Status of preparation at NCBJ Świerk of lead layer photocathodes for SRF injectors
(status in Nov. 2015)

J. Lorkiewicz and R. Nietubyć for Pb layer cathodes collaboration

Narodowe Centrum Badań Jądrowych Świerk

National Centre for Nuclear Research

Contents:

1. **Reminder: the concept of Nb-Pb hybrid SFR photoinjector**
2. **Eucard committments as to photocatodes preparation**
3. **Selection of deposition procedures: dark current measurement and RF quality tests**
4. **Direct UHV arc coating combined with pulsed plasma ion irradiation: modelling and computation of pulsed heat flow through a lead layer, optimization of processing parameters**
5. **Development of instrumentation.**

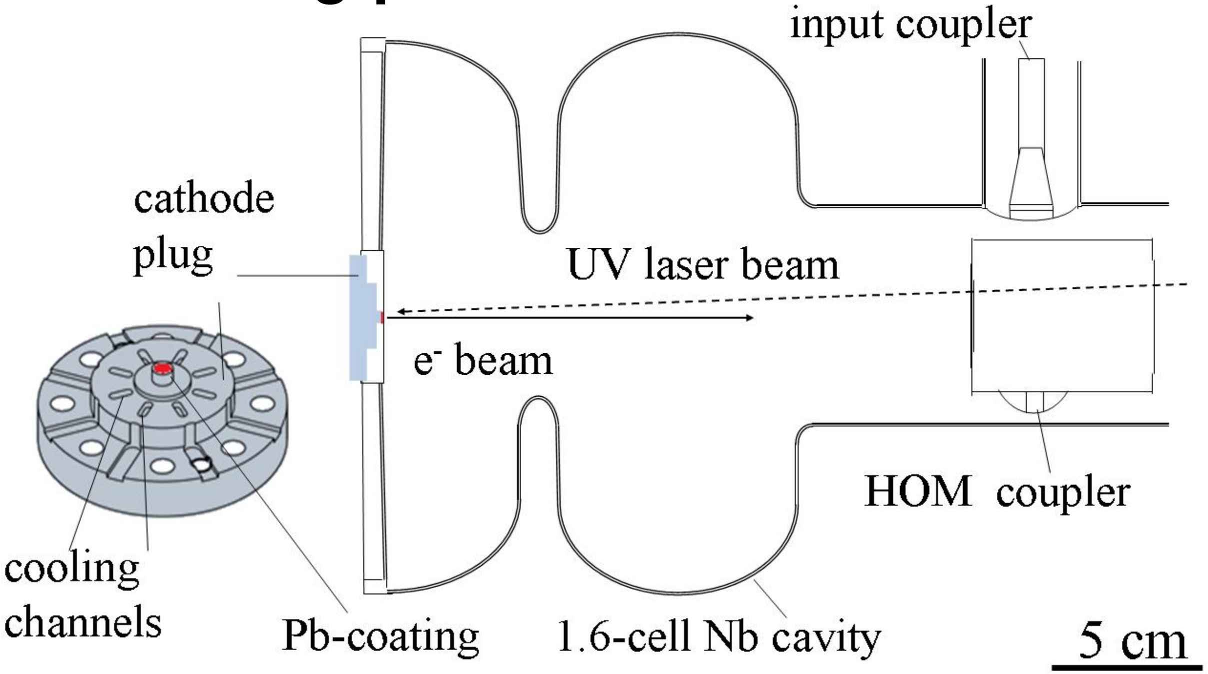
Fully superconducting TESLA/XFEL - type SRF e$^-$ injector

1 mA-class electron foto-injector;

ε_n < 1 μrad;

Q ≈ 1 nC,

CW and long-pulsed envisioned



Concept of a Nb-Pb hybrid electron injector with a lead layer photocathode on the rear wall of a 1.6-cell, 1.3 GHz niobium cavity. Pb (T_c=7.2 K, B_c≈80 mT) is deposited on an exchangeable niobium „plug" integrated with the cavity. Good photoemission characteristics, low dark current and sufficient adhesion are required which is connected with planar surface and low contents of impurities.

Eucard commitments

Pb photocathode deposition for improved performance of SRF guns - deposition improvement, - post-deposition treatment,   - Q and QE measurements, dark current reduction

Workpackage: WP12 Innovative RF technologies

Task: WP12.5 Photocathodes

Milestone

MS80 Demonstrated operation of improved deposition system
M30
Report on samples characterisation NCBJ → delivered Sept. 2015

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 (+ HZB + DESY + NCBJ)

Collaboration

NCBJ:

R. Nietubyć

J. Lorkiewicz

R. Mirowski

M. Barlak

J. Witkowski

W. Kosińska

W. Grabowski

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HZB:

T. Kamps

R. Barday

…………..

HZR:

J. Teichert

R. Xiang

…………..

DESY:

J. Sekutowicz

D. Kostin

…………..

TJNAF:

P. Kneisel

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BNL:

J. Smedley

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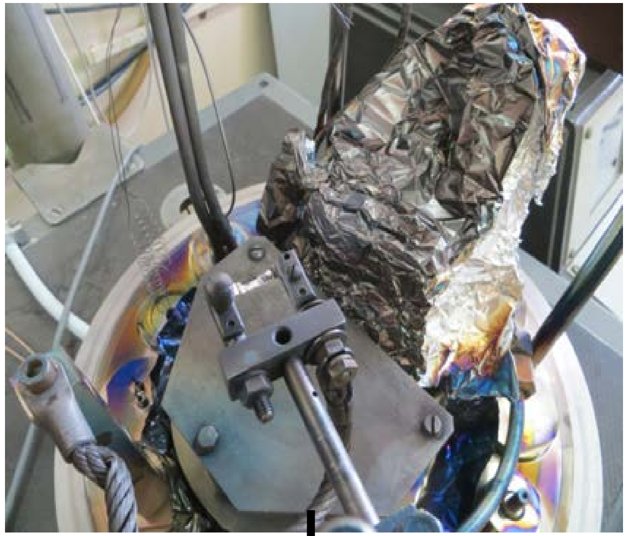
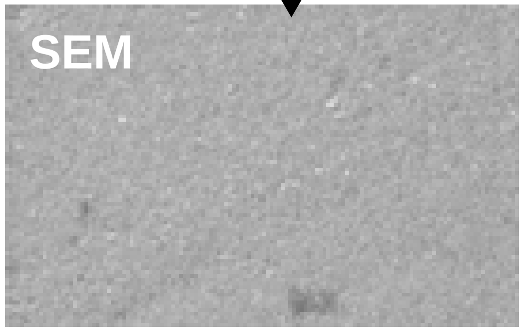
Optimization in lead layers coating and processing to reach uniformity, thickness, reduction of macro-particles at a sufficient thickness and adequate adhesion :

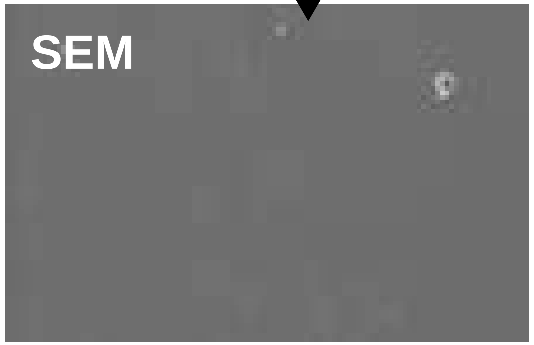
lead coating

(evaporation)

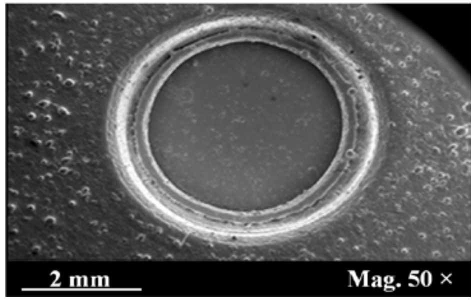




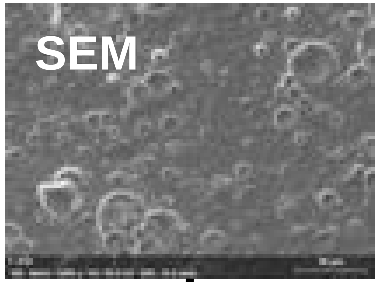
(UHV filtered arc)



(non filtered arc)



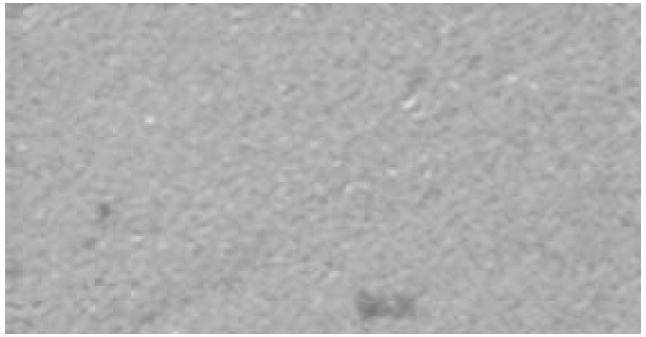
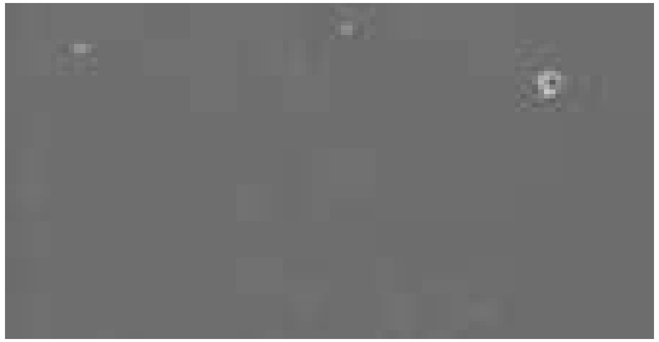
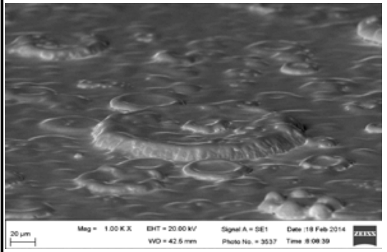
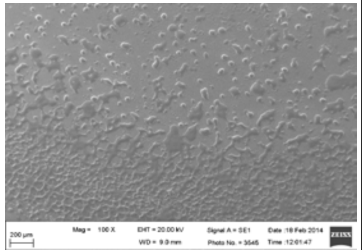
extra surface processing



pulsed plasma ion irradiation

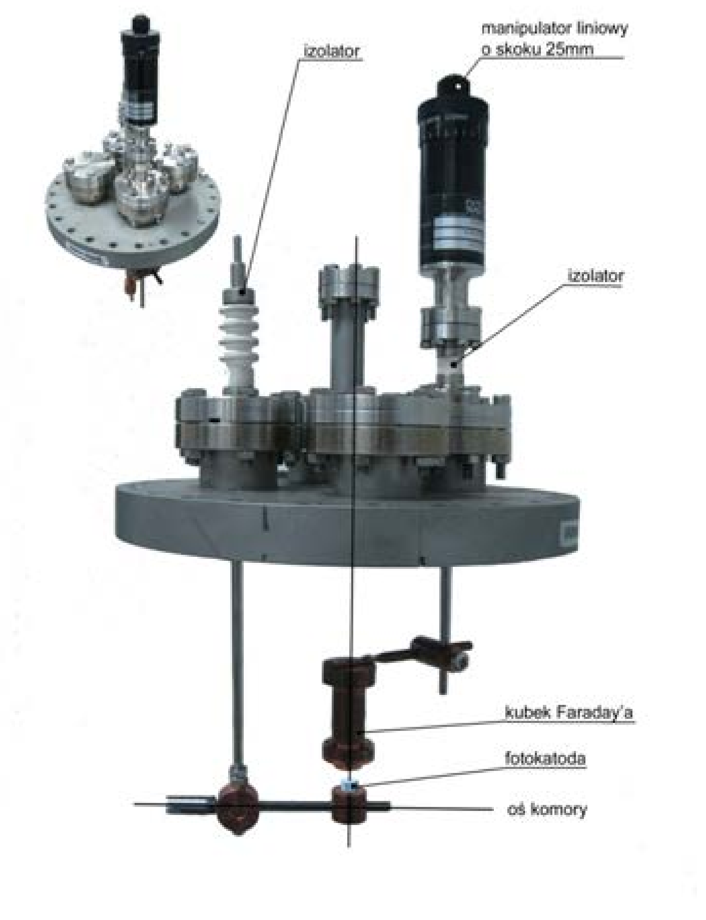
Rod plasma injector

Film surface morphology & EDX results

Coating method	Deposition rate	C, O and N contents (wt %) EDS results	2 µm 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	3000 nm/min.	Pb ≈ 94 % C ≈ 2 % O ≈ 1 %	 	Numerous massive craters can be flattened at a cost of layer perforation and discontinuity

Dark current measurements

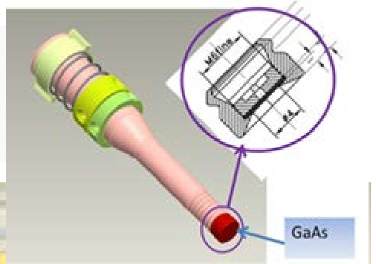
Cathode preparation	E_{max} [MV/m]	I_{max} [nA/cm^2]	E_{min} [MVm]	I_{min} [nA/cm^2]
UHV filtered arc	200	1600	60	283
UHV filtered arc + conditioning	200	412	60	220
UHV non-filtered arc + plasma pulses	200	294	60	22
Evaporated Pb layer	200	390	60	60
Evaporated and coditioned Pb layer	200	210	60	56

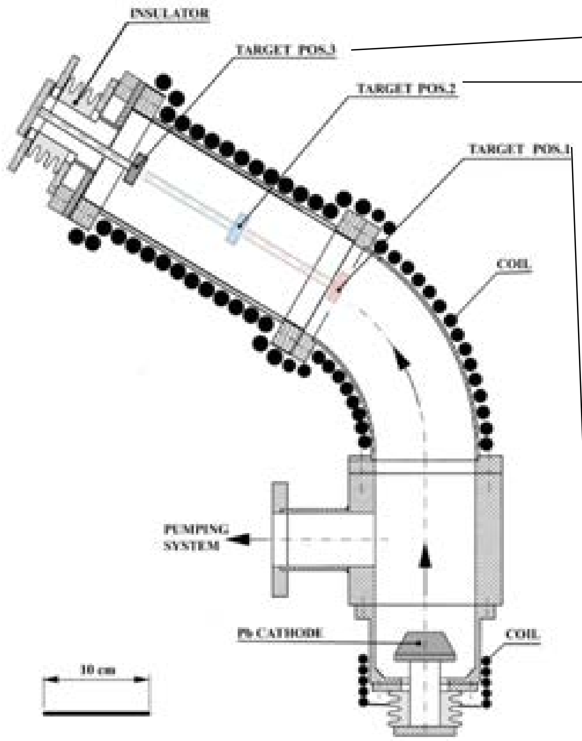


RYS.4 System mocowania układu fotokatoda-kubek Faraday'a

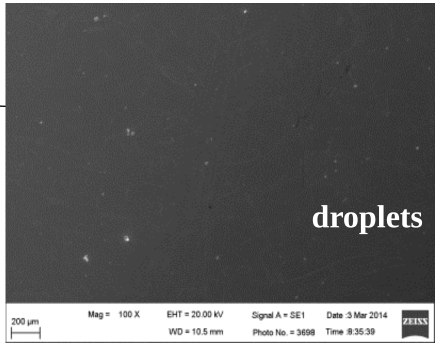
- pulsed dc field in a gap of 100 µm,
- pulse length 1 µs,
- duty factor 0.2%.

Field emission from filtered-arc coated Pb in dc field

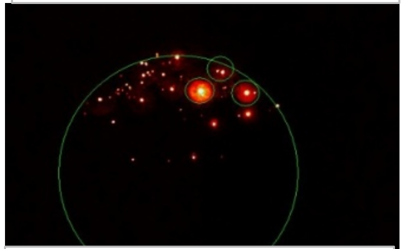




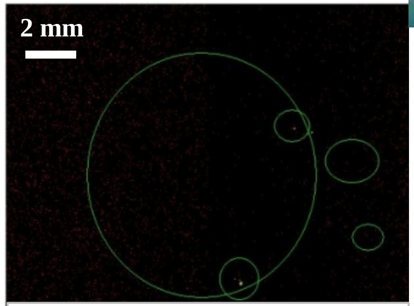
SEM



Field emission mapping



Total dark current 4μA



Total dark current 16 nA

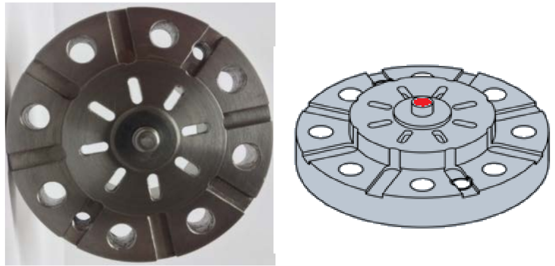
dark current < 50 pA

QE measurements (2e-5 to 1e-4) at HZDR – R. Xiang

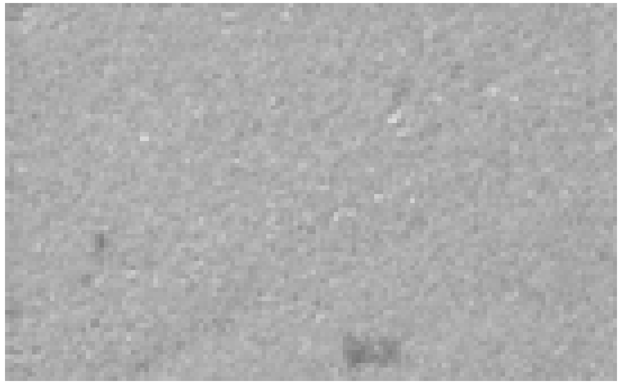
Emitter Surface scanning and mapping at HZB on three Nb-Pb photocathodes lead coated in filtered arc at NCBJ in a 400 µm in electrostatic field up to 25 MV/m.

- \- R. Barday
- results non-reproducible, strongly dependent on the target position and on conditioning

Quality tests of a complete SRF injector with evaporation-coated Pb cathode

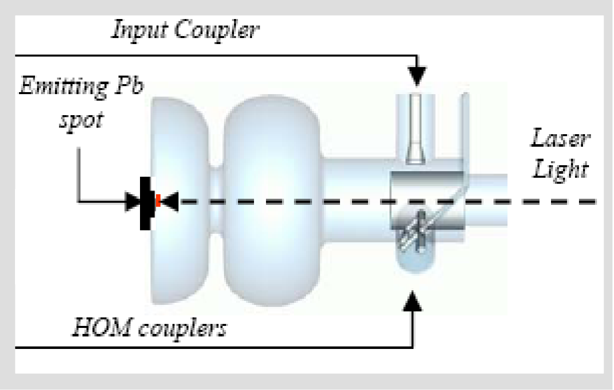


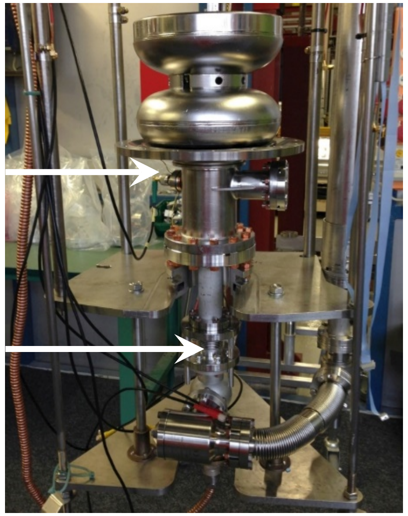
Niobium plug with Pb evaporated on the tip



Evaporated layer, smooth but not adherent and not tight

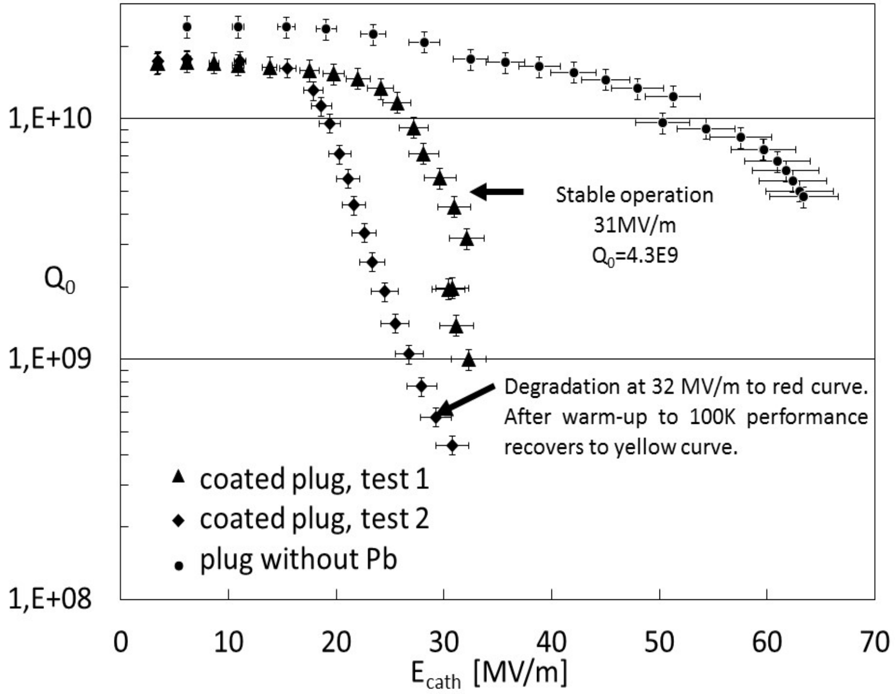
Electron gun with the plug





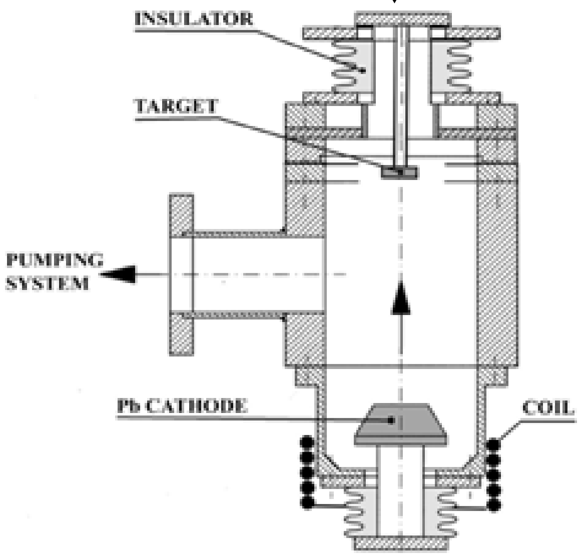
D. Kostin, J. Sekutowicz

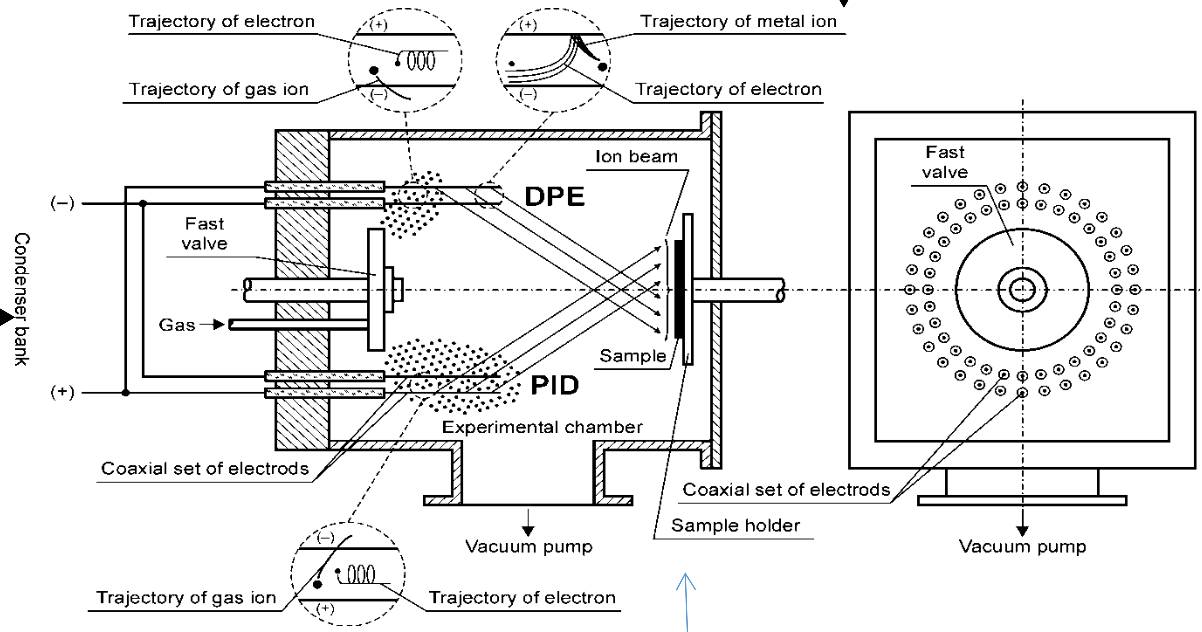
Vertical test stand at DESY



Too weak adhesion of Pb layer – the film non-resistent to HPR

First choice for further development: non-filtered Pb coating + remelting in pulsed plasma ion beam





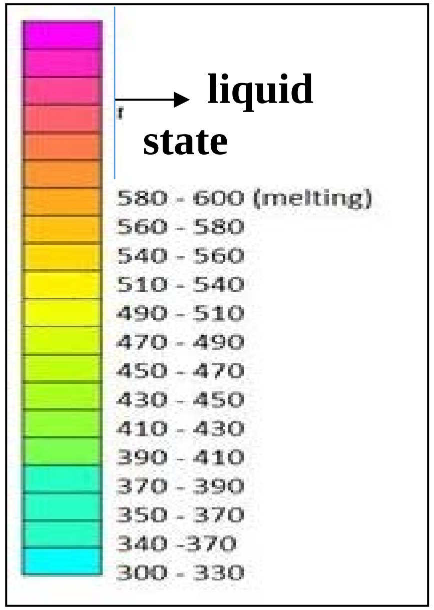
Plasma source: Rod Plasma Injector IBIS

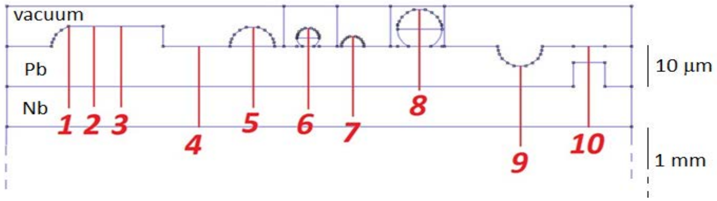
The RPI-IBIS device was equipped with two coaxial electrodes composed of 32 thin metallic rods   placed inside a vacuum chamber, which was pumped out to the background pressure equal to about 10^{-6} Pa. Before each discharge the inter-electrode gap was filled up with some amount of Ar   injected by a fast acting valve. with a chosen delay advance to the discharge190 µs (pulse implantation doping – PID regime). During the discharge the working gas, after its ionization, was accelerated in the injector and emitted along the z-axis towards Pb/Nb target in a form of an intense plasma-ion stream. The energy spectrum of the ions generated in the rod plasma injector consists of a sharp, gaussian peak which lasts about 1 µs and an energetic tail. The average ion energy within this peak falls between several to several tens keV For Pb film processing a single (out of five) capacitor section, charged up to 25-28 kV was used to initiate discharge. A fluency of a single ion pulse measured by a set of thermocouples reached 1 – 1.8 J/cm^2.

Analysis of thermal evolution within a lead layer on niobium

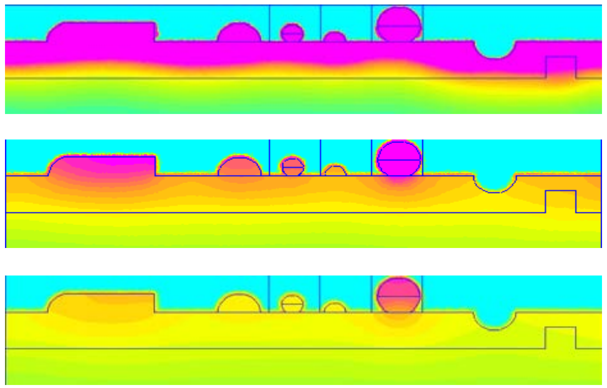
To avoid a lead film destrucion during plasma ion pulse processing which typically results from poor niobium wettability with molten lead, pulsed heat flow through a 10 μm thick Pb layer on Nb was modelled and computed. A numerical heat flow model, proposed by R. Nietubyc in 2014 was further refined so as to reach a better resolution of temperature distribution across a layer. Due to the simplifications assumed the accuracy of calculated results (temperature distribution) is within ± 20%

Assumed lead layer surface profile





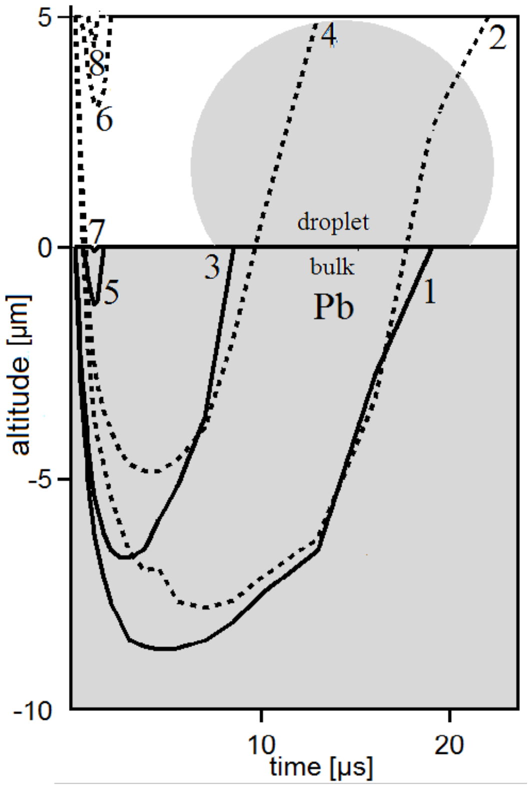
Temperature distribution



4μs

13μs

19μs

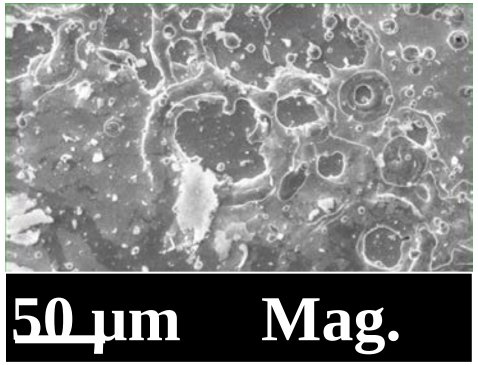


Conclusions:

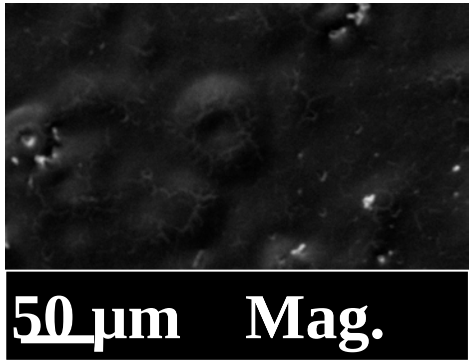
- **At 1.5 J/sqcm bulk Pb is melted down to 9 μm, and under a droplet down to 8 μm, Melting front does not reach Nb-Pb interface.**
- **Extrusions are in liquid state some μm longer than bulk layer**
- **At 1 J/sqcm solidification times amount to half of that at 1.5 J. Bulk ablation rate is negligible**

Practical flattening of non-filtered Pb layers of 10-20 µm with 1µs Ar plasma pulses

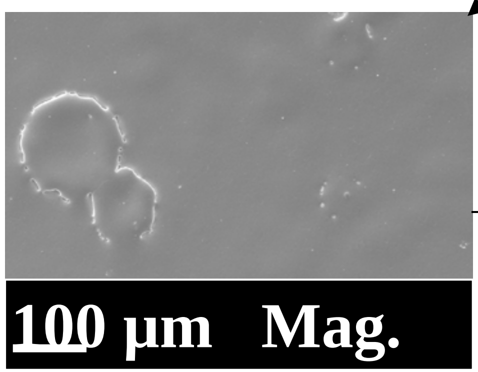
10µm/(1×1.8 J/sqcm)

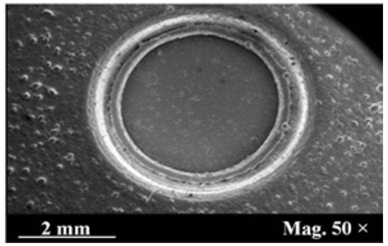


10µm/(10×1 J/sqcm)



10µm/(25×1 J/sqcm)



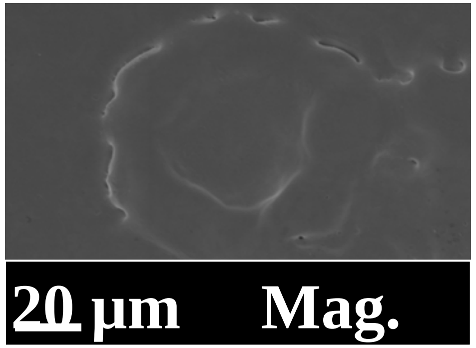


EDX: 3.4 wt% O

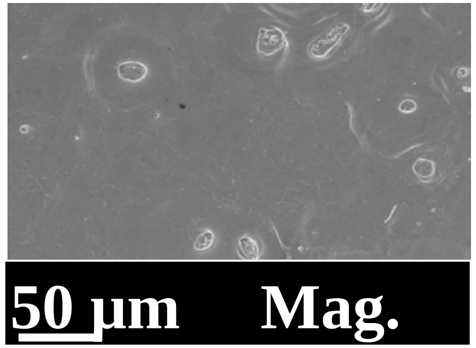
2.4 wt %C

3.4 wt % N

(13µm/2×1.5 J/sqcm)



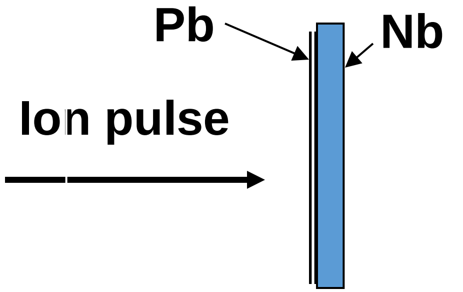
13 µm/ 3 × 1.5 J/sqcm

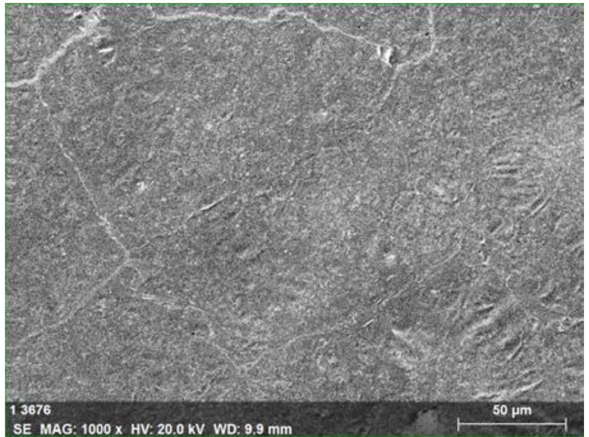


20 µm/ 5 × 1.5 J/sqcm

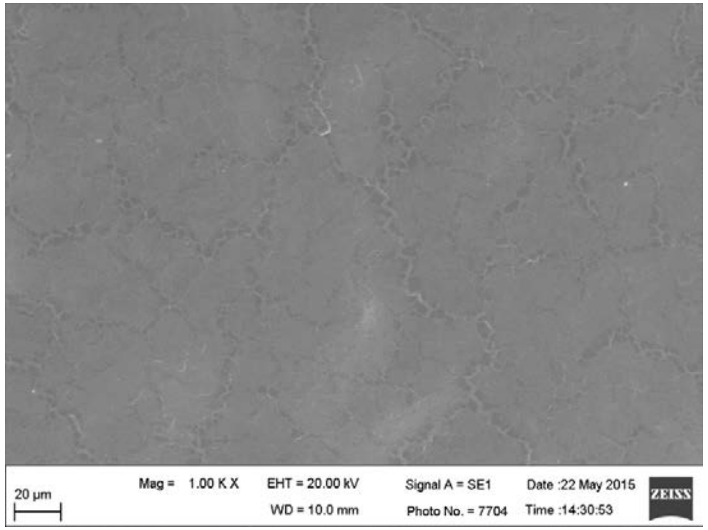
EDX: 1.9 wt% O

2.5 wt %C

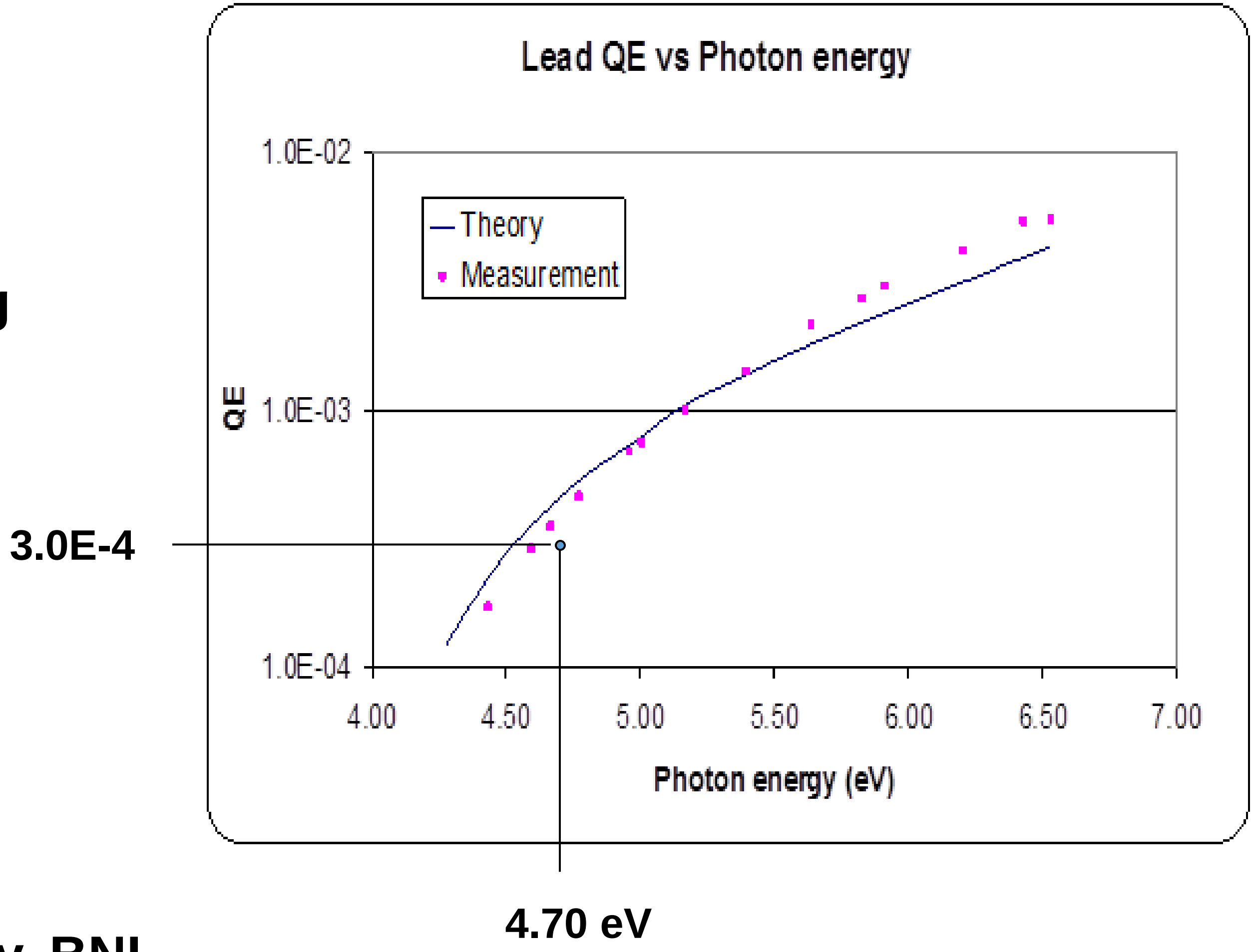




QE measurement from 20 μm thick Pb film on Nb plug; 0.5–cell SRF injector at BNL (Summer 2015)



Aggressive cleaning with 10^5 pulses of 266 nm laser beam at 60 mJ/cm^2



J. Smedley, BNL

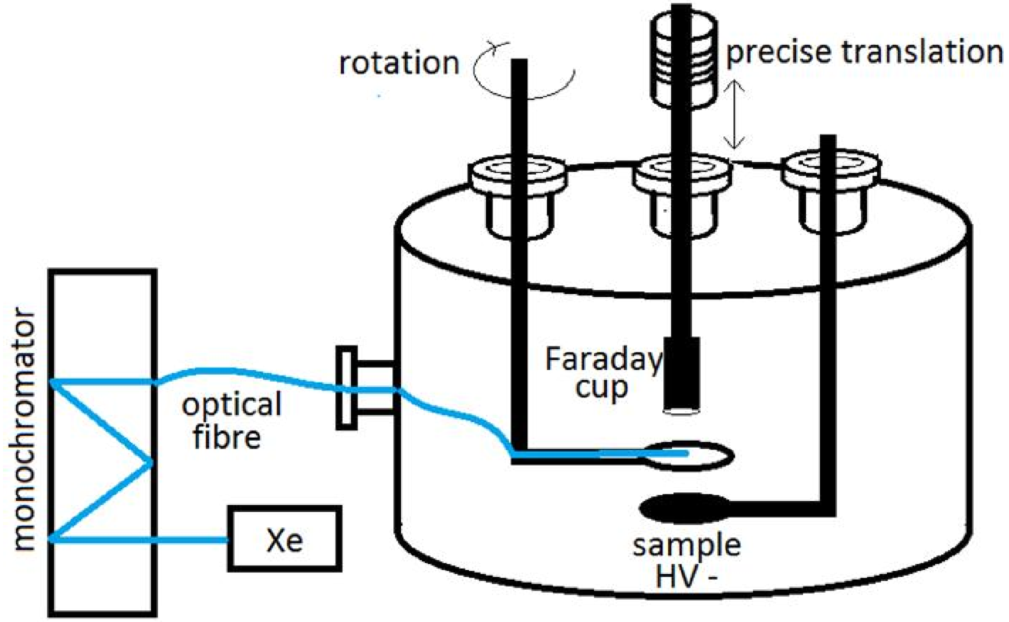
QE and dark current measurement setup at NCBJ

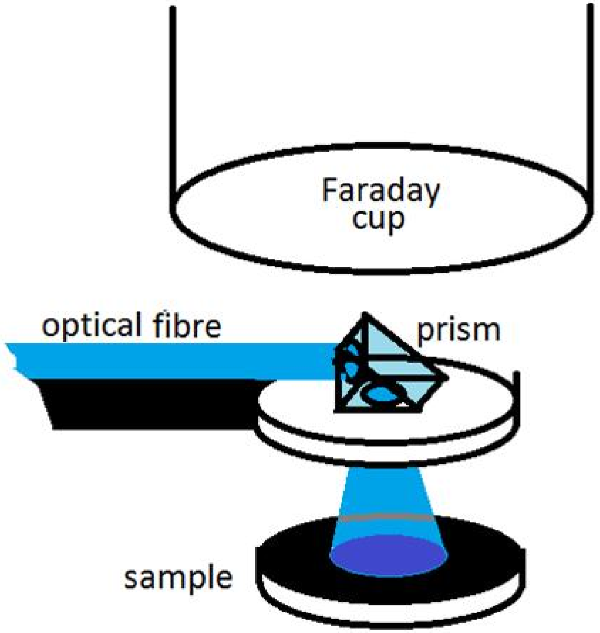
Xenon lamp 150 W,

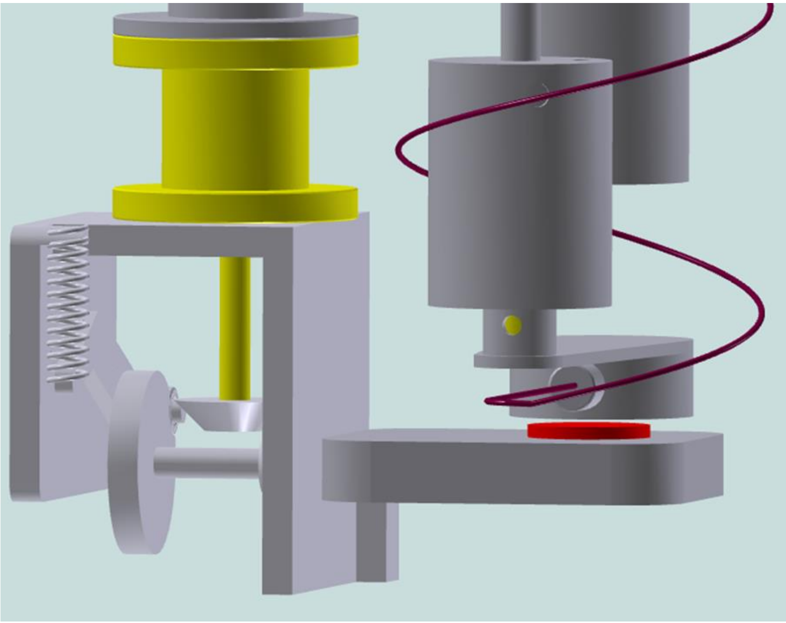
Czerny-Turner Monochromator, → **COMPLETED; to be tested by the end of 2015**

Optical fiber,

Λ = 190 – 700 nm







Thank you …..