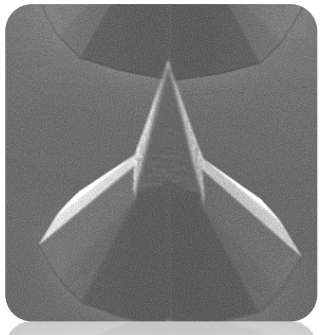
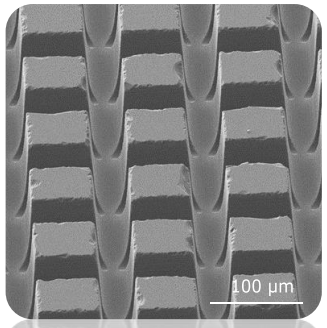
FEX-Ray





Silicon Field Emitter fabrication by TMAH Etching of convex/concave corners

MeVArc 2021

A. Schels, S.Edler, J. Biba, W. Hansch, M. Bachmann, F. Düsberg,
C. Langer, M.Meyer, M. Eder, F.Herdl, M. Dudek, H. Geesmann, A. Pahlke

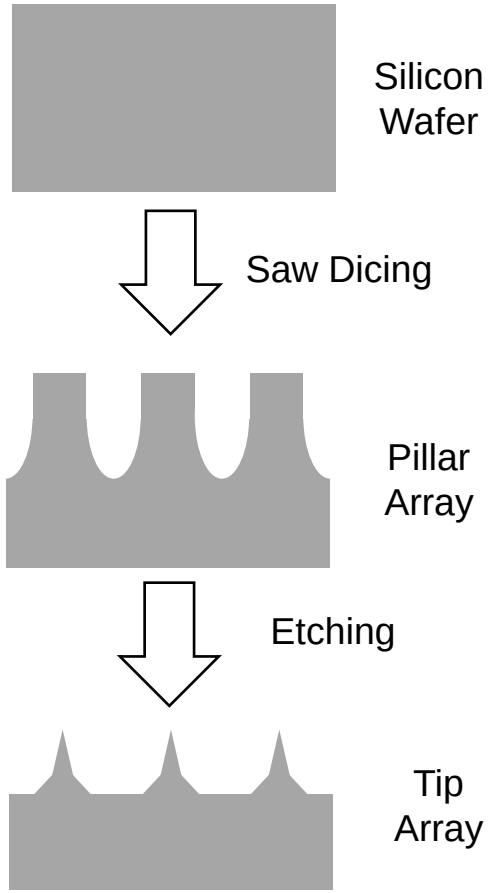
MOTIVATION

- Simple low cost process
  - No cleanroom/lithography

→ Enables newcomers access to field emission

- Easy prototyping of FEAs with different
  - Array sizes
  - Tip densities
  - Tip distances
  - Tip dimensions

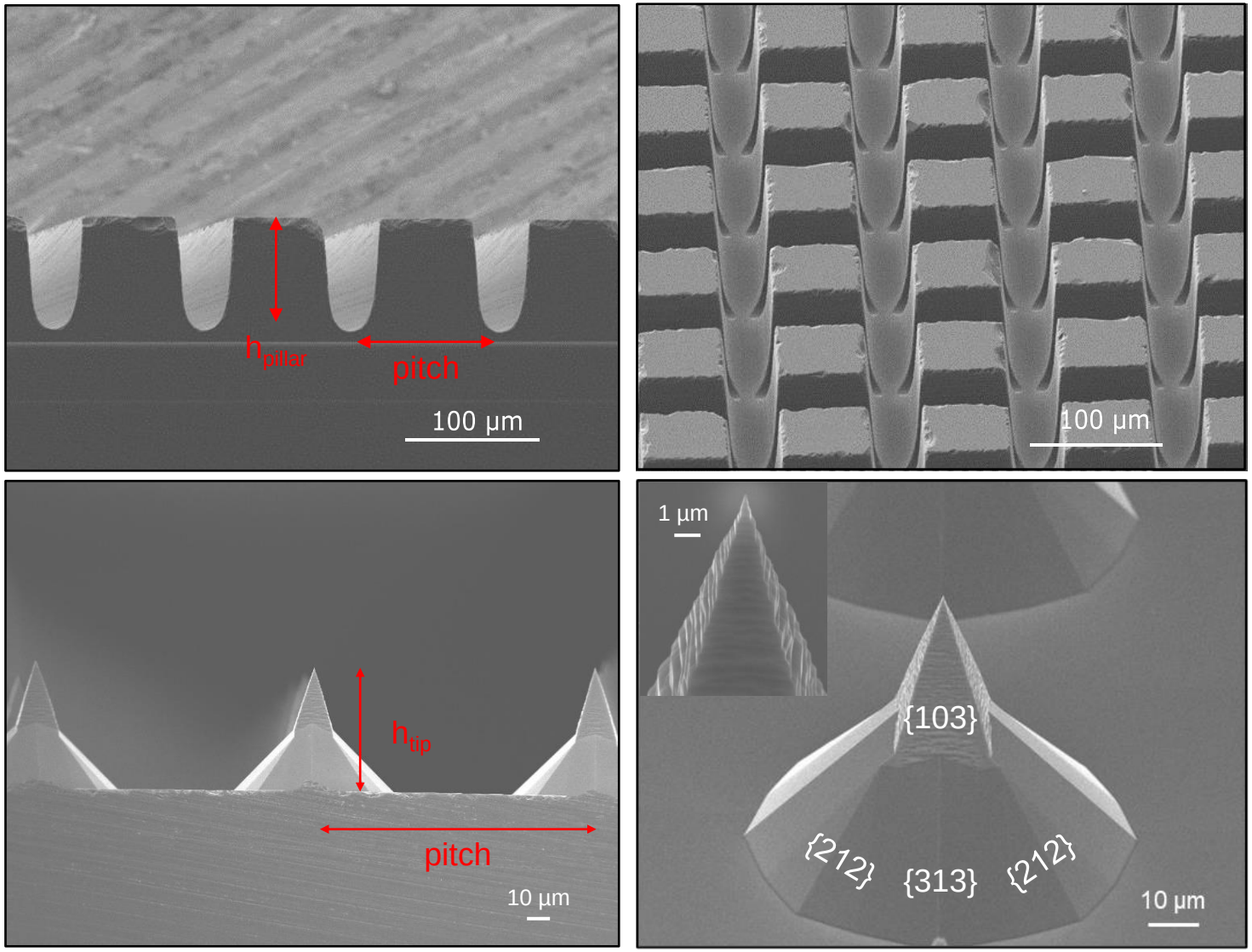
→ Investigation of geometry dependent FE properties



FABRICATION – Fabrication process

1. Sawing of the pillar array:
   - Perpendicular trenches along the <100> axes
   - Adjustable height and pitch

2. Tip etching
   - RCA cleaning procedure
   - HF dip
   - TMAH etching (20 %, 70 °C)



FABRICATION – Variation

Type S

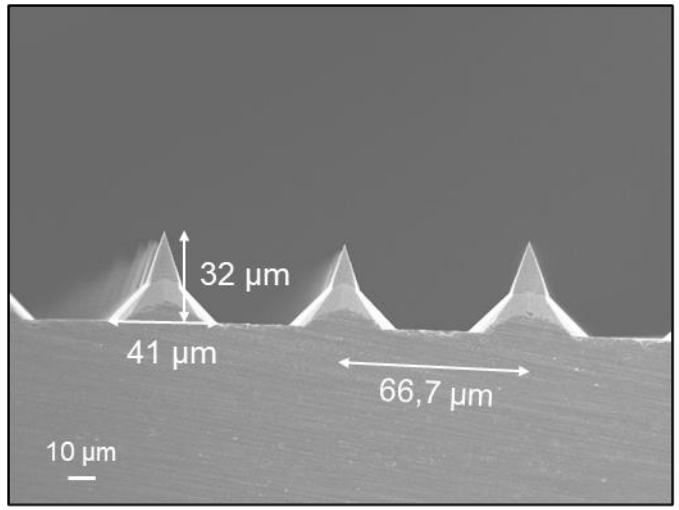
- Pitch 66.7 µm
- Tip height 32 µm
- Tip quantity 60 x 60 = 3600

Type M

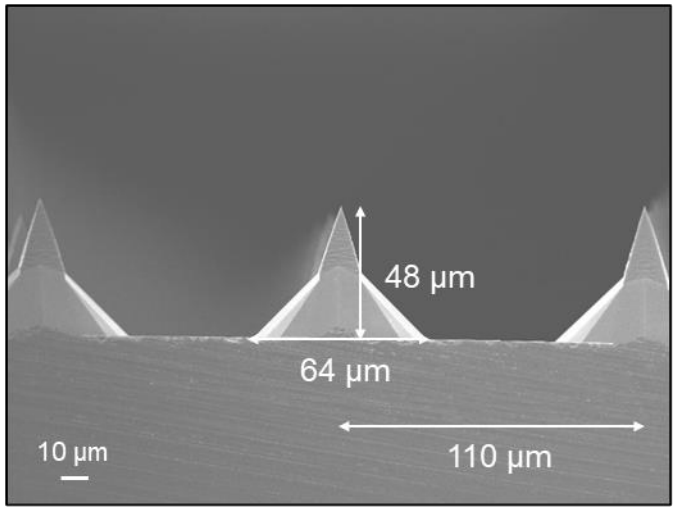
- Pitch 110 µm
- Tip height 48 µm
- Tip quantity 36 x 36 = 1296

Type L

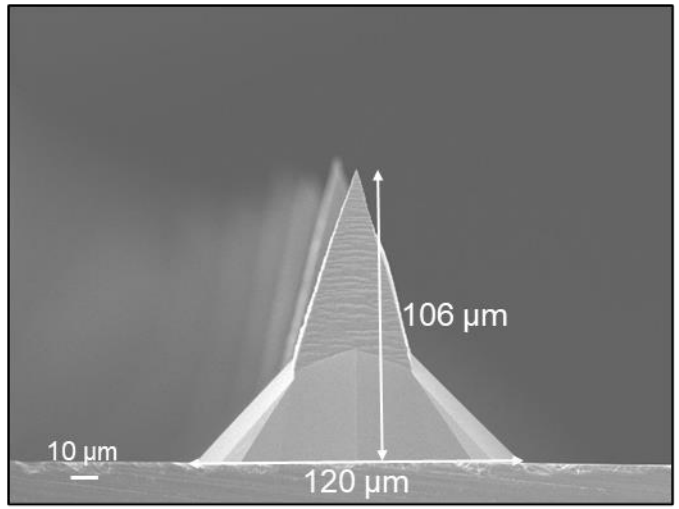
- Pitch 250 µm
- Tip height 106 µm
- Tip quantity 16 x 16 = 256



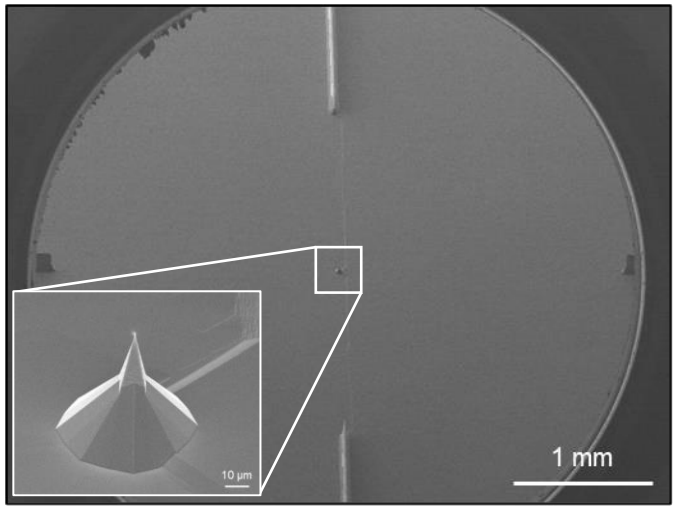
Type S



Type M



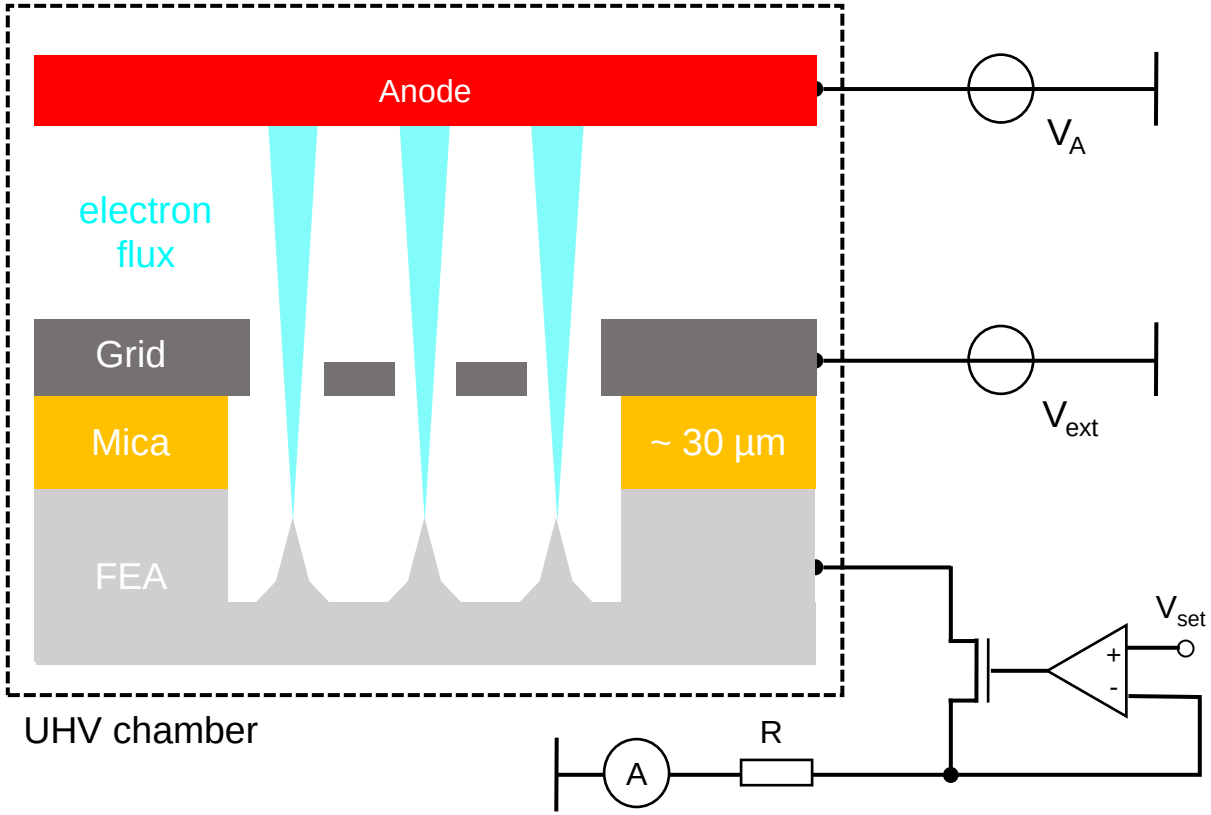
Type L



Single Emitter

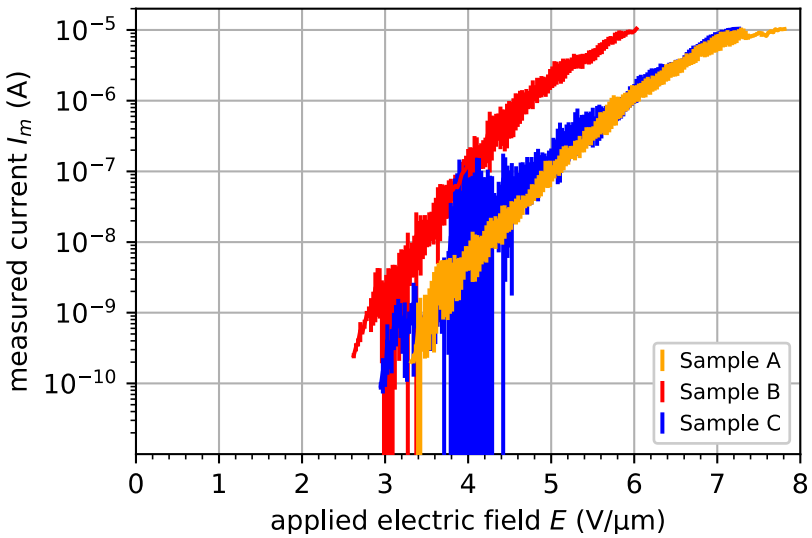
MEASUREMENTS – Setup

- UHV chamber
  - Pressure regulated at $p = 10^{-5}$ mbar
- Sample holder stack
  - FEA
  - Insulating mica sheet
  - Silicon extraction grid
- Anode in triode setup
  - $V_A = 25$ kV
  - $V_{ext} = 0$ V – 1.5 kV
- Current regulation circuit
- SDD x-ray measurement



MEASUREMENTS – Procedure

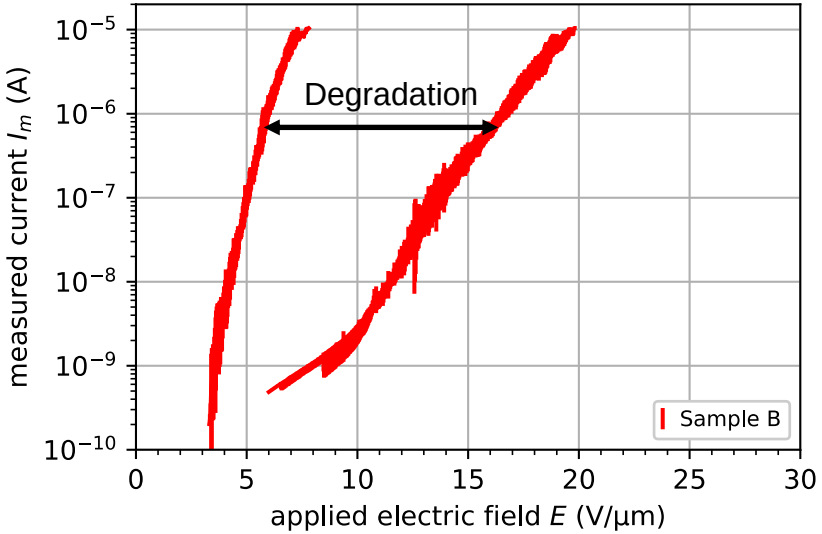
- Characteristics measurement
  - 12 Sweeps in 2 V steps (3 measurements per step)
  - Up-sweep to 10 µA
  - Down-sweep to 500 pA
  - Mean of all sweeps after 5th sweep

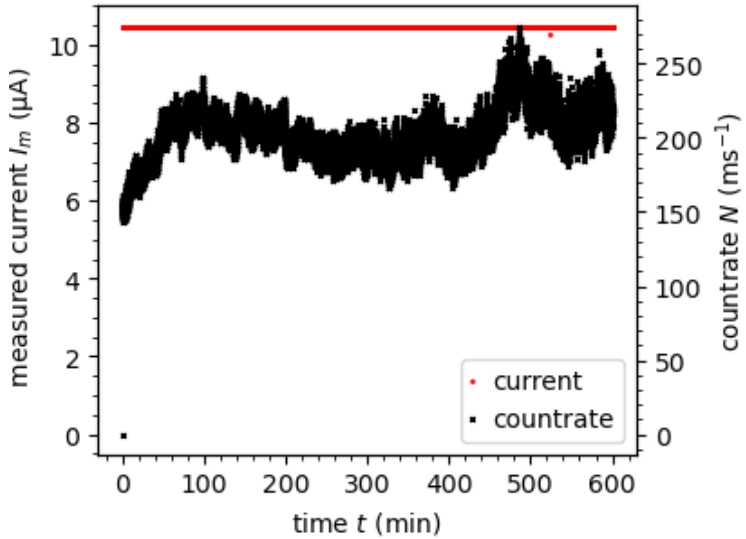


→ Comparable characteristics

@ 10^{-5} mbar

- Lifetime and degradation measurement
  - Initial characteristics measurement
  - Constant current measurement (CCM) with regulated current at 10 µA
  - X-ray count rate detection for validation of free electron emission
  - Characteristics measurement afterwards





MEASUREMENTS – Comparison characteristics

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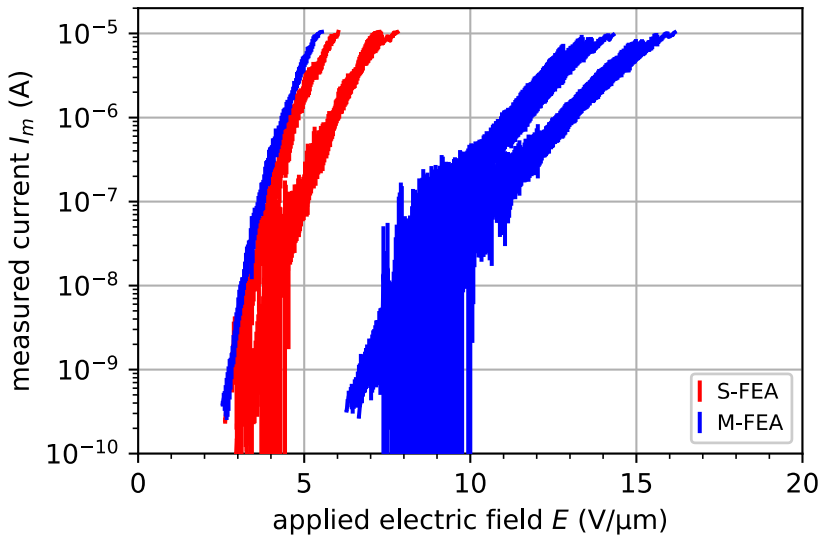
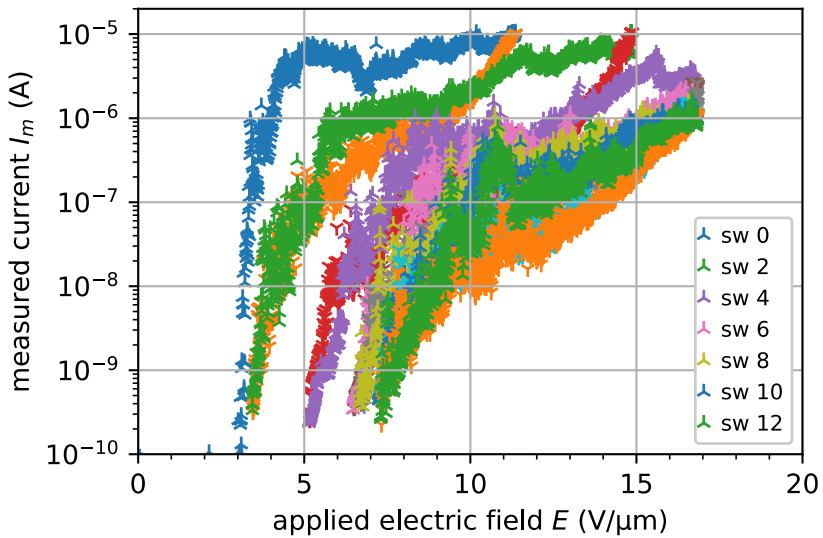
KETEK

Type S, M



- Comparable characteristics for FEAs with lowest onset field
- More fluctuations and variation between different samples for less tips with higher tip sizes

Type L



- Similar first sweep
- Strong degradation during the sweeps

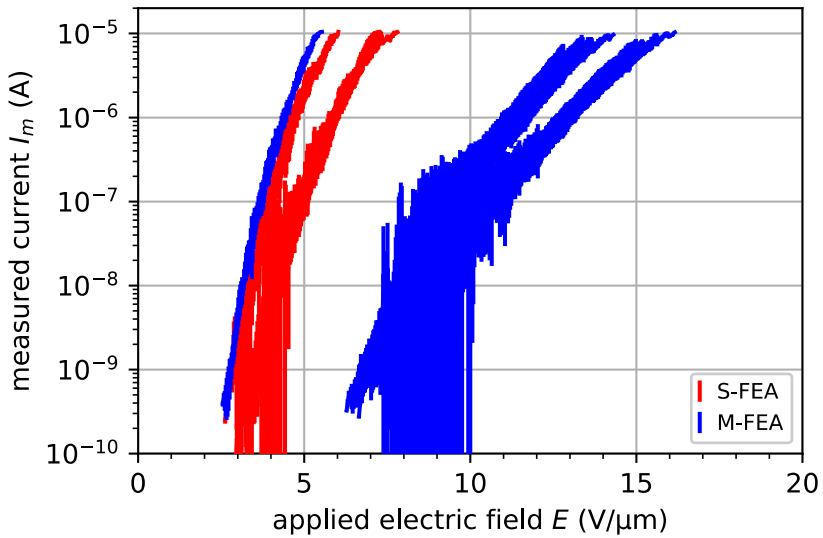
→ No Lifetime for 10 µA

MEASUREMENTS – Comparison of lifetime

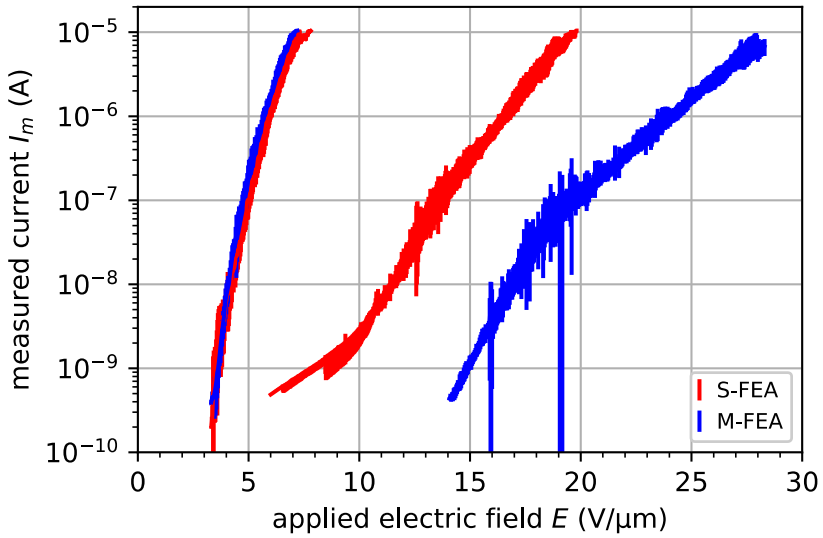
Universität der Bundeswehr München

KETEK

I-E-characteristics



Lifetime/Degradation



Longer LT due to number of tips or tips dimensions?

MEASUREMENTS – Comparison of different geometries

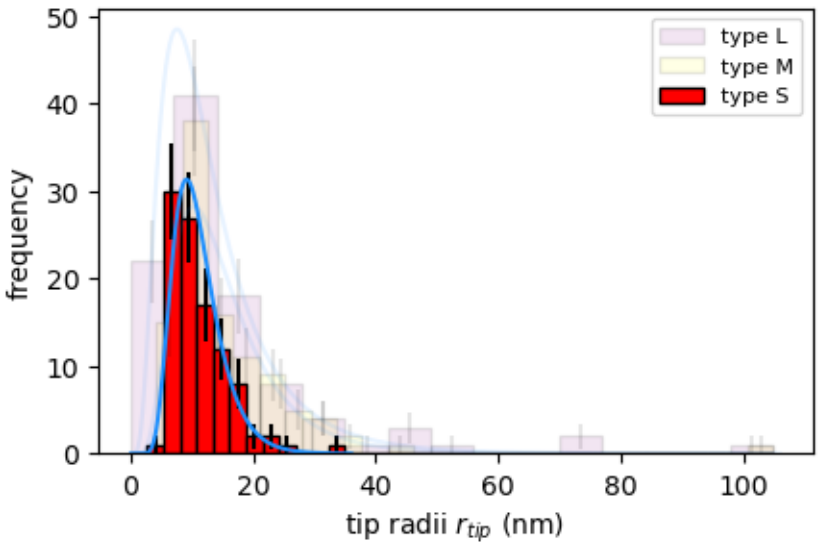
Universität der Bundeswehr München

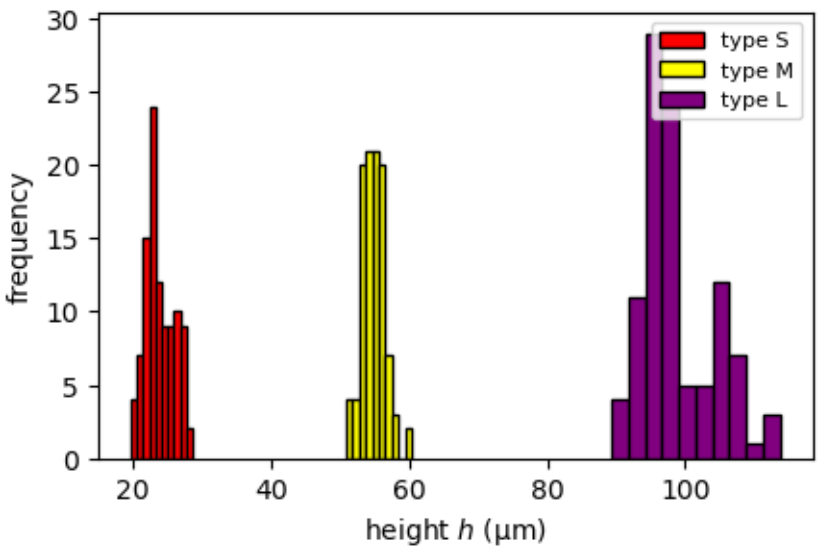
KETEK

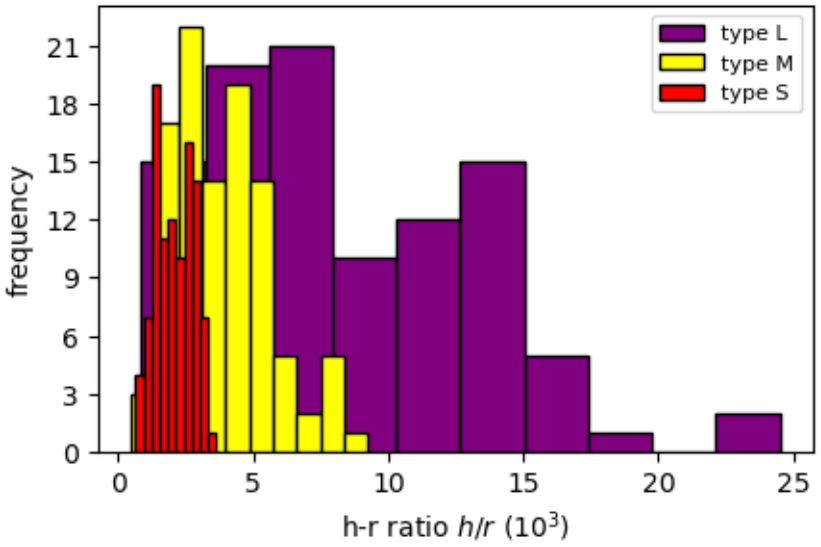
- Tip radii measurement
  - No significant difference in mean radius
  - Wider spread for larger tips
- Height measurement
  - Wider spread for larger tips
- h/r ratio ≈ field enhancement
- Less spread of h/r

  → More tips contributing to the emission current

  → Higher stability







Conclusion:

- larger amount of tips
- less spread of h/r ratio

→ beneficial for LT and stability

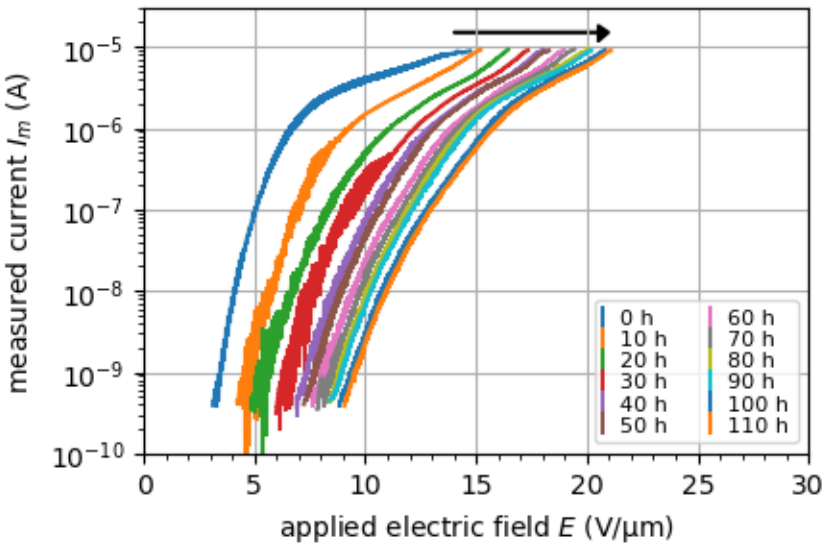
RESULTS AND DISCUSSION

Influence of doping

- n-doped:
  - Metal-like behavior
  - Relatively strong degradation
- p-doped:
  - At low currents/fields: current as function of surface dependent emission probability
  - At high currents/fields: saturation due to limited supply of electrons

  → Strong increase of operating field

  → Less degradation



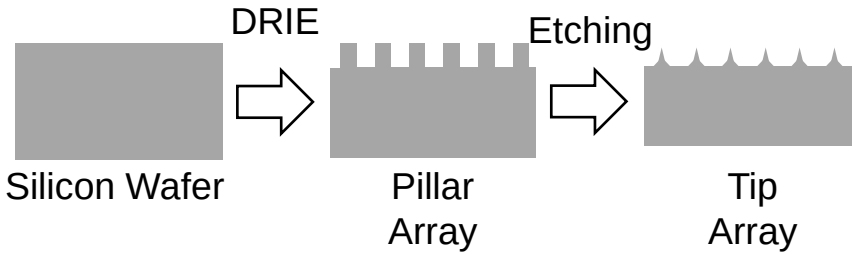
Conclusion

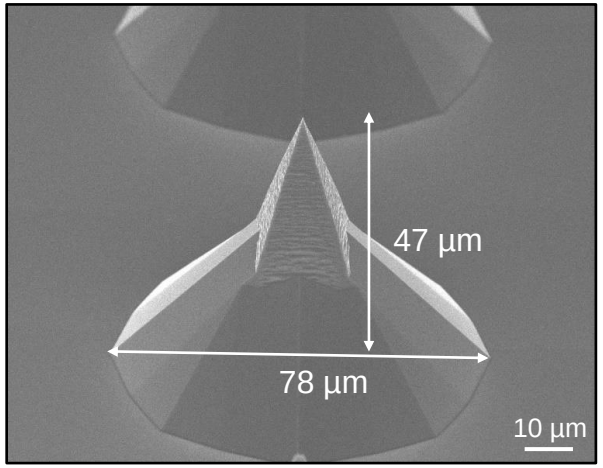
Increased lifetime for FEAs with:

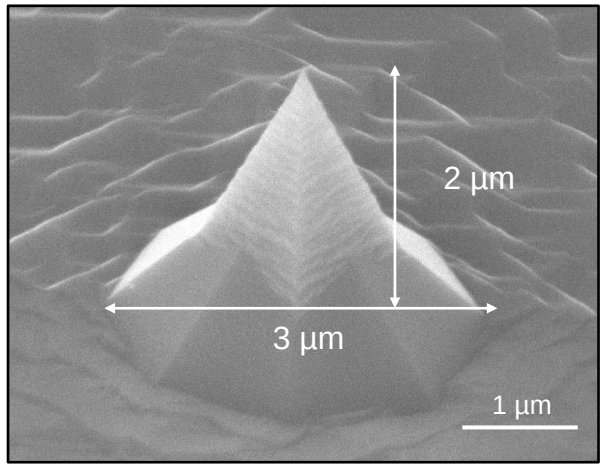
- High amount of tips
- Homogeneous geometry
- P-type doping

OUTLOOK – BoschTMAH-FEAs

- Replacement of the dicing saw step by reactive ion etching
  - → Less structural limitations (scaling)
  - → Higher tip densities possible
  - → Higher reproducibility





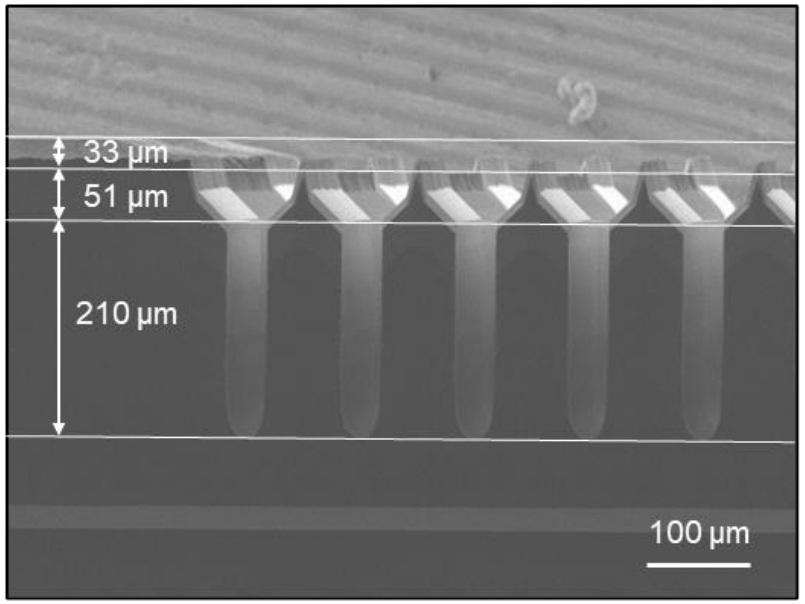


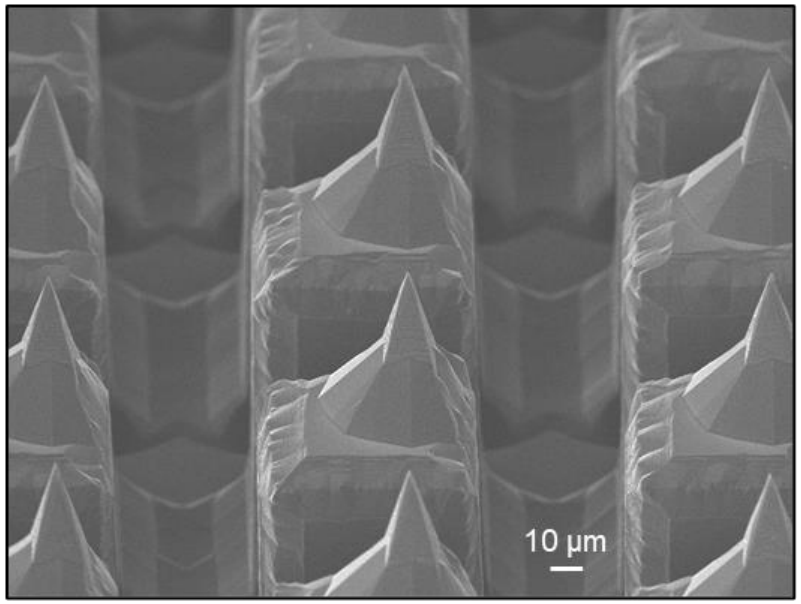
- Problem:
  - No emission current measurable due to the highly reduced h/r ratio

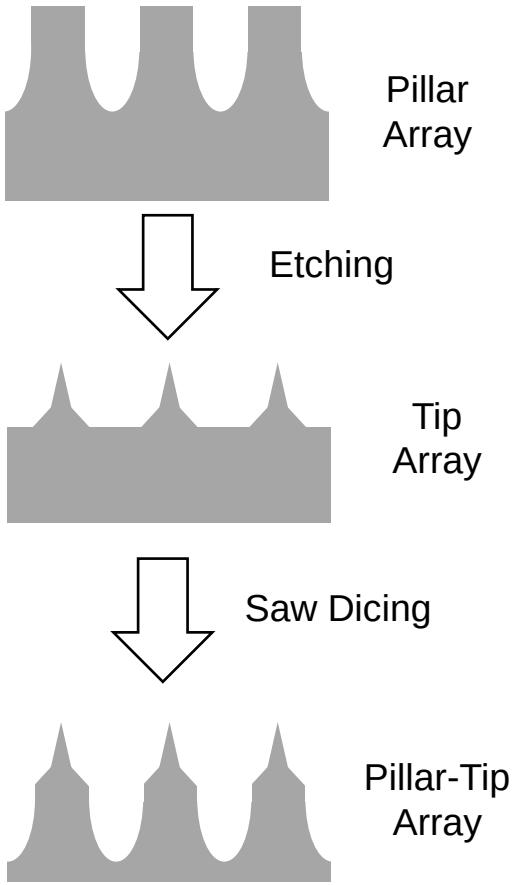
OUTLOOK – Pillar-Saw-FEAs

- Additional process step to increase the h/r ratio without decreasing the amount of tips

→ Maximization of field enhancement/ current density

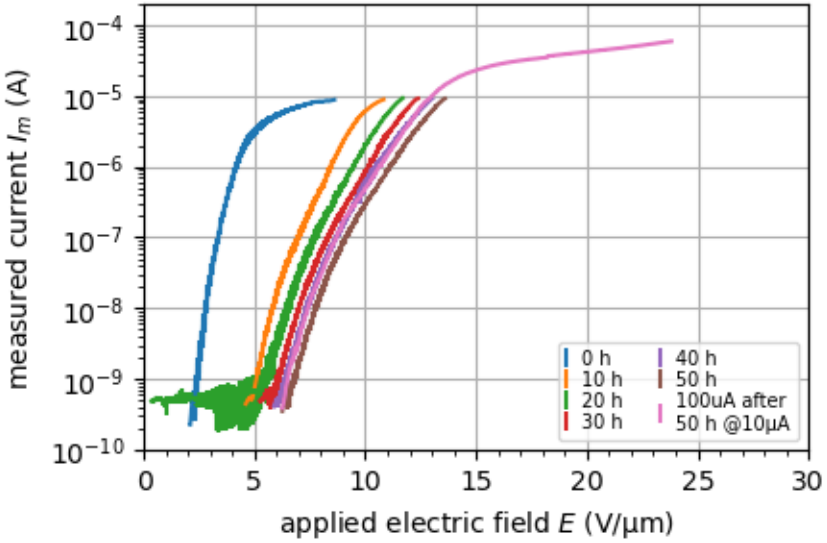






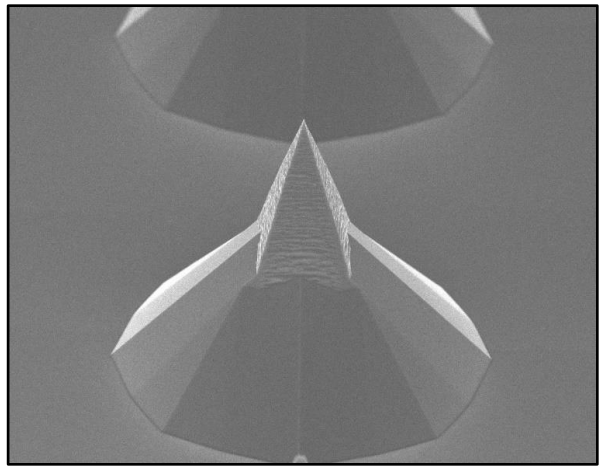
OUTLOOK – Pillar-Saw-FEAs

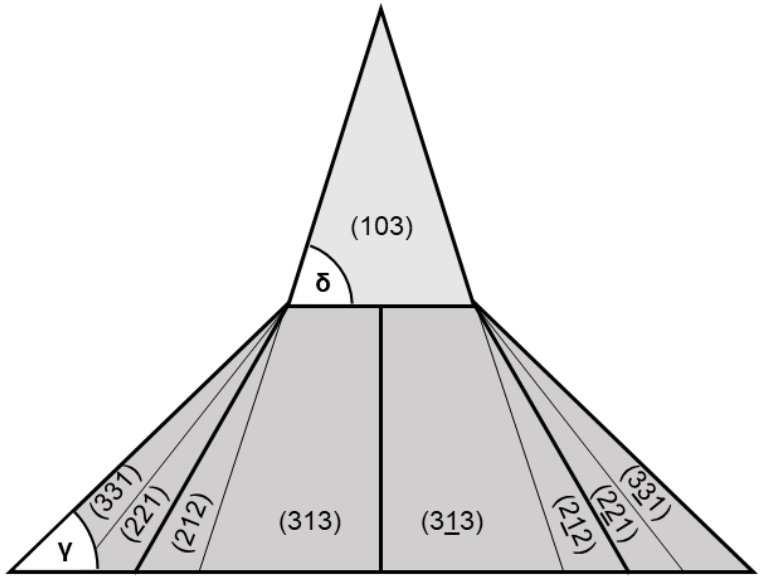
- p-type M-pillar-FEA:
  - Lowest onset field of all FEAs
  - Operating field around value of n-
  - Low degradation rate
  - Very high saturation current



CONCLUSION

- Fast, inexpensive & reproducible process for silicon FEAs
  - Enables newcomers access to field emission
- Tip formation based on anisotropic Si-etching
- Reproducible electrical properties at 10^{-5} mbar and 10 µA
- Investigation showed increase of LT and stability for
  - Higher amount of tips
  - Homogeneous h/r ratios
  - p-doped substrates
- Lifetime of > 100 h for emission currents of 10 µA at 10^{-5} mbar shown
- Pillar formation for enhanced h/r ratio
- Possible combination with cleanroom processes to further increase the tip density without decreasing the field enhancement





Thanks to the Team!