Silicon Field Emitters Fabricated by Saw-Dicing and TMAH Etching

IVeSC 2020

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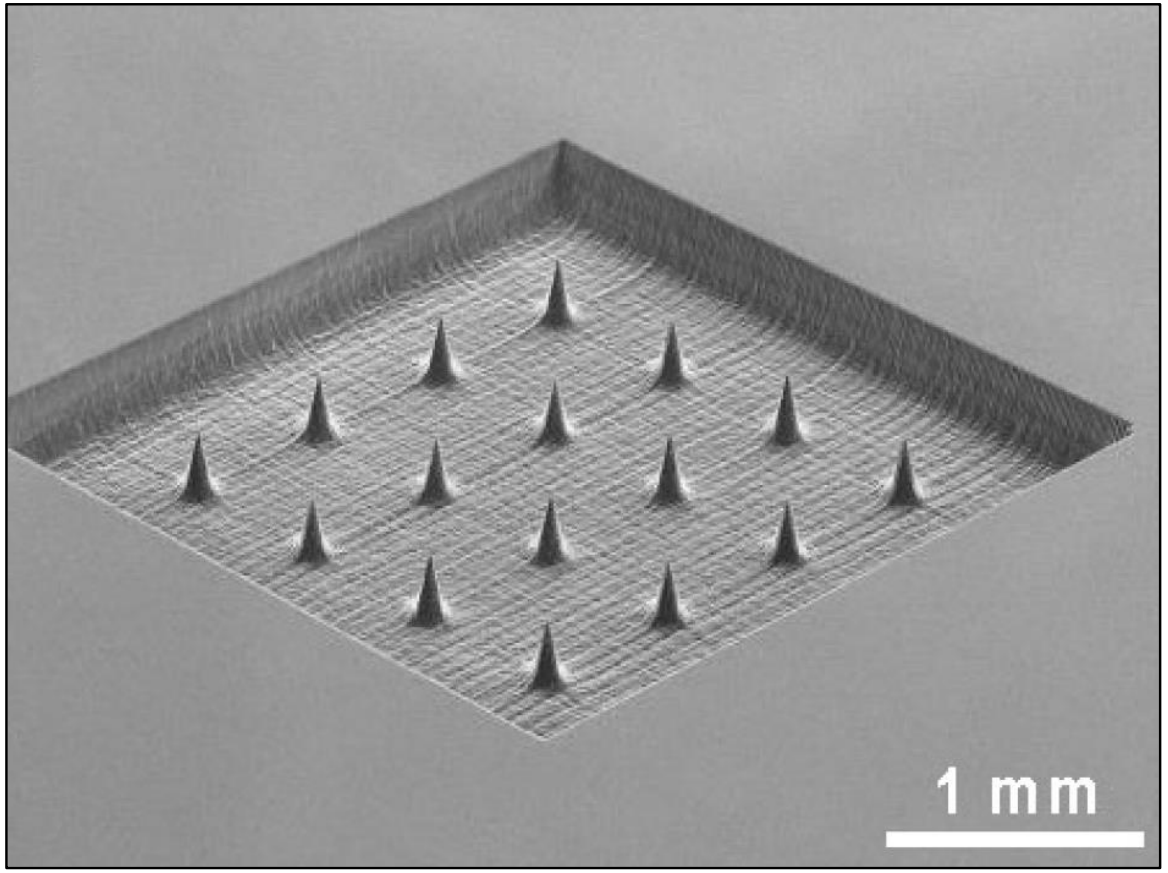
OUTLINE

- Motivation
- Fabrication
- Surface identification & formation
- Measurement setup
- Results
  - Characteristic measurement
  - Characteristic comparison
  - Lifetime measurements
  - Degradation mechanisms
- Conclusion

MOTIVATION

- Easy low cost process
  - Dicing-Saw + wet-chemistry
  - No Cleanroom
- Enables newcomers access to field emission
- Easy to variate
  - Investigation of different aspects



[Langer et al. (2020) *JVST B*, *38*(1), 013202]

FABRICATION

1. Saw-dicing of square pillars
   Si 100-wafer
   Trench 45° to flat
2. RCA-clean
3. HF-dip
4. TMAH-etch
   70 °C
   20 %

➢ Sharp tip remains

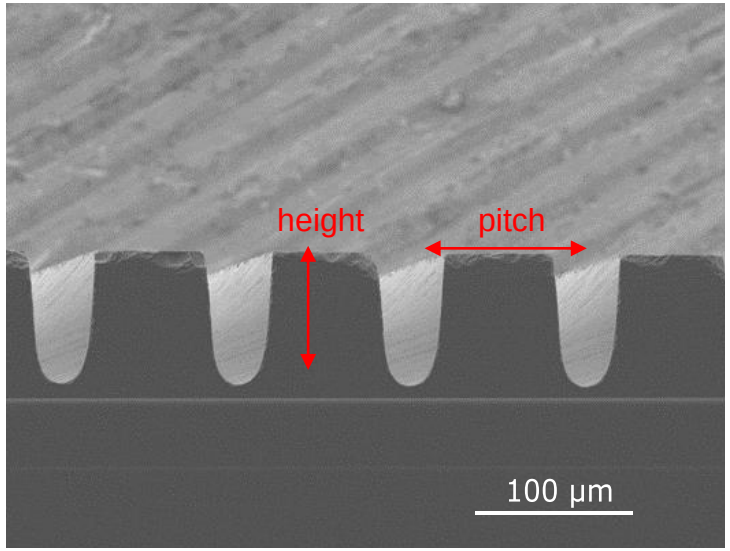
Pitch variation

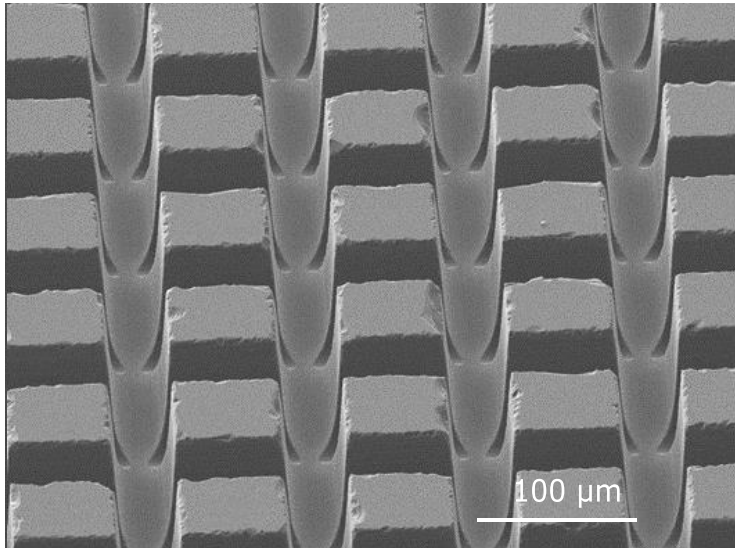
➢ Different tip size

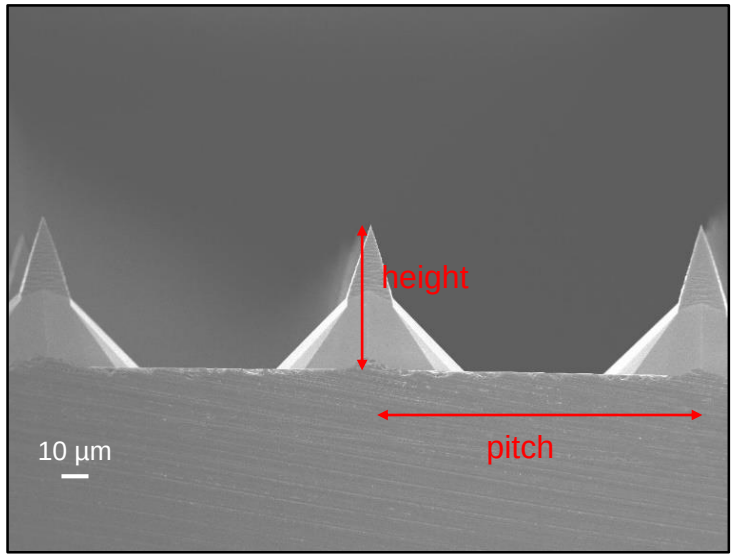
➢ Different tip quantity

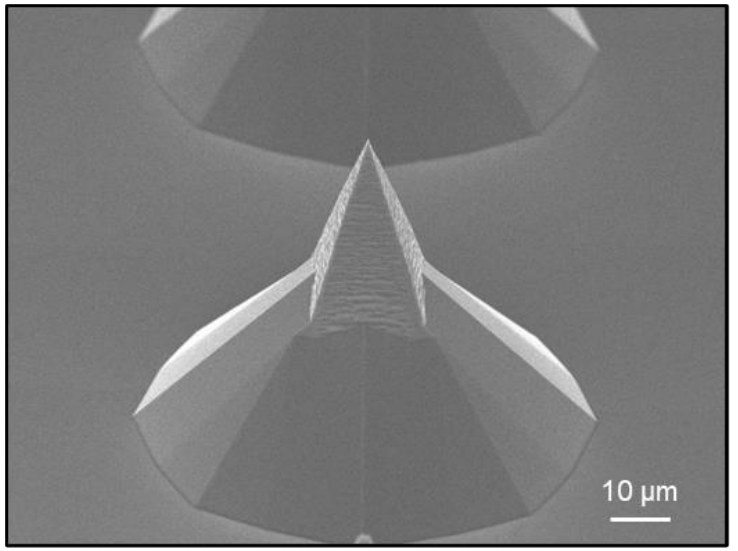
Height variation

➢ Distance between extraction grid and tip









FABRICATION – THREE TYPES

S-emitter:

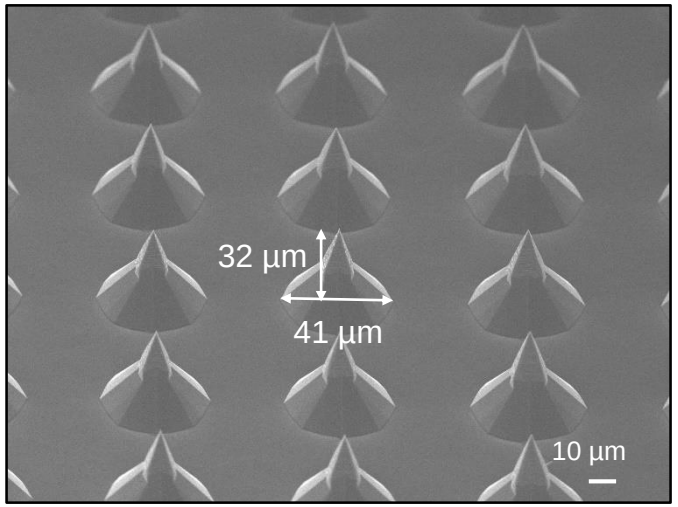
- Pitch 67 µm
- Tip height 32 µm
- Tip quantity 60 x 60 = 3600

M-emitter:

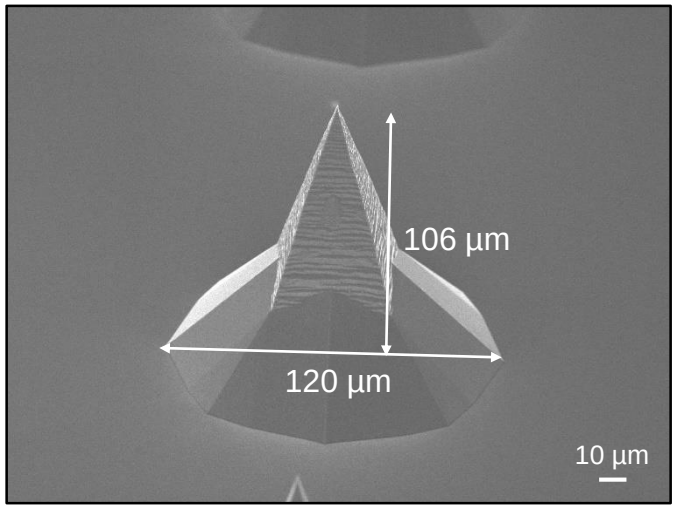
- Pitch 110 µm
- Tip height 48 µm
- Tip quantity 36 x 36 = 1296

L-emitter:

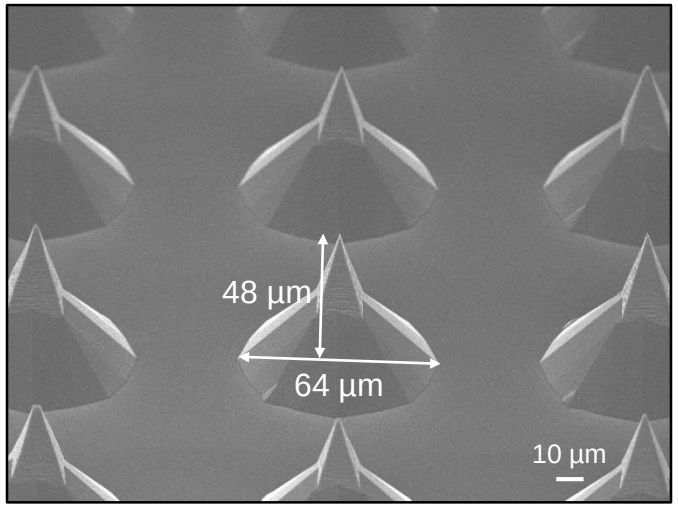
- Pitch 250 µm
- Tip height 106 µm
- Tip quantity 16 x 16 = 256



S-emitter



L-emitter



M-emitter

SURFACE IDENTIFICATION

Top view (bottom pyramid)

- Two different angles:

  α ≈ 143°
  β ≈ 127°

  ➢ {h21} & {h31}

Top view (top pyramid)

- Parallel to trenches

  ➢ {h0l}

Side view (bottom pyramid)

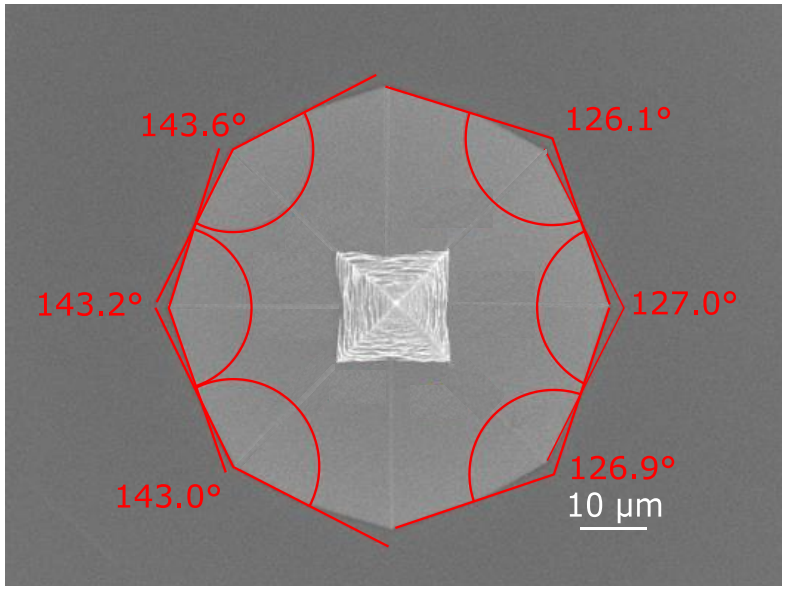
- ≈ 45°

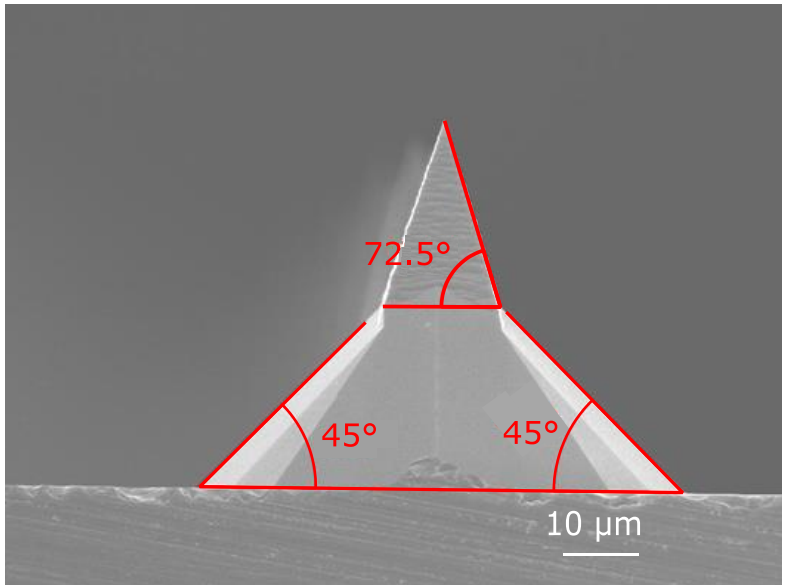
  ➢ {221} & {331}

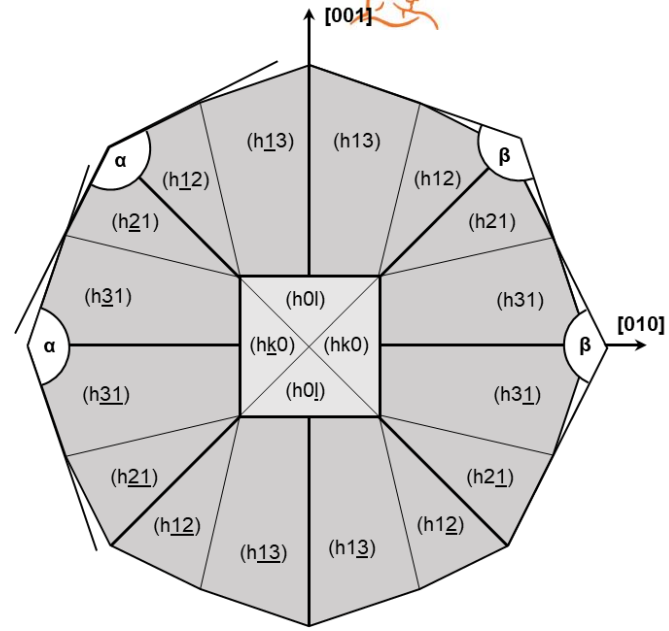
Side view (top pyramid)

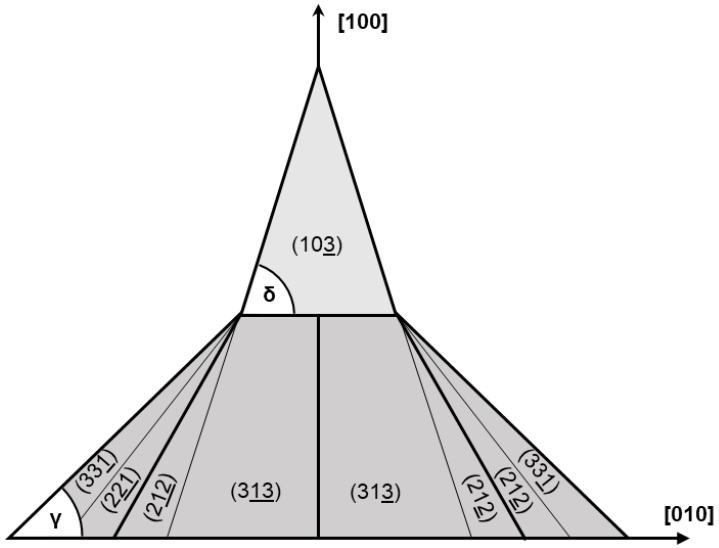
- ≈ 72°

  ➢ {103}





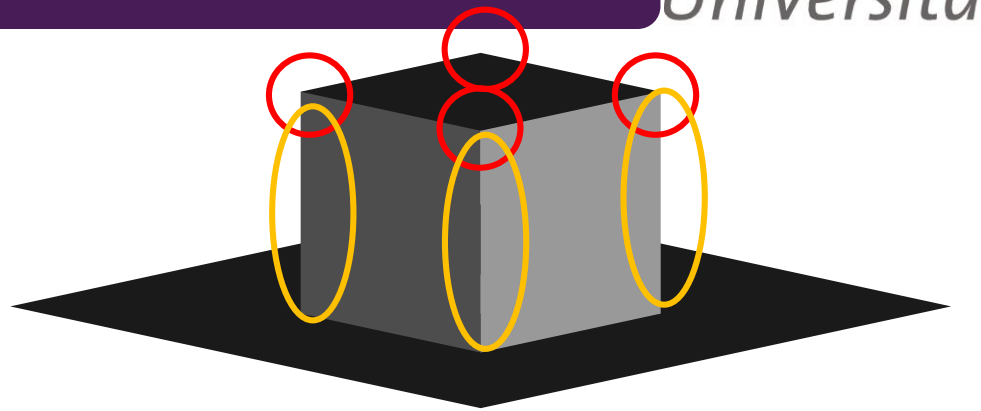




Formation mechanism

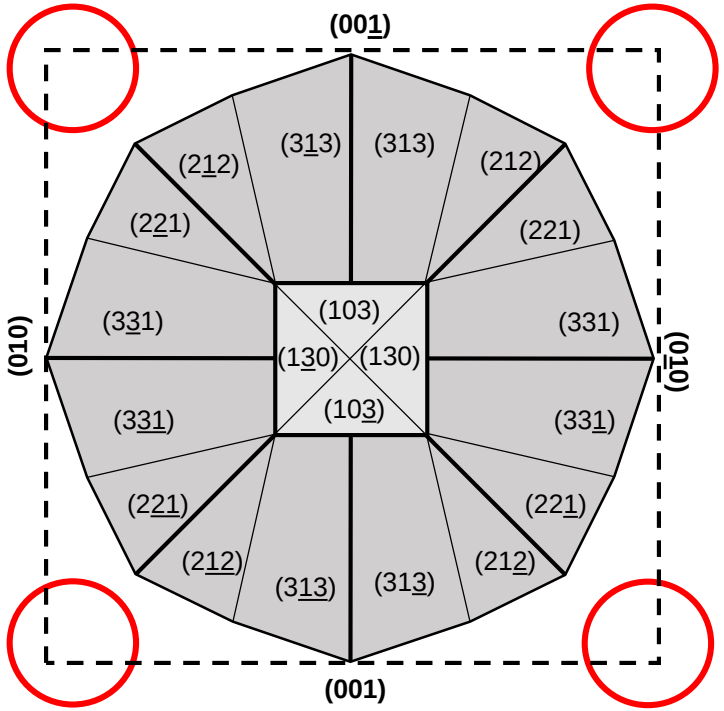
Plane appearance on corners:

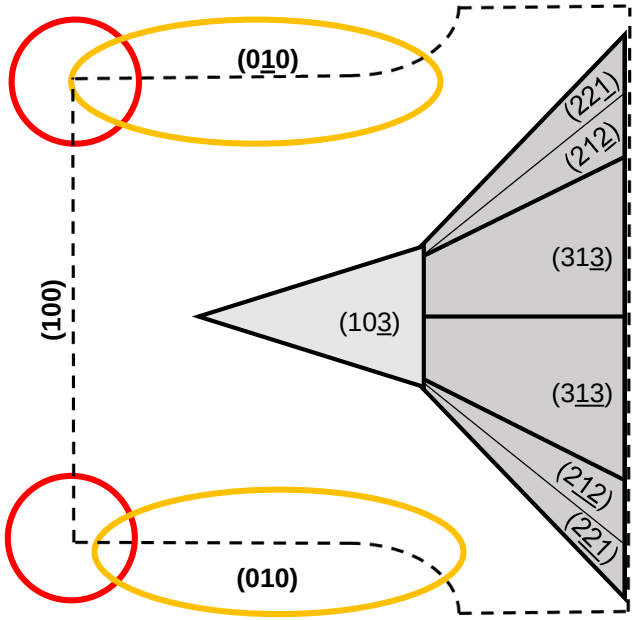
- Convex-corner
  - ➢ Planes with fast etching rates
- Concave-corner
  - ➢ Planes with slow etching rates



Top-pyramid:

- Etching of convex-convex-corners
  - ➢ Planes with fast etching rates {103}





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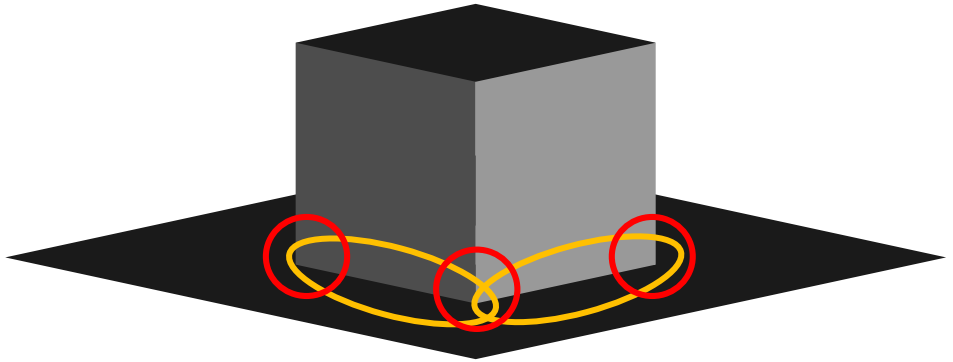
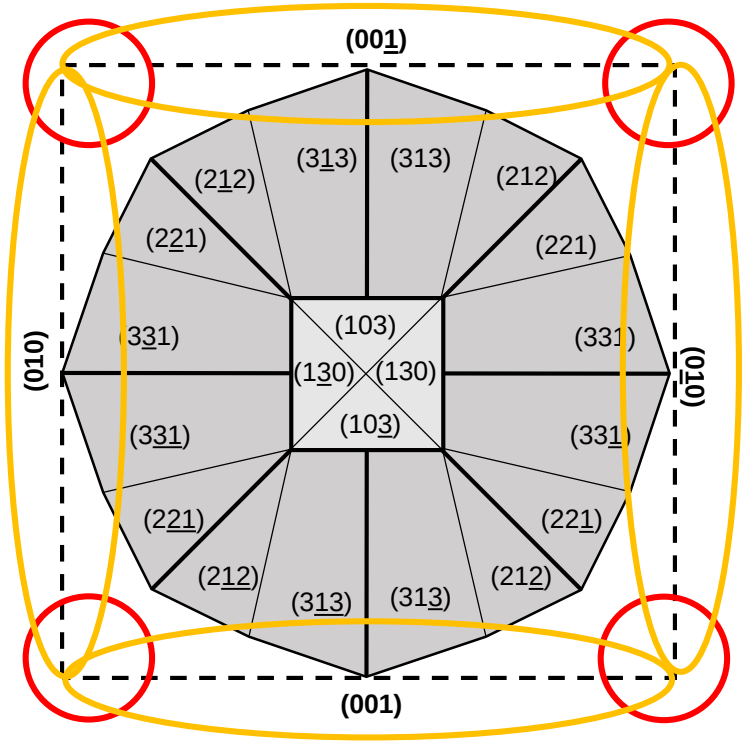


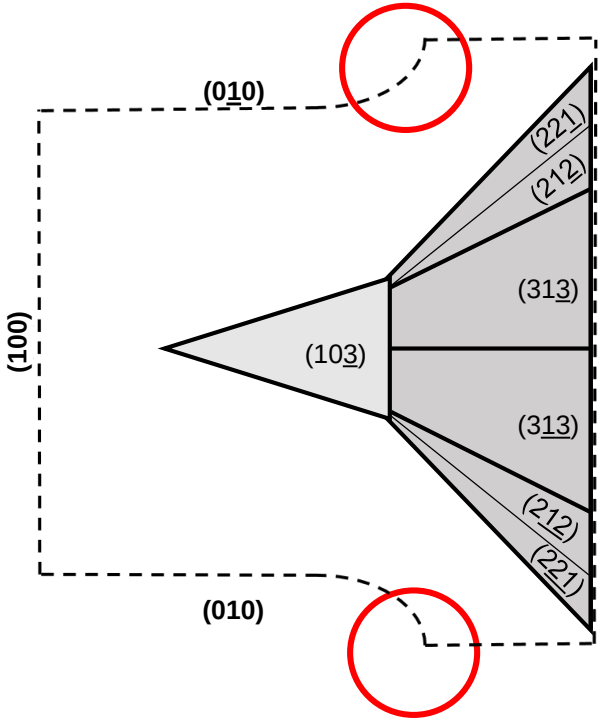
Top-pyramid:

- Etching of convex-convex-corners
  - ➢ Planes with fast etching rates {103}

Bottom-pyramid:

- Etching of convex-concave-conrers
  - ➢ Planes with medium etching rates {221} & {331}





MEASUREMENT SETUP

UHV chamber

- Pressure regulated
  $p = 10^{-5}$ mbar

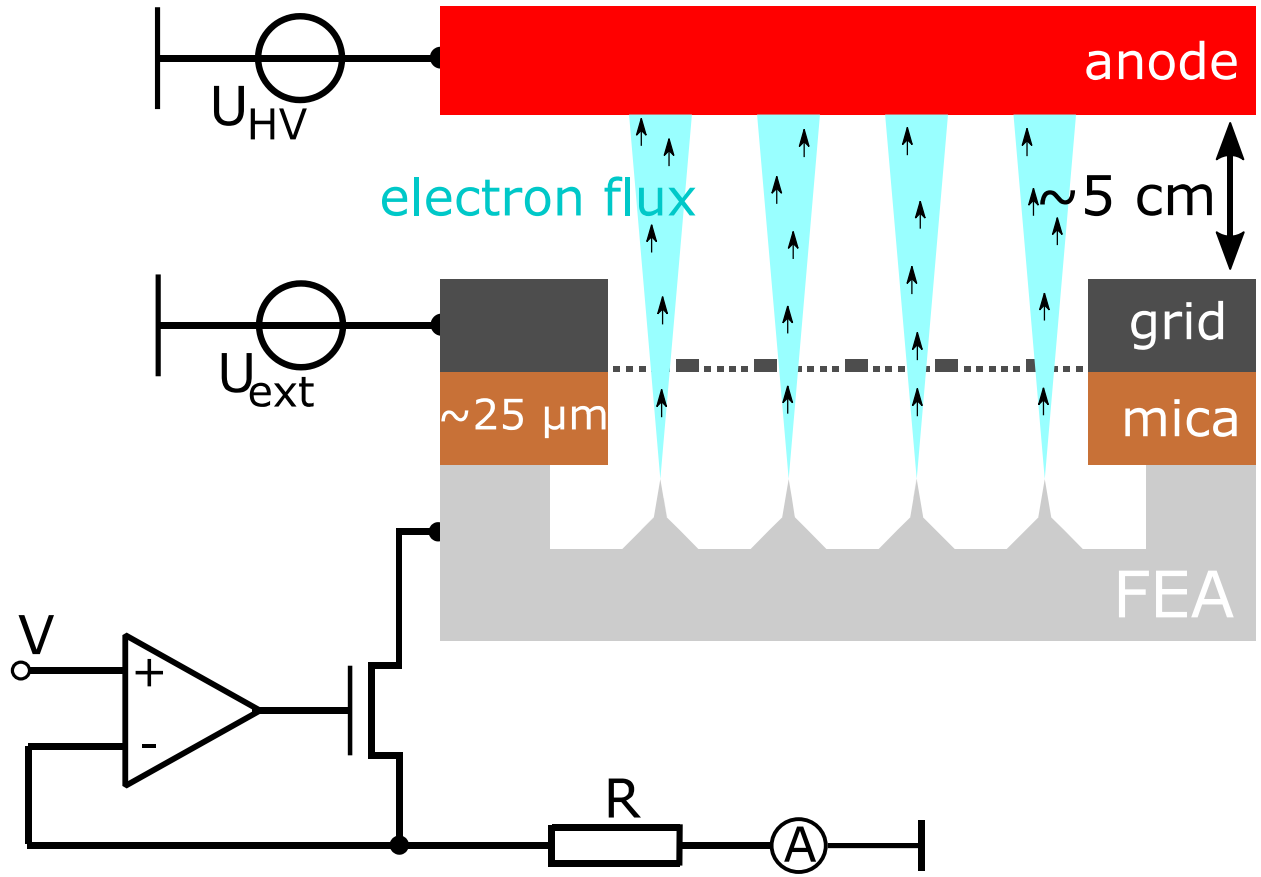
Flexible sample holder

- FEA on bottom
- Insulating mica sheet ≈ 25 µm
- Extraction Grid on top

Anode for X-ray generation

- SDD X-Ray measurement

Current-control regulation circuit



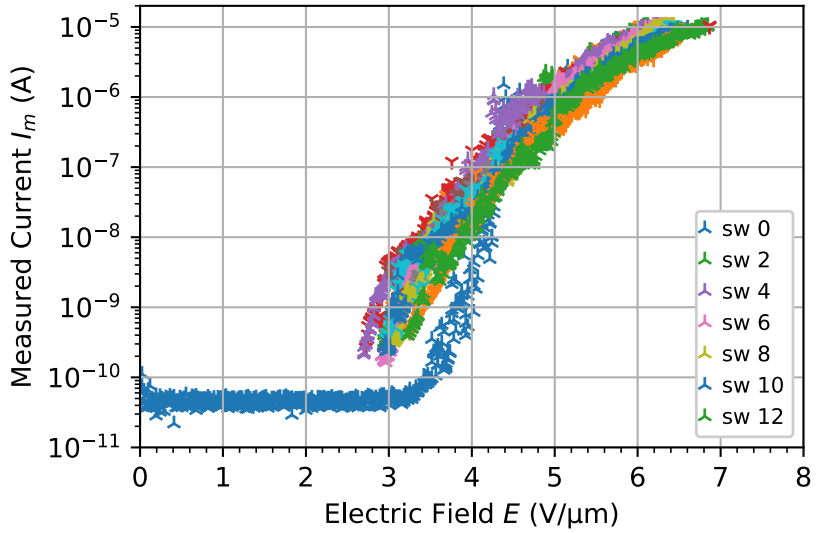
CHARACTERISTIC MEASUREMENT

Characteristics:

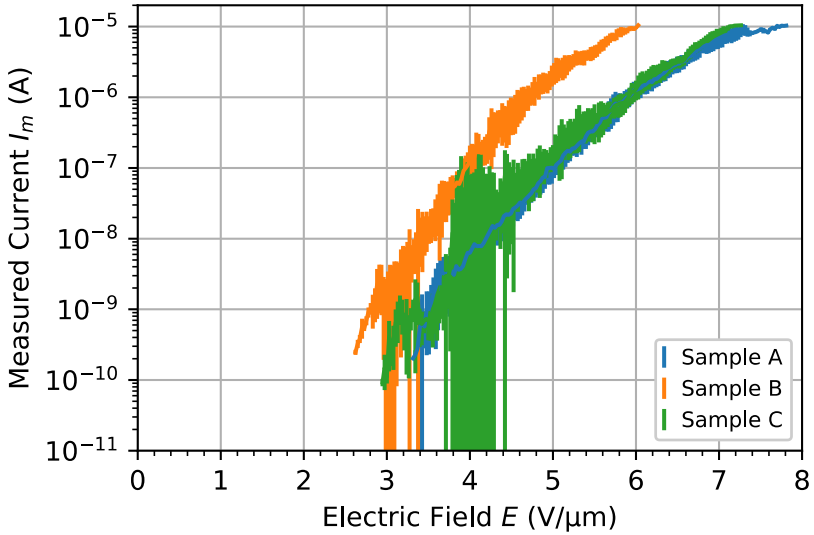
- 12 Sweeps
- 2 V Steps
  - ➢ 3 current measurements
- Up-Sweep to 10 µA
- Down-Sweep to 500 pA

Mean of all sweeps after 5th sweep

➢Comparable characteristics



S-emitter

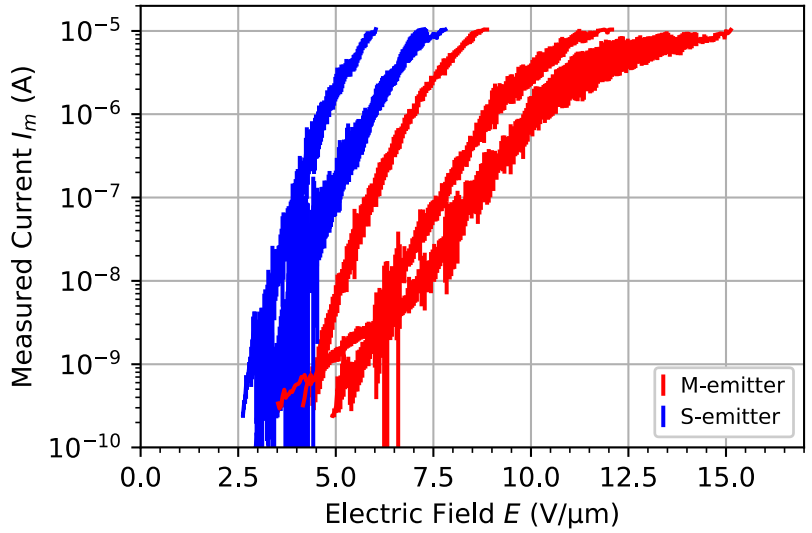


S-emitter

CHARACTERISTIC COMPARISON

M- and S-emitter:

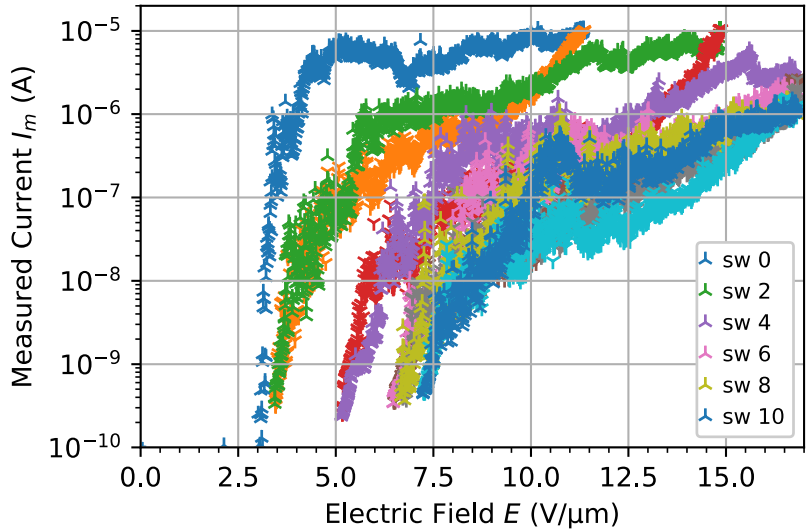
- More tips
  - ➢ More uniform
  - ➢ More stable



L-emitter:

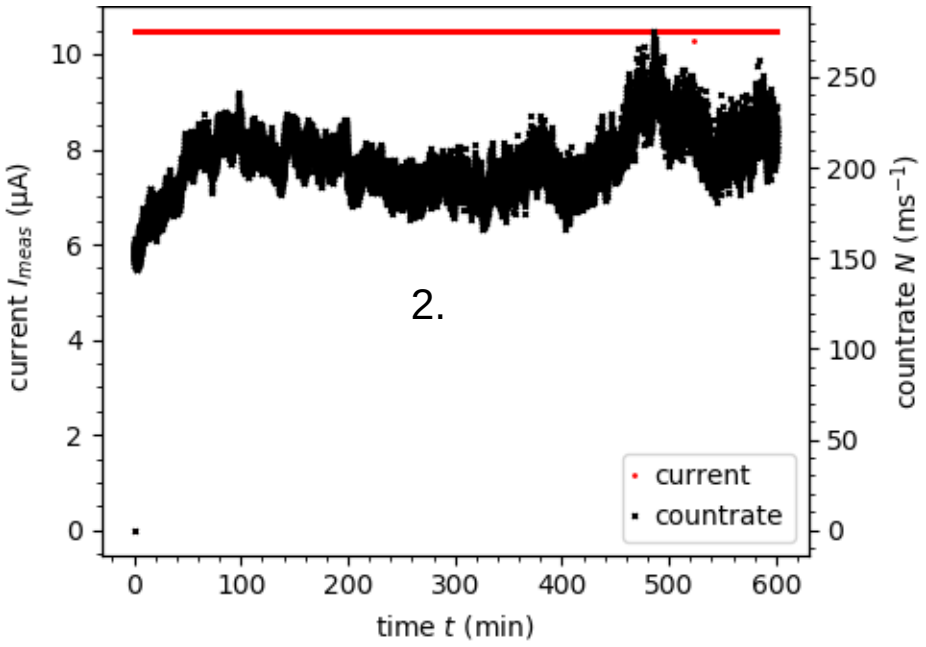
- Similar first sweep
- Just 256 tips
  - ➢ Unstable
  - ➢ Fast degradation

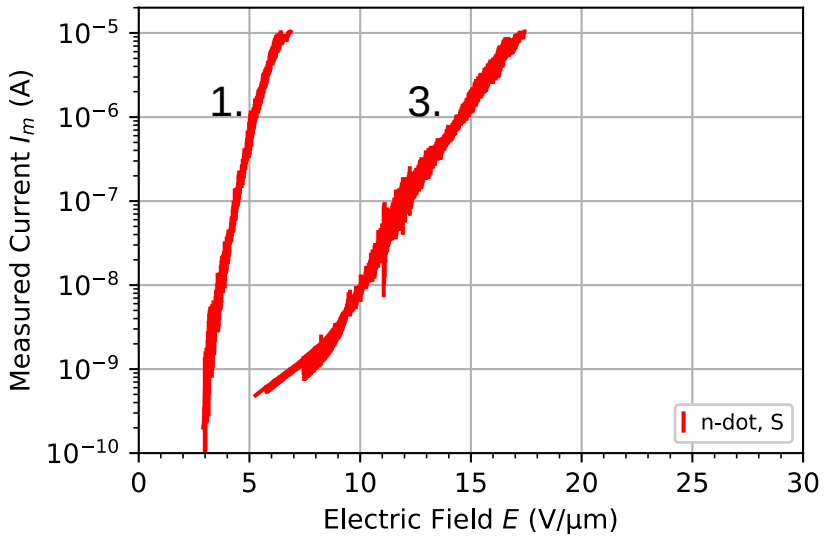
➢ More tips → more stable



LIFETIME MEASUREMENTS

1. Characteristic
2. Lifetime 10 h @ 10 µA
3. Characteristic





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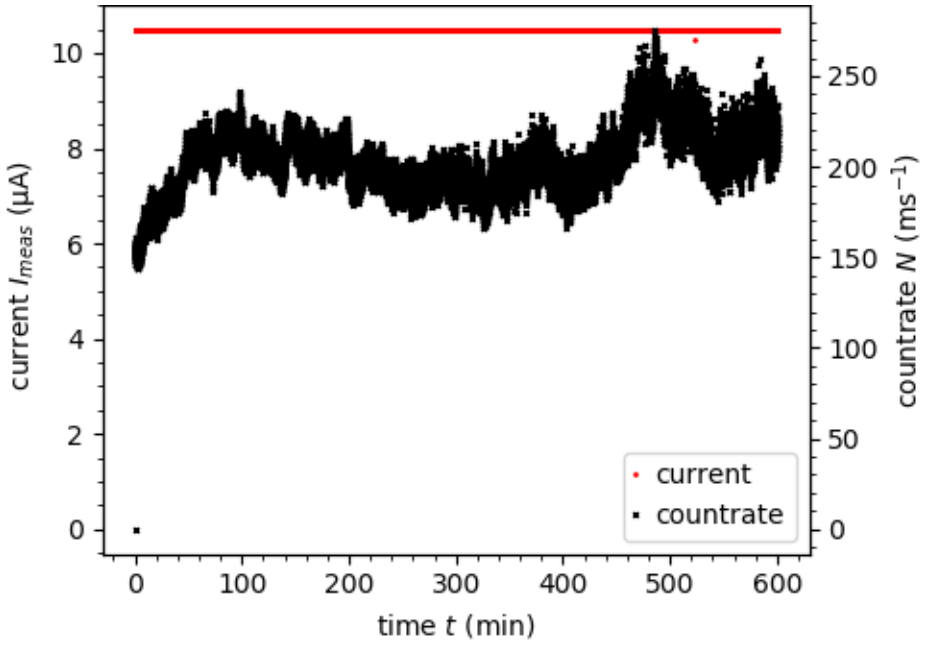
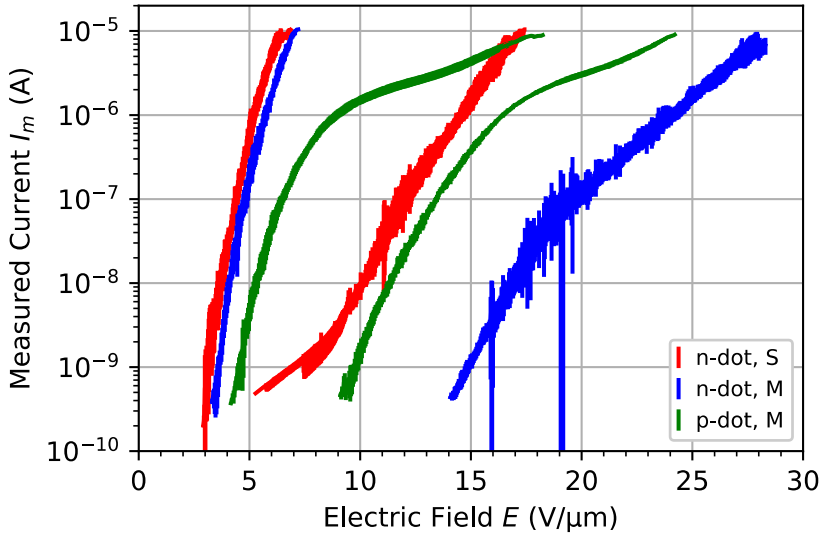


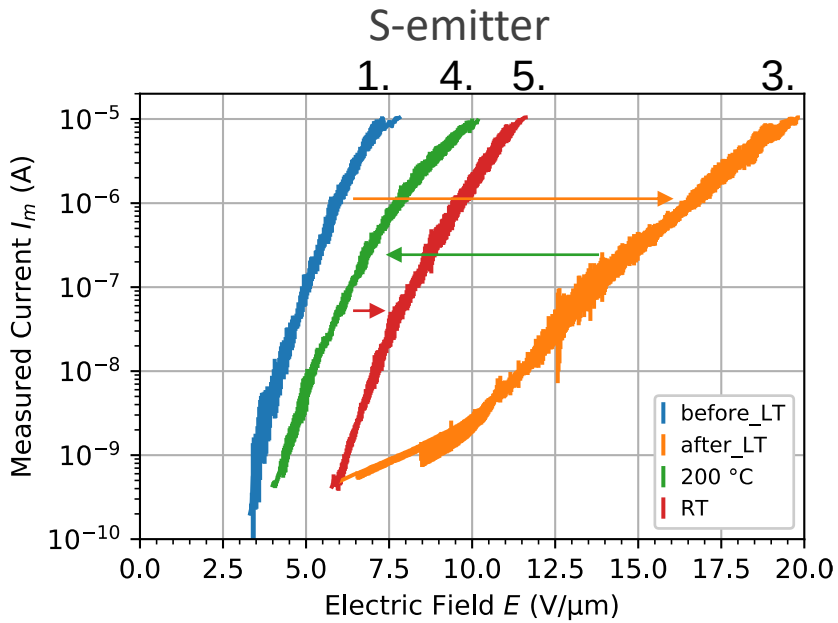


Preferable:

- More tips → less degradation
- p-doped → less degradation

DEGRADATION

1. Characteristic
2. Lifetime 10 h
3. Characteristic
4. Characteristic @ 200 °C
5. Characteristic @ RT



Degradation:

- Reversible
  - Adsorbates
- Irreversible
  - Tip destruction
  - Tip alteration

CONCLUSION

- Easy & reproducible process
  - ➢ Enables newcomers access to field emission
- Tip formation based on anisotropic Si-etching
- Lifetime for 10 h at 10 µA
- Low dispersion of electical characteristics
- More tips → more stable
  - ➢ Lower onset field
  - ➢ Higher lifetime
- Degradation
  - ➢ Partly reversible

THANK YOU FOR YOUR ATTENTION!

Universität der Bundeswehr München

KETEK

QUESTIONS?