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

MeVArc 2021

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
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

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

- 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

→ Comparable characteristics

@ $10^{-5}$ mbar
MEASUREMENTS – Comparison characteristics

**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

I-E-characteristics

Lifetime/Degradation

Longer LT due to number of tips or tips dimensions?
MEASUREMENTS – Comparison of different geometries

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

OUTLOOK – Pillar-Saw-FEAs
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!