OSTBAYERISCHE TECHNISCHE HOCHSCHULE REGENSBURG

Measurement of the Current Distribution of a Field Emission Cathode Array using a CMOS Camera and Comparison with the directly measured Current Values.

M. Hausladen[1+], A. Schels[2], P. Buchner[1], M. Bartl[1], A. Asgharzade[1], S. Edler[2], D. Wohlfartsstätter[2], M. Bachmann[2], R. Schreiner[1]

[1]Faculty of Applied Natural Sciences and Cultural Studies, OTH Regensburg, D-93053 Regensburg, Germany
[2]Ketek GmbH, D-82737 Munich, Germany

[+]matthias.hausladen@oth-regensburg.de

9th VDE ITG International Vacuum Electronics Workshop (IVEW) 2024
August 28-30th, 2024

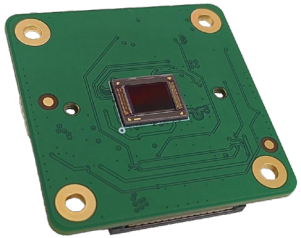
Outline

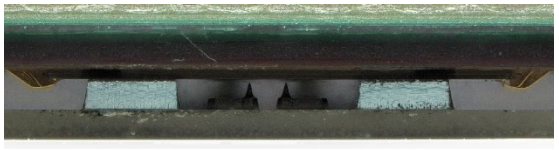
Essentials

- Method was/is developed in collaboration with Ketek GmbH
  - Optical Image Sensor:

Camera-Model	Raspberry Pi HQ-Camera
Image Sensor	Sony IMX477
Resolution | Area	4056x3040 px² | ≈ 6.3x4.7 mm²

  - First demonstration by A. Schels [1] using an image sensor as commercially available
  - Assumed detection mechanism: XRay (Bremsstrahlung)
  - Camera signals are mapped as factorial shares on the electrically measured integral current of the FEA:



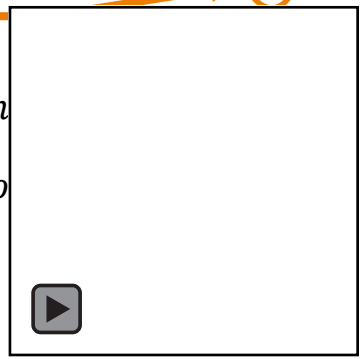


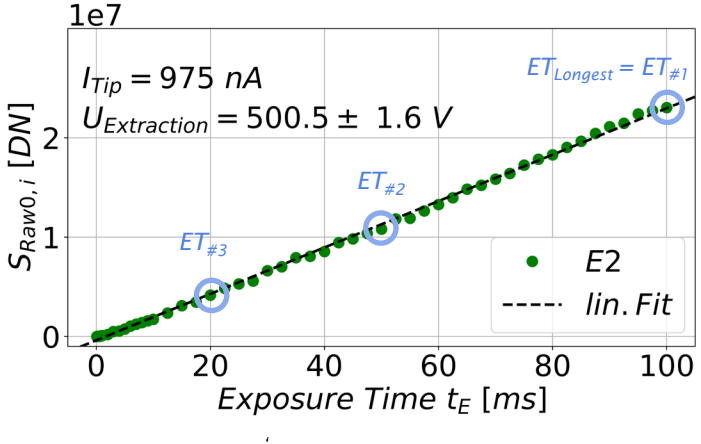
Factorial shares F

$$I_{\mathrm{OMap.},Tip\ x} = I_{Total} \cdot F_{Tip\ x} \qquad F_{Tip\ x} = \frac{S_{Tip\ x} \cdot f_{Tip\ x}}{\sum_n S_{Tip\ n} \cdot f_{Tip\ x}}$$

Upscaling factors f

$$f_{Tip\ x} = \frac{ET_{Longest,Tip\ x}}{ET_{not\ overexposed,Tip\ x}} \begin{cases} = 1 & if\ n \\ > 1 & if\ o \end{cases}$$





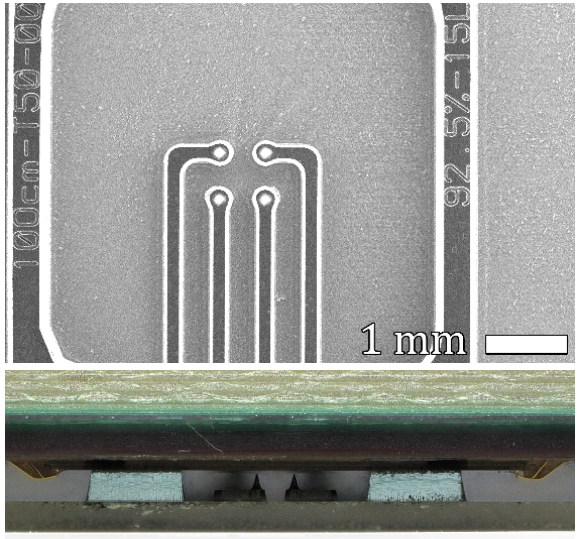
[1] A. Schels *et al.*, "In-situ quantitative field emission imaging using a low-cost CMOS imaging sensor," *Journal of Vacuum Science & Technology B*, vol. 40, no. 1, p. 014202, Jan. 2022, doi: 10.1116/6.0001551.

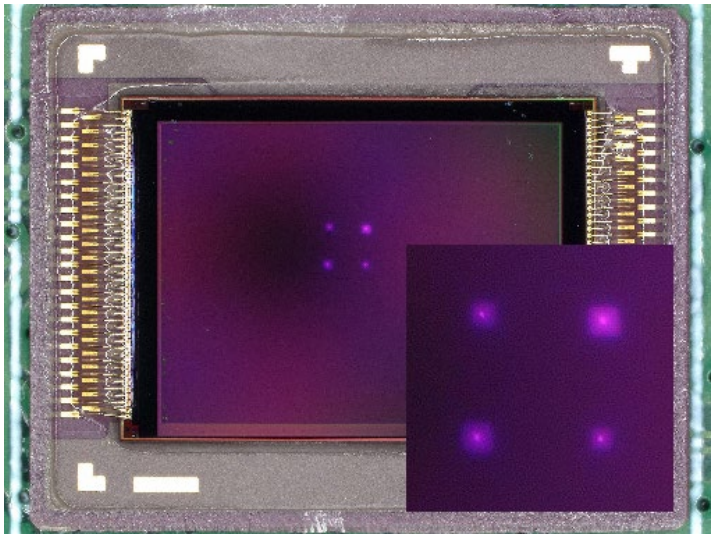
Outline

Intention and Problems

Intention:
- Measuring higher currents in the microampere range
- Reliability of the optical sensor signal

Problem:
- Damaged areas of microlenses occurred already at a few 100 nA
- Microlenses made from carbon-combounds (bad- or non-conductive)





Damaged Image Sensor Surface

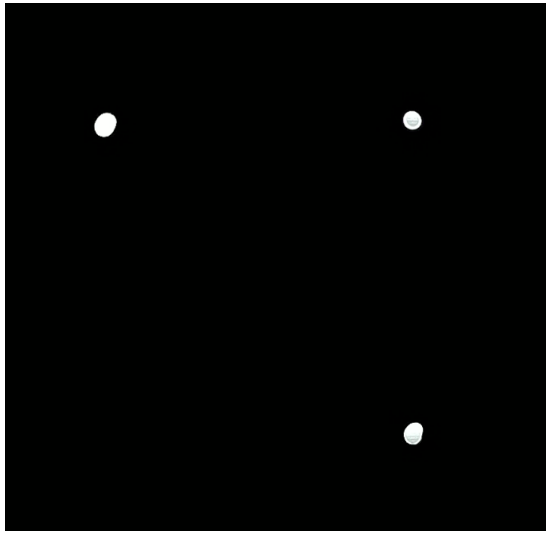


Image of a damaged sensor
(no voltage/field emission)

Solution:
➔ Metallic coating (Copper) of the sensor
→ Conductive surface and increased heat dissipation
→ Copper is a XRay-source target material
➔ n-Si FEA with 4 individually addressable tips [2] (direct comparison of electrical tip current and camera-signal)

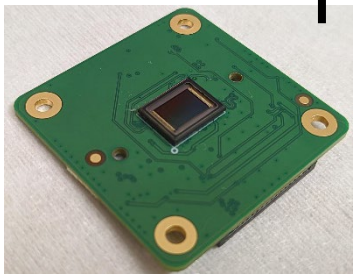
[2] R. Lawrowski, M. Hausladen, and R. Schreiner, "Individually Addressable Fully Integrated Field Emission Electron Source Fabricated by Laser Micromachining of Silicon," in 2020 33rd International Vacuum Nanoelectronics Conference (IVNC), Lyon, France: IEEE, Jul. 2020, pp. 1–2. doi: 10.1109/IVNC49440.2020.9203470.

Outline

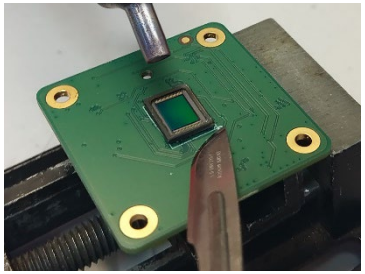
Camera preparation

Cleaning step
(acetone & isopropanol
bath using ultrasonic)

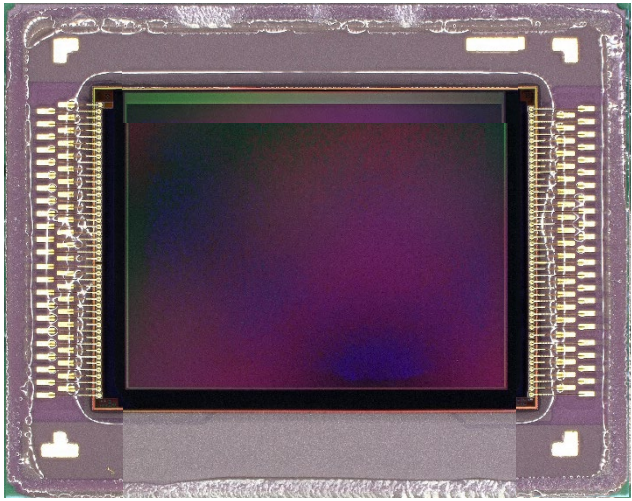
HQ-Camera as commercially available



HQ-Camera with removed C-Mount and sealing lip (underneath the C-Mount)

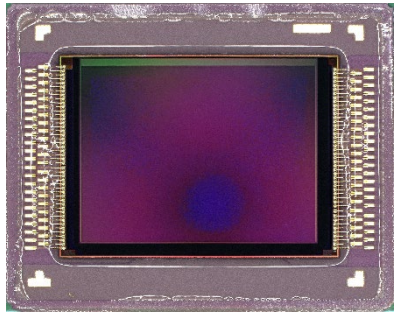


Removement of protection glass and spacer frame

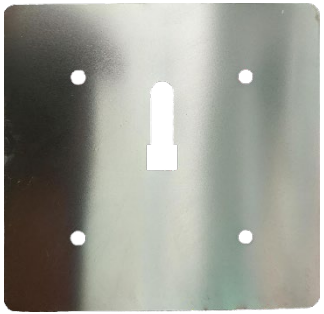


Blank unmodified sensor chip of the HQ-Camera with secured bond-wires and ramps for the coating process (UV-curing adhesive)

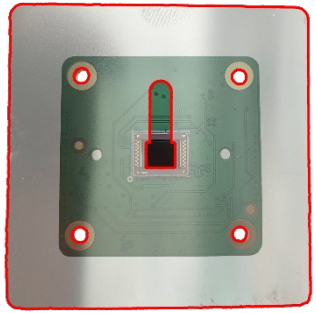
Camera coating



HQ-Camera with secured bond-wires



Shadow-mask for the coating process (laser-cutted stainless steel sheet)



Shadow-mask as semi-transparent overlay on the HQ-Cam PCB (red lines indicate the mask contour)

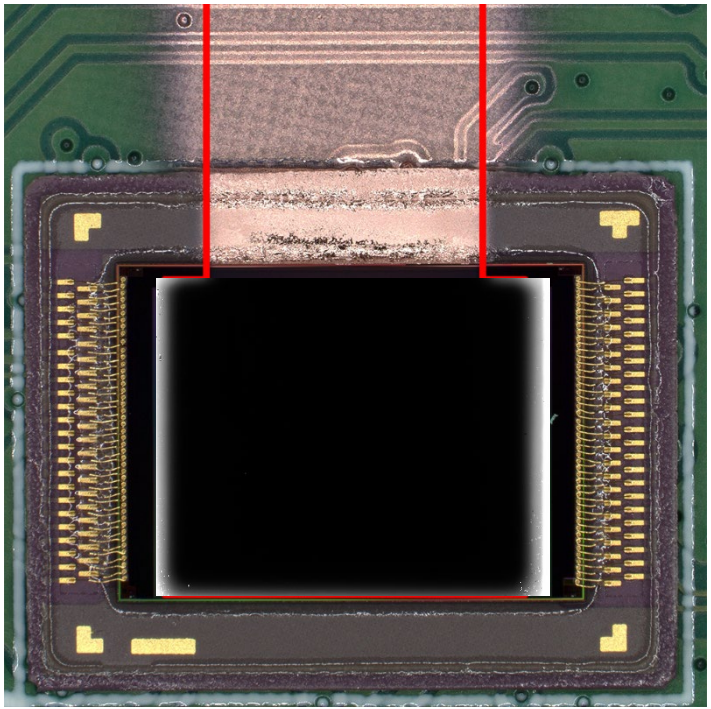
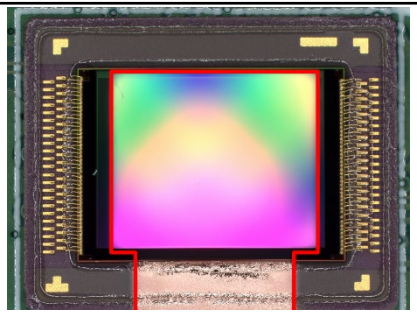
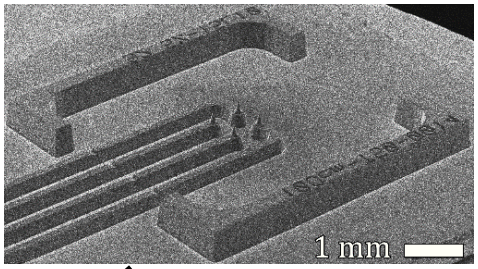


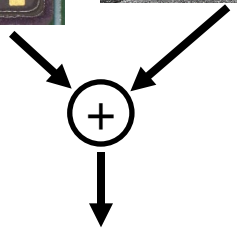
Image sensor with copper coated surface with an light-illuminated image (coldwhite, $P_{El.}$=1.5 W), captured by the image sensor as overlay

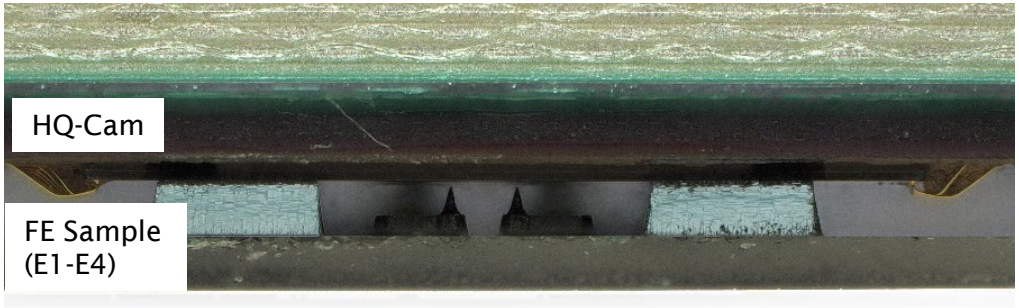
Outline

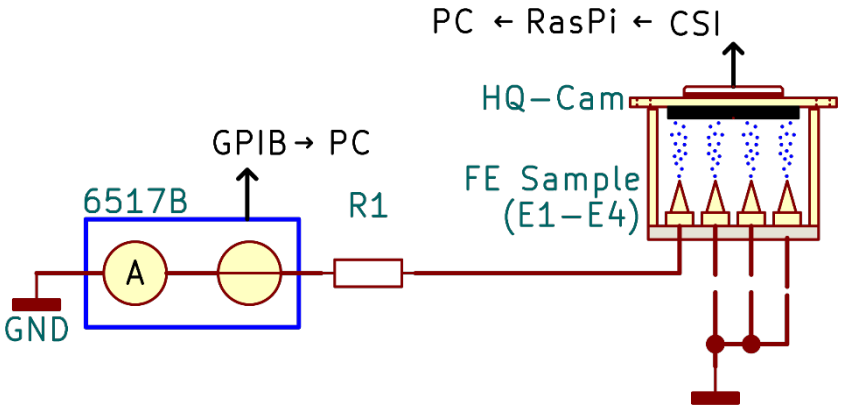
Measurement Setup for the 2x2 FEA





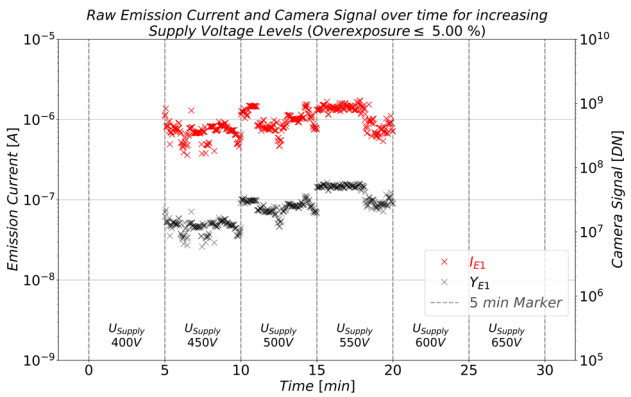


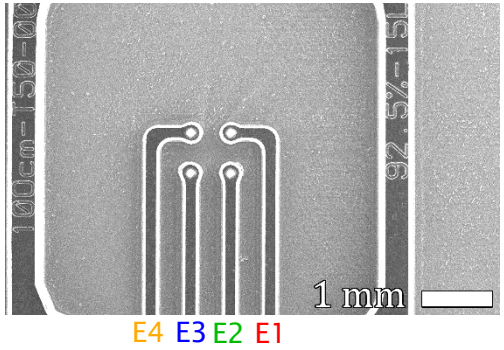


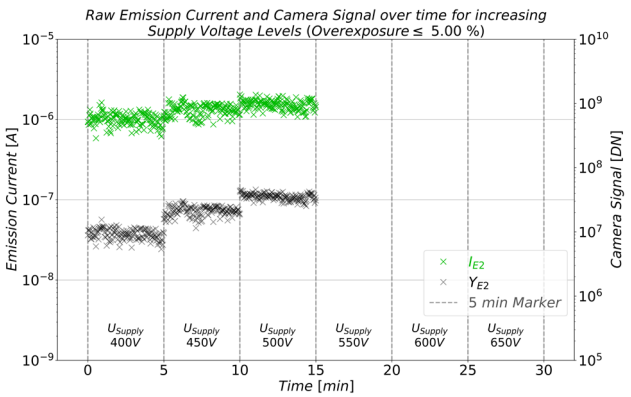


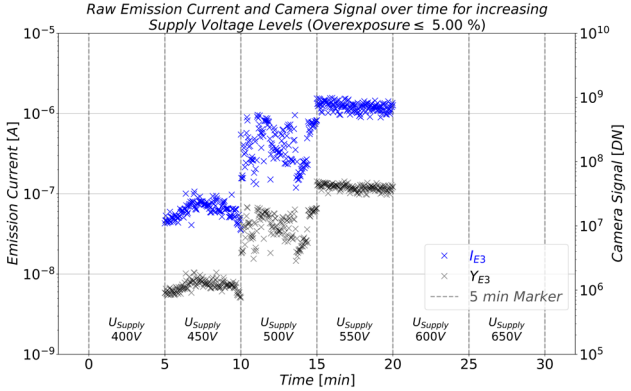
- Measured tip by tip
- Multiple supply voltages were applied to the FEA (hold for 5 minutes for statistics)
- Each current and camera signal known individually
- Used only one exposure time
  → High temporal correlation between a tips current I and its camera signal Y

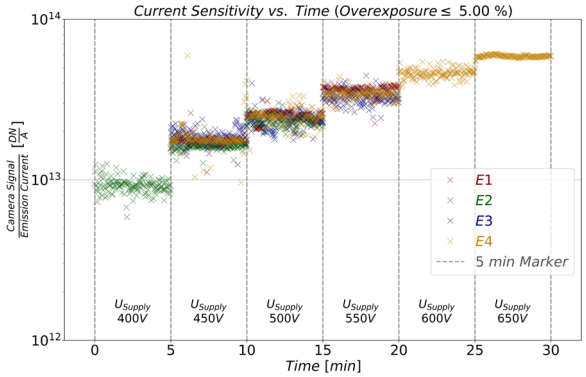
Single Tip Measurements

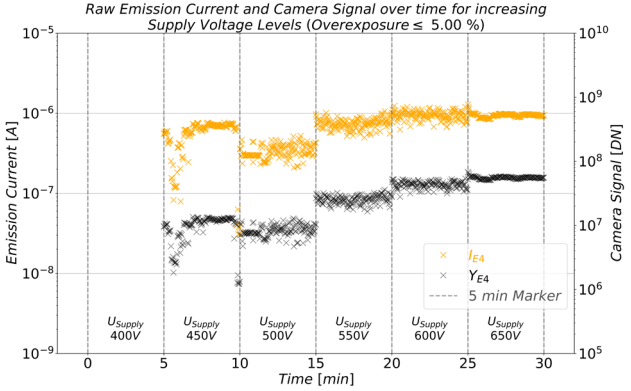




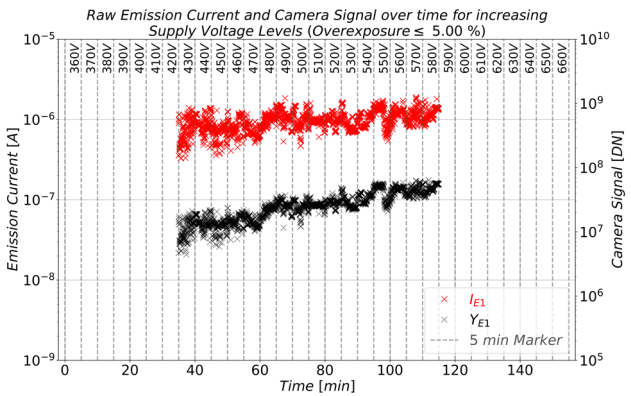


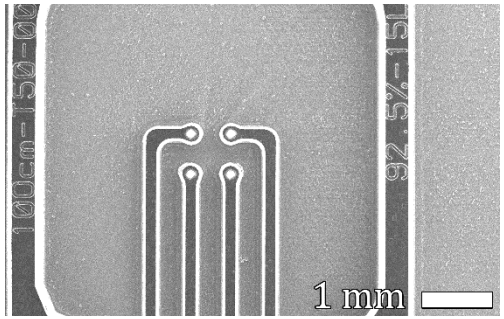


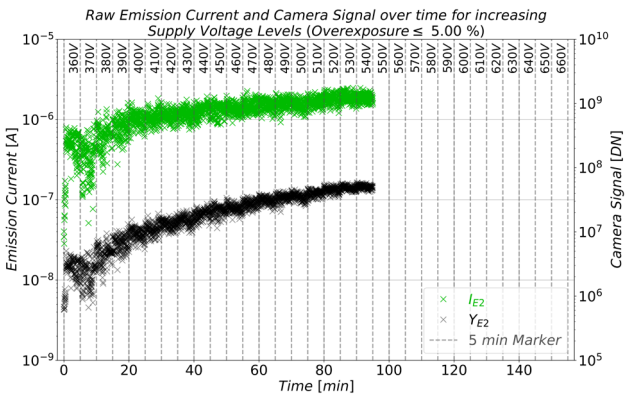


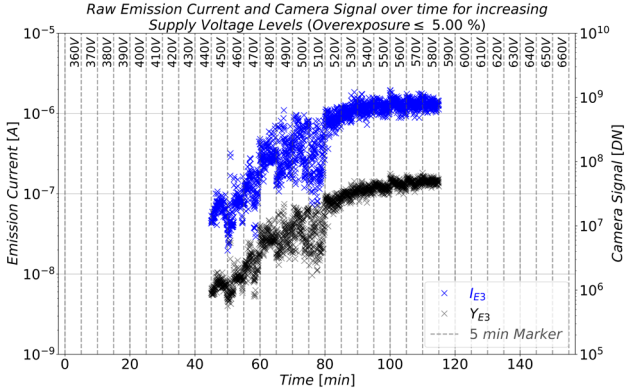


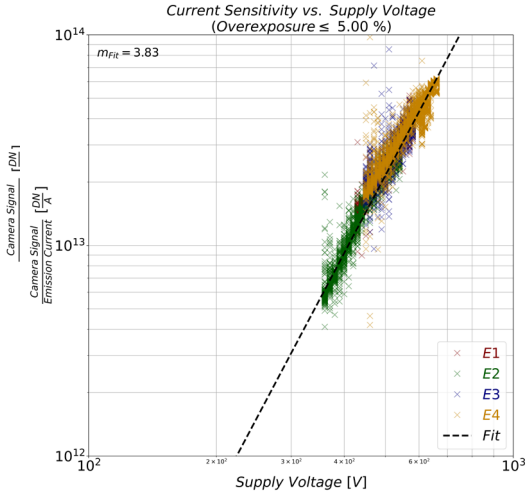
Single Tip Measurements

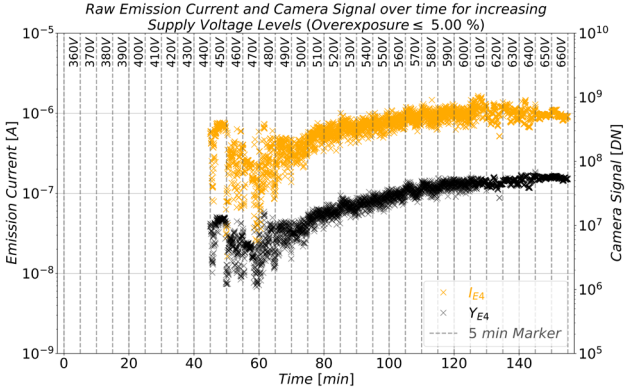










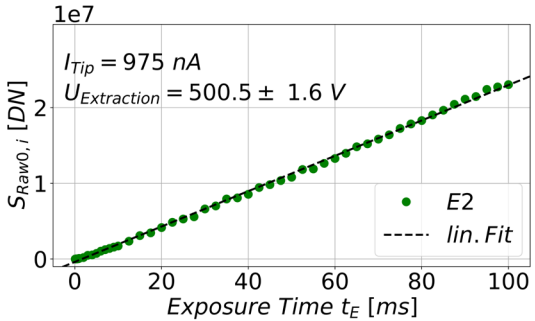


Sensitivities (Exposure Time, Current, Voltage)

Sensor signal behaves like (first approximation): $Y(t_E, I, U) \overset{\approx}{\propto} t_E \cdot U^b \cdot I$

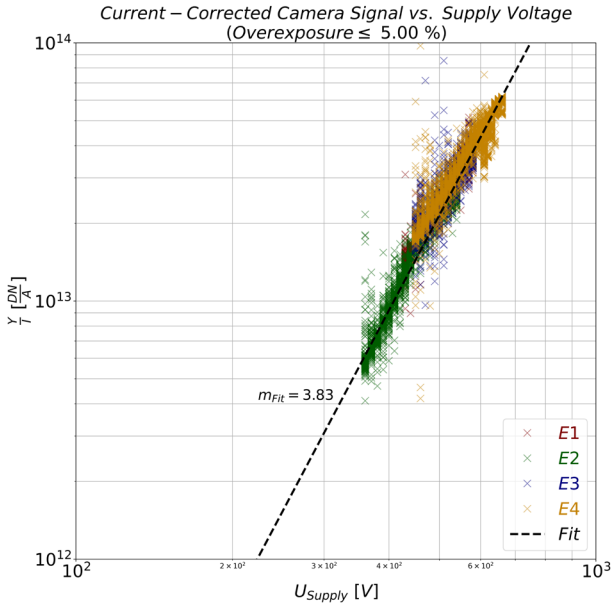
$$\boldsymbol{Y(t,I,U) \propto t_E}$$

$(I = const., U \approx const.)$



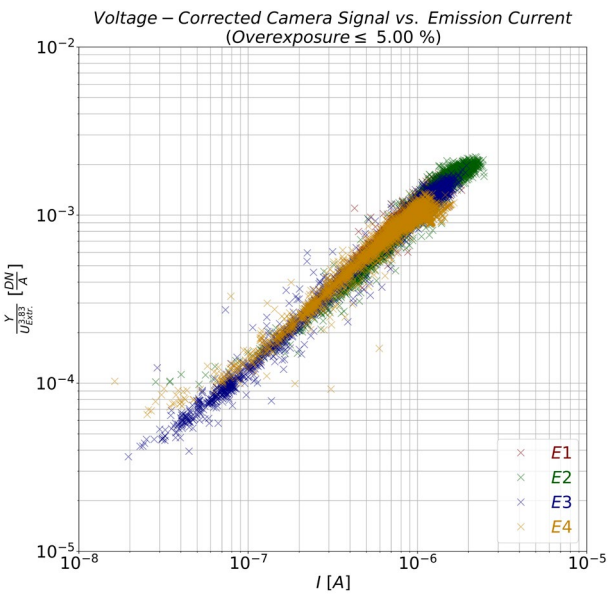
$$\frac{\boldsymbol{Y(t,I,U)}}{\mathbf{I}} \overset{\approx}{\propto} \boldsymbol{U^b}$$

$(t_E = const.)$



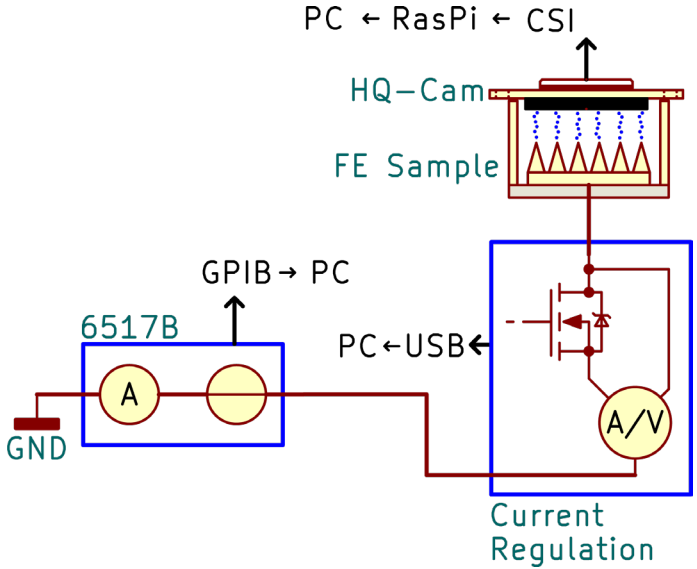
$$\frac{\boldsymbol{Y(t,I,U)}}{\mathbf{U^b}} \propto \boldsymbol{I}$$

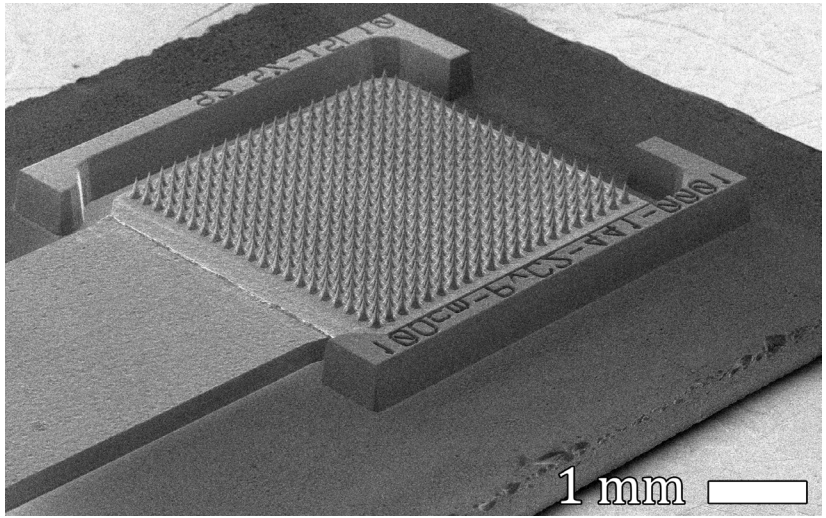
$(t_E = const.)$



Outline

Measurement Setup 21x21 FEA





Supply voltage:

1. 0V → 350V in 25V steps
2. 350V → 700V in 5V steps

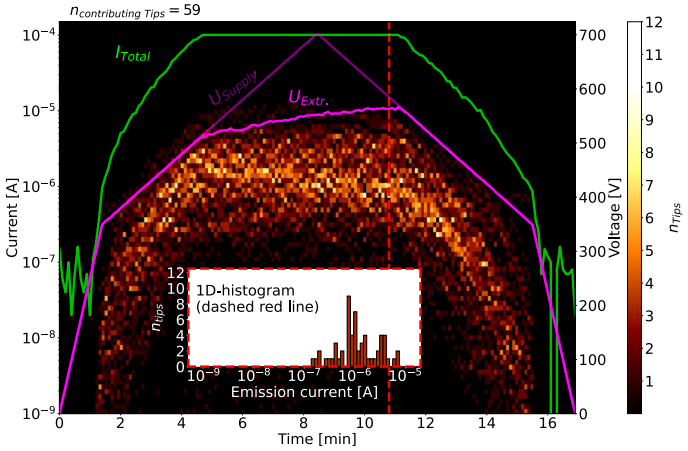
} Up-ramp

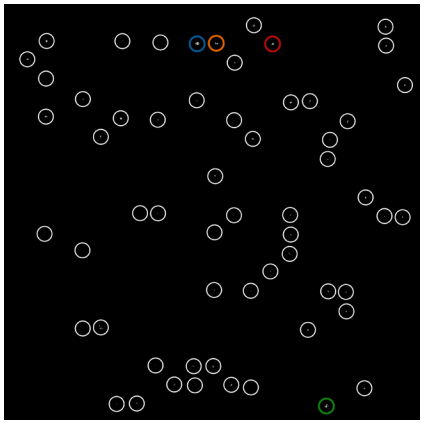
3. 2. and 1. in reverse → Downramp

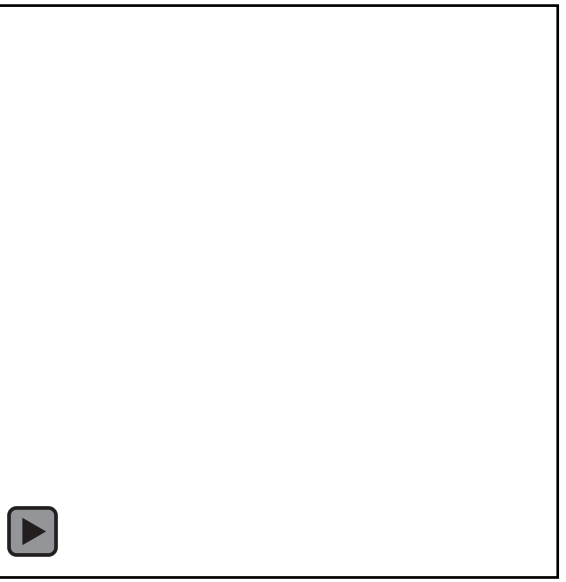
Current Regulation:

- Regulation only if the cathode current would overcome a maximum set-current
  → I_{max} = 100µA

FEA (21x21) Measurements







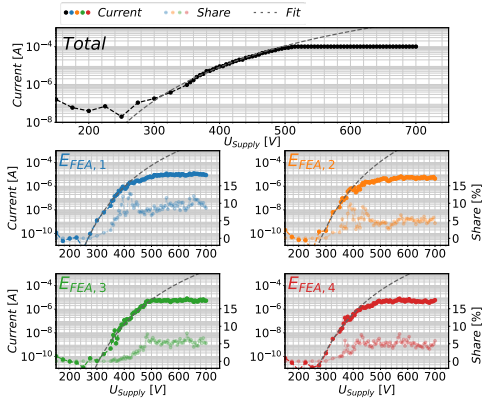


Table 2: Extracted parameters and key values from the OMap currents.

Tip	Coordinate (x,y) [px]	Maximum FE Current [µA] → → → ([%])	Onset Voltage [V]	Field Enhancement Factor [#]
$E_{FEA,1}$	(1299, 266)	12.15	(12.05)	300	578
$E_{FEA,2}$	(1428, 262)	8.29	(8.23)	313	484
$E_{FEA,3}$	(2169, 2704)	8.01	(8.01)	343	496
$E_{FEA,4}$	(1807, 267)	7.85	(7.77)	314	532
Total FEA	-	100.82	(100)	230	1016

Conclusion and Outlook

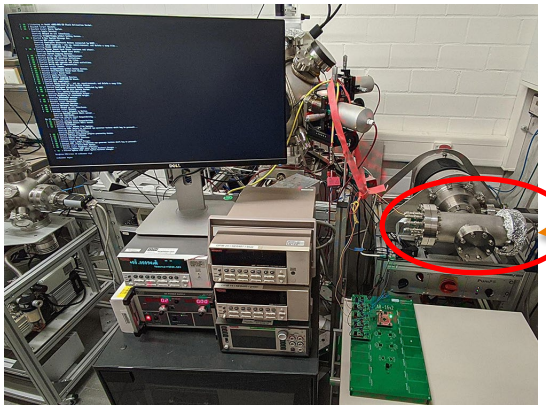
Conclusions:

- Optical signals
  - Generated most likely by (soft) XRays
  - reliably mappable onto the electrically measured integral FEA current
  - tips have to emit on the same potential, as the voltage has a non-linear influence
- Metallic coating
  - Far higher FE Tip currents were measureable (> x20) without damaging the lenses (increased heat dissipation)
  - No instablities due to a conductive surface for the electrons (no feedback from charged lenses)

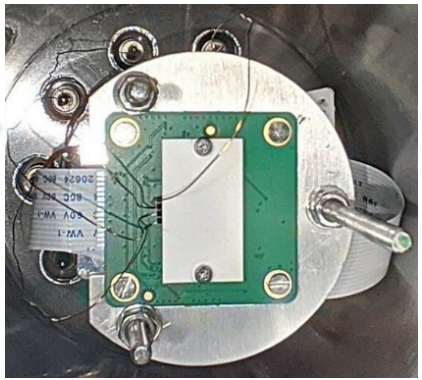
Outlook:

- Paper in progress about the camera system, covering
  - a detailed description of the modification process
  - the theory and influences on the measured optical camera signal
- Release of the source-code of the camera-capturing via GitHub (less effort for replication) → Stay tuned

Thank you for your Attention



Window view



Any Questions?

BRNO UNIVERSITY OF TECHNOLOGY

ISI CAS Institute of Scientific Instruments The Czech Academy of Sciences

BERGISCHE UNIVERSITÄT WUPPERTAL

Wrocław University of Science and Technology

KETEK

Bayerische Forschungsstiftung