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AN OVERVIEW OF THE DEVELOPMENT OF SILICON NANOWIRE ELECTRON SOURCES

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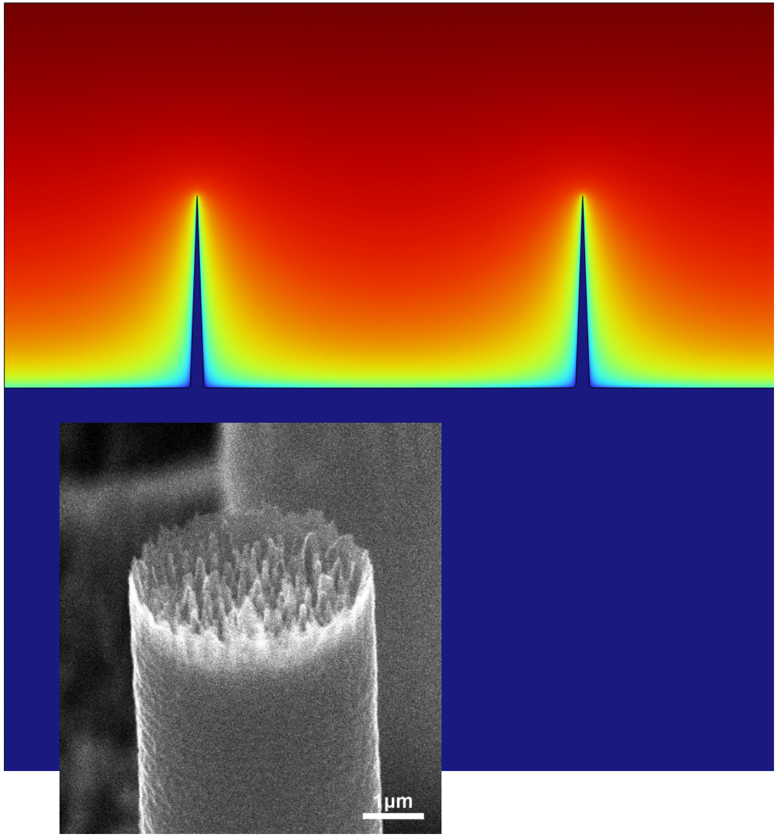
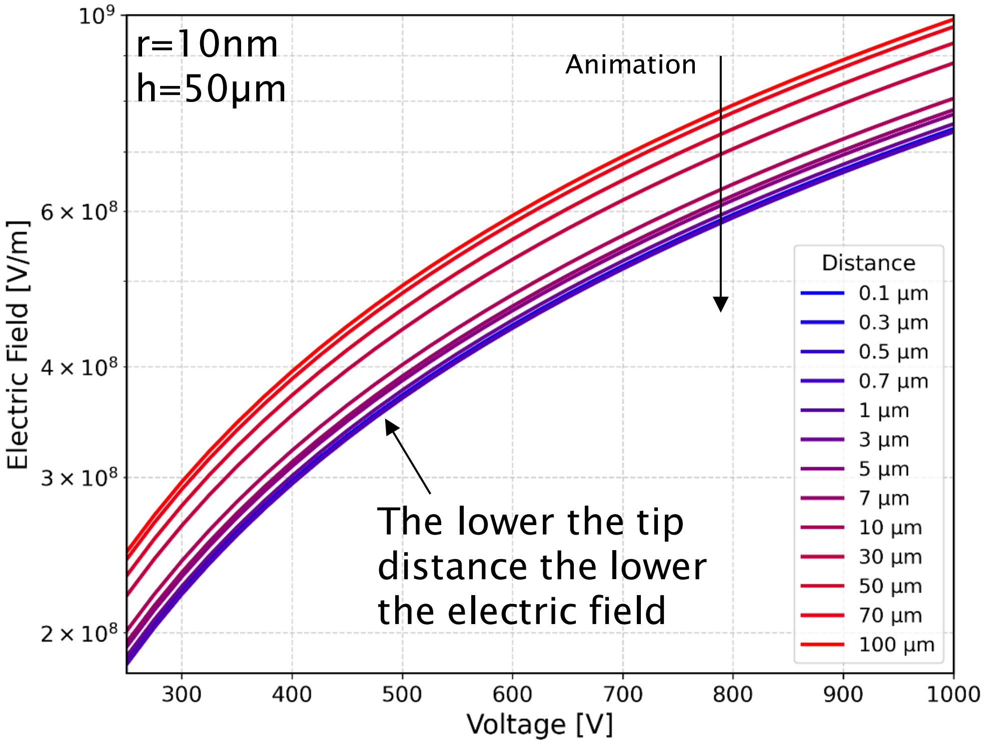
Studies on Field-Shielding





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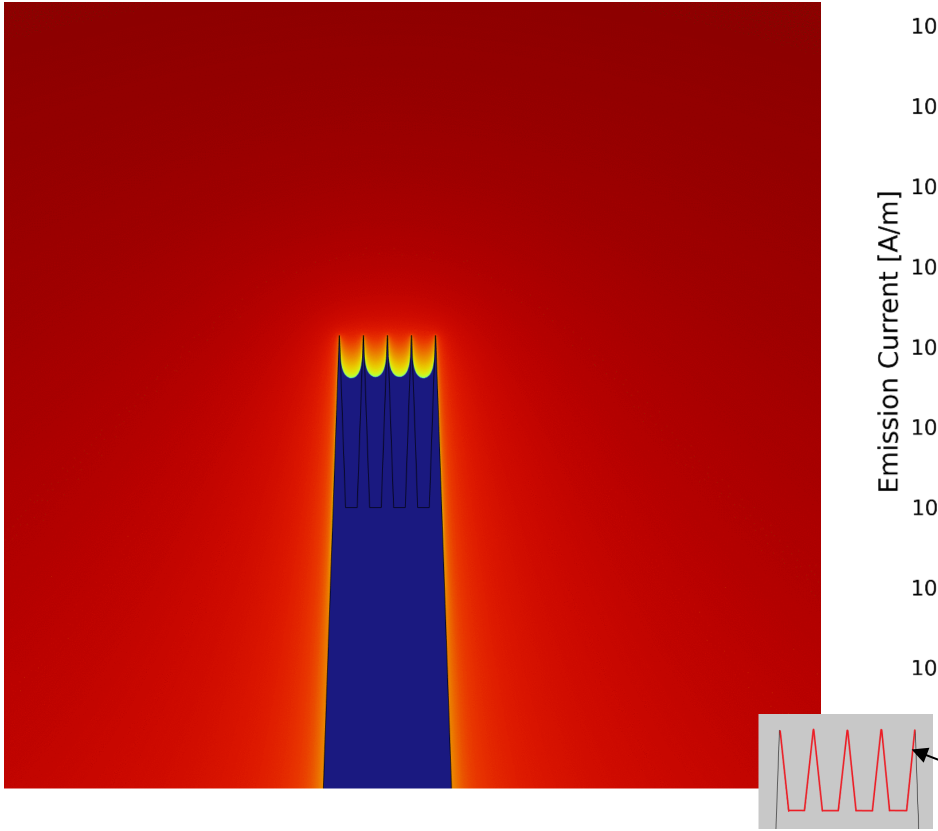
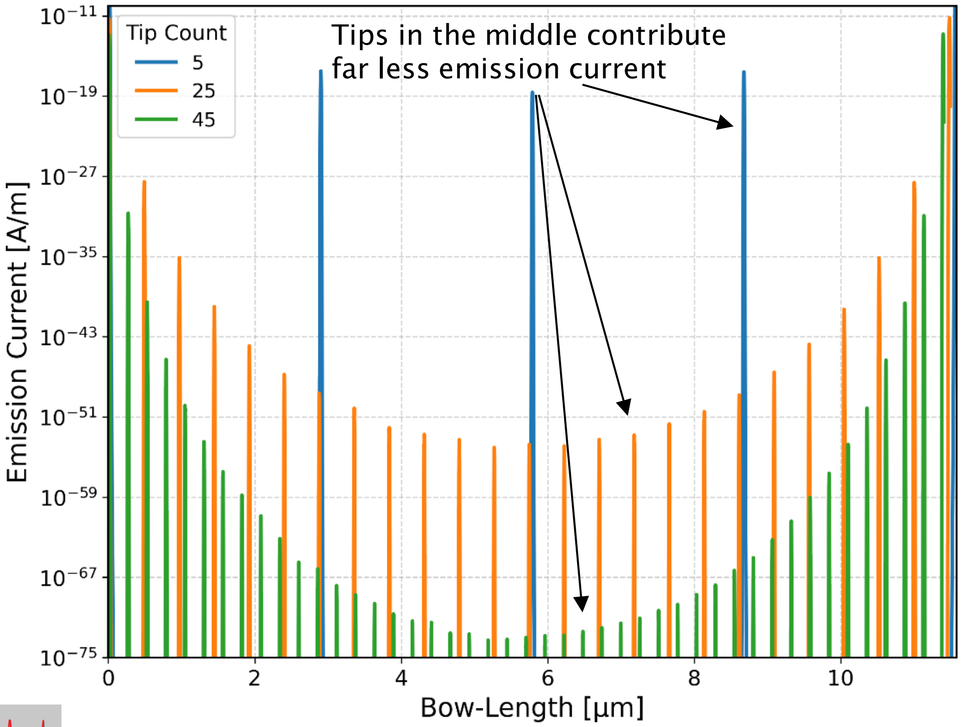
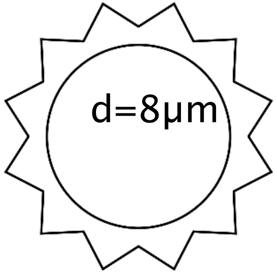
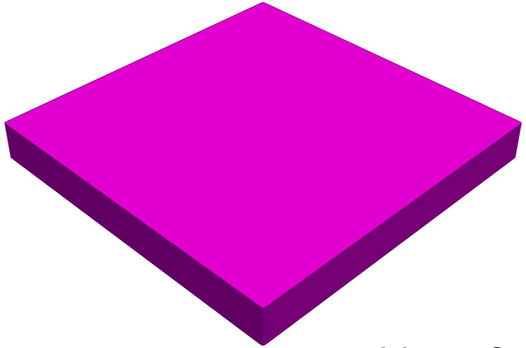
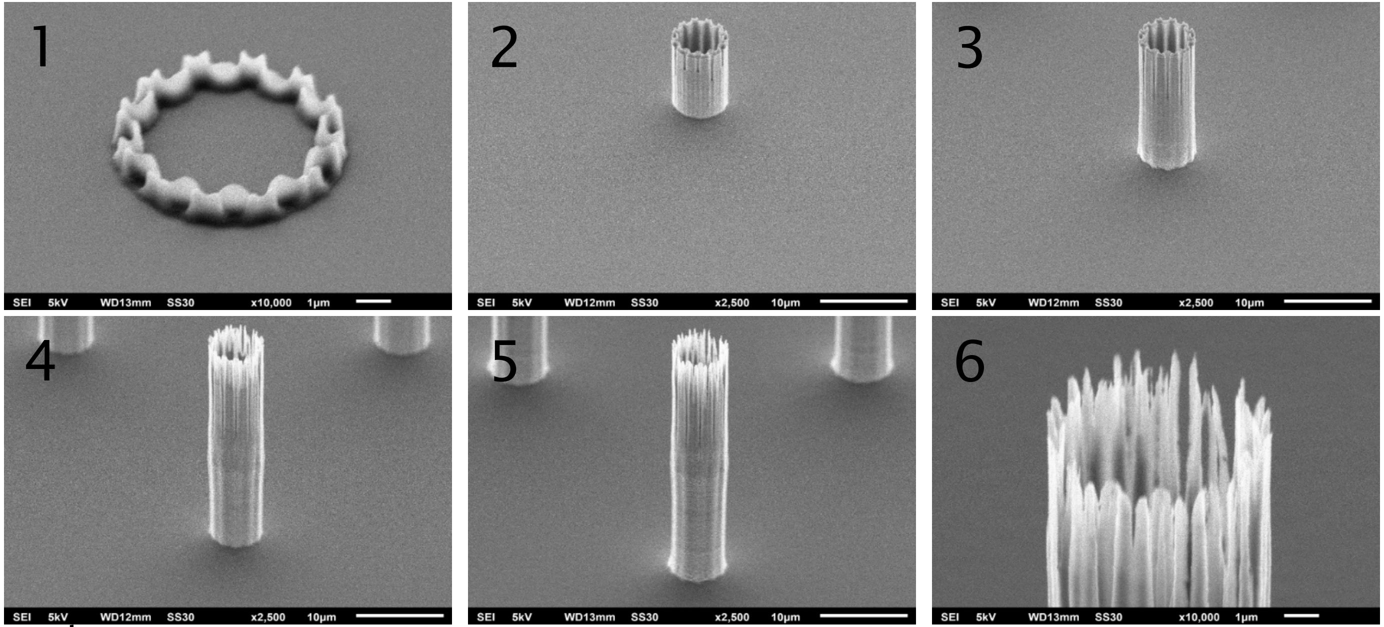




Development of Silicon Nanowire Field-Emitters







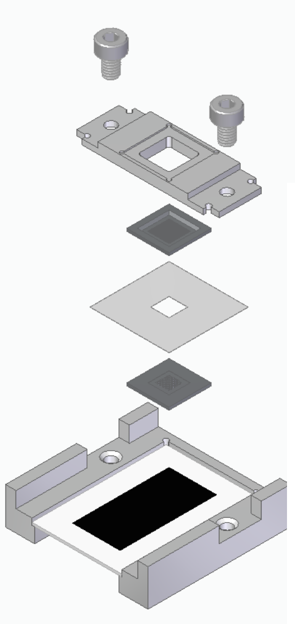
Emitter structured by a four step process:

- generating an irregular ring of photoresist
- anisotropically etching the silicon
- removing the photolaquer
- repeating the etching step

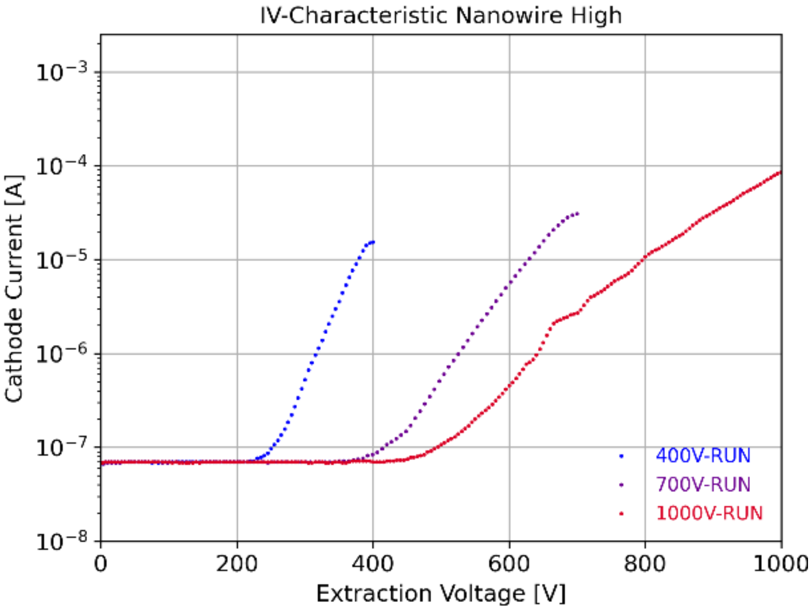
Two types of silicon used:

- n-Type (Ph), <100>, 1-10 Ωcm
- n-Type (Ph), <100>, <0.005 Ωcm

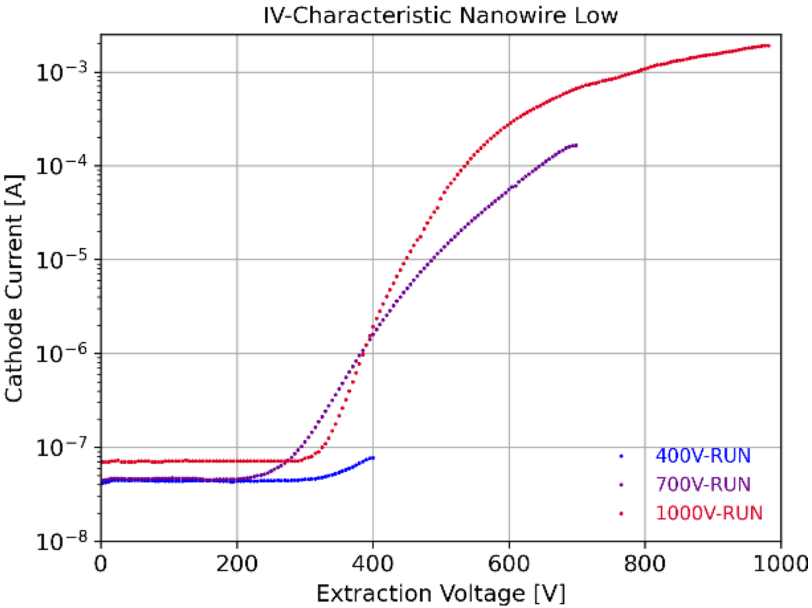
Development of Silicon Nanowire Field-Emitters



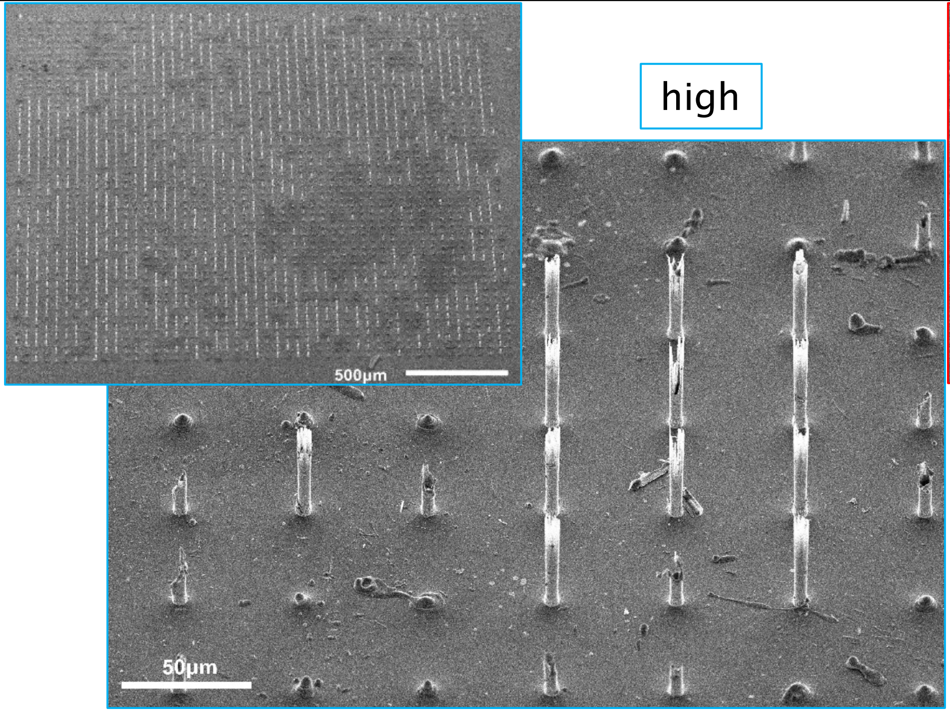
- n-Type (Ph), <100>, <0.005 Ωcm

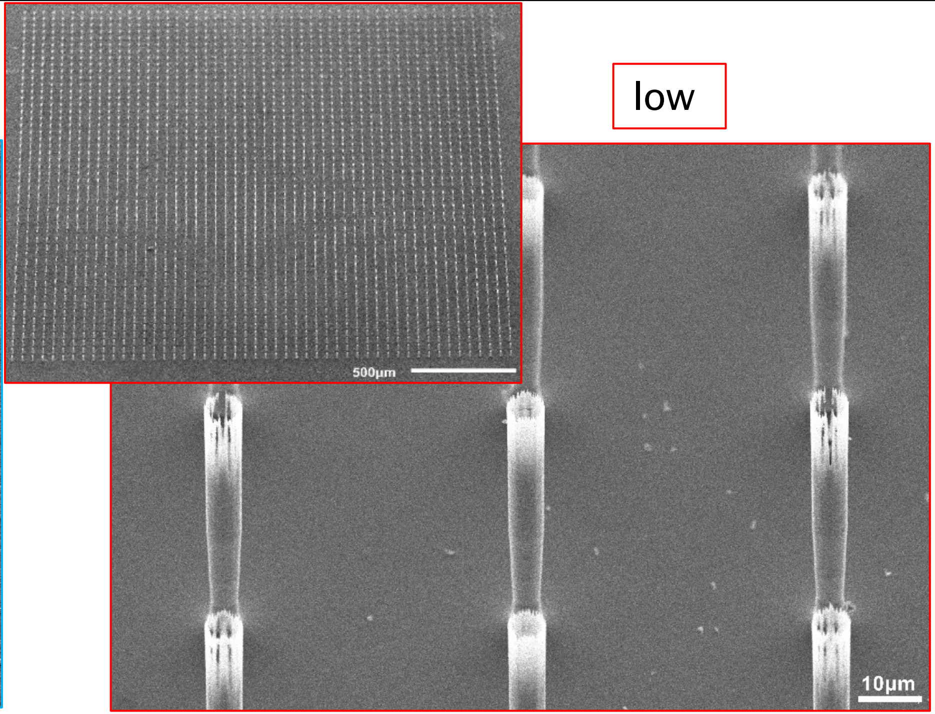


- n-Type (Ph), <100>, 1-10 Ωcm



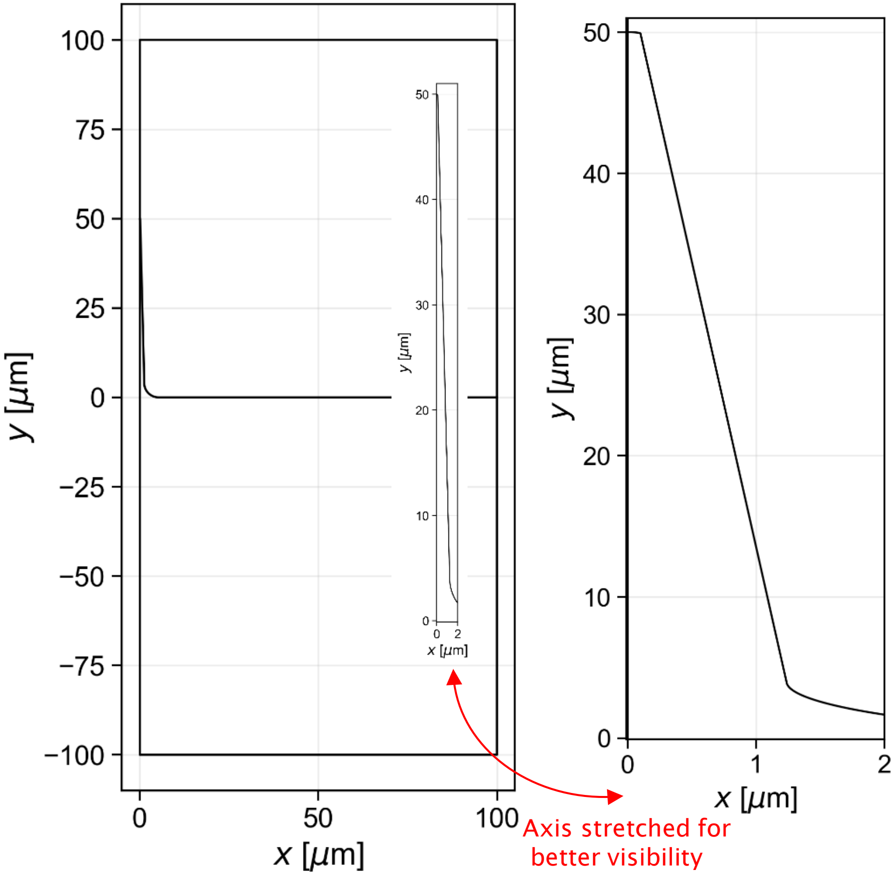
Low Doped vs. Highly Doped Silicon





- SEM images after measurement show strong degradation for highly doped silicon samples
- Lowly doped samples show no virtually no degradation in SEM images after measurements
- → Unregulated rise in current leads to thermal runaway for high doped emitter

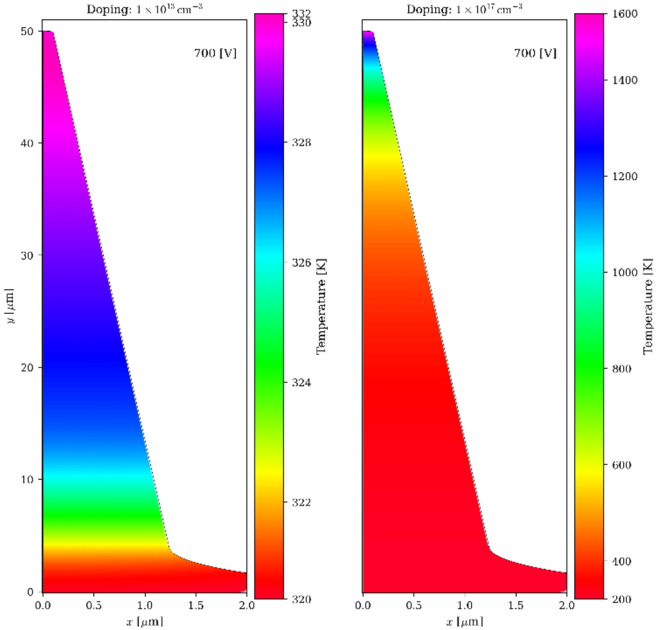
Low Doped vs. Highly Doped Silicon

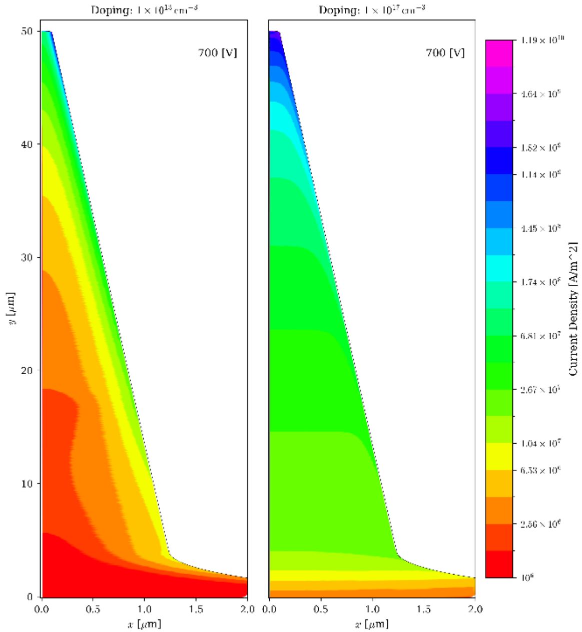


- Semiconductor module
  - Electric fields
  - Field emission (modified)
  - Electron concentration (Temperature)
  - Electron mobility (Temperature)
  - Generation/Recombination (Temperature)
  - Surface states and recombination
  - Permittivity
- Electric currents
  - Voltage drop due to resisitvity
- Heat transfer in solids
  - Joule heating due to current and resistivity
  - Nottingham Effect due to Field Emission
  - Radiative cooling
  - Convective cooling
  - Heat conduction

- Sweeps of extraction voltage for different doping levels

Low Doped vs. Highly Doped Silicon



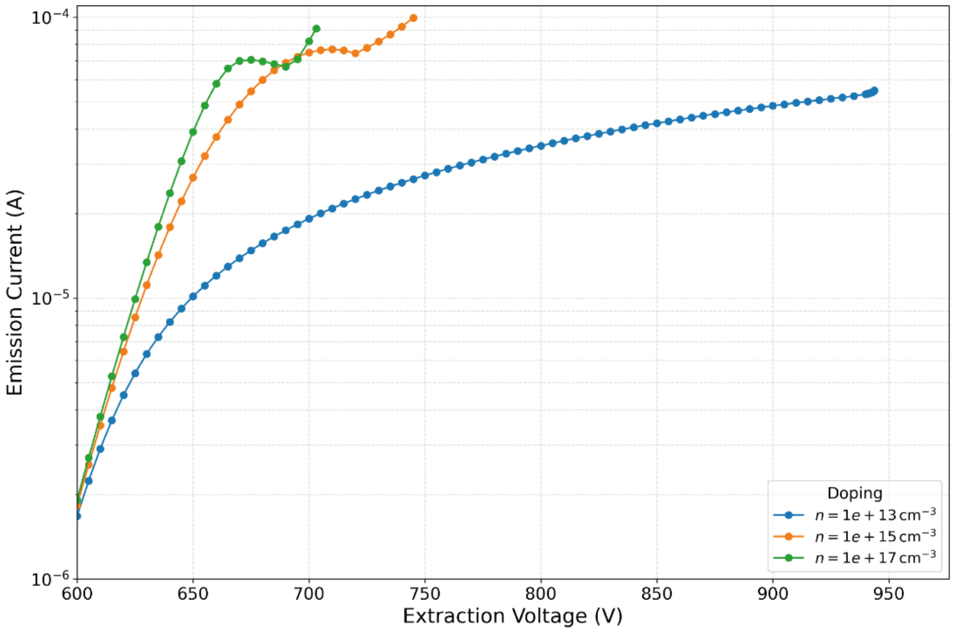


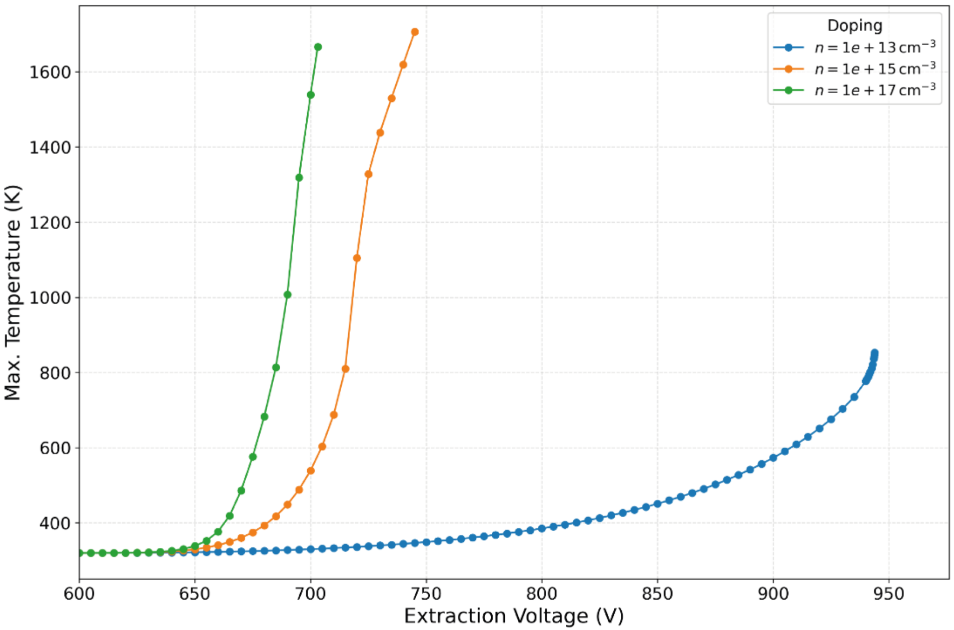
- High doped emitter heats up more locally and gets therfore hotter in a smaller volume
- Low doped emitter heats up more evenly and therefore reaches lower temperatures

Note: same geometry and extraction voltage only difference: doping level

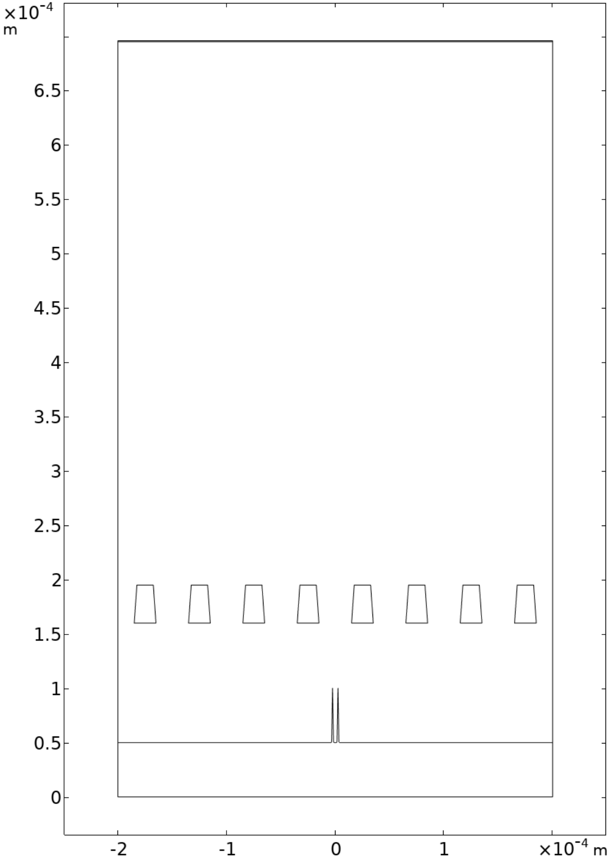
- High doped emitter: the whole bulk conducts electrons
- Low doped emitter: only the edge conducts

Low Doped vs. Highly Doped Silicon



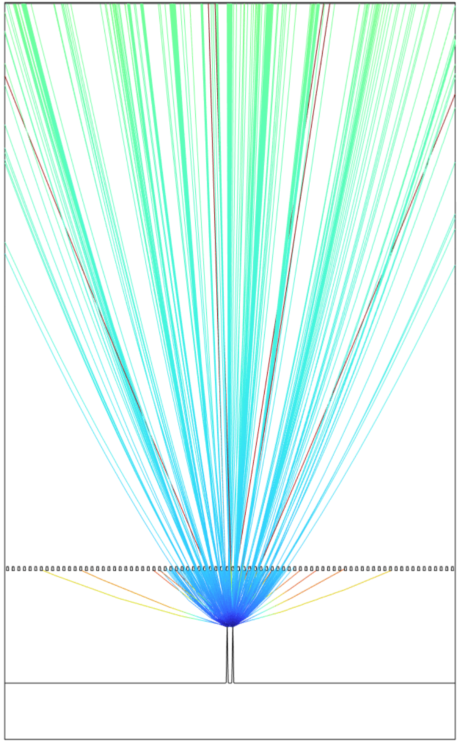


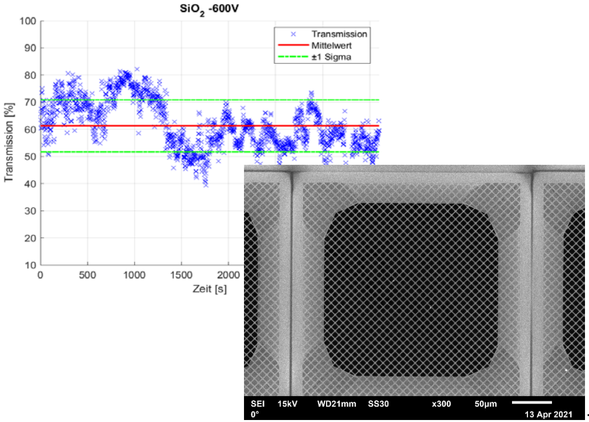
Studies on Electron Transmission

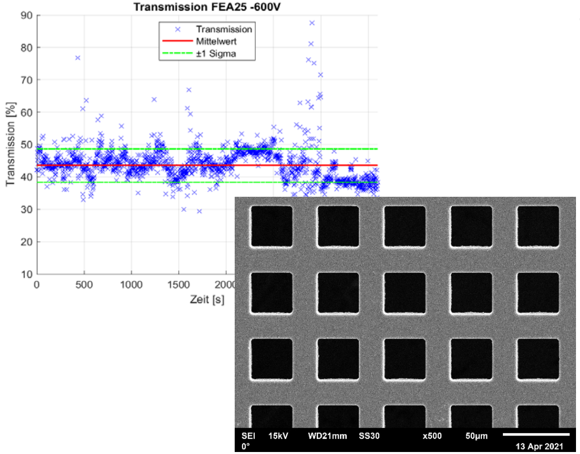


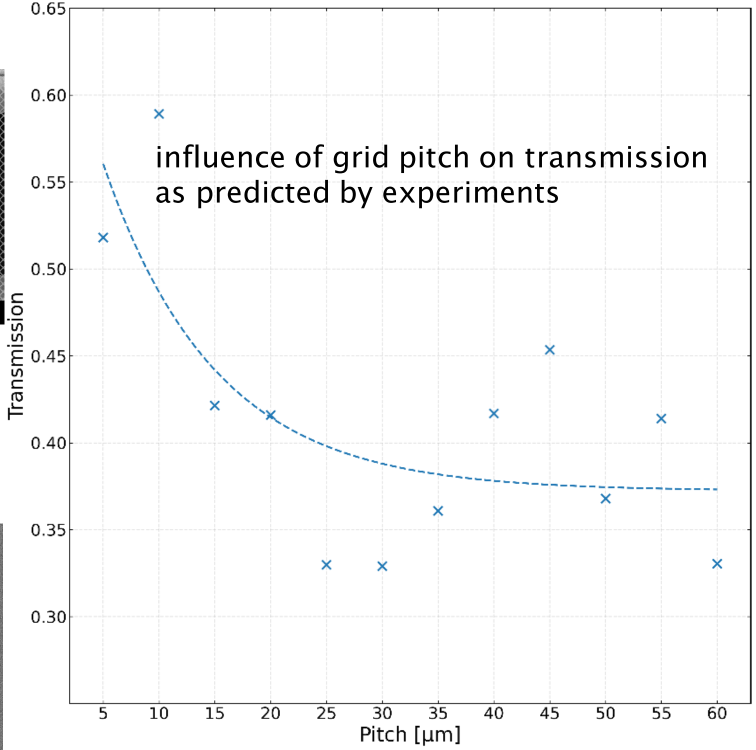
- Electric fields, semiconductor properties and cathode geometry as described before
- Coupled to charged particle tracing module
  - 10 electrons per released particle
  - 0 – 400ps in 2.5ps steps
  - Number of released particles calculated by FE-Boundary Condition
- Extraction grid geometry controlled by parameters
- Multiple studies varrying geometries

Studies on Electron Transmission









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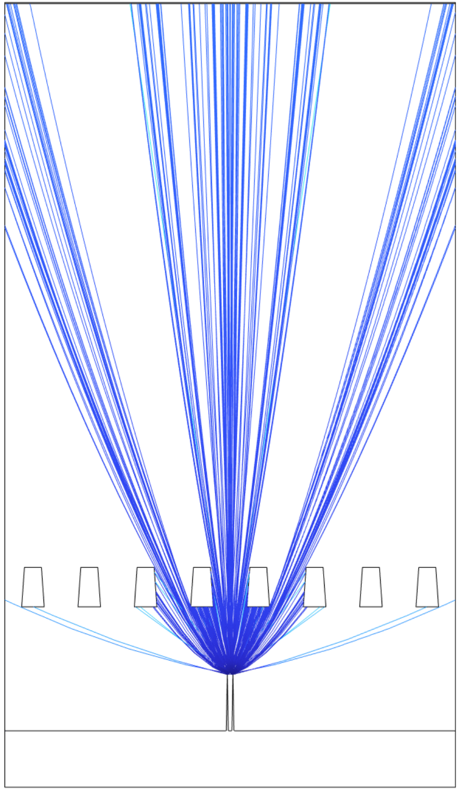

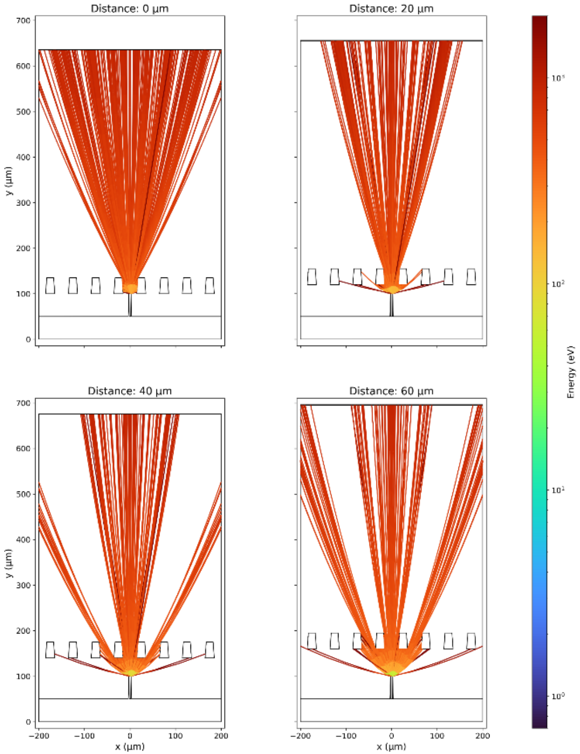

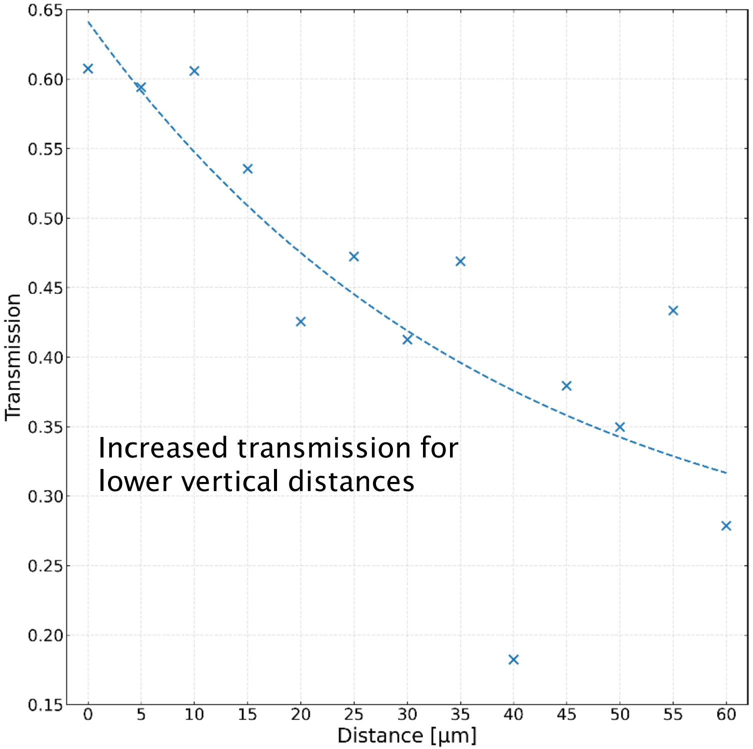

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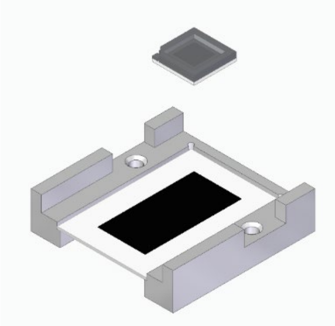

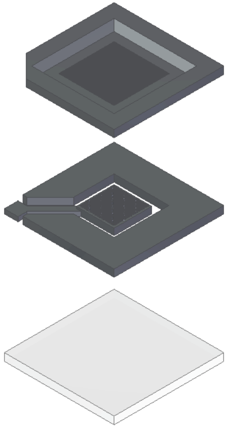

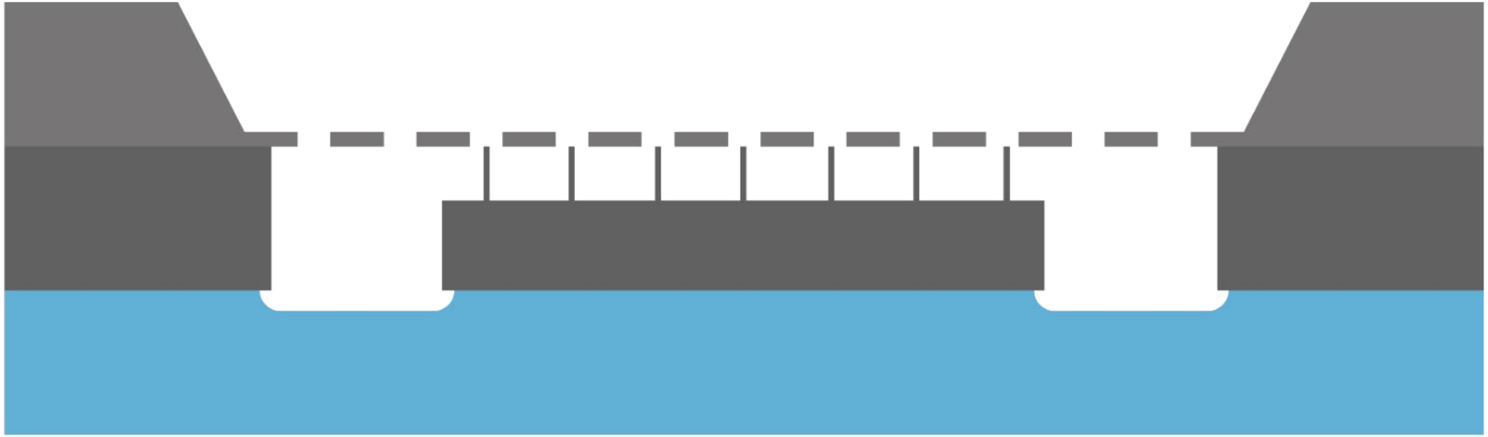

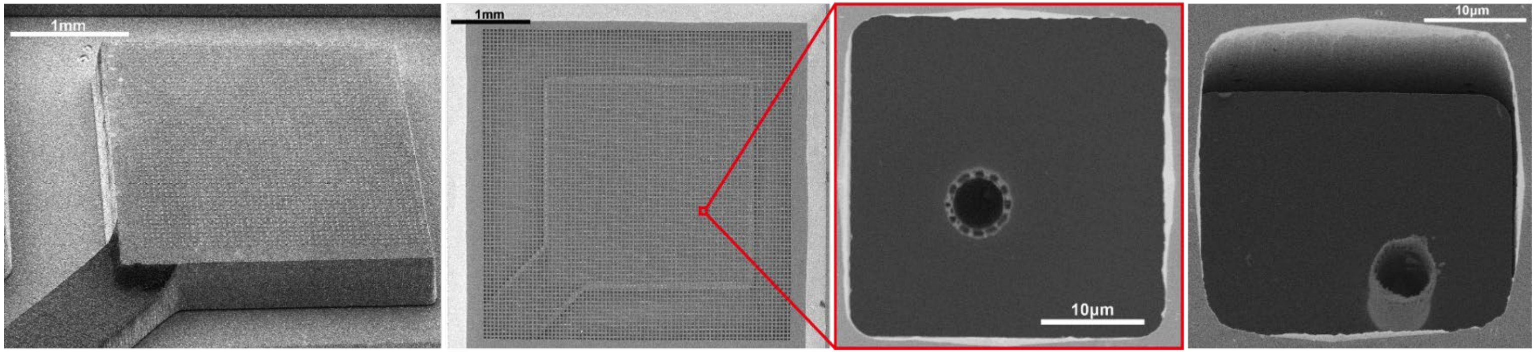

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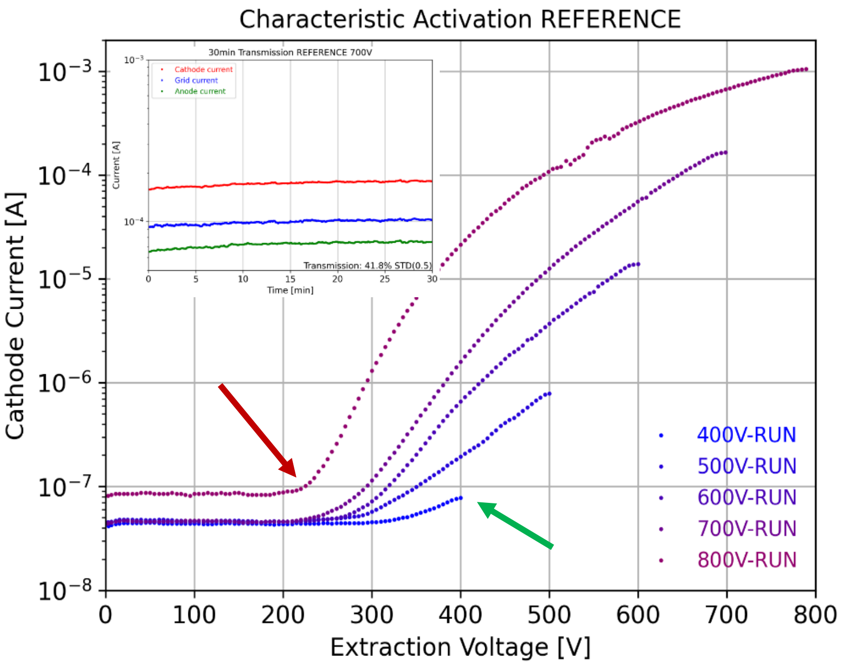
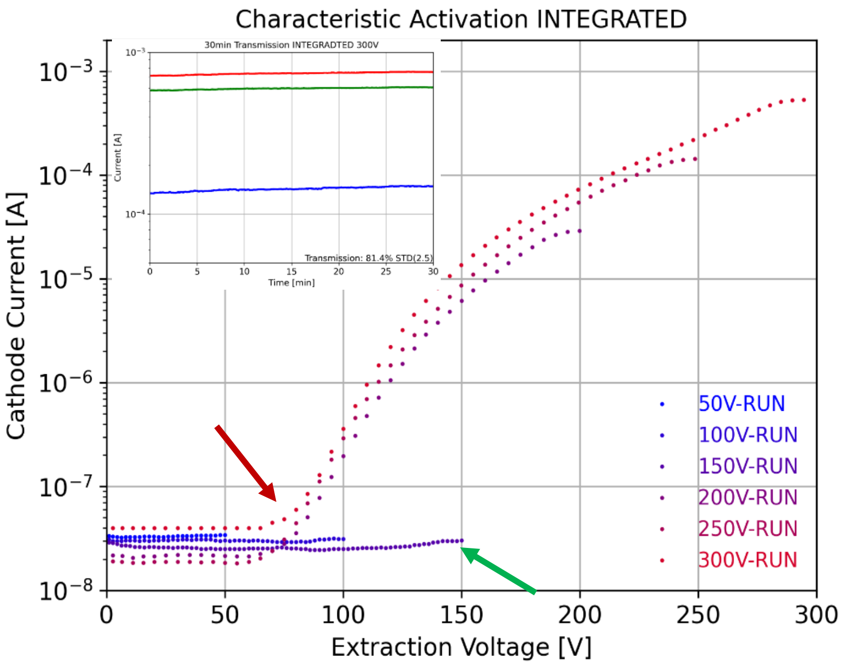
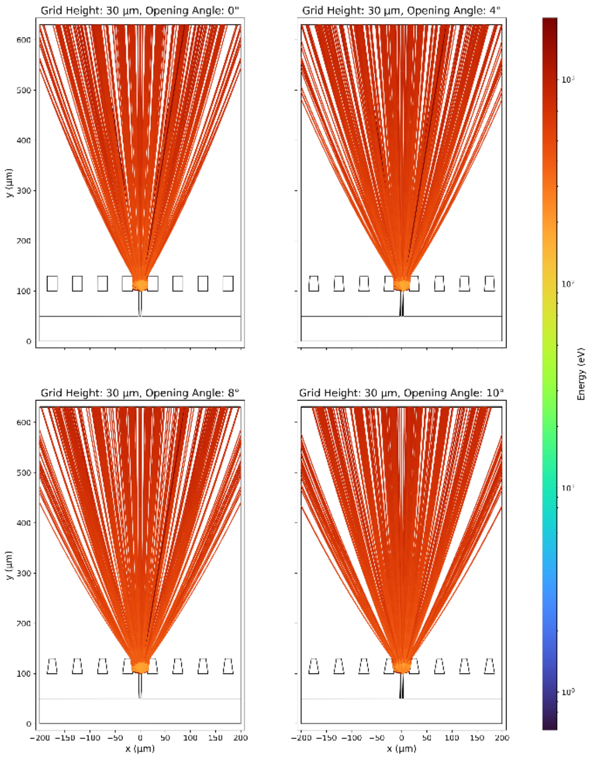
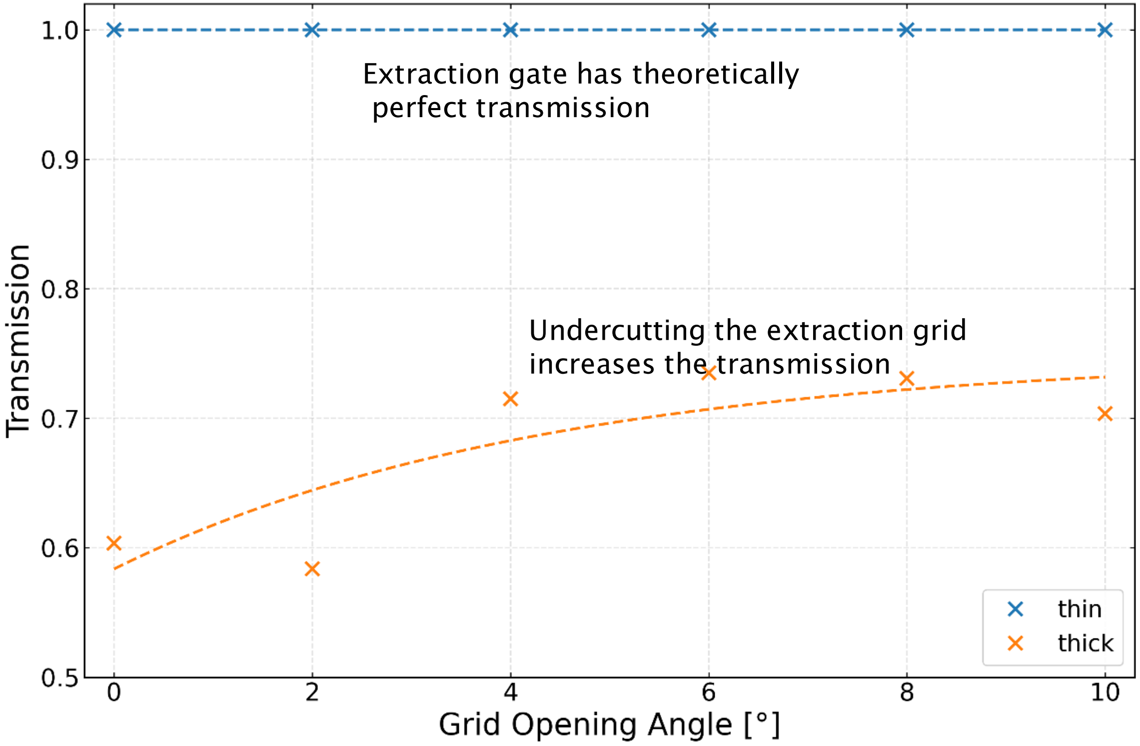




- Onset voltage reduced by 200 V (from ~300V to 75V)
- First emission at 150 V with new sample (old one 400 V)
- About 700 µA emission current at 300V (old sample same level at 700V)
- Transmission of 41.8% (StD: 0.5%) with the mica spacer due to missalignment
- Glass insulation path: transmission of 81.4% (StD: 2.5%)

Optimizing Transmission





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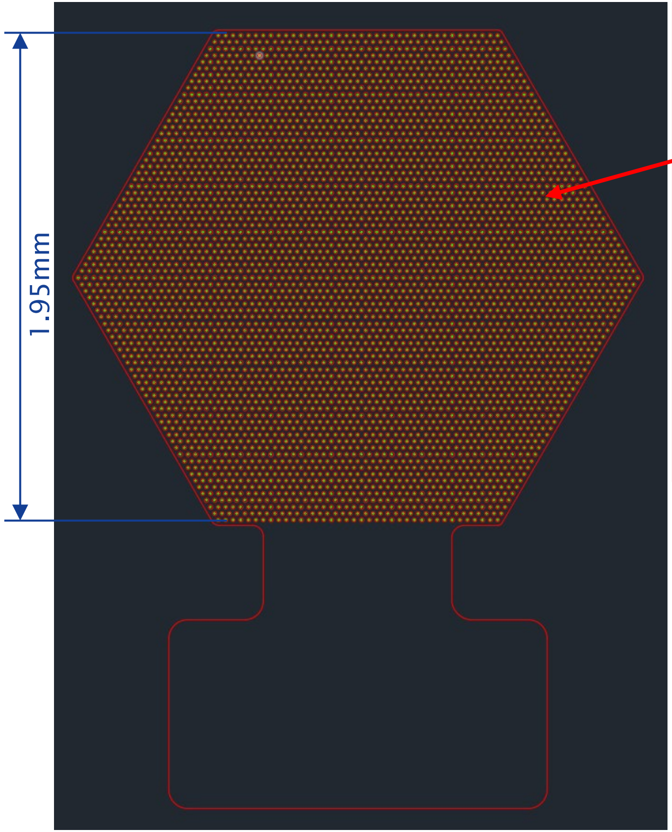
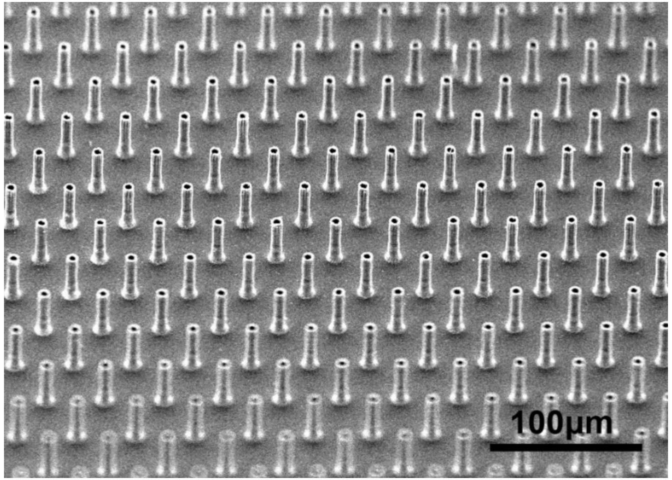




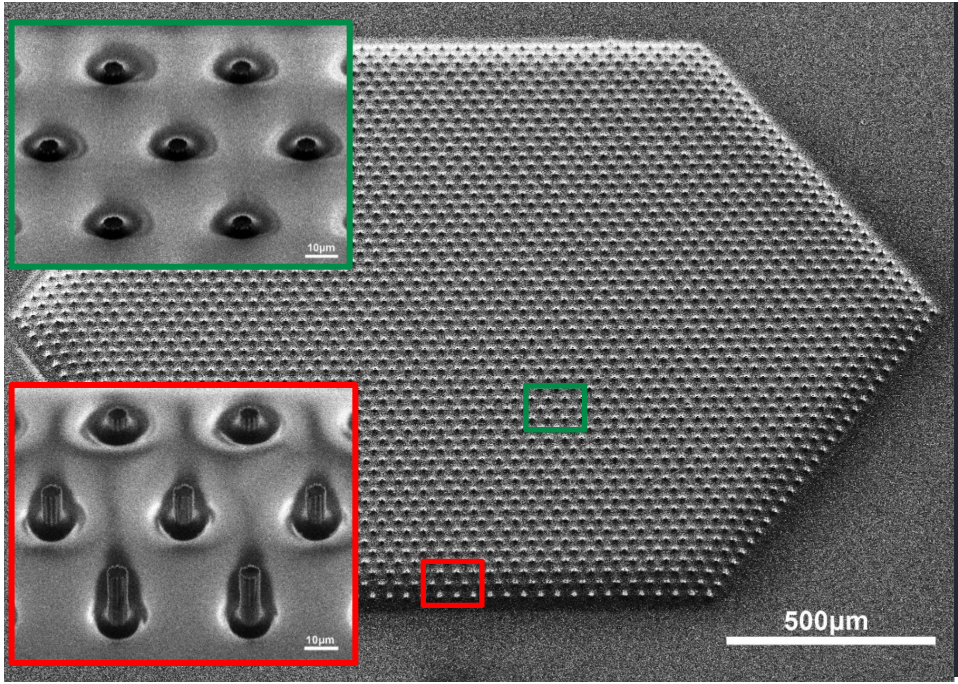
- Hexagonal arrangement for the emission array
- Emitter spacing: 40µm

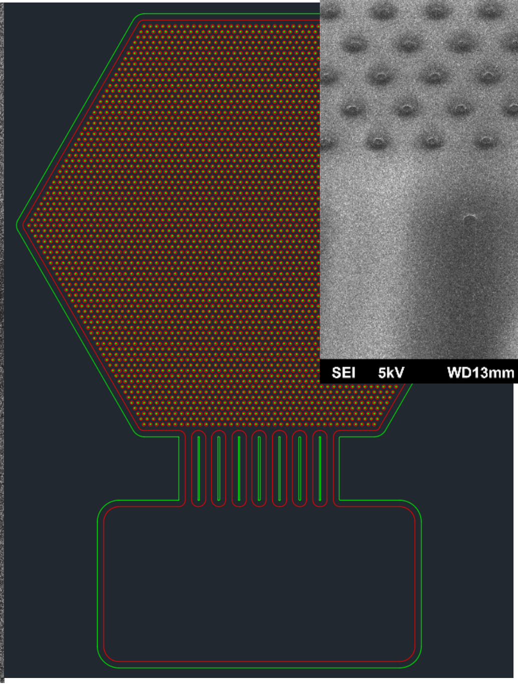
- Emitter density: 722 Emission pillars/mm^2
- Increase compared to square arrangement (50µm): 1.8

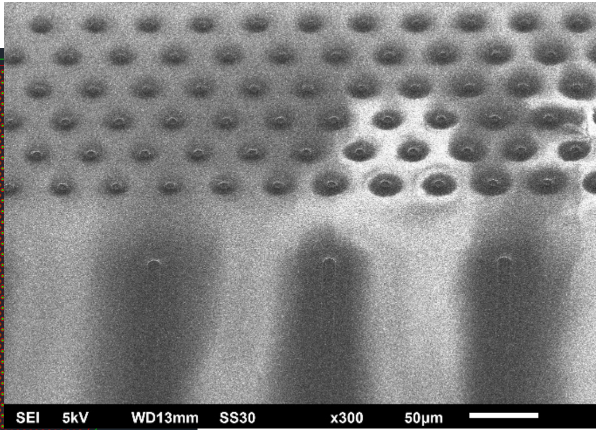
- 2437 Emission pillars per array (area: 3.38mm^2)
  (area square: 6mm^2)

Optimizing Transmission

- Irregular coverage with BCB due to flow resistance at the border of the array
  → New mask with the emitters sunken into a valley







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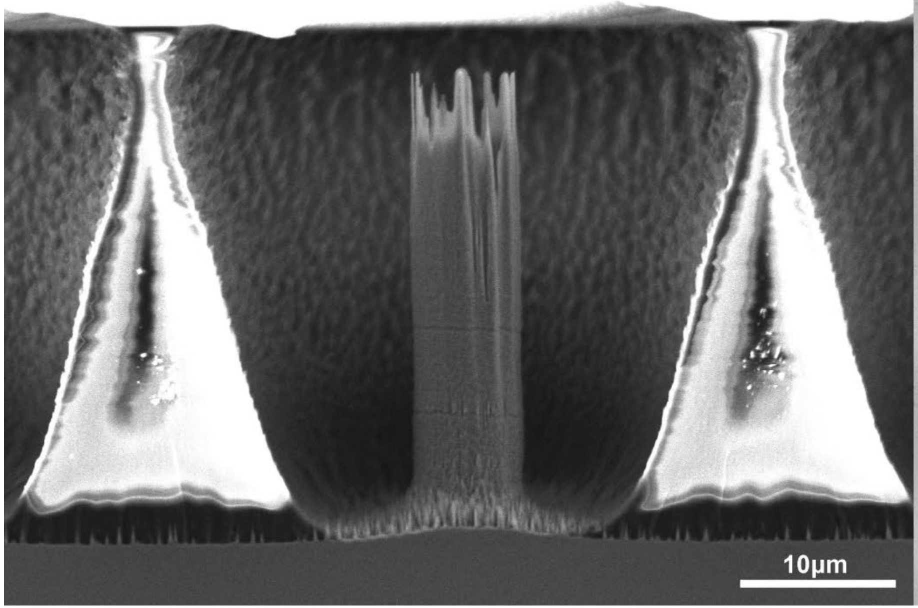

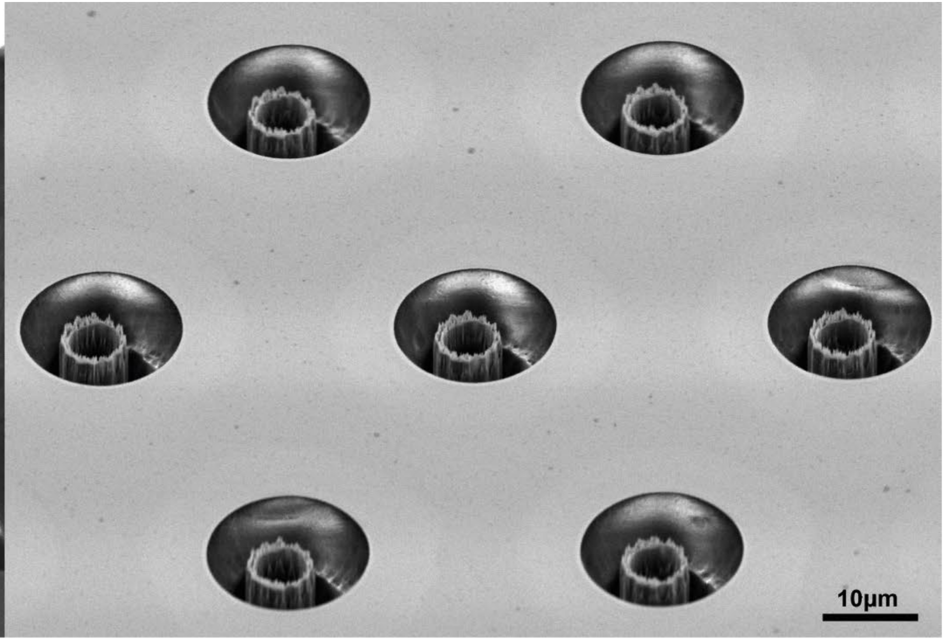

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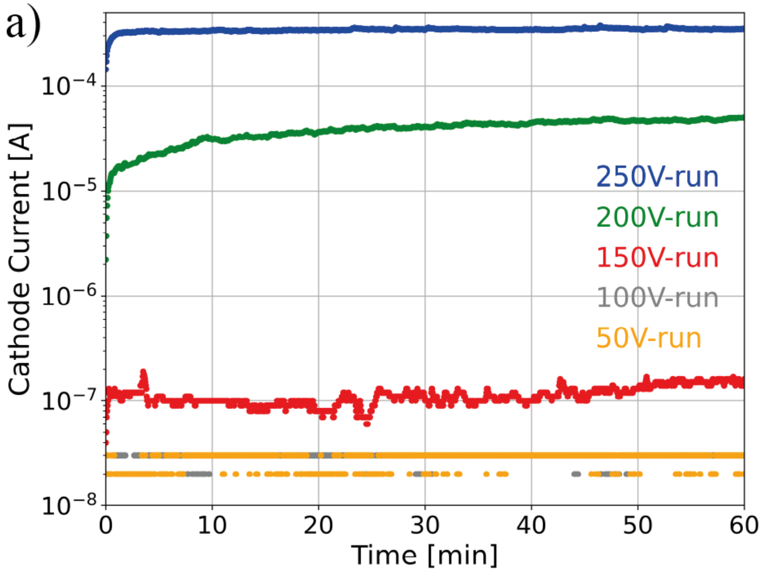
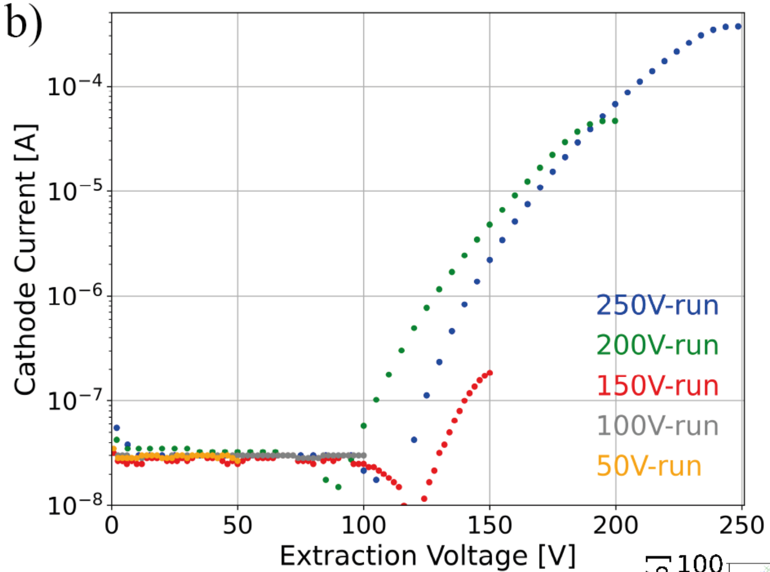
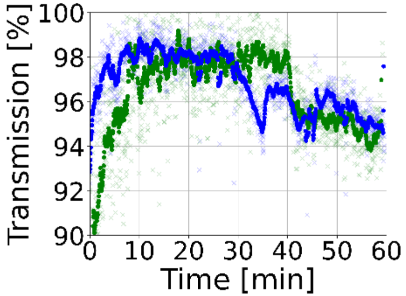




- 400 µA of emission current reached at 250V extraction voltage
- the best transmission figures reached were:

→ Anode voltage 500V
→ Cathode voltage 200V/250V
→ Average transmission: 97% over measurement periode



Thank you for your attention