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INDIVIDUALLY ADDRESSABLE SILICON FIELD EMISSION CATHODES FABRICATED BY LASER MICROMACHINING

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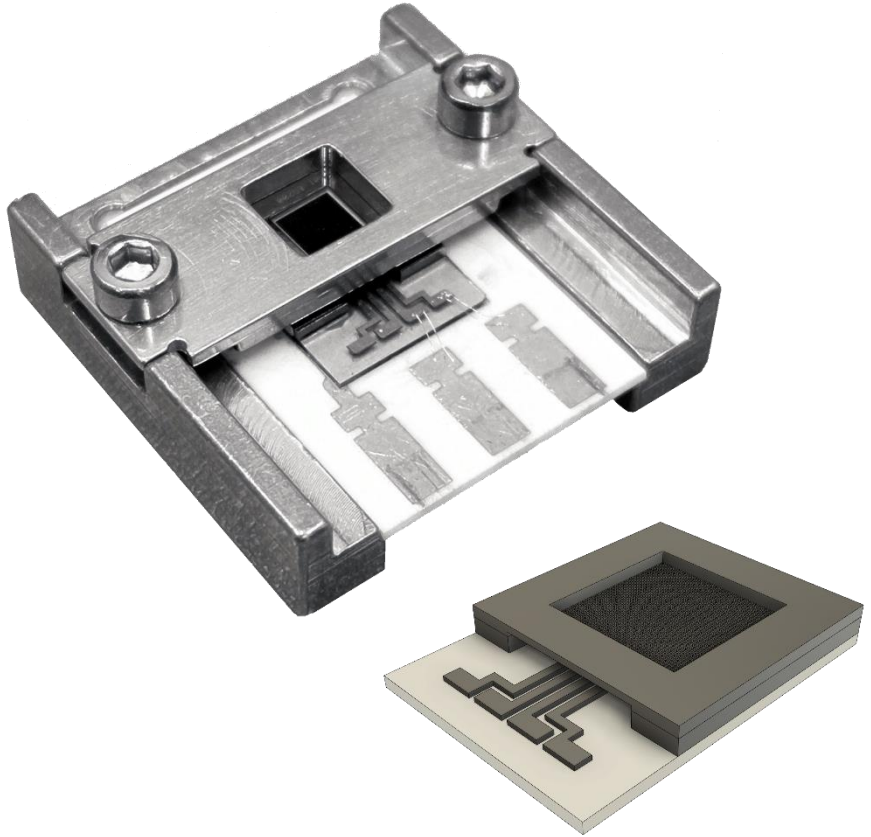
Agenda

- **Underlying work**
- **Fabrication process**
- **Measurement setup** (without regulation)
- **Field emission beahaviour**
  - **Integral measurement**
  - **Separated measurement**
  - **Chronological measurements**
  - **Separated measurements (optimized geometry)**
- **Summary**



Silicon chip field emission electron source fabricated by laser micromachining

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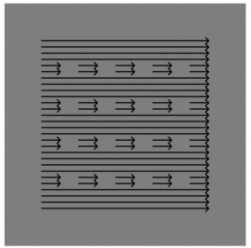
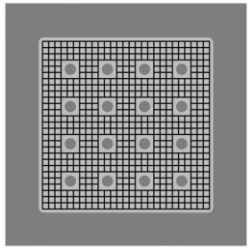
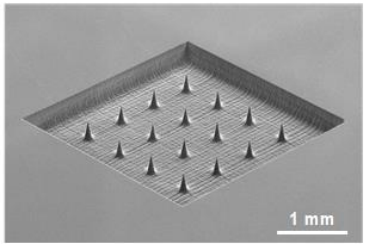
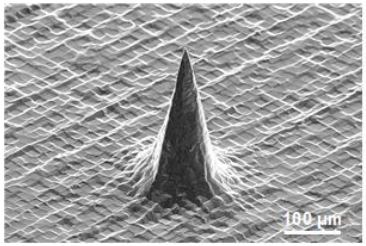
ABSTRACT

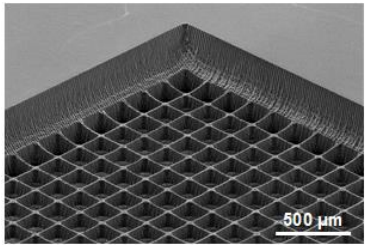
The components for a silicon chip electron source were fabricated by laser micromachining using pulsed laser ablation and wet chemical cleaning and etching dips. The field emission electron source consists of a silicon field emission cathode with 4 × 4 conical shaped emitters with a height of 250 μm and a tip radius of about 50 nm, a 50 μm thick laser-structured mica spacer, and a silicon grid electrode with a grid periodicity of 200 μm and a bar width of 50 μm. These three components are combined to a single chip with the size of 14 × 10 mm^2 and the thickness of 1 mm to form the electron source. Several of these devices were characterized in ultrahigh vacuum. Onset voltages of about 165 V and cathode currents of about 15 μA for voltages lower than 350 V were observed. Operating the electron source with an anode voltage of 500 V and an extraction grid voltage of 300 V yielded a cathode current of 4.5 μA ± 8.9%, an anode current of 4.0 μA ± 9.6%, and a corresponding grid transmittance of 89%. Regulating the anode current by the extraction grid voltage, an extremely stable anode current of 5.0 μA ± 0.017% was observed. A long-term measurement over 120 h was performed, and no significant degradation or failure was observed.

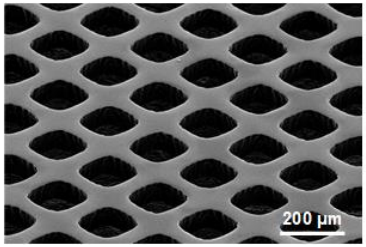




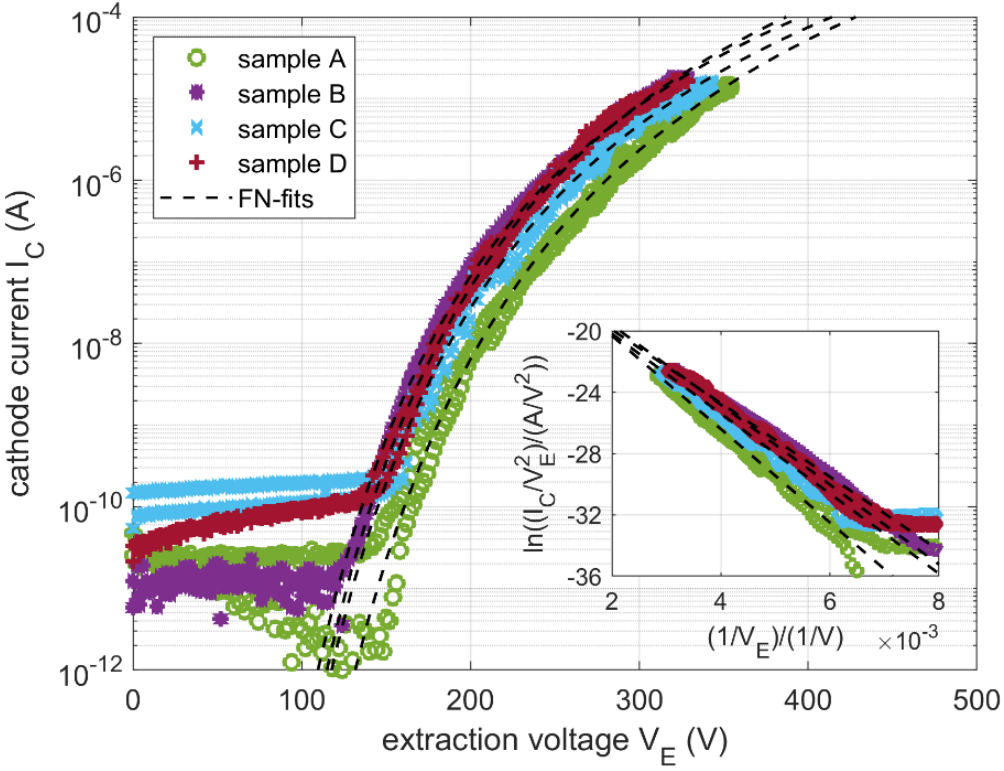








Underlying work



Sample (16 emitters)	A	B	C	D
onset voltage V_{Eon} (V)	178	155	163	162
max. applied voltage V_{FE} (V)	354	325	342	327
max. emission current I_C (µA)	14.6	17.8	15.8	17.3
aFN (10^{-7} A V^{-2})	6.7	2.7	3.2	5.6
bFN (10^3 V)	3.0	2.4	2.6	2.6
voltage conversion factor γ (10^7 m^{-1})	1.9	2.4	2.3	2.3
field enhancement factor β (10^3)	1.5	1.8	1.7	1.7
emissive surface S (10^{-15} m^2)	4.9	1.2	1.7	1.2

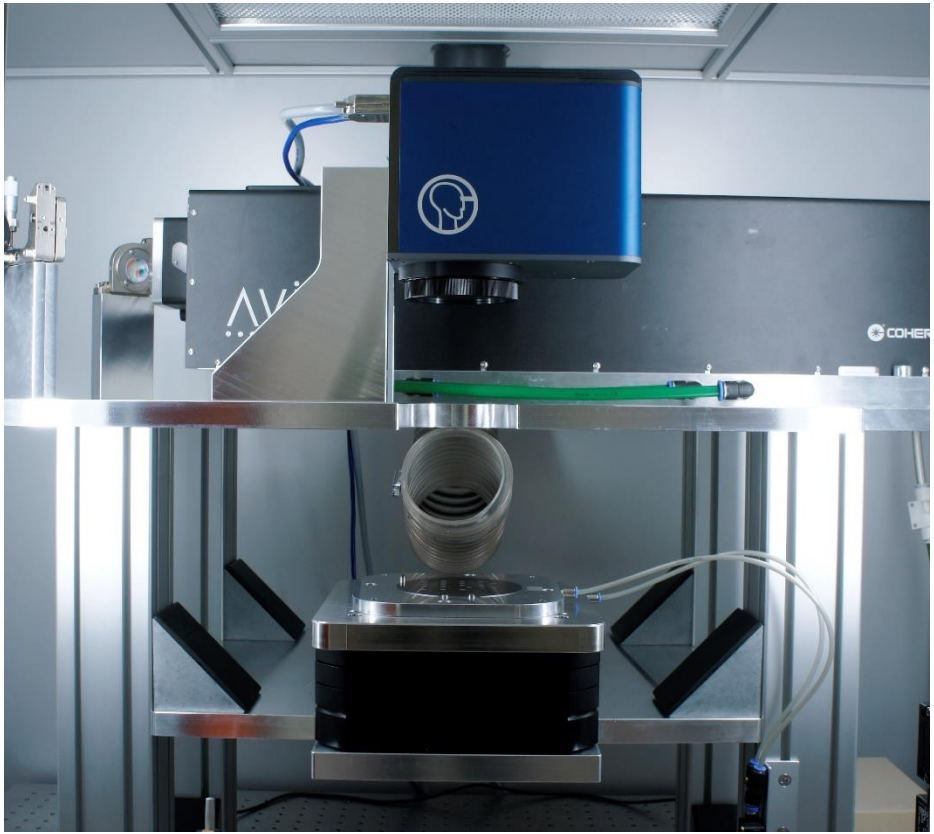
Fabrication process

Laser ablation system

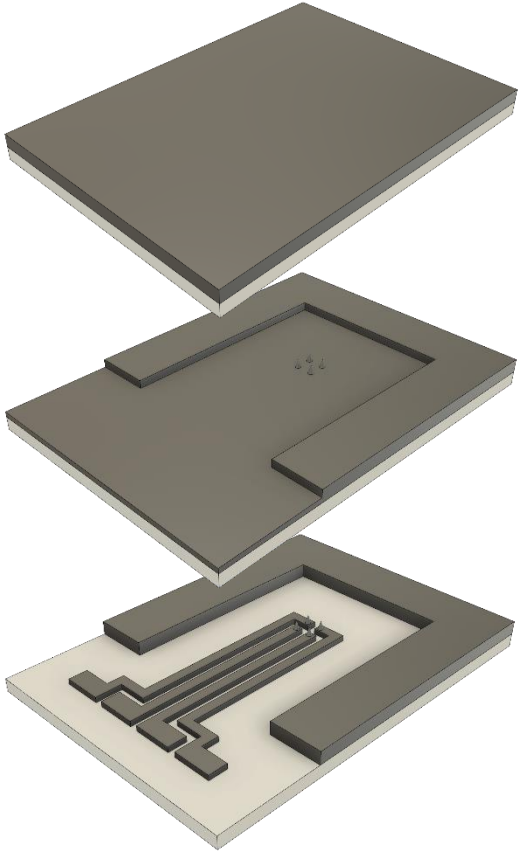
- solid-state Q-switched UV-Laser:
  355 nm wavelength, 10 W average power at 60kHz pulse repetition rate, 35 ns pulse width
- scan head (beam deflection system)
  maximum speed of 5000 mm/s
- F-theta lens: in focal plane, the laser beam has a diameter of approx. 25 µm

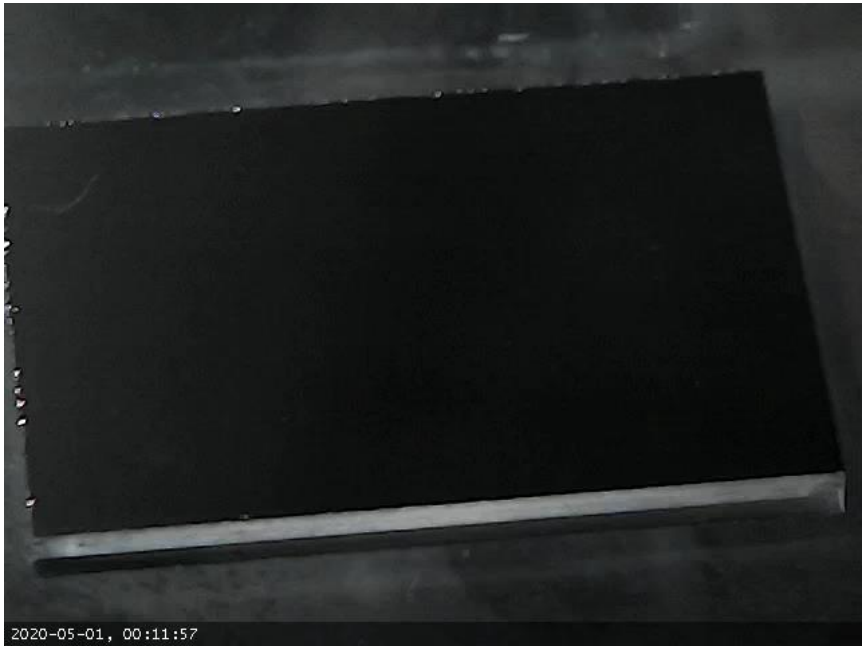
Laser parameters:

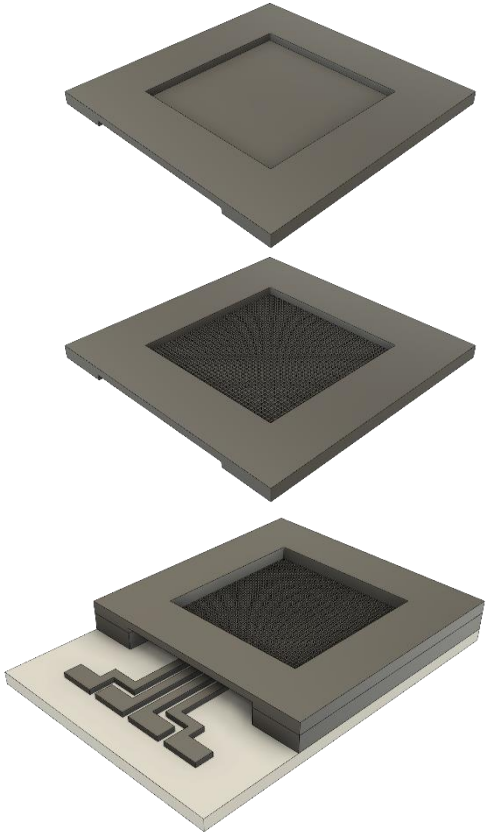
- pulse energy of 180 µJ to 220µJ
- 53 kHz pulse repetition rate
- 1000 mm/s scan speed



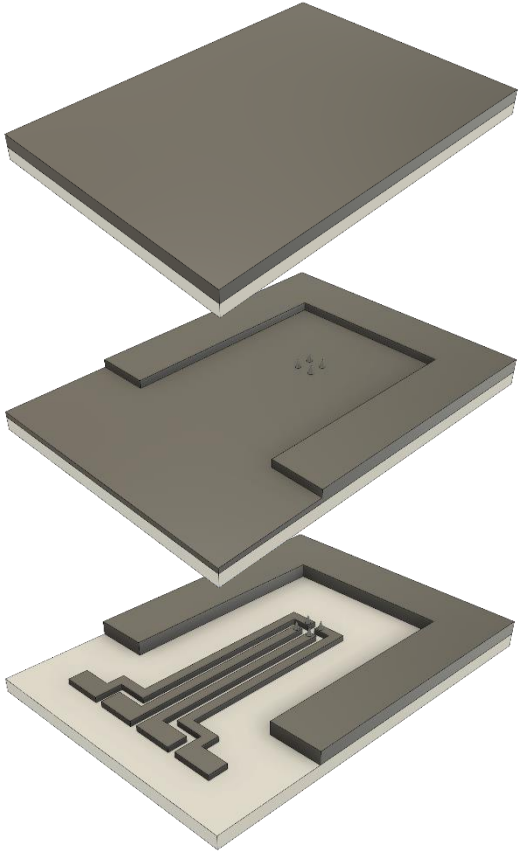
Fabrication process

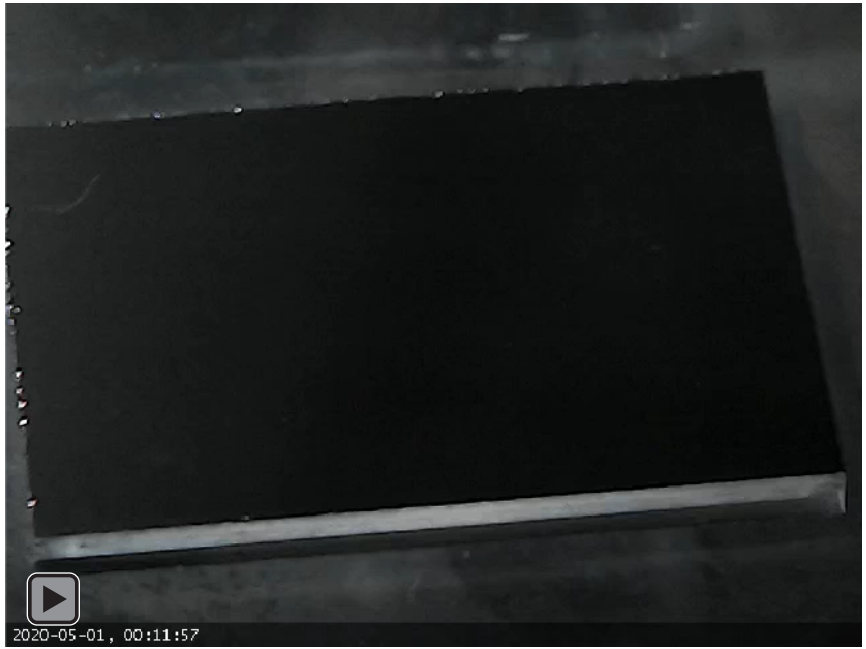


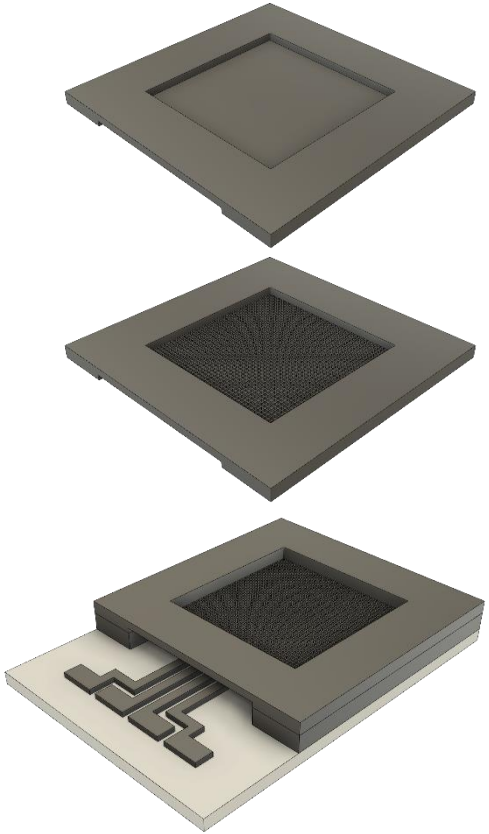




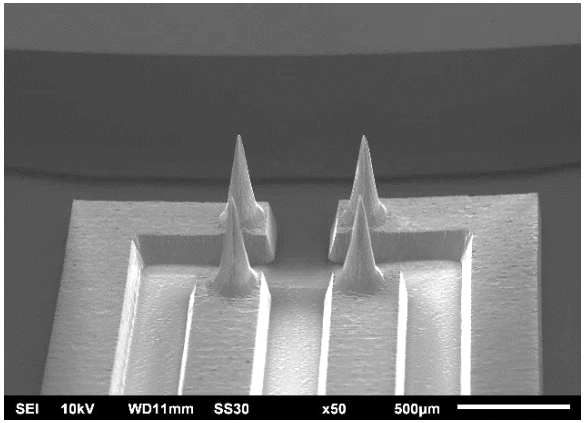
Fabrication process

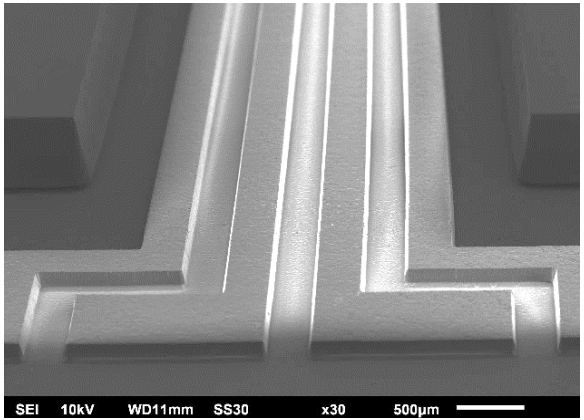


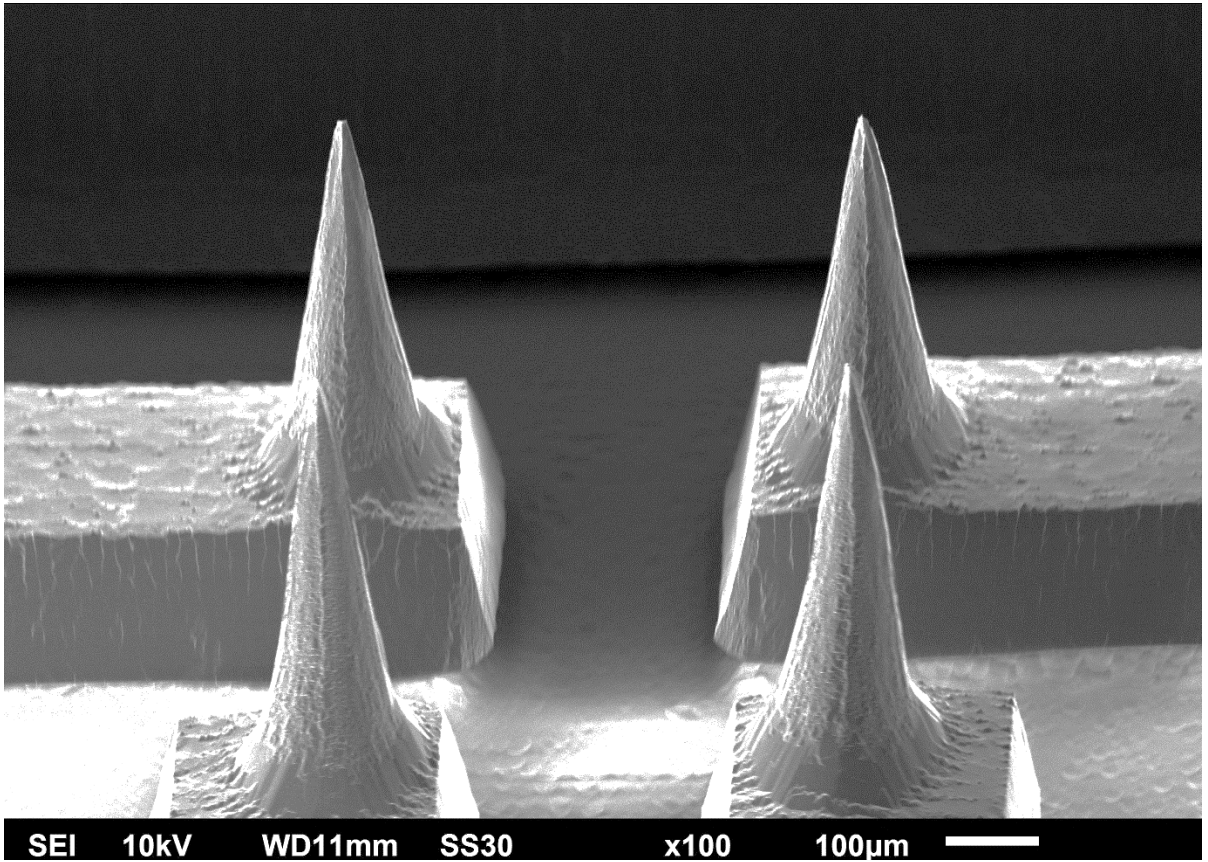




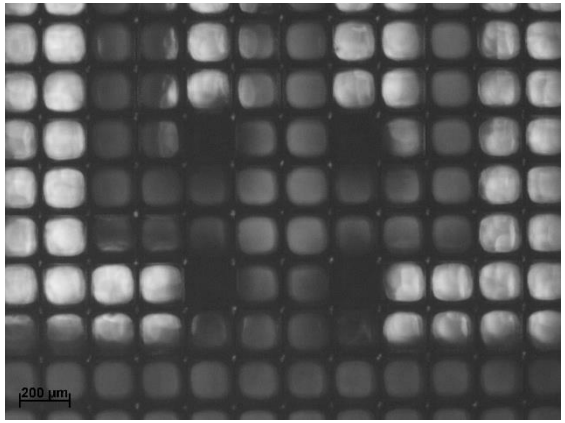
Fabrication procress

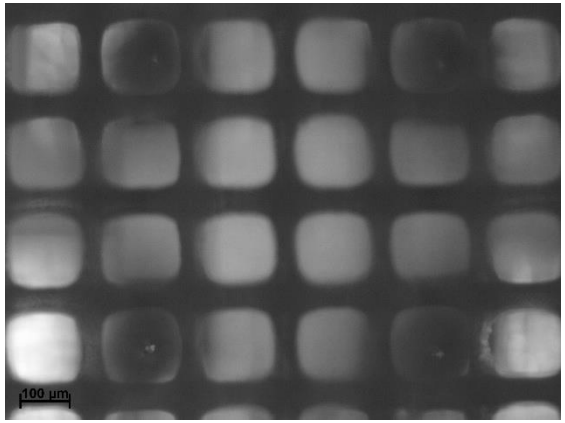


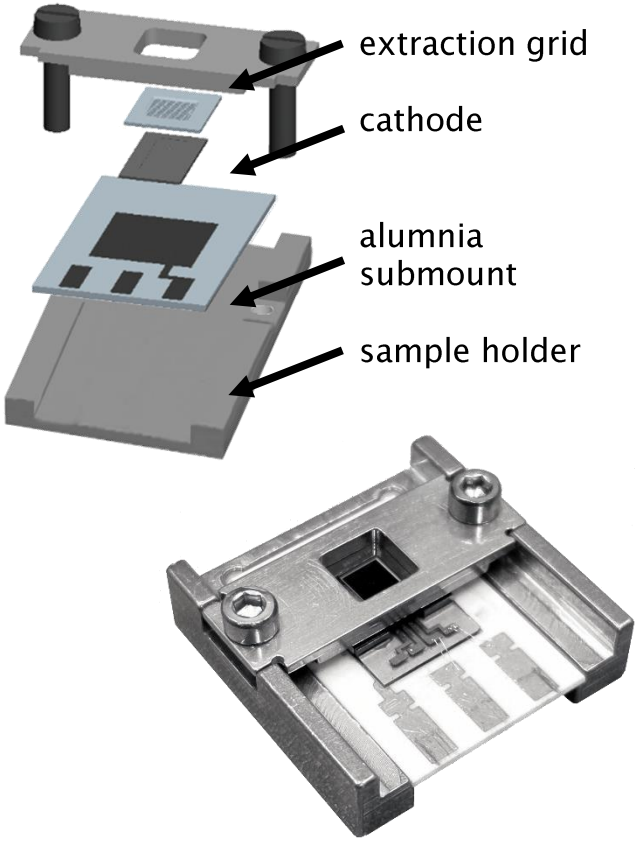


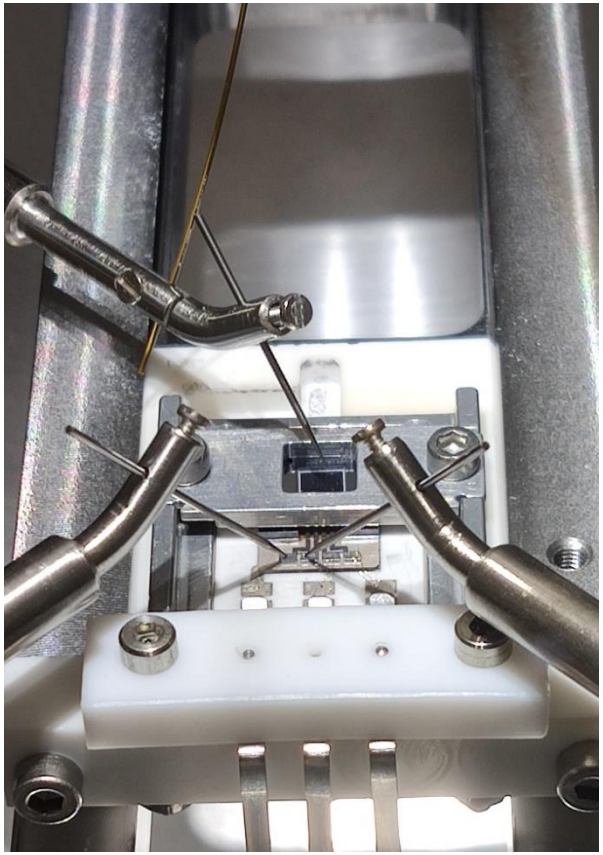


Measurement setup

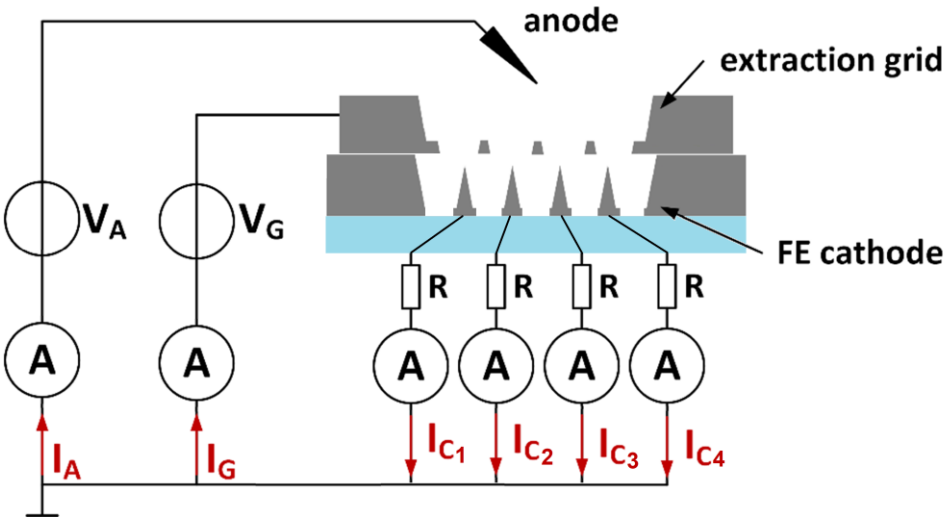


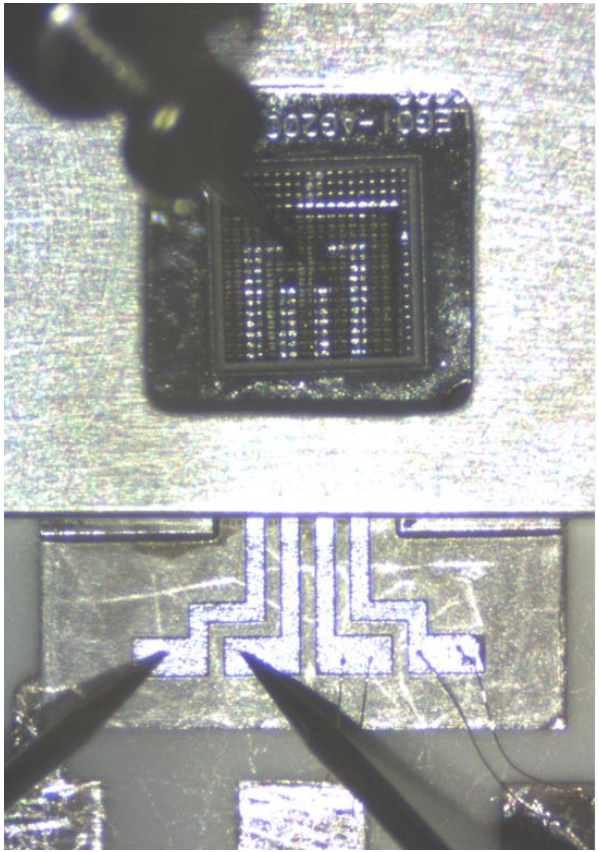






Measurement setup

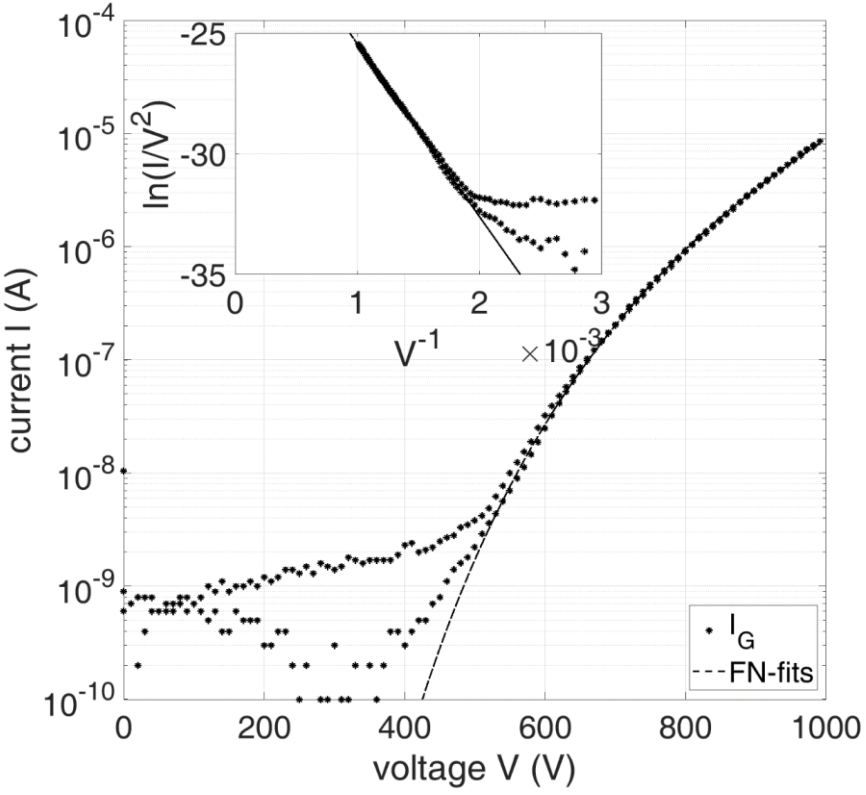


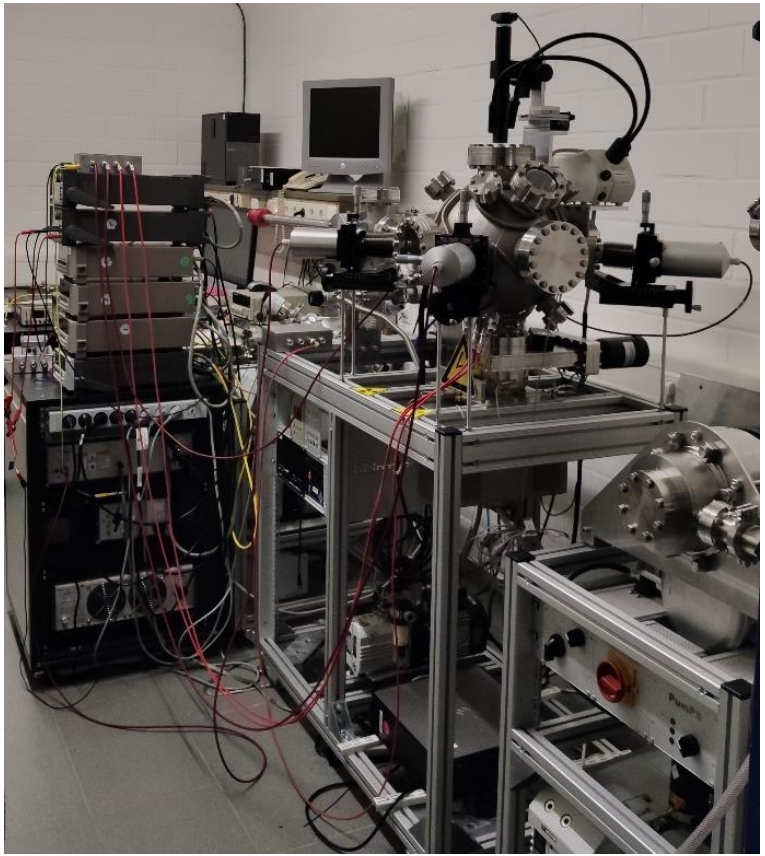


Measurement Devices:

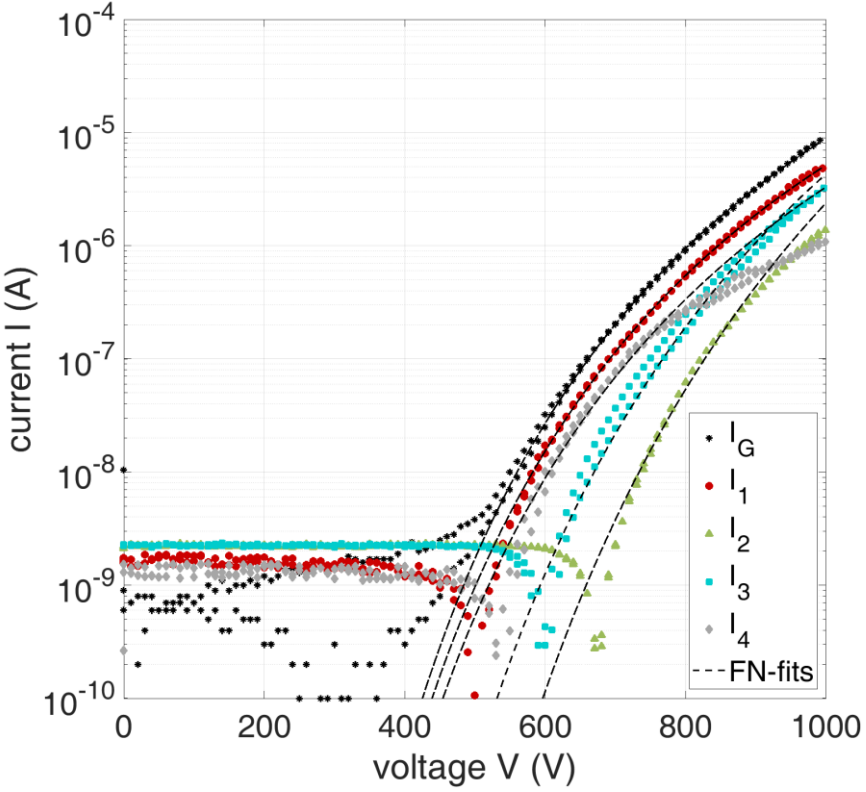
- Keithley 7510 Graphical Sampling Multimeter (2x)
- Keithley 6485 Picoammeter
- Keithley 6487 Picoammeter/Voltage Source (2x)
- Keithley 6517B Electrometer/High Resistance Meter
- FuG HCP350 High Voltage Power Supply

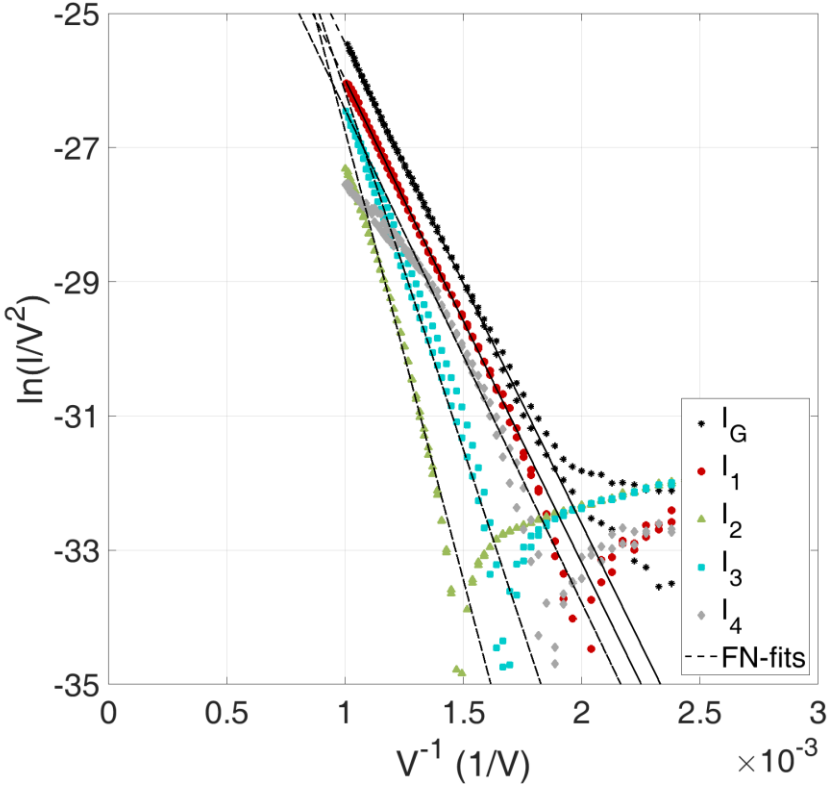
Integral measurement





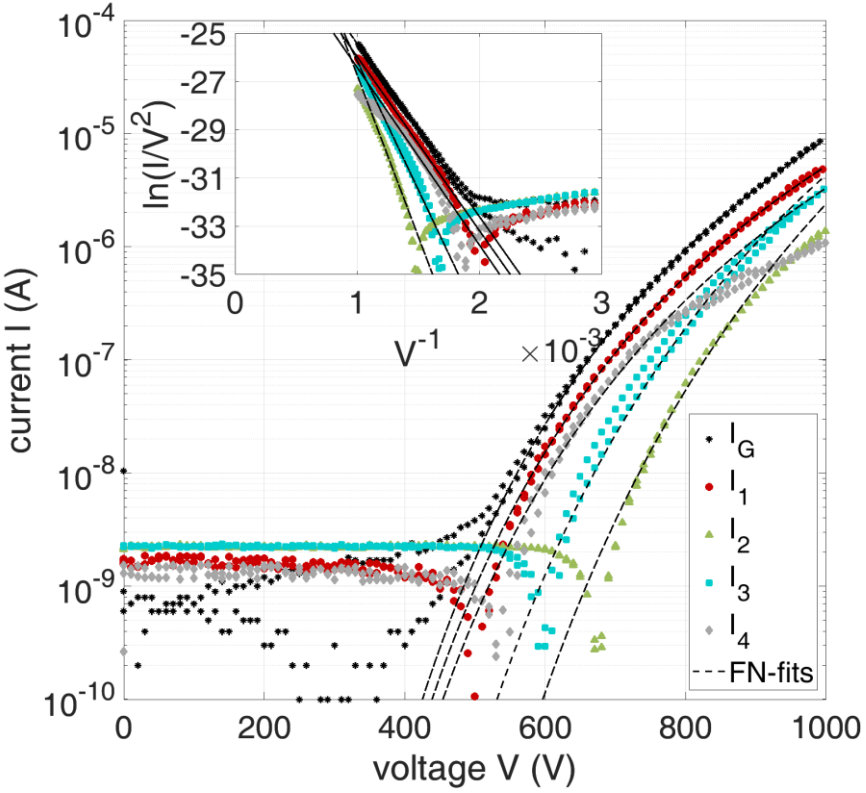
Separated measurement





→ **emission current for individual emitters (current distribution)**

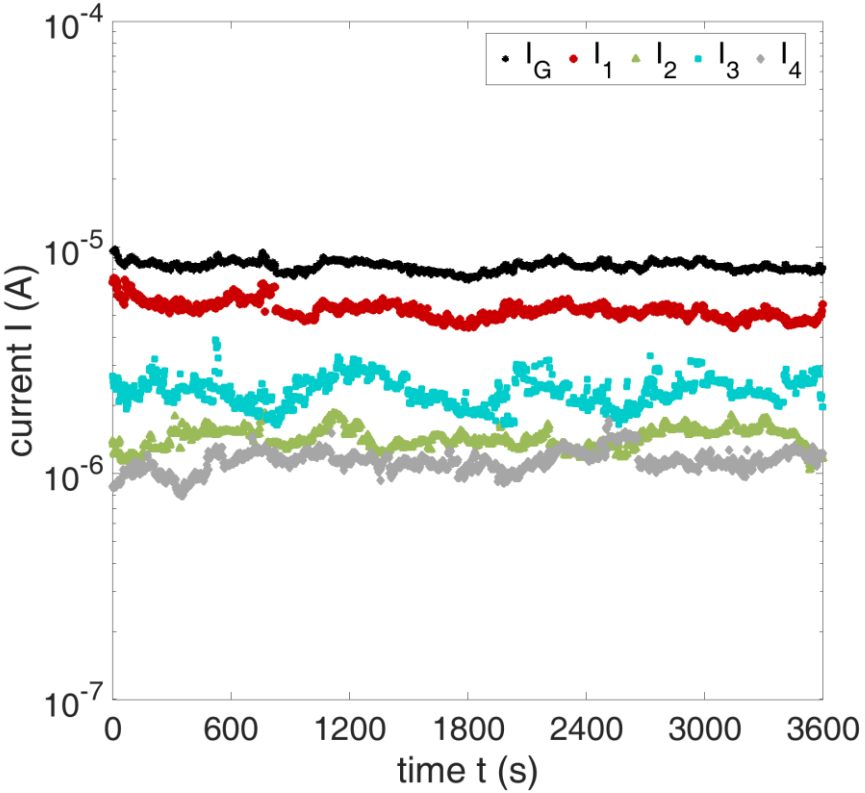
Separated measurement



sample	#1	#2	#3	#4	all
onset voltage V_{Eon} (V)	500	650	600	550	500
max. applied voltage V_G (V)			1000		
max. emission current I_C (µA)	4,8	1,4	3,2	1,1	8,6
aFN (10^{-8} A V^{-2})	0,7	155	19	0,5	1,2
bFN (10^3 V)	7,2	13	11	7,4	7,2
voltage conversion factor γ (10^5 m^{-1})	1,0	0,6	0,7	1,0	1,0
field enhancement factor β (10^2)	5,0	3,0	3,5	5,0	5,0
emissive surface S (10^{-14} m^2)	2,4	0,2	1,4	1,9	4,0

- **moderate field emission behaviour**
- **uneven distribution of the emission current**

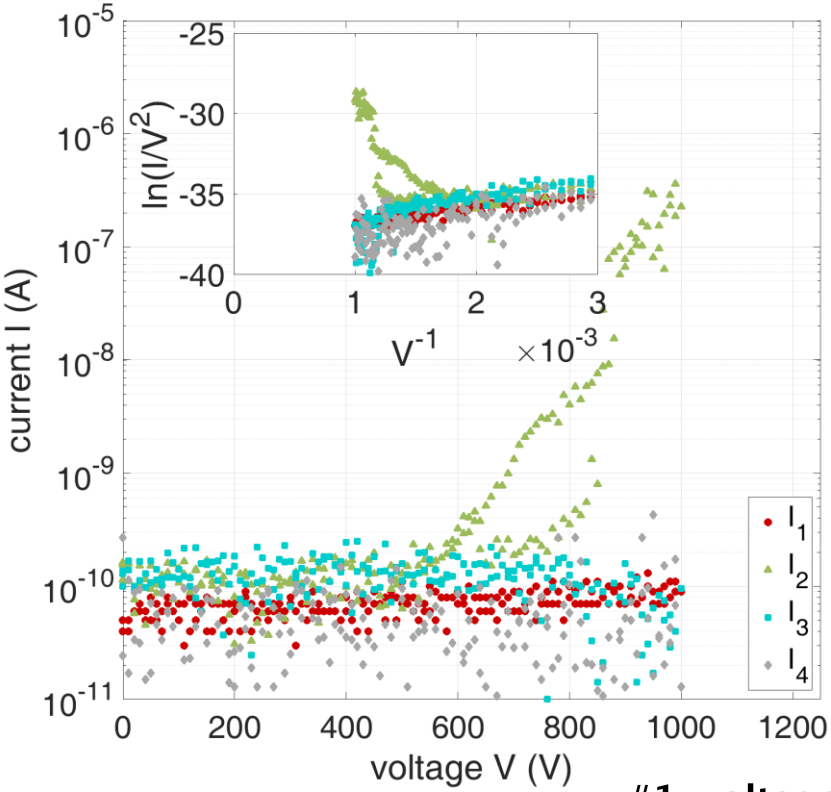
Longterm measurement

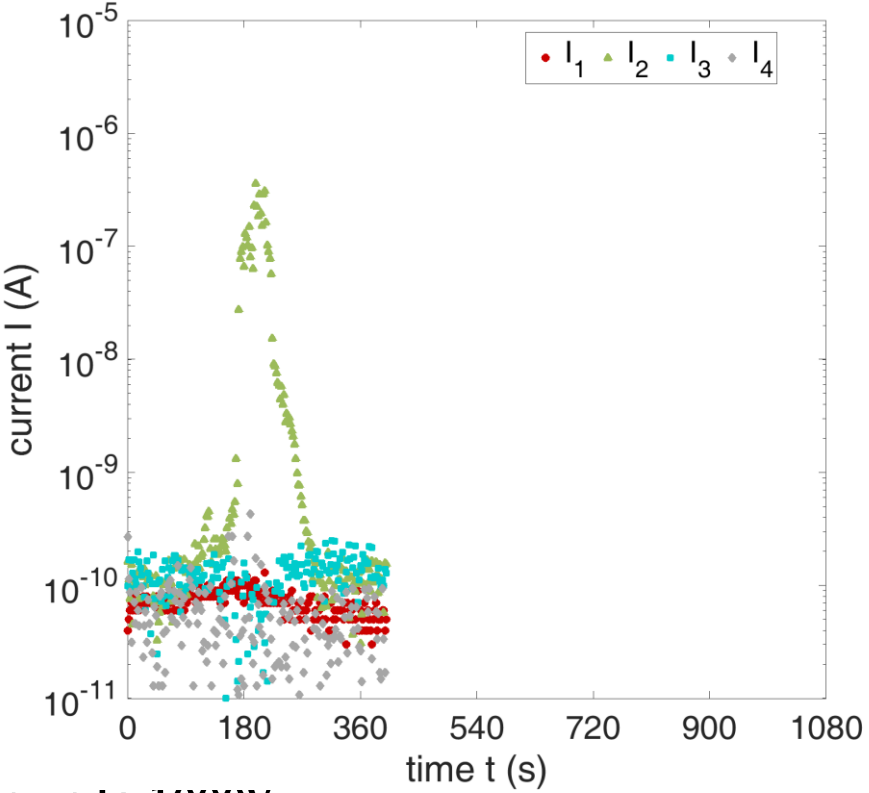


sample	#1	#2	#3	#4	all
applied voltage V_G (V)			1000		
I_{mean} (µA)	5,3	1,4	2,3	1,1	8,3
±ΔI (µA)	0,7	0,3	0,6	0,2	0,6
$\pm\Delta I_r$ (%)	13	21	26	18	7
I_{drift} (nA/h)	-900	+46	-8	+128	-275

- **emission currents differ and vary up to 26% for individual emitters**
- **total emission current varies less (only by 7% without regulation)**

Chronological measurements

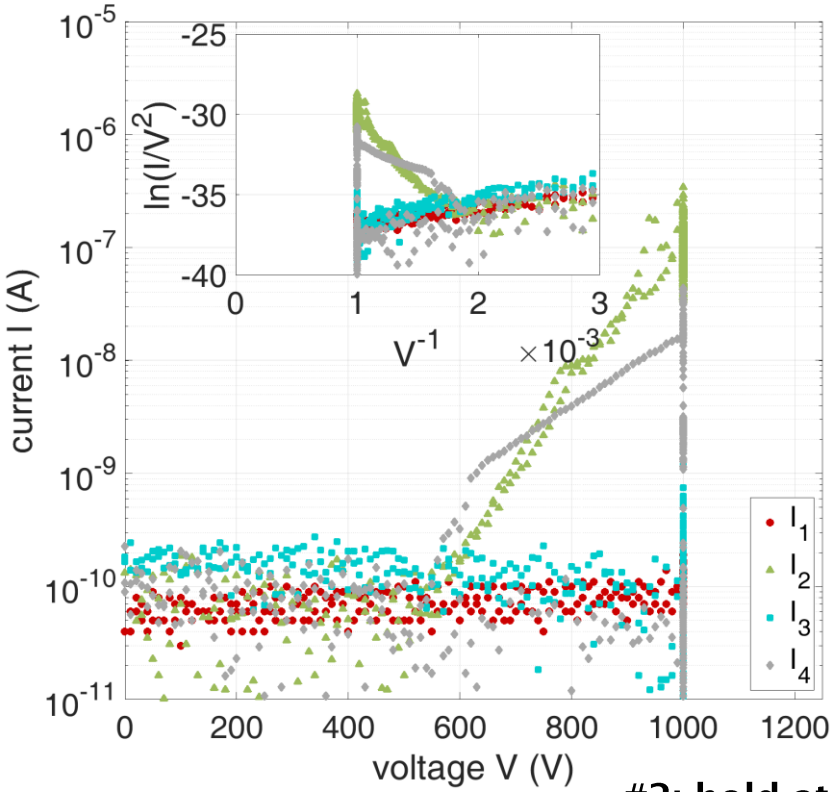


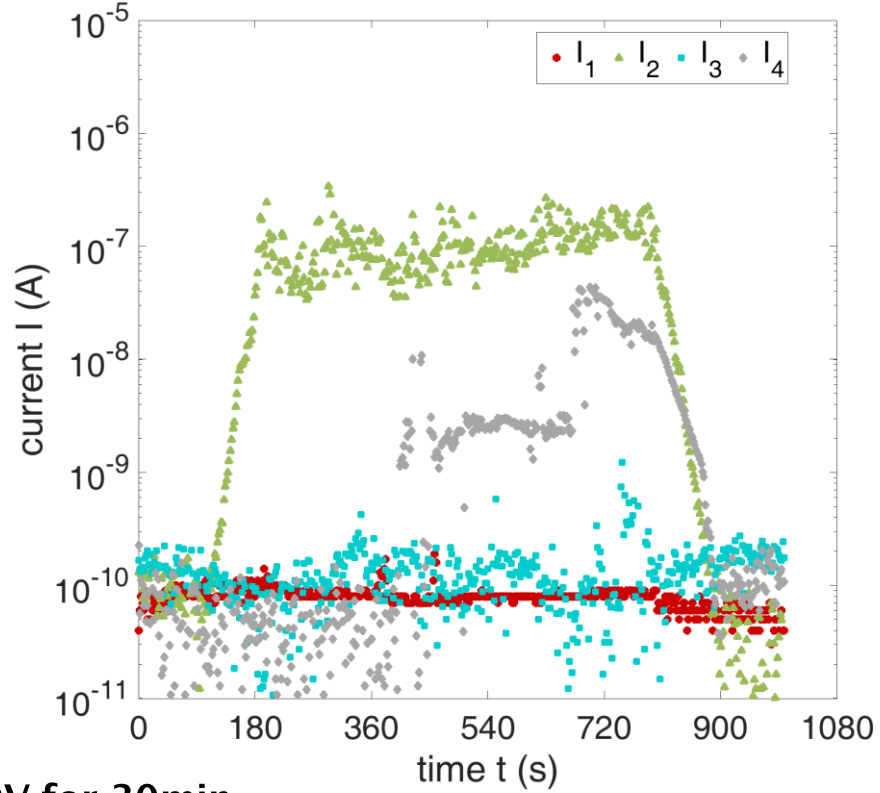


#1: voltage sweep up to 1000V

→ activation of the first emitter (#2)

Chronological measurements

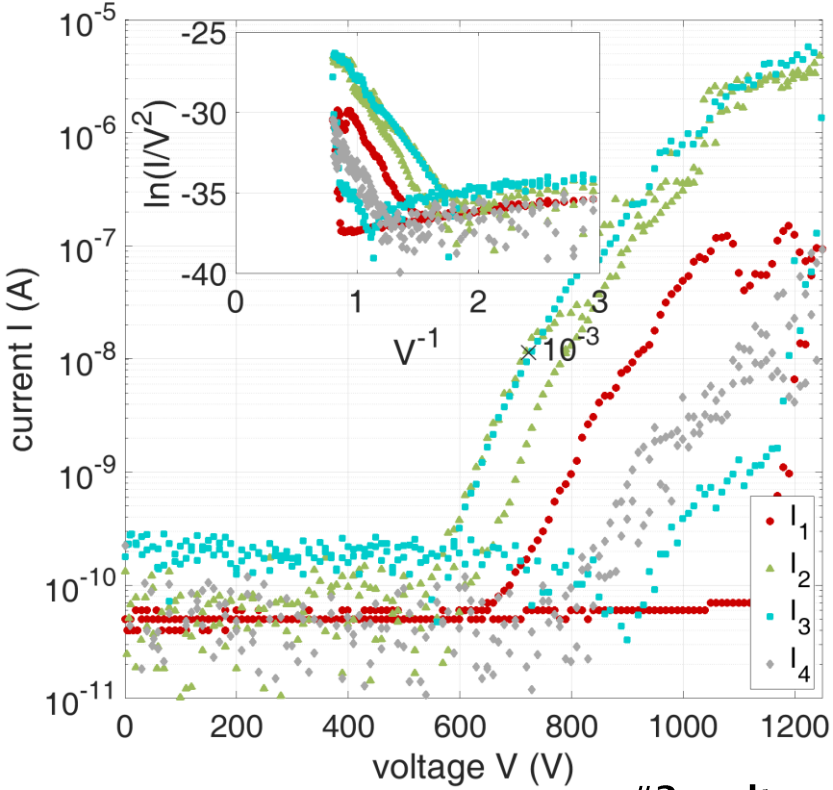


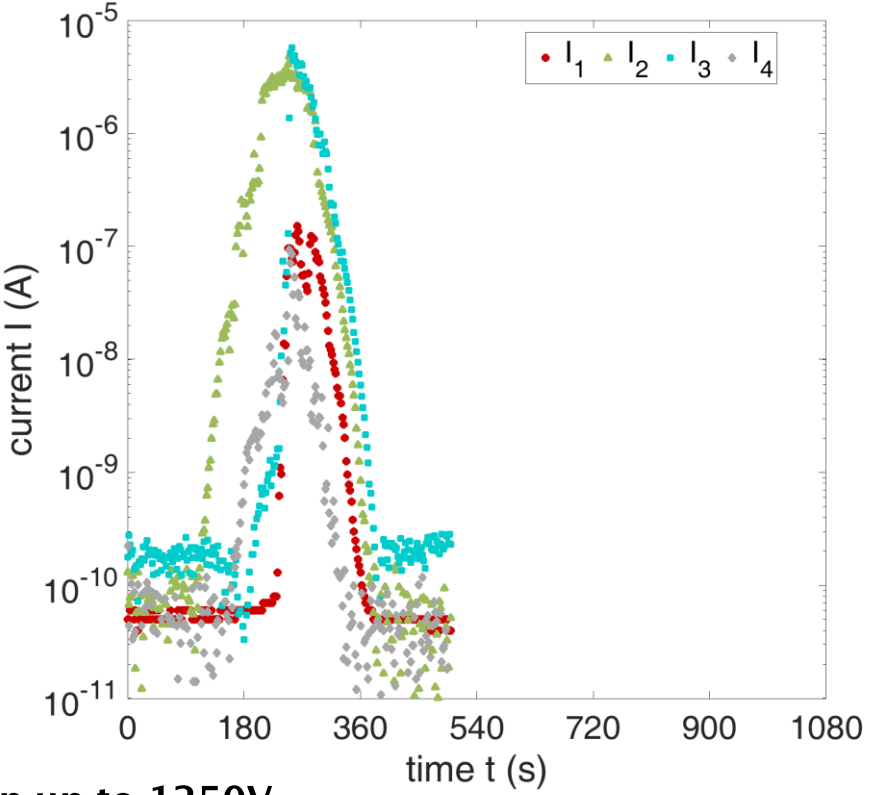


#2: hold at 1000V for 30min

→ activation of the second emitter (#4)

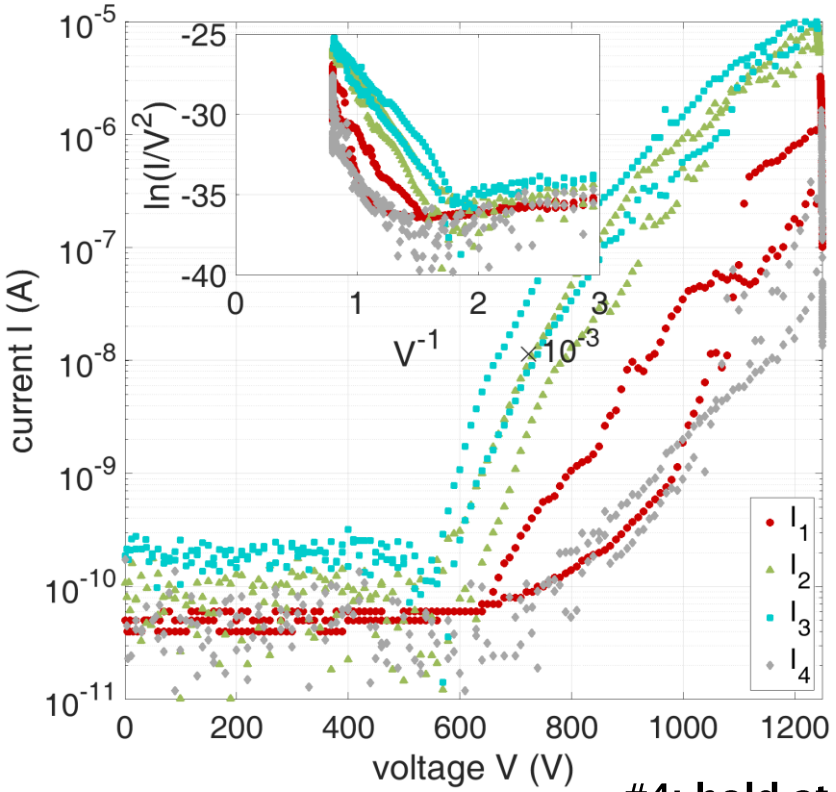
Chronological measurements

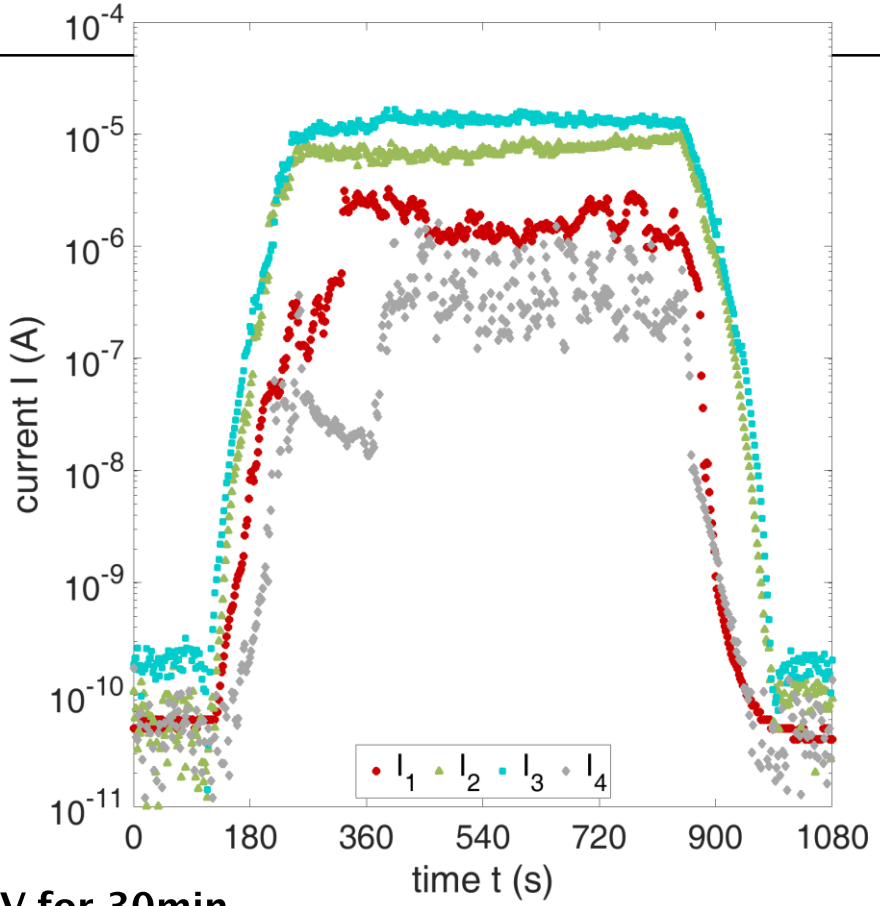




#3: voltage sweep up to 1250V

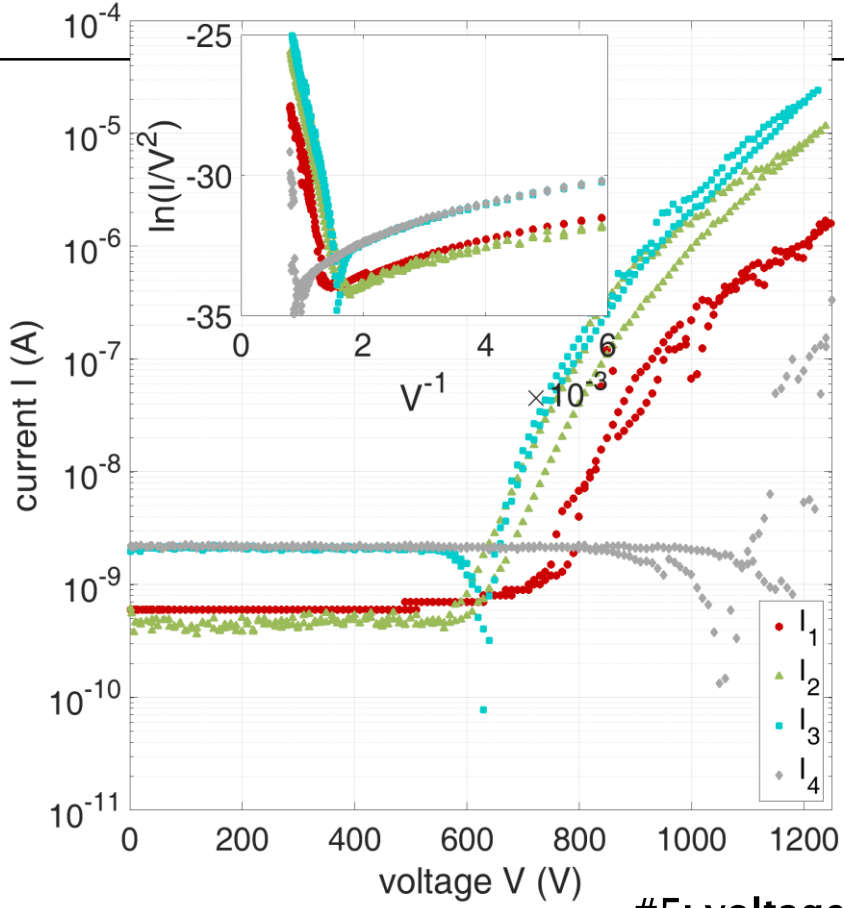
→ activation of the last two emitter (#1, #3)

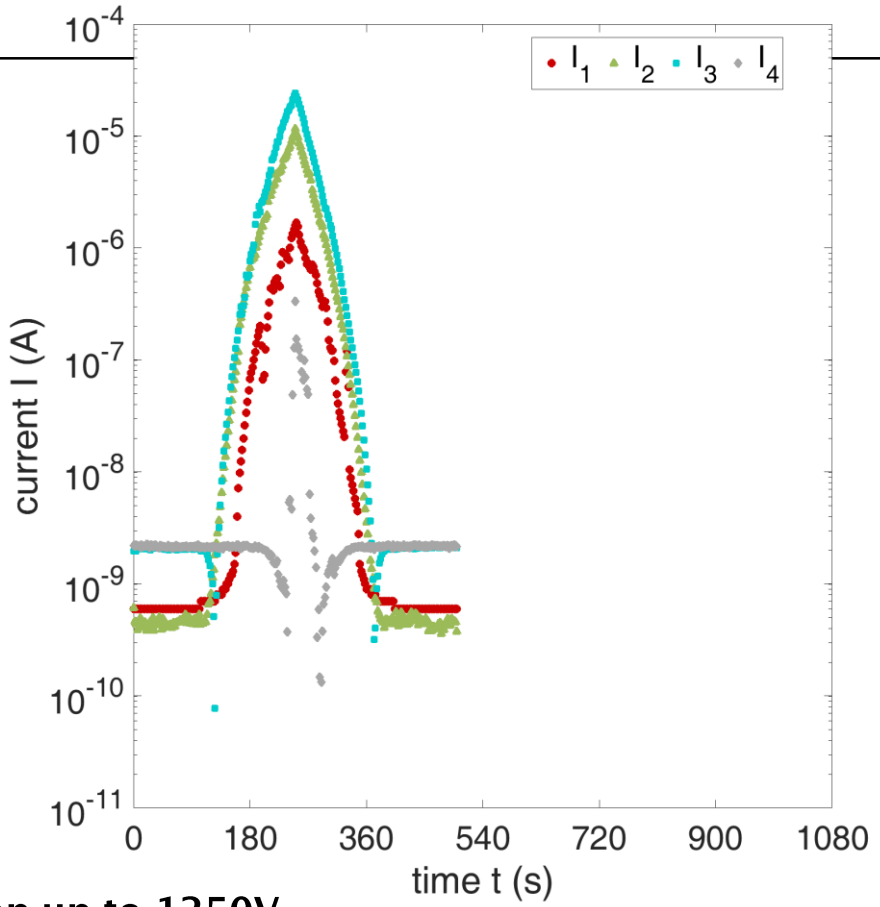




#4: hold at 1250V for 30min

→ increase of the emitter performance (#2)

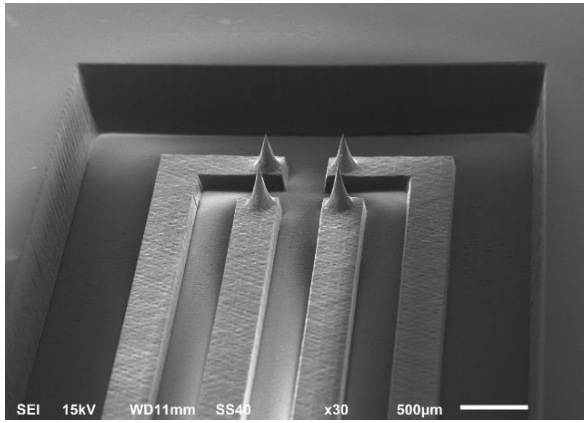


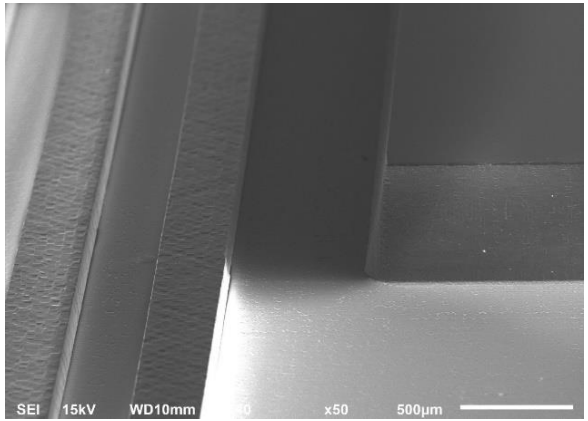


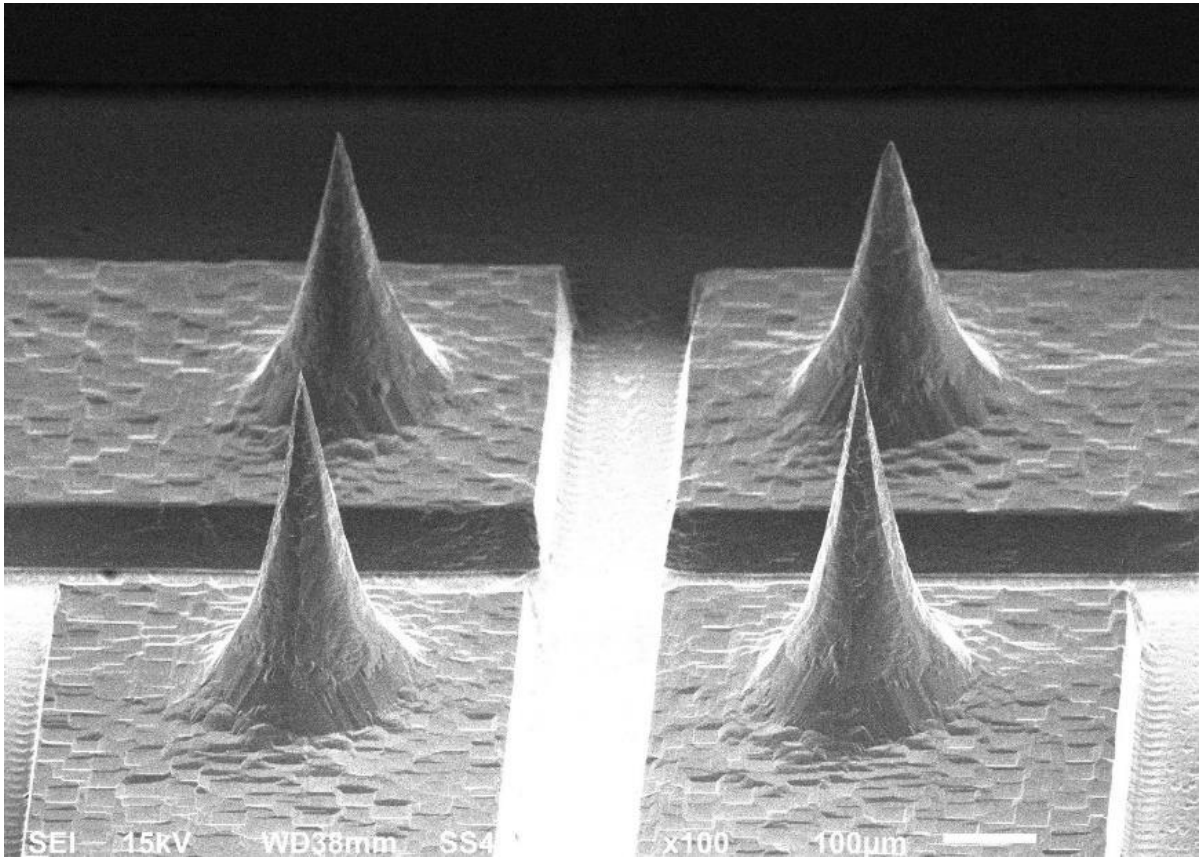
#5: voltage sweep up to 1250V

→ no further increase or activation

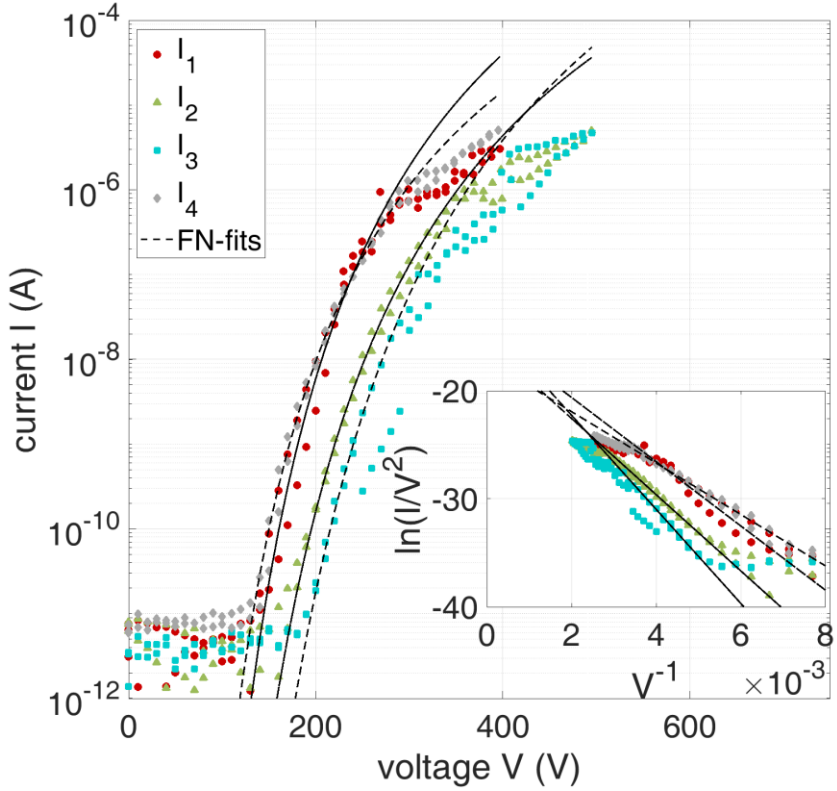
Optimized fabrication process







Separated measurements



sample	#1	#2	#3	#4
onset voltage V_{Eon} (V)	190	210	210	190
max. applied voltage V_{FE} (V)	400	500	500	400
max. emission current I_C (µA)	3,0	5,0	4,7	5,1
aFN (10^{-7} A V^{-2})	4,1	1,9	1,2	3,4
bFN (10^3 V)	−3,0	−3,5	−4,4	−2,4
voltage conversion factor γ (10^5 m^{-1})	2,5	2,1	1,7	3,1
field enhancement factor β (10^4)	1,2	1,0	0,9	1,6
emissive surface S (10^{-13} m^2)	2,5	1,6	16	0,1

→ **performance comparable to our underlying / previous work**

Thank you for the attention

Measurement conclusions of the individually addressable cathode design:

- uneven distribution of the emission current
- emission currents differ and vary up to 26% for individual emitters
- total emission current varies less (about six times lower)
- evolution of the emission is clearly visible

Optimized fabrication process:

- moderate field emission behaviour of the first samples
  → performance comparable to underlying work (Langer et. al)

Further measurements could provide information on:

- understanding of the activation process of individual emitters (impact on the total current)
- time dependency of the emission current for individual emitters (current distribution)