Scanning Electron Microscope (SEM) in situ field emission measurement in Uppsala Univ.

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Outline

- Background
- Field emission measurements
- Post-breakdown analyses
- Collaborations/ applications

Keep in mind that the system is available for you.

Background

- **Location**: Developments & Experiments in Uppsala Univ. (UU).
- **Motivation**: CLIC feasibility study / fundamental interest.
- **Purpose**: Find dependences (field, time, gap, geometry, material, treatment, …, crystal orientation,…)
- **Speciality 1**: Local filed emission and breakdown measurements inside an SEM.
- **Speciality 2**: Post-breakdown surface & sub-surface analyses by Focused Ion Beam (FIB) and SEM.

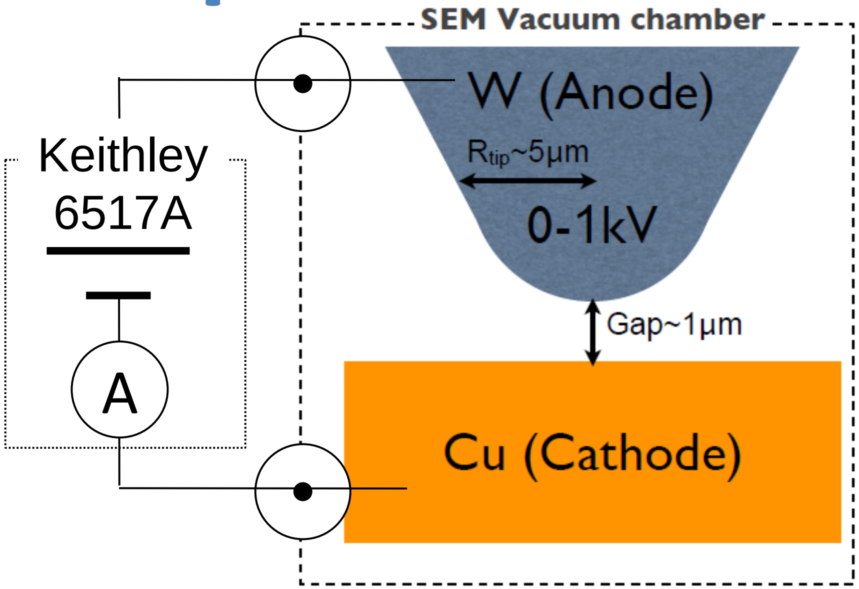
Ideas – What we can do

- Reproduce high-gradient electric field condition in μm range (1kV/ μm = 1GV/m).
- Local field emission and vacuum discharge study using SEMs.
- Measurement and observations in one instrument.
- Compact & transportable experimental setup.
- Post-breakdown analyses using a Focused Ion Beam (FIB) and X-ray.

Outline

- Ideas
- **Field emission measurements**
- Post-breakdown analyses
- Collaborations/ applications

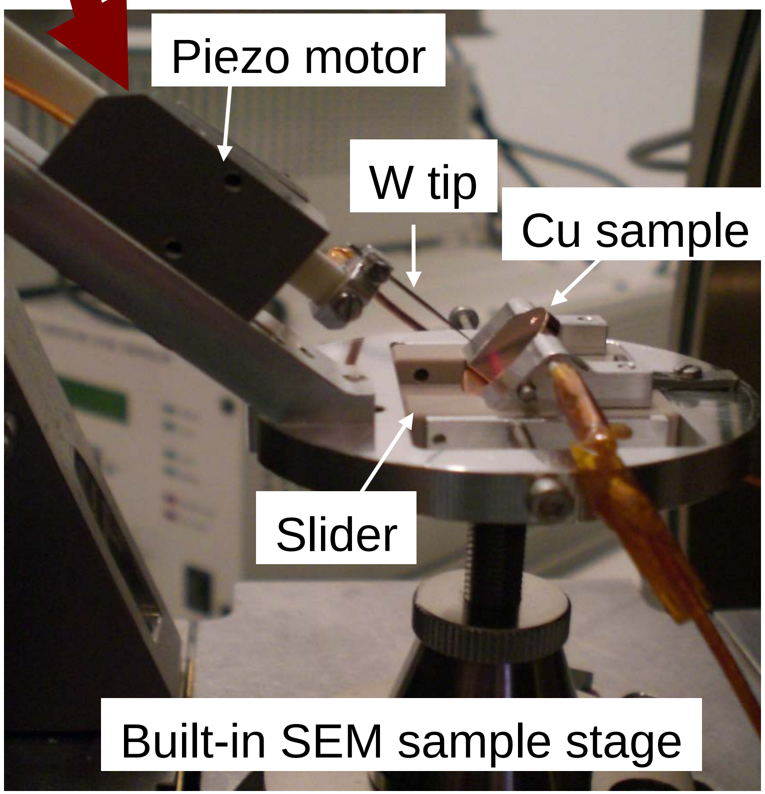
Experiment setup

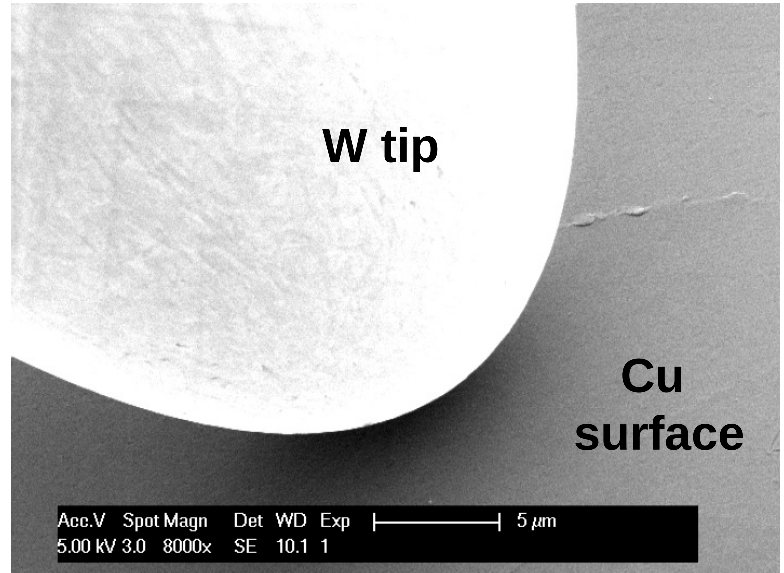


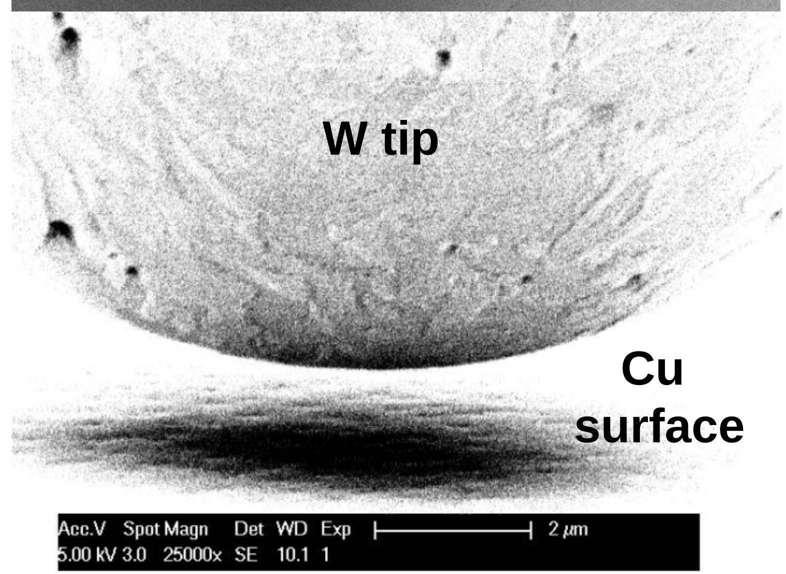
- Cathode: Cu samples provided by CERN, 12mm-D
- Anode: W tip commercially available, 5μm-R, cleaned by NaOH
- Gap: 1.0 ± 0.1 μm
- Background current ≈0.02pA

Real life


Philips XL30 ESEM


Piezo motor
W tip
Cu sample
Slider
Built-in SEM sample stage

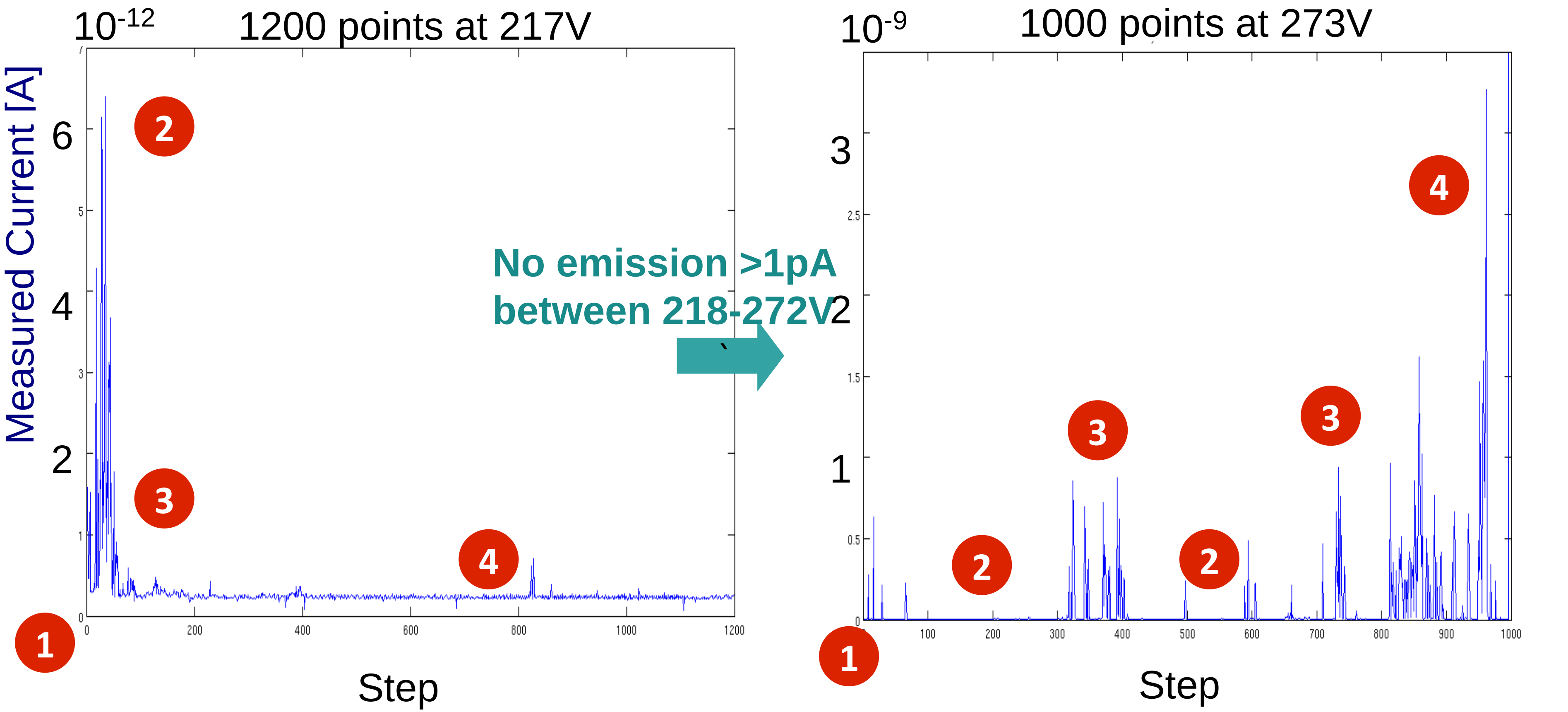

W tip
Cu surface
Acc.V Spot Magn Det WD Exp 5 µm
5.00 kV 3.0 8000x SE 10.1 1


W tip
Cu surface
Acc.V Spot Magn Det WD Exp 2 µm
5.00 kV 3.0 25000x SE 10.1 1

Emission stability measurement

1. Approach W tip to the sample surface ~1μm
2. Take SEM images of target area
3. Apply HV on W tip from 0V up to 1kV with 1V step
4. Measure emission current from Cu sample
5. Once the measured current exceeds 1pA, keep the voltage and continue current measurement for 20 minutes
6. Repeat 3-5
7. Stop measurement once the measured current exceeds 10nA.

Emission stability measurement



1. Measured current exceeded 1pA
2. Up to 6 pA
3. Decreased to the bg-level
4. Stayed at the bg-level

1. Measured current exceeded 1pA
2. Decreased to the bg-level
3. Spikes ~1nA
5. Emissions > nA then exceeded 10nA

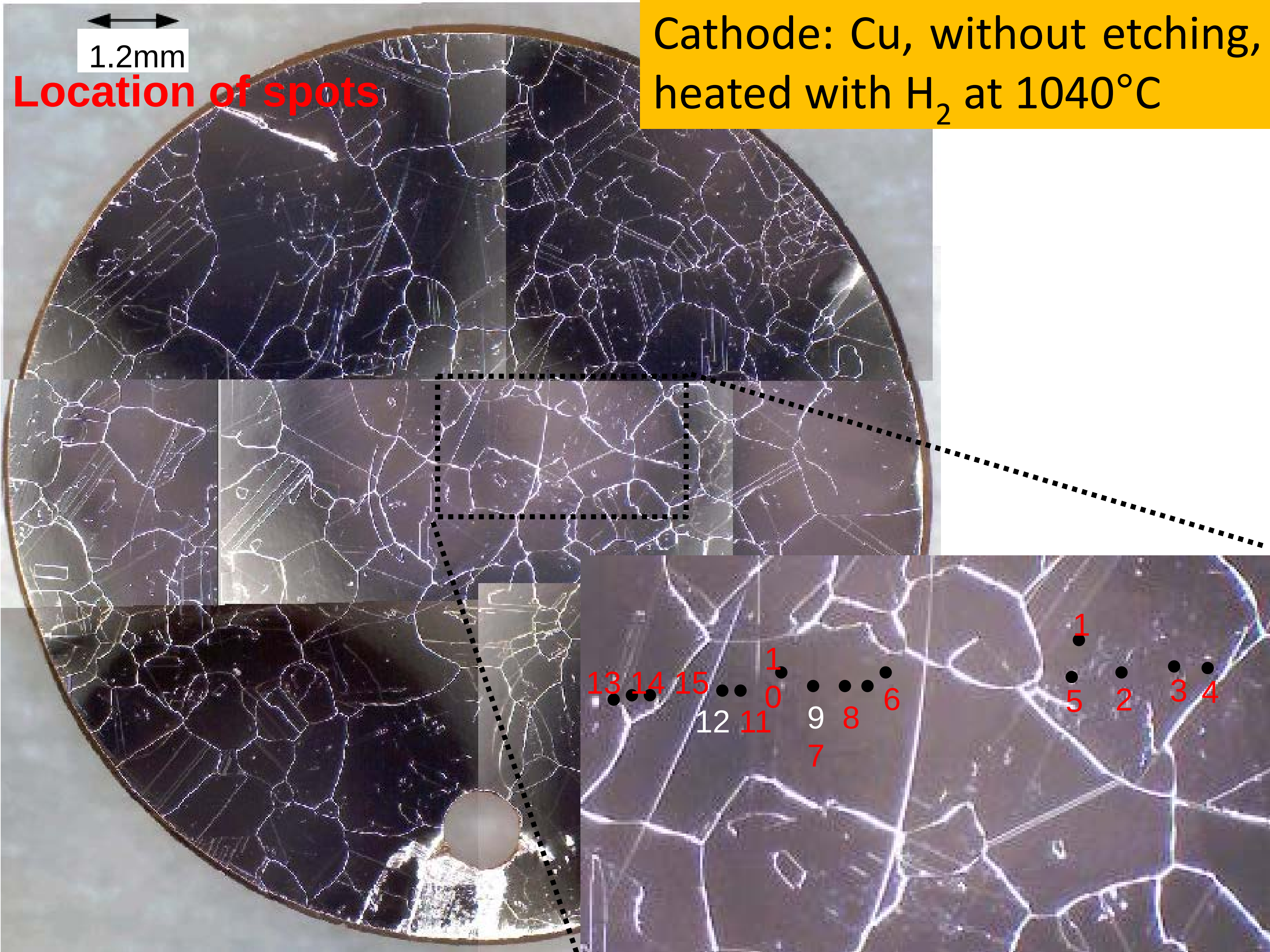
Summary: Emission stability

- Spikes appeared and disappeared as if field emitters were growing and evaporating.
- Still the tendency is that higher the E-field, higher the current.
- Macroscopic emission current that follows Fowler-Nordheim might be an average of (unstable) local emissions.
- The assumption above could be tested by statistical measurements and/or measurements with anodes of various sizes.

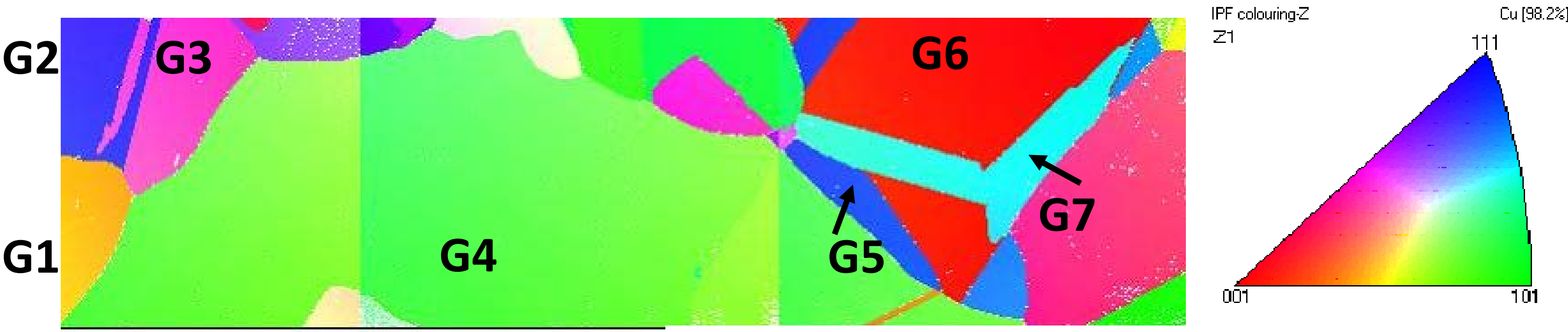
Grain orientation dependence

1. Approach W tip to the sample surface ~1µm
2. Take SEM images of target area
3. Apply HV on W tip from 0V up to 1kV with 1V step
4. Measure emission current from Cu sample
5. Stop HV supply once the current exceeds 10 nA (onset voltage)
6. Repeat 5 runs at the same spot
7. Move sliders to a new spot (blind)
8. Analyses: Comparison of onset voltage of each spots, Electron Backscatter Diffraction (EBSD) in order to identify grain orientations of spots.

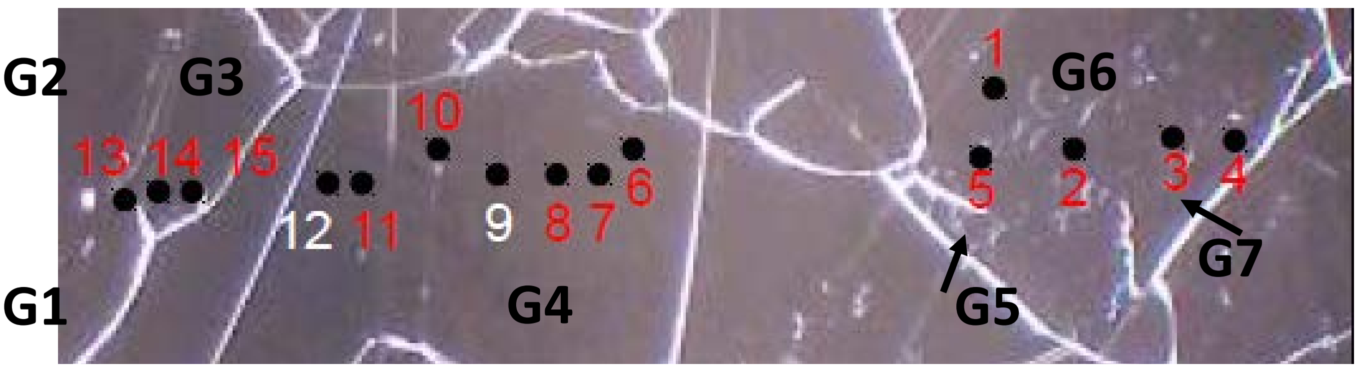
Cathode: Cu, without etching, heated with H_2 at 1040°C



Grain orientations of measured area

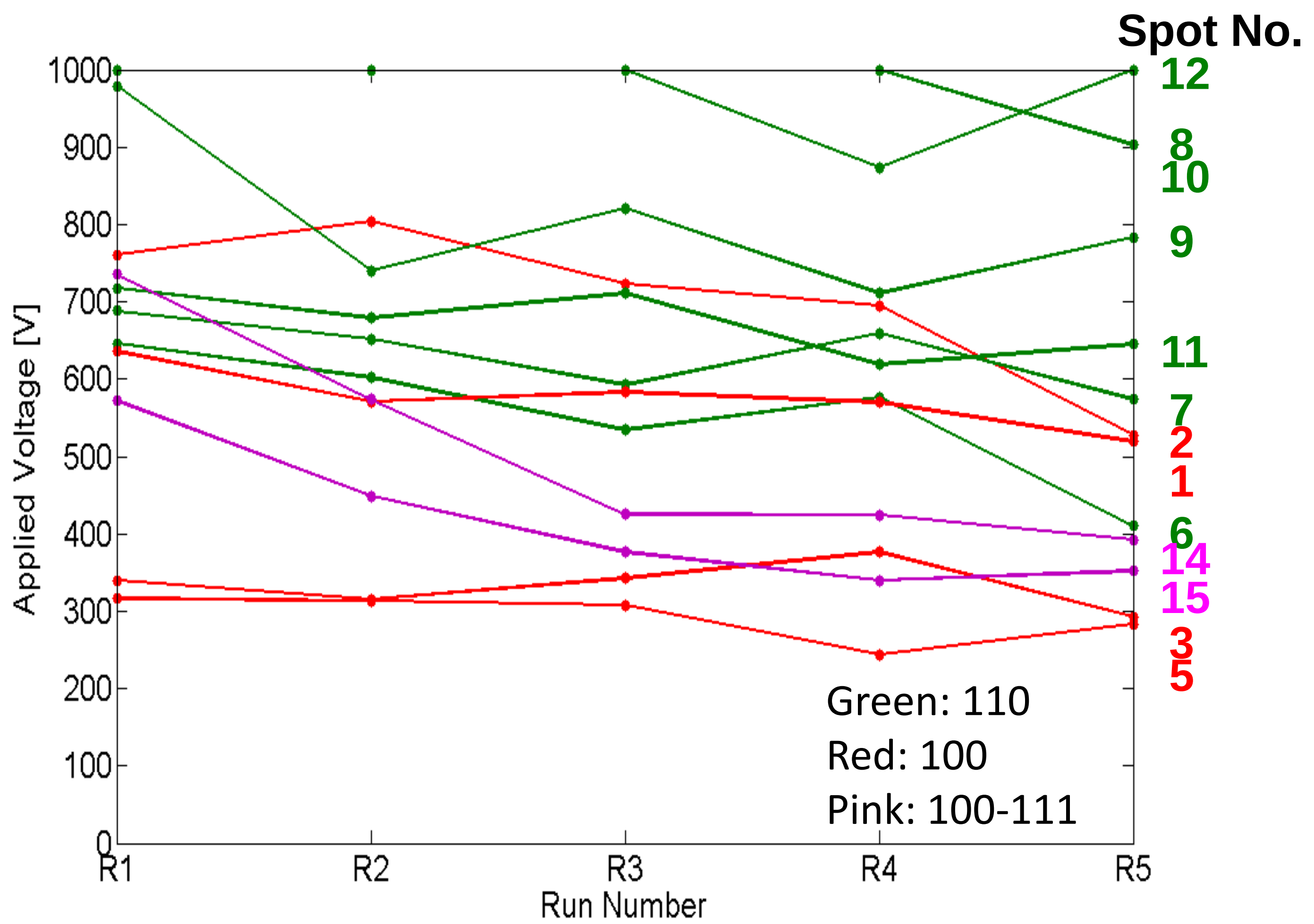


EBSD image: courtesy of M. Aicheler, CERN



Grain	G2 (111)	G3	G4 (110)	G6 (100)	G7
Spot	13	14, 15	6-12	1,2,3,5	4

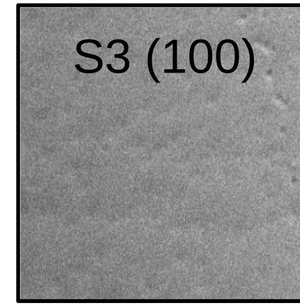
Grain orientation dependence

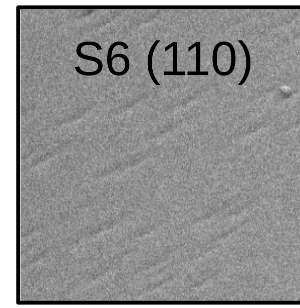


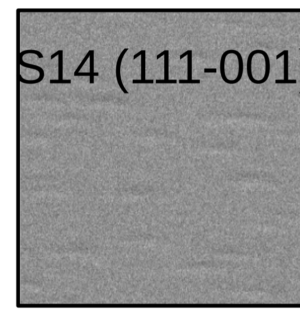
Summary: Grain orientation dependence

Grain	Spot	Von_R1 (V)	Von_R5 (V)	Work function (calc.)	Reduced WF with single adatom*
100	1-3,5	300 - 750	300 - 520	4.43eV	4.00eV
110	6-12	650 - over1000	410 - over1000	4.38eV	4.26eV
111	2	over1000	over1000	4.88eV	4.46eV
100-111	14,15	580-730	360-400		

* From F. Djurabekova's presentation







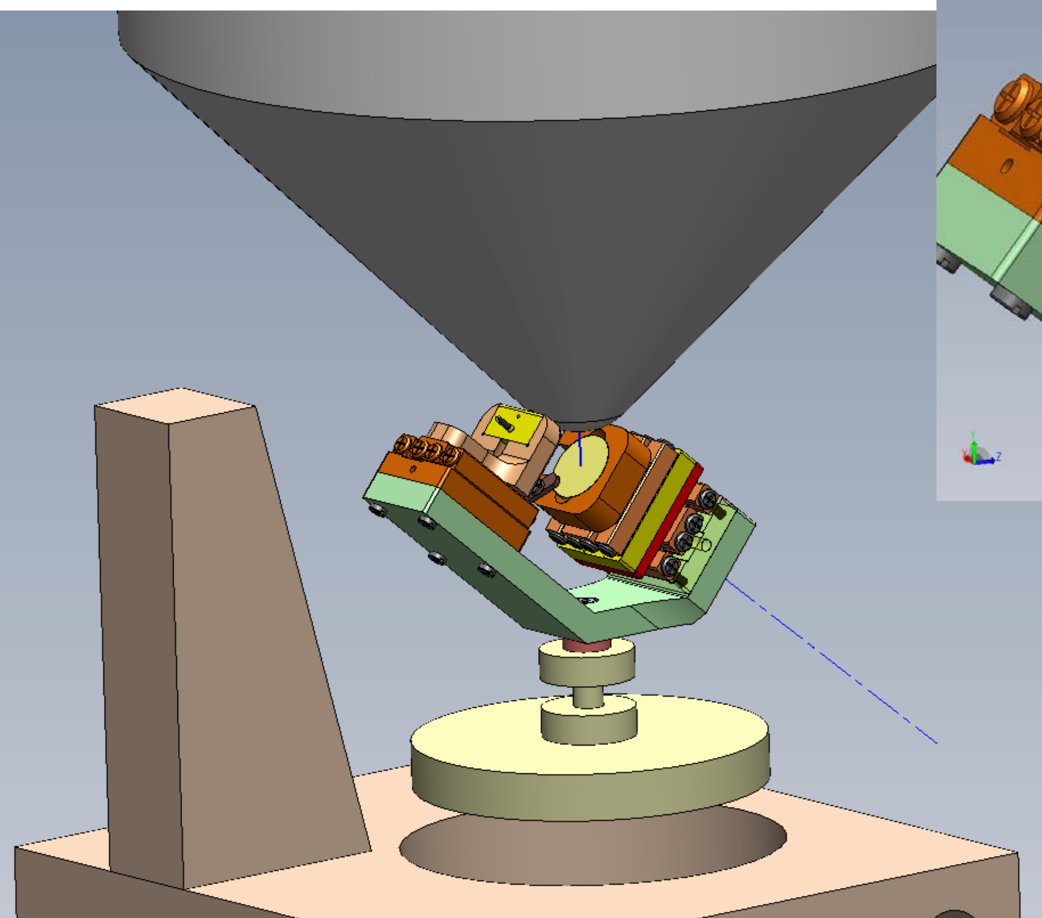
- The onset voltages where the measured current exceeded 10 nA were varied from 300 V to over 1000 V.
- The onset voltages were decreased at subsequent runs at most of spots.
- Average V_{onset} didn't correlate to the work function of each grain orientations, but to the reduced WF.

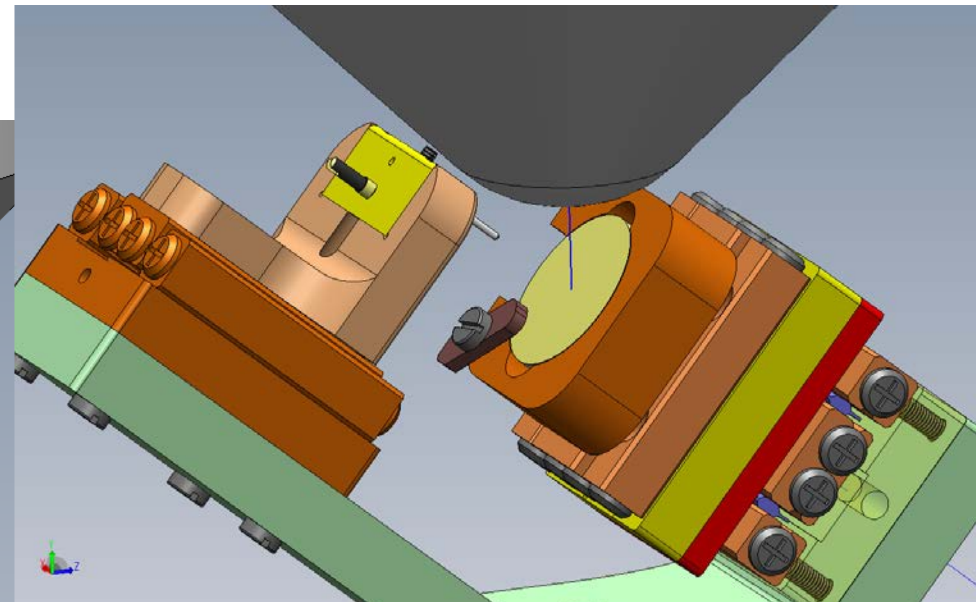
Summary: field emission measurements

- We are now finally able to perform local field emission measurement.
- Experimental results shows that local emission behavior couldn't be completely described by F-N equation.
- In order to study any dependences of emission behavior, more statistics are required.

Outlook: field emission measurements

- Remotely controlled sample stage is now (almost) available. Setting up and first experiments in Oct. 2012.





Drawings: courtesy of M. Noor, UU

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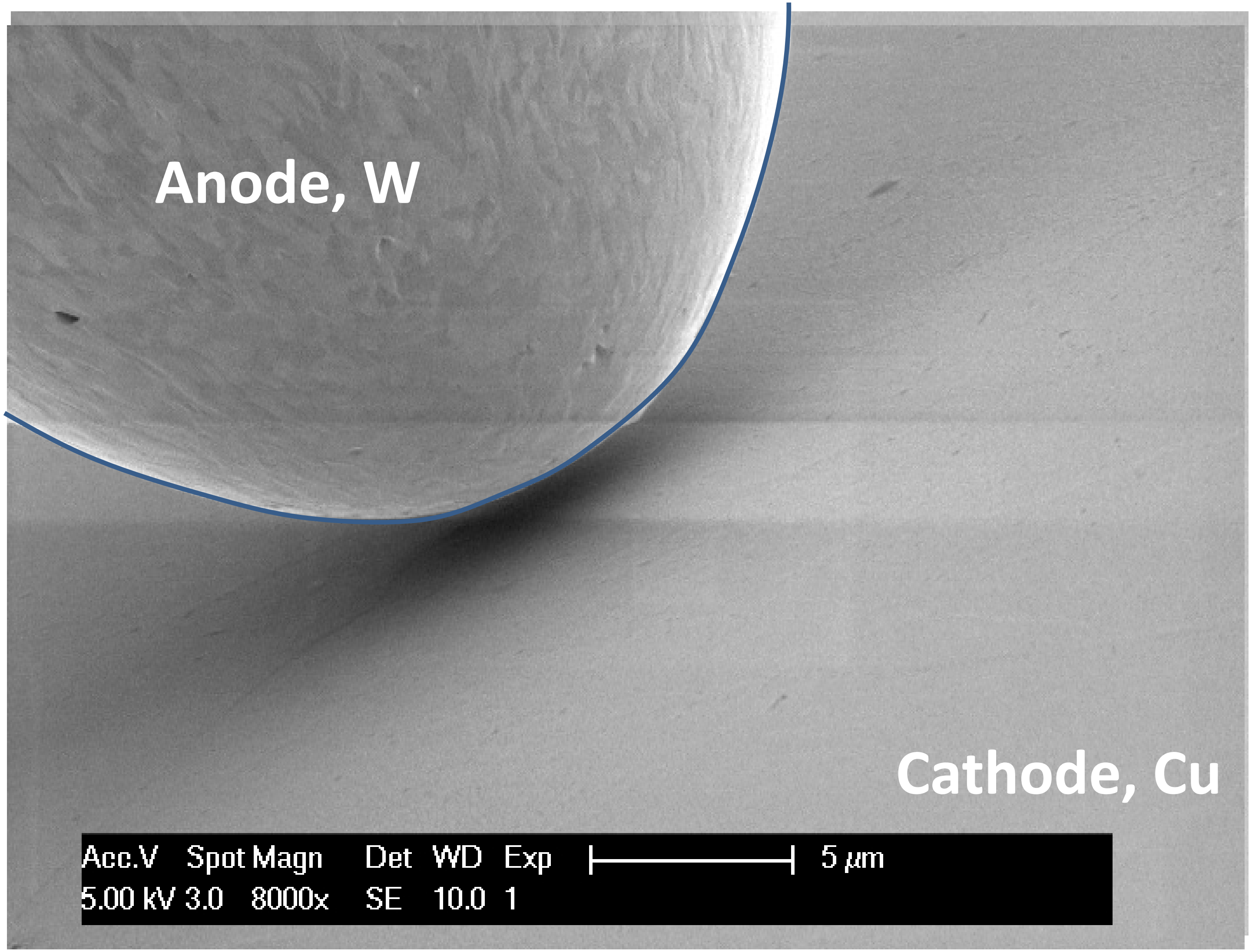
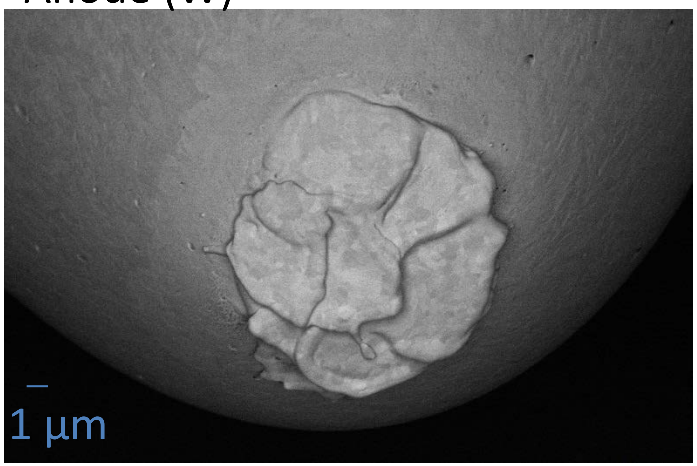
Cathode and anode damage observation

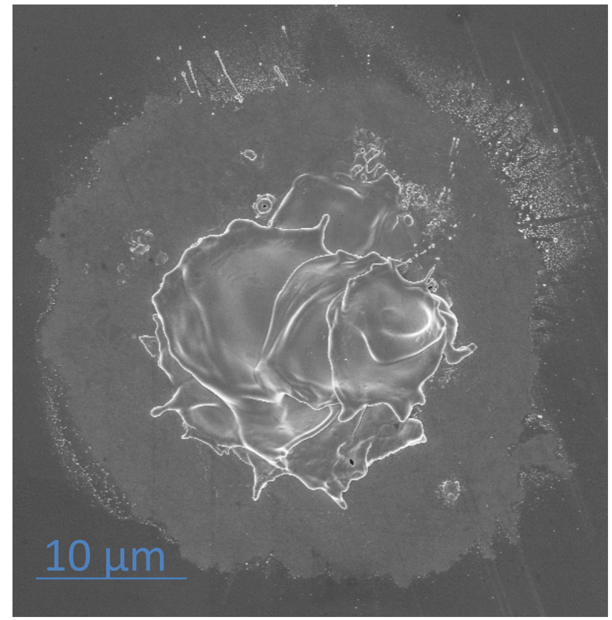


Cathode and anode damage observation

Anode (W)



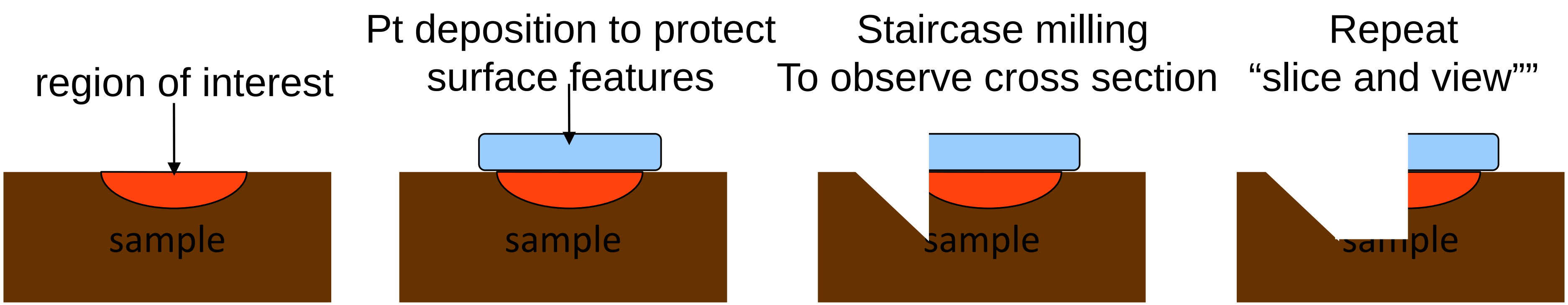
Cathode (Cu)

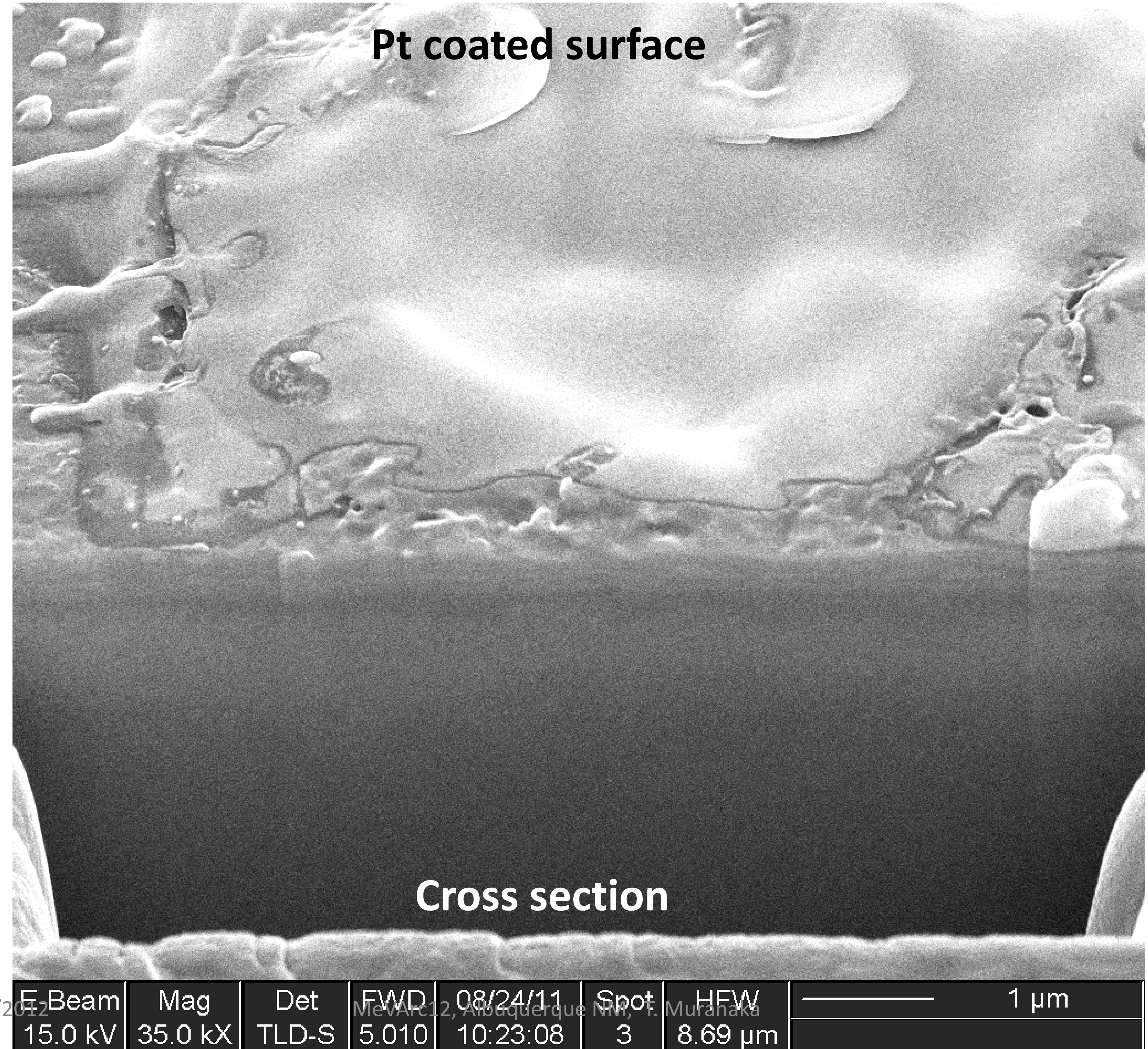


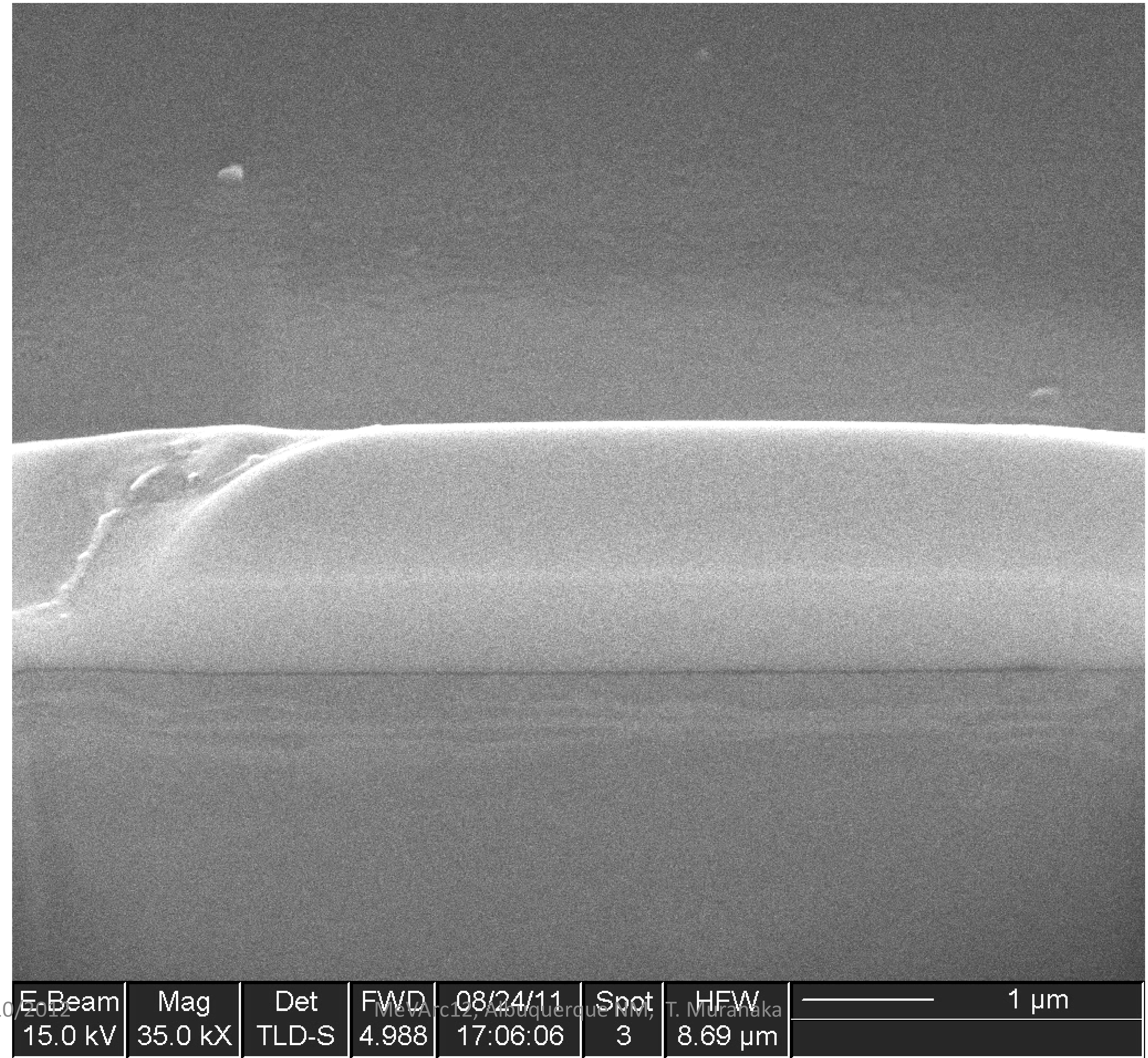
- Cathode: Main craters (d≈20µm), Sub craters, Halo, Splashes, Ripple, W particles.
- Anode: Craters (d≈13µm), , Halo. (no Cu particle found)

Sub-surface observation

- Cross section observation under the crater using "Slice and View" method (inspired by F. Soldera's presentation at MeVArc '11).
- 1st one: Damaged area due to a few BDs
- 2nd one: Pristine area (randomly chosen)




Pt coated surface
Cross section
E-Beam 15.0 kV
Mag 35.0 kX
Det TLD-S
FWD 5.010
08/24/11 10:23:08
Spot 3
HFW 8.69 µm
1 µm


E-Beam
15.0 kV
Mag
35.0 kX
Det
TLD-S
FWD
4.988
08/24/11
17:06:06
Spot
3
HFW
8.69 μm
1 μm

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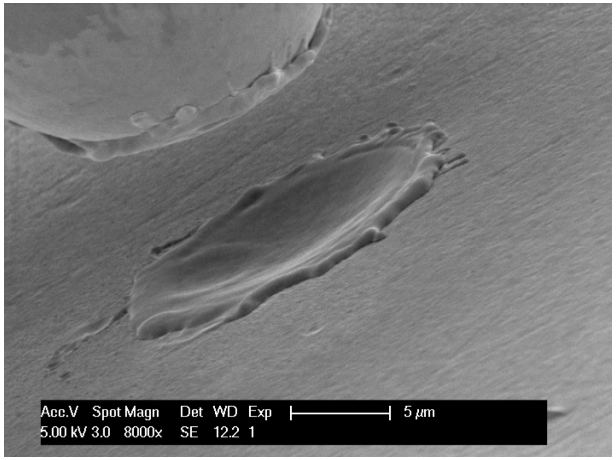
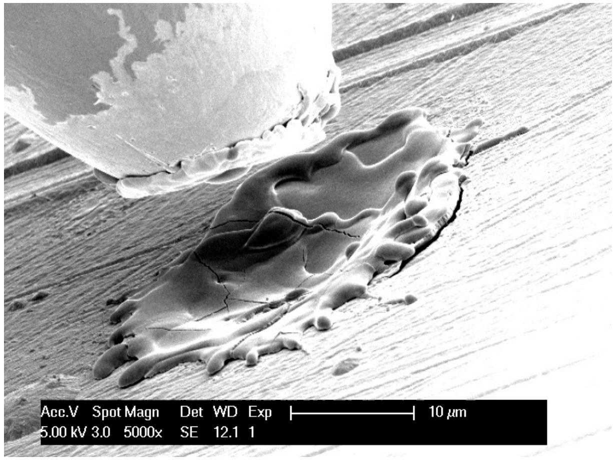
Collaborations/ applications

- Cr, CrN cathode (provided by ABB)





EuCARD-REP-2012-001, http://cdsweb.cern.ch/record/1428134?ln=en

- **And you! – the whole setup is available in Uppsala. Or, FE system is possibly rented out.**

Co-workers

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Tobias Blom

Mechanical drawing and manufacture

Masih Noor

Lars-Erik Lindquist

25 Feb. 2012, Abisko, Sweden

Thank you!