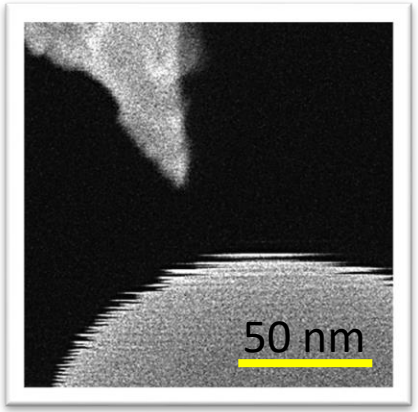
UNIVERSITY OF TARTU
Institute of Physics

MATTER

UNIVERSITY OF TARTU
Institute of Technology

Diffusion processes in metals at the nanoscale: experimental studies

2st CERN Baltic Conference (CBC 2022)



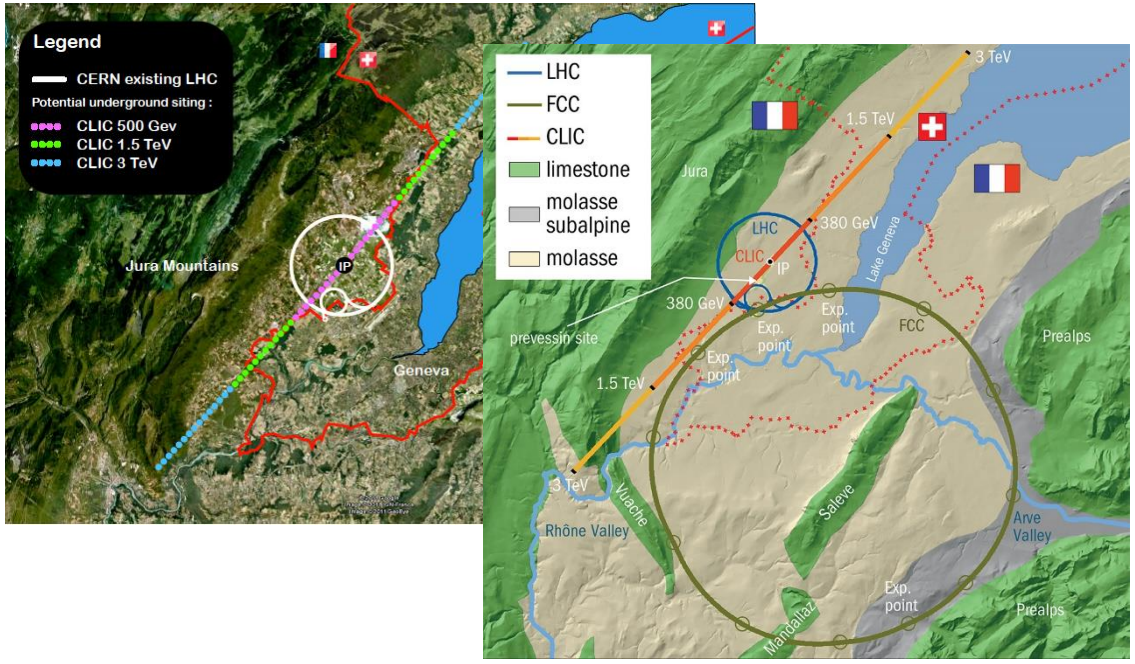
Sergei Vlassov
Institute of Physics, University of Tartu, Estonia
EraChair MATTER project

Seniour Team: Sergei Vlassov, Sven Oras, Tauno Tiirats, Andreas Kyritsakis, Veronika Zadin

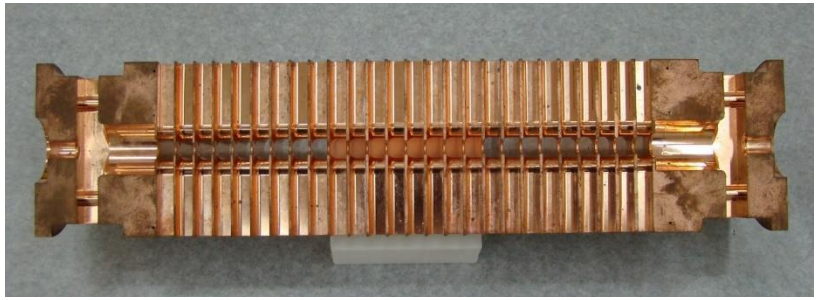
CLIC – Compact Linear Collider in https://clic.cern/

CLIC:

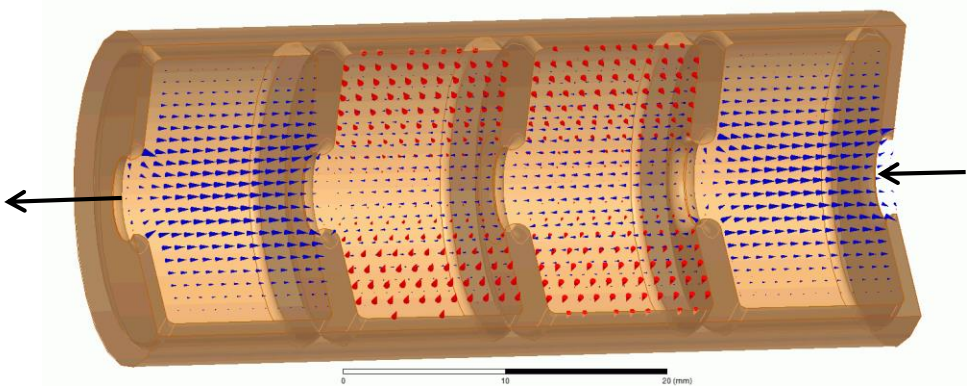
- collision energies 0.5-5 TeV
- Proposed length 50 km requires **E ~ 100 MV/m** causing vacuum breakdowns
- $p_{required} < 3 \cdot 10^{-7} \frac{\#}{pulse \cdot m}$ → BD mechanisms must be understood



CLIC accelerating structure (AS) made of copper



6 mm diameter beam aperture, 25 cm long

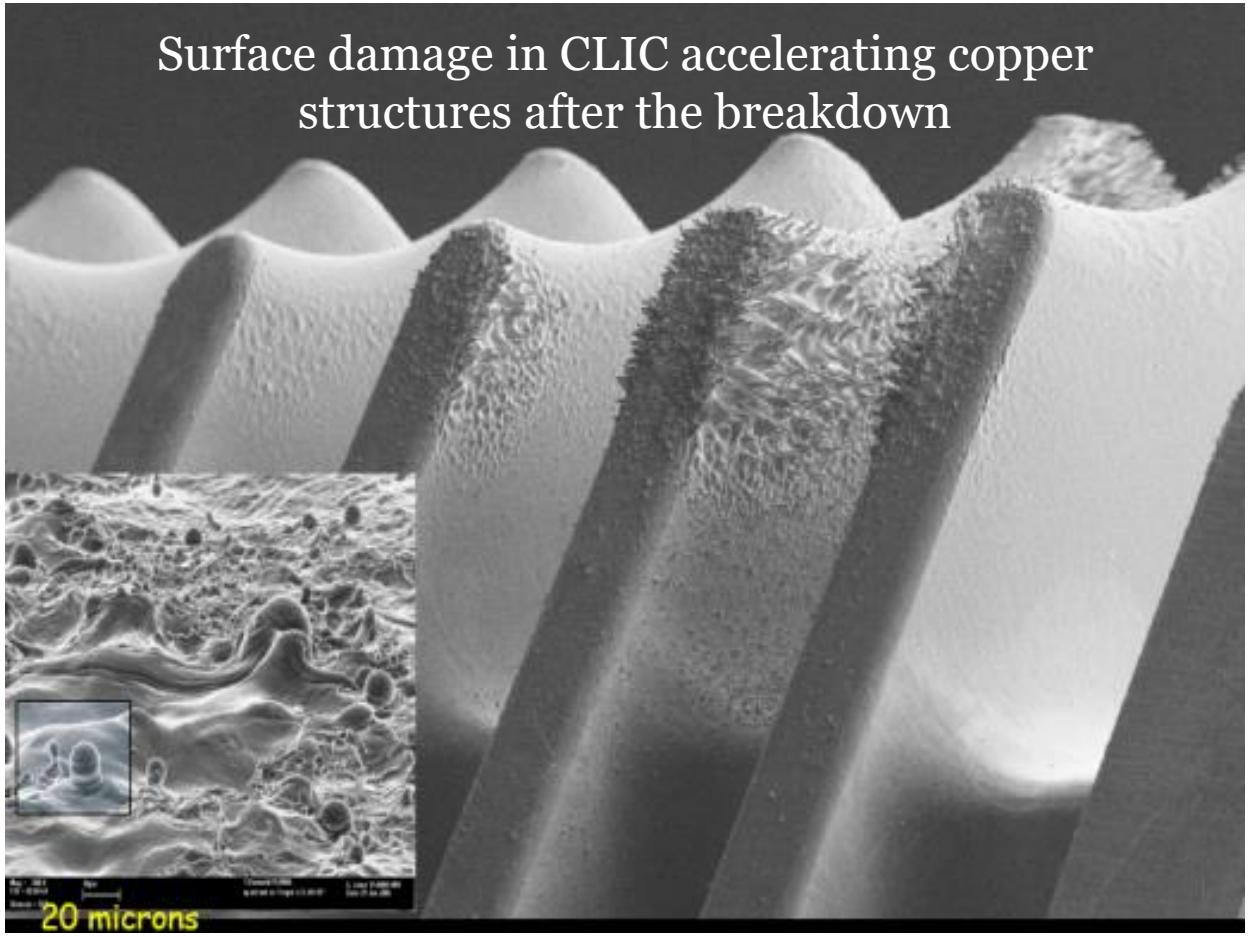


beam propagation

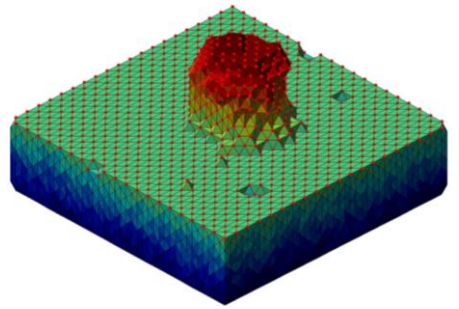
11.994 GHz X-band

Images from Walter Wuensch, CERN

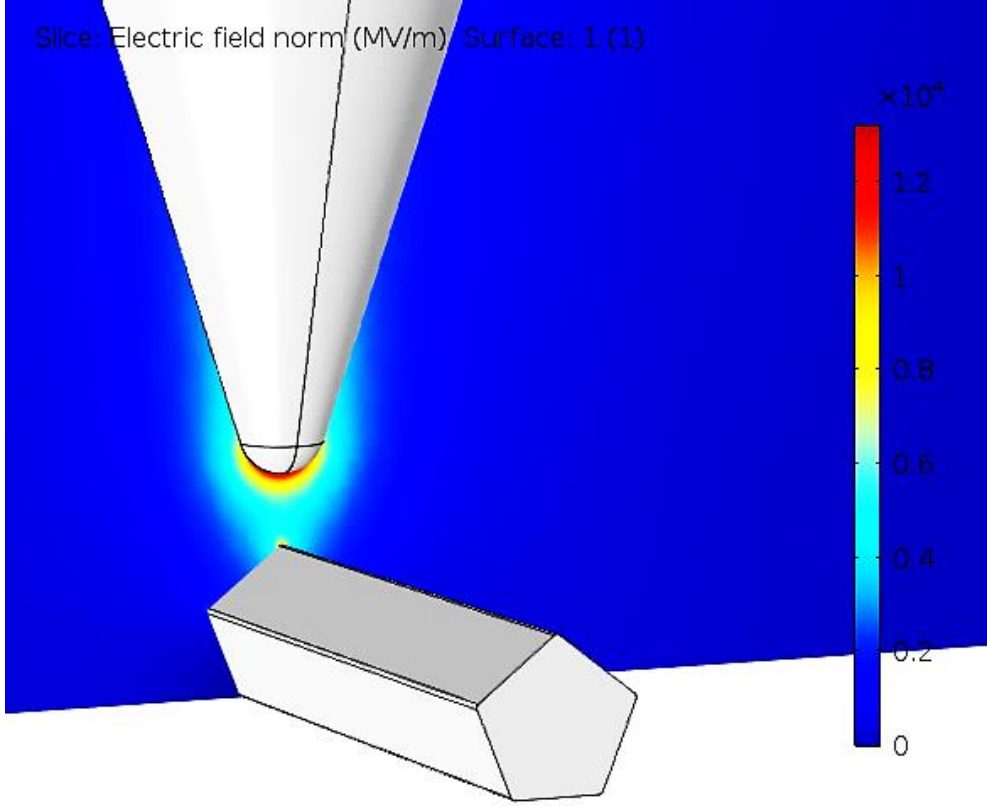
Vacuum breakdown problem



Possible reason is surface reconstruction and formation of field emitters that act as field enhancers leading to generation of plasma and vacuum breakdown *(see **prof. Zadin** presentation for details)*



Generation of strong electric fields inside Scanning Electron Microscope (SEM)

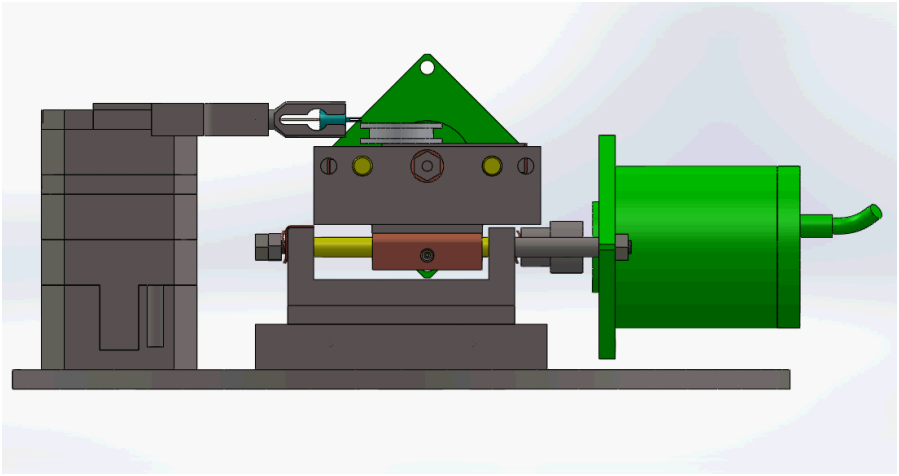


- Our intent is to create conditions for **controlled single emitter formation and growth** under a strong electric field, in predetermined locations and with an immediate visual feedback.

- The strong electric field is created by applying voltages between the investigated surfaces and a **sharp probe** that will be brought to a **close proximity** to the sample.
- The use of **sharp probes** (or even individual nanowires) allows to reach **extreme local electric field gradients at low voltages** due to the curvature effect.
- **Local heating** by laser through optical fiber will be utilized for temperature ramping to boost surface diffusion.

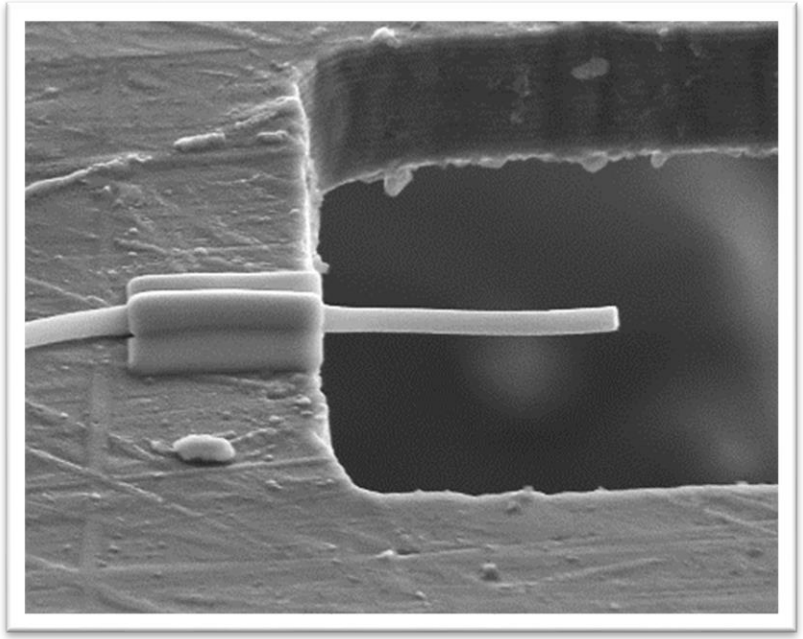
Nanomanipulation platforms for in situ SEM experiments

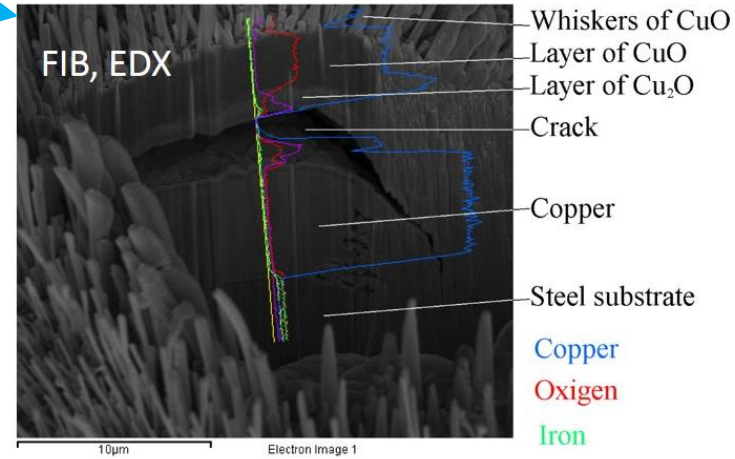
Nanomanipulation platforms based on piezo-positioners (partially commercial, partially home-built) are installed inside SEMs allowing to perform very fine experiments with individual nanostructures



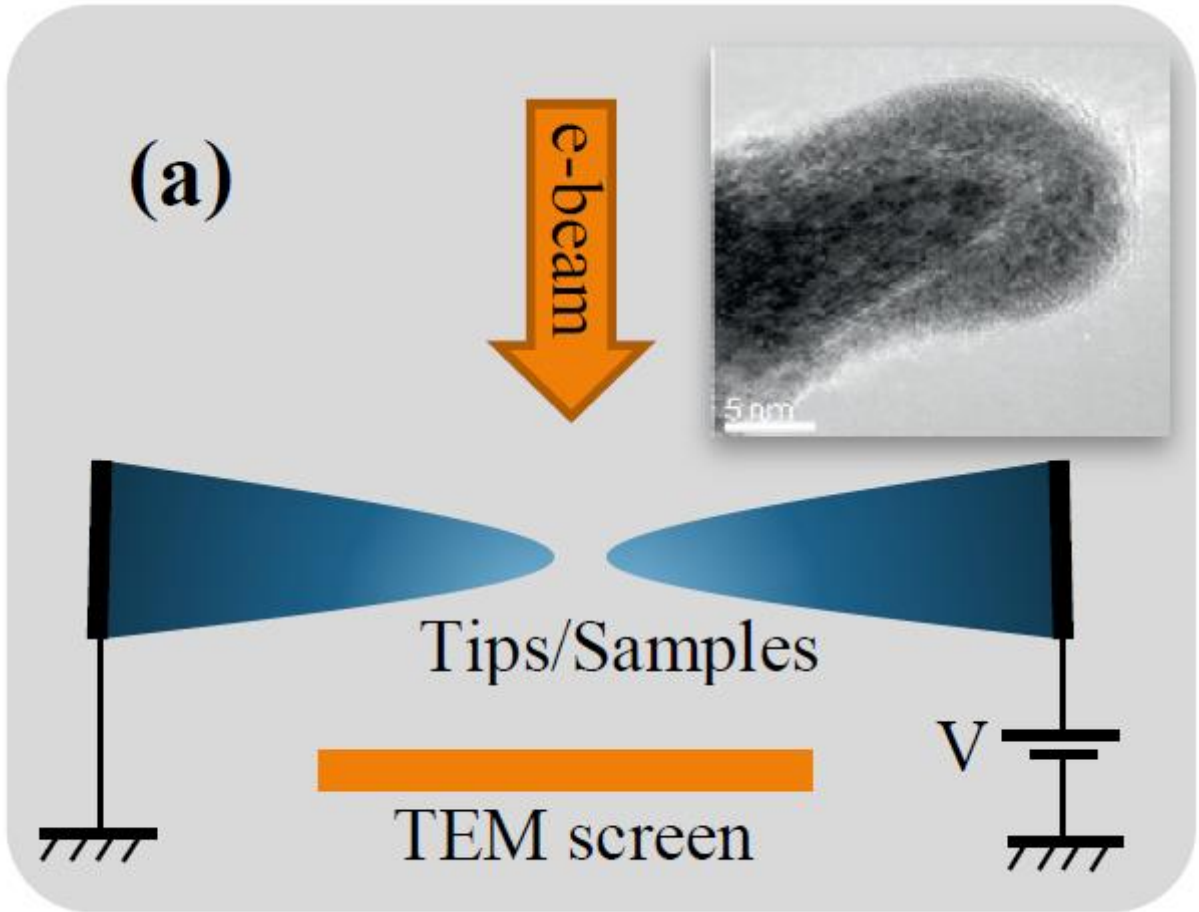
Peculiarities of inside-SEM experiments

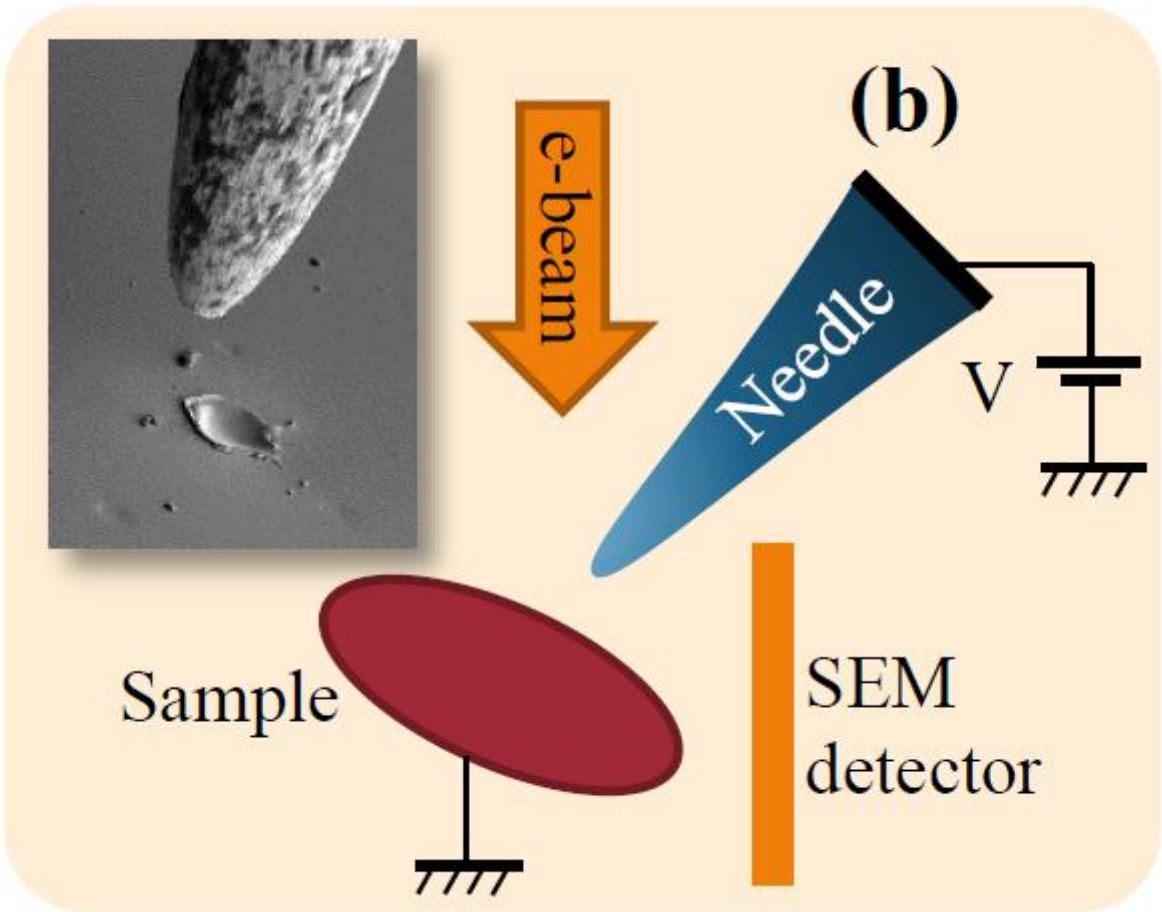
- **Visual guidance**
- Vacuum conditions (order of 10^{-4} Pa)
- **Focused Ion Beam (FIB) capabilities**
  - **In situ welding**
  - **In situ cutting**
- **Elemental analysis**
- Electrical conductivity
  - (choice of materials is limited to metals and semiconductors)
- Electron-beam induced effect
  - Some materials may be sensitive to e-beam
  - Carbon deposition can occur on irradiated areas

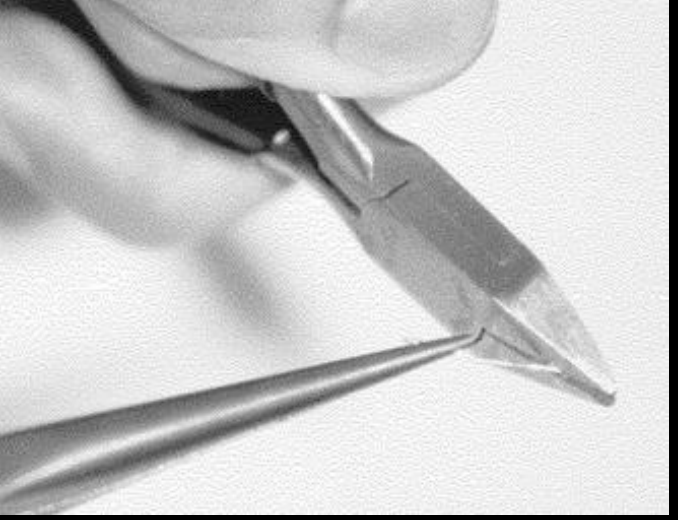




Field assisted surface diffusion: the experiment







Sharp tips are produced by cut and pull method

Au-coated Al

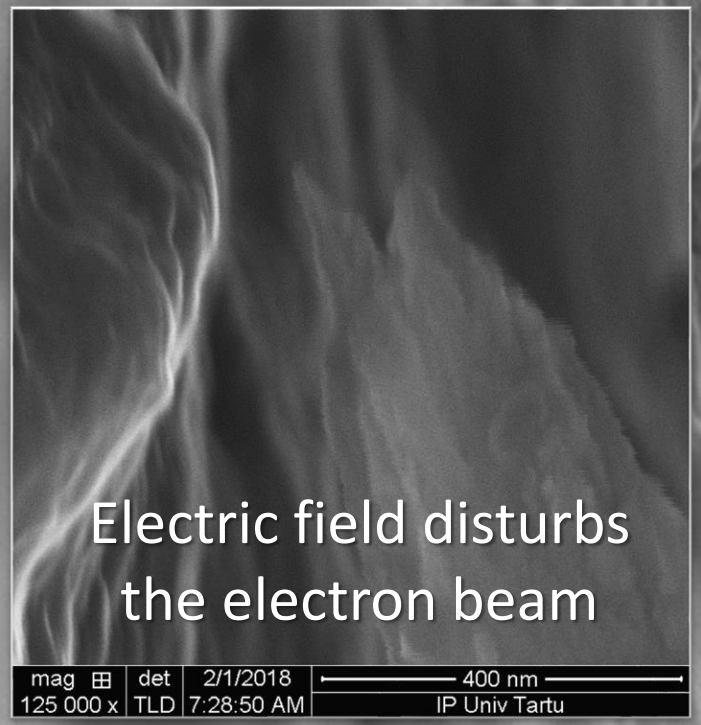
Voltage between surfaces is up to 10 V

PtIr

	HV	WD	mag ⊞	det	2/1/2018	50 µm
	10.00 kV	5.0 mm	846 x	TLD	7:23:50 AM	IP Univ Tartu

Voltage up to **10V**
No growth observed

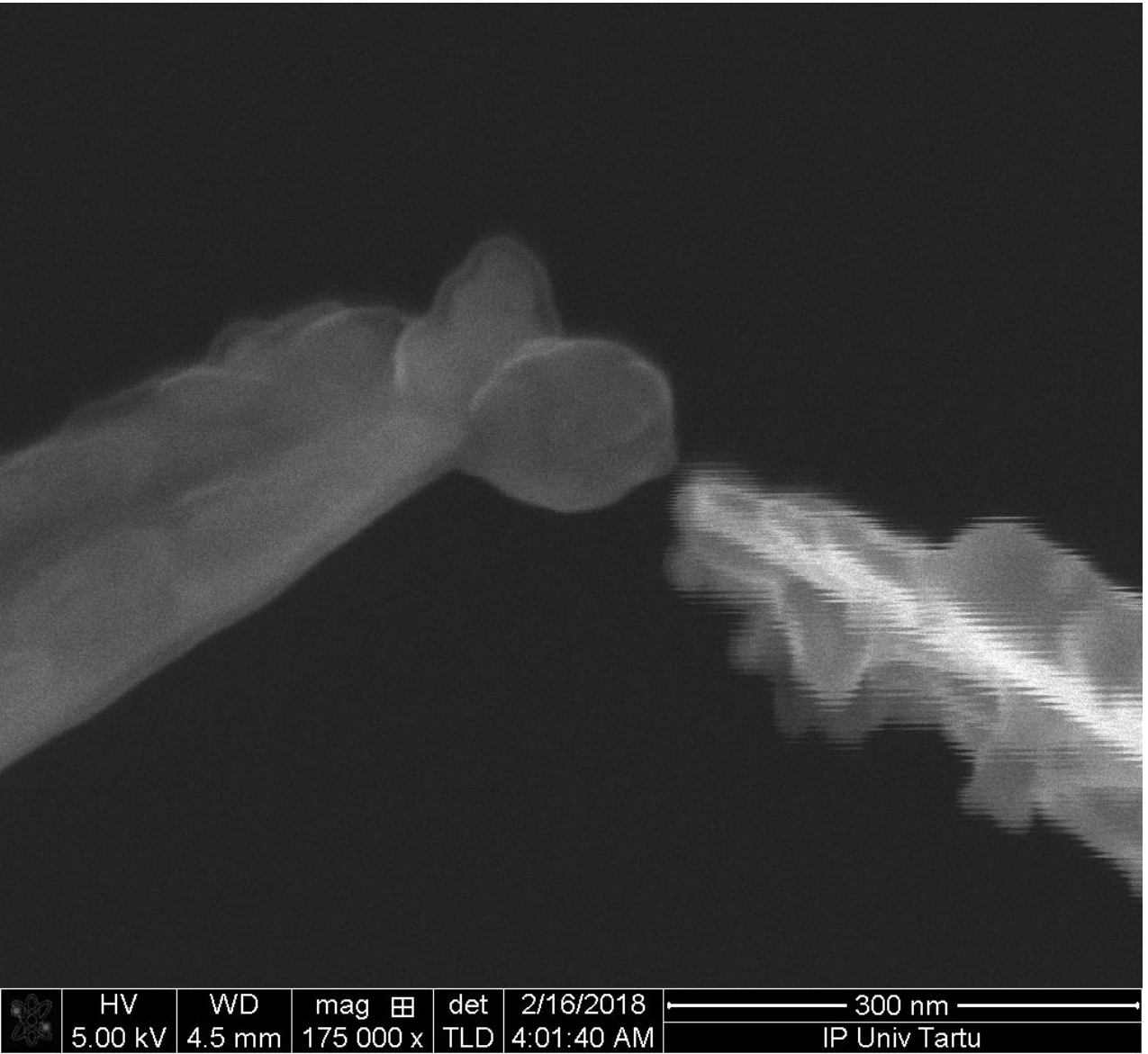
Au-coated Al

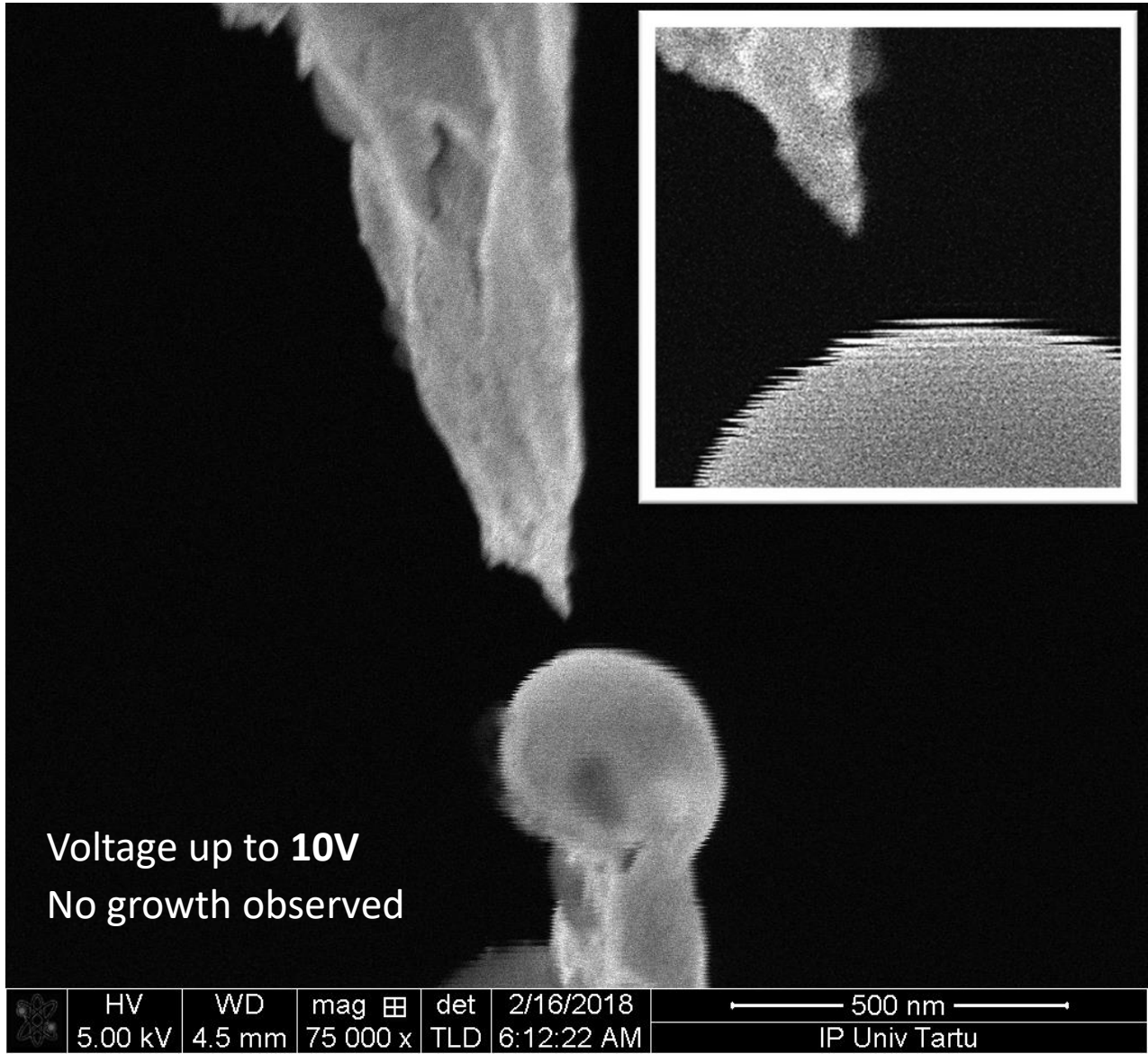


PtIr

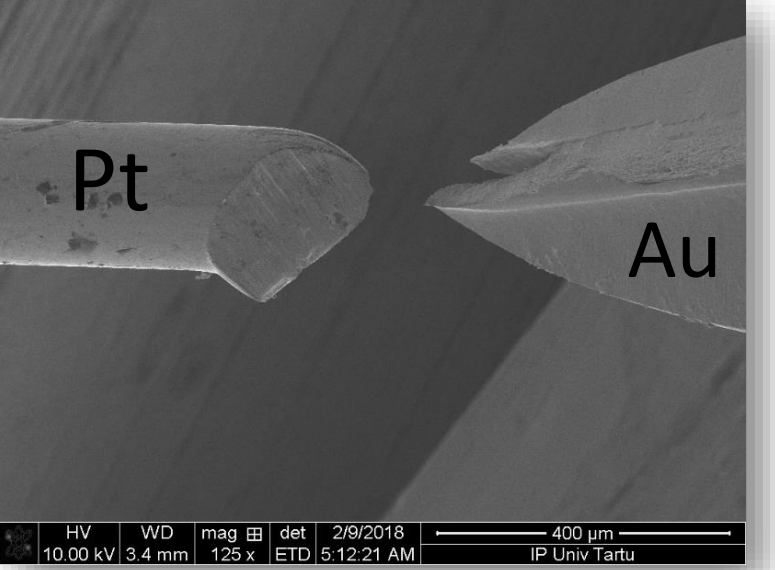
HV	WD	mag ⊞	det	2/1/2018	1 µm
10.00 kV	5.0 mm	32 500 x	TLD	7:25:53 AM	IP Univ Tartu

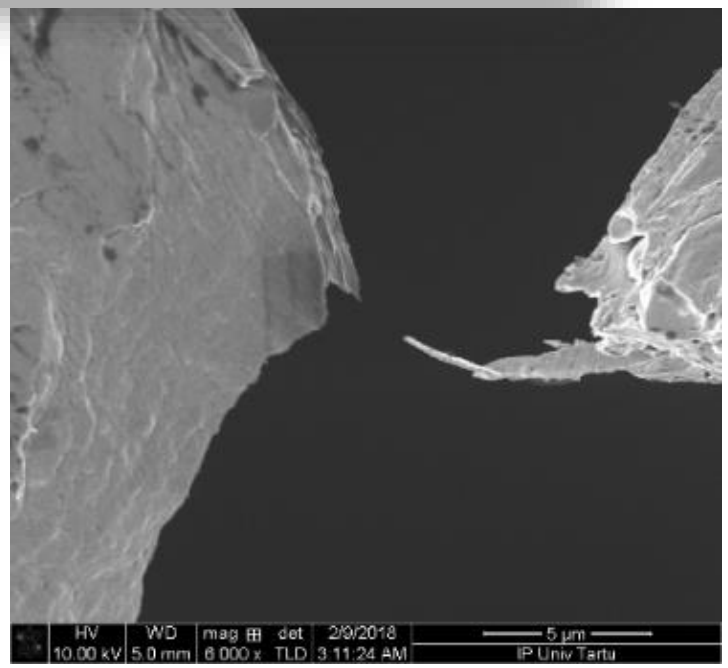
Two **PtIr** wires

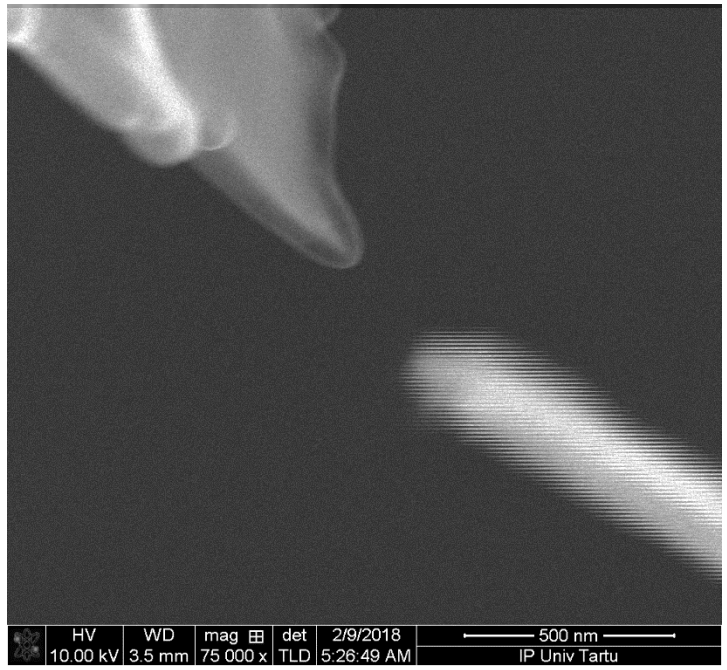


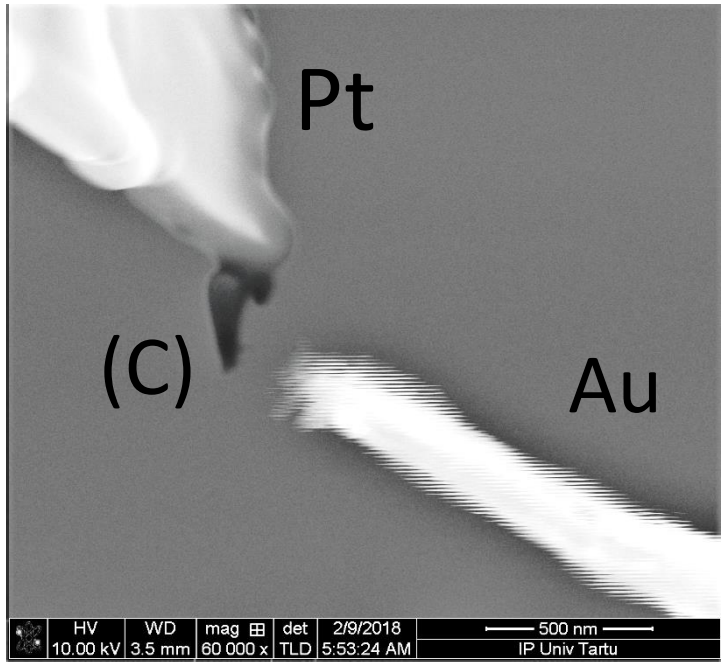


Non-uniform carbon deposition on Pt



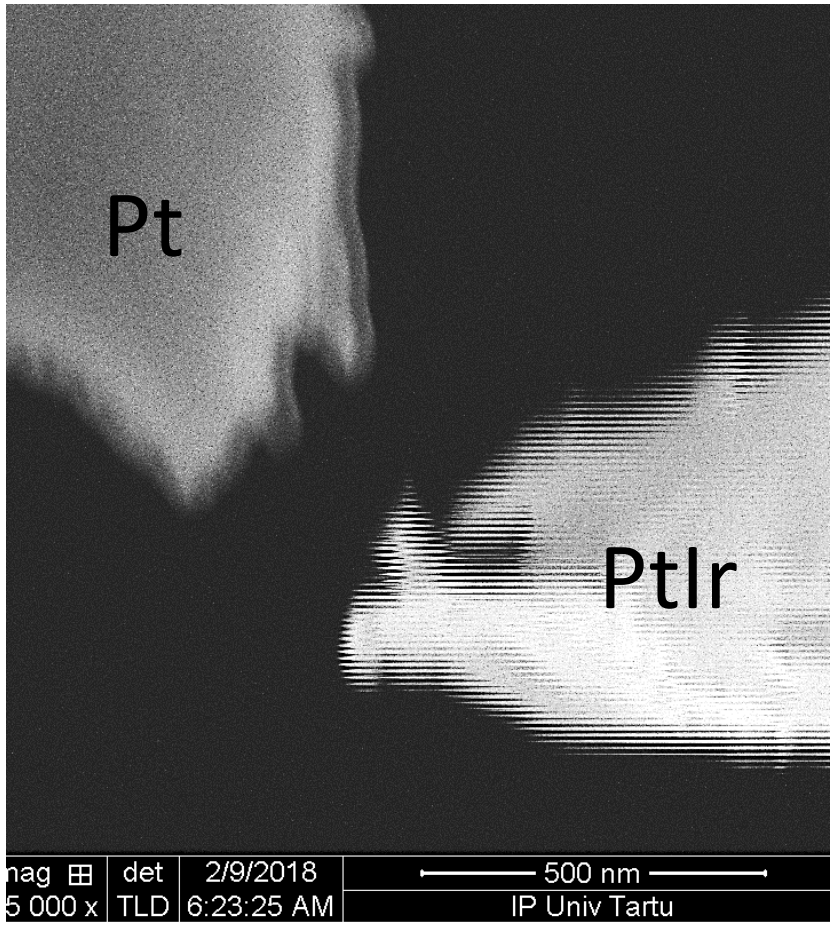


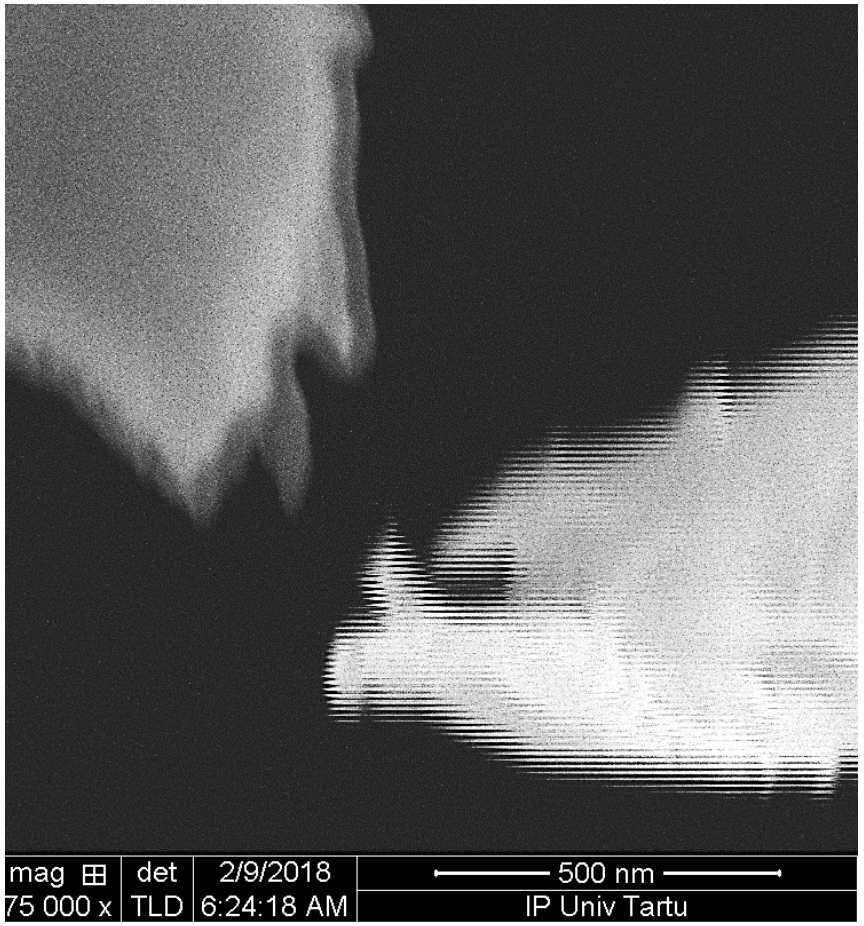


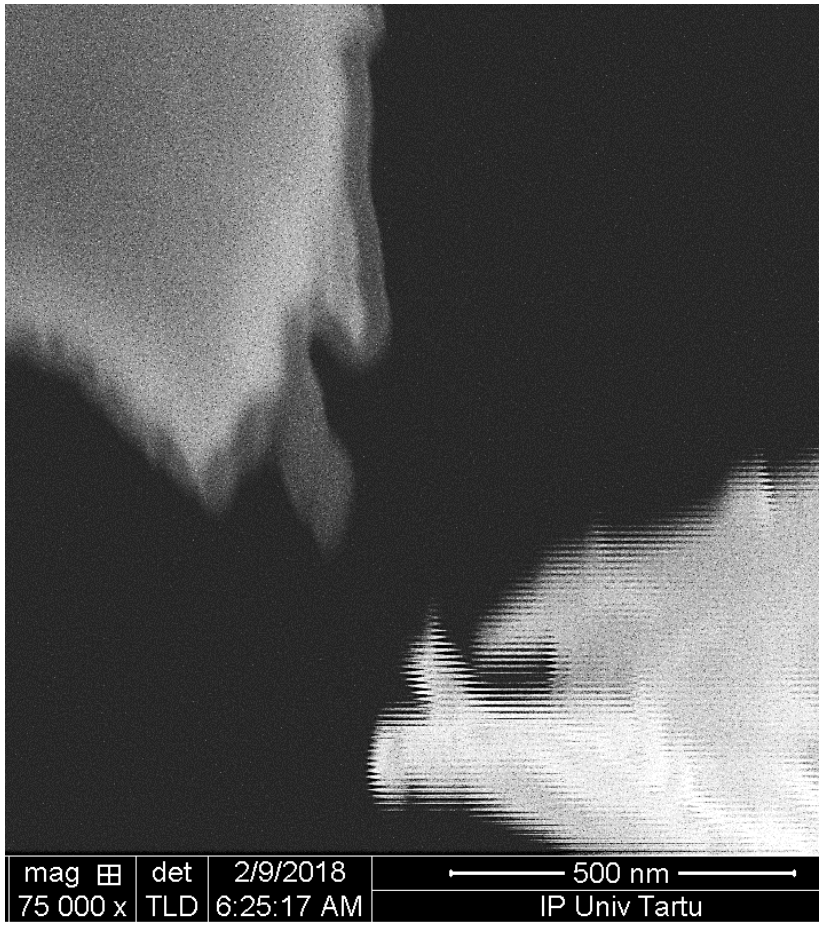


- Chamber pressure is 10^{-6} mbar (in order of **10^{15}** gas molecules in the SEM chamber)

Non-uniform carbon deposition

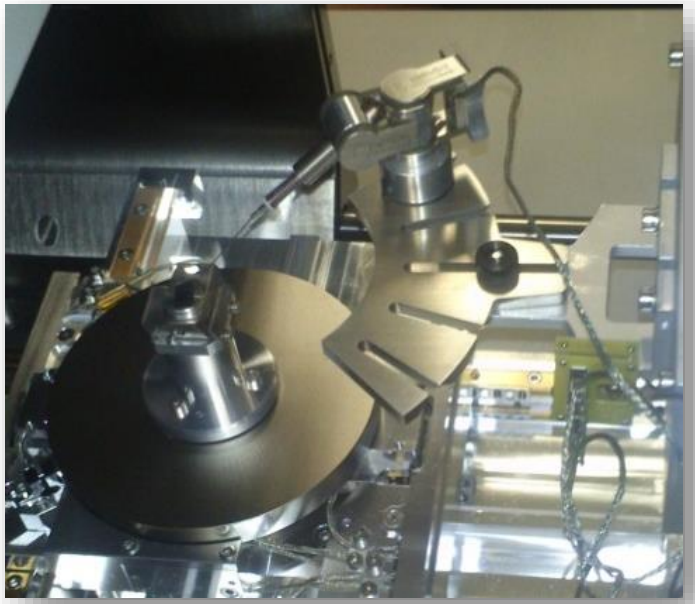






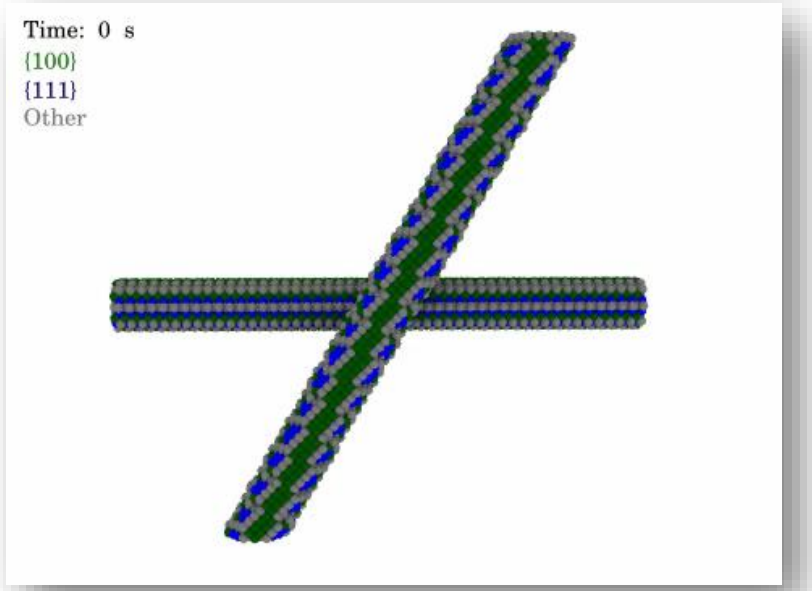
Note! No carbon deposition on PtIr

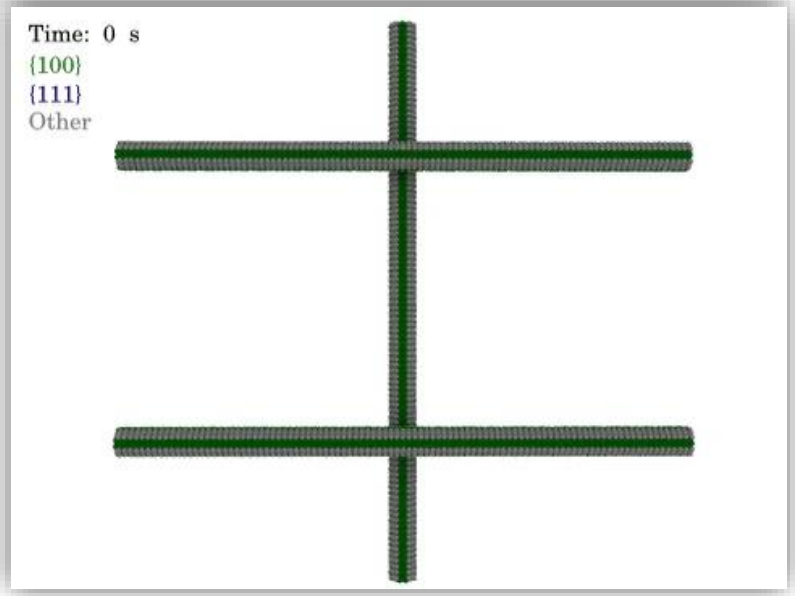
Problems and future plans

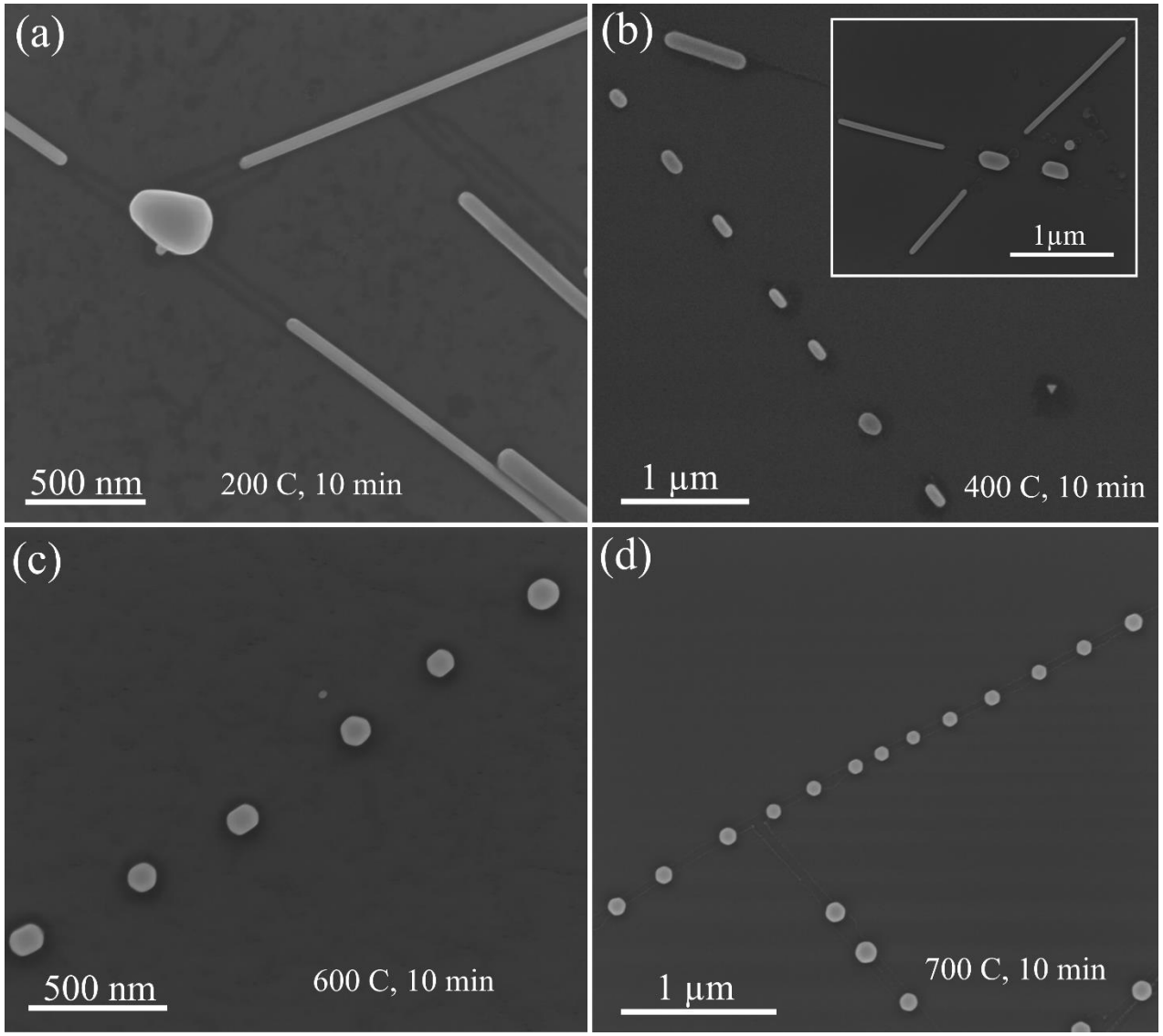


- Electric field disturbs the electron beam
  - Low voltage should be used (below 10 V)
  - E-beam should be switched off when voltage applied
- Carbon deposition on many materials
  - Choice of materials should be corresponding (Au, PtIr, W, …)
  - Blind experiments
- Drifts
  - Prevents “blind” experiments at low separation
  - More rigid system should be built with shorter parts.

Diffusion in action: simulations & experiments



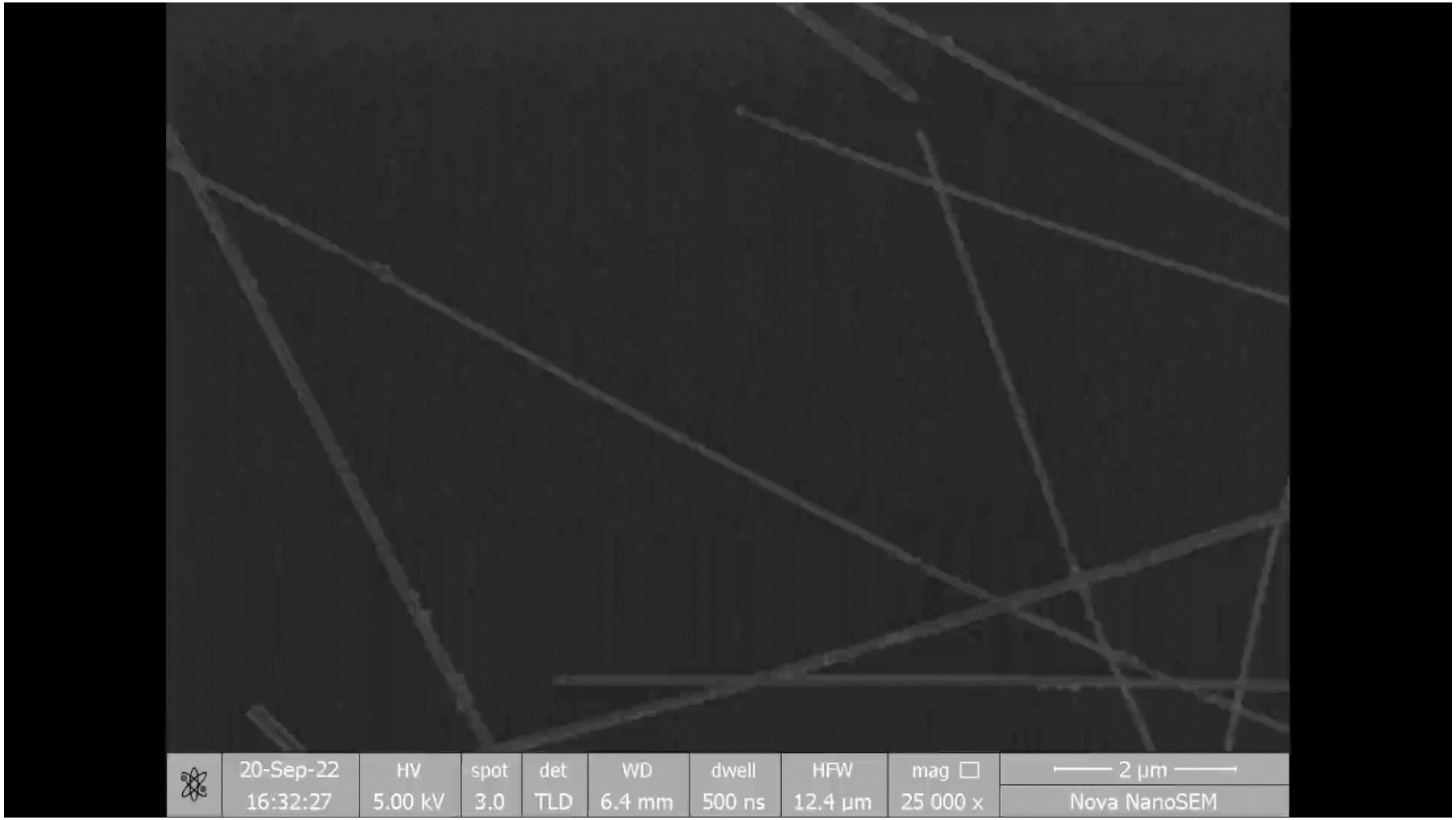




Gold nanowires heat-treated at different temperatures

Simon Vigonski *et al* 2018 *Nanotechnology* **29** 015704

Ongoing studies:
real-time experiments inside SEM



Diffusion processes in Ag nanowires at 350C. Video