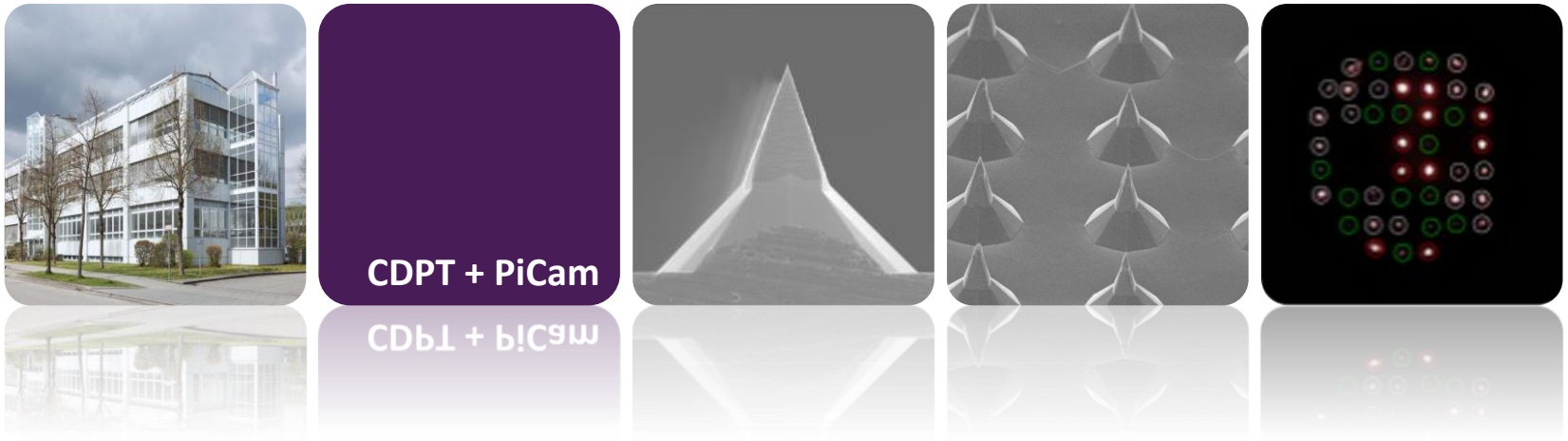


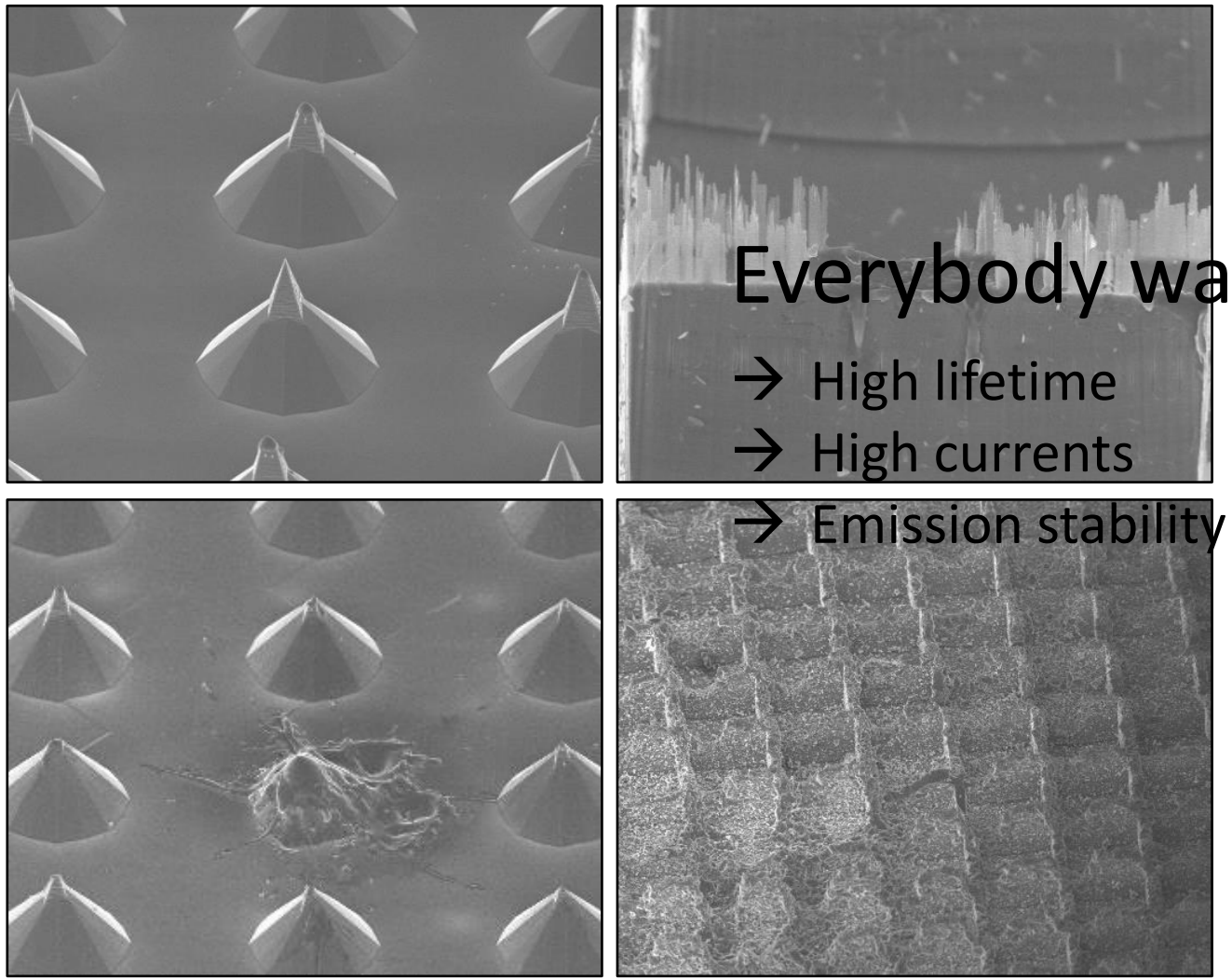
Current dependent field emission performance test using a CMOS imaging sensor

8th ITG IVEW

Simon Edler, Andreas Schels, Florian Herdl, Walter Hansch, Michael Bachmann, Dominik Wohlfartsstätter, Felix Düsberg, Andreas Pahlke, Matthias Hausladen, Philipp Buchner, Rupert Schreiner

Motivation

Everybody gets:



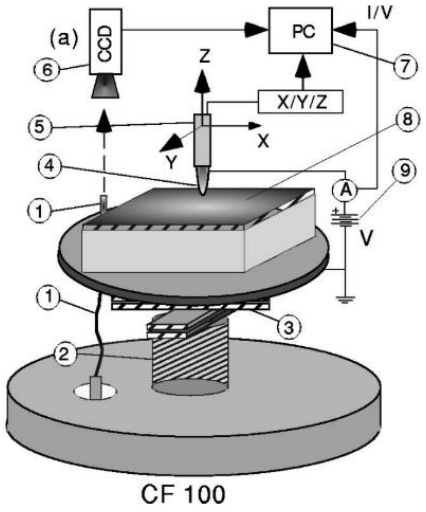
Everybody wants:

→ High lifetime
→ High currents
→ Emission stability

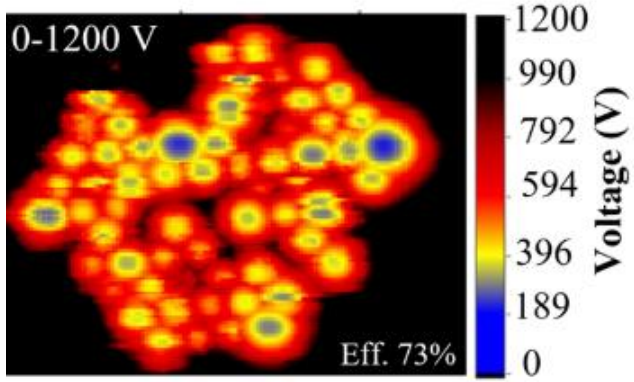
Need for Homogeneous current distribution

Available methods

- Field emission scanning microscope

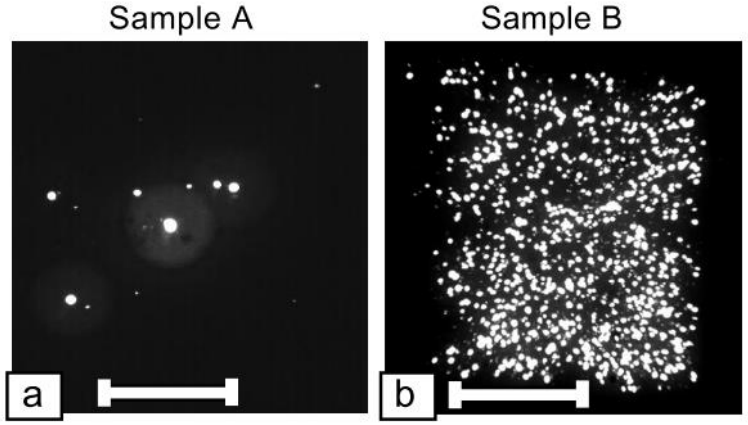


J. Vac. Sci. Technol. B Microelectron. Nanom. Struct. **20**, 326 (2002)

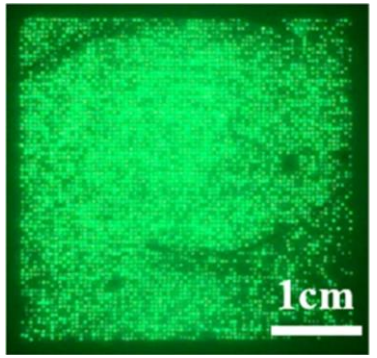


Rev. Sci. Instrum. **91**, 083906 (2020)

- Phosphor screen



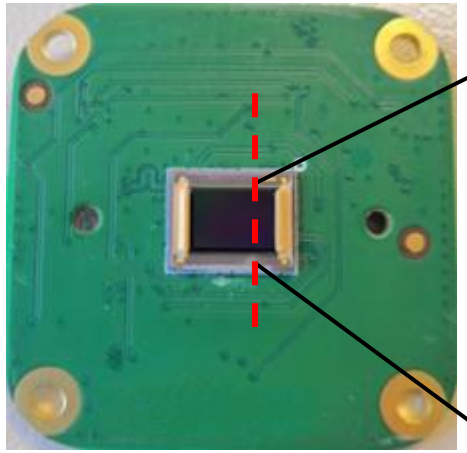
J. Appl. Phys. **90**, 768 (2001).



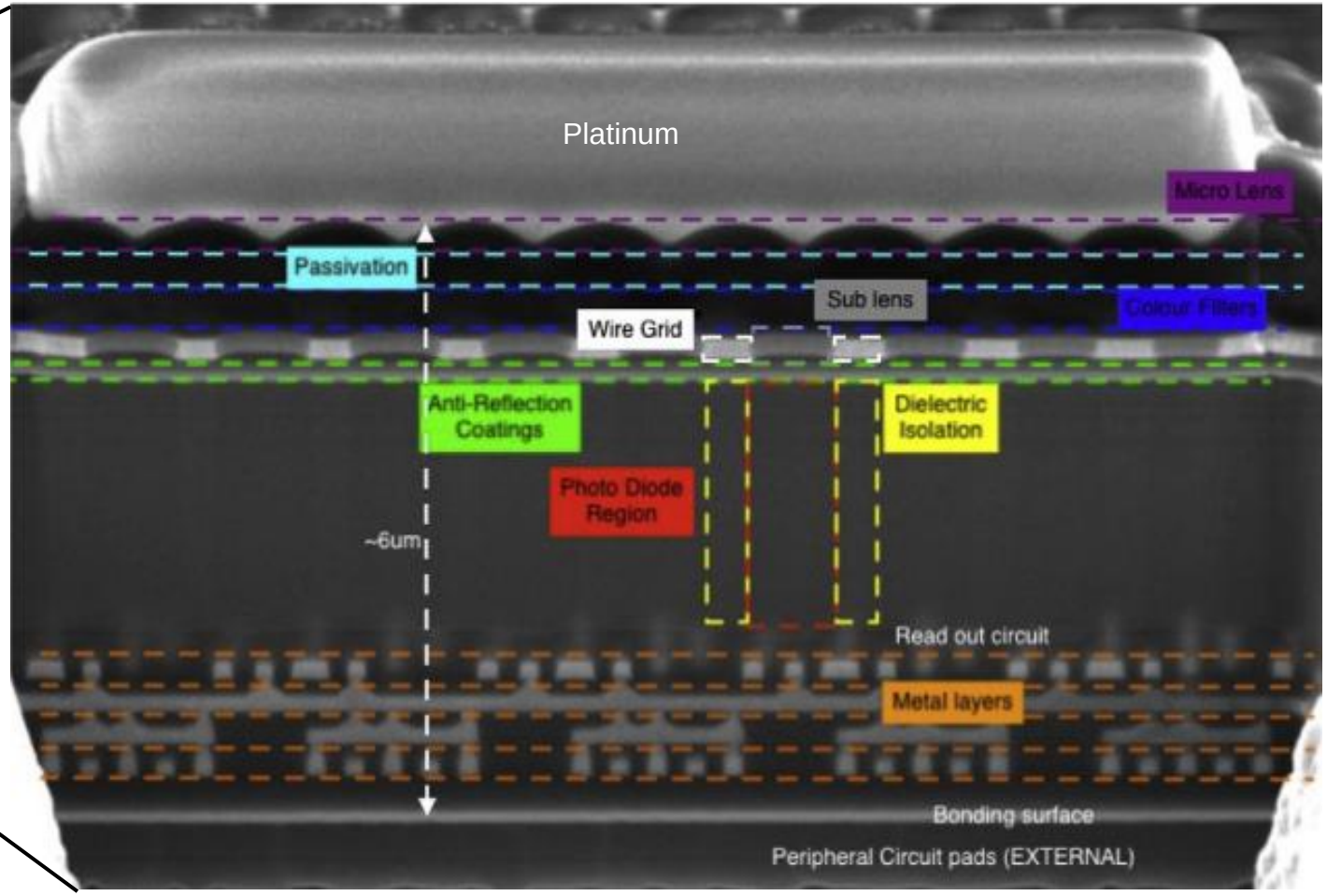
Sci. Rep. **8**, 12294 (2018).

Expensive and limited

Field Emission Imaging



~ 1 – 1.5 µm



Forensic Sci. Int. Digit. Investig. **32**, 200900 (2020)

→ Raspberry Pi HQ Camera:

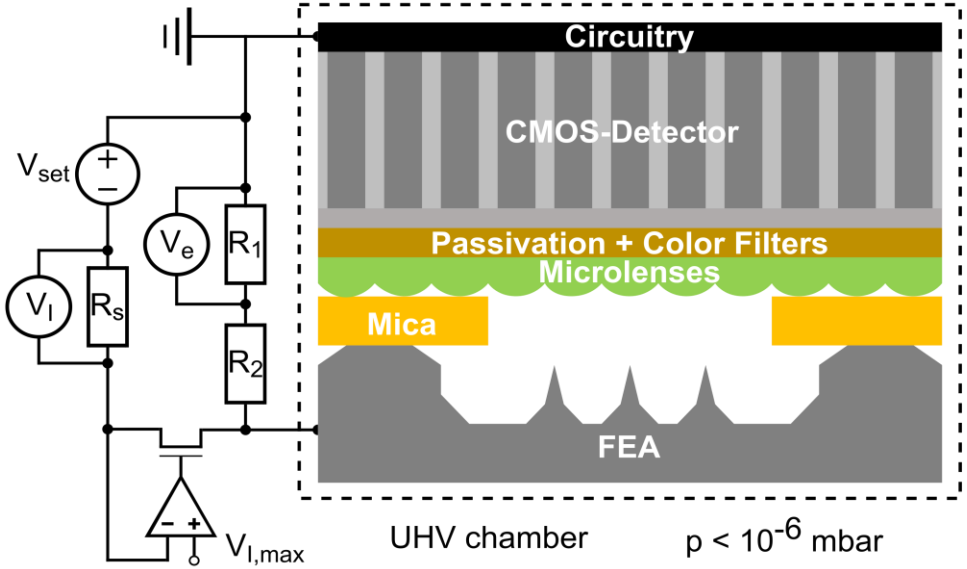
- Costs approx. 50 USD
- Easy to integrate
- Reasonable resolution
- High dynamic range
- Easily controllable

⇨ **Electrons don't pass the top layers** ⇨ **X-ray detection**

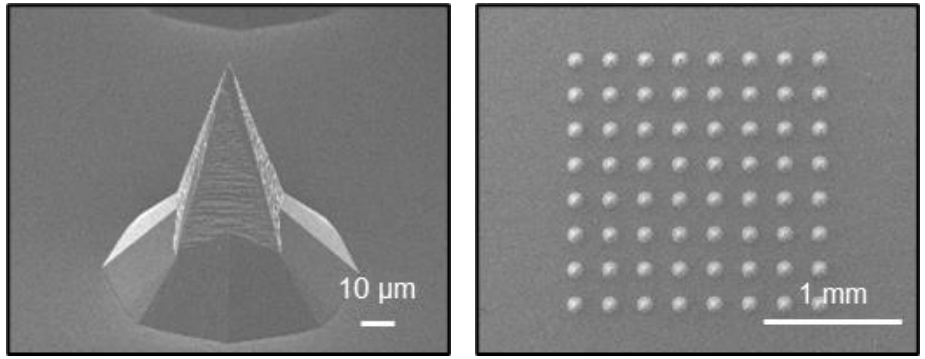
Field Emission Imaging

- Measurement Setup
  - Camera connected to ground
  - Mica sheet for insulation (approx. 30 µm)
  - FEA at up to – 1.1 kV
  - Regulation circuit for constant current measurements
  - $p < 10^{-6}$ mbar

J. Vac. Sci. Technol. B 40, 014202 (2022).

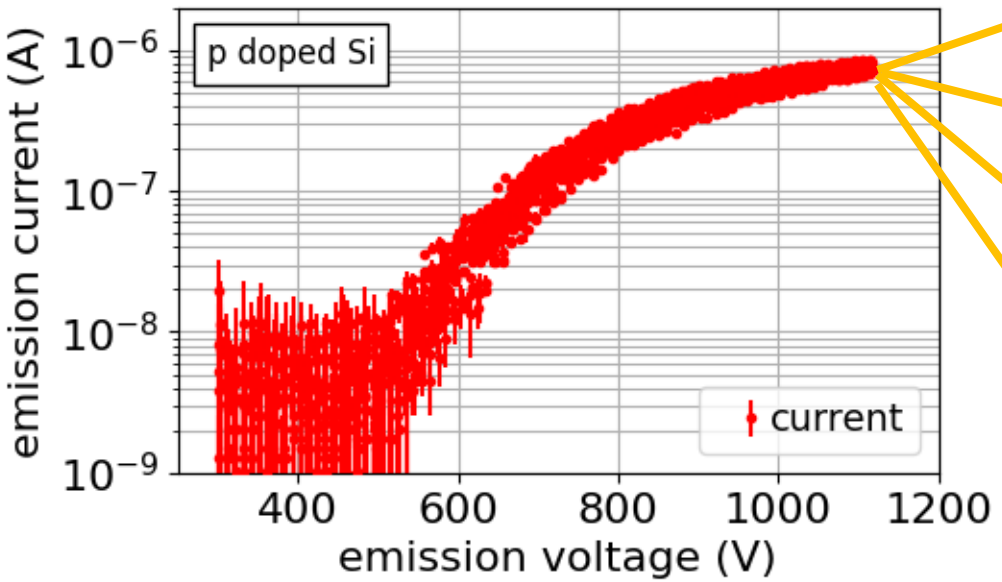


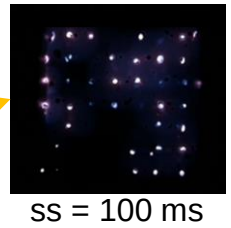
- Samples
  - Wafer diced and TMAH etched silicon FEAs
  - 2 types:
    - 8x8-Array: tip height of 100 µm, pitch of 250 µm
    - 20x20 Array: tip height of 50 µm, pitch of 110 µm
  - Different doping

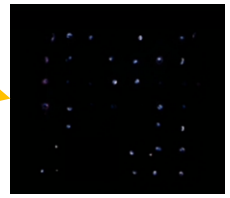


Characteristics + Emission Images

IV characteristics (2 measurements/voltage) + PiCam images (4 different shutter speeds) = Extrapolated Image (1 per voltage)

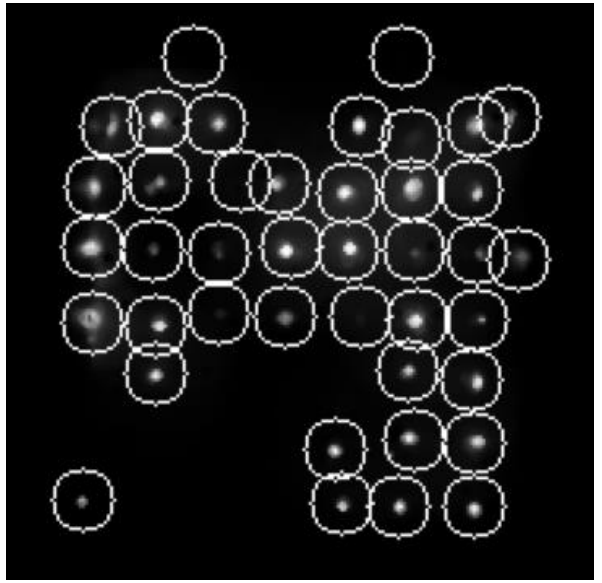



ss = 100 ms


ss = 10 ms

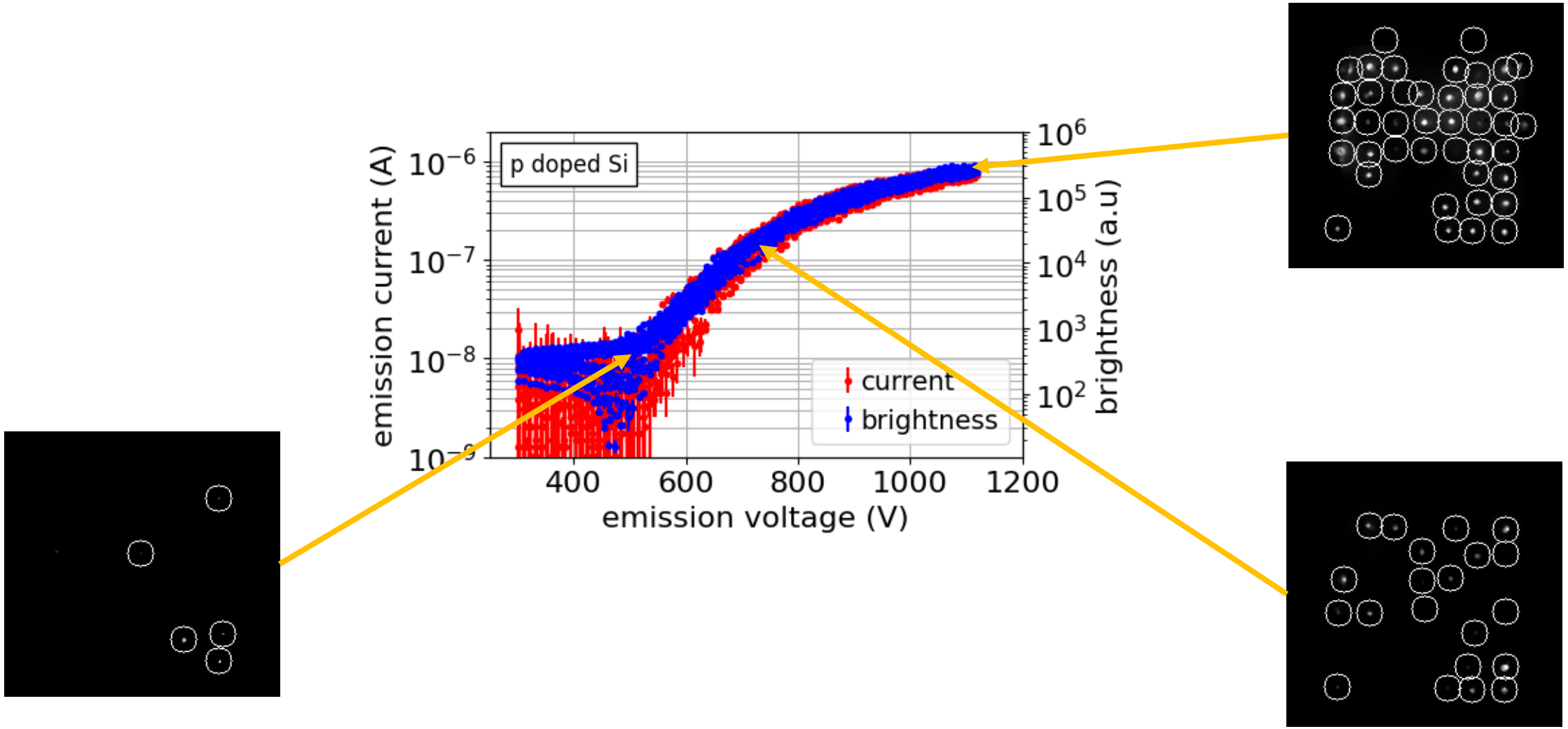

ss = 5 ms


ss = 1 ms



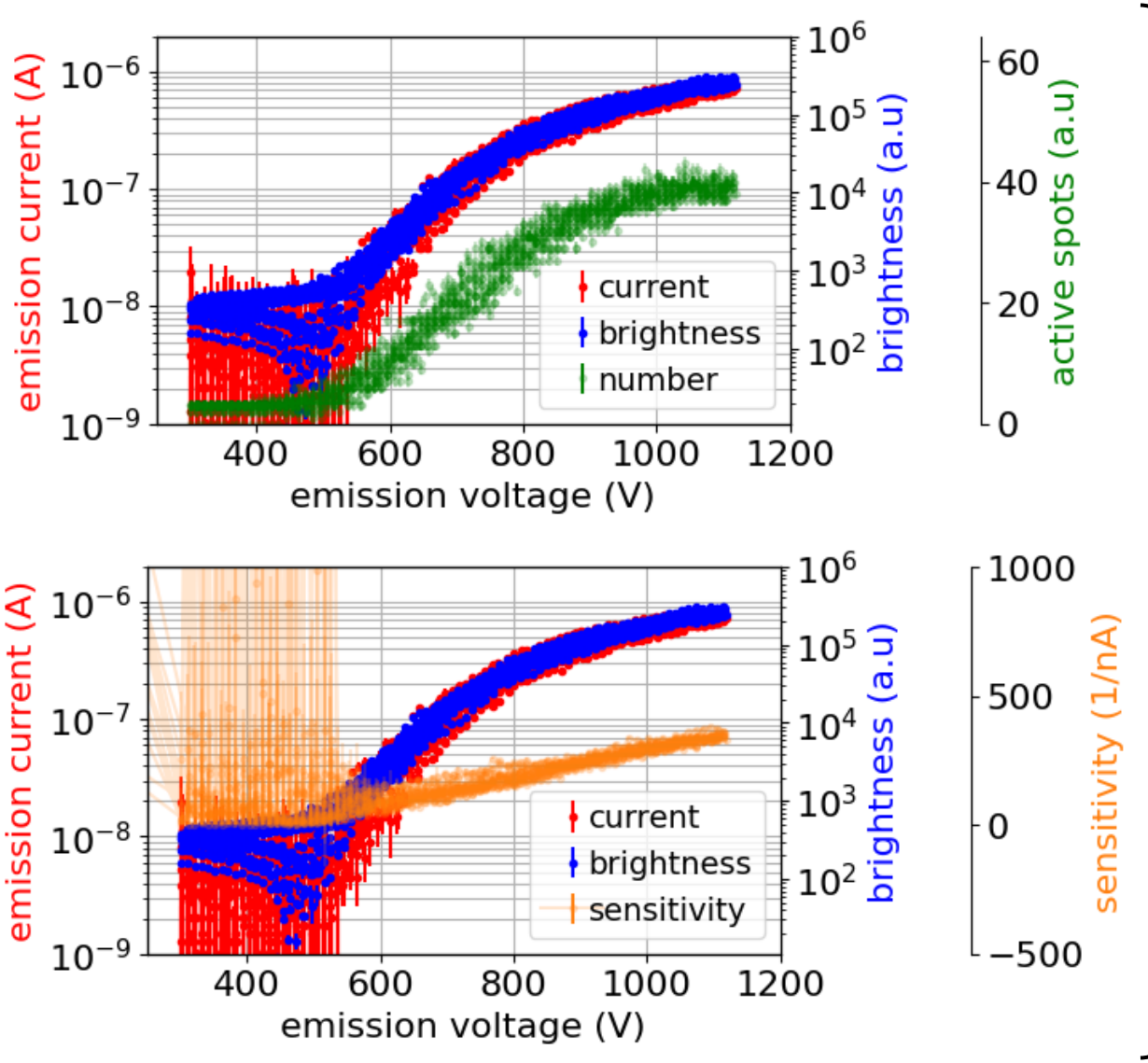
Different shutter speeds to enhance dynamic range

Measurements - Characteristics

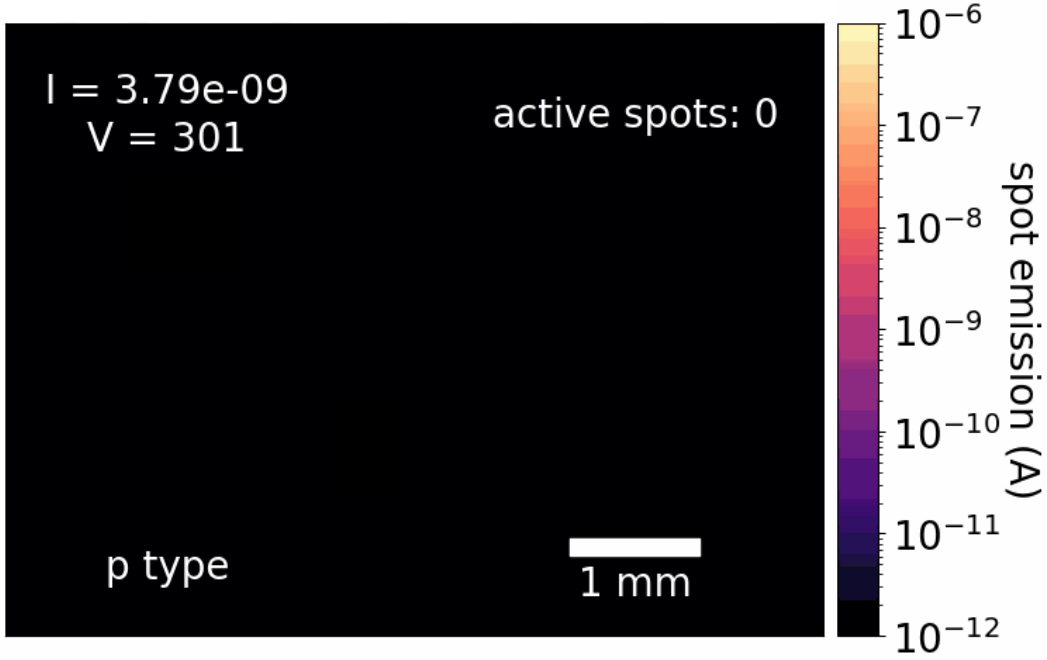


Brightness per emitter tip + integral brightness

Characteristics

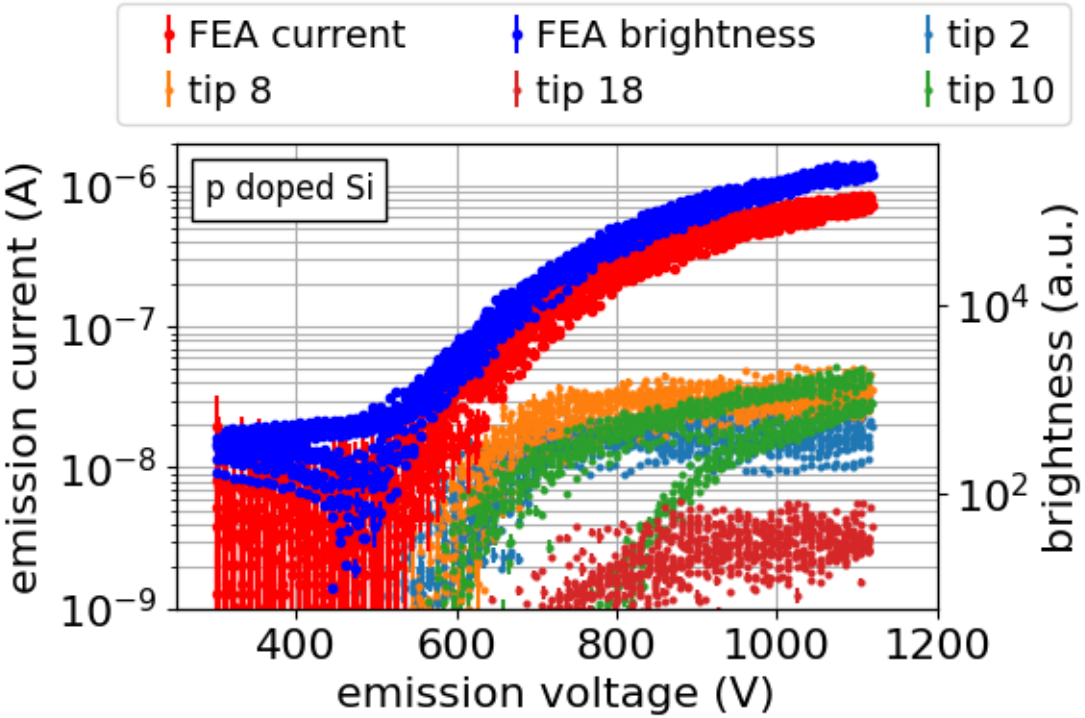


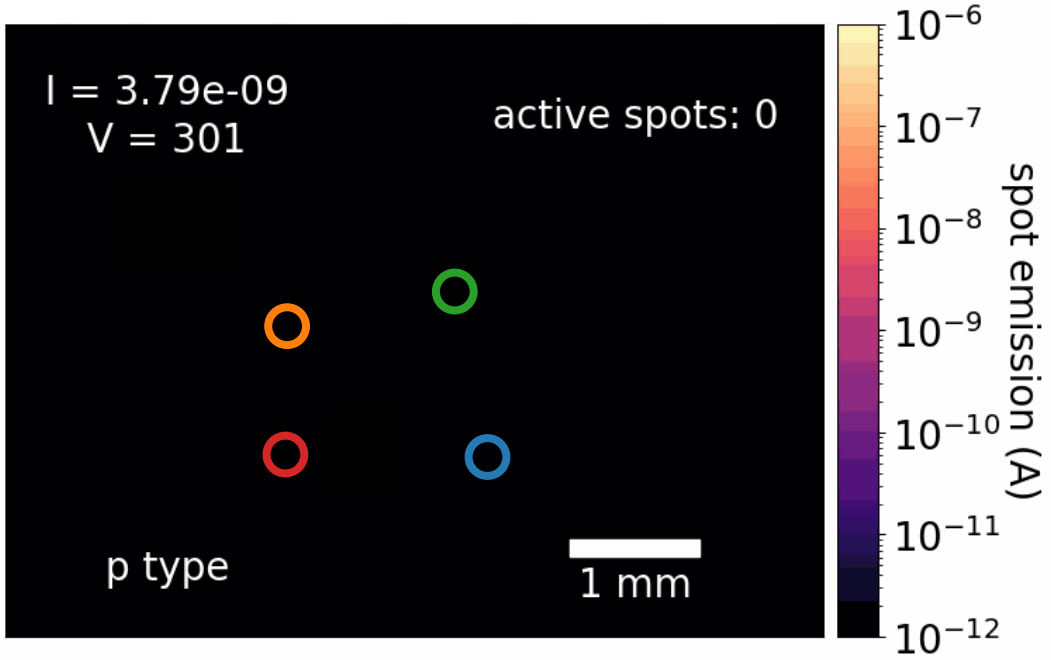
Single Spot Emission Heatmap



Characteristics of single tips

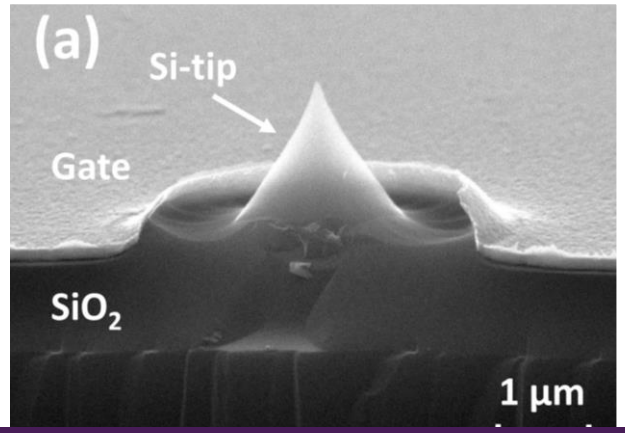
IV + BV characteristics → single tip characteristics

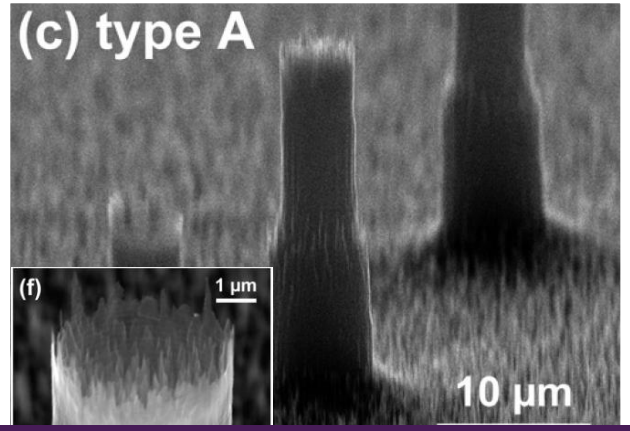




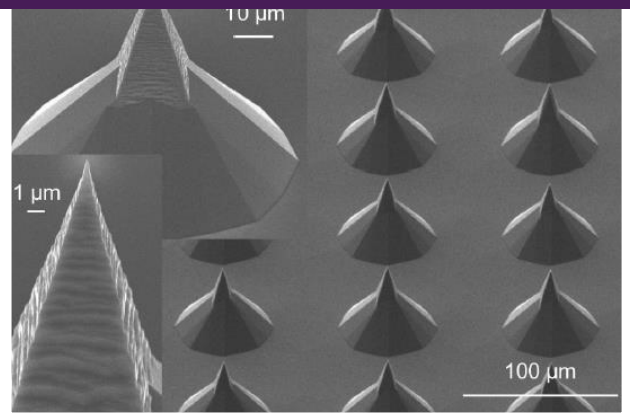
Current dependent performance test

Motivation

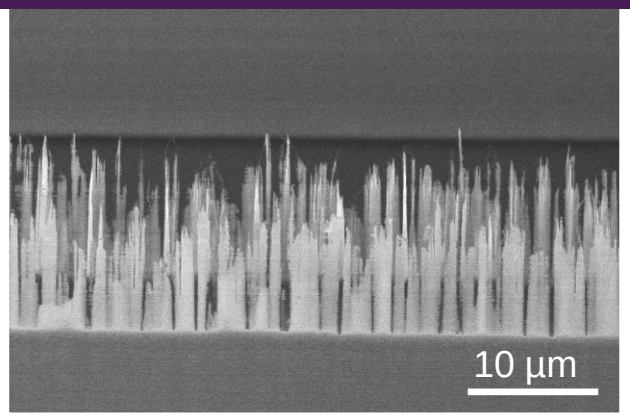




What is the best emitting structure?



J. Vac. Sci. Technol. B 39, 013201 (2021)



J. Vac. Sci. Technol. B **40**, 010605 (2022)

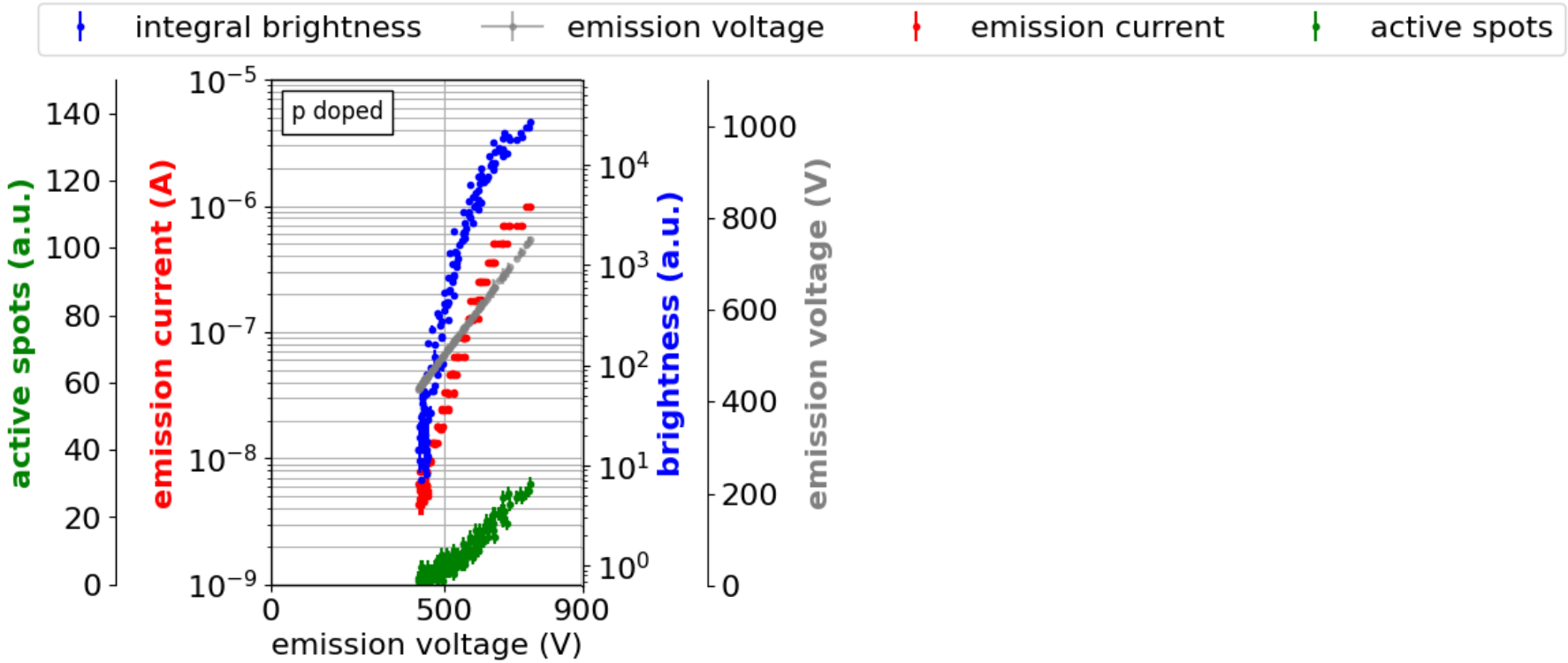
Just characteristics

don‘t allow good comparision

Current dependent performance test

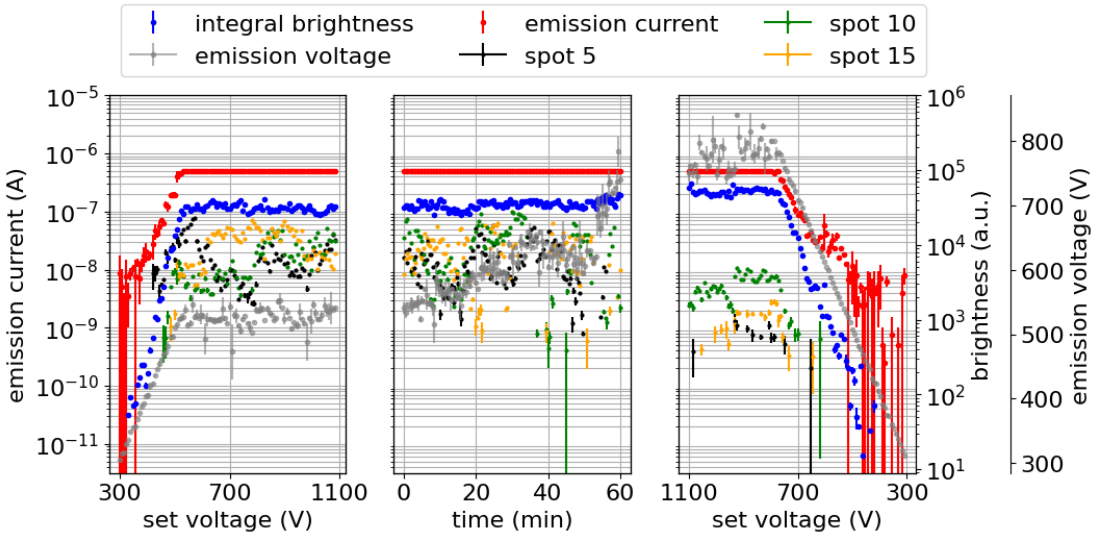
Characteristics before → Constant current measurement → Characteristics after

Current increase

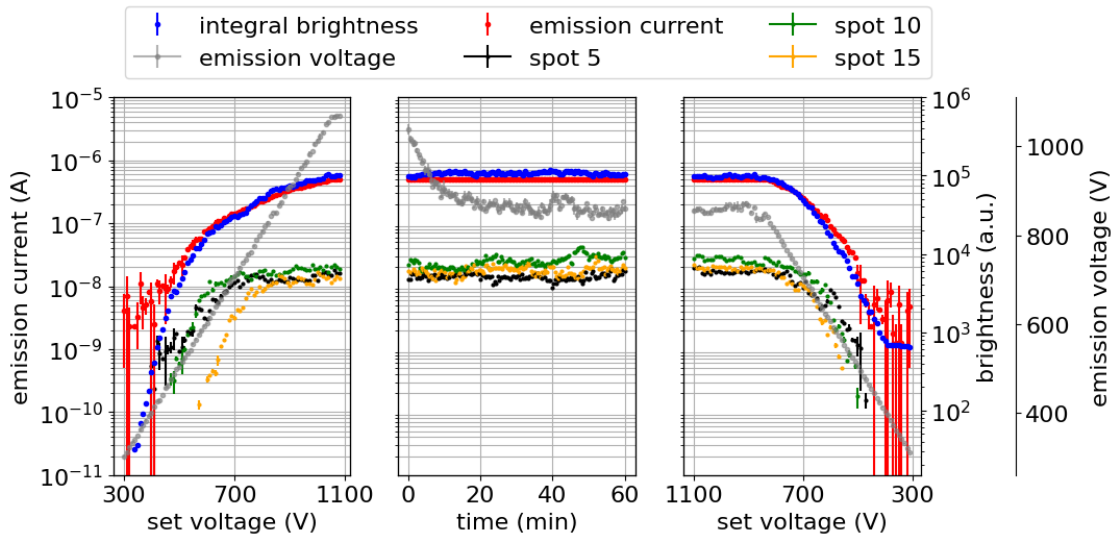


CDPT coupled with PiCam

n-type Si



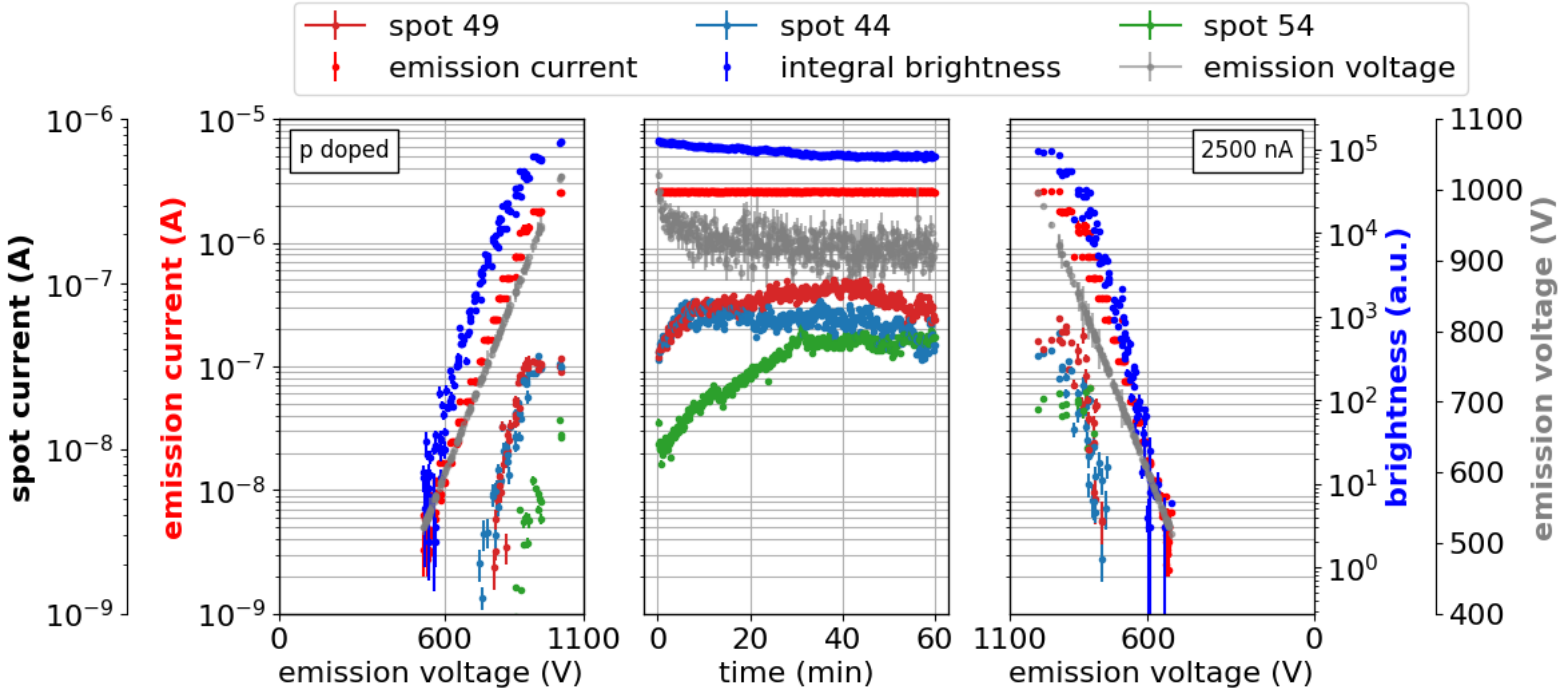
p-type Si



Homogenization via doping now observable

Current dependent performance test

- Increase of single tip saturation level during CCM:
  - Increased charge carrier generation



Summary

- Integral measurement of field emission
- High dynamic range by different shutter speeds
- Emission current and characteristics of single tips
- Homogenisation of field emission by p-doping

Questions?

Outlook

- Comparision of SEM pictures before and after CDPT
- Triode setup
- Comparison of different types of FEAs