Field emission measurement on flat Mo-substrates

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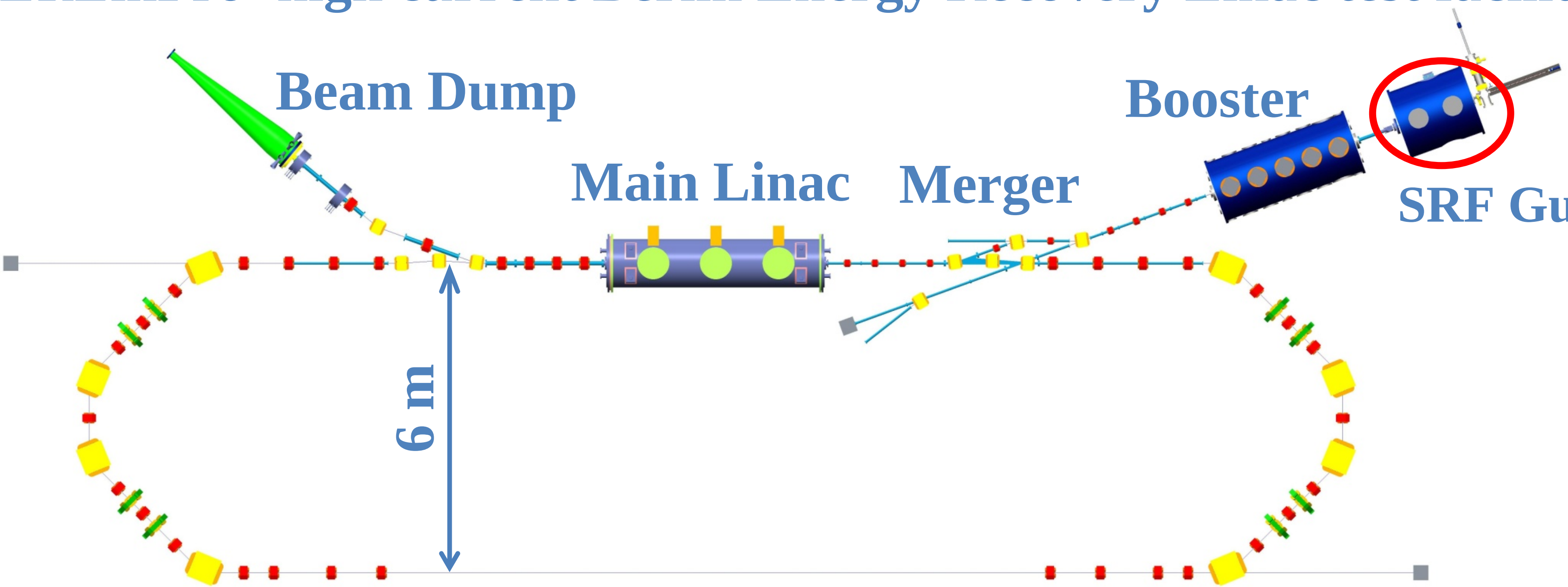
Electron source for B*ERL*inPro

B*ERL*inPro=high current Berlin Energy Recovery Linac test facility



Beam energy	50 MeV
Average current	100 mA
Bunch charge	77 pC
Normalized emittance	1 mm·mrad
Resonance frequency	1.3 GHz

demonstration of the feasibility to use ERL technology for future 4th generation multi-user light sources

Electron source for B*ERL*inPro

Development of an electron source with I=100 mA and ε<1.0 mm·mrad

High average current I_{ave}=100 mA

Photomaterials with high QE in the green part of the light spectrum→ cathode work function φ<2.5 eV

Semiconductor CsK_2Sb is a baseline photocathode for B*ERL*inPro

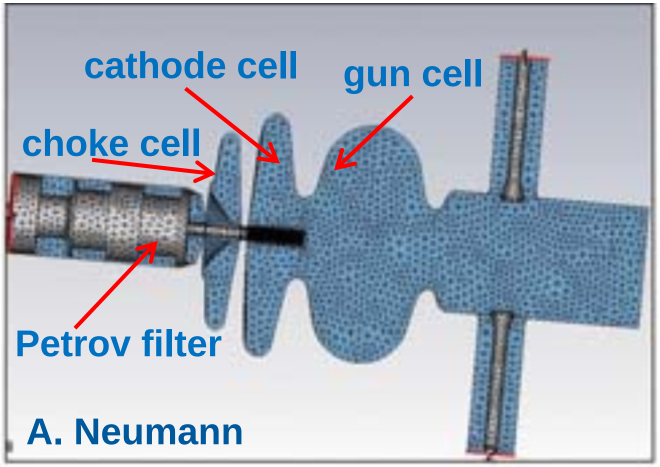
φ(CsK_2Sb)~1.9 eV; φ(Cs_2Te)~3.6 eV, φ(Mo)~4.6 eV

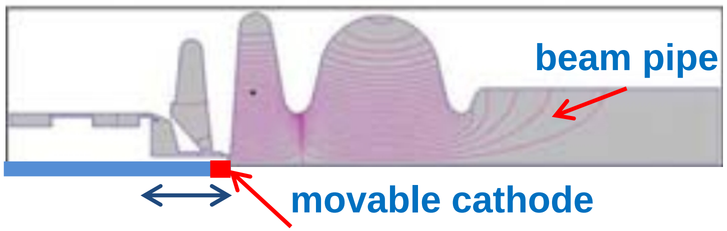
Field emission current *I*=*I*(β, φ) → **morphology**, **work function**

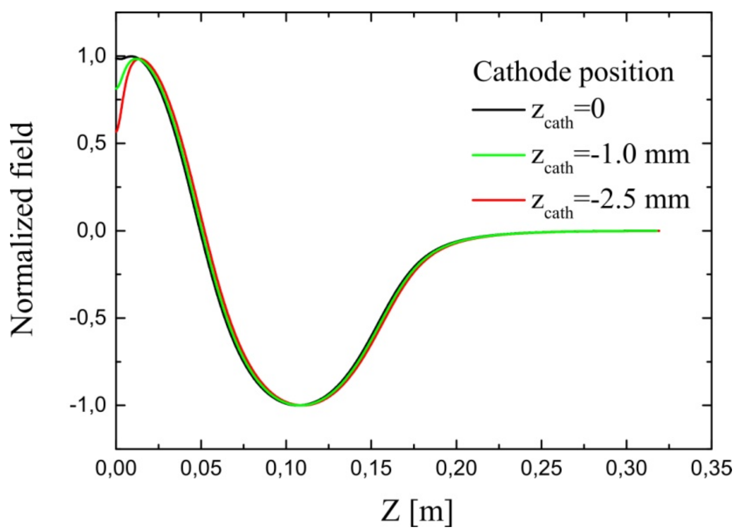
Low beam emittance required for B*ERL*inPro demands high field gradient on the cathode surface during beam extraction $E_{launch}=E_{cath}\cdot\sin(\Phi) \Rightarrow$ high peak field E_{cath} on the cathode surface

Field emission grows exponentially with the field amplitude

Electron source for B*ERL*inPro

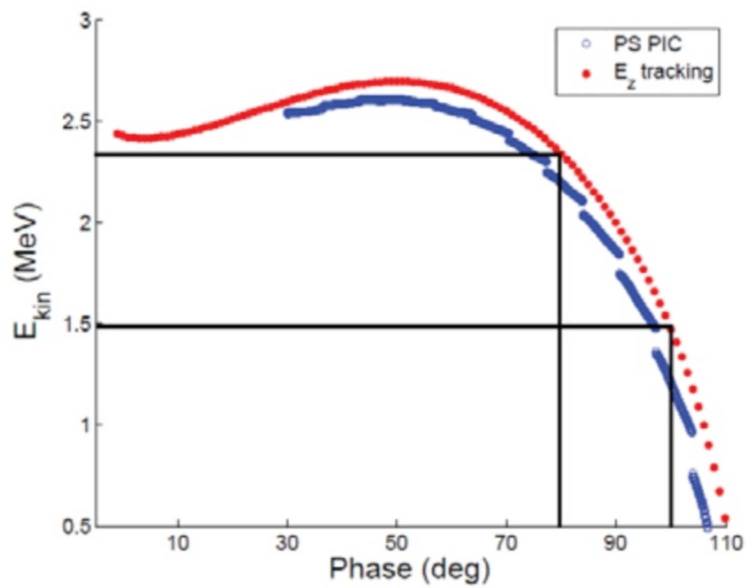






E_{axis}~30 MV/m (E_{iris}=45 MV/m)
E_{kin}=2.3 MeV, I=100 mA→P=230 kW
Power limit of ~230 kW by two KEK-style fundamental power couples

Retracted cathode z_{cath}=-2.5 mm (relative to the backwall)→ E_{cath}~0.57·E_{axis}
E_{cath}=17-30 MV/m



Field Emission as "Show Stopper"

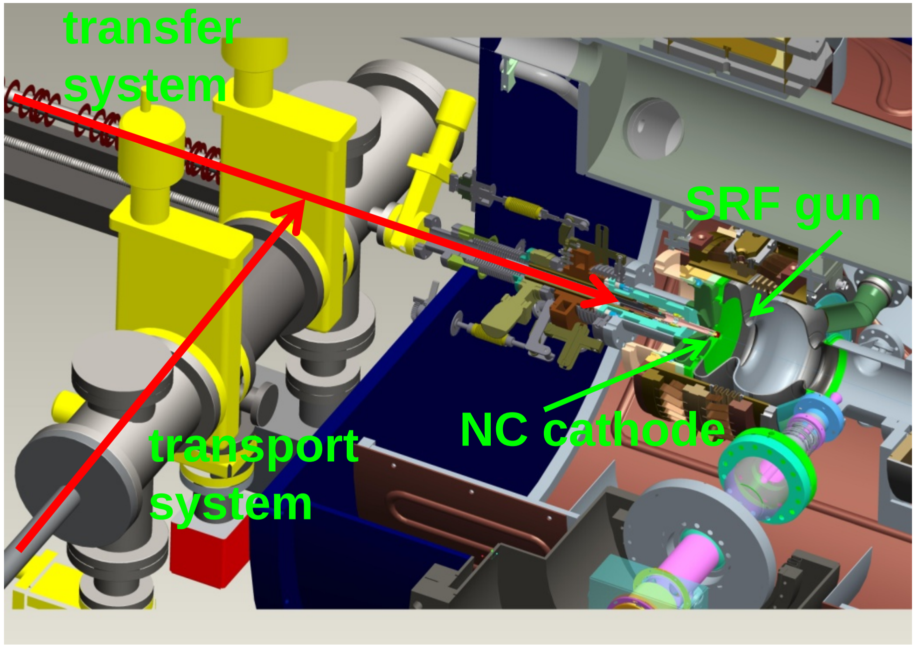
Limiting factors:

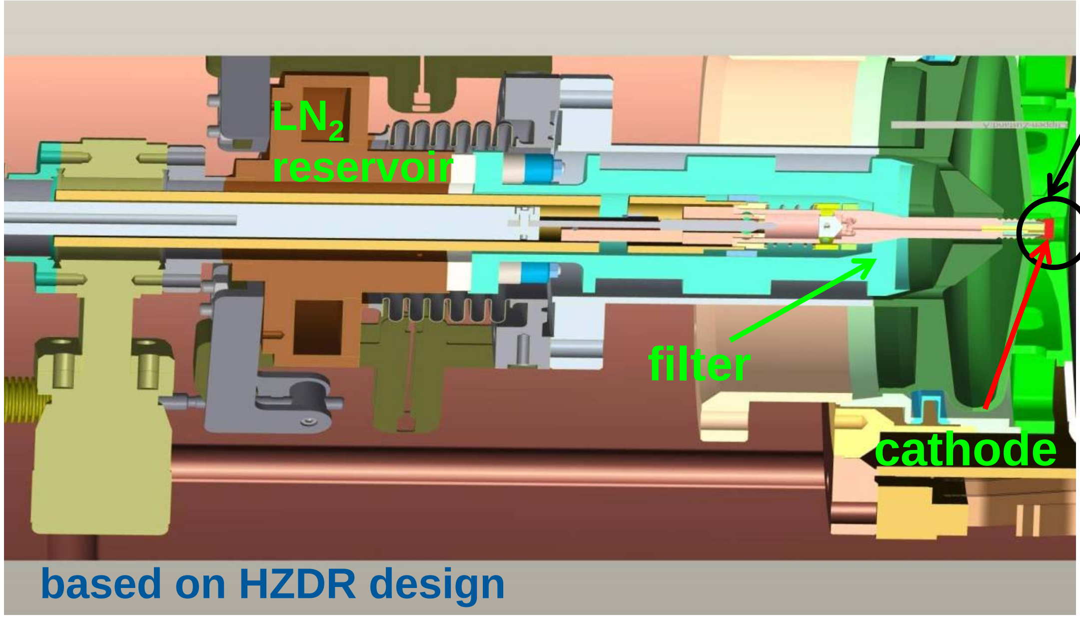
Field emission (unwanted beam) extracted from the cavity can limit the operation of the SRF gun:

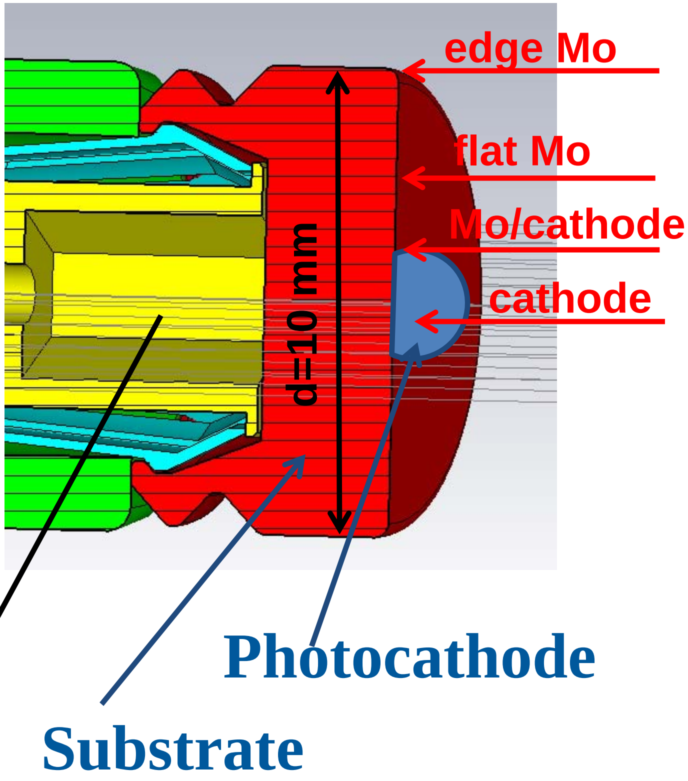
- particles loss in the booster
- damage of the machine components…
- pressure rise (ESD)
- electron-backbombardment (influence on cathode QE, production of secondary electrons, heating,…)

Field emission is relevant for understanding of multipacting, which can also limit the performance of the SRF gun

Sources of Field Emission



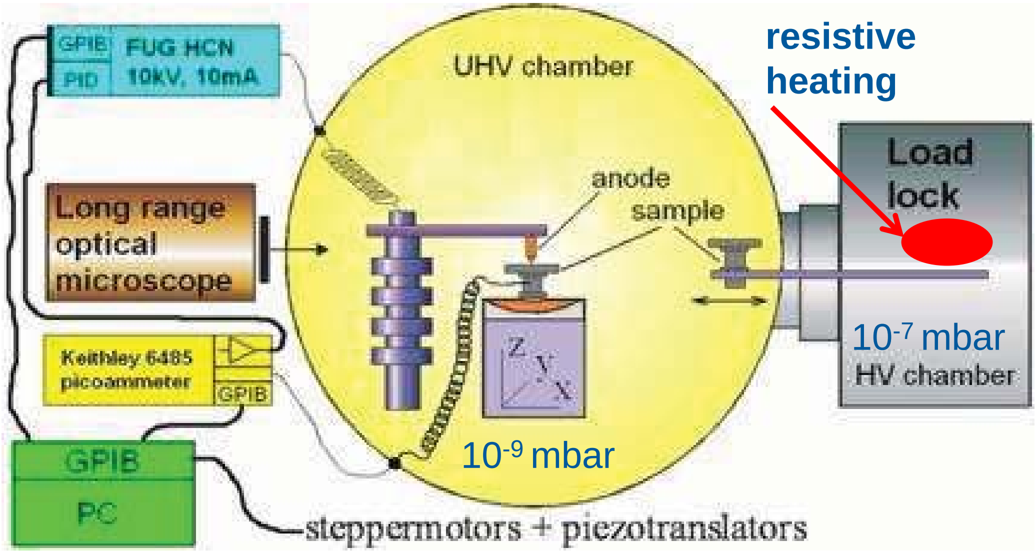


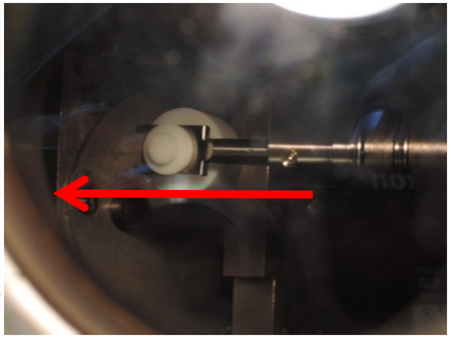


Sources of FE:

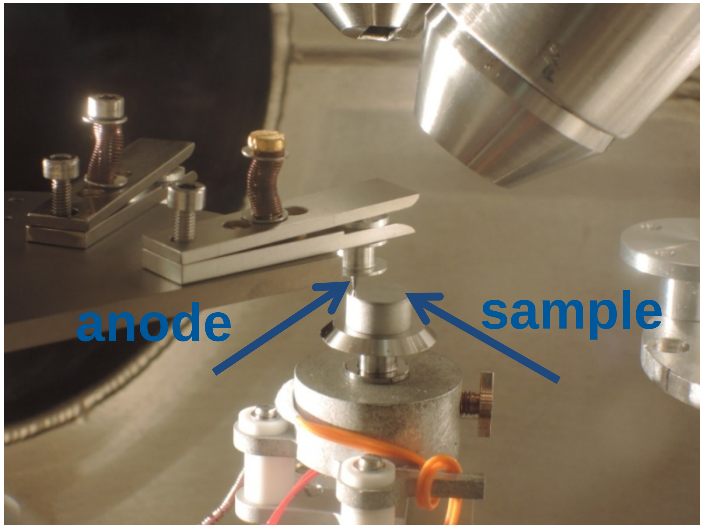
- Substrate (incl. edges)
- Boundary substrate/cathode
- Cathode

Field Emission Scanning Microscope in Wuppertal





- **Regulated voltage scan V(x,y)**
- **Local measurements of emitters I(U)→β_{FN}, S_{FN}**



E=k*V/d

k - geometric correction factor (gap, anode diameter, shape,…)

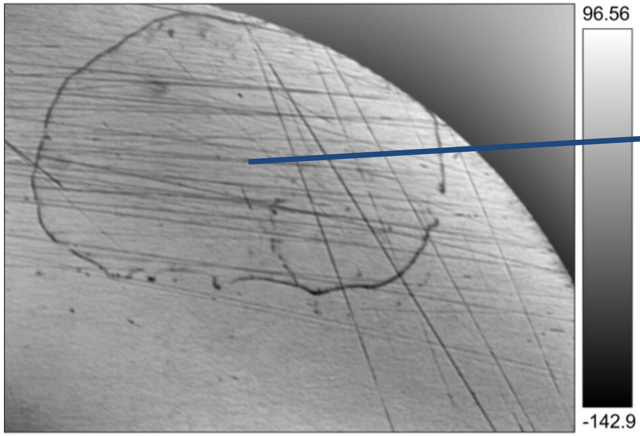
V – voltage, *d*- gap

Truncated conical tungsten anode with a flat tip of diameter ~150 μm (300 μm), gap *d*=50 μm, for a flat surface → **E=V/d**

Field gradient was adjusted using a 10 kV power supply

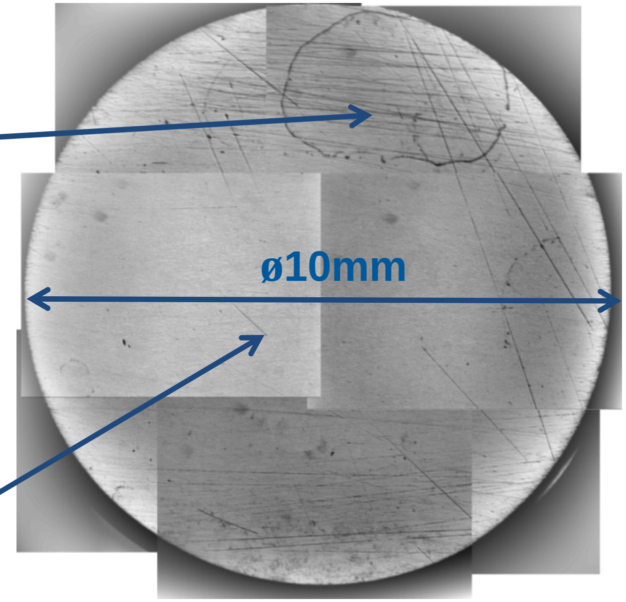
Polycrystalline Mo-Substrate

Area: 5018 x 3763 um   Sda: 659.9



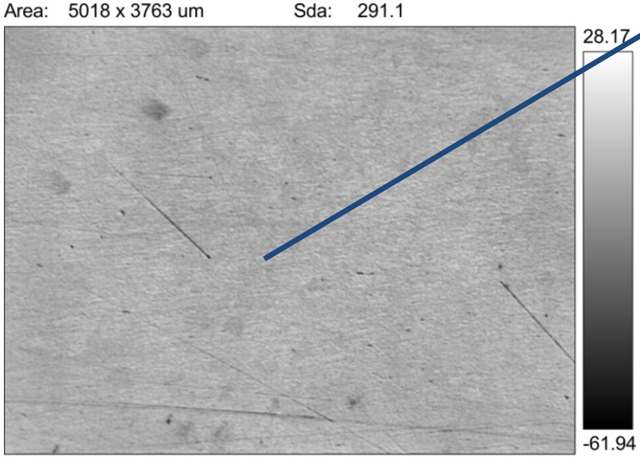
Sq: 26.81   640x480
Sa: 19.53   1/2" CCD
St: 239.5   0.5X Body
No Relay
Points: 307200   520 nm White
QUARTIC   2.5X

(5x3.8) mm^2
S_q=27 nm
S_a=20 nm



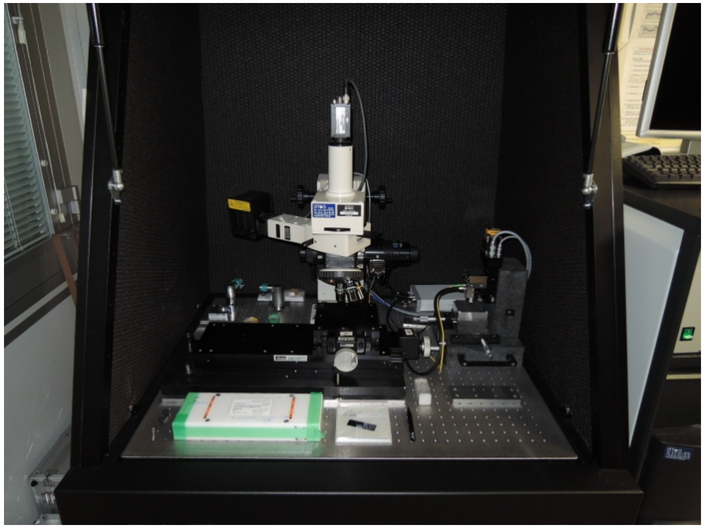
Surface of the polycrystalline Mo sample measured with a white light interferometer

Op:
Area: 5018 x 3763 um   Sda: 291.1



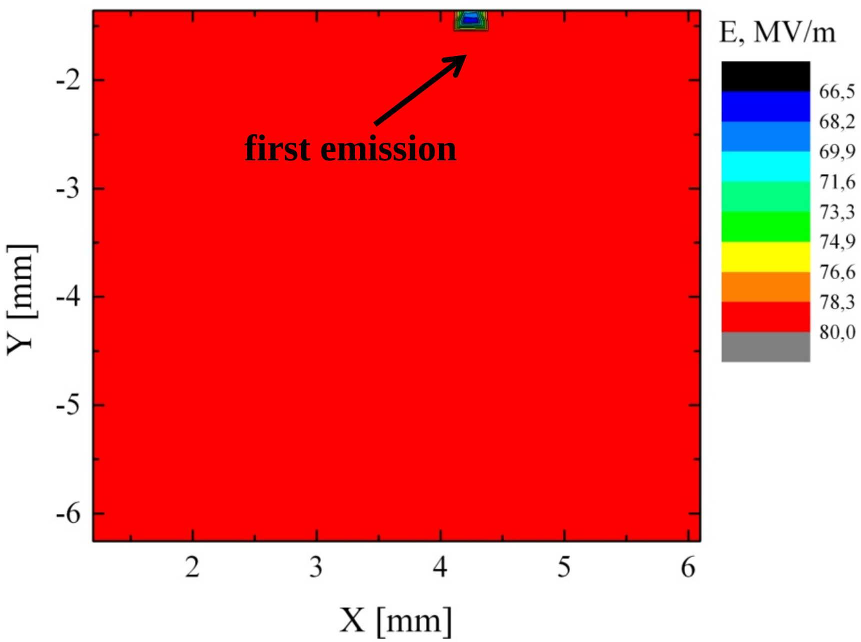
Sq: 4.837   640x480
Sa: 3.683   1/2" CCD
St: 90.11   0.5X Body
No Relay
Points: 307200   520 nm White
QUARTIC   2.5X

(5x3.8) mm^2
S_q=4.8 nm
S_a=3.7 nm

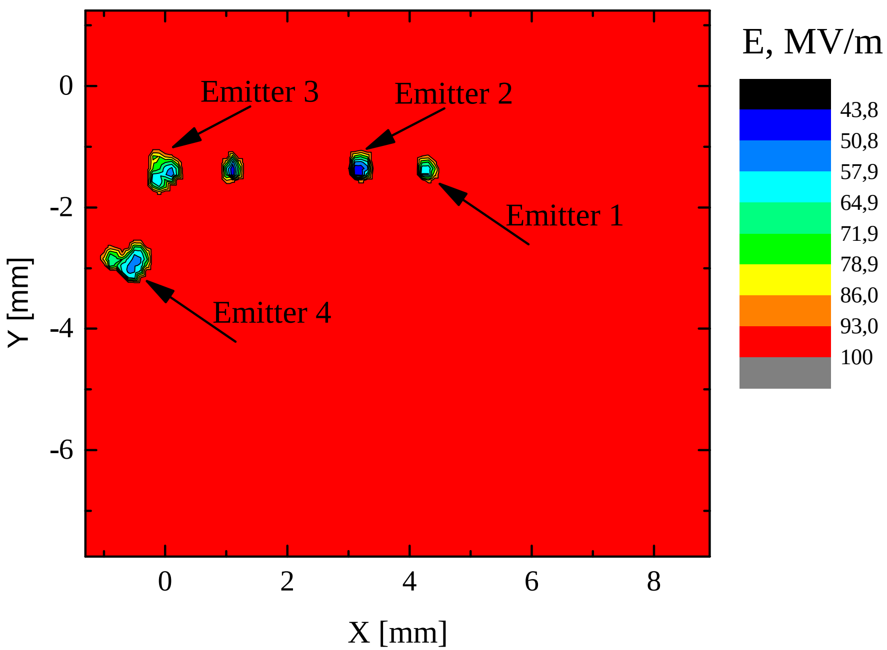


FESM Measurement

No Dry Ice Cleaning (high pressure jet of pure CO_2), ionized nitrogen,…
FE measurement was performed over the entire surface of the Mo sample
Applied voltage was adjust for I=1 nA emission current, gap is constant d=50 µm
First emission at E=80 MV/m
5 emitters were observed at E=100 MV/m



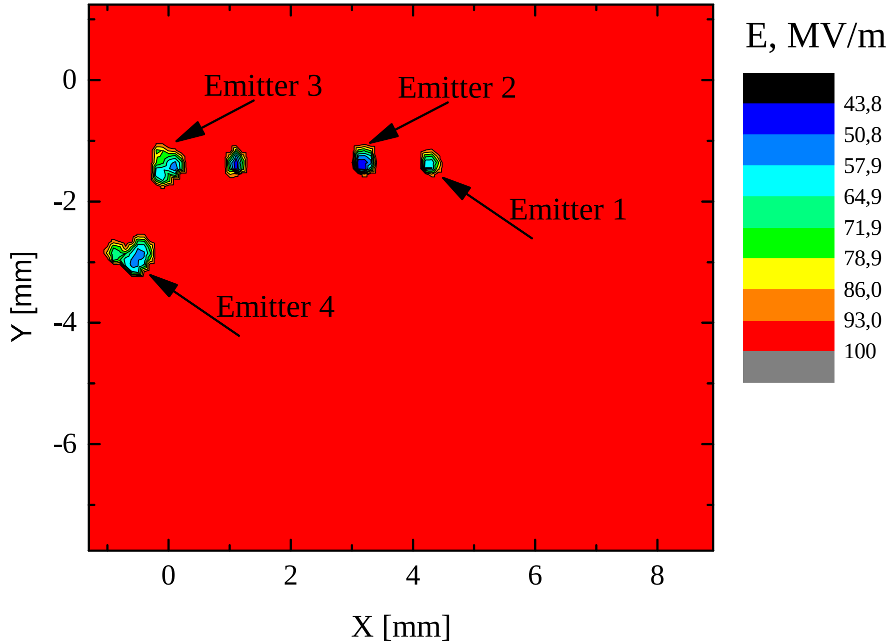
FE Map of the polycrystalline Mo sample at E=80 MV/m $5x5\ mm^2$



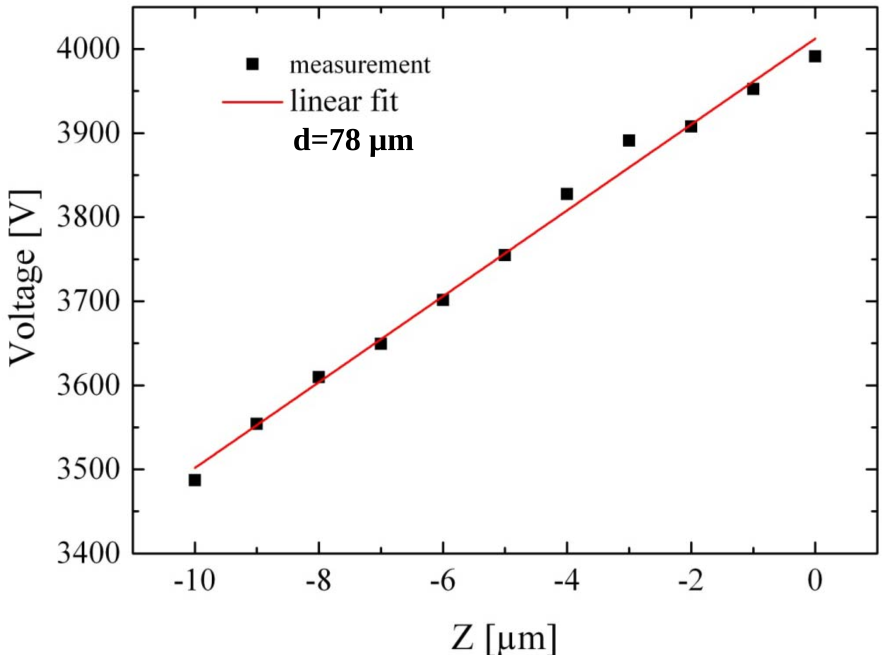
FE Map of the polycrystalline Mo sample at E=100 MV/m $10x10\ mm^2$

Local Measurements

Characterization of the emitters
I(E), enhancement factor β, effective emitting area *S*



FE Map of the polycrystalline Mo sample at E=100 MV/m

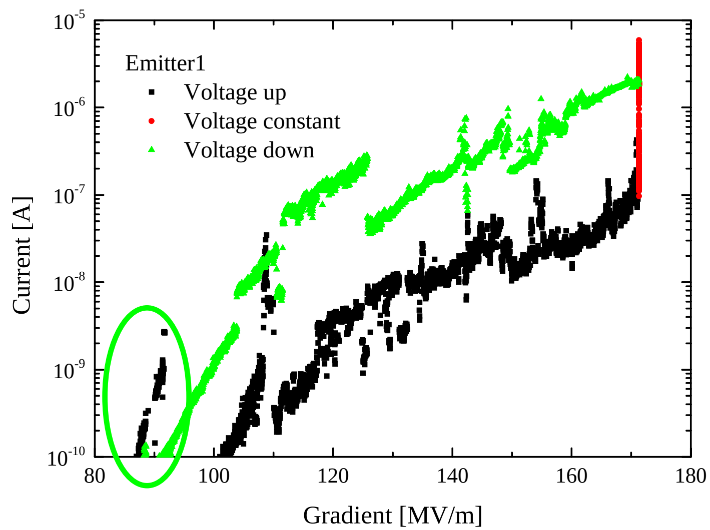


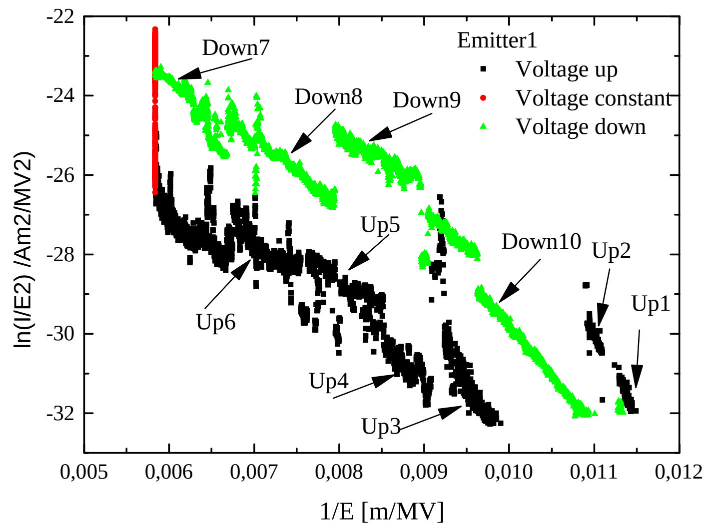
Calibration of gap

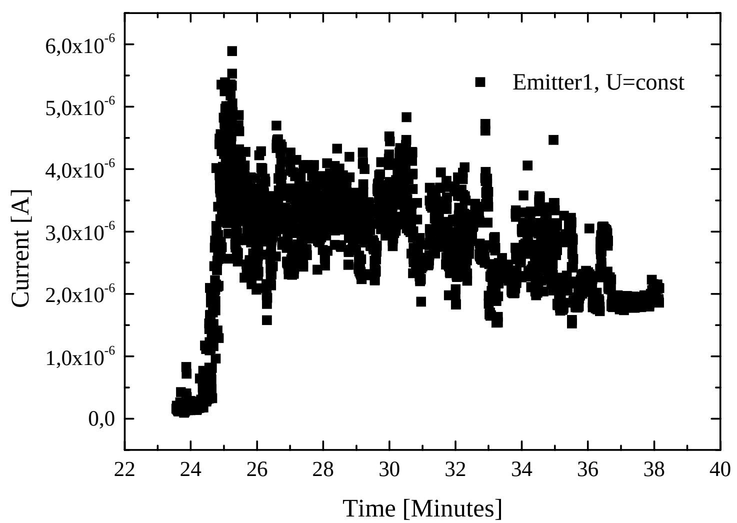
Gap estimation using a long-distance optical microscope

- **Centering the anode at the emission site**
- **Reducing the gap while adjusting HV to maintain a constant current (1 nA)**
- **Extrapolation to *V*=0 is set as a gap *d*=0**

Local Measurements (Emitter 1)



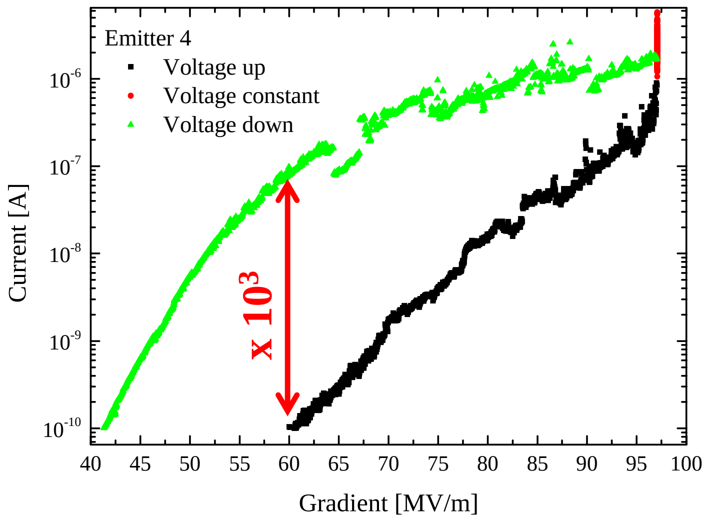


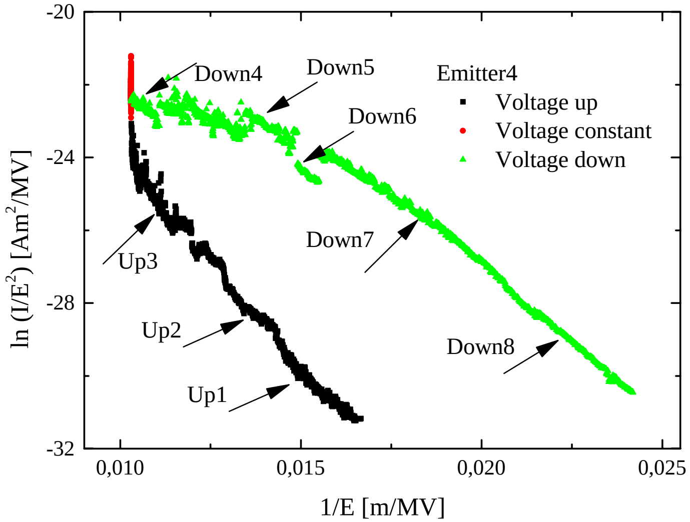


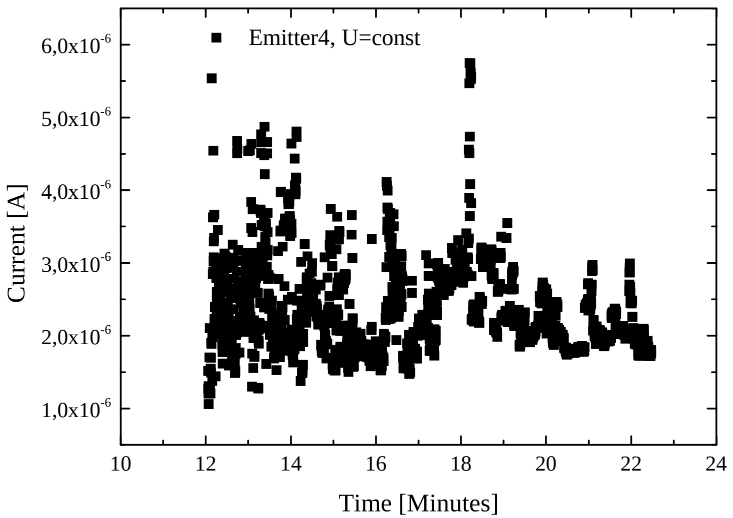
Unstable
Non Fowler-Nordheim (F-N) behaviour
No emission between 92 MV/m and 101 MV/m
Emitter activation (except E<90 MV/m)

S, m^2	*3.4E7*	*4.3E-2*	*4.3E-8*	1.7E-16	9.6E-18	**2.5E-19**
β	10.4	14.9	17.6	37.1	46.9	**66.2**
Pos.	Up1	Up2	Up3	Up4	Up5	Up6
S, m^2	2.8E-16	9.8E-15	1.6E-16	**3.5E-11**		
β	44.7	33.9	52.3	**24.4**		
Pos.	Down7	Down8	Down9	Down10		

Local Measurements (Emitter 4)







E_{onsett}(1nA)=70 MV/m

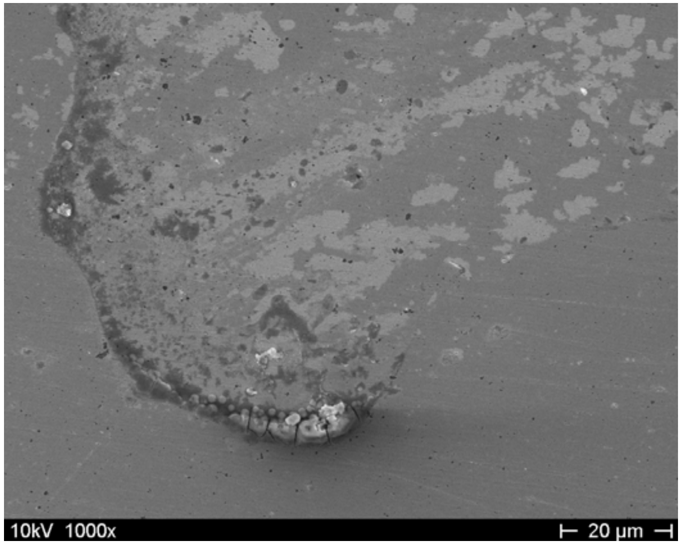
FN-dependence

Strong activation

E_{onsett}(1nA)=46 MV/m

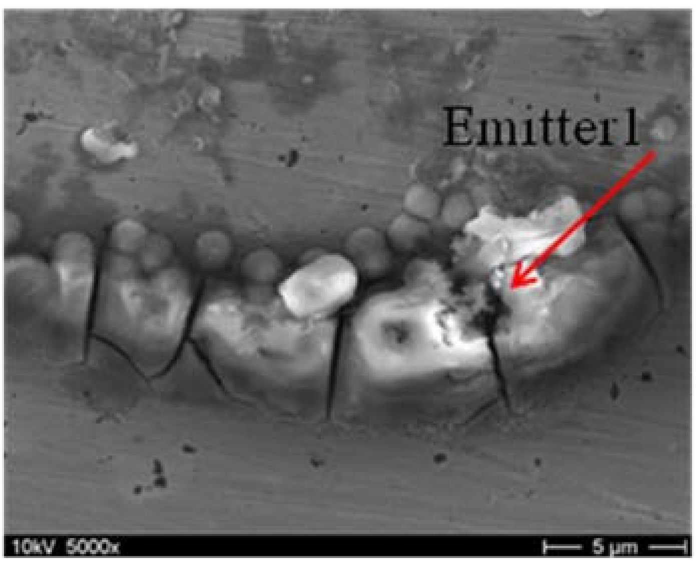
***S*, m²**	1.1E-16	5.1E-17	**7E-12**		
β	64.3	69.4	**34.6**		
Pos.	Up1	Up2	Up3		
***S*, m²**	5.5E-17	6.4E-17	1.3E-15	3.1E-16	**1.7E-14**
β	92.2	107.2	78.9	94.9	**73.1**
Pos.	Down4	Down5	Down6	Down7	Down8

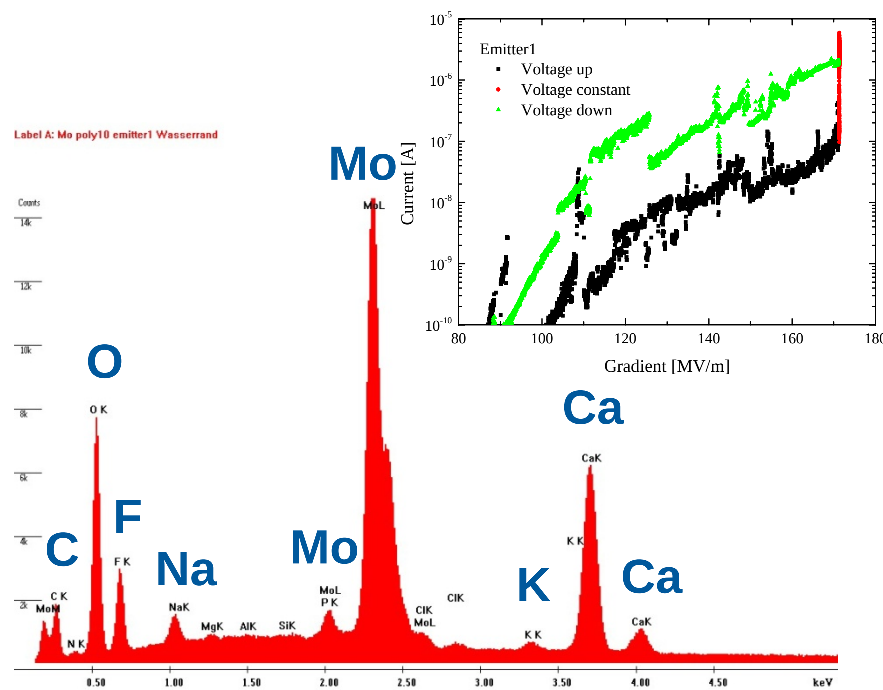
Morphology and Composition of Emitters (Emitter 1)



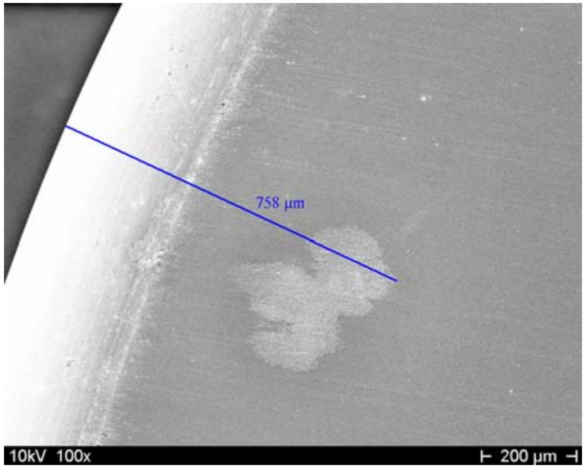
The emitters were investigated by:

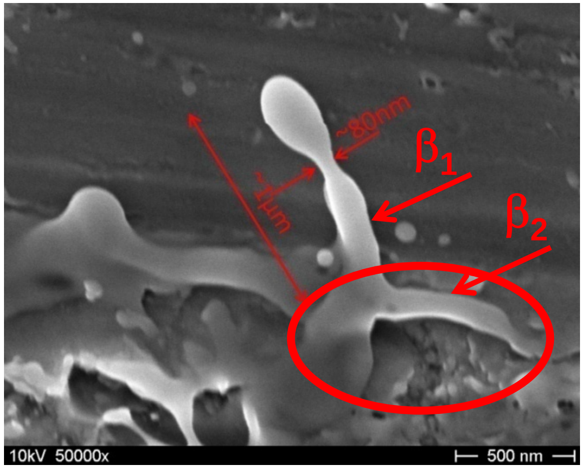
- **SEM (Scanning Electron Microscope)**
- **EDX (Energy Dispersive X-ray)**





Morphology and Composition of Emitters (Emitter 4)

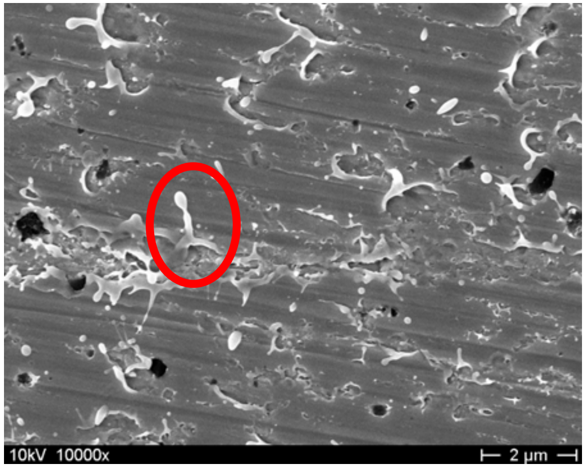


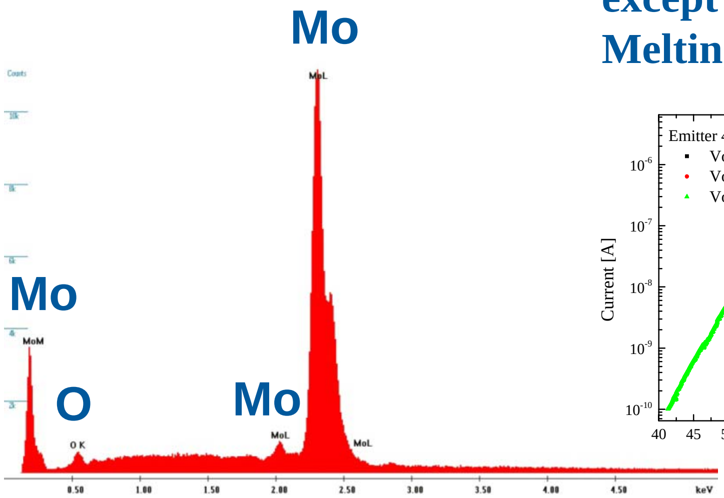


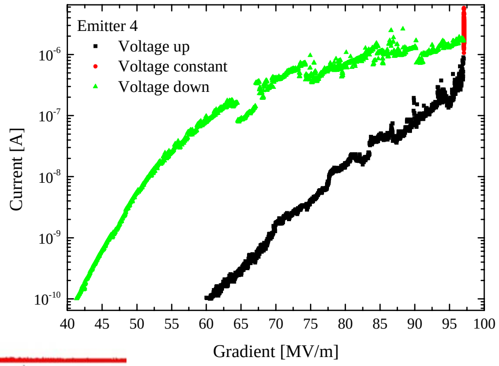
E_{onsett}(1nA)=70 MV/m
FN-dependence
Strongly activated
E_{onsett}(1nA)=46 MV/m

d=80 nm, I=1µm→β_1~10
$\beta_{eff}=\beta_1*\beta_2>10$

EDX shows no elements except of Mo and O
Melting point (Mo) ~2617 ^{0}C

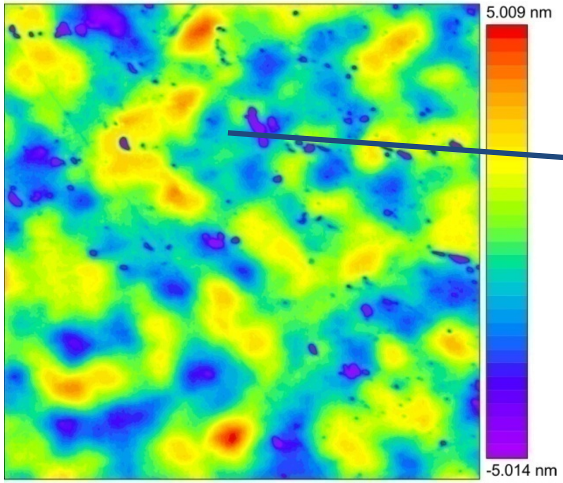






Single Crystal Mo-Substrate

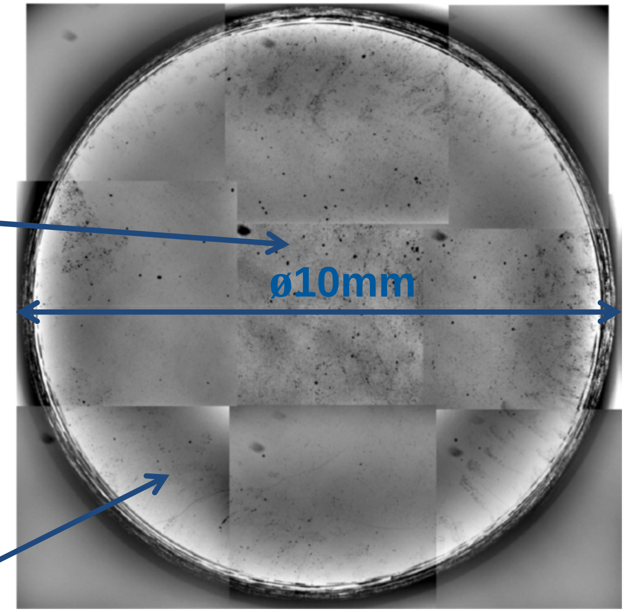
Op: at centre position
Area: 235.2 x 235.2 um



Sq: 1.671 nm
Sa: 1.241 nm
St: 35.45 nm
Points: 230400
QUARTIC

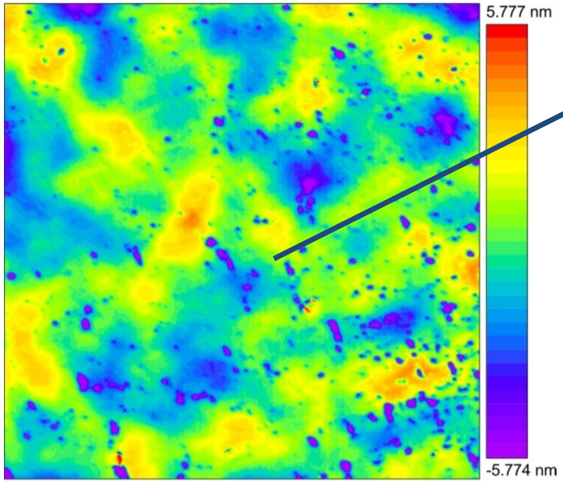
480x480
1/2" CCD
1.0X Body
No Relay
520 nm White
20X

Centre
(235x235) mm²
S_q=1.7 nm
S_a=1.2 nm



Surface of the single crystal Mo sample measured with a white light interferometer

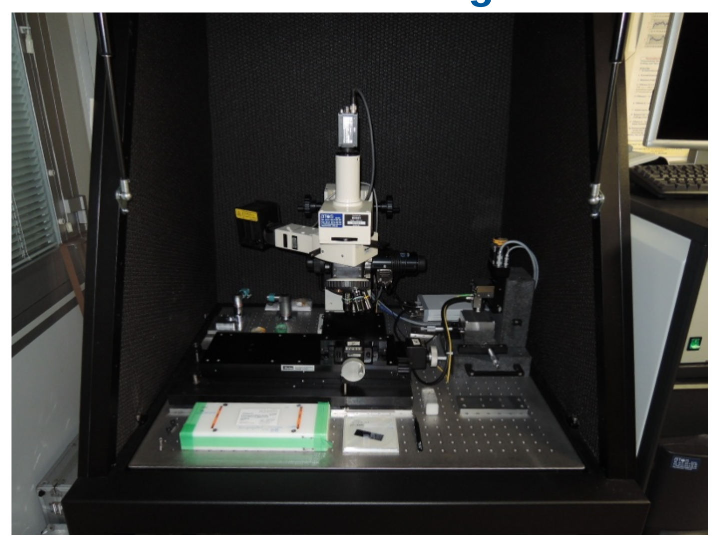
Op: at edge
Area: 235.2 x 235.2 um



Sq: 1.925 nm
Sa: 1.359 nm
St: 54.00 nm
Points: 230400
QUARTIC

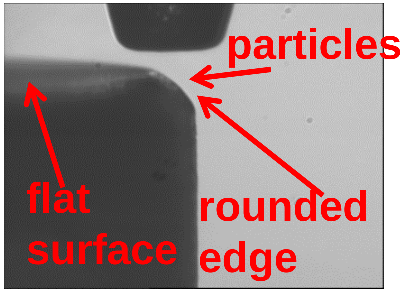
480x480
1/2" CCD
1.0X Body
No Relay
520 nm White
20X

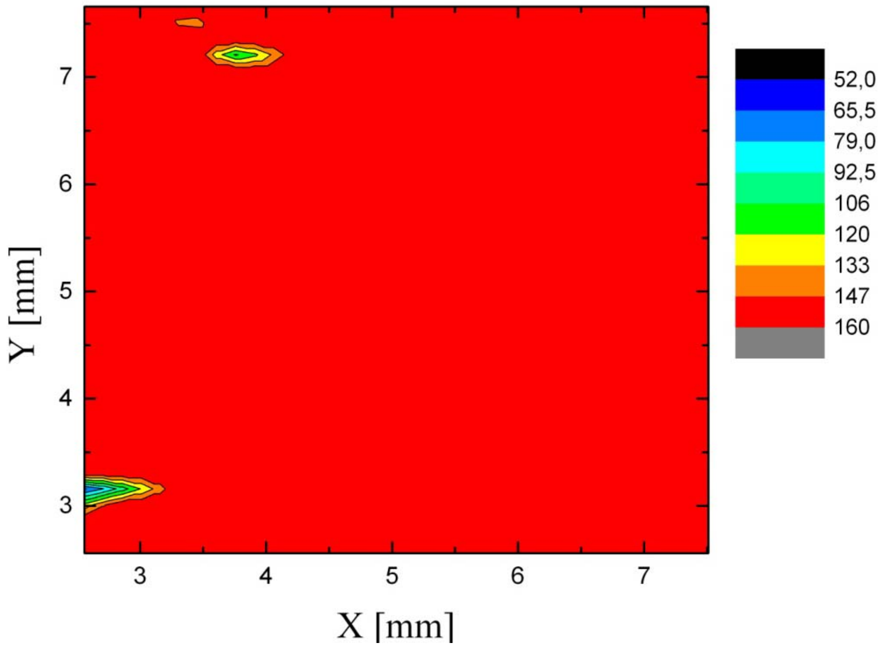
Edge
(235x235) mm²
S_q=1.9 nm
S_a=1.4 nm



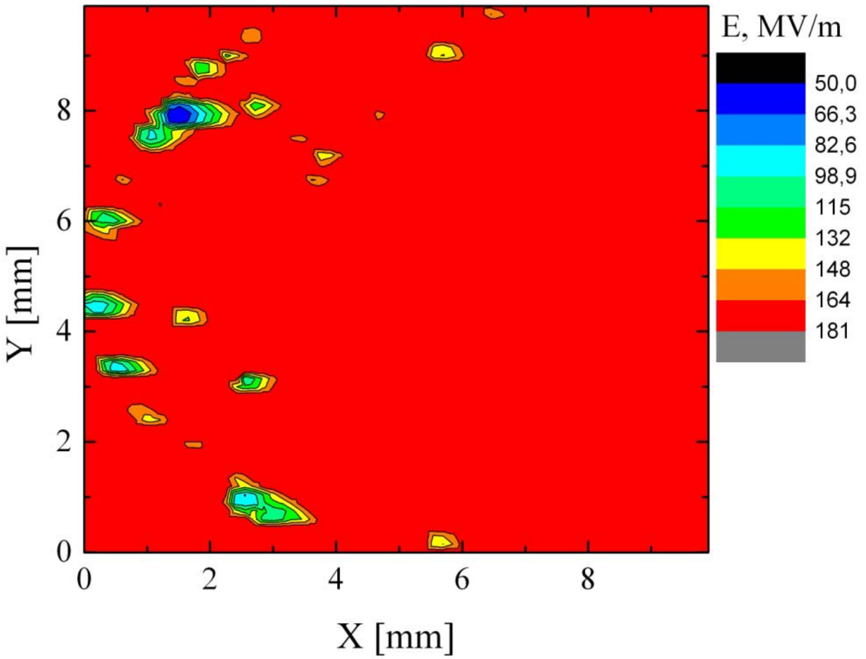
FESM Measurement

Ionized nitrogen, DIC (5 minutes)
Much less particles on the surface
First emission was observed at 160 MV/m
Strong emission from the edges





FE-Map at E=160MV/m
<u>5x5 mm²</u>



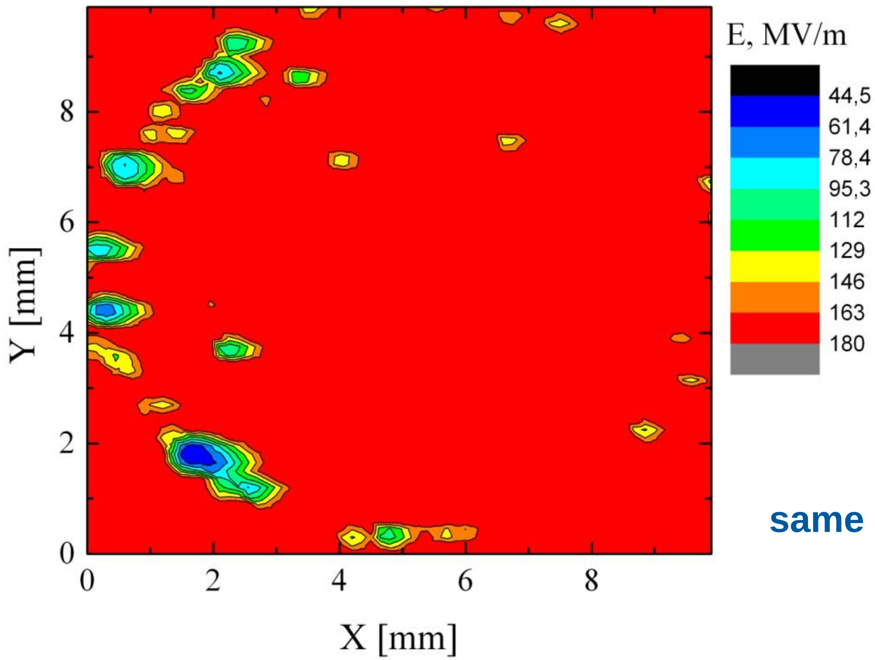
FE-Map at E=180MV/m
(probably some problems with tilt)
<u>10x10 mm²</u>

Heat Treatment

Cathode preparation → clean surface (heat treatment)

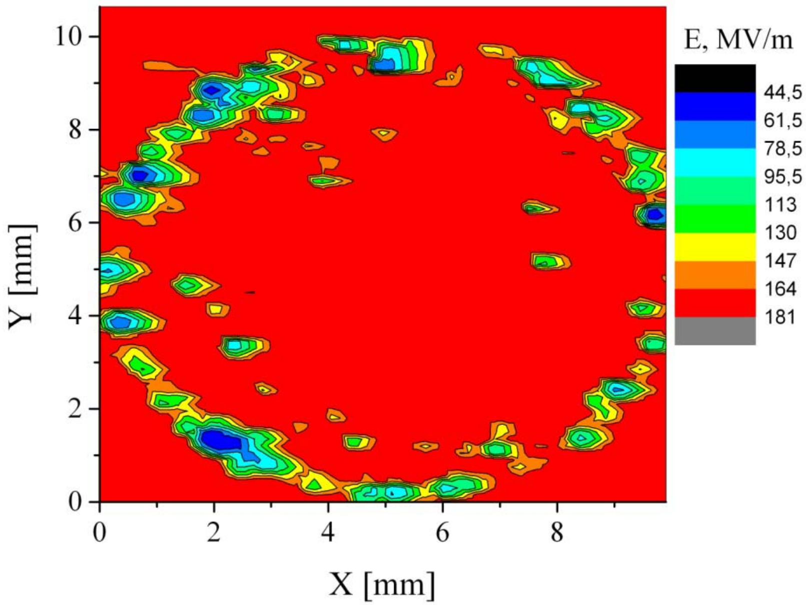
Temperature dependence:
- **activation of new emitters**
- **modification of existing emitters**

Heating at 100 ^{0}C, 200 ^{0}C, 300 ^{0}C, 400 ^{0}C and 600 ^{0}C
The most dominant effect was observed after heat treatment at T=400 ^{0}C
Molybdenum trioxide MoO_3? $MoO_3 \rightarrow 2MoO_2 + O_2$



FE-Map at E=180 MV/m
10x10 mm^2, T=300 ^{0}C

same area



FE-Map at E=180 MV/m
10x10 mm^2, T=400 ^{0}C

Conclusions

First emission was observed at 80 MV/m for polycrystalline Mo and 160 MV/m for single crystal Mo

Strong emission from the edges of the sample2

It seems that heat treatment of the substrate surface increases the number of emission sites for the same gradient
It seems that the emitters become more stable

The most dominant effect was observed after heat treatment at T=400 ^{0}C

Acknowledgements

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S. Lagotzky, G. Müller, FB C Physics Department, University of Wuppertal