OSTBAYERISCHE TECHNISCHE HOCHSCHULE REGENSBURG

Silicon Nanowire Field Emitters with Integrated Extraction Gates Using Benzocyclobutene as an Insulator

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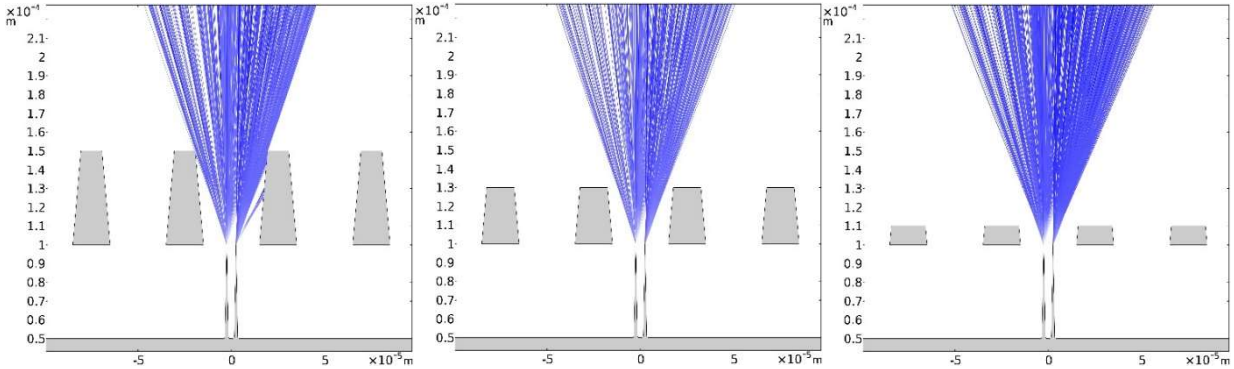
Overview

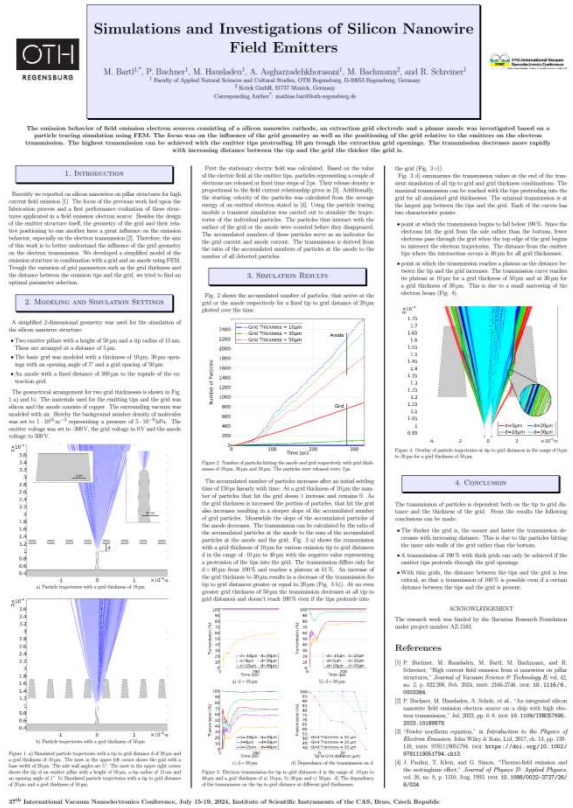
1. Introduction
2. Emitter Fabrication
3. BCB Insulator
4. Gate Electrode
5. BCB Etching
6. Measurement Setup
7. Performance
8. Electron Transmission
9. Failure Modes / Outlook

Introduction I

- Effective electron transmission for electron sources is of high priority

→ simulation studies presented by M. Bartl right after my talk





Simulations and Investigations of Silicon Nanowire Field Emitters

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The emission behavior of field emission electron sources consisting of a silicon nanowire cathode, an extraction grid electrode and a planar anode was investigated based on a particle tracing simulation using FEM. The focus was on the influences of the grid geometry as well as the positioning of the grid relative to the emitters on the electron transmission. The highest transmission can be achieved with the emitter tips protruding 10 µm trough the extraction grid openings. The transmission decreases more rapidly with increasing distance between the tip and the grid the thicker the grid is.

1. Introduction

2. Modeling and Simulation Settings

3. Simulation Results

4. Conclusion

Acknowledgement

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References

[1] P. Buchner, M. Hausladen, M. Bartl, M. Bachmann, and R. Schreiner, "High current field emission from si nanowires on pillar structures," Journal of Vacuum Science & Technology B, vol. 42, no. 2, p. 022 208, Feb. 2024, issn: 2166-2746. doi: 10.1116/6.0003364.

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[3] "Fowler–nordheim equation," in Introduction to the Physics of Electron Emission, John Wiley & Sons, Ltd, 2017, ch. 13, pp. 139–149, isbn: 9781119051794. doi: https://doi.org/10.1002/9781119051794.ch13.

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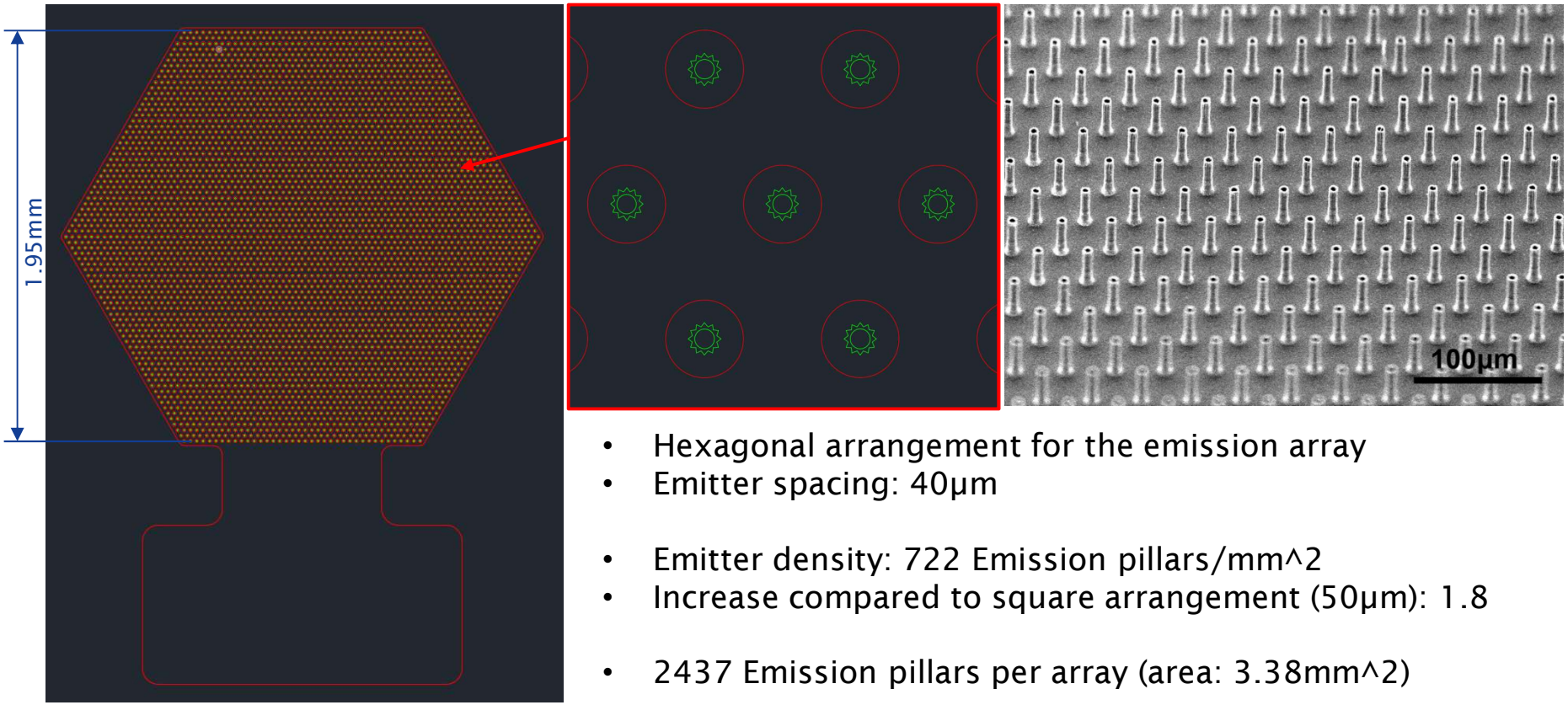
General II

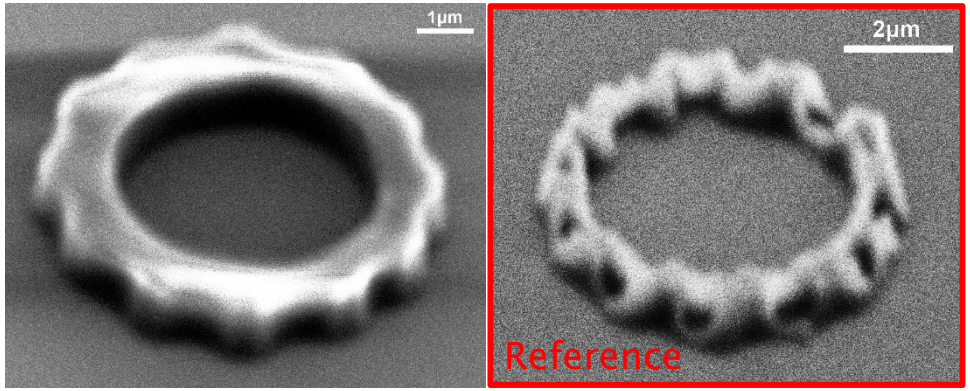


- Hexagonal arrangement for the emission array
- Emitter spacing: 40µm

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

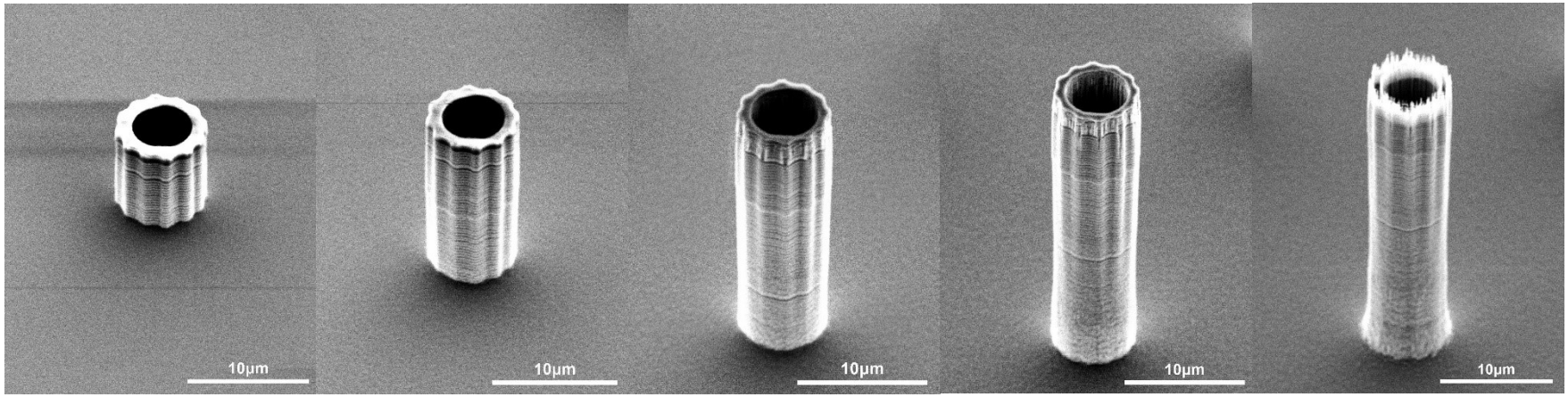
- 2437 Emission pillars per array (area: 3.38mm^2)

Emitter Fabrication

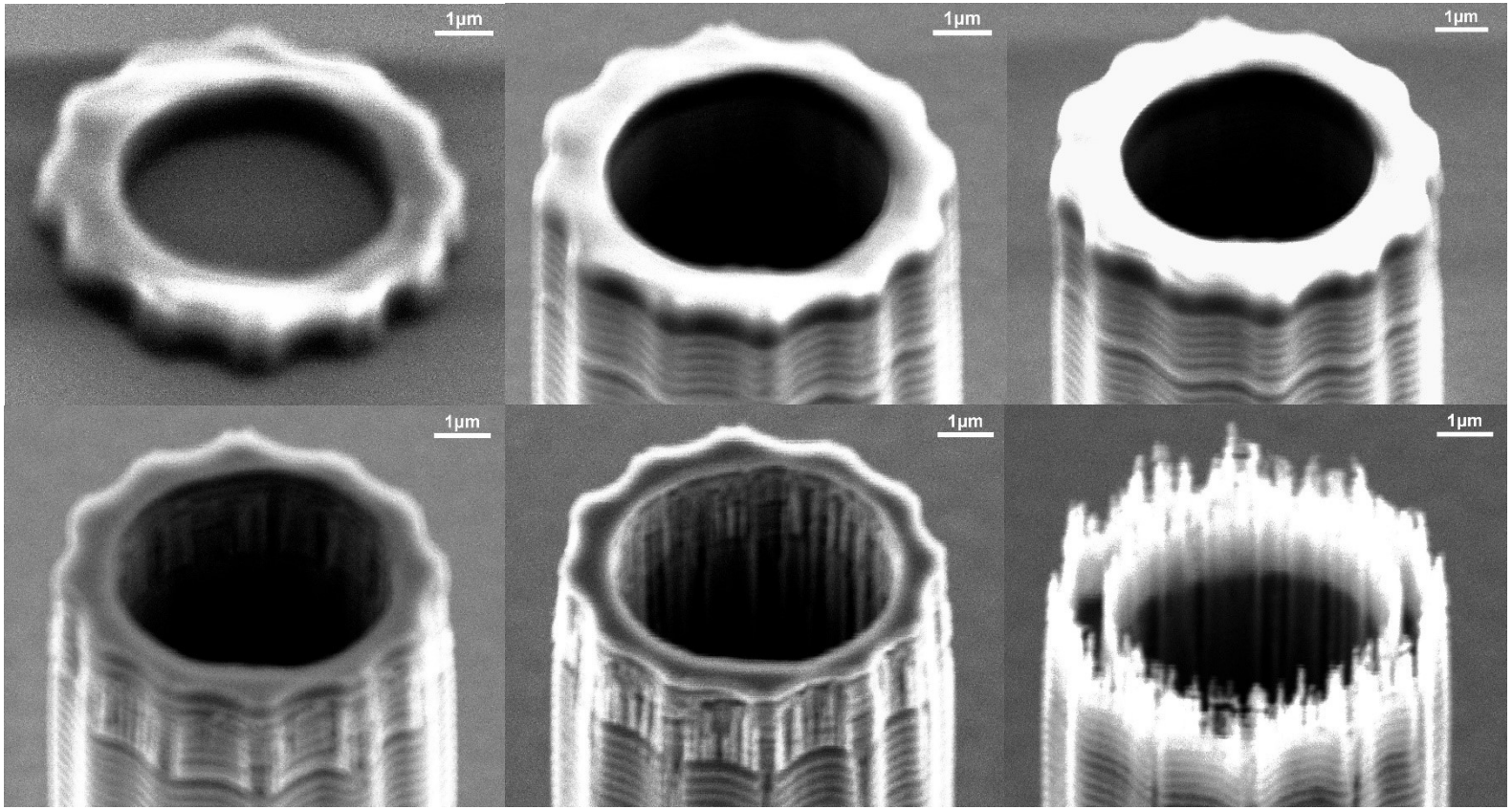


- n-Type silicon (1-10Ωcm)
- Anisotropic silicon etching interrupted by oxygen plasma etching of photo resist

→ Even better process stability
→ No need for overexposing and over developing to create irregular restist ring

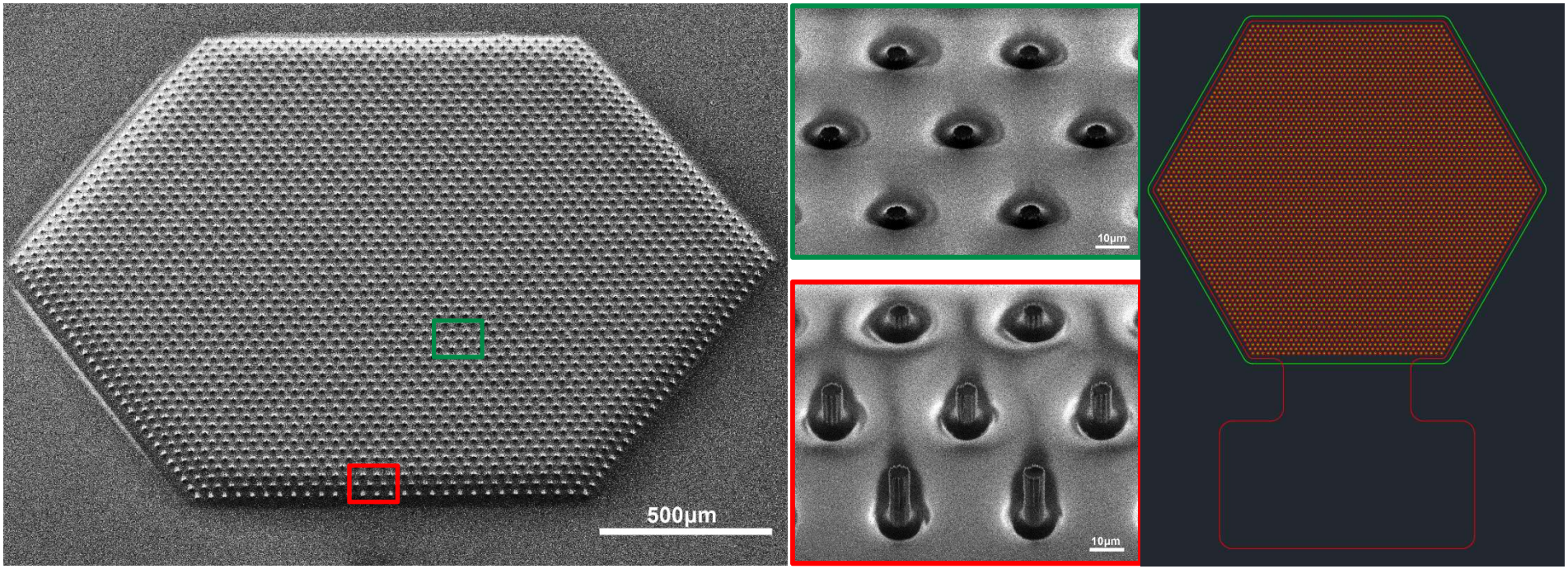


Emitter Fabrication II



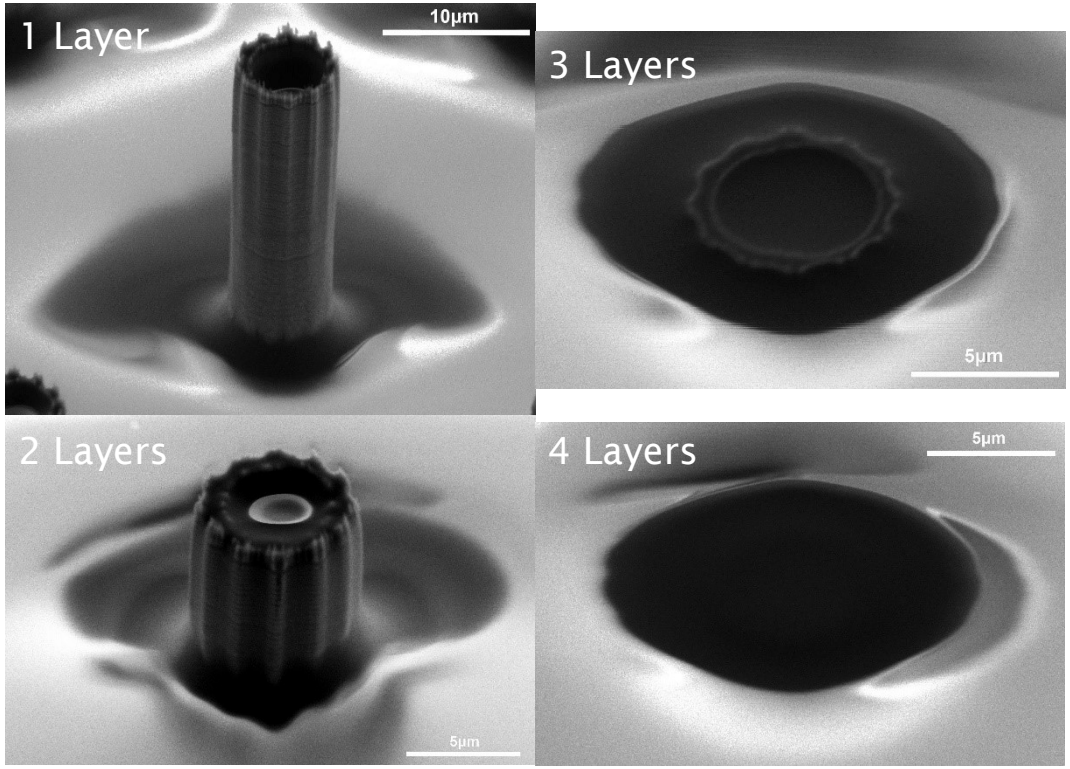
Insulator I

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



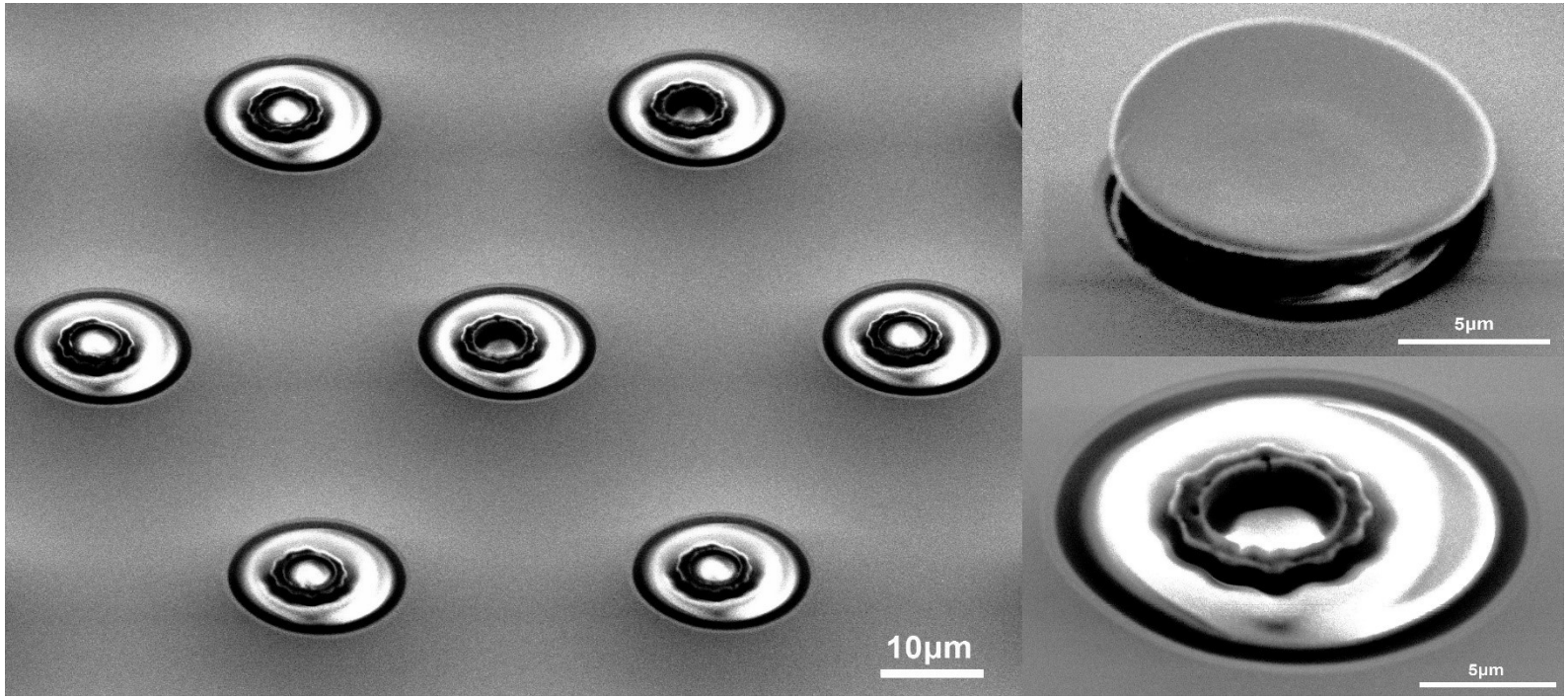
Insulator II

- BCB spunn directly onto finished emitters
- Emitters were not harmed by the lithography process
- Multiple layers of BCB needed to fully cover the emitters

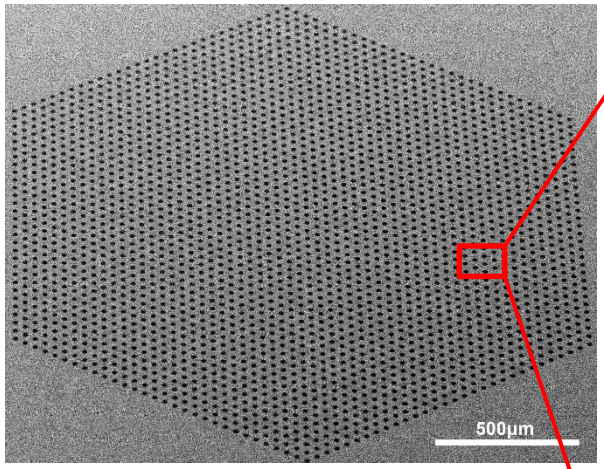


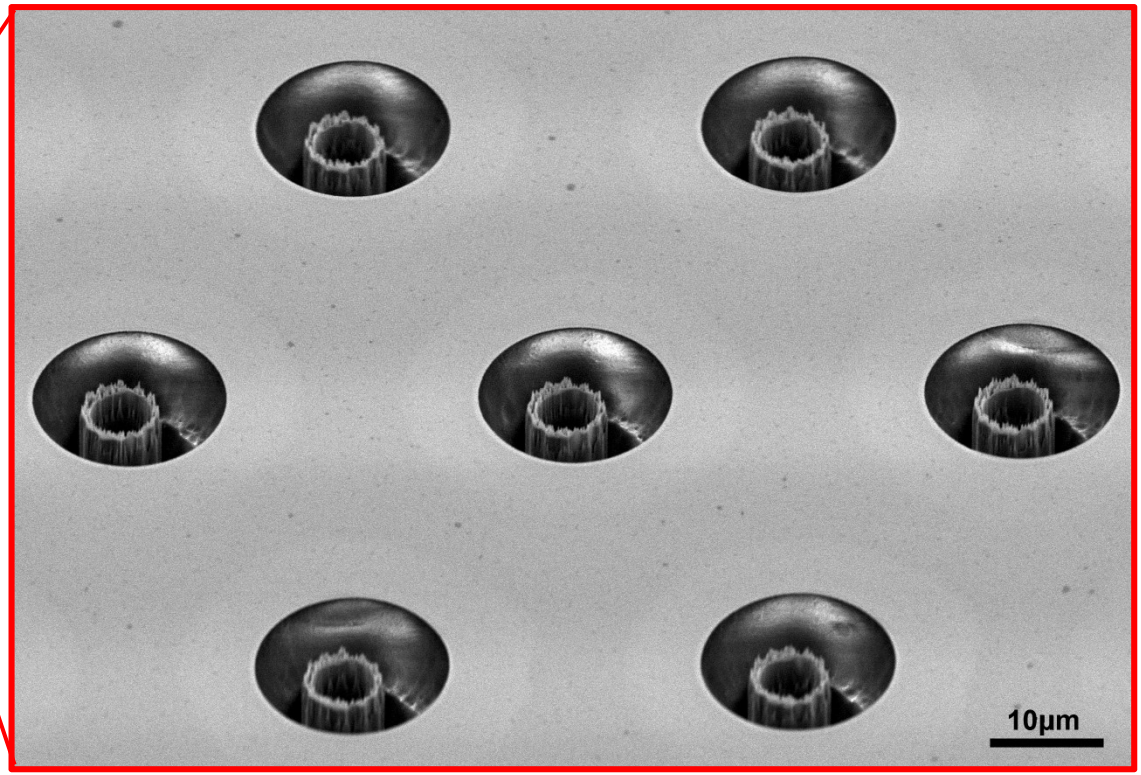
Gate Electrode

- Lift-Off with NLOF2070 and Cr (10nm)/Ni (150nm) Metallisation
- Short bursts of ultrasonic used



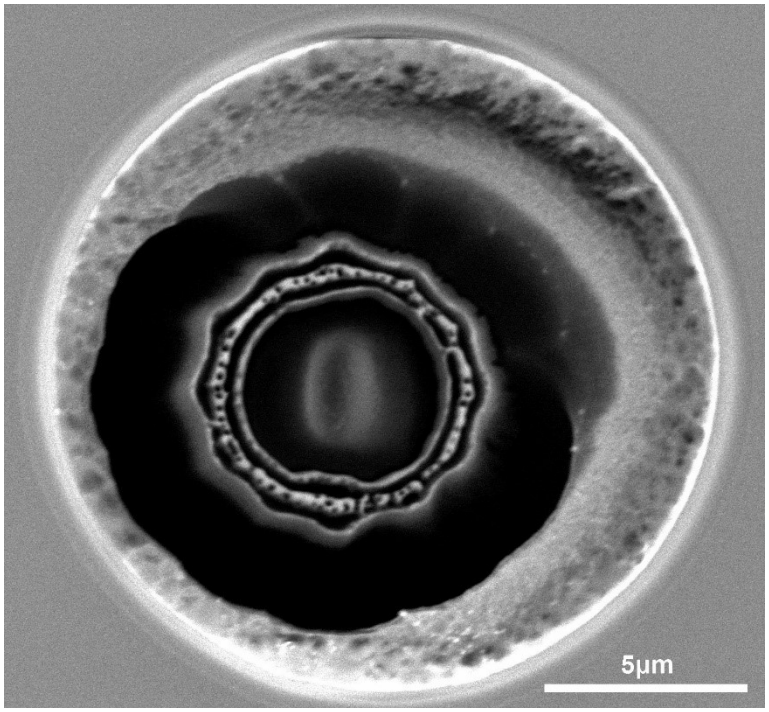
BCB Etching

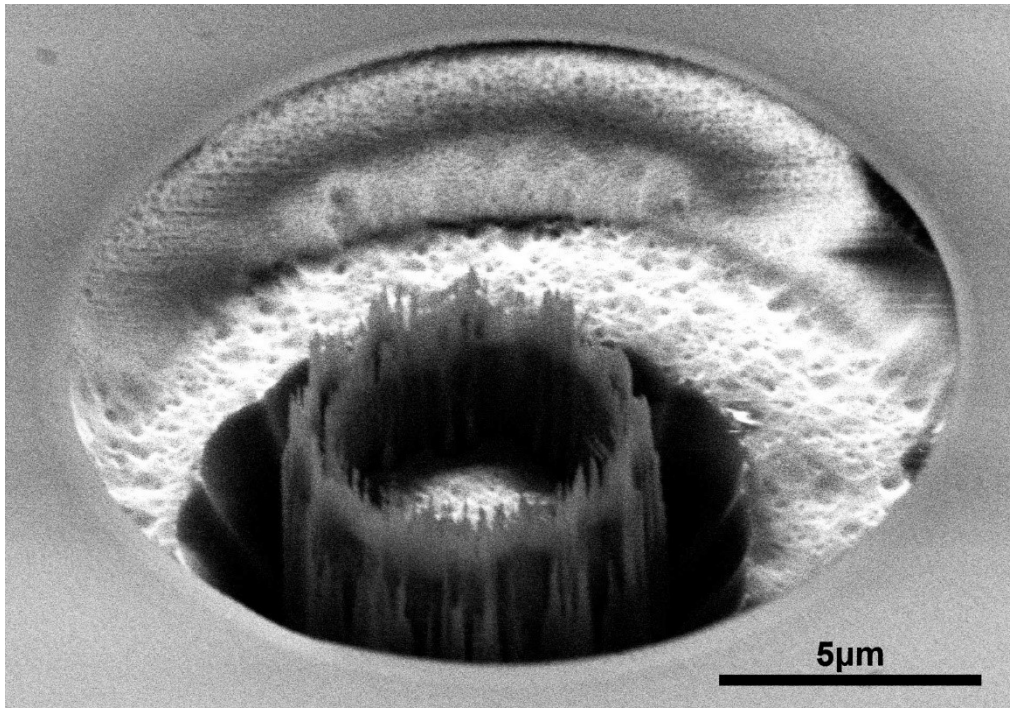




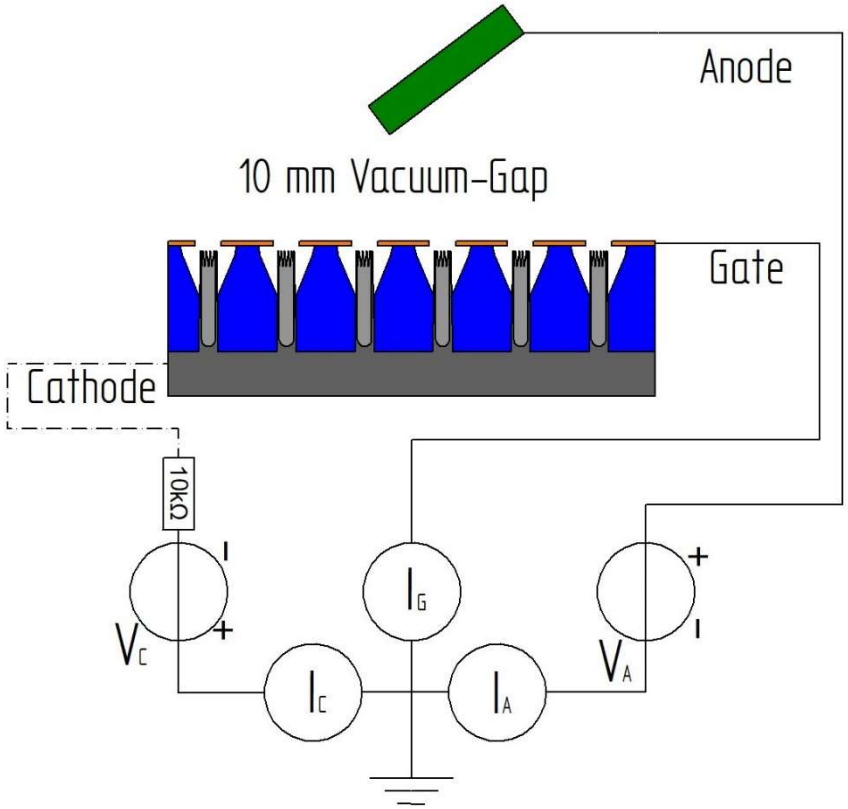
- Plasma etching of BCB
- CF4/O2 (20W RF 150W ICP)
- Duration: 30min

BCB Etching II



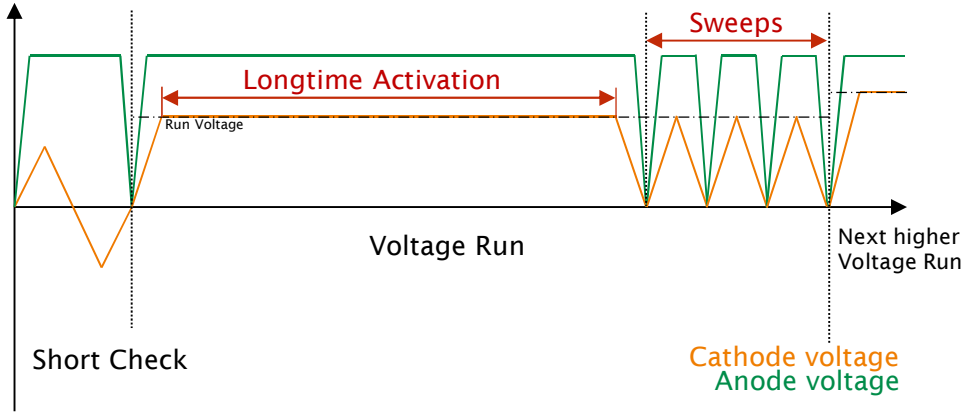


Measurement Setup

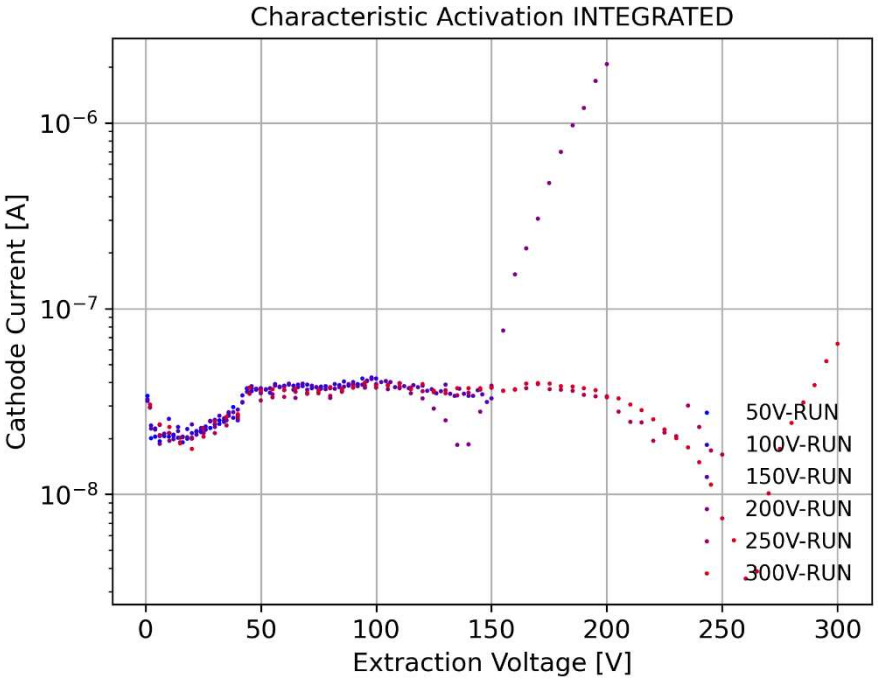


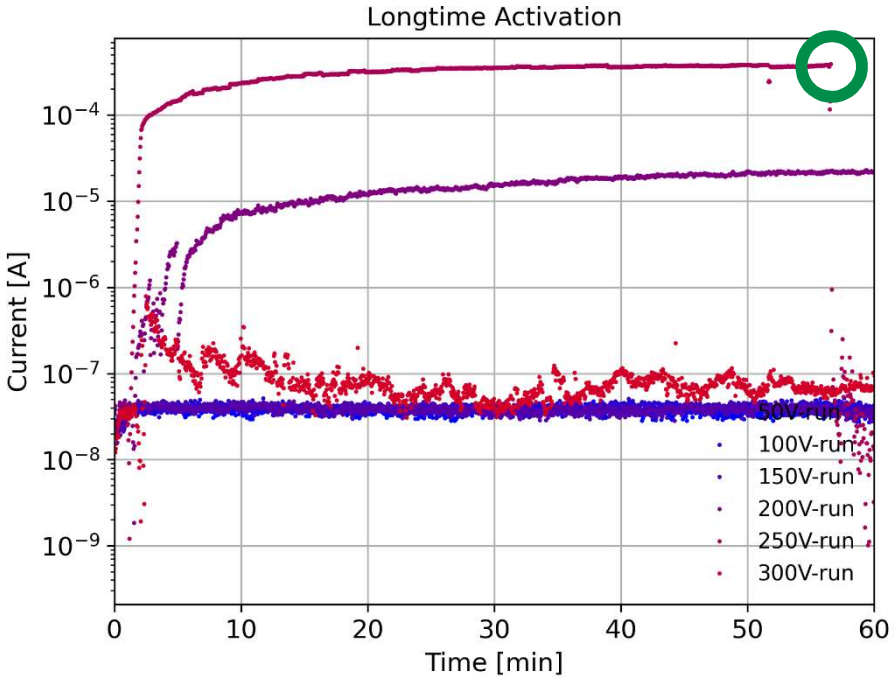
- Measurement pressure: 10^{-9}hPa
- Starting voltage 50V
- Max. cathode voltage 500V

- For each voltage 1h of holdtime
- After that three sweeps



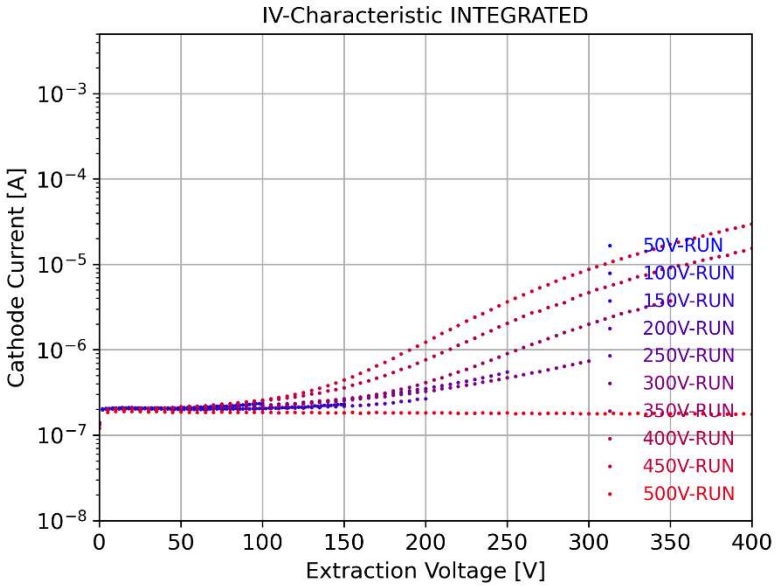
Performance Sample I

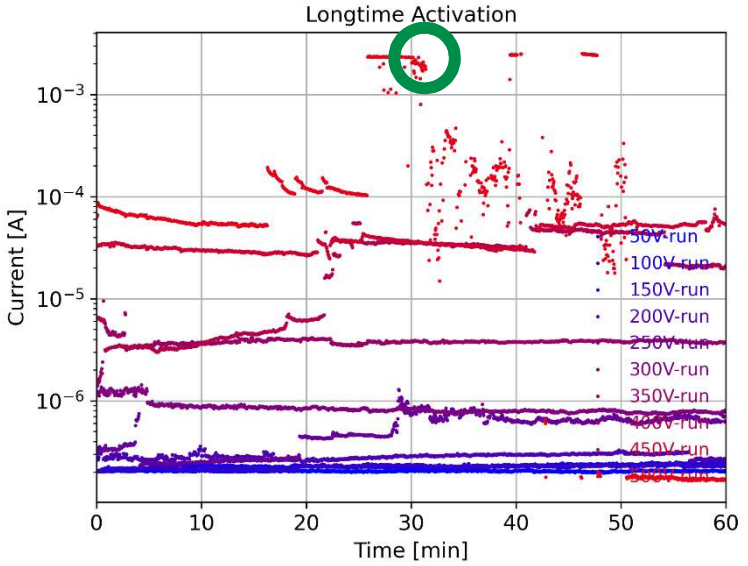




- Sudden destruction of the electron source during 250V run
- 400 µA of emission current reached at 250V extraction voltage

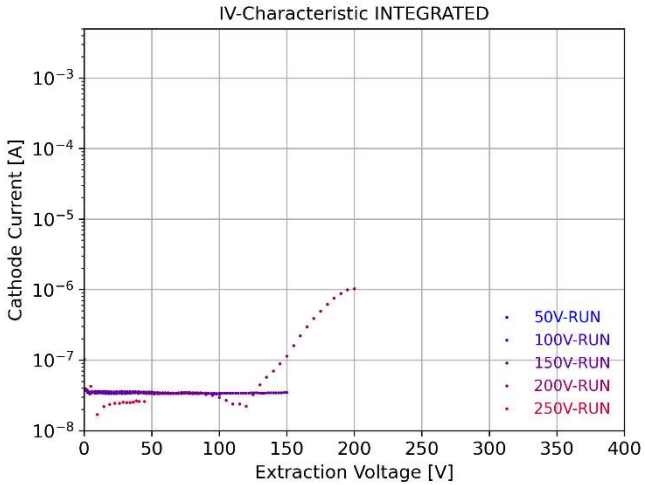
Performance Sample II

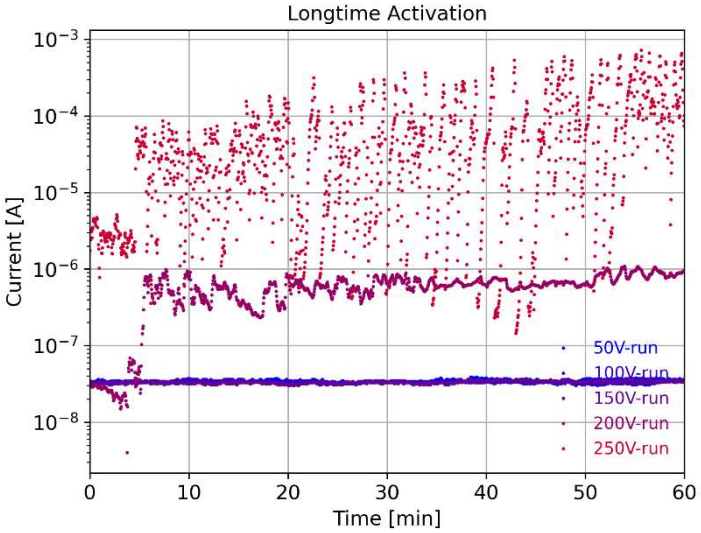




- Sudden destruction of the electron source during 500V run
- 2 mA of emission current reached

Performance Sample III





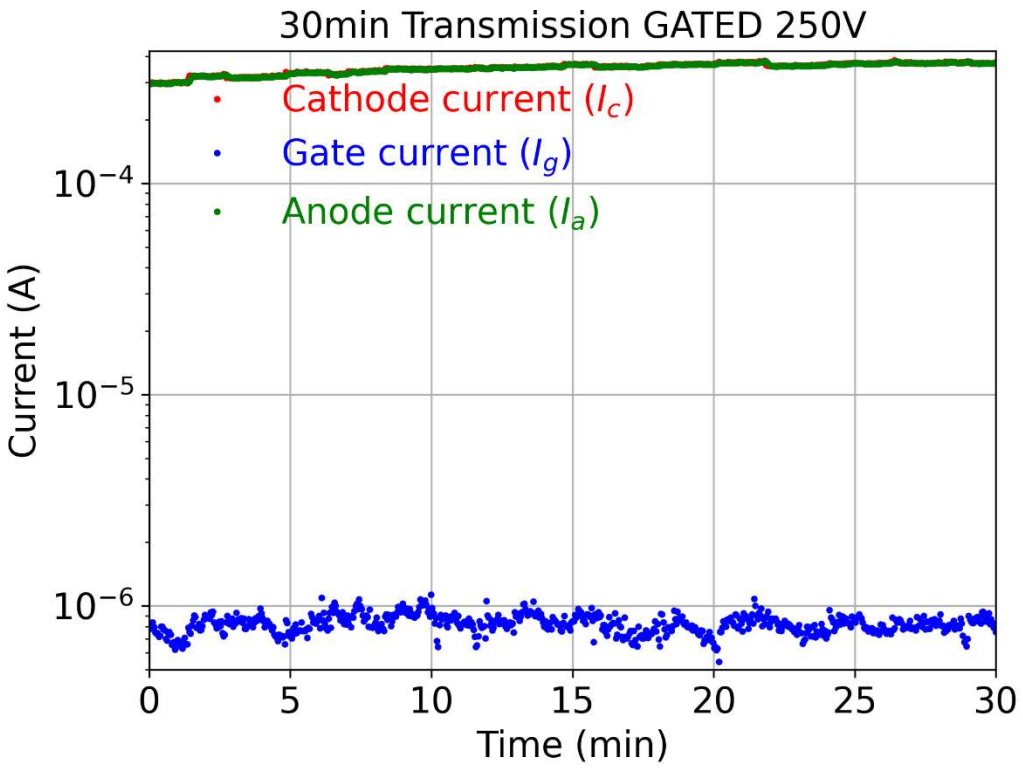
- Electron source startet flickering during 250 V run

Transmission

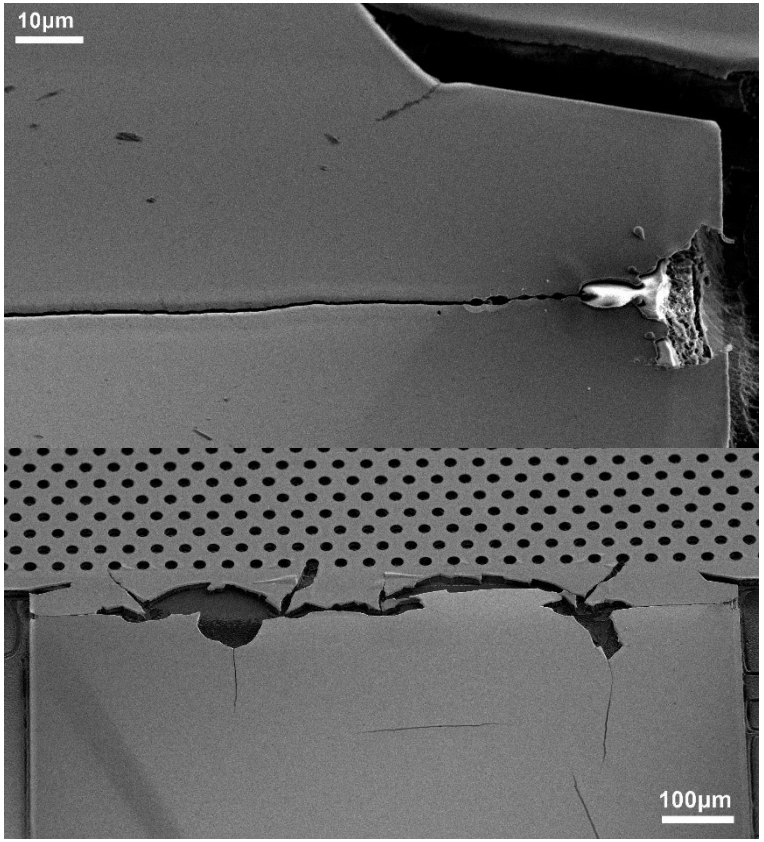
- For sample I the best transmission figures were reached:

→ Anode voltage 500V
→ Cathode voltage 250V
→ Average transmission: 99.61% over 30min measurement periode

- Other samples reached on average Transmissions over 95%



Failure Modes and Conclusions I



- Cr/Ni not ductile enough

→ Gate tears during emission due to themal missmatch with the BCB

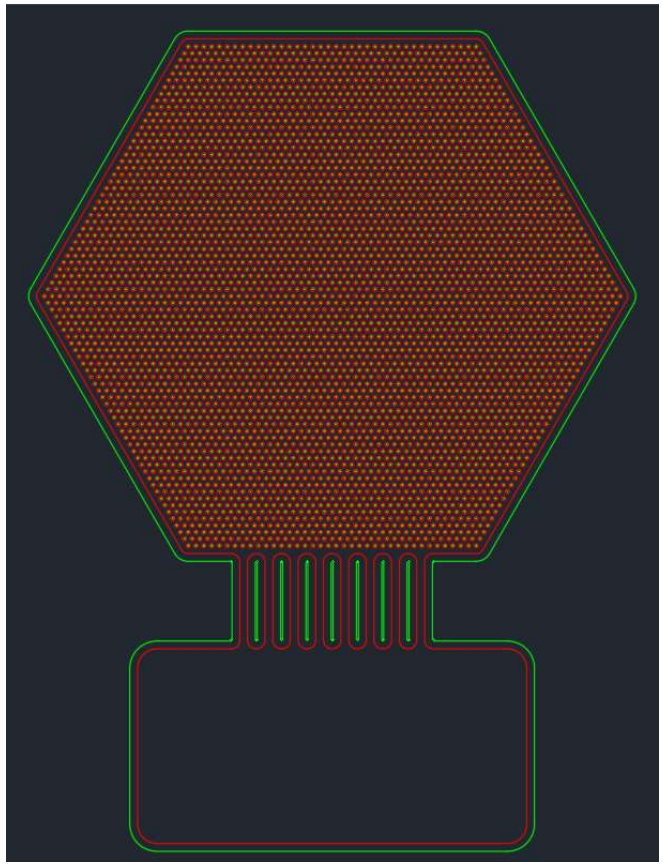
→ Possible reason for sudden breakdown in Samples I and II

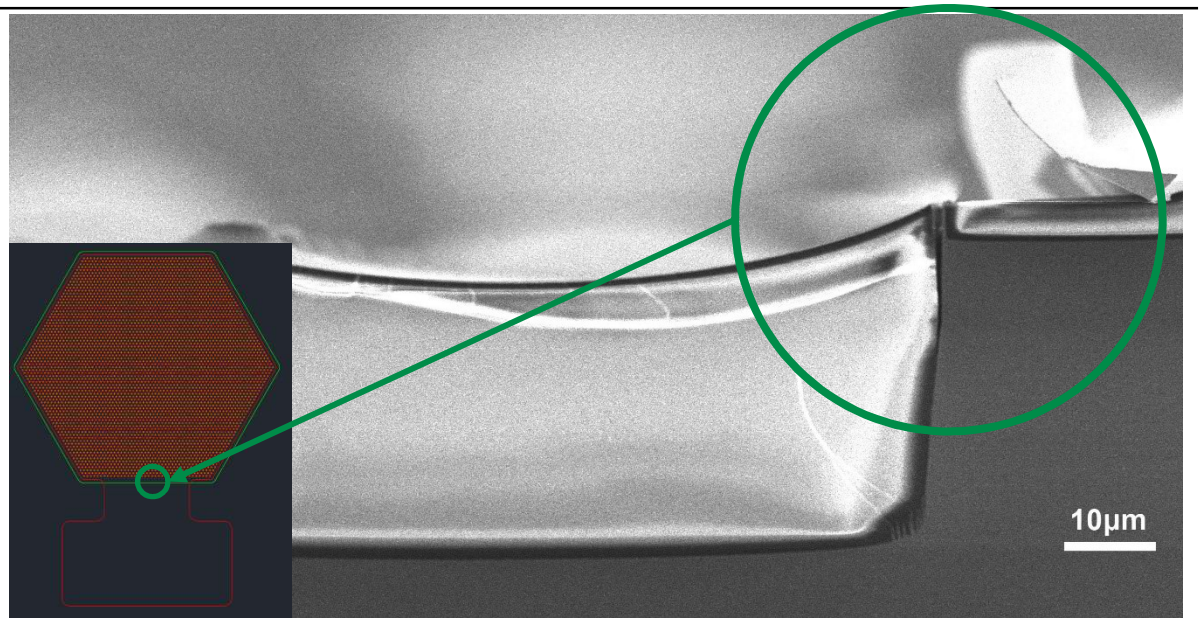
→ If the Gate tears in such a way, that with the cooling of the BCB recontacts the gate. The emission is restartet untill thermal expansion severse the contact again and the emission stops

→ Stuttering of Sample III

→ Solution: more ductile Gate material like Gold

Failure Modes and Conclusions II





- BCB on the edge of the emitter cavity much thinner
- Easy route for breakdown

  → New Mask

Thankyou For Your Attention