_{arc} = 140A V_{bias} = 40V substrate at room temperature.

Magnetic Field on the cathode surface about 150G (I_{coil} = 3A)

Niobium microdroplets

(SEM images no tilt for quantitative analisys)



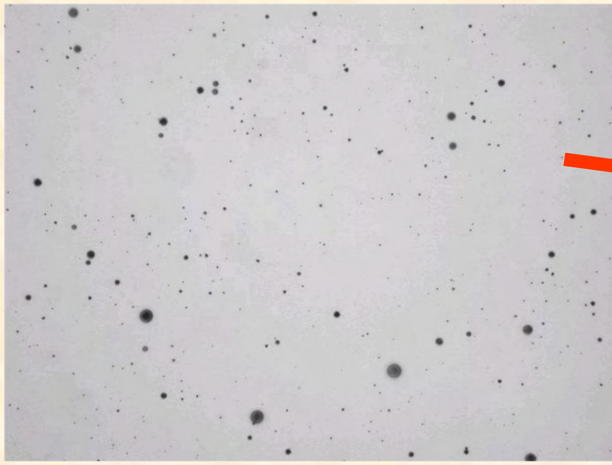
55 ± 10 microdroplets in $1000 \mu m^2$
(average on 7 pictures on 4 samples = 28 photos)
$55000/mm^2$ or $5.5 \times 10^6/cm^2$

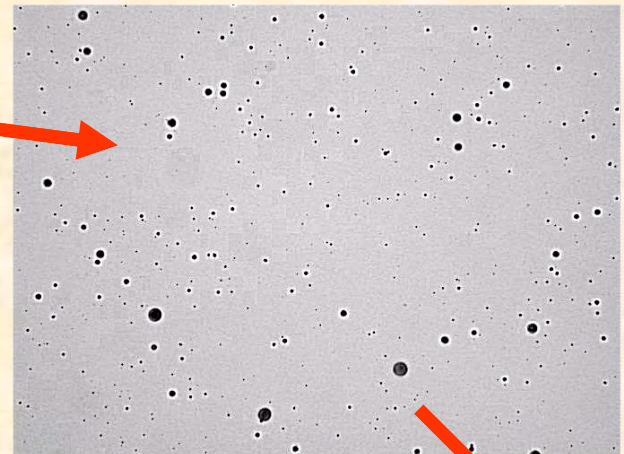
Averaging on 28 photos
1 drop. > 5µm
1µm < 5 drop. < 4µm
49drop. < 1µm

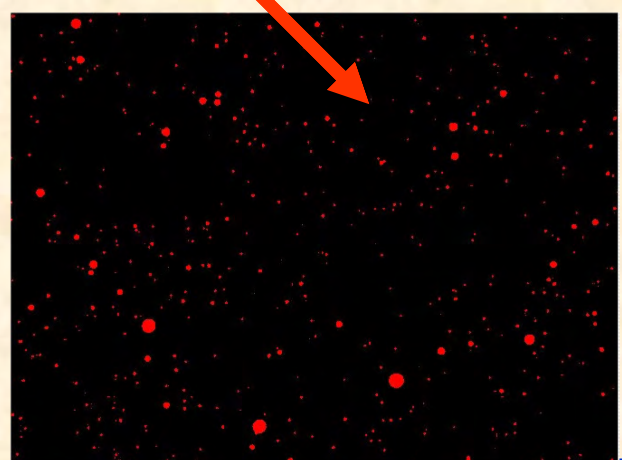
Most of them have diameters ranging from 0.3 µm to 0.5 µm

The biggest droplet detected was 13 µm
The smallest 0.2 µm

Droplets estimation usign optical microscope and computer code

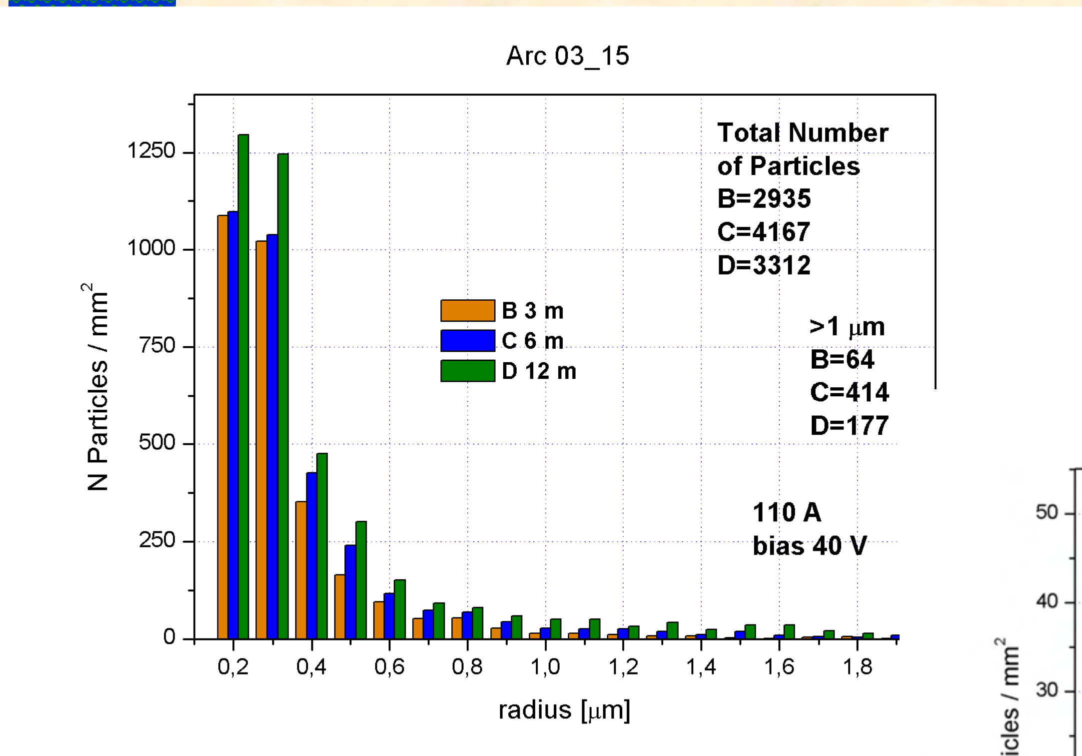


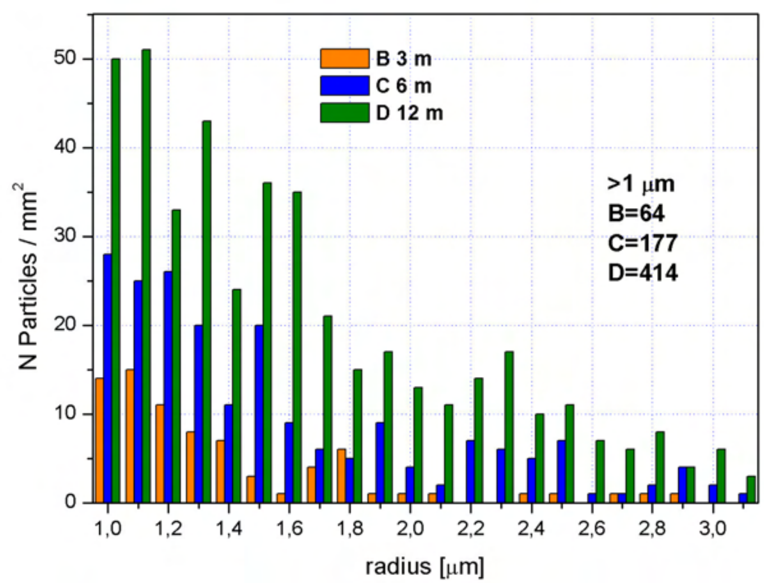




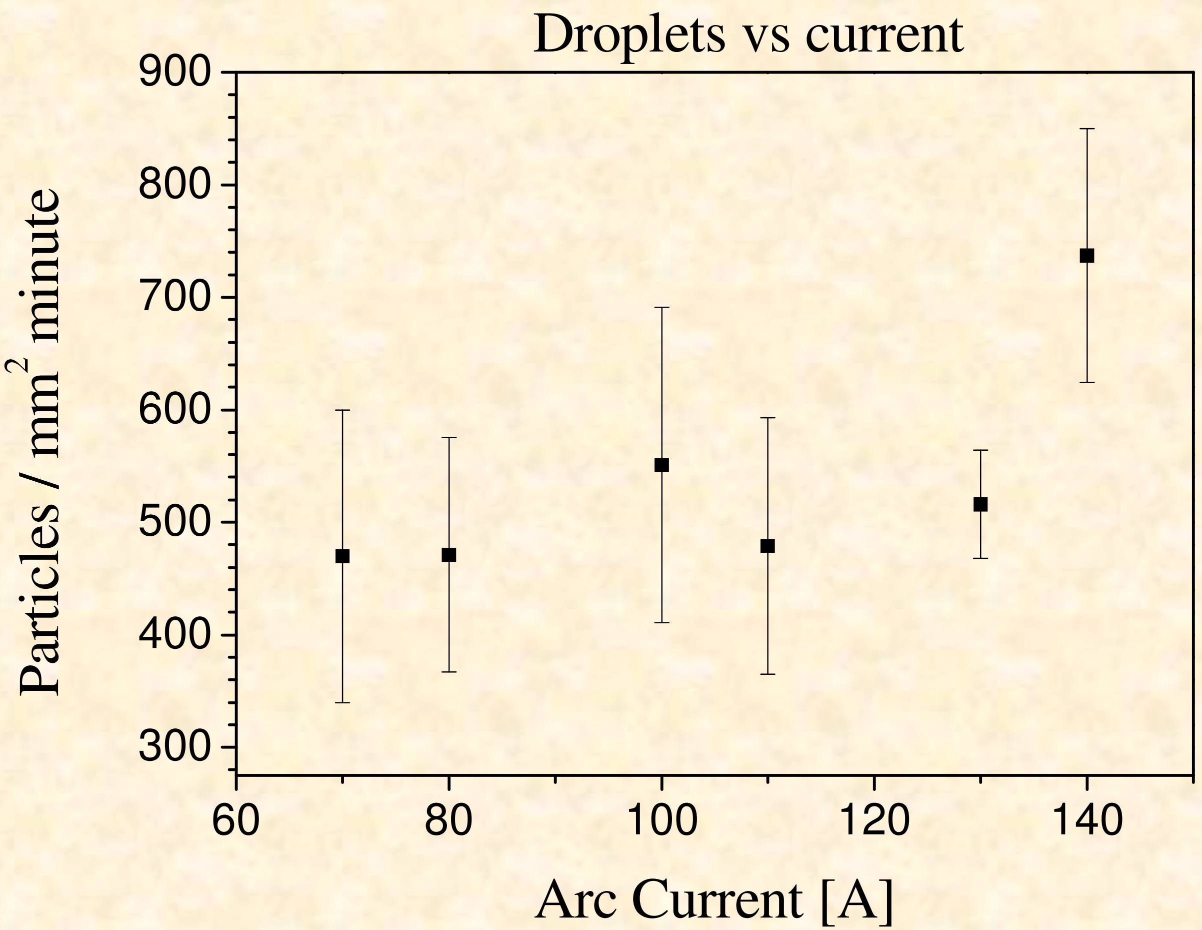
- **Optical analysis of the samples**
- **Computer program to count the particles**

Droplets results

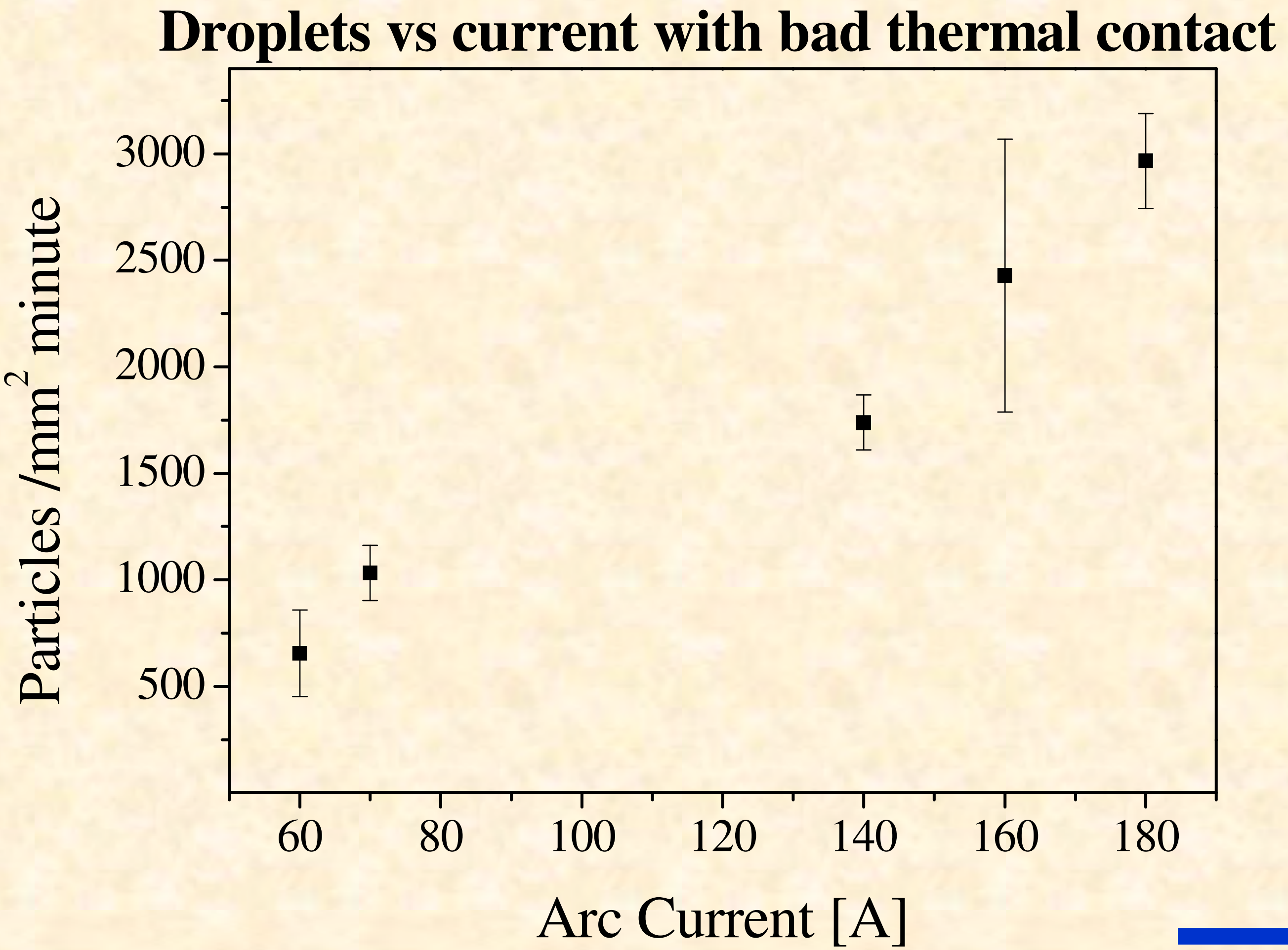




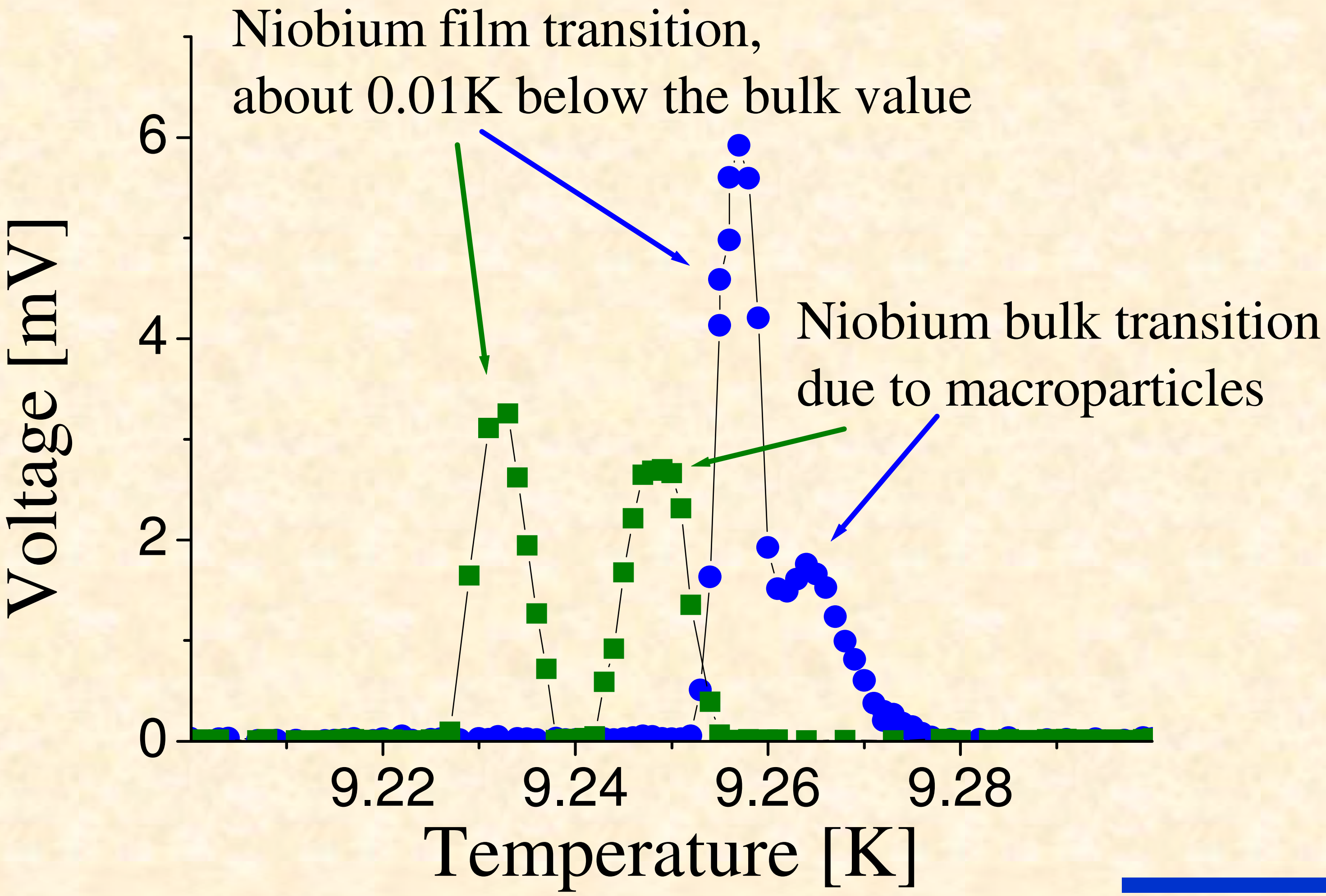
Macroparticles Vs Arc Current



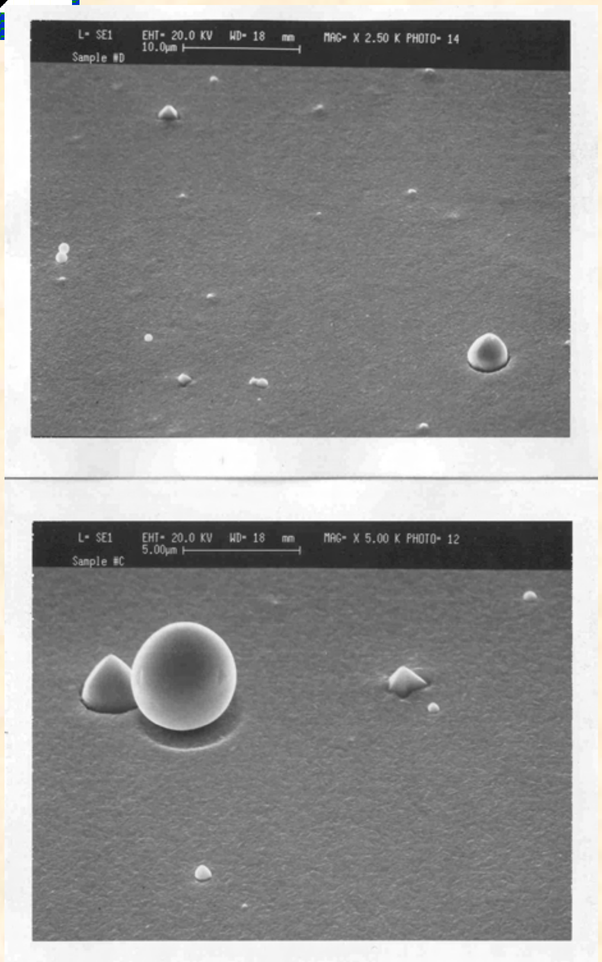
Bad thermal contact



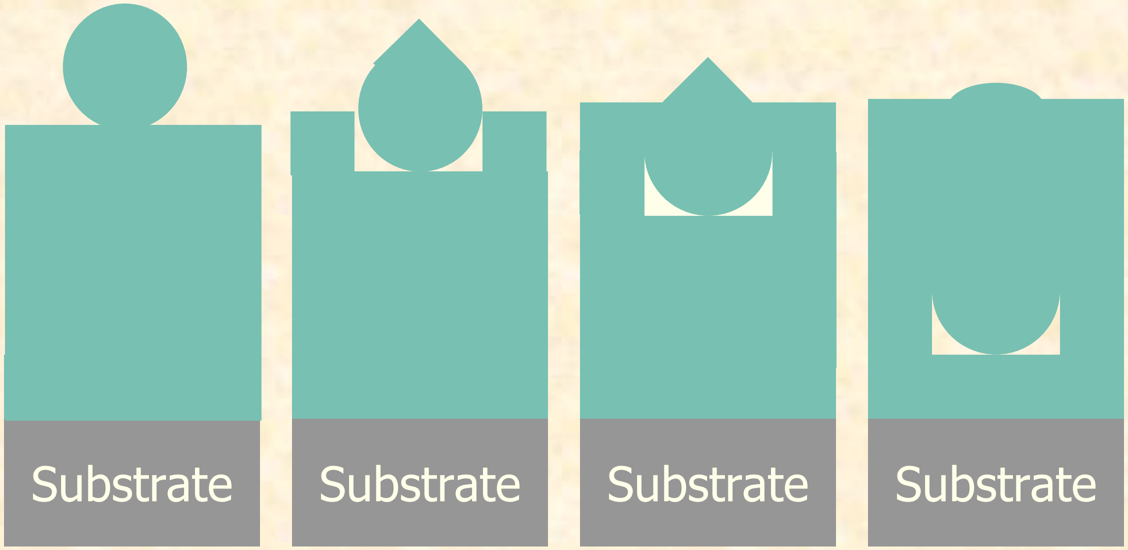
Effect of Macrodroplets on T_c



Microdroplets using planar arc source

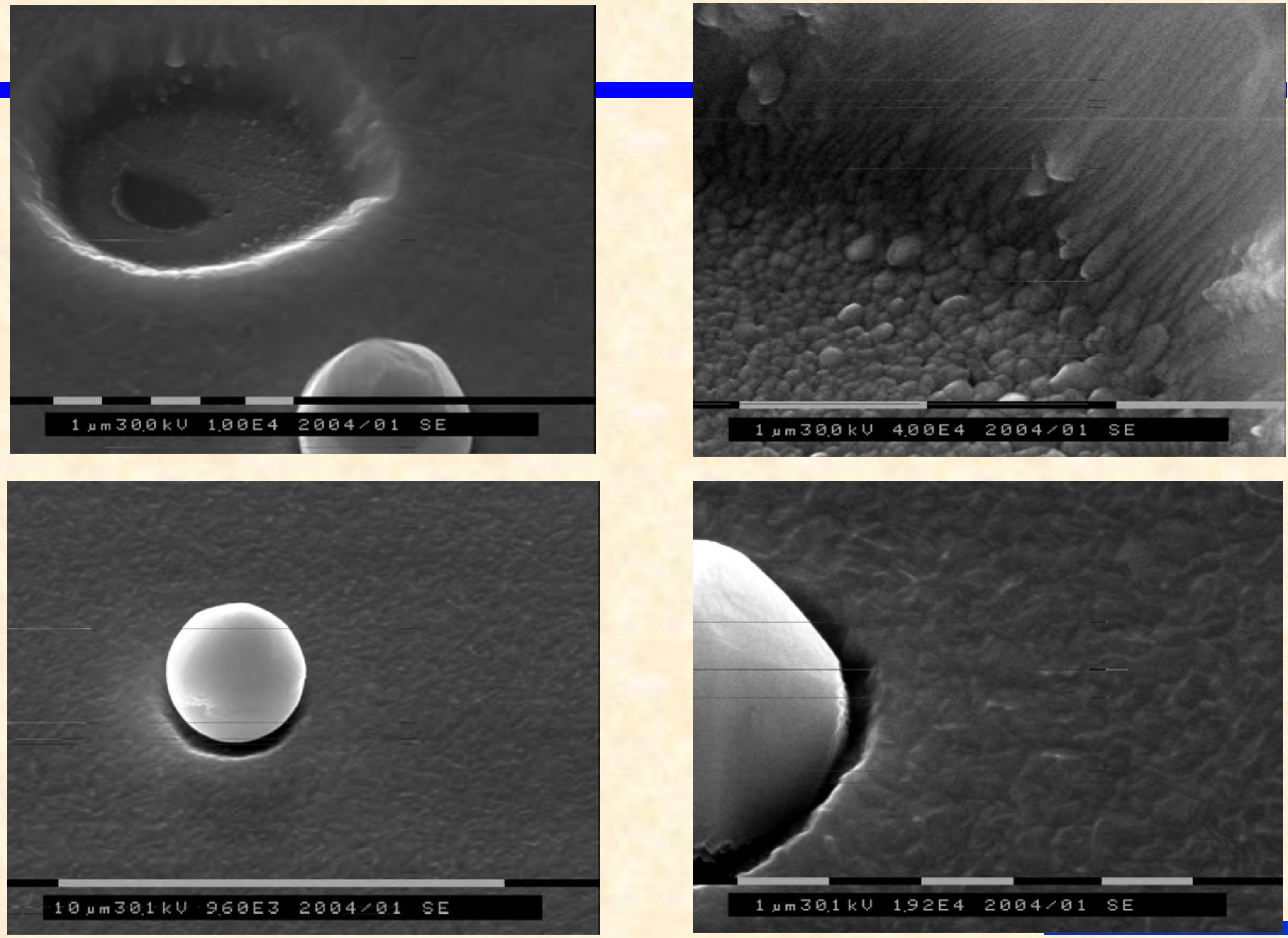


SEM Images of microdroplets

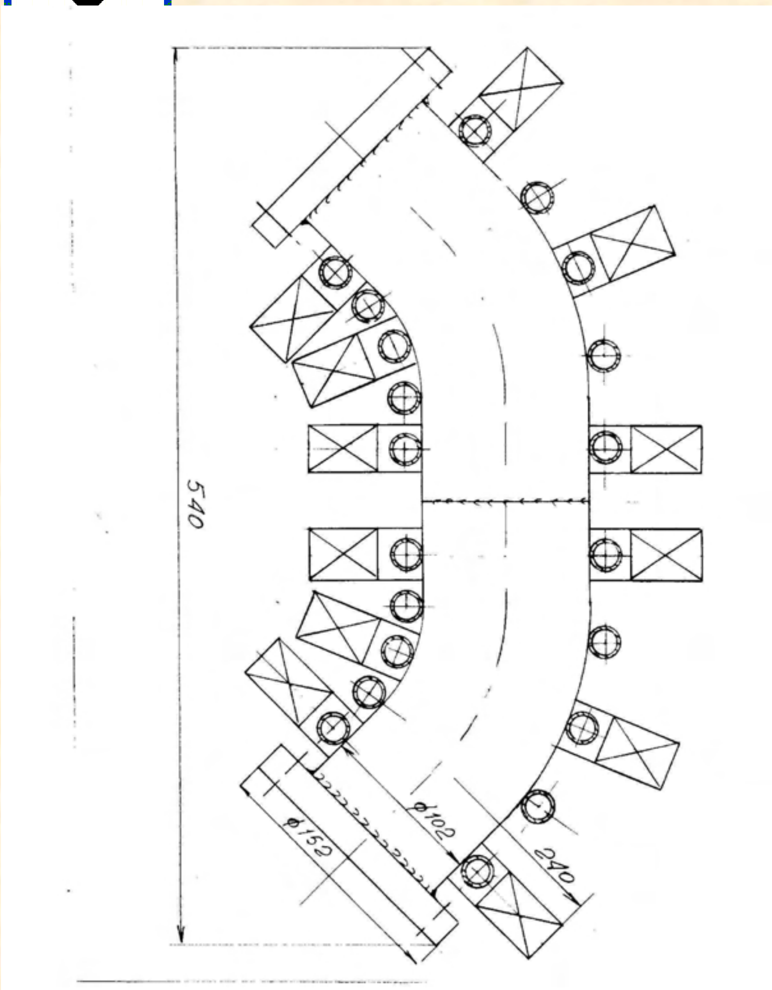


Main problem could be field emission and void in the film. We need field emission measurement on samples (before and after HPWR)

Macroparticles on Niobium films II



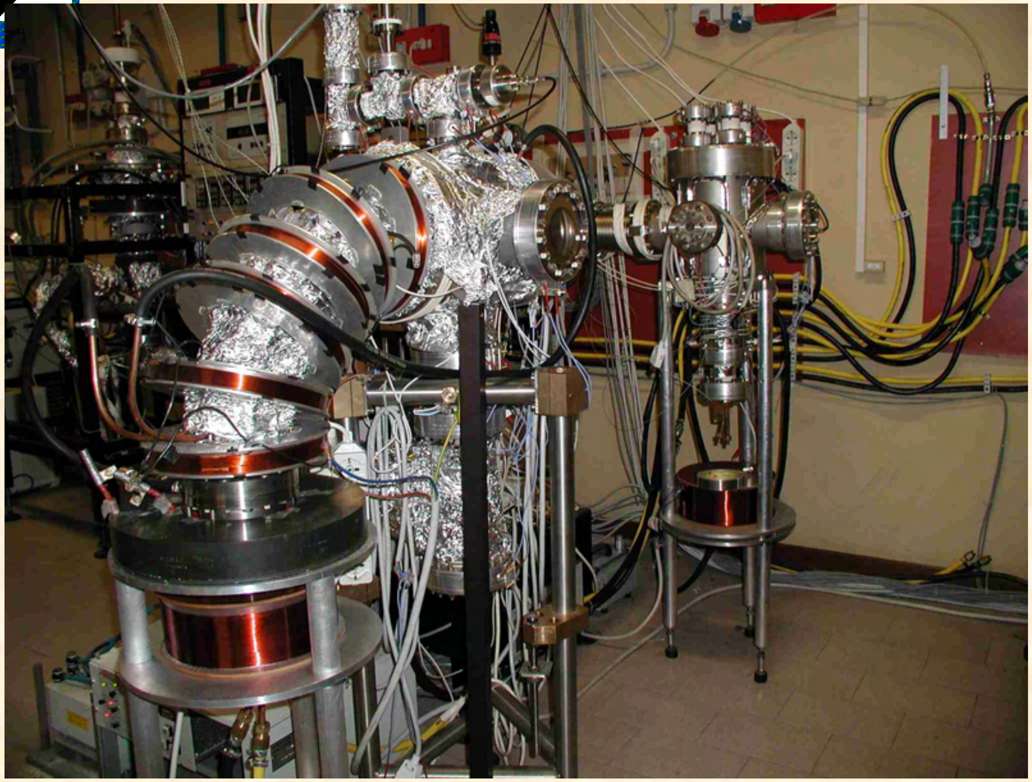
Magnetic filter project



Coils for the filter are designed to force the electron to follow the magnetic field lines with an orbit radius less than the vacuum elbow radius.

Since the plasma is quasi-neutral the ions will follow electrons in the elbow, while microdroplet will stop un vacuum walls.

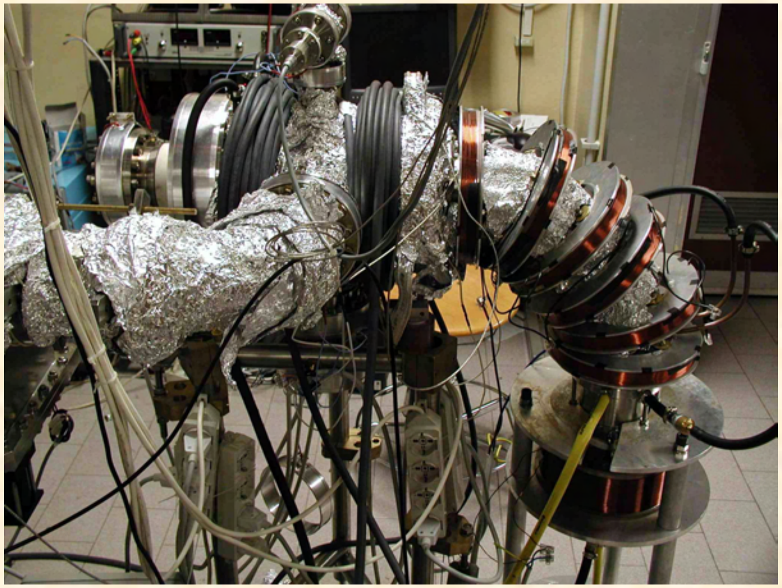
First UHV apparatus with magnetic filter

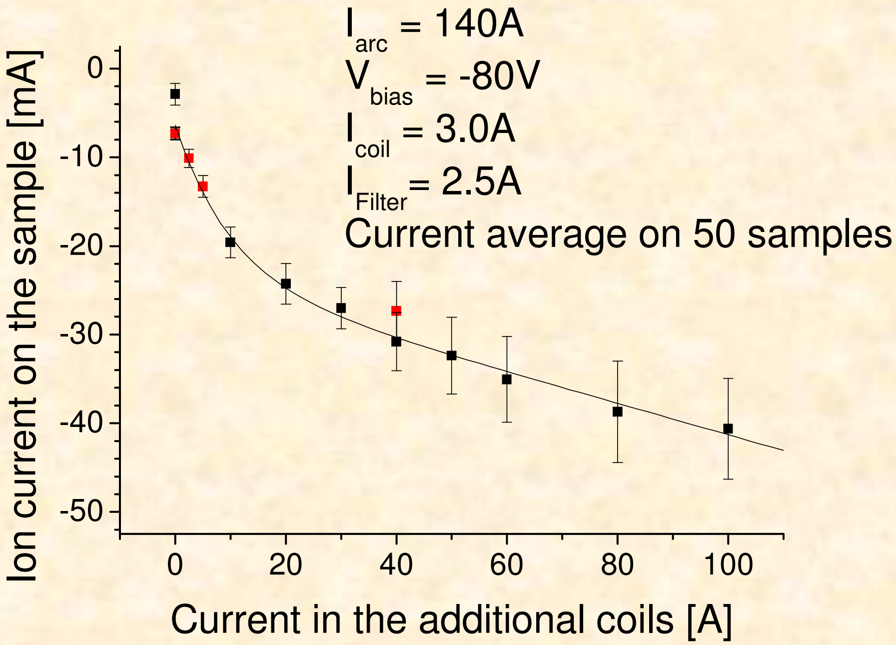


- Chamber and filter are water cooled
- Coil for driving magnetic field has been improved
- Main problem was trigger to ignite the discharge

Efficiency (current trasmitted divided initial current) was very low: about 1-2% of the ion current reachs the sample.

Improvement of the magnetic filter configuration

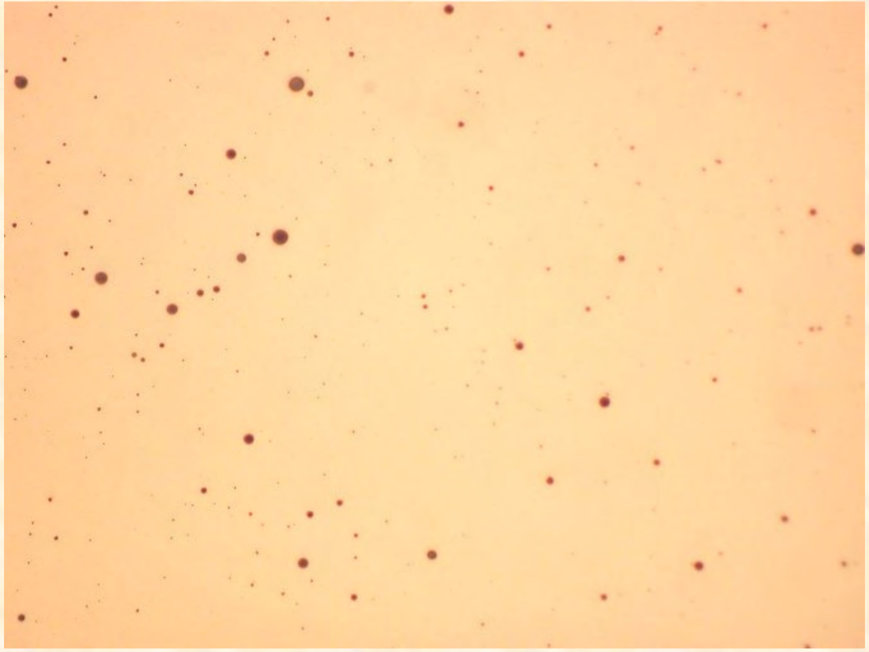




Filter efficiency improved up to 15%
Maybe possible to reach 25% by further improvement
It is very difficult to apply bias to the duct

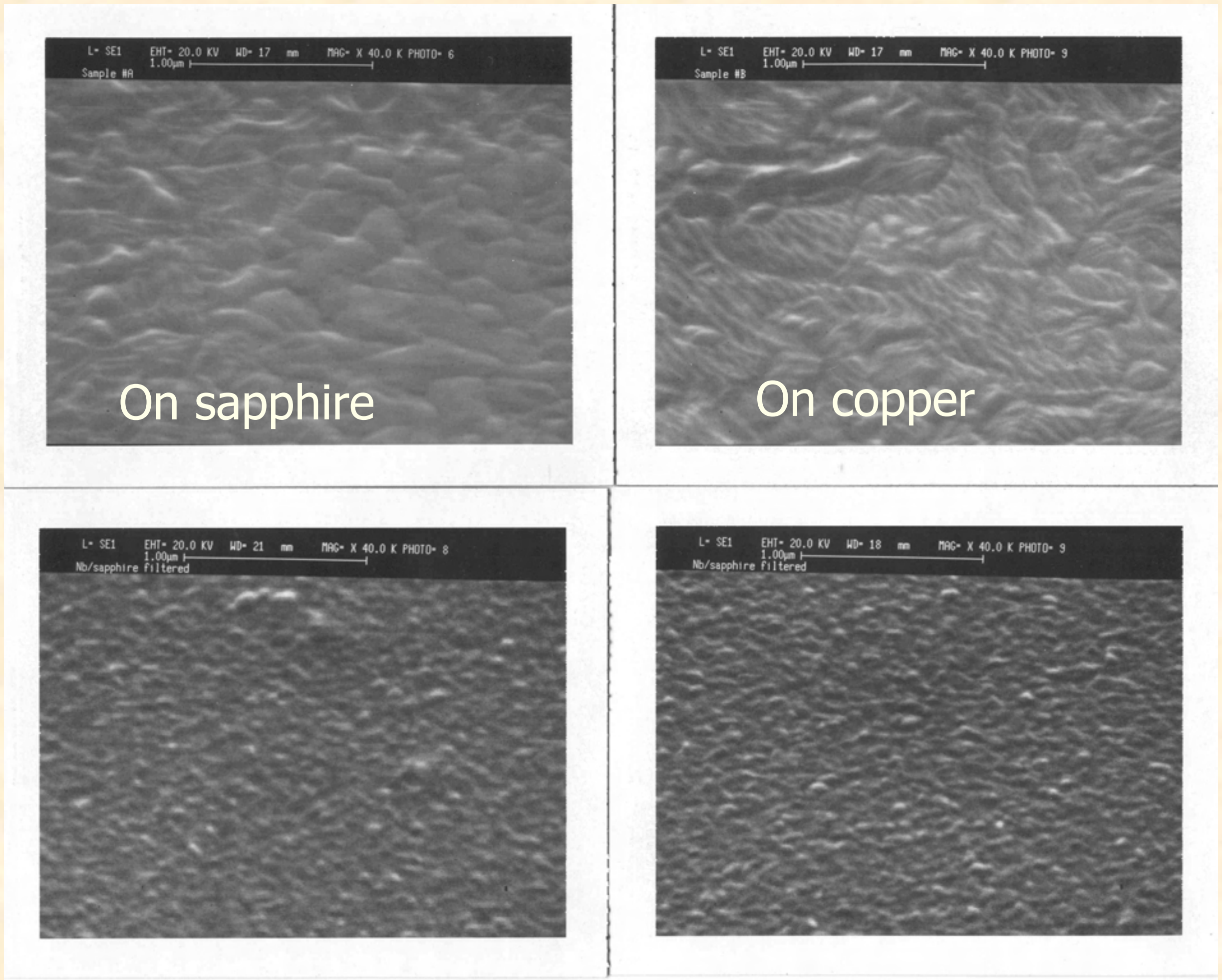
Examples of filter efficiency

Less than 100 particles / mm^2



About 6000 particles / mm^2

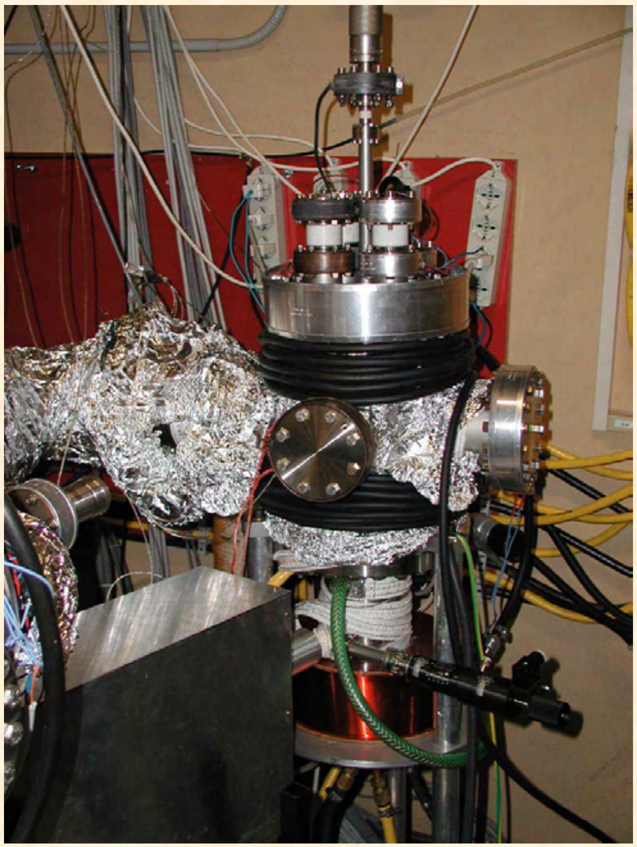
Morphology as seen by SEM (Tilted)

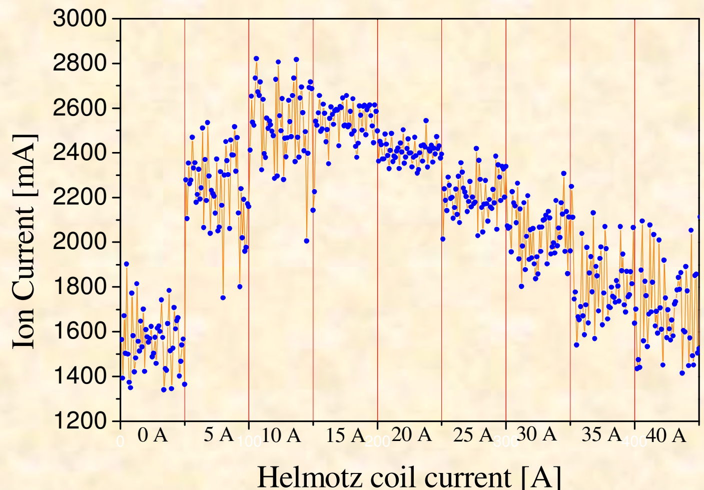


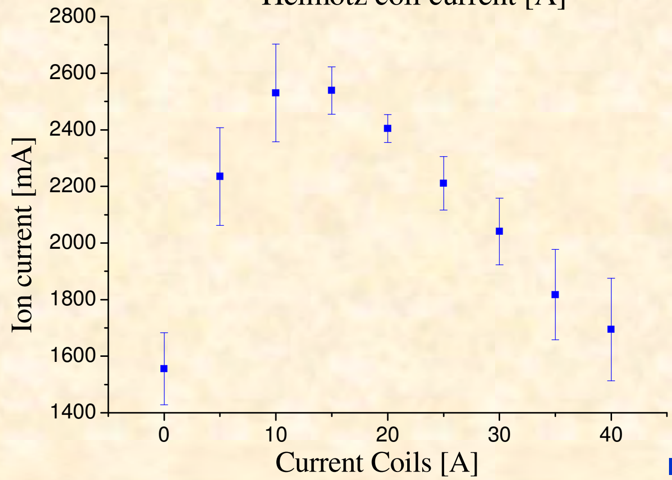
Without filter

With filter

Improvement of the magnetic field configuration for planar arc





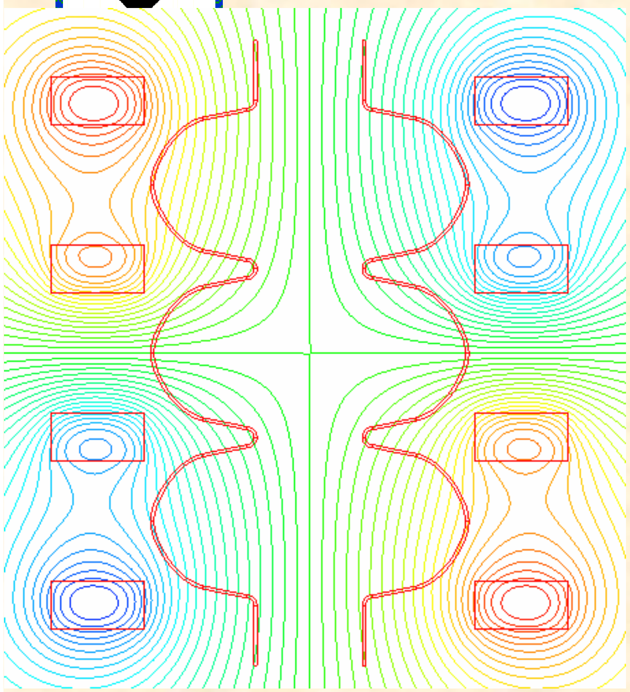


Possible approaches to cavity coating

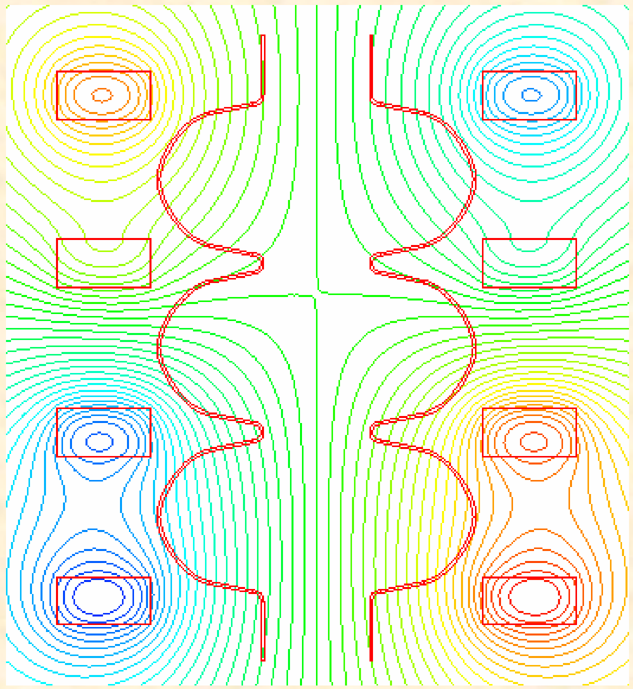
1. Using a magnetic field to introduce the plasma generated by a planar arc source in to the cavity cell
   a) Without a magnetic filter
   b) With a magnetic filter

2. Cylindrical cathode with arc generated in the cavity cell
   (simplest but probably need a macroparticle filter)

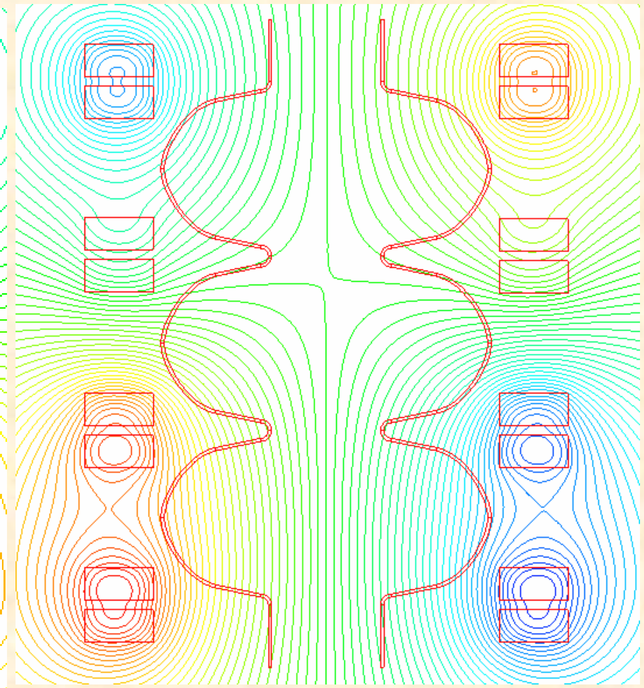
Magnetic field lines study



4 x 2000 A-t

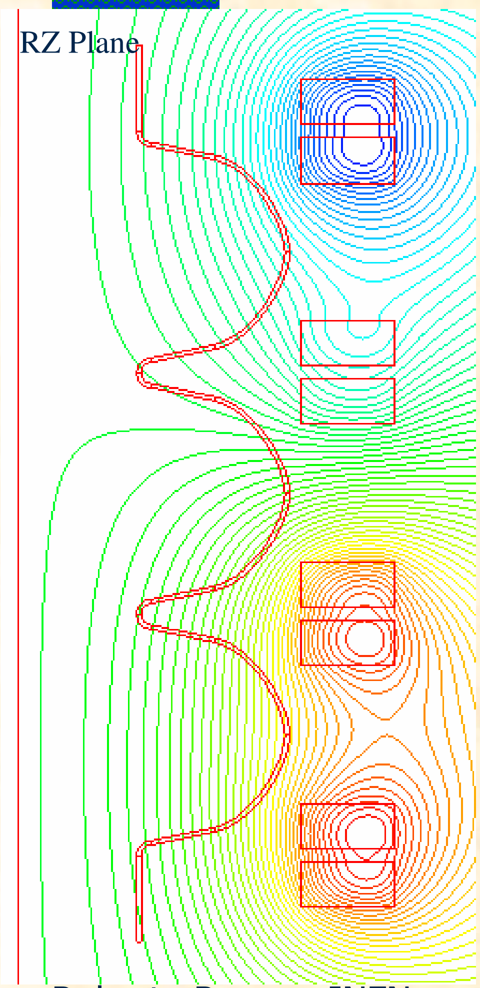


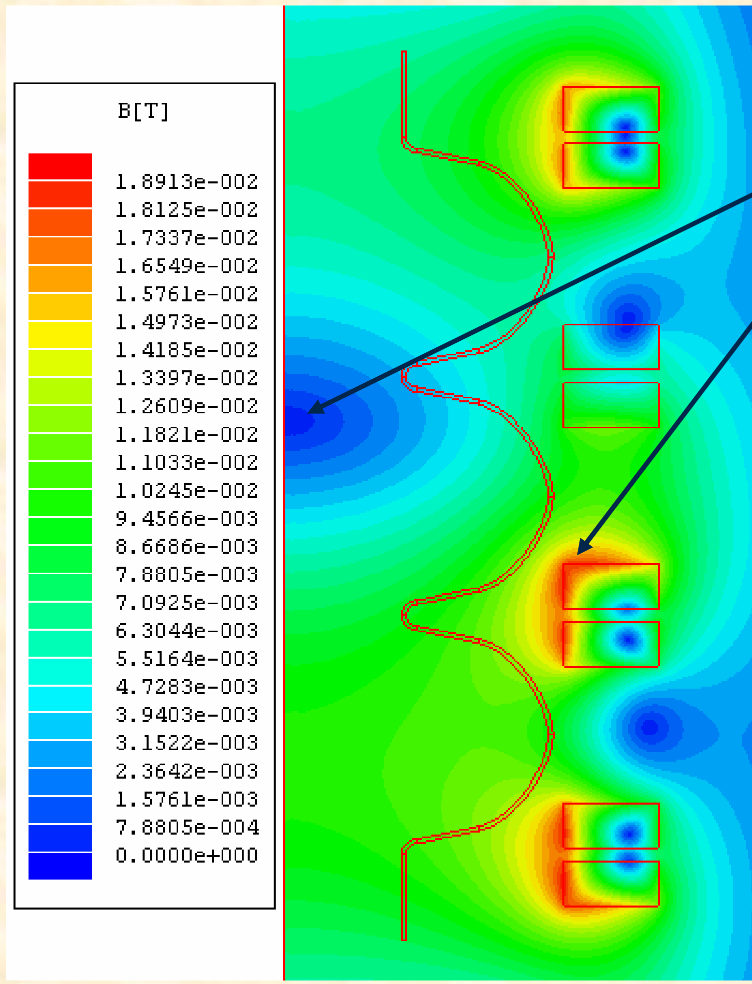
2 x 2000 A-t, 1000 A-t, 2000 A-t



2x900A-t, 2x900, 2x400, 2x900

Magnetic field intensity





Magnetic field gradient

$$\mathbf{F}_{\parallel} = -\mu \frac{\partial B}{\partial \mathbf{s}},$$

2x900A-t, 2x900, 2x400, 2x900

possible set-up for cavities deposition

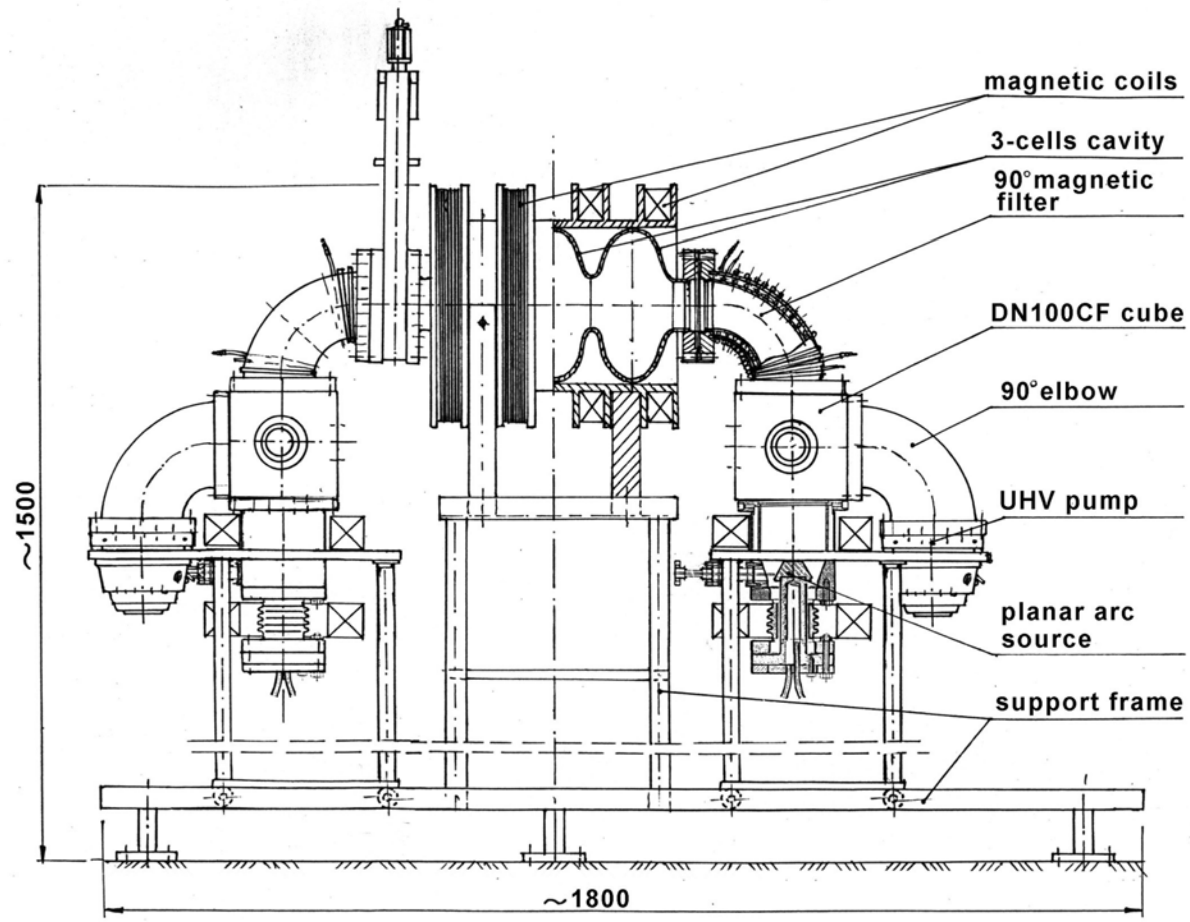
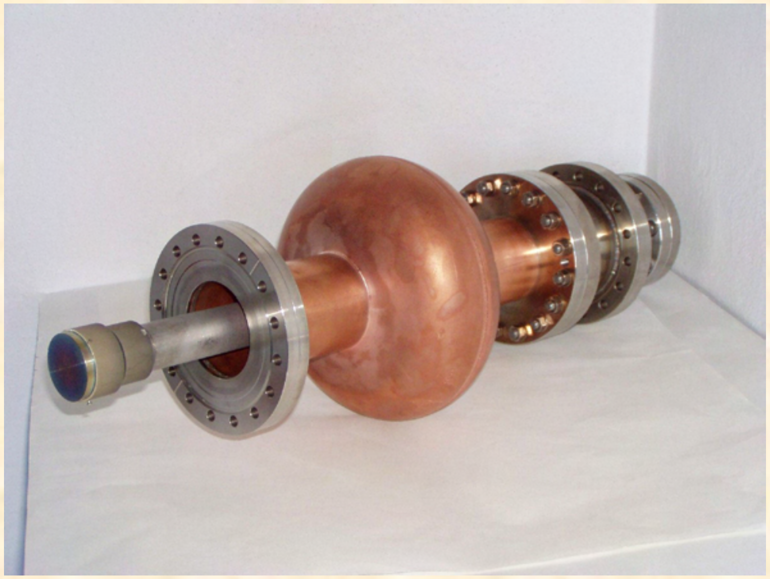


Fig.2 UHV set-up with 90°magnetic filter for one 3- cells cavity.

possible set-up for cavities deposition



System built in Swierk
First tests started in april 2005

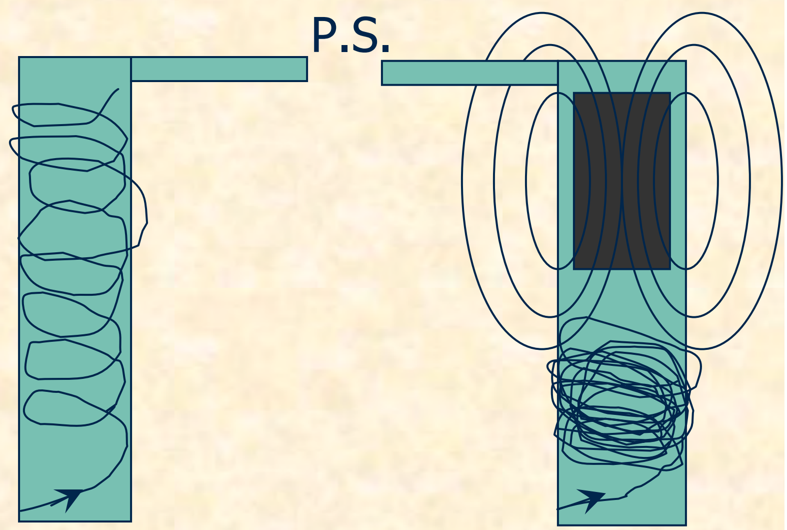
Cylindrical arc: working principle

In linear arc the arc current flowing along the cathode generates a magnetic field that interacts with the arc current. This interaction push the arc spot to move along a spiral around the cilindrical cathode in the up direction.

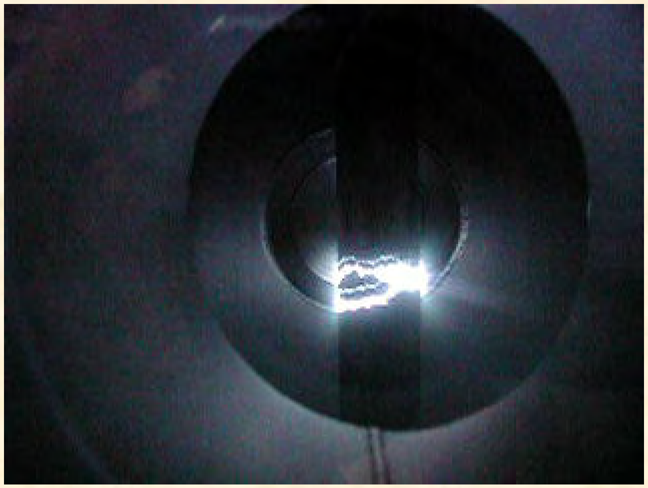
2 mode of operation are possible:

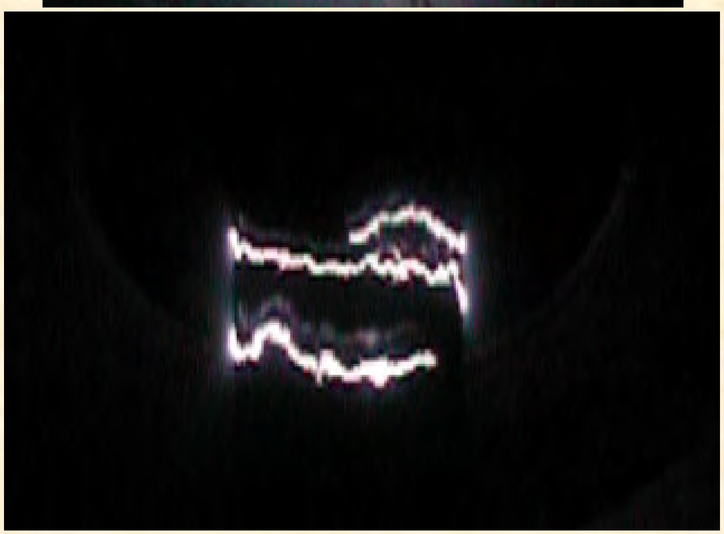
Arc is generated from the bottom part of the cathode and stops on the upper floating potential electrode**

A strong permanent magnet "reflects" the arc spot, confining the movement of the arc in the region below the magnet.



Arc spot motion on linear arc





Speed of the arc hot spot is about 3 m/s.
In this configuration we should speak about "cilyndrical" arc.
Since there are no edges on the cathode surface the arc is more stable even at I_{arc} about 50A

Summary

- UHV planar arc was designed, realized and characterized
- Superconducting thin Nb films with bulk material properties have been obtained (to be verified in RF conditions)
- filtered UHV planar arc has been put in to operation and partially characterize
- New UHV filtered system have been designed and commissioned
- Linear cylindrical UHV arc has been put in to operation
- System to deposit cavities is under study using stainless steel cavities (also dummy copper cavities in Poland)

Future plans

- Pulsed Arc
- Use Pulsed high voltage bias (PIII&D)
- Niobium Nitrides deposition (already started)
- Implement discharge diagnostic system
- Cavity deposition (early 2006)