



UNIVERSITY OF TARTU



MATTER

Characterization of Cu electrodes after vacuum breakdown with AFM and SEM

9th International Workshop on
Mechanisms of Vacuum Arcs (MeVArc
2021)

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POSTDOCTORAL RESEARCHER

09.03.2021



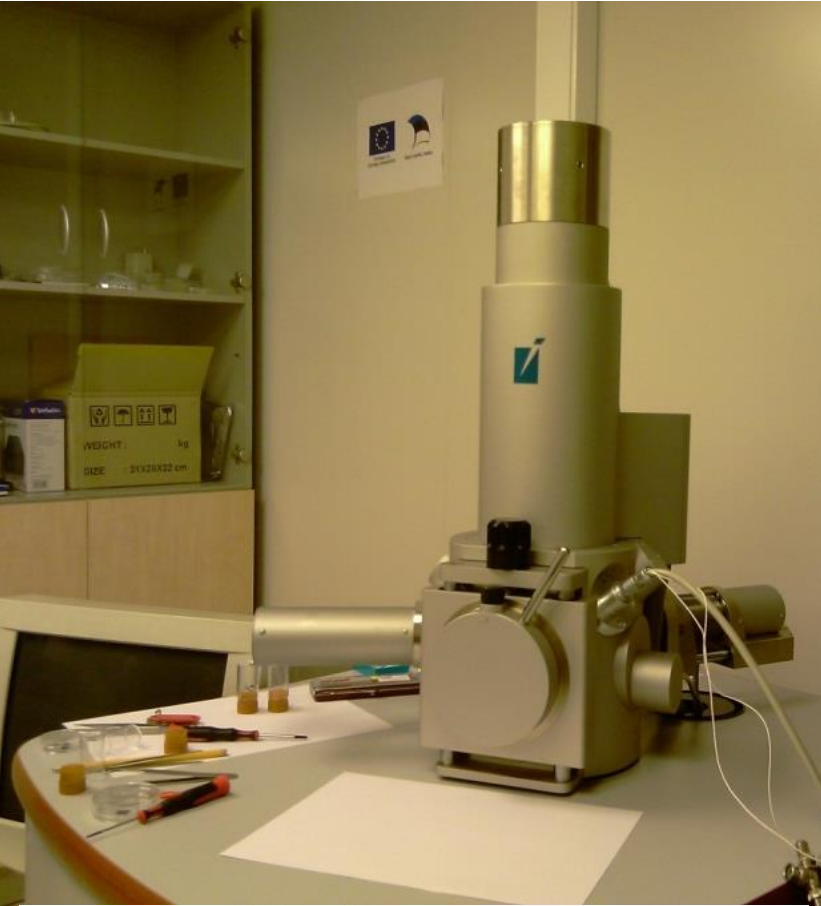
Introduction

We have received a pair of Cu electrodes from Helsinki.

Backside was removed by turning.

Aim was to characterize with SEM and AFM.

All experiments were done on cathode. We haven't looked at anode yet.



SEM

Vega-II SBU TESCAN

Applied voltage 10 kV.

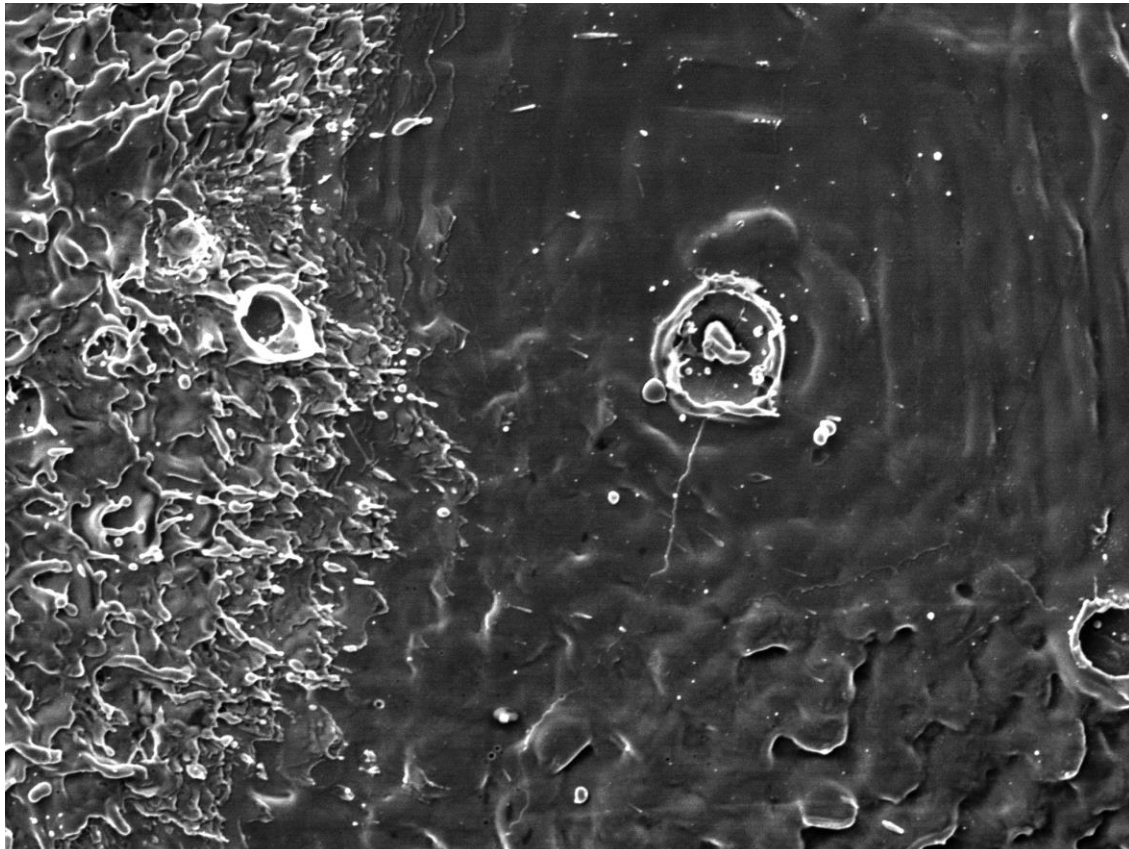
Pressure around $4 \cdot 10^{-4}$ mbar

Stage can be tilted up to 20 deg.



Center structure

A particle like structure in the middle of the crater (but not always).

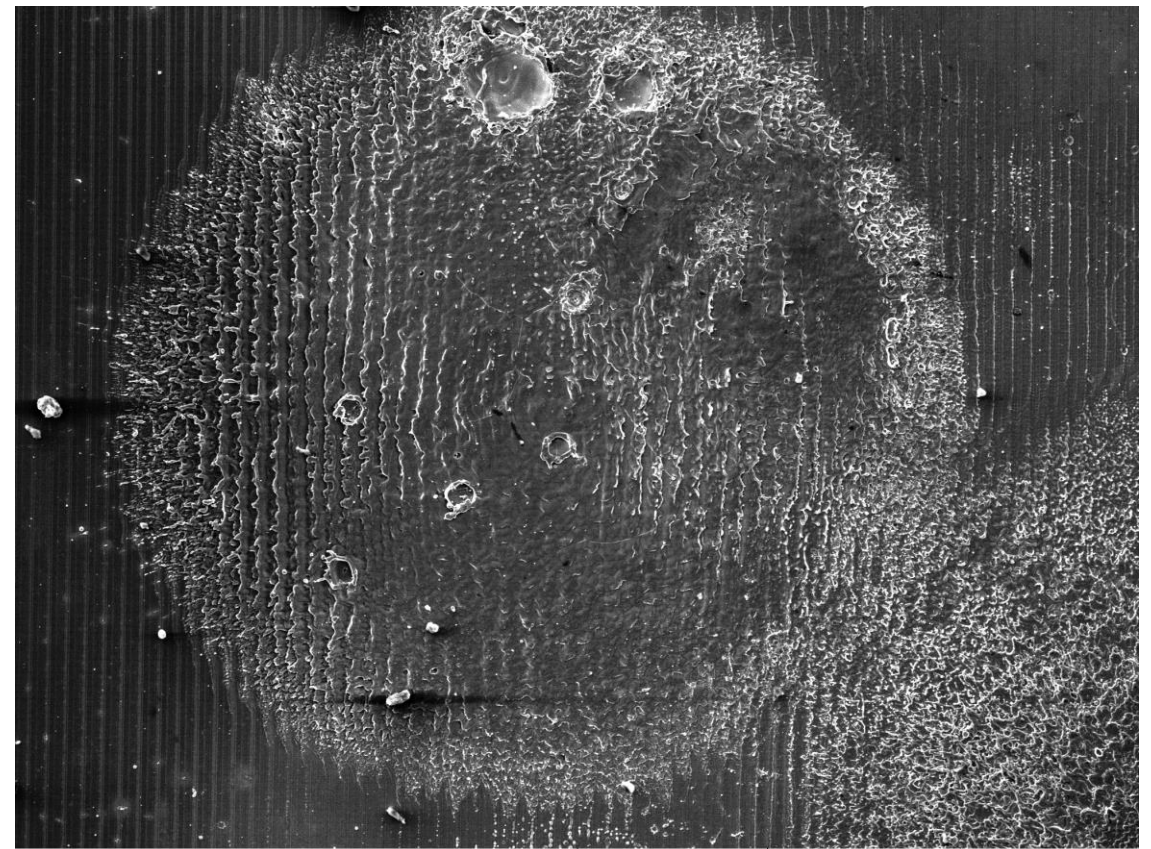


SEM HV: 10.00 kV WD: 22.9890 mm
View field: 84.84 μm Det: SE
Date(m/d/y): 03/07/21 Sergei

20 μm

VEGA\\ TESCAN

Performance in nanospace



SEM HV: 10.00 kV WD: 23.0030 mm
View field: 295.9 μm Det: SE
Date(m/d/y): 03/07/21 Sergei

50 μm

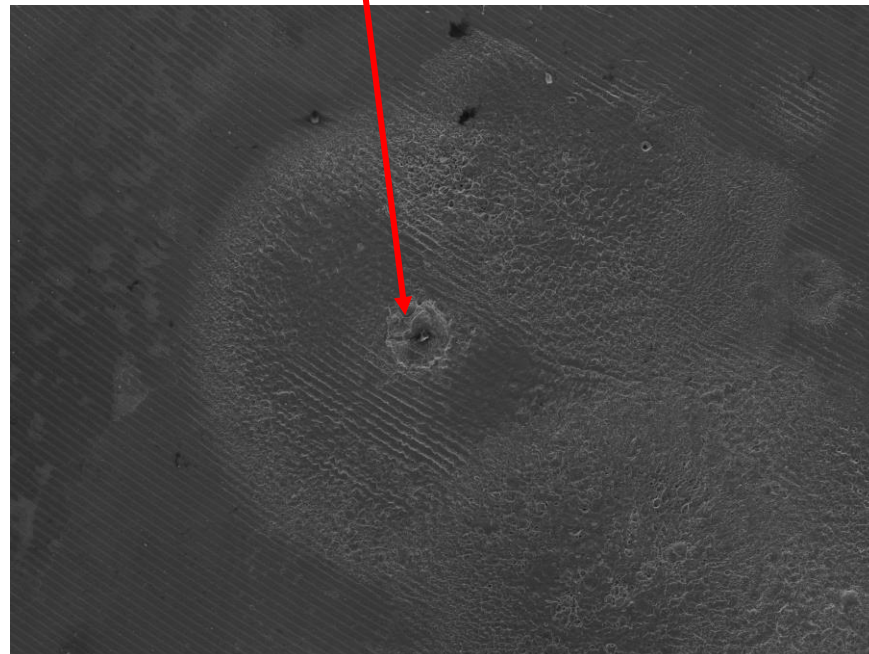
VEGA\\ TESCAN

Performance in nanospace

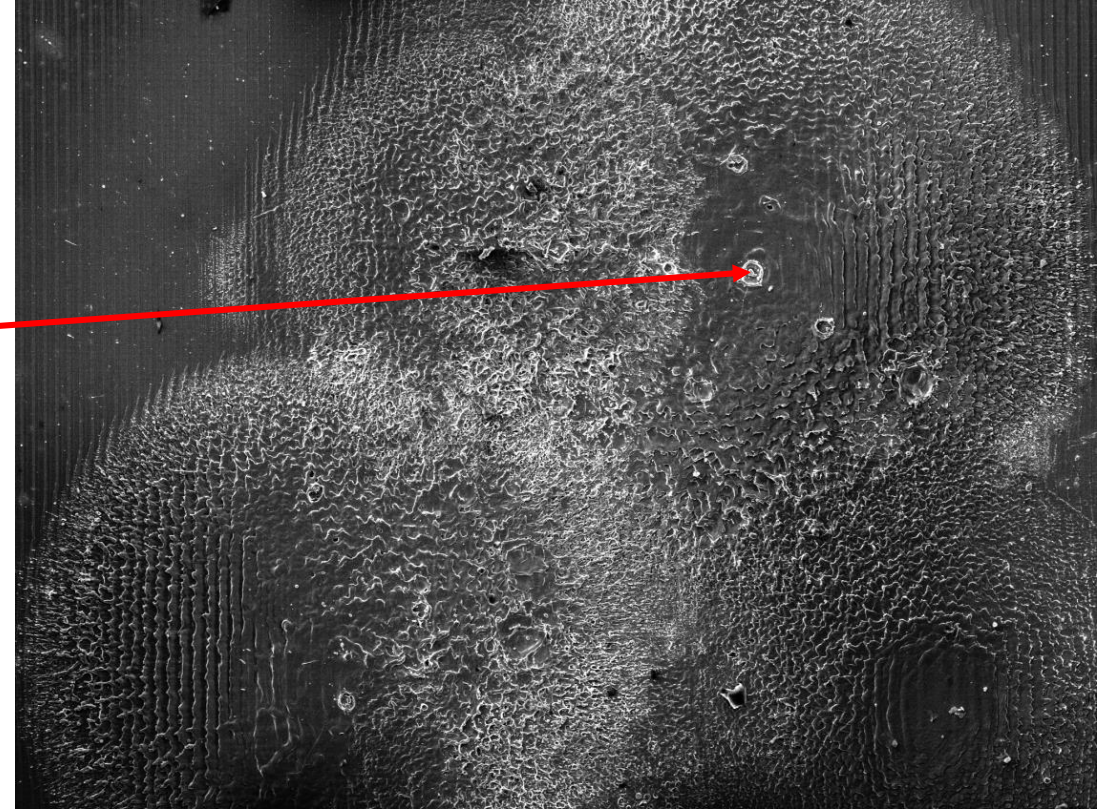
Protrusions

Usually no protrusions in the center area of the crater.

The width of the protrusion-free area can vary.



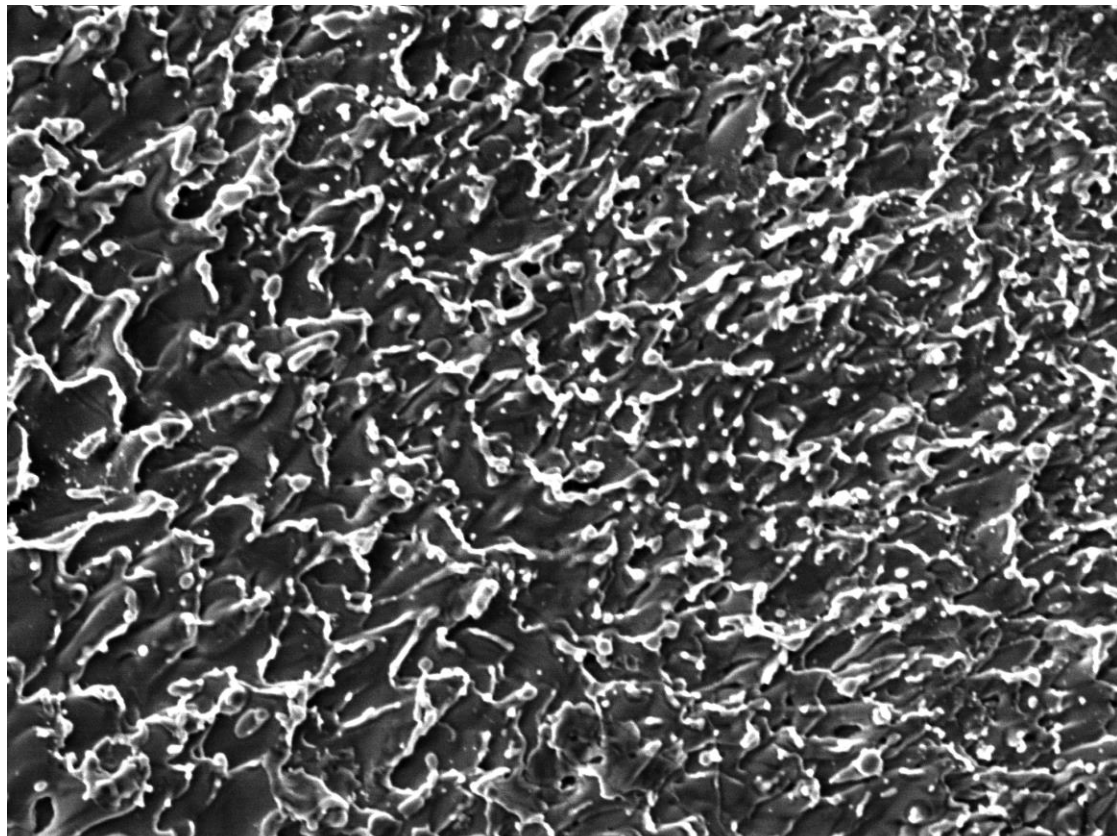
SEM HV: 10.00 kV WD: 9.2488 mm
View field: 507.8 μm Det: SE
Date(m/d/y): 12/11/20 Sergei
Performance in nanospace



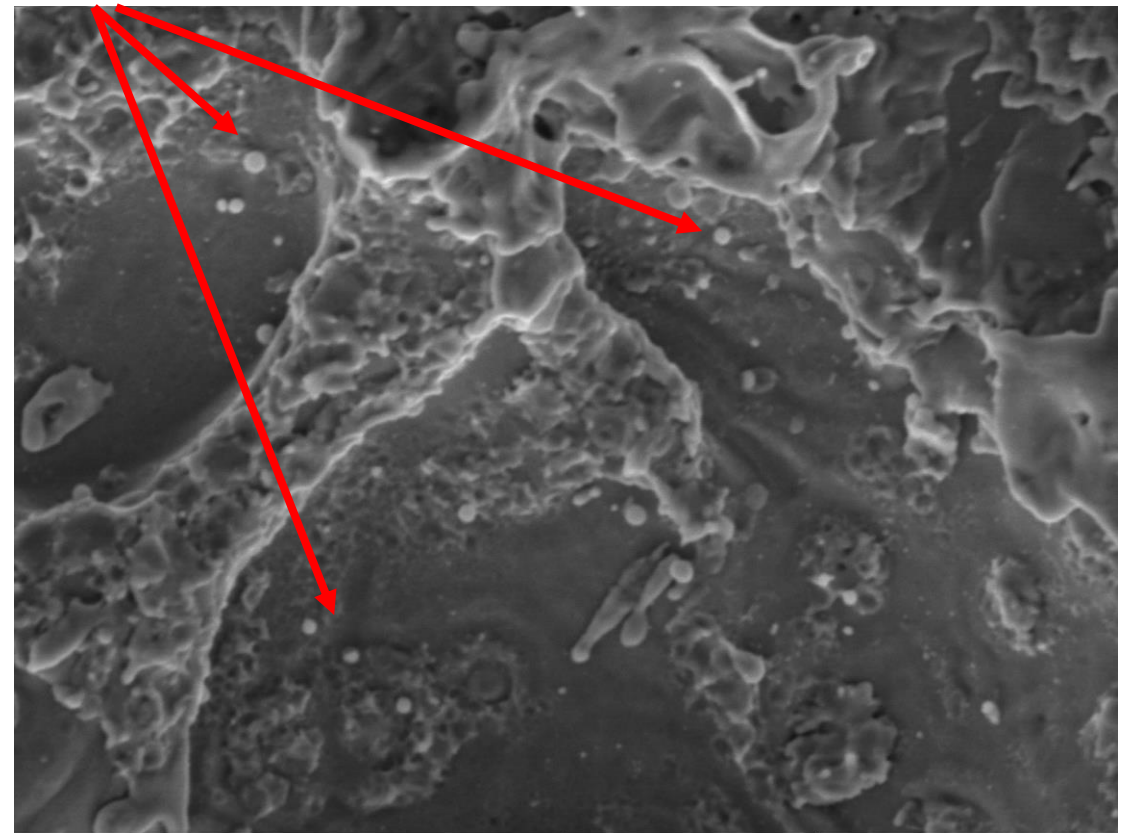
SEM HV: 10.00 kV WD: 22.9870 mm
View field: 445.6 μm Det: SE
Date(m/d/y): 03/07/21 Sergei
Performance in nanospace

Protrusions and particles

The sides of the crater are filled with various protrusions.
In some cases there are some ball-like particles.



SEM HV: 10.00 kV WD: 23.0830 mm
View field: 59.22 μm Det: SE
Date(m/d/y): 03/07/21 Sergei
Performance in nanospace



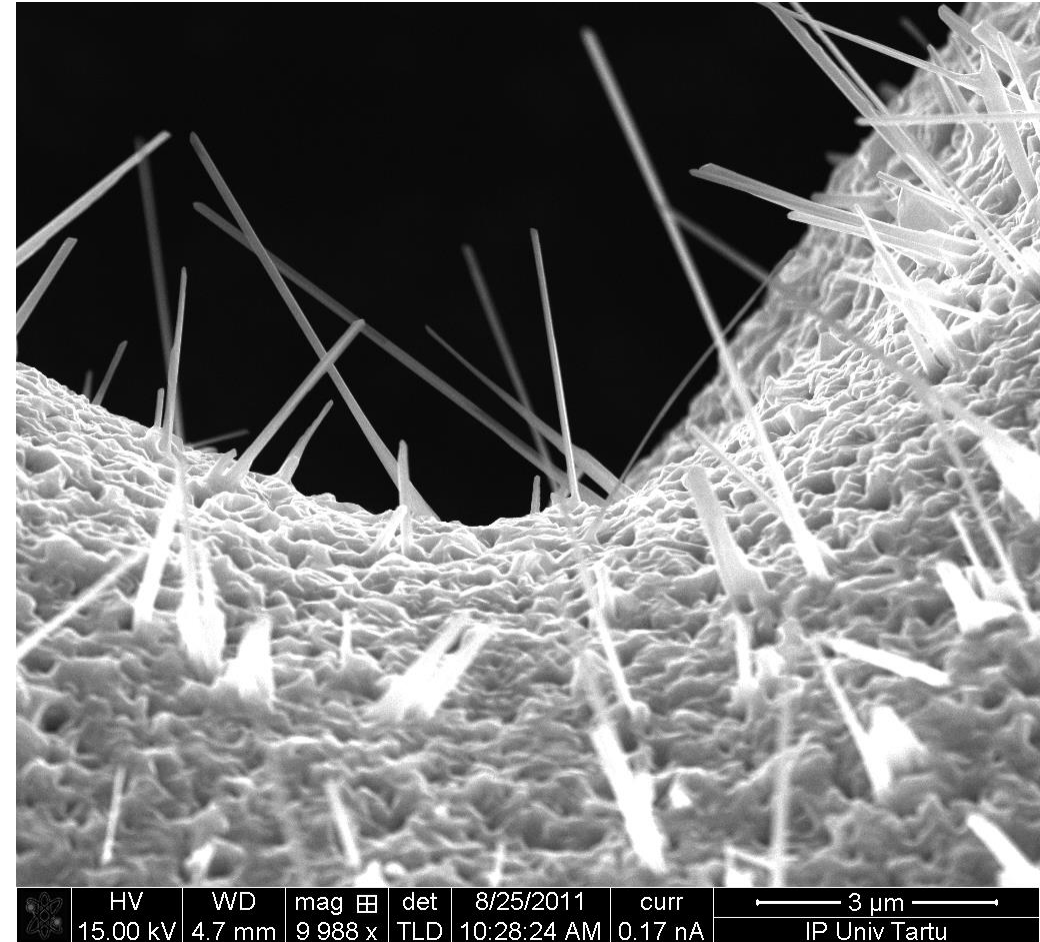
SEM HV: 10.00 kV WD: 9.2222 mm
View field: 22.31 μm Det: SE
Date(m/d/y): 12/11/20 Sergei
Performance in nanospace

Growth of CuO nanowires

Another candidate for protrusions:

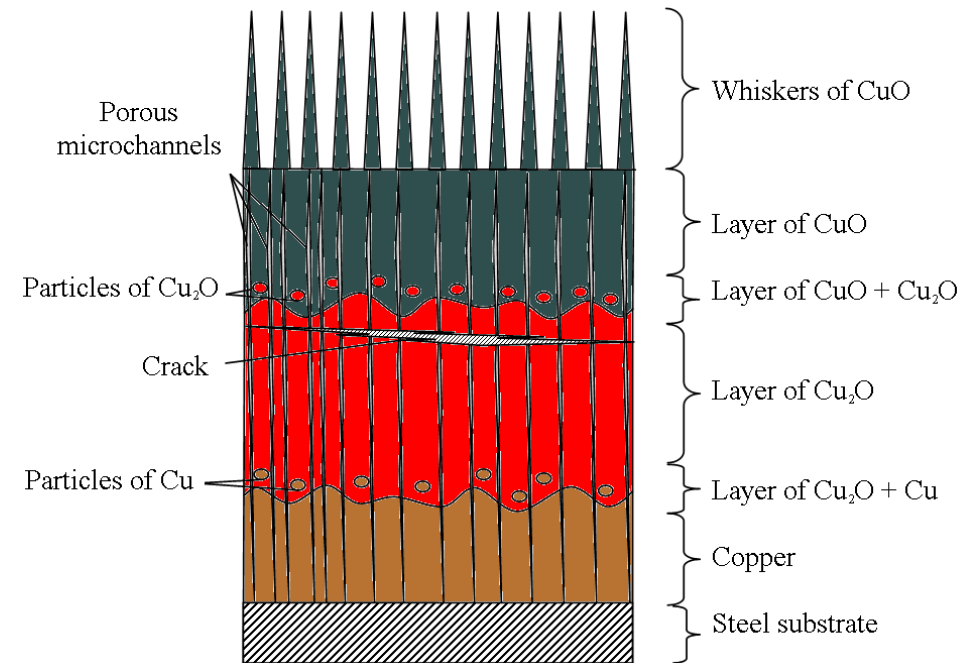
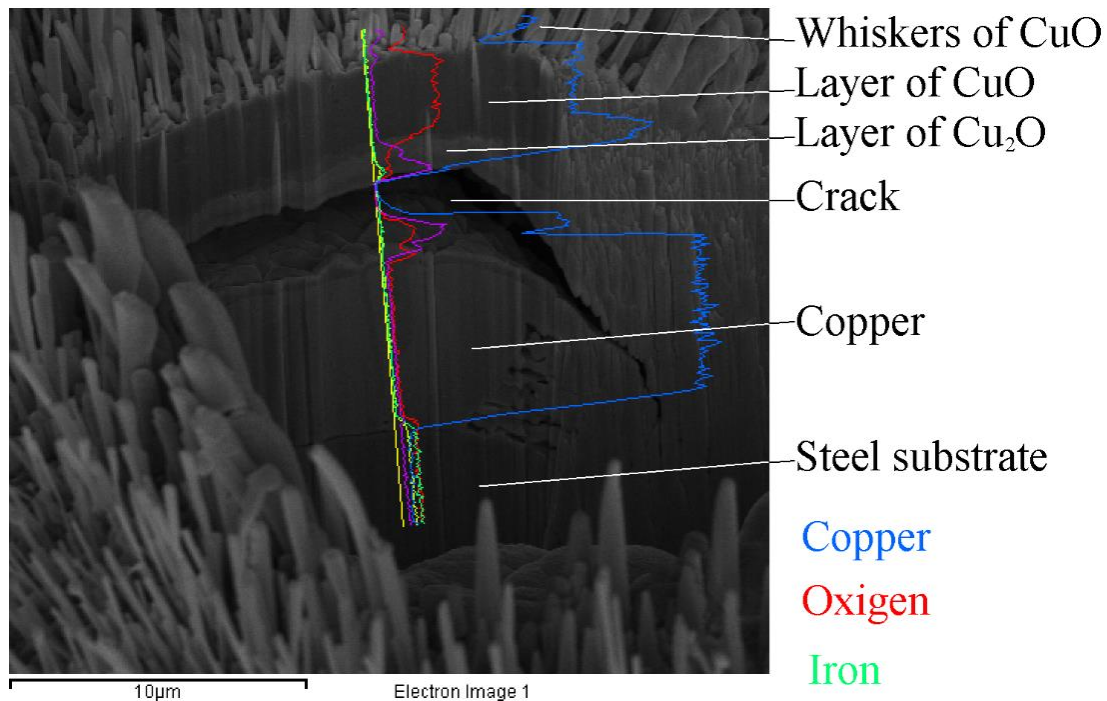
CuO NWs can be synthesized by heating Cu in air. **Nano Lett., Vol. 2, No. 12, 2002**

Temperatures 400°-700° results in NWs.
Higher temperatures produces particles.



Cu sample with CuO nanowires:

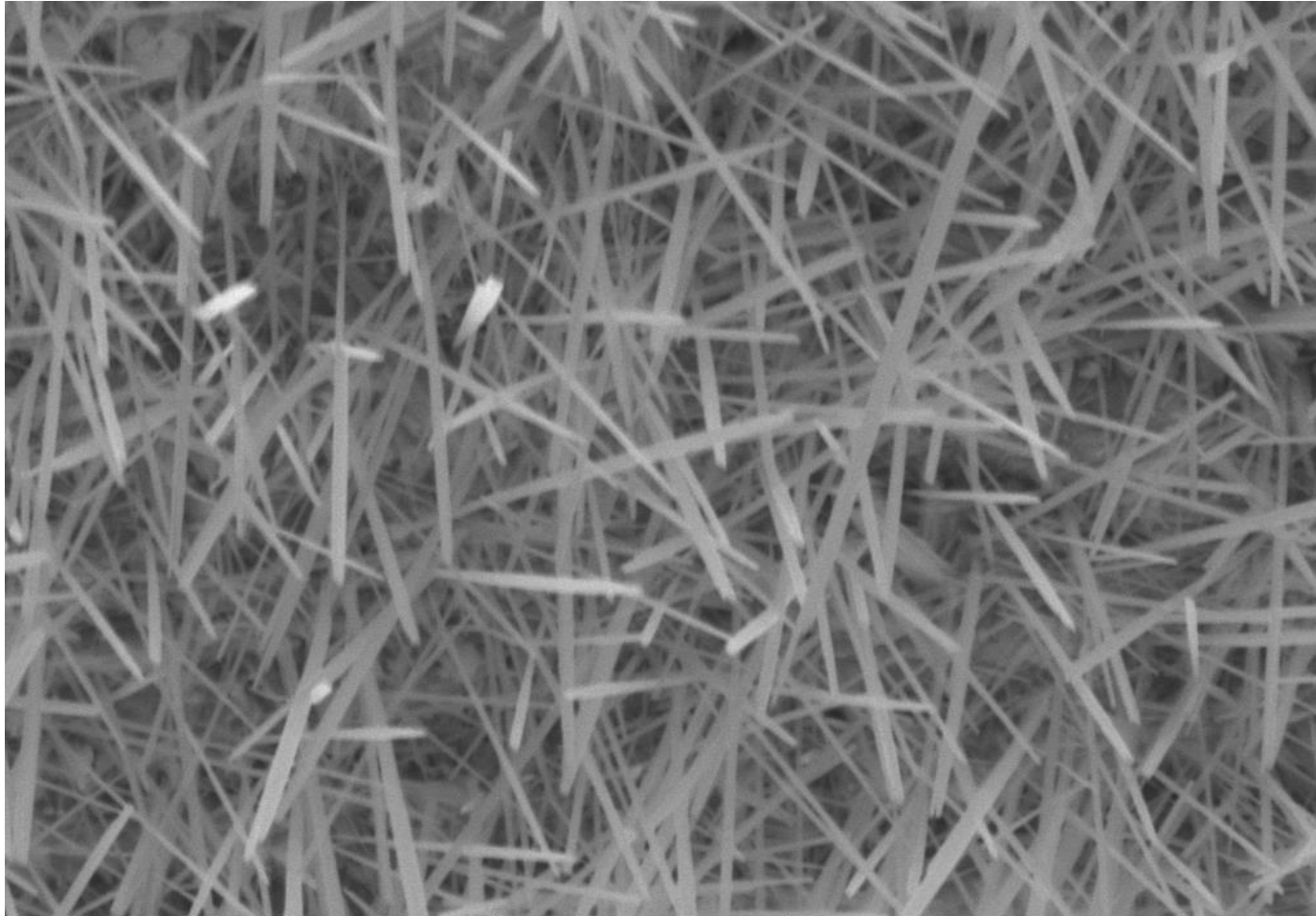
inner structure after heat-treatment
Cut by FIB, analysed by EDX (NSFL, IPUT)






Dorogov, et. al, *Appl. Surf. Sci.* **246**, 423 (2015).

SEM tungsten filament

Tungsten Oxide NWs grown on burnt tungsten filament used in SEM



	HV 10.00 kV	WD 4.0 mm	mag  15 004 x	det ETD	10/10/2011 12:45:08 PM	curr 0.17 nA	 2 μ m IP Univ Tartu
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Estimating the amount of molecules in CLIC

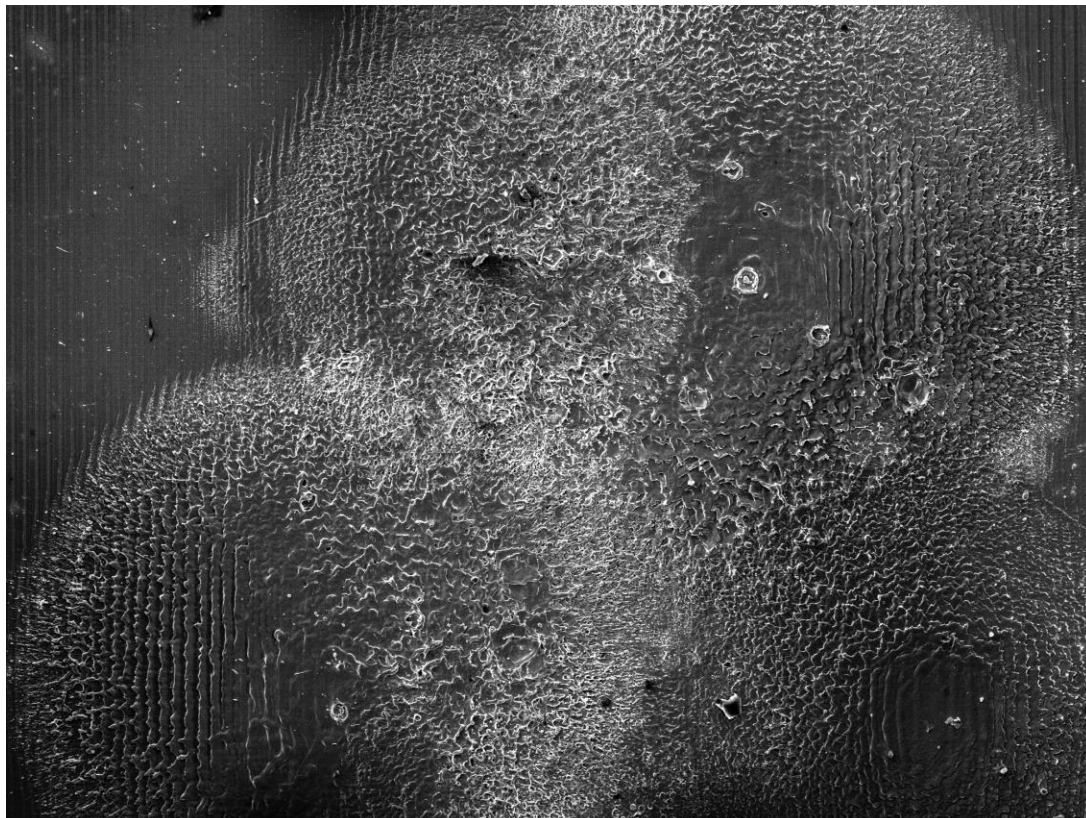
$$T = 293K$$

$$P = 10^{-9}mbar$$

$$\frac{n}{V} = \frac{P}{R \cdot T} = 2^{14} \frac{\text{molecules}}{m^3}$$

Clustering of craters

Can protrusions in craters cause next breakdown?

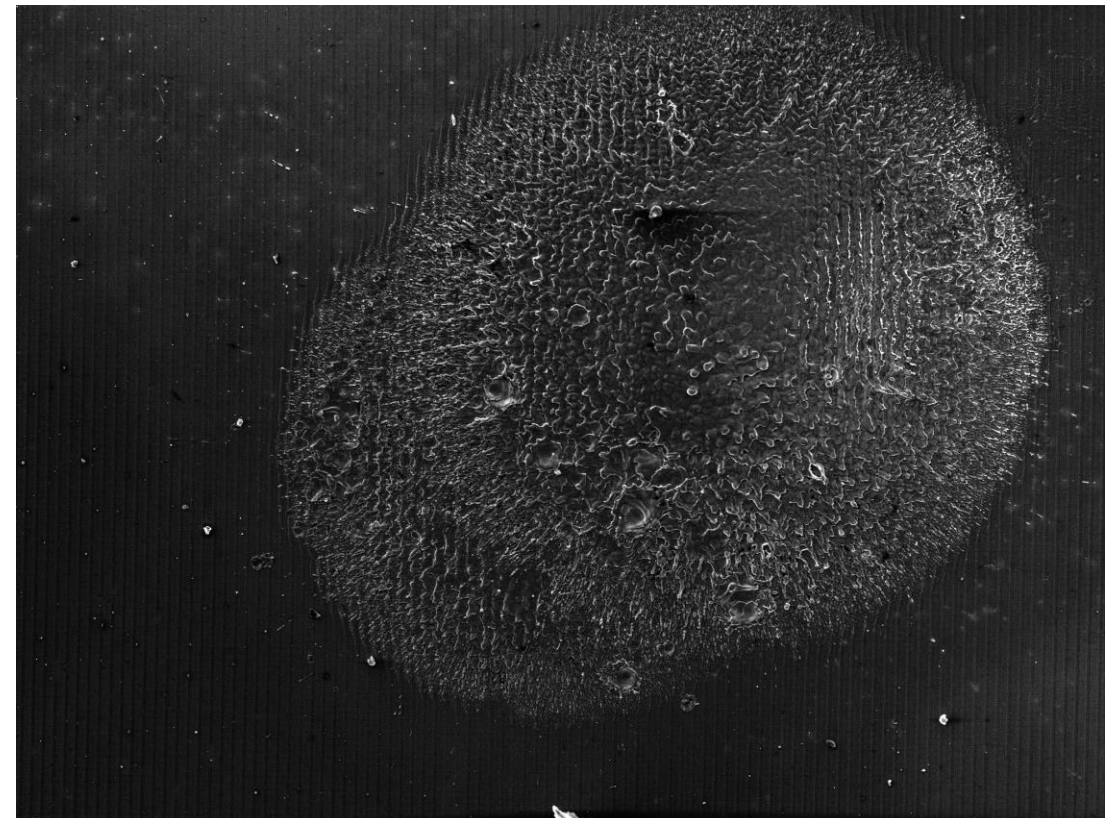


SEM HV: 10.00 kV WD: 22.9870 mm
View field: 445.6 μm Det: SE
Date(m/d/y): 03/07/21 Sergei

100 μm

VEGA\\ TESCAN

Performance in nanospace



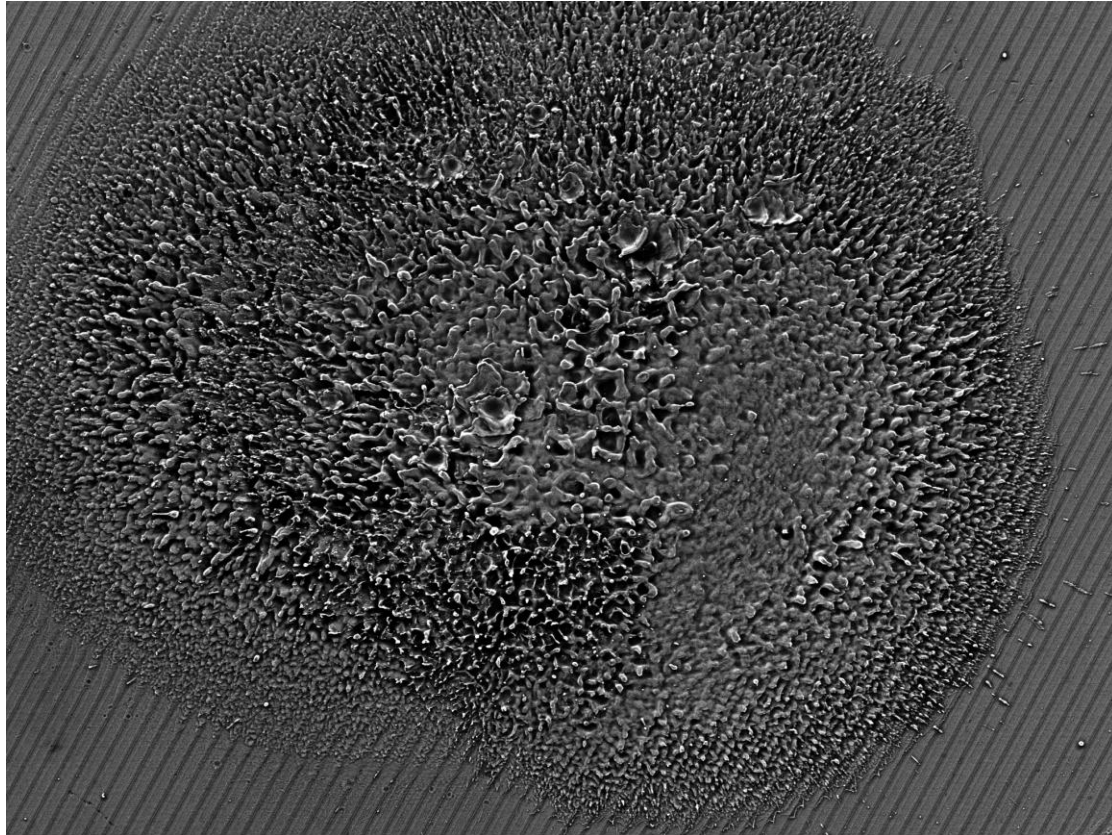
SEM HV: 10.00 kV WD: 23.2460 mm
View field: 485.1 μm Det: SE
Date(m/d/y): 03/07/21 Sergei

100 μm

VEGA\\ TESCAN

Performance in nanospace

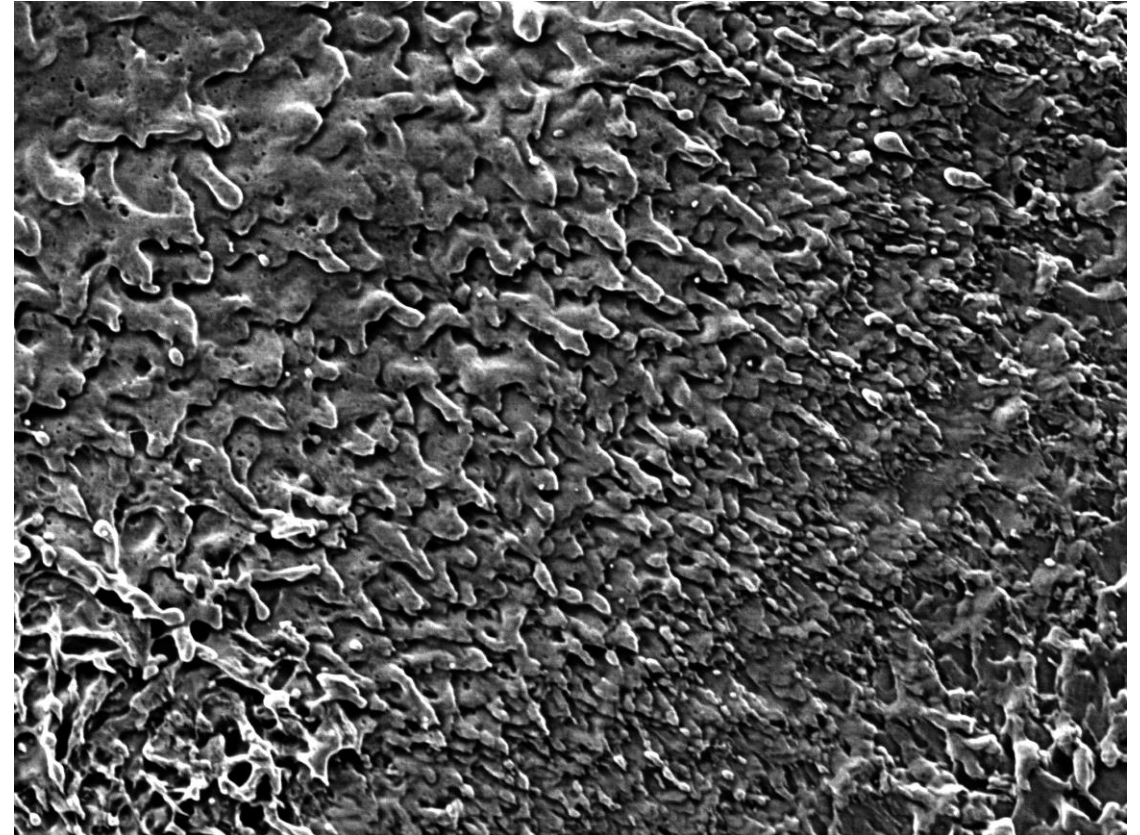
Portrusions at 20° angle



SEM HV: 10.00 kV WD: 22.5680 mm
View field: 312.5 μm Det: SE
Date(m/d/y): 03/07/21 Sergei

50 μm

VEGA\\ TESCAN
Performance in nanospace



SEM HV: 10.00 kV WD: 22.6590 mm
View field: 83.57 μm Det: SE
Date(m/d/y): 03/07/21 Sergei

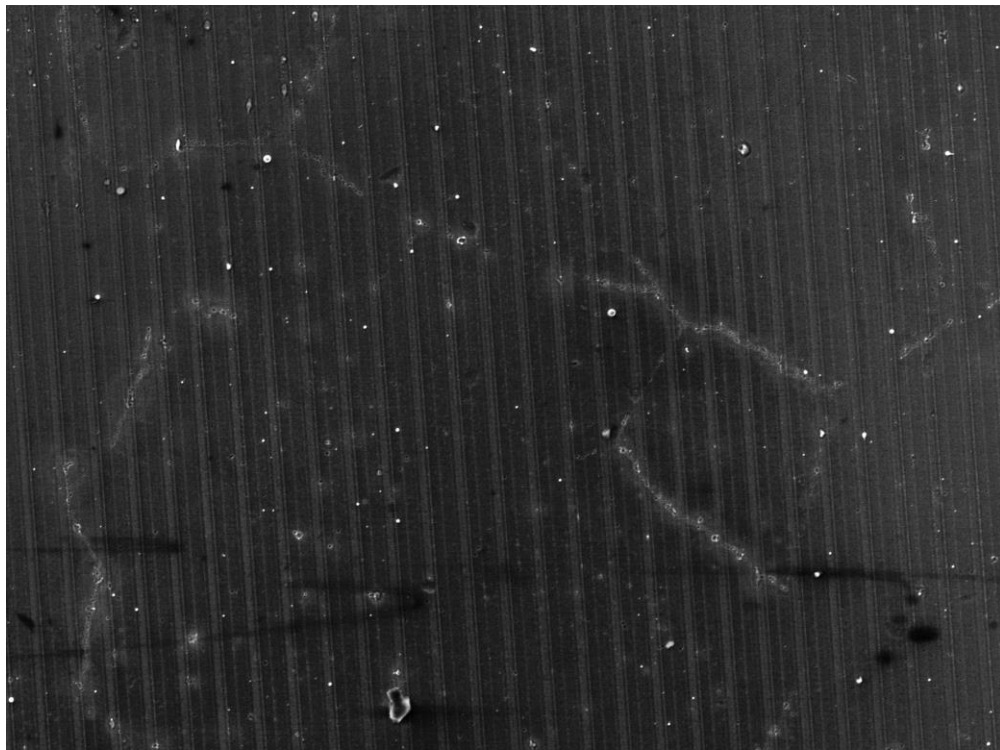
20 μm

VEGA\\ TESCAN
Performance in nanospace

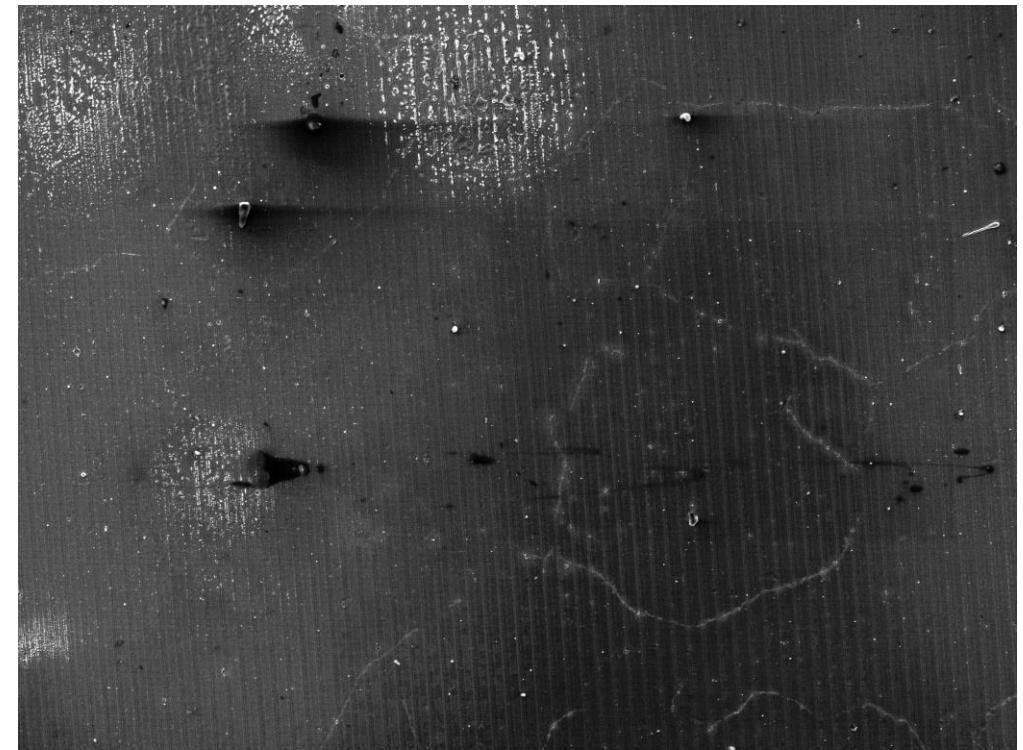
Lines

Lines in some places on the electrode.

They seem to be formed of smaller particles.



SEM HV: 10.00 kV WD: 23.0810 mm
View field: 136.9 μm Det: SE
Date(m/d/y): 03/07/21 Sergei
20 μm VEGA\\ TESCAN
Performance in nanospace



SEM HV: 10.00 kV WD: 23.0810 mm
View field: 321.4 μm Det: SE
Date(m/d/y): 03/07/21 Sergei
100 μm VEGA\\ TESCAN
Performance in nanospace

AFM



Allows mapping of topology.

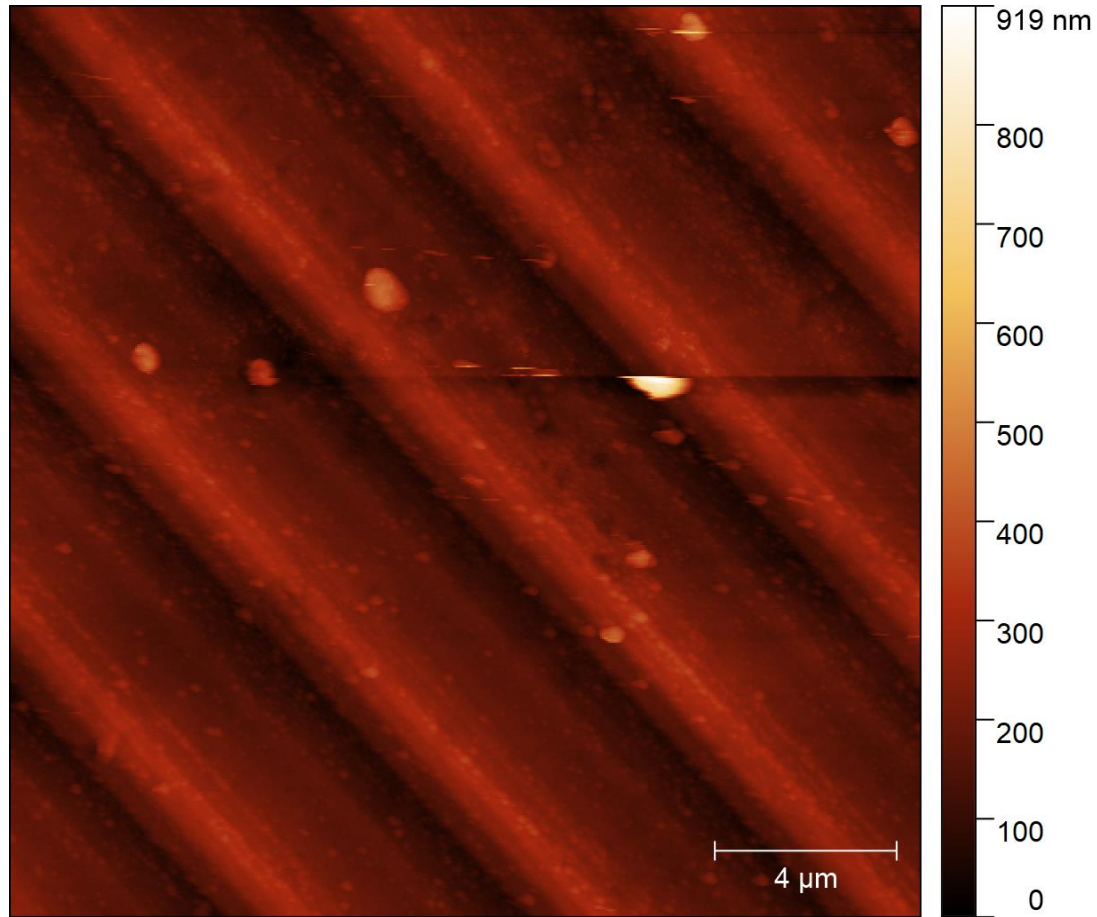
Ambient conditions.

Equipped with kelvin probe – allows mapping of work function on the sample.

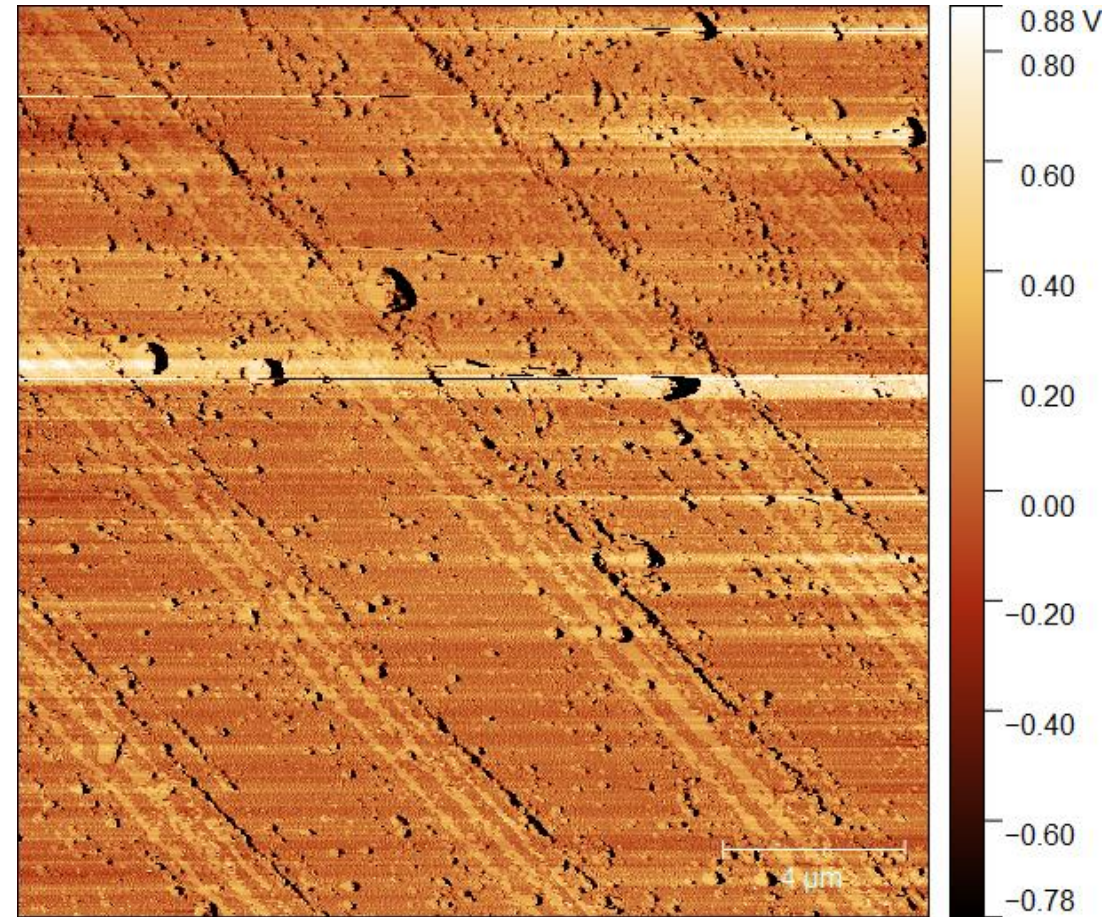
3 types of surfaces were mapped:

- Plain surface
- Crater edge
- Crater

Plain surface topography & surface potential

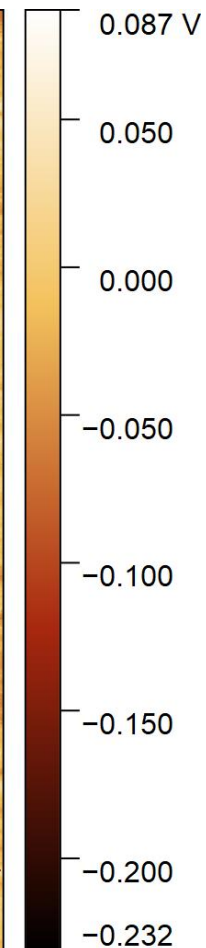
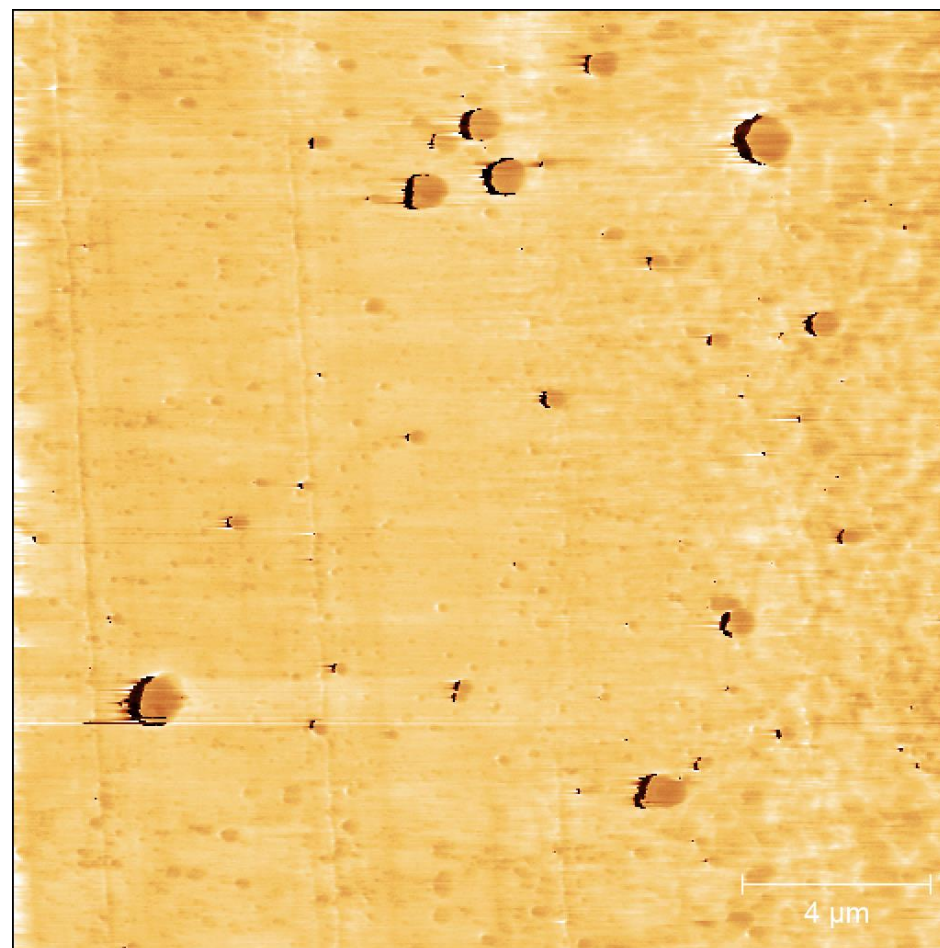
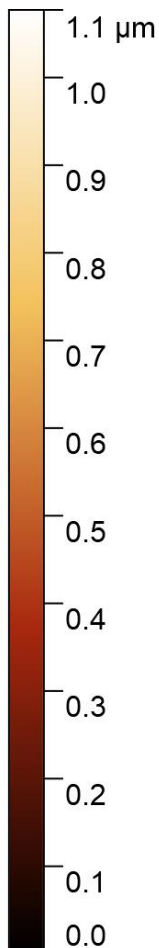
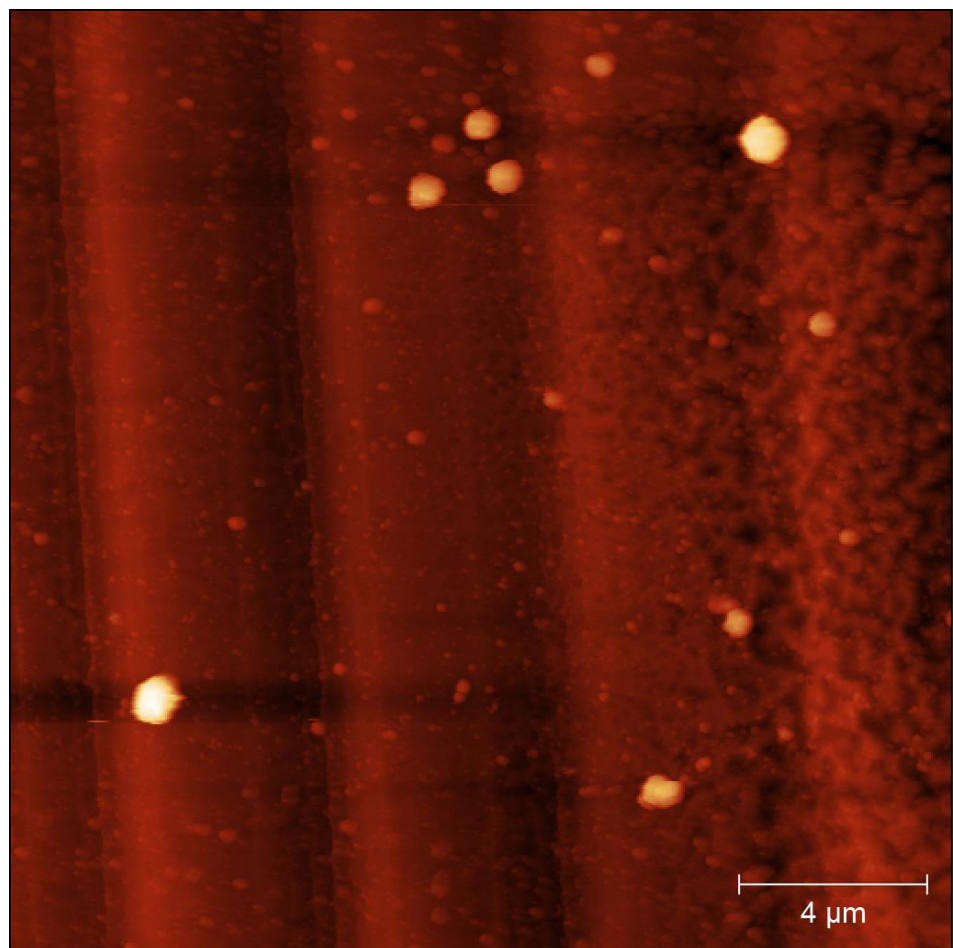


Topography



Potential image

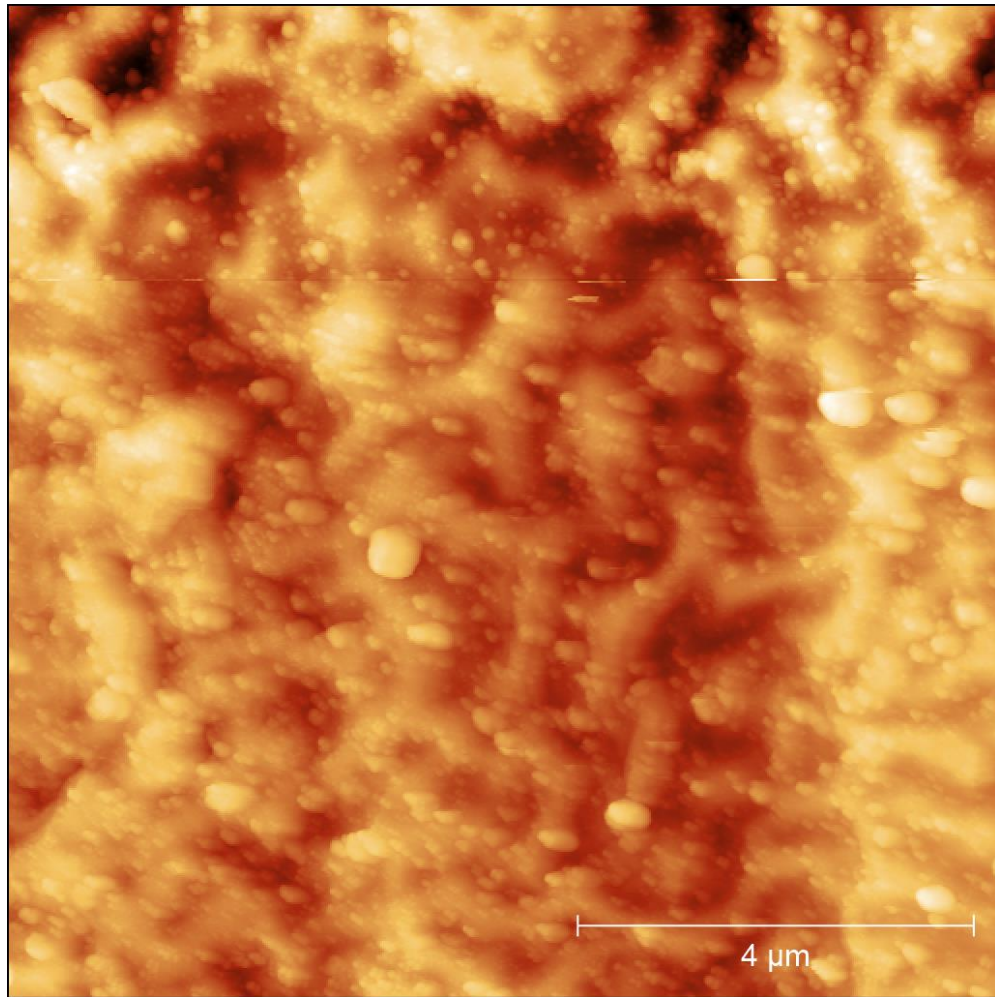
Crater edge topography & potential



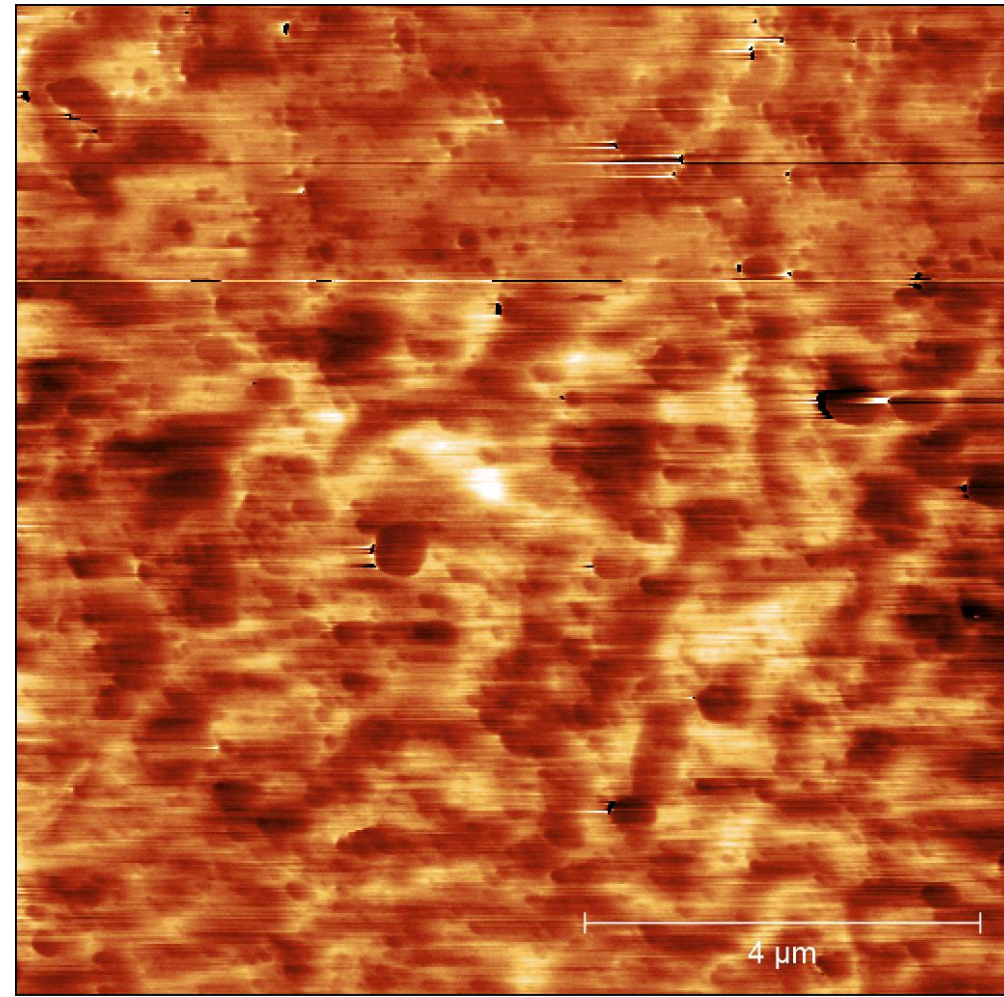
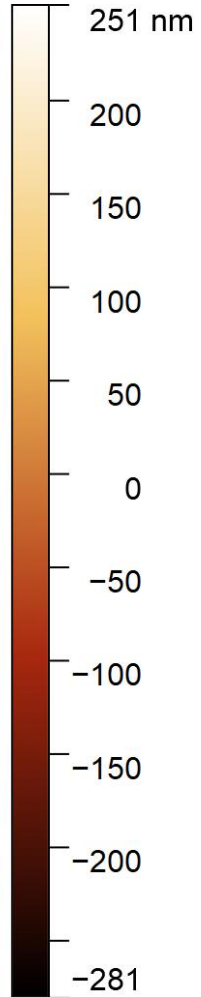
Topography

Potential image

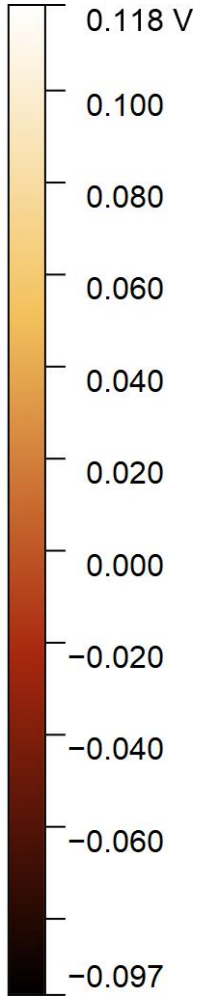
Crater topo vs potential



Topography

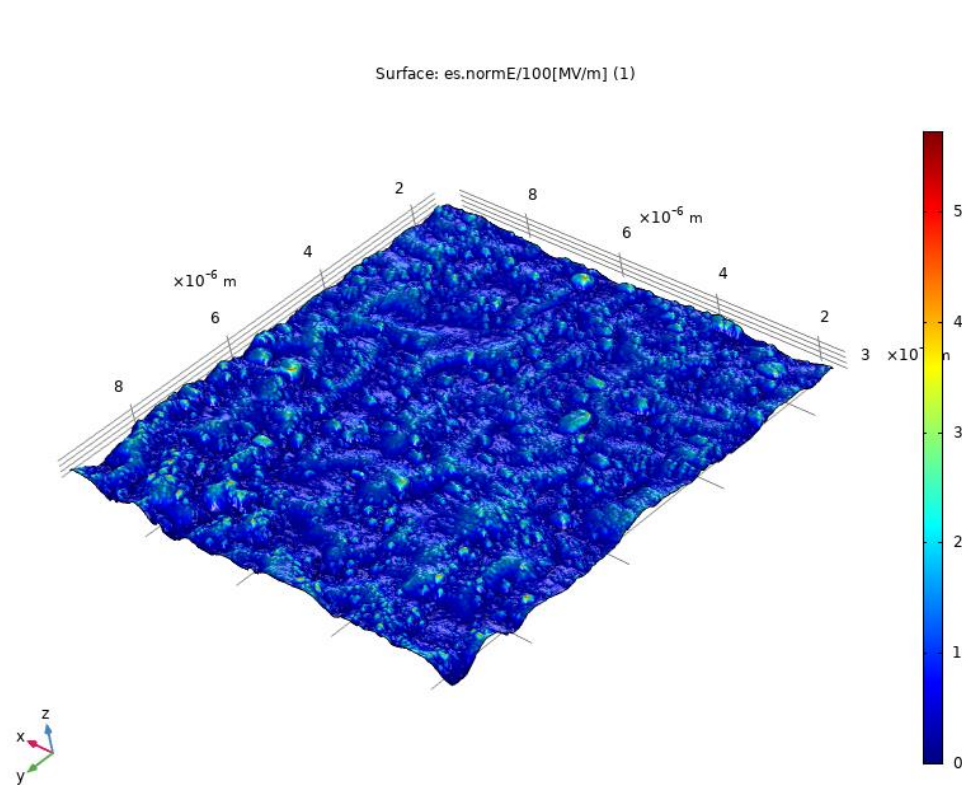
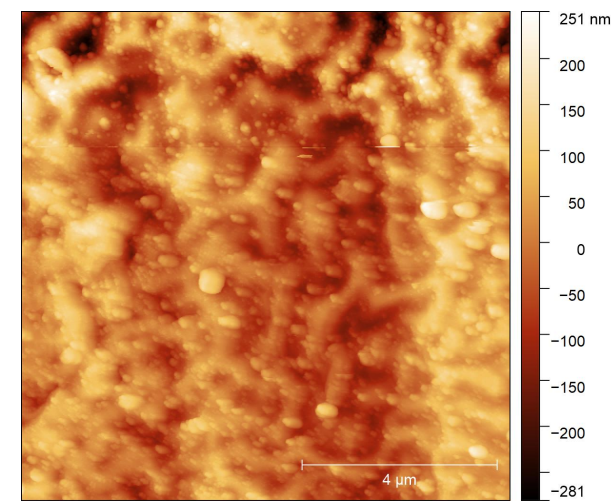


Potential image

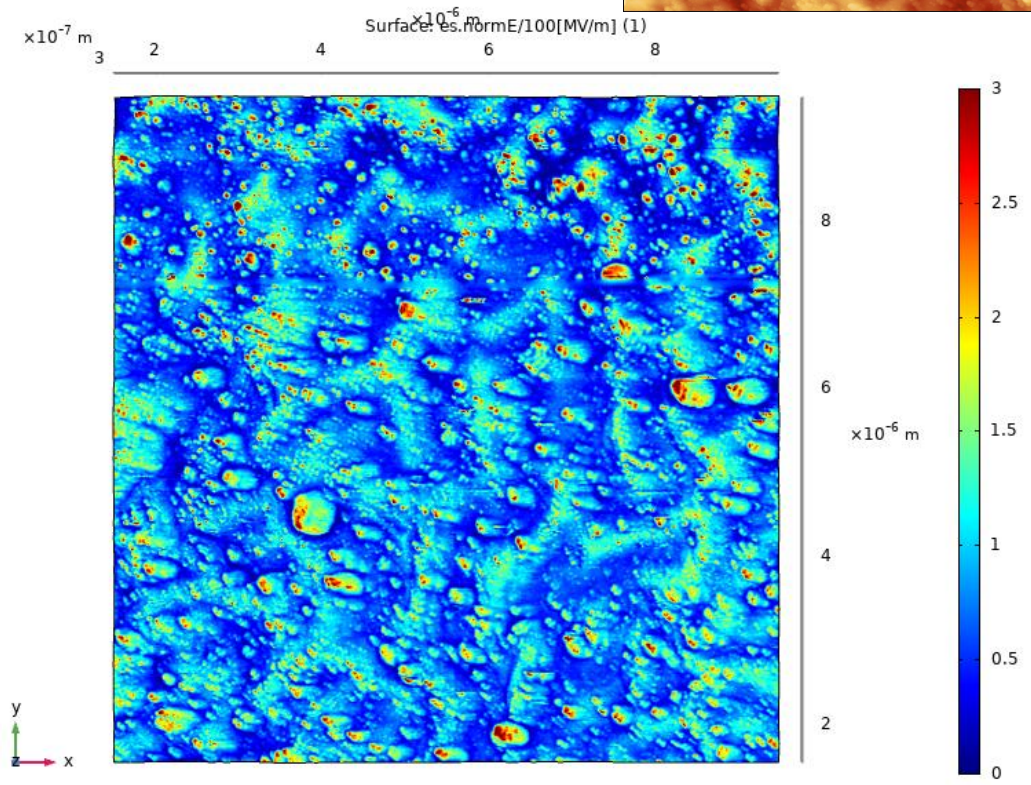


Field enhancement image

Field enhancement up to 5 times due to topology.



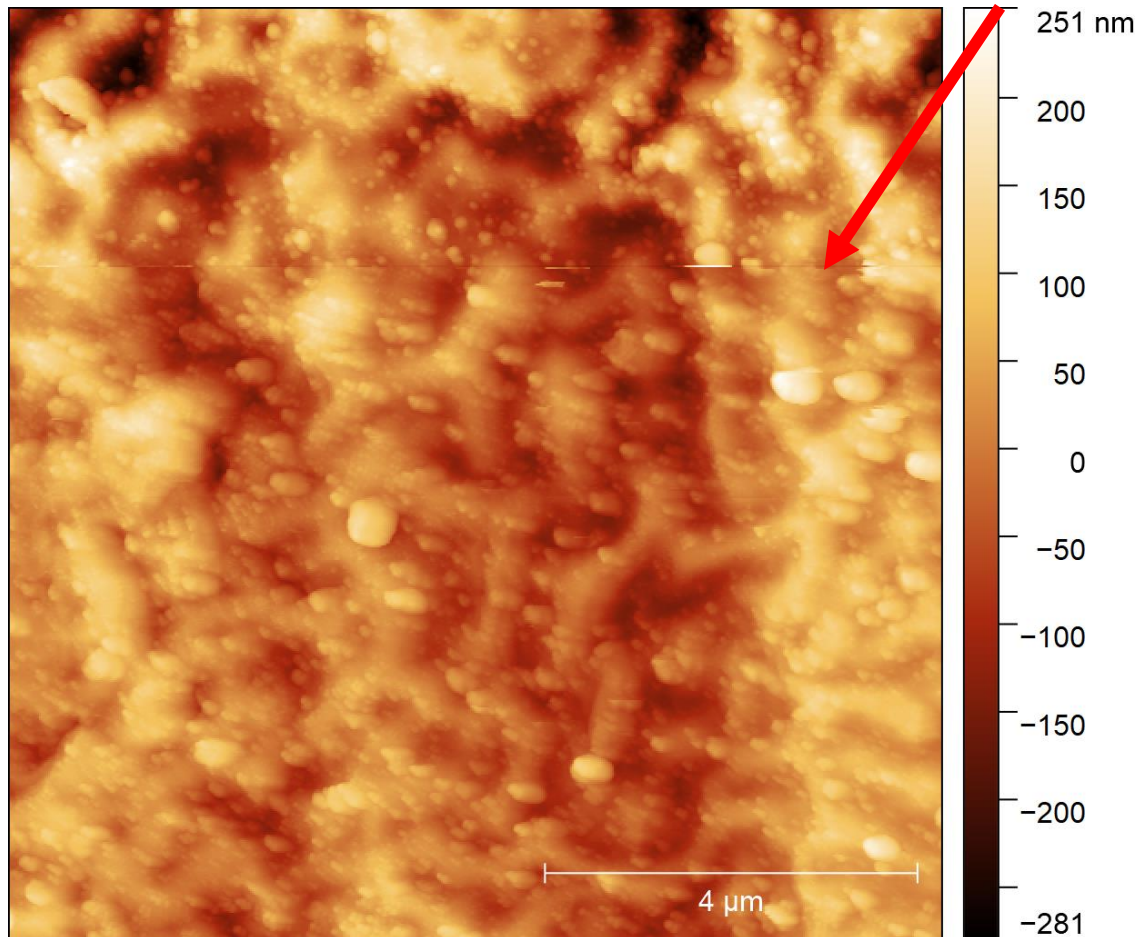
Field enhancement modeling



Field enhancement capped at 3

Mapping large craters

Mapping of the most interesting part is almost impossible.



¾ of image with dull tip

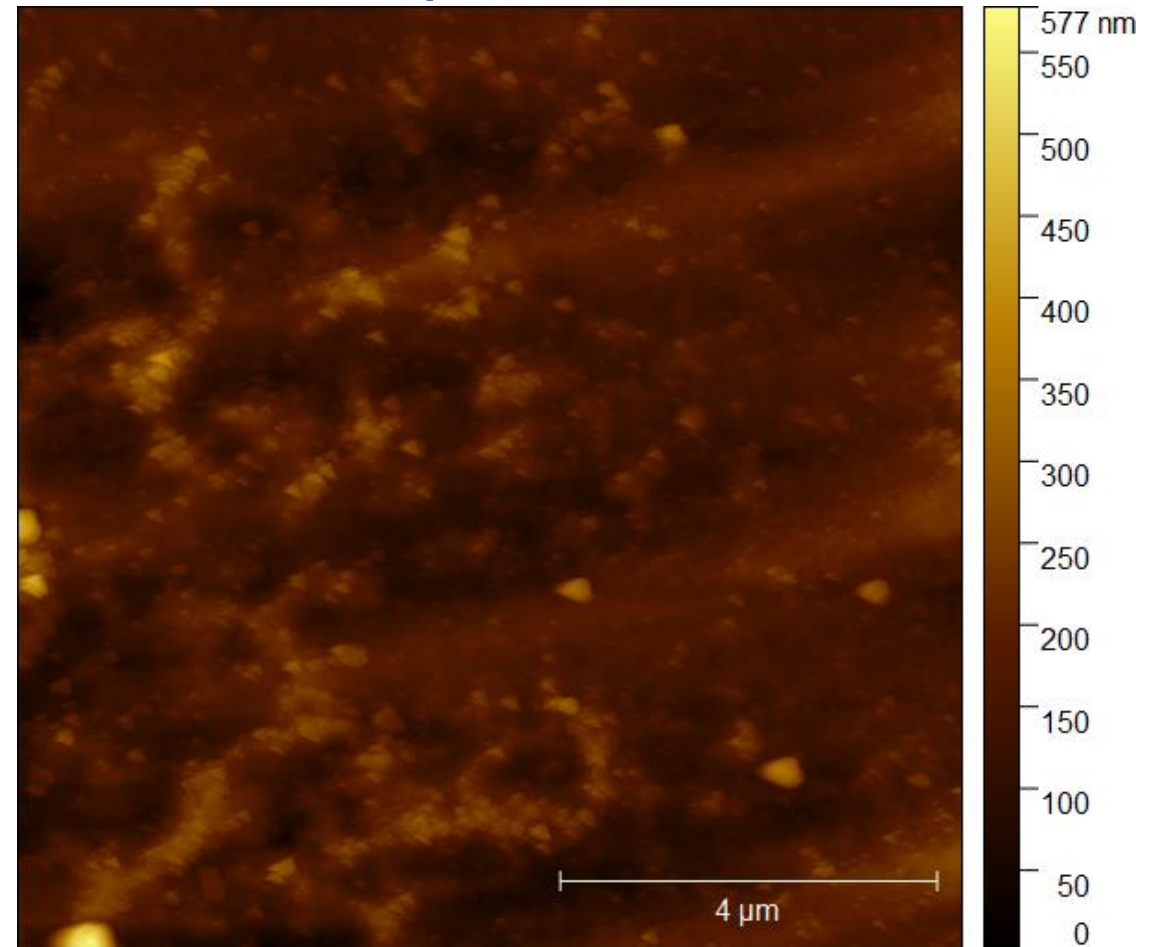


Image of crater with artefacts



Conclusions & plans

The surface topology in craters is very rough, forming a lot of interesting structures.

The field enhancement of the small craters can be at least up to 5.

Not a lot to conclude. There are a lot of hypotheses.

Plans:

Obtaining the topology image of rougher parts of the craters.



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Thank You!



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