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Electron Trajectories in Scanning Field-Emission Microscopy (SFEM)

Presentation Overview

- Scanning Field-Emission Microscopy (SFEM)
- A multiscale simulation
- The non-confocal model of the electrostatic junction
- The primary electron beam
- Secondary electrons
- Examples of results

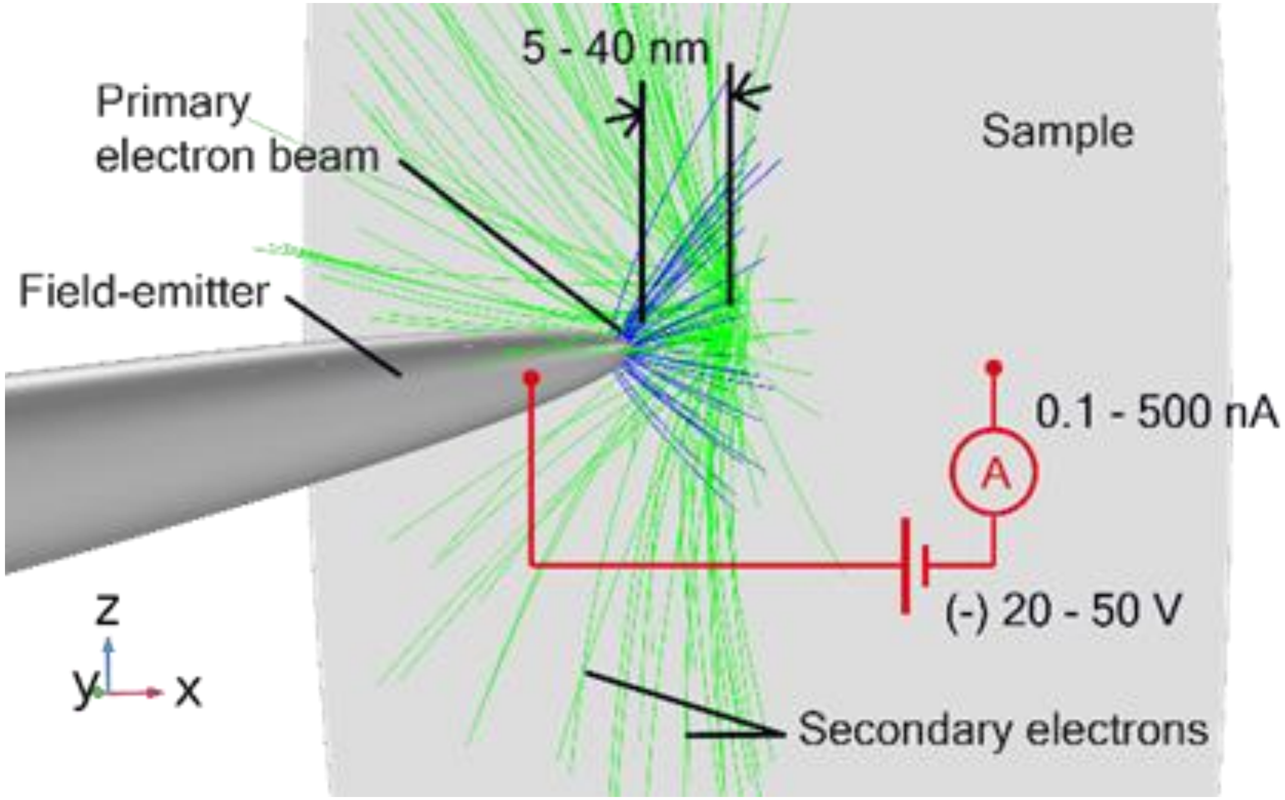
Scanning Field-Emission Microscopy (SFEM)
The electrostatic junction

Schematic diagram of the electrostatic junction in the SFEM technology.

The primary electron beam (blue) produced by field emission (locally) generates secondary electrons SE (green).

The field-emitter (tip) can be seen on the left hand side, in a scanning position a few nanometers in front of the sample, which is represented by a light gray surface.

Two channels: secondary electrons (SE) and absorbed current (AC).

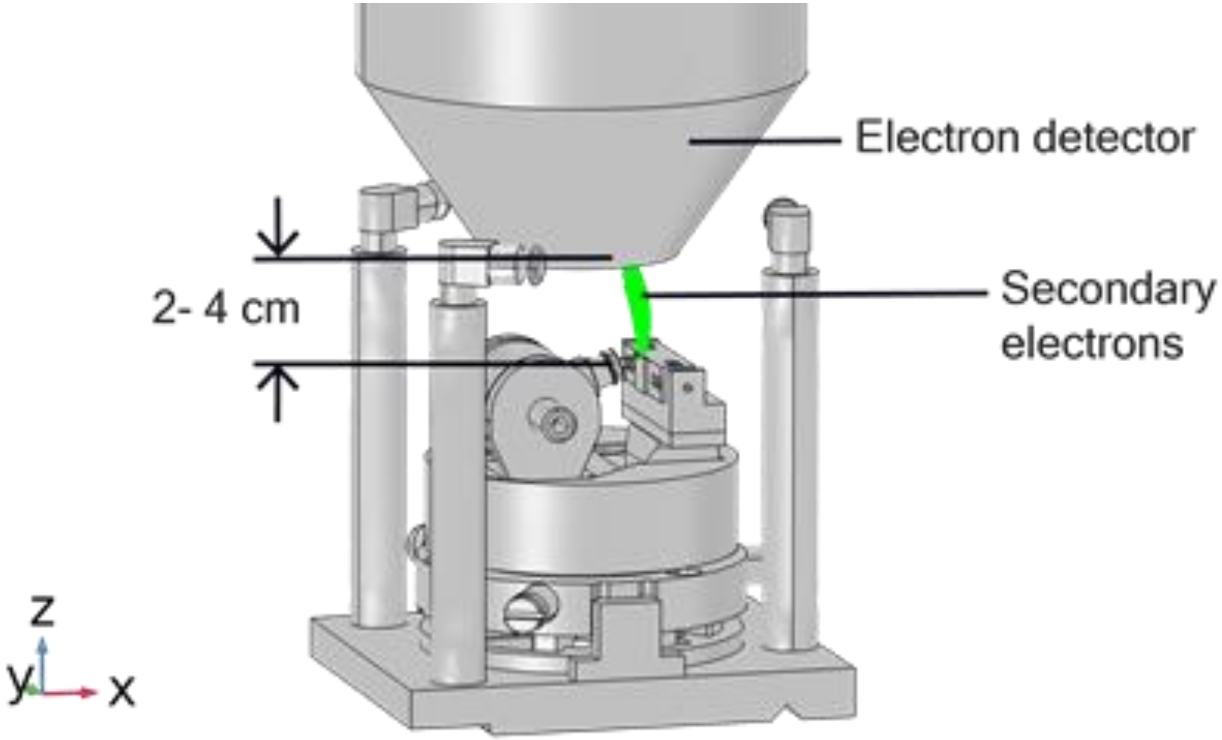


Scanning Field-Emission Microscopy (SFEM)
Catching the secondary electrons

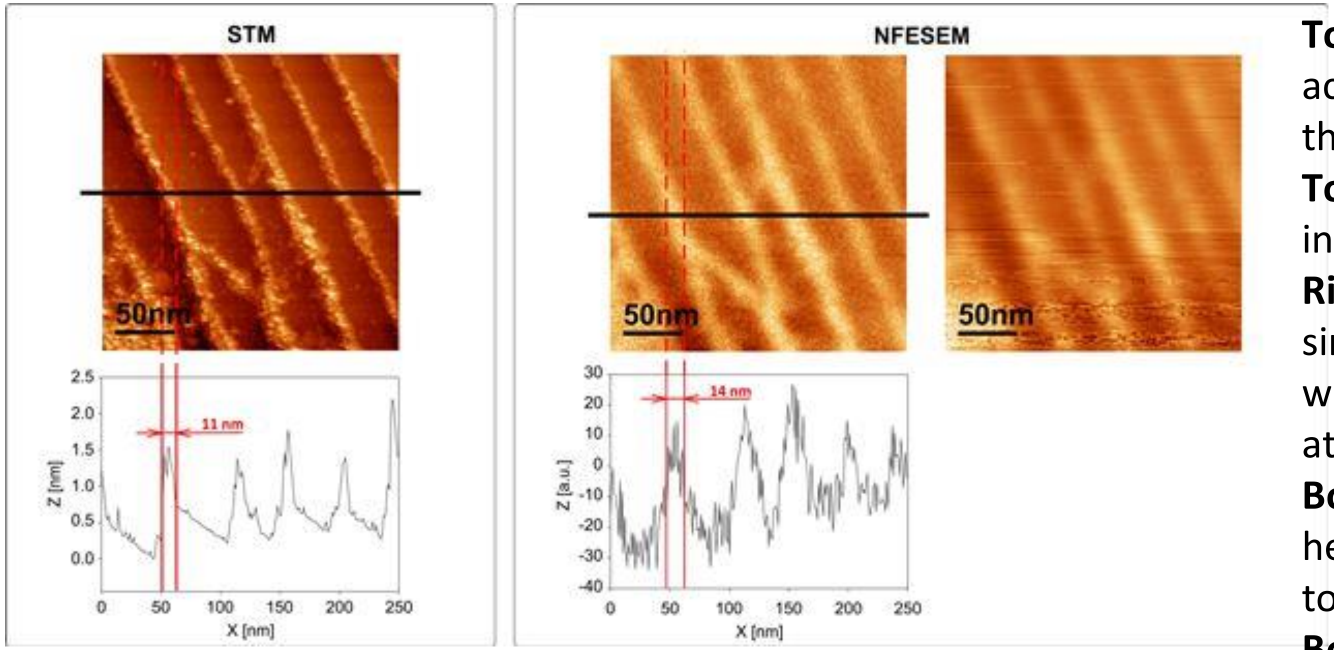
A three-dimensional view of the SFEM imaging setup.

The SE are seen to enter the electron optical column, located some centimeters over the electrostatic junction in the z direction [diss].

Crucial to the experiment: to optimize the amount of detected (low-energy) SE.



Scanning Field-Emission Microscopy (SFEM)
SE and AC-channels imaging



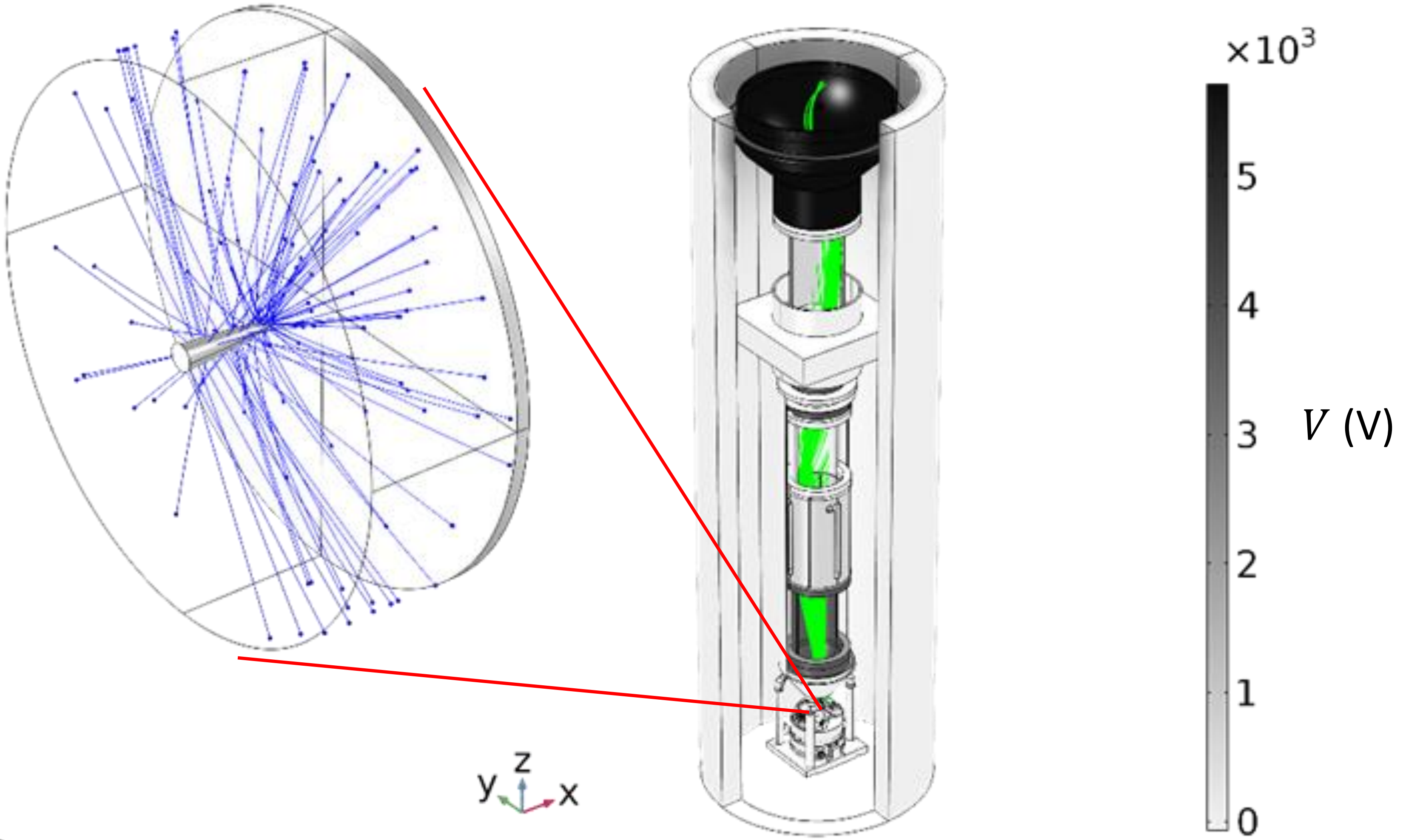
Top left: STM image of a nanostructured W(110) surface, with accumulation of matter along the surface steps (running along the diagonal of the image).
Top center: The same surface spot imaged by recording the intensity of the backscattered electrons.
Right: The same surface spot imaged by recording simultaneously with the middle image the field emission current while scanning the tip at fixed tip-surface distance of 40 nm and at fixed voltage.
Bottom left: Line scan through the STM image: plotted is the height of the surface structures along the black line indicated in top.
Bottom center: Line scan through the STM-FE image: plotted is the detector signal along the black line. The recording of both STM and STM-FE images can be used to calibrate the STM-FE height. A vertical spatial resolution of less than 10-1 nm has been observed at distances of about 20 nanometers.

D.A. Zanin, M. Erbudak, L.G. De Pietro, H. Cabrera, A. Redmann, A. Fognini, T. Michlmayr, Y.M. Acremann, D. Pescia, and U. Ramsper, Proceeding of the 26th International Vacuum Nanoelectronics Conference, IEEE (2012).

A multiscale simulation
From nanometers to centimeters

Junction-Component: the electrostatic junction inhabits a space in nanometer scale.

System-Component: in the SFEM-setup electrons have to fly about 80 centimeters long.

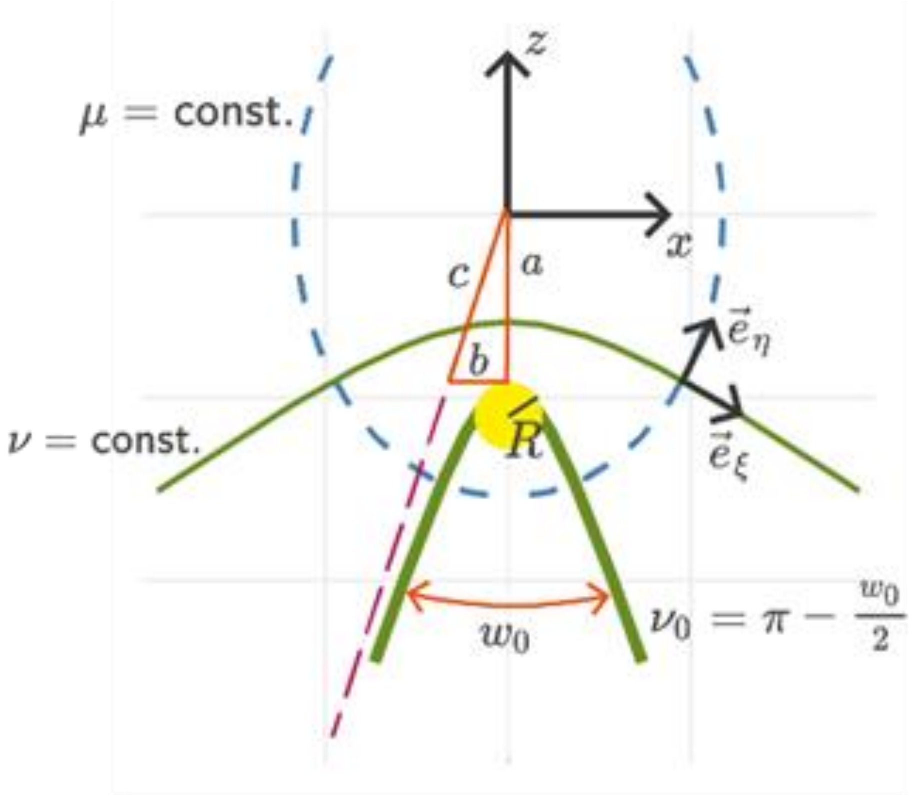


The non-confocal model of the electrostatic junction
Use of the parametrization features

Definition of prolate-spheroidal coordinates and of the parameters specifying a hyperboloid of revolution.

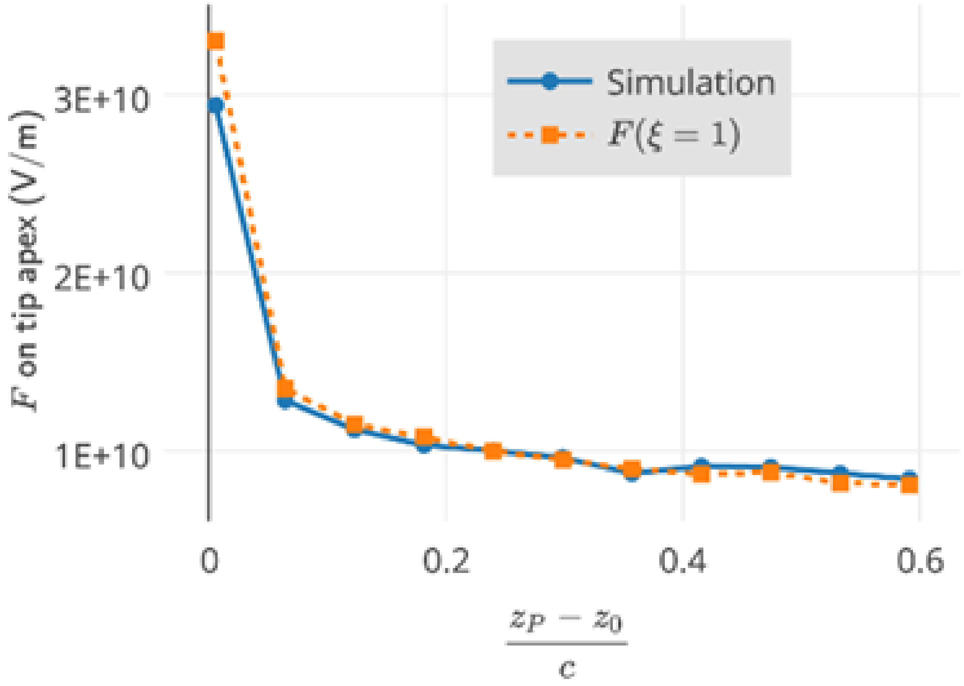
The model must work for a wide range of distances between tip and target.

The geometry has to represent real electrostatic-junctions (very sharp tips).



The non-confocal model of the electrostatic junction
Validation of the model

$$F(\varepsilon = 1, \eta_0) = \frac{\frac{2(R+a)}{Rc}}{\ln\left[\frac{(1+\eta_p)(1-\eta_0)}{(1-\eta_p)(1+\eta_0)}\right]} \qquad (1)$$



Electric field F at the tip apex as a function of the relative position of the planar electrode.

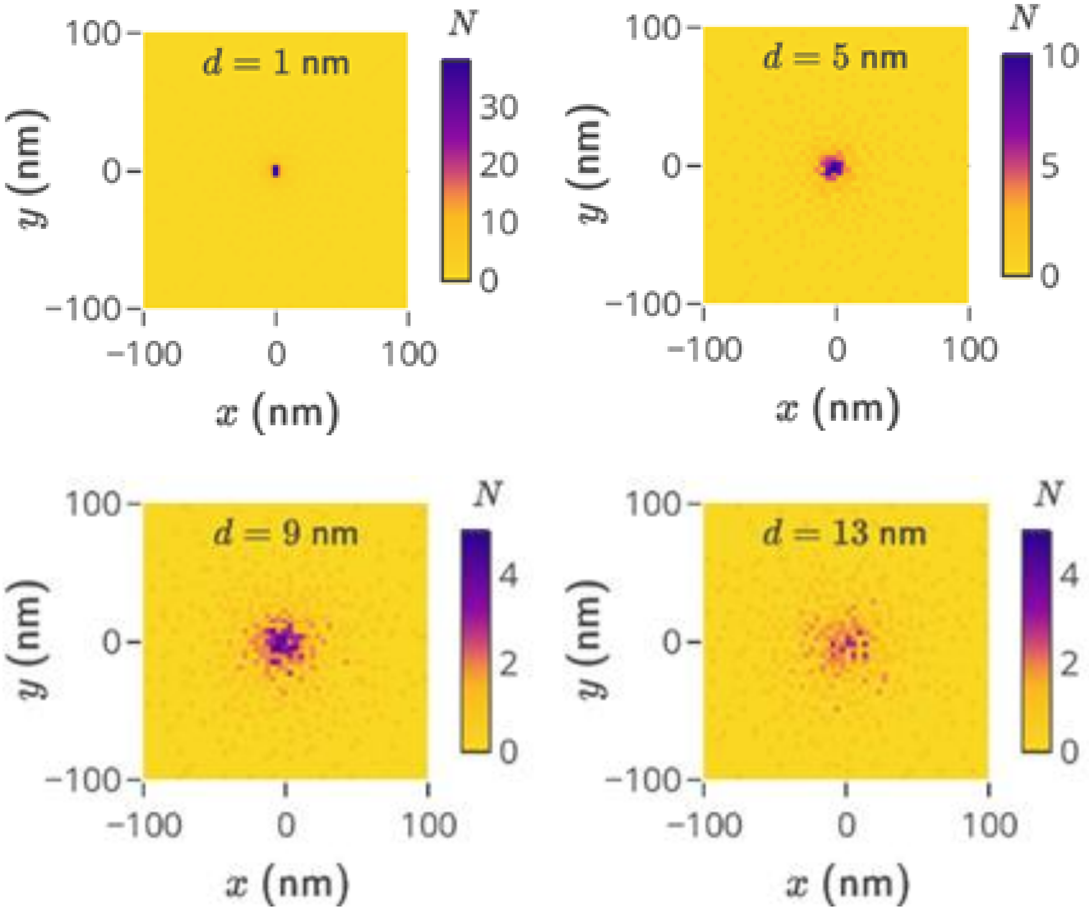
In the considered range the two curves agree within a few percent.

The primary electron beam
Spot dimensions

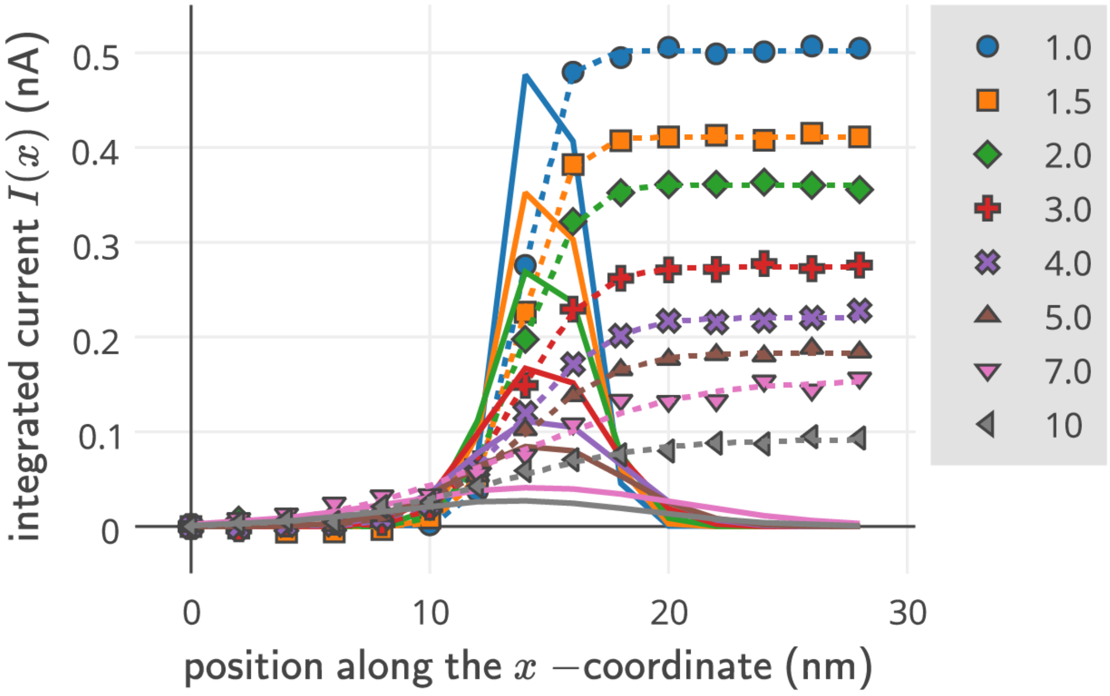
2D-Histograms showing the final position of 1000 electrons ejected from the field-emitter at four different emitter-anode distances d and a bias voltage V_{Bias}=-56.9 V.

The electrons are distributed in 100 bins in each direction x and y on the target.

A colour code is used to render the number of electrons in each bin.



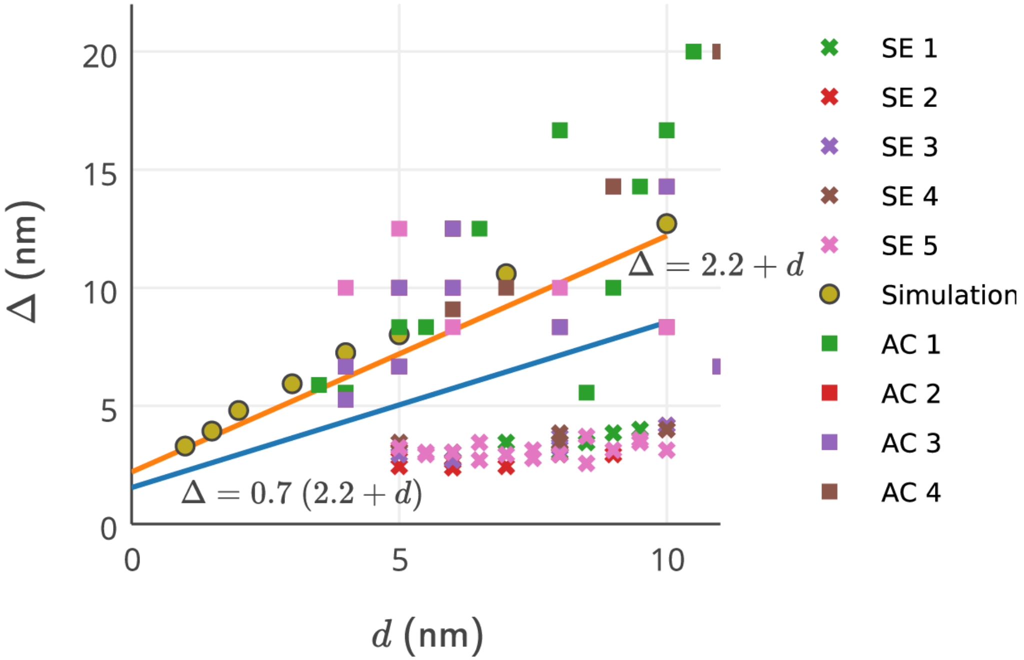
The primary electron beam
FEM simulated step detection



Total emitted current $I = \iint J(F(\varepsilon))$ as a function of the tip position x with respect to a step on the target (symbols) and the corresponding derivative (solid lines).

The largest change in the calculated current occurs for 1 nm, the minimal distance between tip and target.

The primary electron beam
Resolution



Width of a monoatomic step as seen by a FEM simulation of the field emitted current (brown circles).

The two straight lines are obtained with the non-confocal, symmetrized model.

The experimental data points are labeled SE for the secondary electrons and AC for the absorbed current.

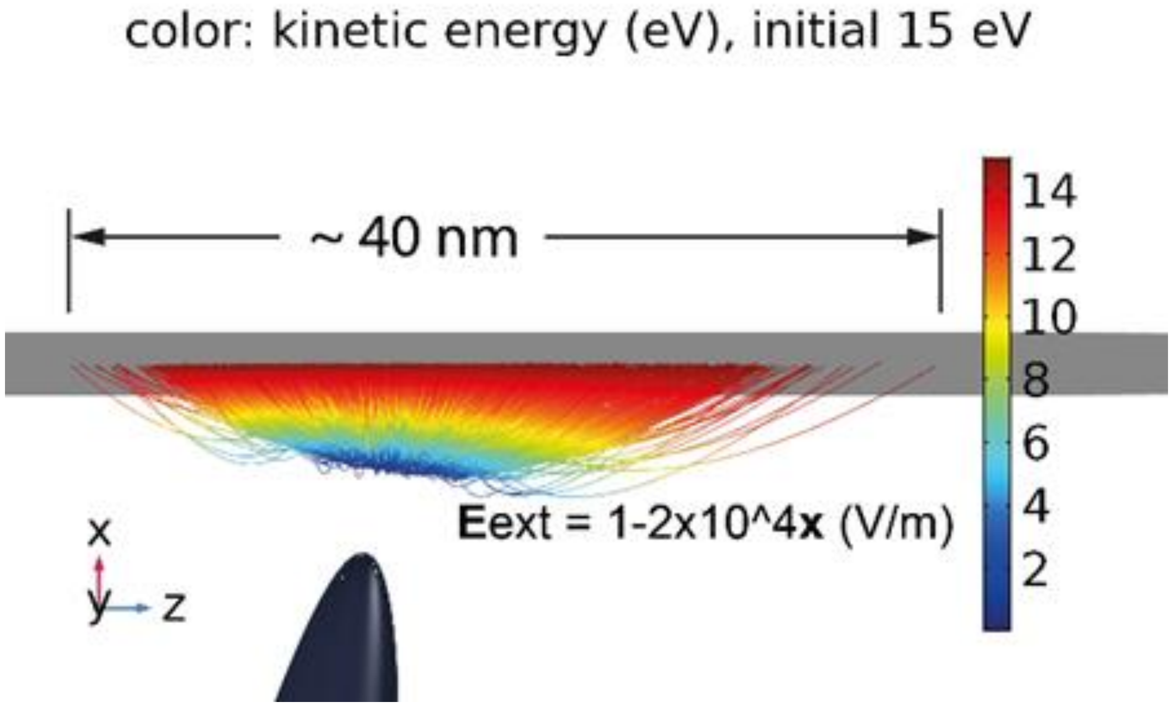
Secondary electrons
Kinetic energy and geometrical parameters

Simulation of 15 eV secondary electron trajectories generated in front of the field-emitter.

For this specific simulation, the tip is given a voltage of -60 V, the sample is biased with -5 V.

The tip axis is tilted by 10° away from the target normal.

The kinetic energy of the electrons along their path is given by the colour code specified in the vertical bar.

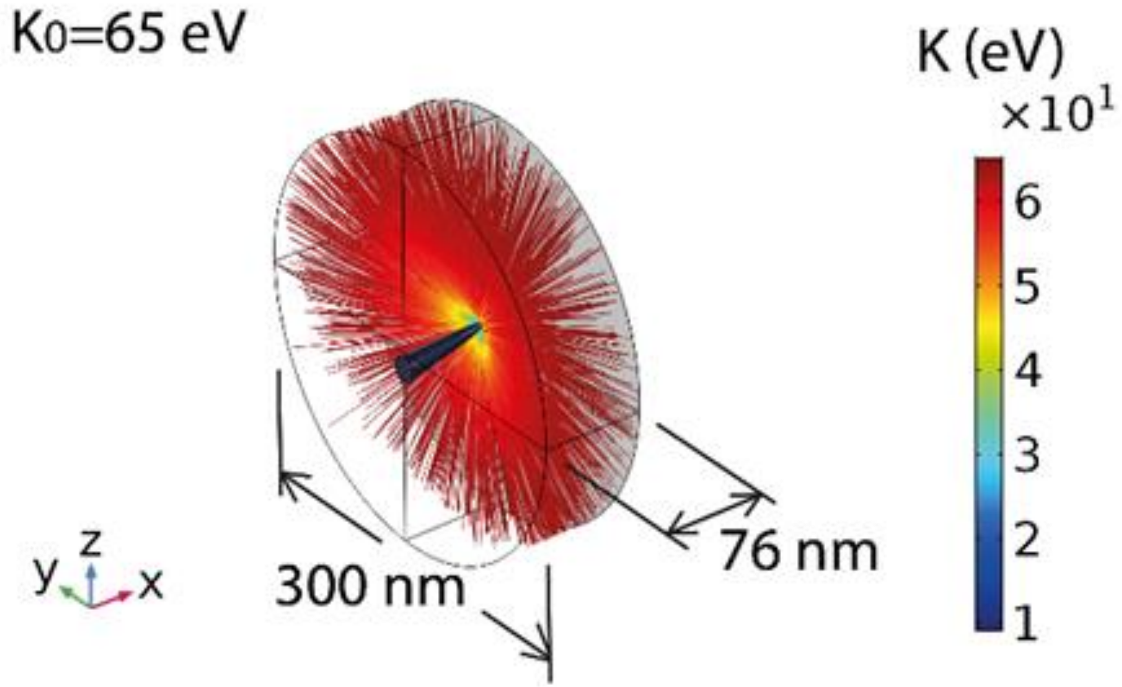


Secondary electrons
Escaping from the junction

Trajectories of 65 eV-secondary electrons in the Junction-Component.

The tip is at -60 V and the target at -5 V. The field-emitter has a tilt angle of 10°. An electric field of 2×10^4 V/m is applied along the z-axis.

Notice that we release SE electrons with a kinetic energy which is unphysically higher than the energy of the primary electrons, in order to enhance the role of the various electrostatic fields applied.

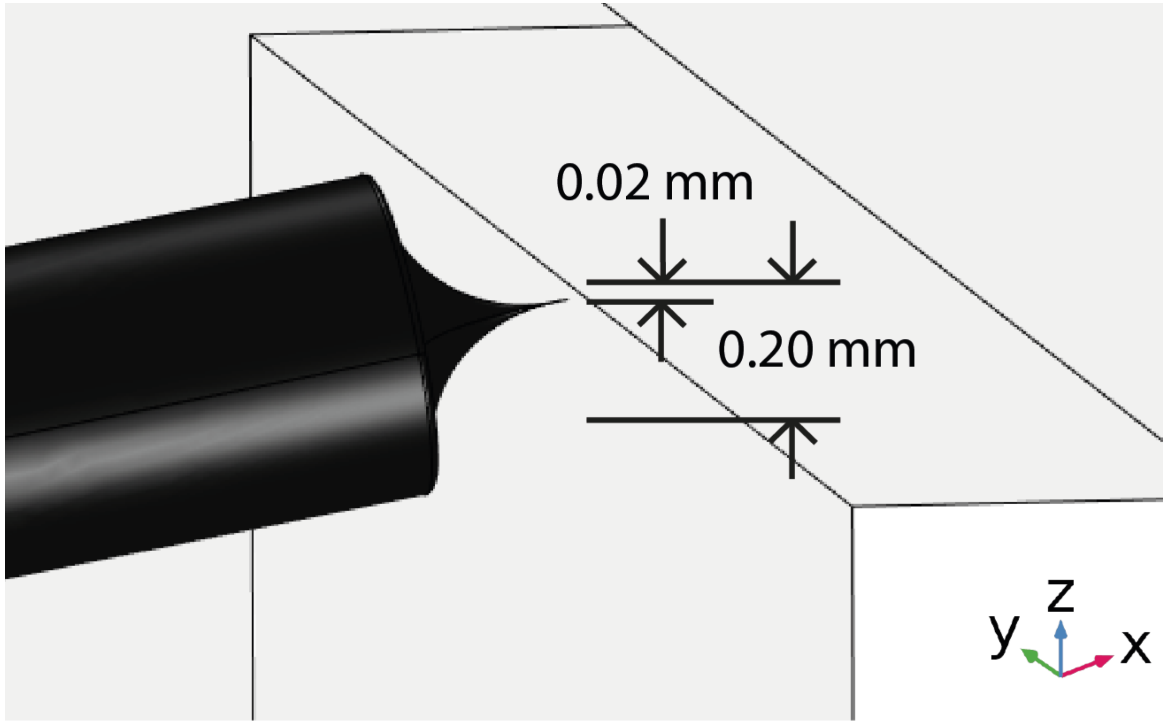


Examples of results
Optimizing the geometry

Number of secondary electrons N escaping from the junction and reaching the electron detector for different values of the initial kinetic energy K_0 (eV) and two different initial positions.

In the first position, the tip was pointing to a point on the target located 0.20 mm away from the target edge and 2500 electrons were started.

In the second position, the tip was pointing at a point on the target located 0.02 mm away from the border of the sample and 3000 electrons were started.



Examples of results
Considering different energies

Number of secondary electrons N escaping from the junction and reaching the electron detector for different values of the initial kinetic energy K_0 (eV) and two different initial positions.

In the first position, the tip was pointing to a point on the target located 0.20 mm away from the target edge and 2500 electrons were started.

In the second position, the tip was pointing at a point on the target located 0.02 mm away from the border of the sample and 3000 electrons were started.

K_0(eV)	0.20 mm		0.02 mm	
	N/2500	%	N/3000	%
35	0	0	0	0
45	1	0.04	32	1.1
55	11	0.44	170	5.7
65	178	7.1	318	10
75	341	14	467	16
85	402	16	585	20

Contact information

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Contents, data and figures taken from:
Analytical and numerical models for Scanning Field-Emission Microscopy and their experimental validation
Zurich, ETH Zurich, 2017, 107 p
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ETH Diss No.: 24382
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Thank you very much for your attention!