EUCARD^2 ; Sub-task 12.5.1

Pb photocathode deposition for improved performance of SRF guns

status in March 2015

Recent achievements in cathodic arc deposited thin film Pb photocathodes flattening

R. Nietubyc and J. Lorkiewicz for thin-layer Pb cathode collaboration:

J. Sekutowicz (DESY), D. Kostin (DESY), M. Barlak, A. Kosińska, R. Barday (HZB), R. Xiang, J. Teichert (HZDR), R. Mirowski, W. Grabowski, M. Frelek, W. Pawlak, Ł. Kurpaska, T. Sworobowicz, J. Witkowski

Contents

Workpackage: WP12 Innovative RF technologies

Task: WP12.5 Photocathodes

Pb photocathode deposition for improved performance of SRF guns

deposition improvement, post-deposition treatment, Q and QE measurements

Milestone

MS80 Demonstrated operation of improved deposition system

M30

Report on samples characterisation NCBJ

Deliverables

D12.8 Optimised procedure for microdorplets flattening with an UV laser

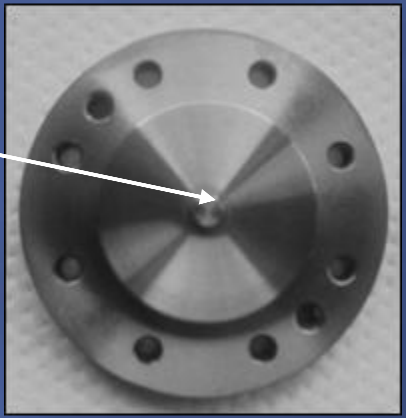
M36

Report NCBJ

D12.9 Pb/Nb plug photocathodes measurements and characterization.

M42

Report HZDR (+DESY + NCBJ)

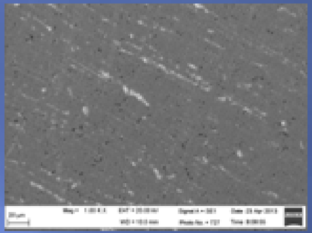


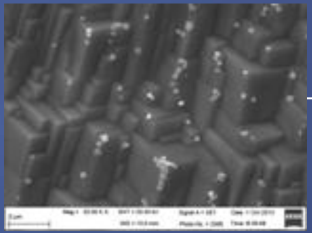
Approach

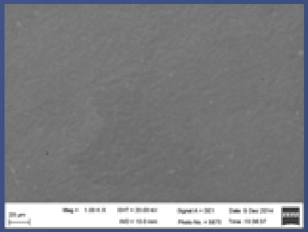
To improve Pb photocathode preparation

pre-deposition Nb substrate preparation

polishing → BCP → EP

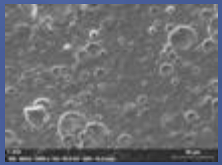




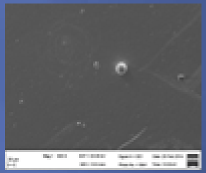


Deposition system reconstruction to find better compromise between thickness and low micro-droplets population:

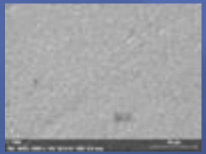
- UHV non-filtered arc



- UHV filtered arc



- Evaporation



Post–deposition flattening:

plasma ion pulses irradiation

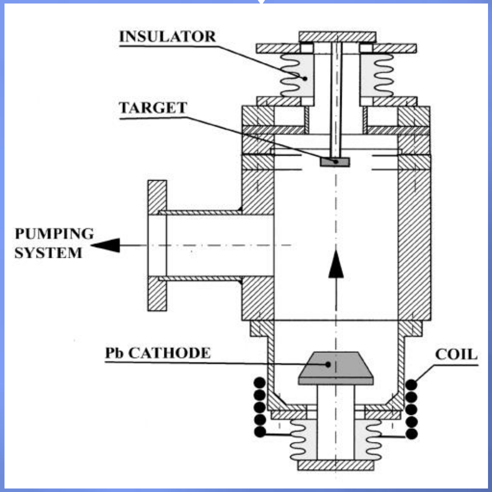
laser irradiation

annealing

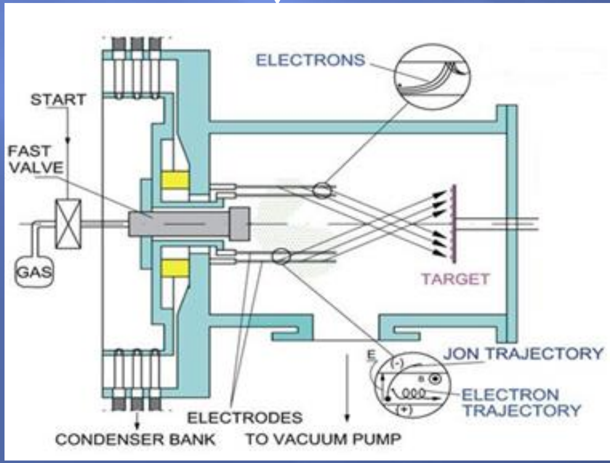
MS 80

D12.8

Reminder:
Non-filtered UHV deposition + smoothing by pulsed plasma ion irradiation



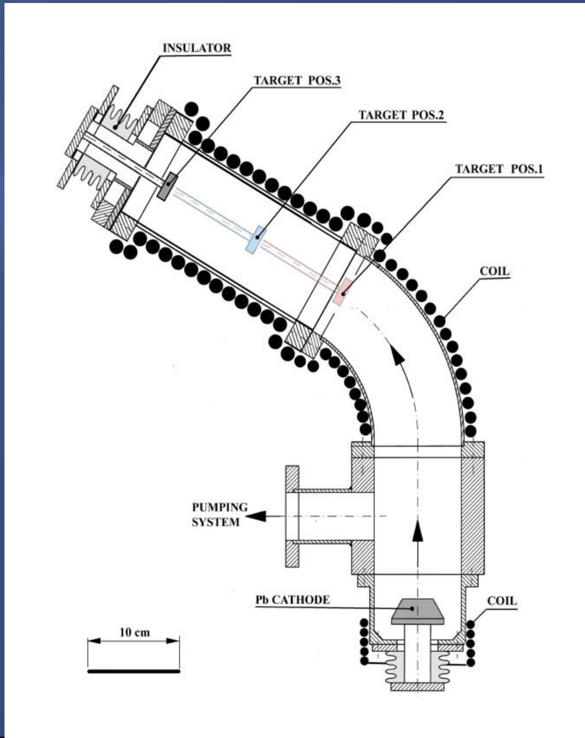
straight UHV arc coating device



rod plasma injector for melting and crystallizing of a lead layer

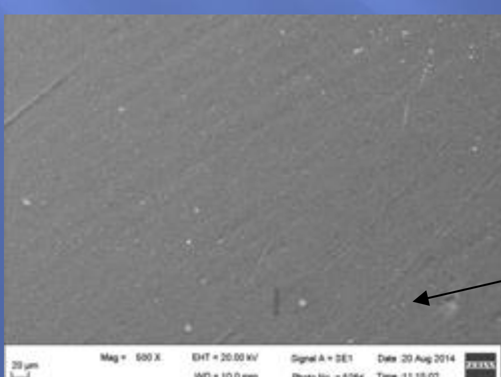
…vs…filtered UHV coating

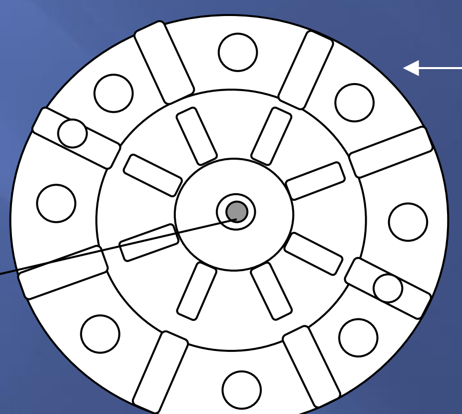
curved lead plasma stream designed to intercept droplets on walls



Alternative deposition method of thin-layer lead photocathodes on niobium - evaporation deposition

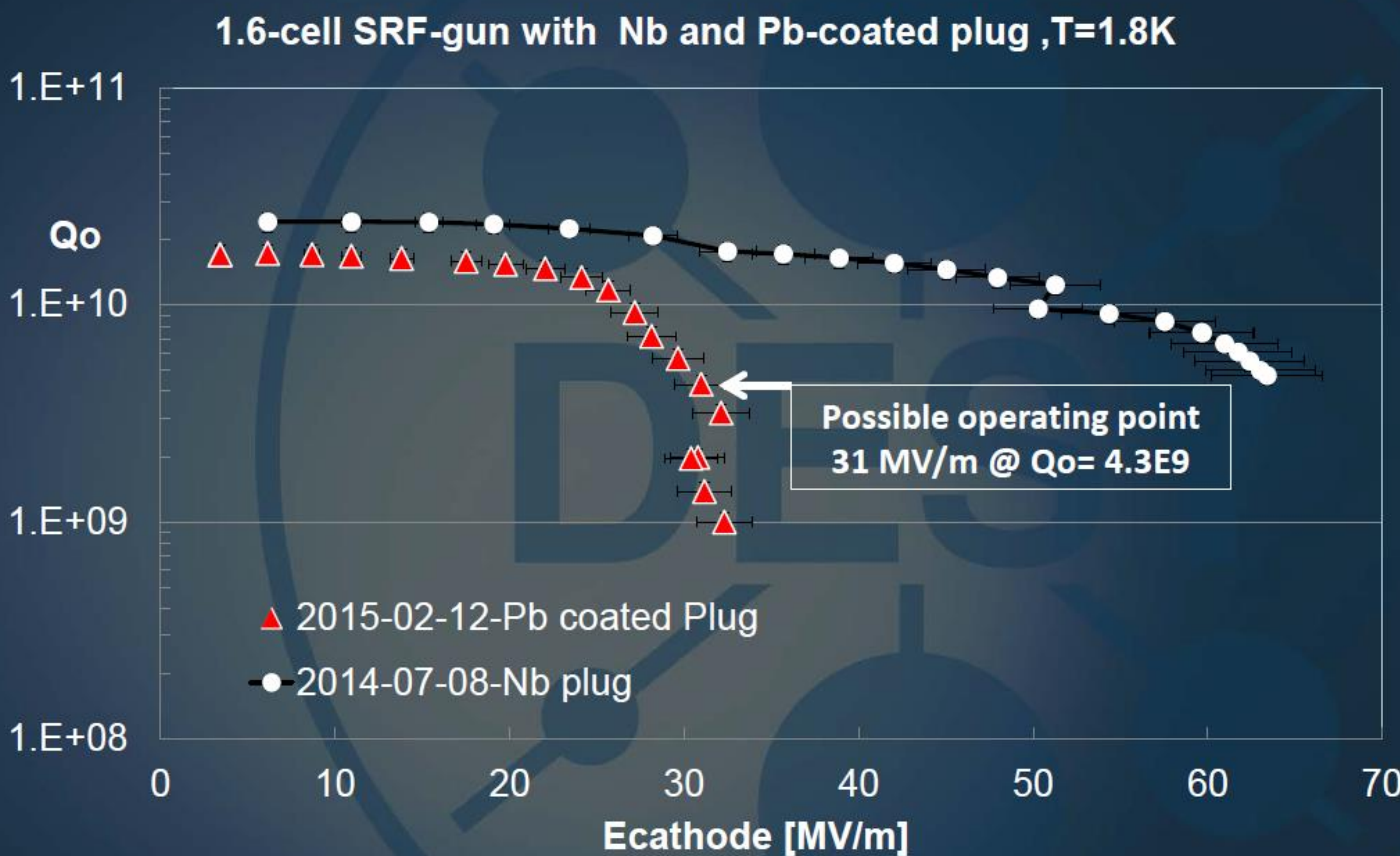
Apart from UHV lead deposition a series of thin lead layer depositions by evaporation were performed on glass or niobium samples. Evaporation from liquified (by resistive or e-beam heating) Pb at a rate of 60 nm/min resulted in continuous layers with small, regular, hemispherical extrusions (which might result from degassing) sized <5 μm as confirmed by SEM observation.



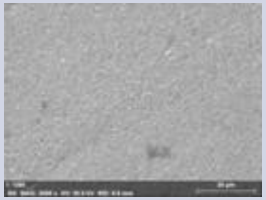
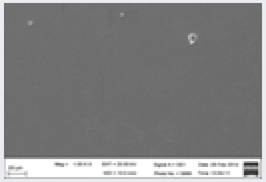
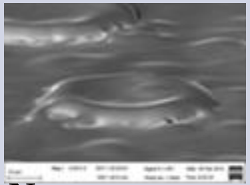


A test plug mounted into a back wall of a hybrid Nb-Pb, sc photoinjector was evaporated in its centre with 2μm thick Pb layer. RF quality tests of the injector are underway at DESY

SRF-gun; Status on February 12th, 2015



Comparison of morphology of thin (2 μm) lead layers reached by different deposition methods

Coating method	Deposition rate	C, O and N contents (wt %) EDS results	Pb layers' morphology and continuity; SEM observations
Evaporation	60 nm/min	Pb ≈ 90 % C ≈ 3 % O ≈ 3 % N ≈ 2 %	 **Semi-spherical extrusions of diameters < 5 μm density <50mm^{-2} ,**
UHV filtered arc deposition	200 nm/min	Pb ≈ 93 % C ≈ 2 % O ≈ 1 %	 **Spherical extrusions of diam. up to 40 μm density <50mm^{-2} ,**
UHV non-filtered arc deposition + remelting in pulsed plasma ions	3000 nm/min.	Pb ≈ 94 % C ≈ 2 % O ≈ 1 %	  **Numerous massive craters can be flattened at a cost of layer perforation and discontinuity**

To avoid problems with lead layer perforation during layer melting the starting layer thickness must match the ion pulse fluency and the procedure has to be based on ……

Heat transfer calculations

The aim: was to evaluate how tick Pb layer can be melted by the plasma pulses available at RPI Ibis 1.5 J/cm^2 , 1 μs

Method: 2D FEM calculation solving the heat transfer equation:

Time dependent measurements

Assumptions:

•C_v depends on temperature and the state of matter

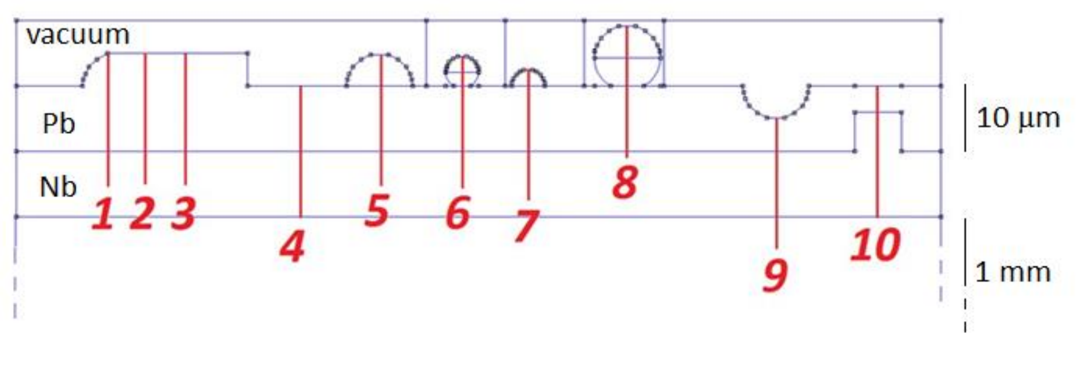
•Energy is deposited in the 10 nm thick surface layer

•Melting and vaporisation were accounted by assuming $C_v = \infty$ for the time needed to accumulate $\Delta Q = dm * c_L$

• Pb: T_m=600 K, T_b=2200 K ,

•Sample in air p=10^{-6} bar

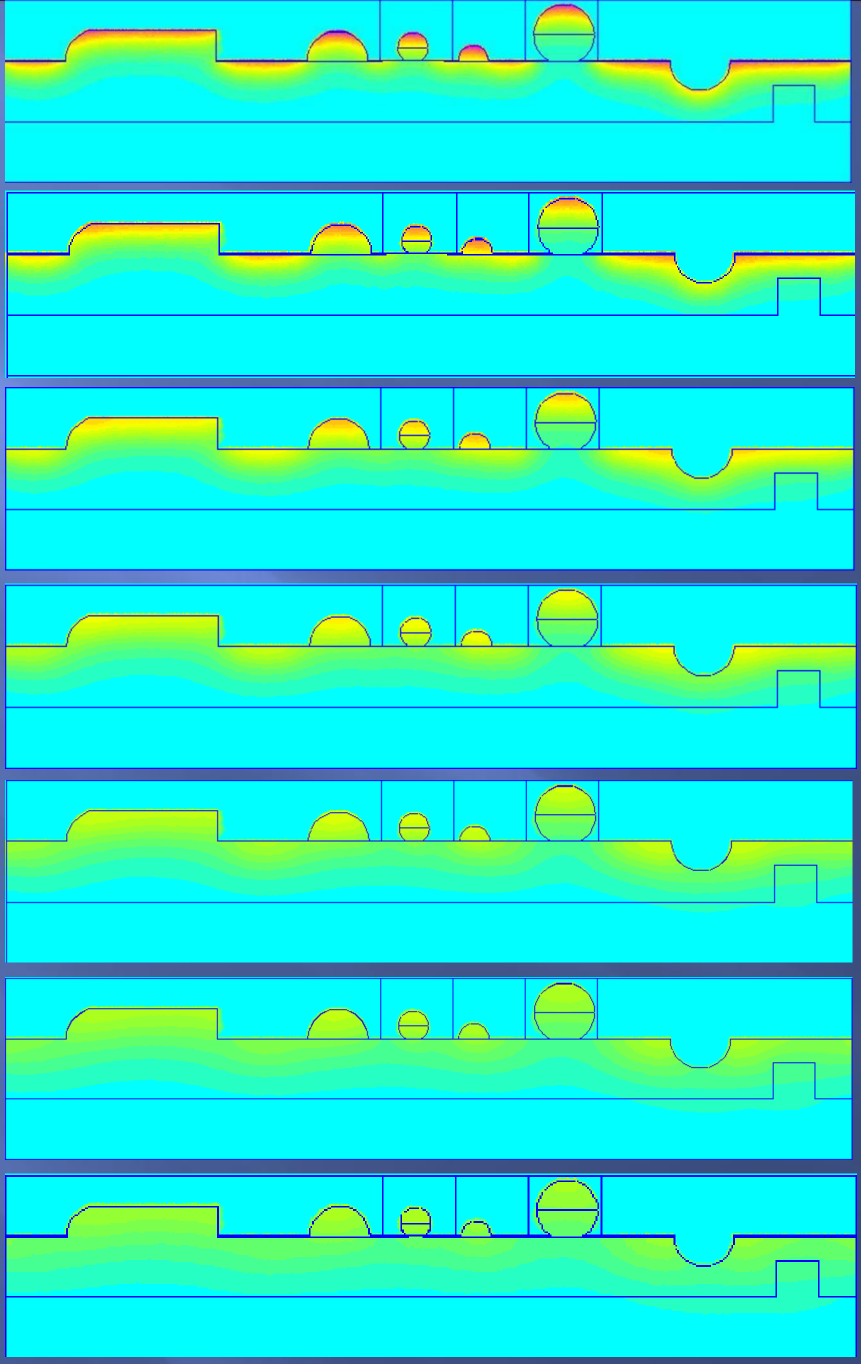
•Morphology



R. Nietubyć et al, NCBJ,
DESY, Apr. 2015

Results

Movie



1.0 µs pulse end

1.1 µs

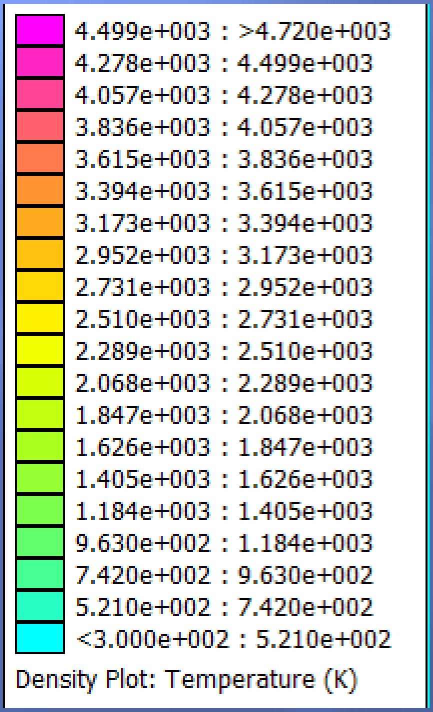
1.3 µs

1.6 µs

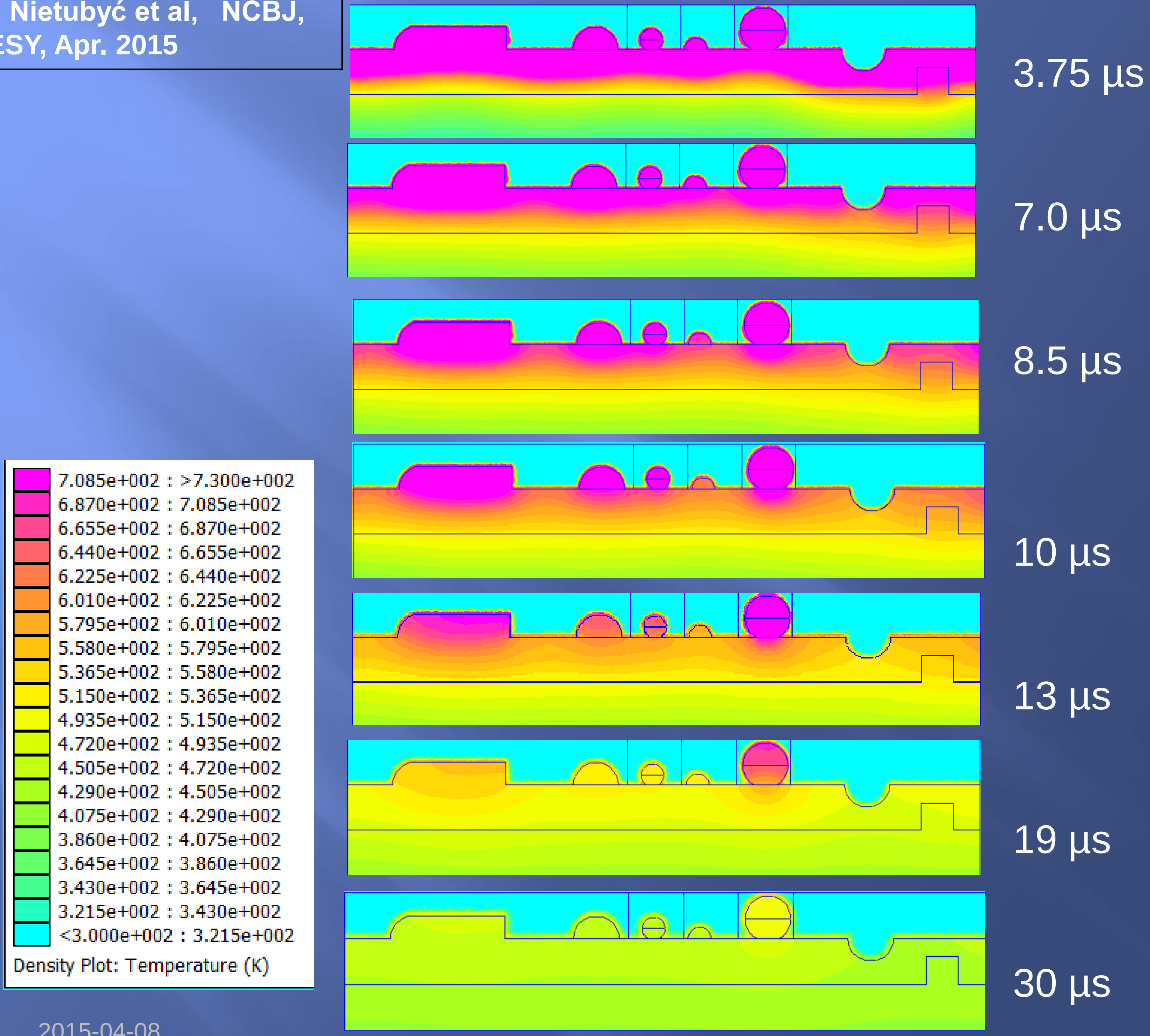
2.0 µs

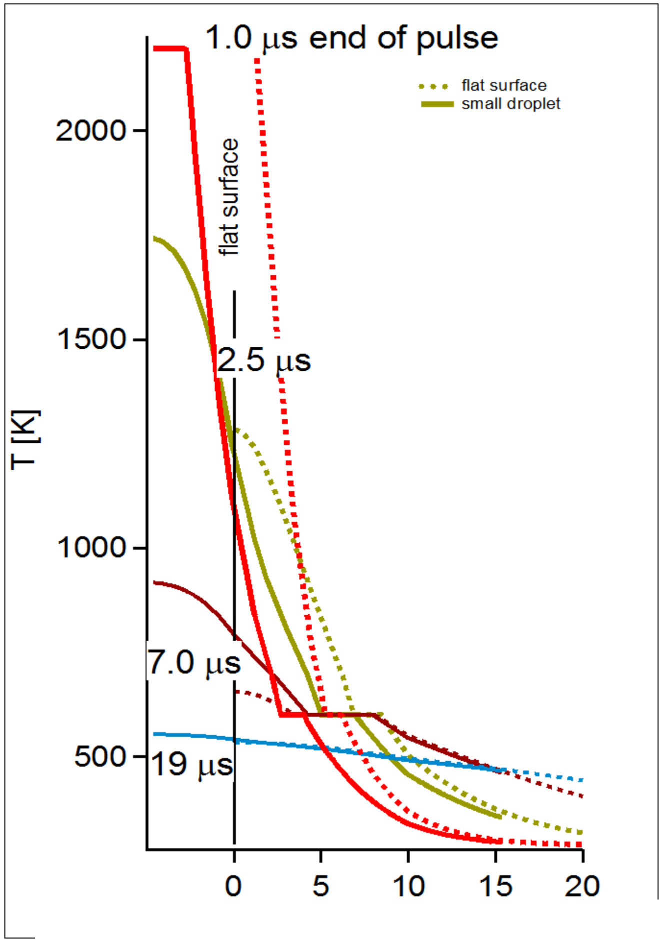
2.5 µs

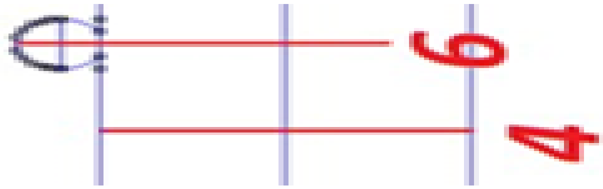
3.0 µs

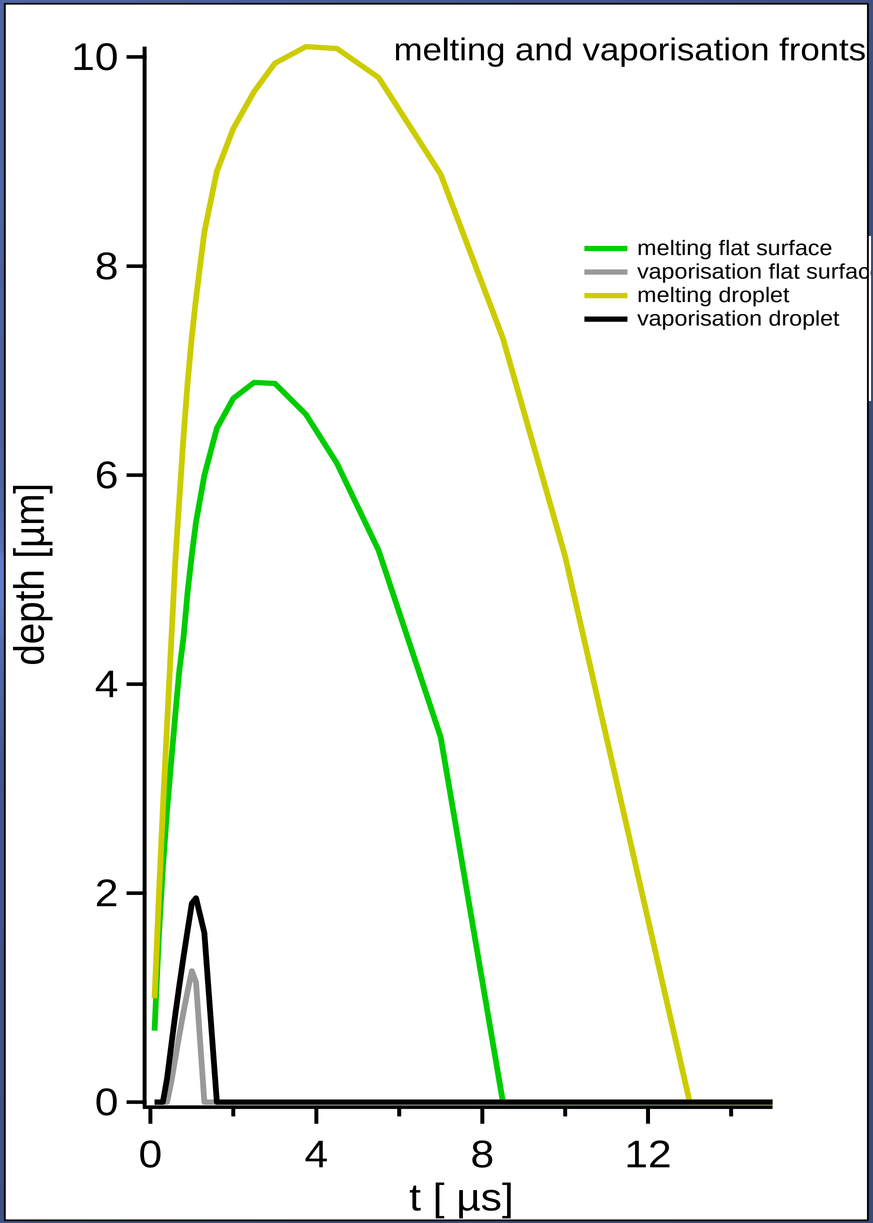


R. Nietubyć et al, NCBJ,
DESY, Apr. 2015




1.0 µs end of pulse
flat surface
small droplet
flat surface
2.5 µs
7.0 µs
19 µs
T [K]
2000
1500
1000
500
0
5
10
15
20


6
4

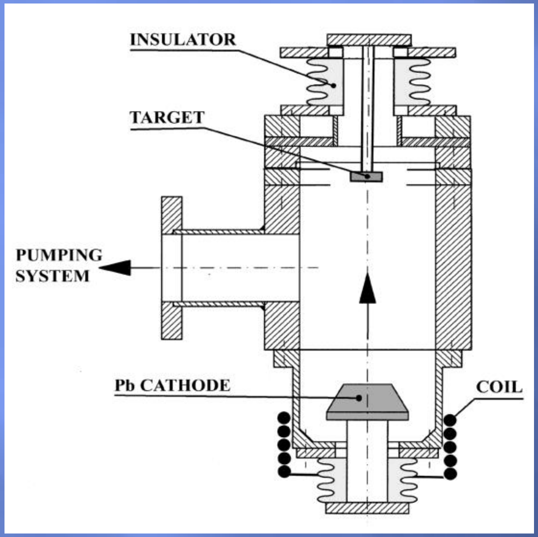

melting and vaporisation fronts
melting flat surface
vaporisation flat surfac
melting droplet
vaporisation droplet
depth [µm]
10
8
6
4
2
0
0
4
8
12
t [µs]

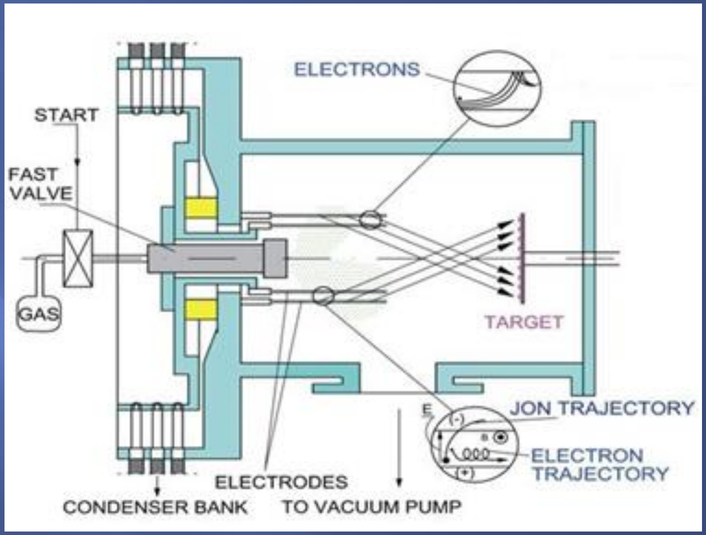
An RPI pulse 1.5 J/cm^2 , 1 μs melts 7μm of Pb layer

The layer remains in liquid state, dependently on thickness, approximately up to 8 μs at flat areas and 12 at the droplets, which is the time enough long to enable smearing and flattening the droplets

Practical flattening of ≈ 10μm thick Pb layers on nobium – treating with 1 μs argon plasma ion pulses

UHV non-filtered arc coating + treating with pulsed plasma ions





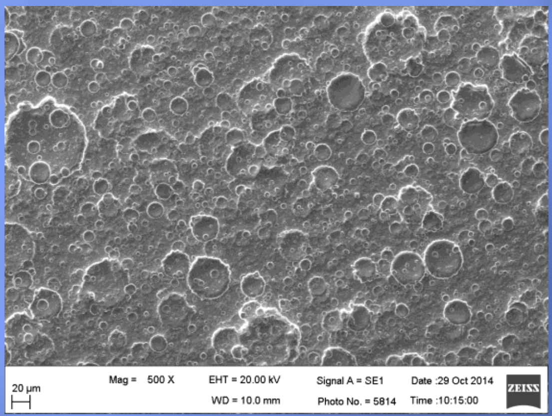
Lead coating up to more than 10 μm followed by layer treatment with 1μs long argon ion pulses in a rod plasma injector at NCBJ. The flattening process was supported with detailed 2D computations of pulsed heat flow through a lead layer on niobium substrate:

- Pb melting depth for a single heat pulse of 1.5 J/cm^2 fluency ≈8 μm,
- solidification time of the top lead layer: 10 to 30 μs
- ablation time of the top lead portion can be computed

Morphology and continuity of lead layers of different thickness on niobium after deposition in non-filtered UHV arc and at different stages of processing by treating with 1µs argon plasma pulses of 1.5 J/cm^2

(2014) 8 µm Pb

after UHV arc deposition

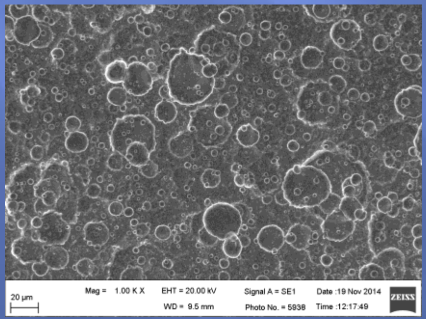


1 ion pulse of 1.8 J/cm^2

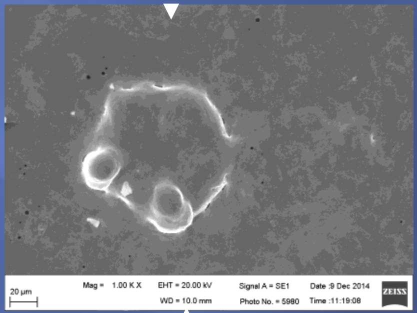
after coating

(2014) 12 µm Pb

after coating

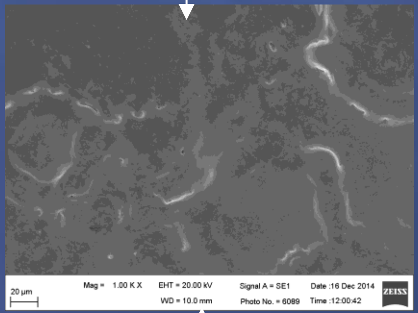


after: 1 ion pulse 1.5 J/cm^2



no perforation

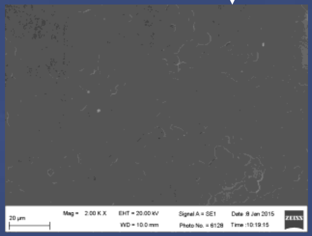
2 ion pulses 1.5 J/cm^2



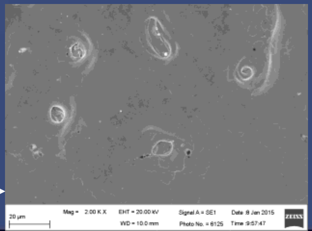
no perforation

3 ion pulses 1,5 J/cm^2

Uniform, recrystallized Pb coating



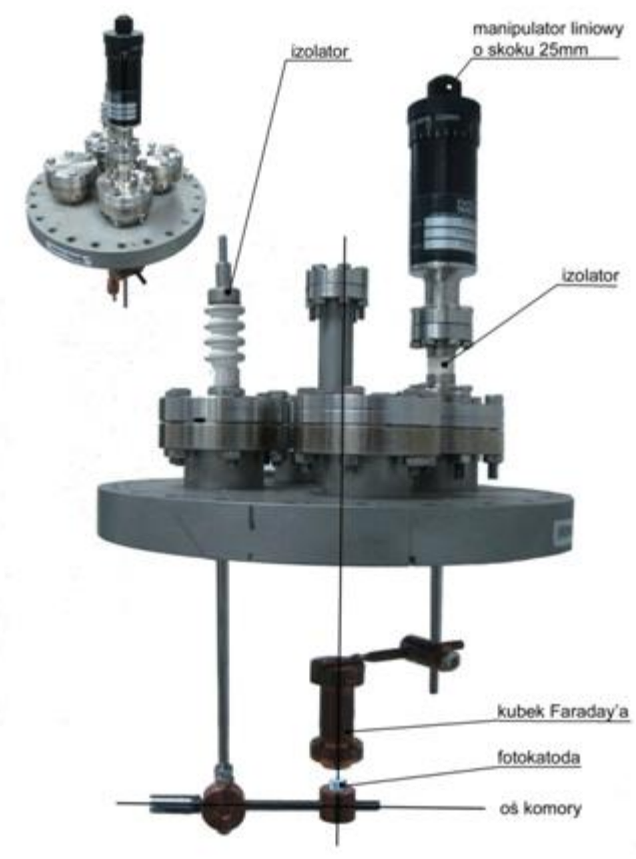
locally perforated area



Tests with 15 µm Pb - underway

Development of instrumentation

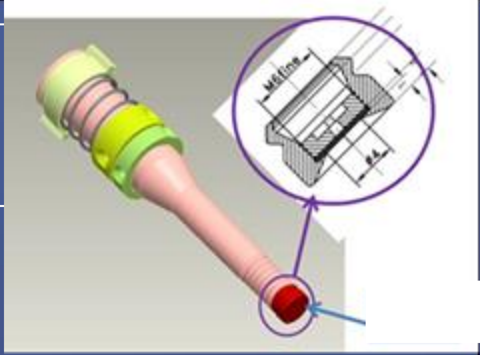
A system for direct measurement of break-down and dark current



RYS.4 System mocowania układu fotokatoda-kubek Faraday'a

Studies of breakdown current were started for variously prepared Pb layers using a dedicated experimental setup consisting of UHV chamber, sub-millimeter precise manipulator and 12 kV, 1 µs pulser. Pb layer samples were mounted in the holder. A copper anode was installed in a manipulator which enabled approach to Pb-Nb cathode as close as 50 µm with accuracy of ± 5 µm. The mean electric field intensity was varied from 30 to 240 MV/m to induce dark current and reveal occurrence of breakdown between the cathode and anode accompanied by strong increase in dark current.

HZDR



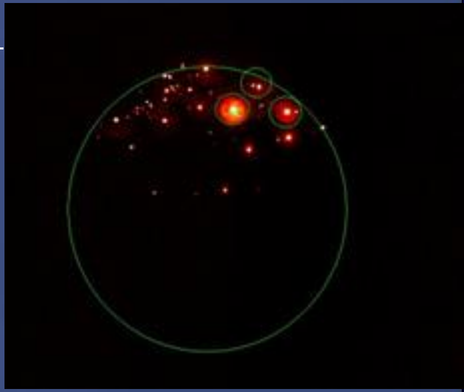
Current density from a thin layer Nb-Pb cathodes reached by different deposition methods

Cathode preparation	E_{max} (MV/m)	I_{max} (nA/cm^2)	E_{min} (MVm)	I_{min} (nA/cm^2)
UHV filtered arc	200	1600	30	140
UHV filtered arc + conditioning	200	400	30	106
UHV non-filtered arc	200	294	30	18
Evaporated Pb layer	200	190	30	30
Evaporated conditioning	200	200	30	28

R. Barday HZB, Field Emission Lab. ;

Nb-Pb emitter surface image at

E=18.5 MV/m

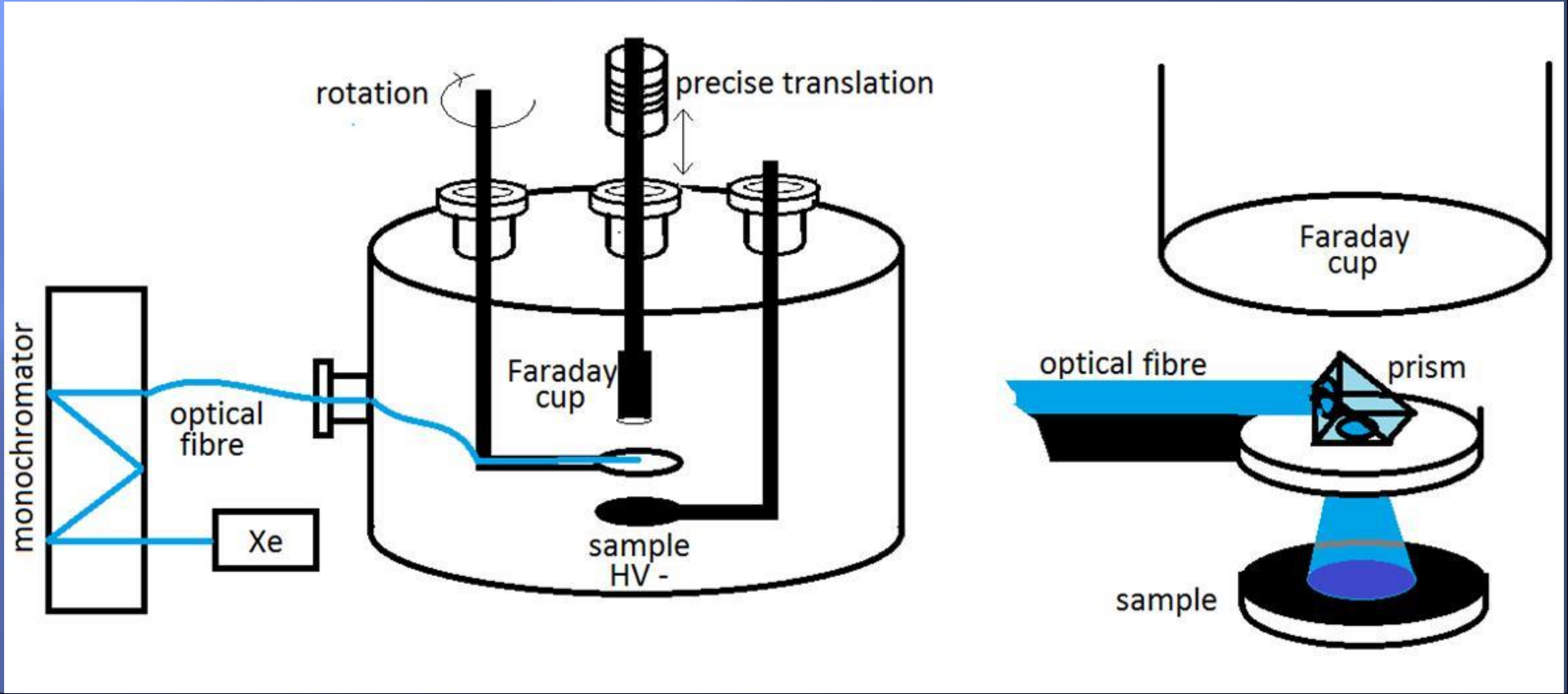


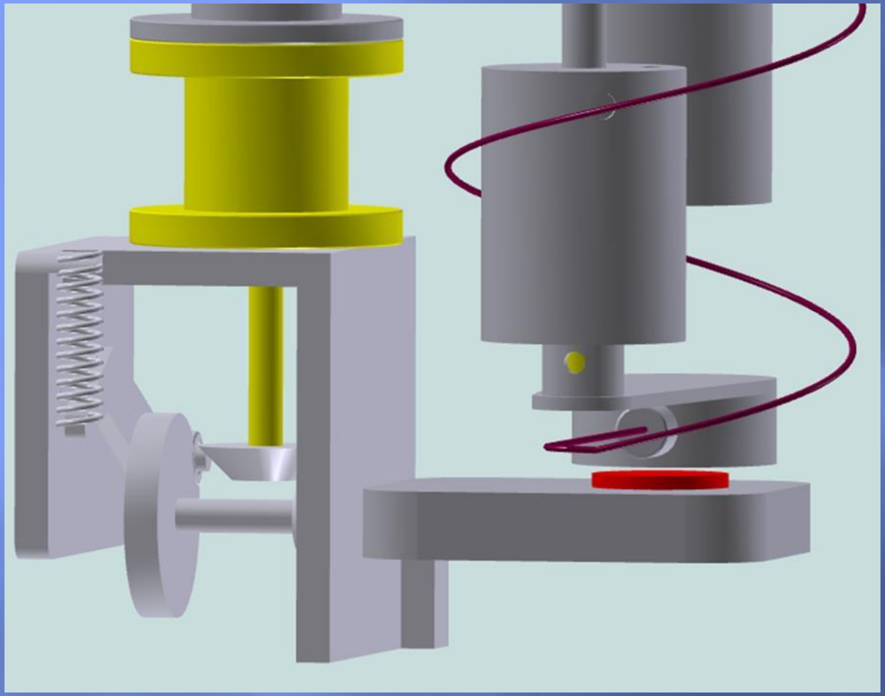
Field enhancement coef: β=136

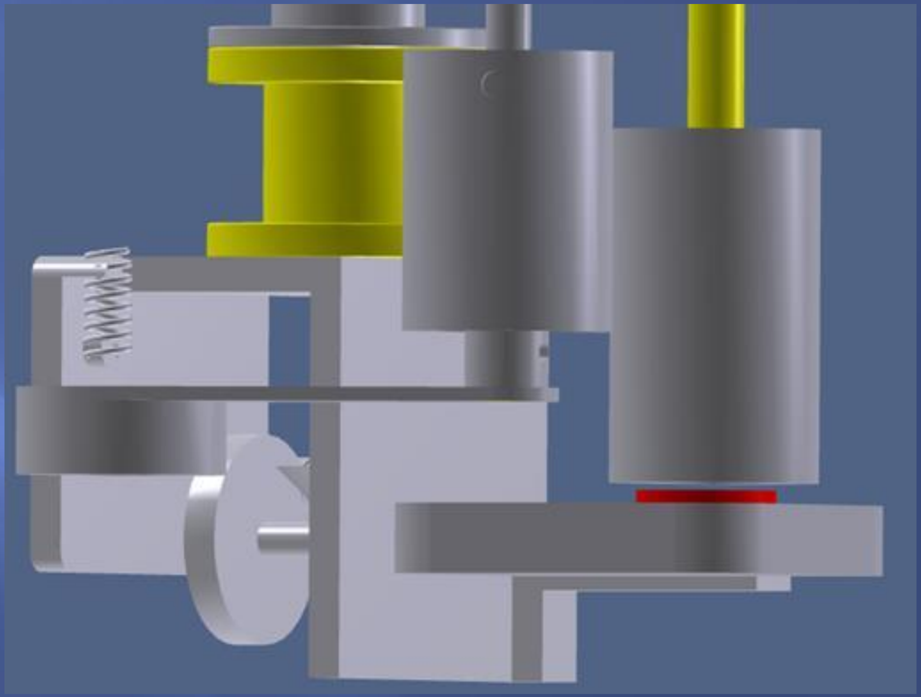
Conditioning effect; !

Beakdown and photo – current measurement setup

- Xenon lamp 150 W
- wavelength range 200 – 1000 nm
- Czerny – Turner monochromator with
- diffraction grating 1200 lines/mm optimised for 250 nm
- calibration photodiode
- picoampermeter 10 pA – 1 μm







Designed by MEASLINE, Janusz Budzioch

QE measurement with fiber and prisme on the anode

Sparc current measurement with the Farday cup

Thank you!