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Emission Properties of Silicon Nanowire Field Emitters

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Overview

Examples of field emission electron sources
- Silicon Nano Wire on Pillar Structures, with mica-spacer
- Silicon Nano Wire on Pillar Structures, with glass isolation path

FEM-Simulation
- Model of simplified silicon nano wire on pillar structures
- Fist Simulation Step: Electrostatic Field
- Second Simulation Step: Electron-Trajectories

Results
- The influence of tip-to-grid distance and grid thickness on the electron transmission

Conclusion

Silicon Nano Wire on Pillar Structures I

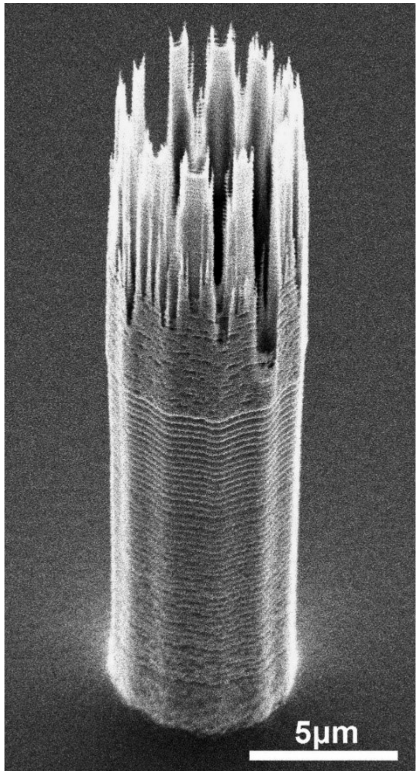


Fig. 3: SEM image of a single emission pillar of a silicon nanowire field emitter.

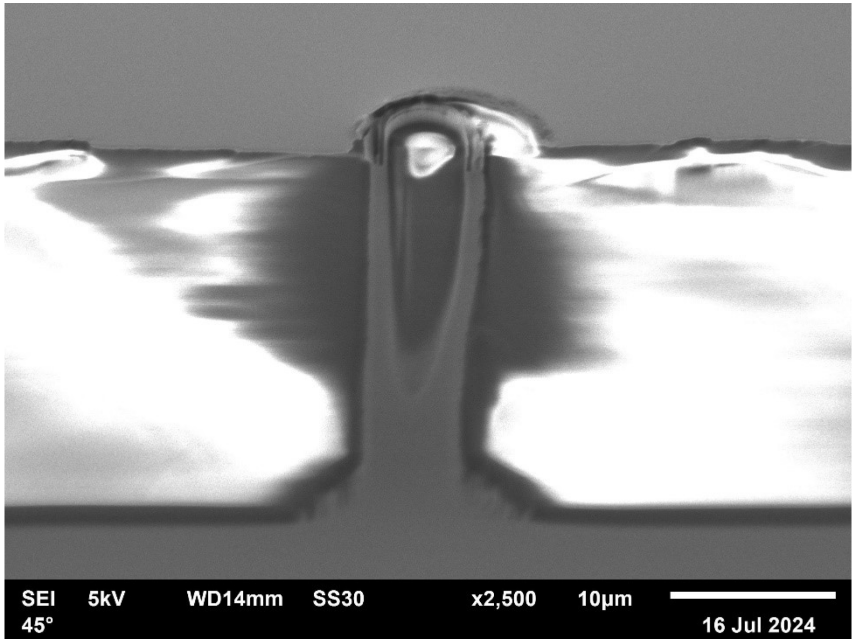


Fig. 4: SEM cross section of an emission pillar. The pillar is surrounded with Benzocyclobutene (BCB) with a Ni gate on top.

Silicon Nano Wire on Pillar Structures II

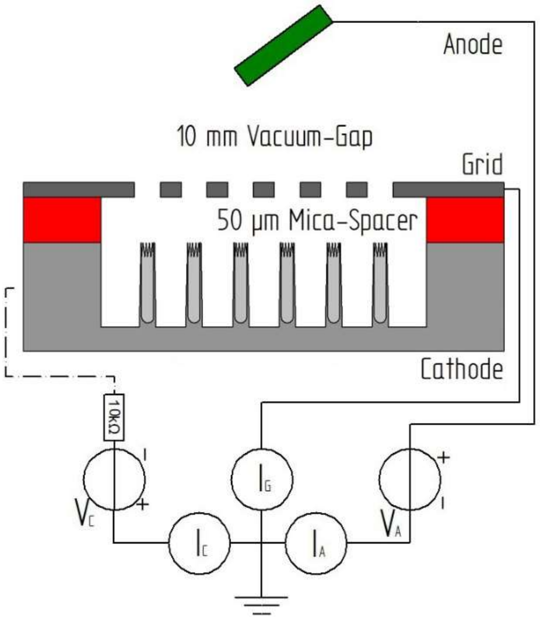


Fig. 5: Schematic of the measurement setup. The cathode is connected via a 10 kΩ resistor through the cathode voltage source (Vc) and the cathode current meter (Ic) to the ground. The grid is mounted on top of the cathode with a 50 µm mica spacer and is also connected to the ground. Based on[3)]

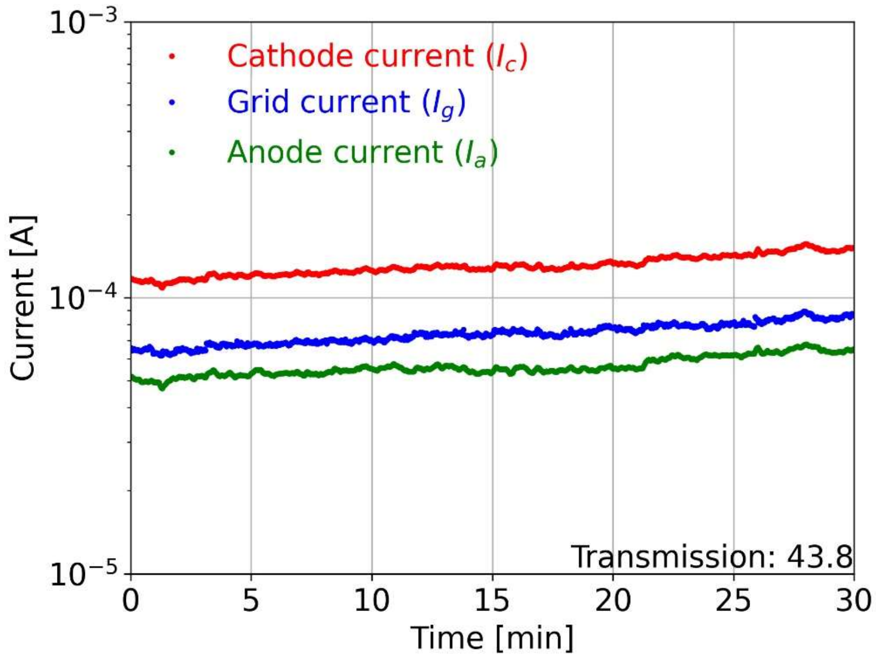


Fig. 6: Measurement at 900 V cathode voltage (Vc) and an anode voltage of 1 kV for a clamped sample. Here, the average electron transmittance is 43.8%. Based on[3)]

[3)] Philipp Buchner, Matthias Hausladen, Mathias Bartl, Michael Bachmann, Rupert Schreiner; High current field emission from Si nanowires on pillar structures. J. Vac. Sci. Technol. B 1 March 2024; 42 (2): 022208. https://doi.org/10.1116/6.0003384

Silicon Nano Wire on Pillar Structures III

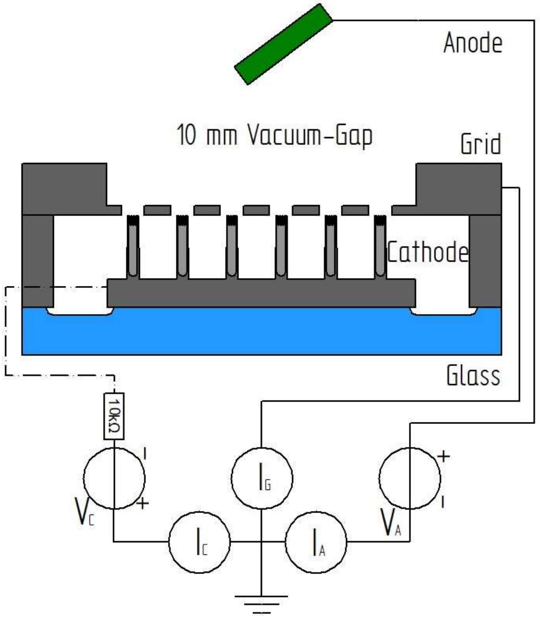


Fig. 7: Measurement setup for the electron source. A tungsten needle is used as the transmission anode. [3)]

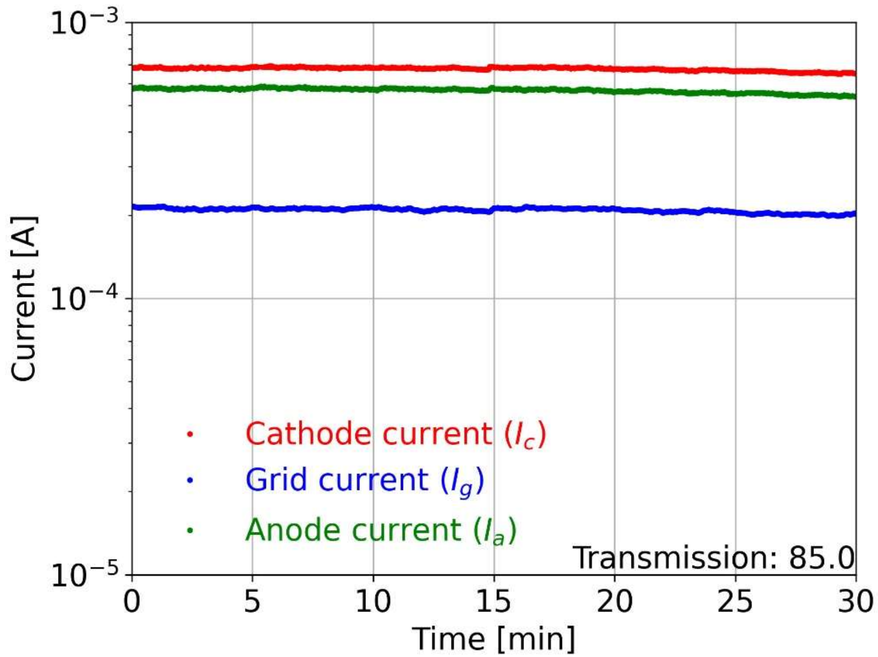


Fig. 8: 30 min transmission measurement for an electron source at a cathode voltage (Vc) of 250 V and an anode voltage (VA) of 500 V. A electron transmittance of 85.0% was achieved. [3)]

[3)] Philipp Buchner, Matthias Hausladen, Mathias Bartl, Michael Bachmann, Rupert Schreiner; High current field emission from Si nanowires on pillar structures. J. Vac. Sci. Technol. B 1 March 2024; 42 (2): 022208. https://doi.org/10.1116/6.0003384

Model of Silicon Pillars

Anode
Material: Copper
Voltage: 500V

Vacuum
Pressure: $5 \cdot 10^{-9}$hPa

Grid
Material: Silicon
Voltage: 0V

Emitter
Material: Silicon
Voltage: -300V

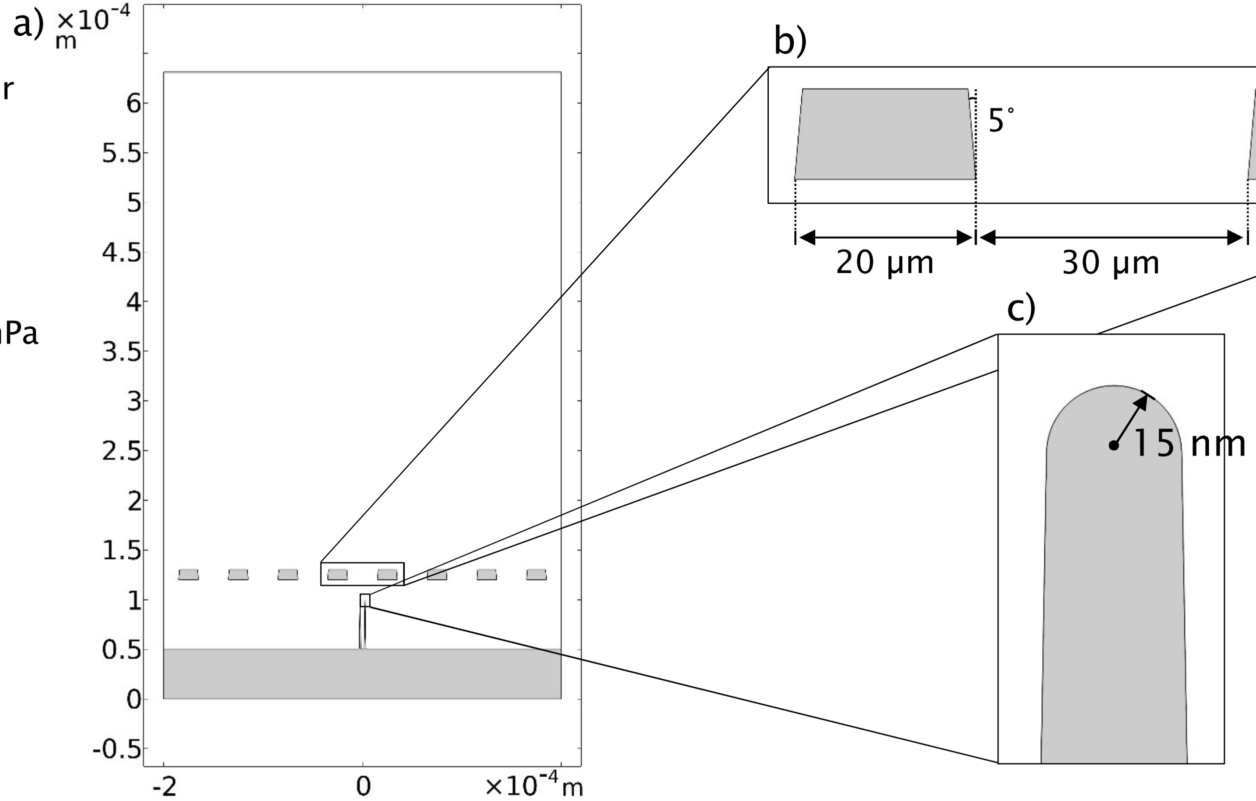


Fig. 9: a) General geometry used in the simulation and the geometry of b) the grid and c) the emitter

1st Step: Simulation of the Electrostatic Field I

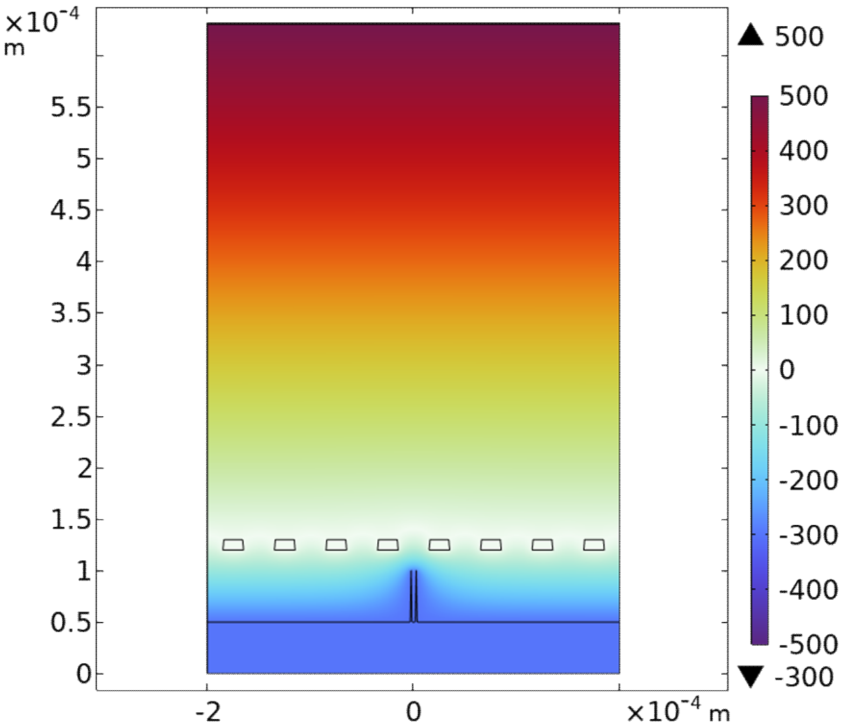


Fig. 10: The electric potential for a grid thickness of 10 µm and a tip-tp-grid distance of 20 µm

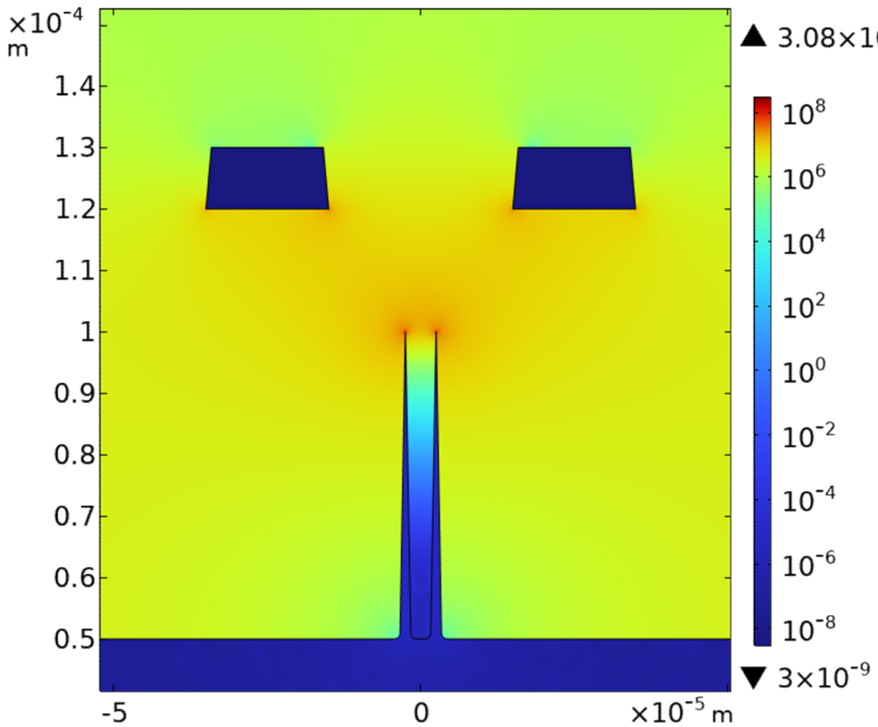


Fig. 11: The electric field strength for a grid thickness of 10 µm and a tip-tp-grid distance of 20 µm

1st Step: Simulation of the Electrostatic Field II

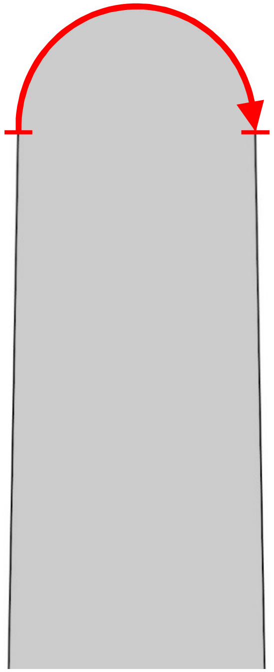


Fig. 12: Arc length along the tip of an emitter.

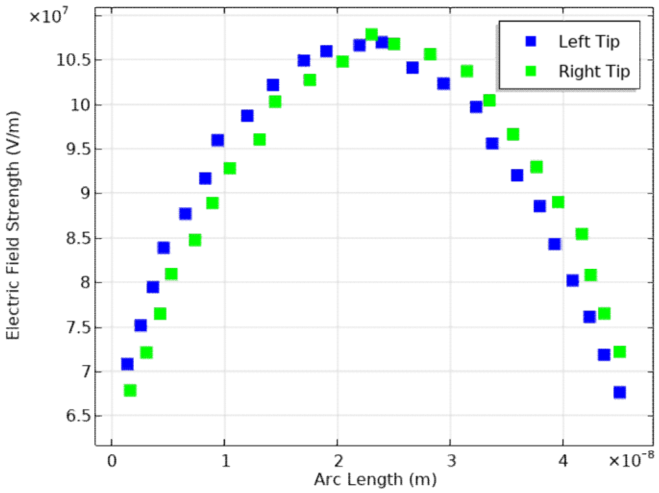


Fig. 13: Electric field strength along the left (blue) and right (green) tip of an emitter with a grid thickness of 50 µm and a tip-tp-grid distance of 40 µm.

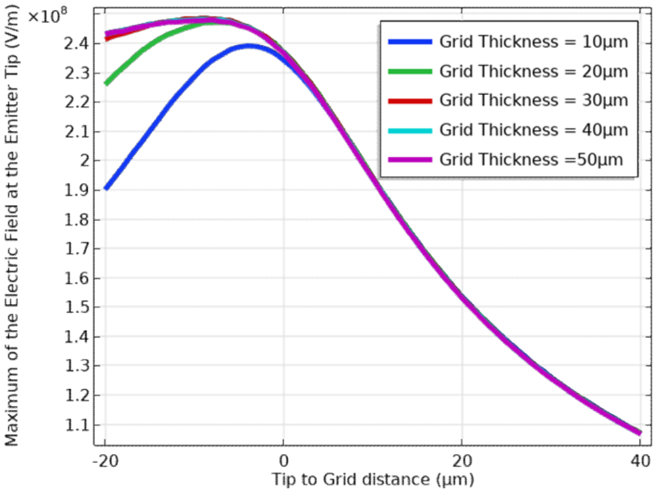


Fig. 14: Electric field strength along the left (blue) and right (green) tip of an emitter with a grid thickness of 50 µm and a tip-tp-grid distance of 40 µm.

2nd Step: Simulation of the Electron-Trajectories

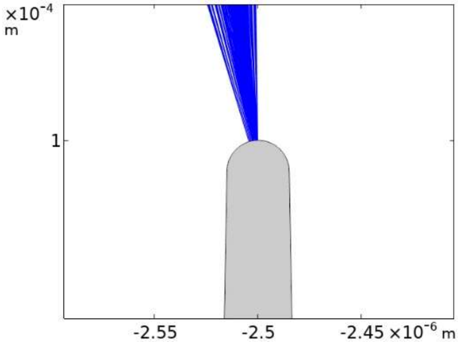


Fig. 15: Starting positions of the electron trajectories on the left emitter tip.

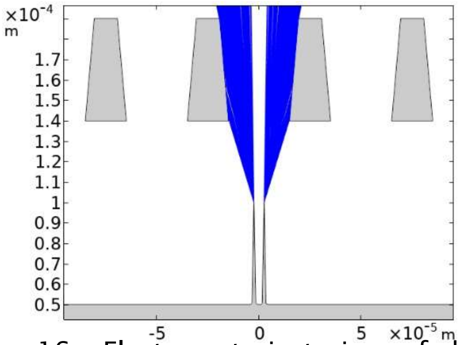


Fig. 16: Electron trajectories of both emitter tips.

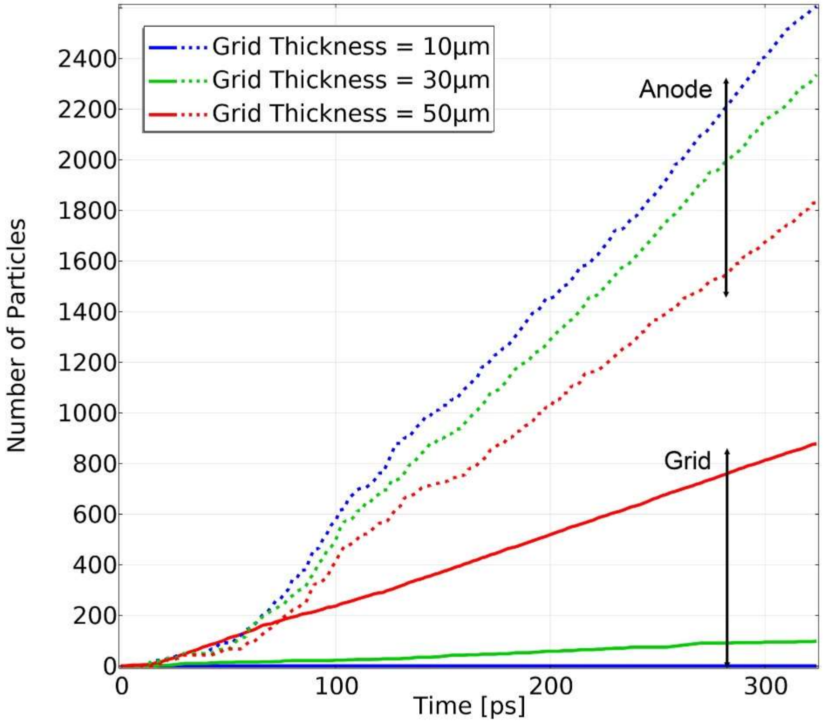


Fig. 17: Number of particles hitting the anode and grid respectively with grid thicknesses of 10 µm, 30 µm and 50 µm. The particles were released every 2 ps.

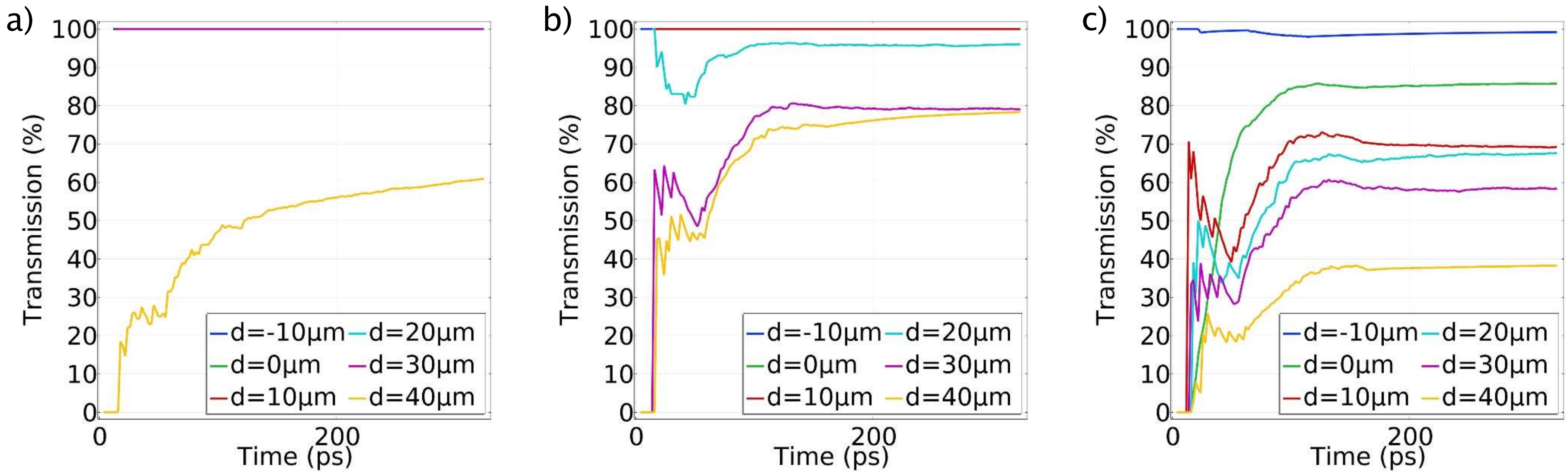


Fig. 18: Electron transmission for tip to grid distances in the range of -10 µm to 40 µm and a grid thickness of a) 10 µm, b) 30 µm and c) 50 µm.

Simulation Results II

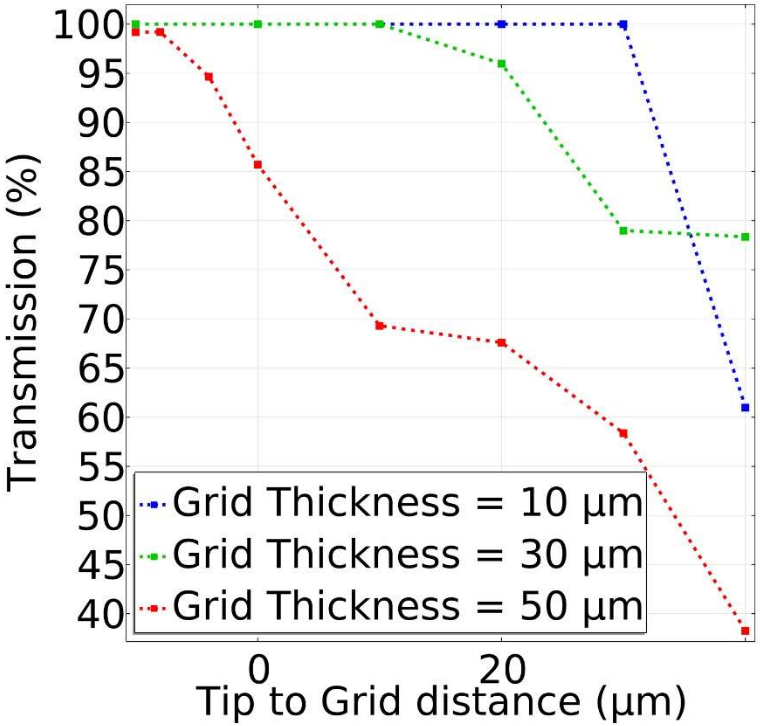


Fig. 19: The dependency of the transmission on the tip-to-grid distance at different grid thicknesses.

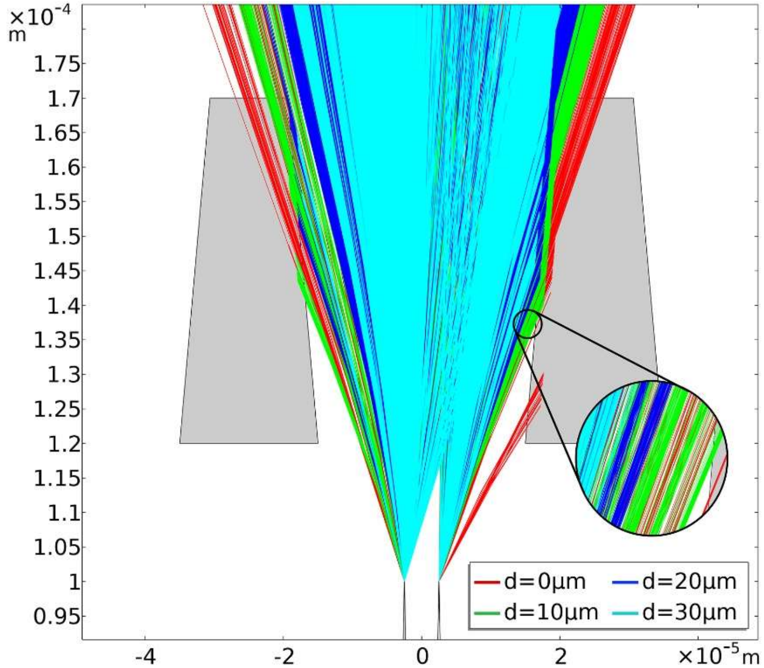
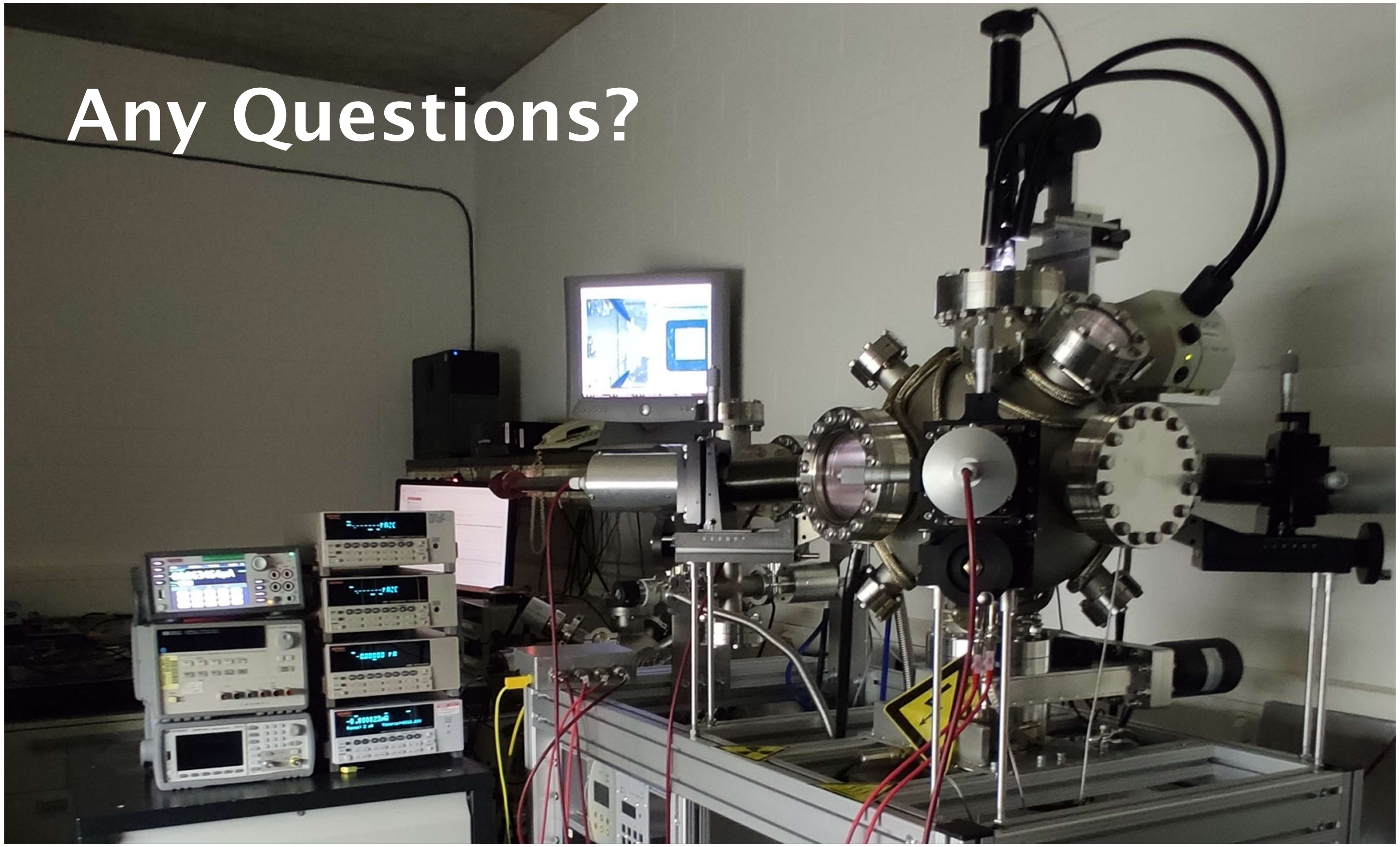


Fig. 20: Overlay of particle trajectories at tip to grid distances in the range of 0 µm to 30 µm for a grid thickness of 50 µm.

Conclusion

- The electric field strength at the tips is the highest at a tip-to-grid distance in the range of -10 to -5 µm.
- The thicker the grid is, the sooner and faster the transmission decreases with increasing distance. This is due to the particles hitting the inner side walls of the grid rather than the bottom.
- A transmission of almost 100% with thick grids can only be achieved if the emitter tips protrude through the grid openings.
- With thin grids, the distance between the tips and the grid is less critical, so that a transmission of 100% is possible even if a certain distance between the tips and the grid is present.

Thank you For Your Attention



FE Electron Source, Laser micromachining

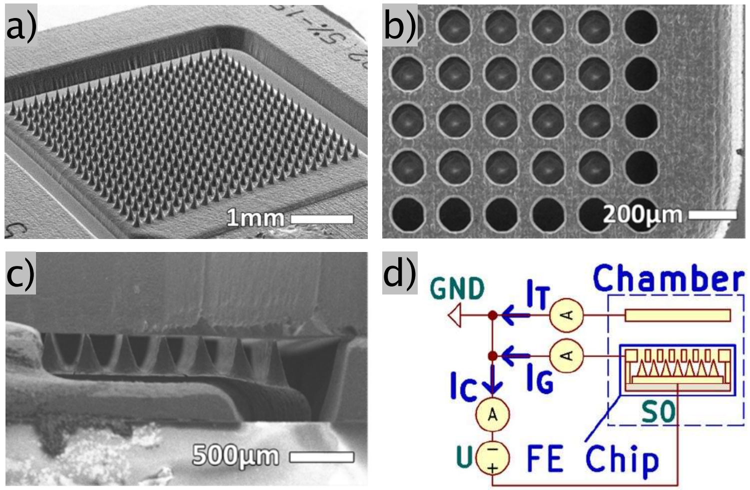


Fig. 1: SEM images of a) the chathode in isometric perspective, b) the tips aligned to the apertures from the top, and c) the tips protruding into the grid apertures (side view). d) Electrical schematics of the triode measurement setup for a single FE chip [1)]

Transmission @ 250V: 98.9% ± 0.4%

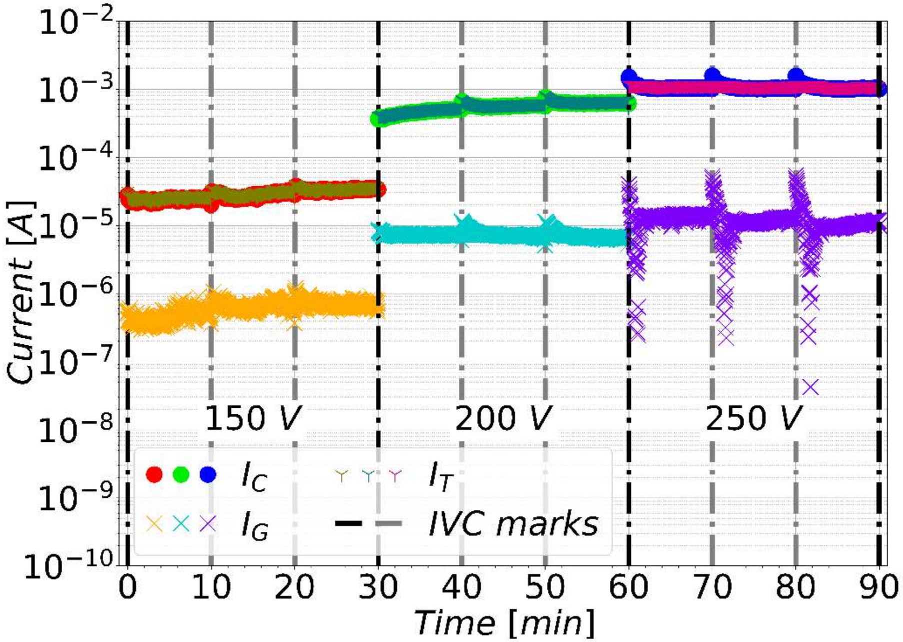


Fig. 2: Cathode- (I_C), transmission- (I_T), and grid-currents (I_G) of 30-min operations at the voltage levels 150, 200, 250 V concatenated over time. [1)]

[1)] M. Hausladen, P. Buchner, M. Bartl, M. Bachmann, R. Schreiner; Integrated multichip field emission electron source fabricated by laser-micromachining and MEMS technology. J. Vac. Sci. Technol. B 1 January 2024; 42 (1): 012201. https://doi.org/10.1116/6.0003233