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Design and Development of a Micro- Field Emission Electric Propulsion Thruster

Manufacturing Study and First Prototype Results

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FEEP-Fundamentals

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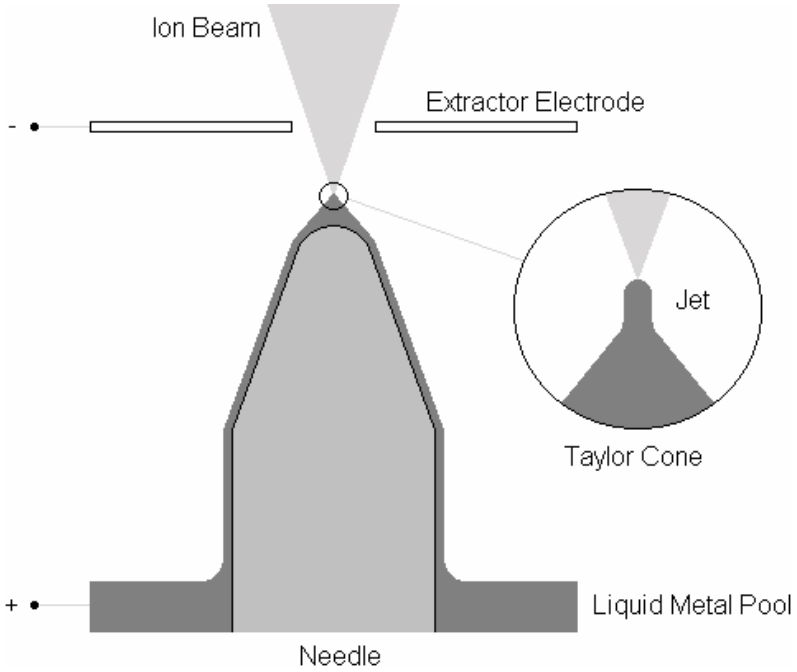
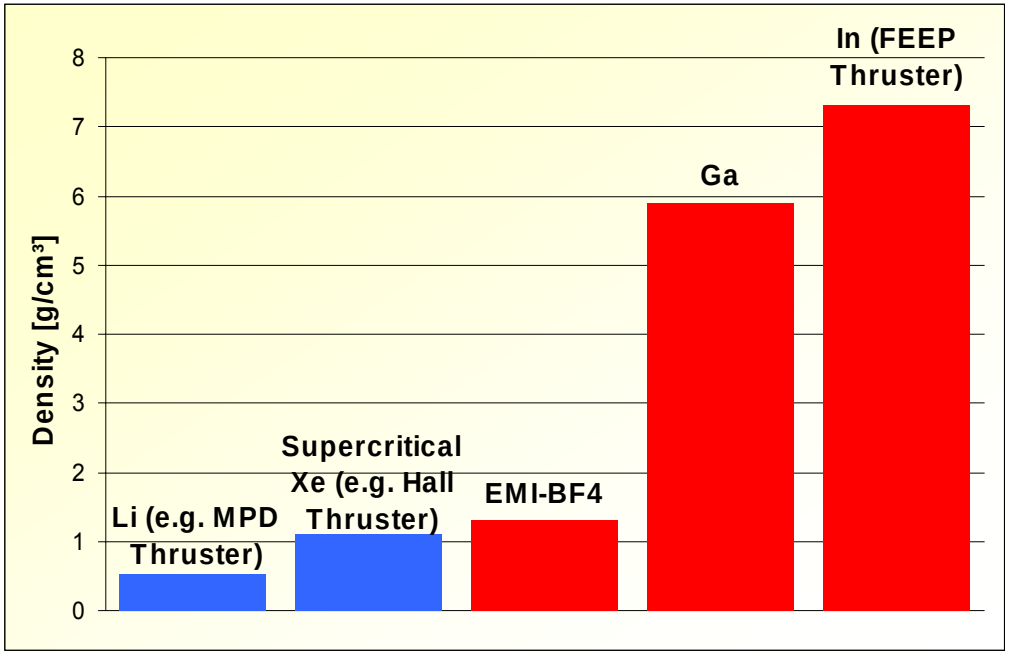
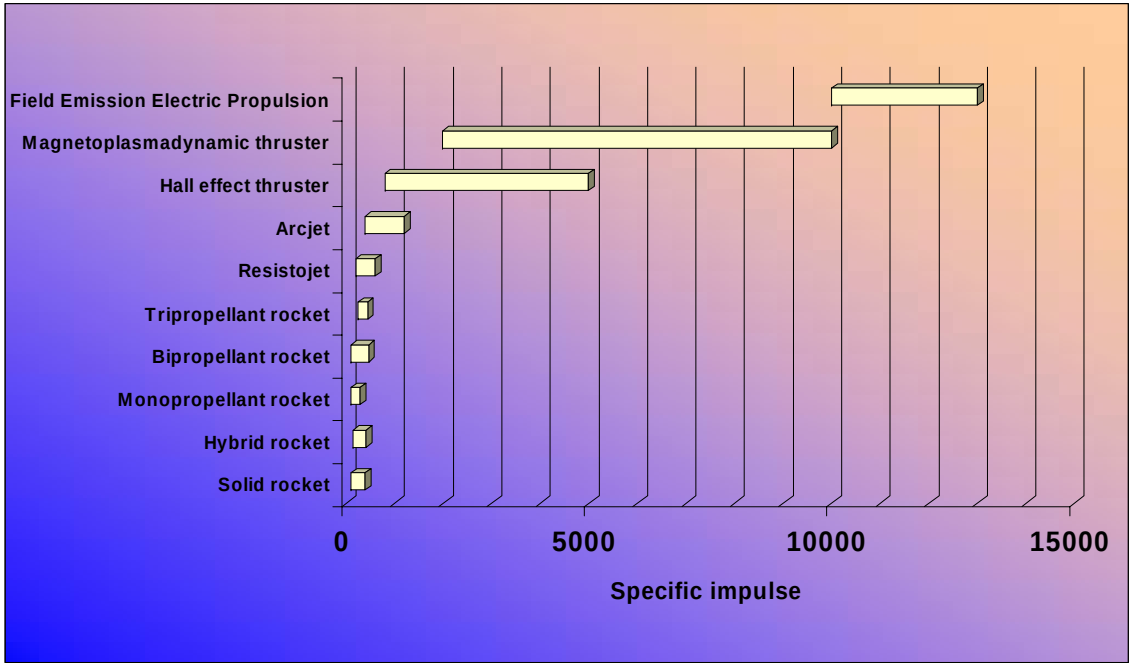




Properties

- Electrical efficiency > 95%
- Indium propellant has high density → small tank size
- Single emitter produces µN thrust → clustering
- High power to thrust ratio (70W/mN)



- Very high I_{SP}
- Very low noise in thrust
- Very fast intrinsic reaction time (ns-µs)
- High degree of control over thrust → Drag-free control for scientific satellites, e.g. space-based gravitational wave detectors (LISA/PF)

Internally and Externally Wetted Emitters

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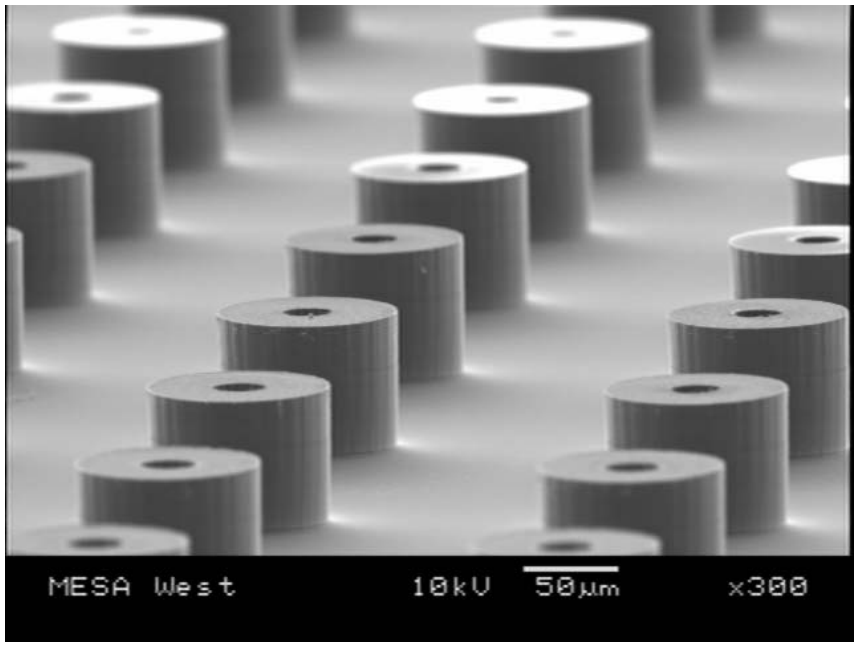
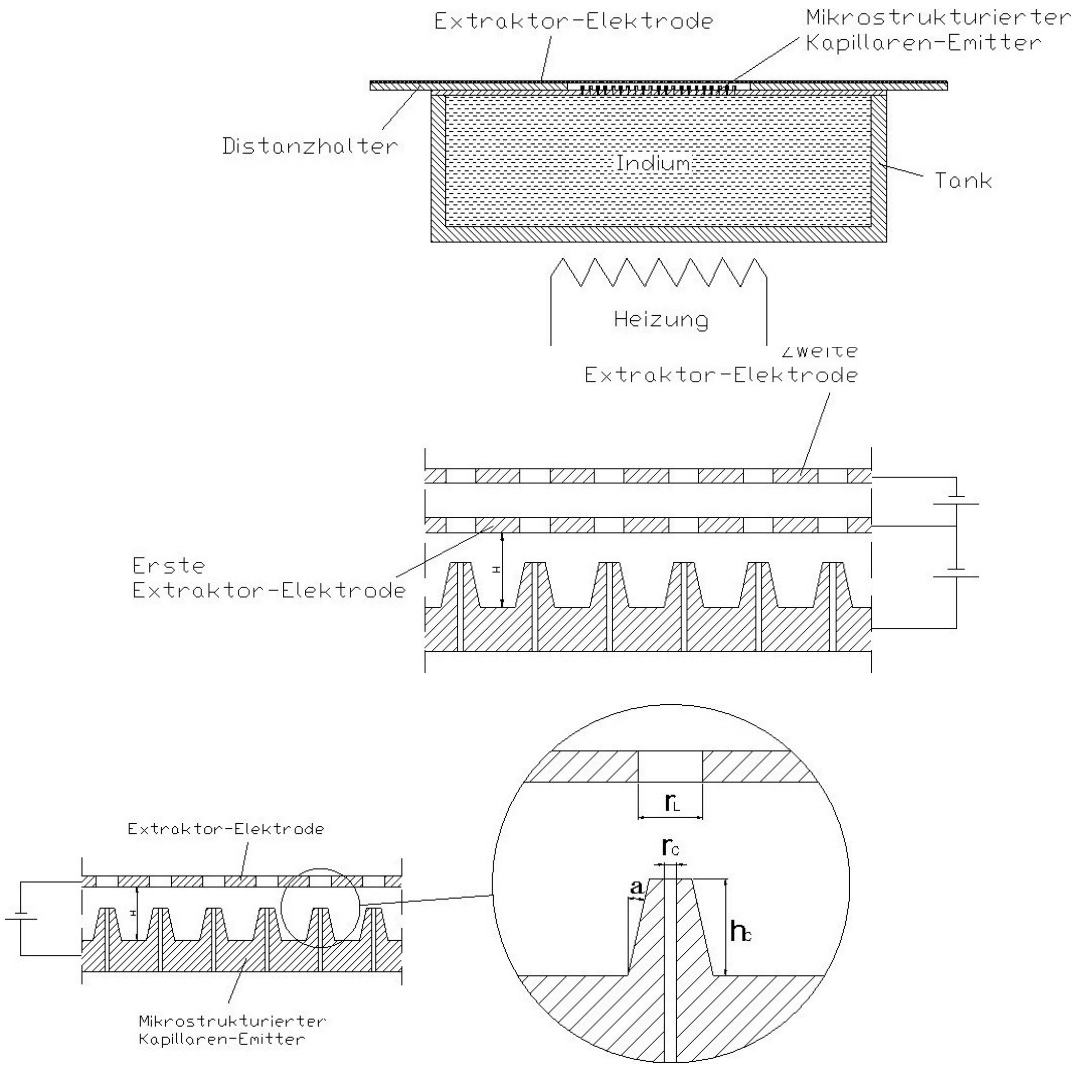
- Differentiation
  - Internally wetted (capillaries, slit emitters, …)
  - Externally wetted (needles and needle-like structures)

- The capillary approach promises to be the easiest method for an initial MEMS approach in the design study.
  - No de-wetting during thermal cycles
  - Easy tank interface



µFEEP Patent



- A multitude of factors determine the lifetime and performance of a µFEEP cluster
  - Emitter spacing
  - Capillary diameter to length
  - Extracted currents
  - Extractor design
  - Materials

Material Considerations

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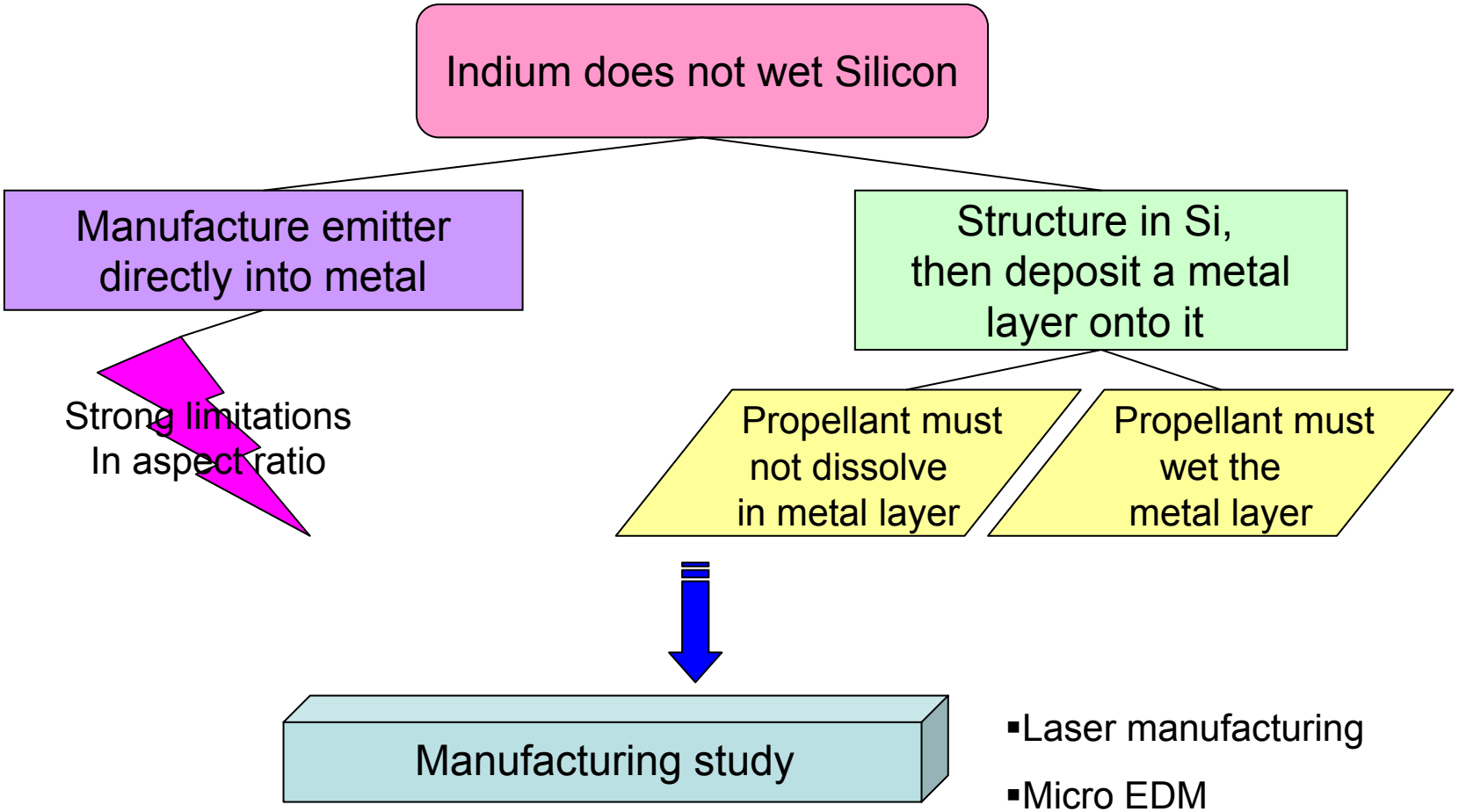
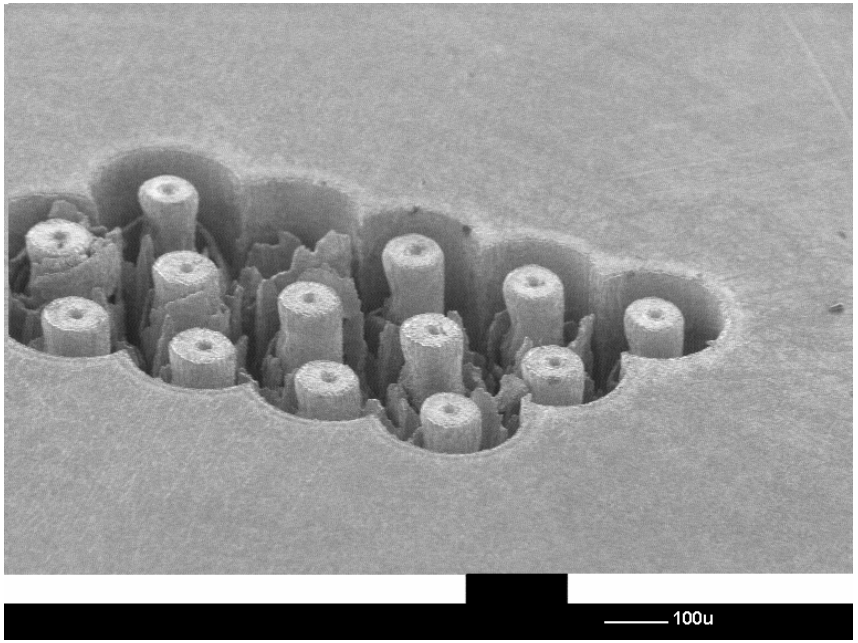


- Laser manufacturing
- Micro EDM
- Photochemical etching
- Silicon etching

EXITECH



- Excimer Laser at 532nm
- Prototyping in stainless steel

- Material re-depositioning prevents laser from penetrating deeper
- Artefacts remain between the structures

→ Shorter wavelength, shorter pulses, higher pulse energy and fluid assist system.

Laser Manufacturing

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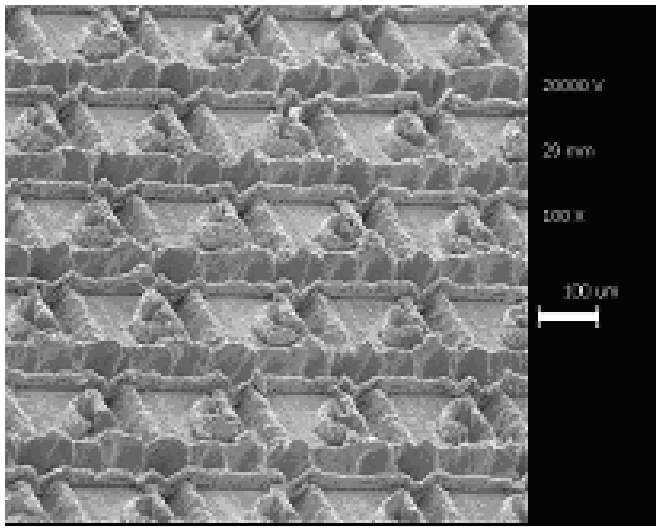
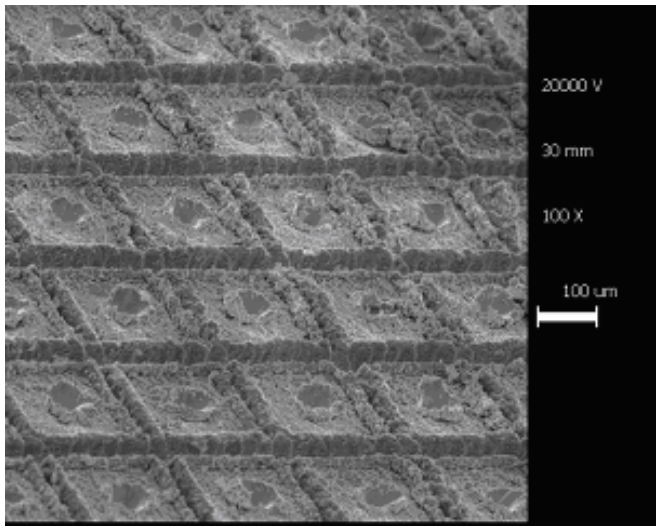
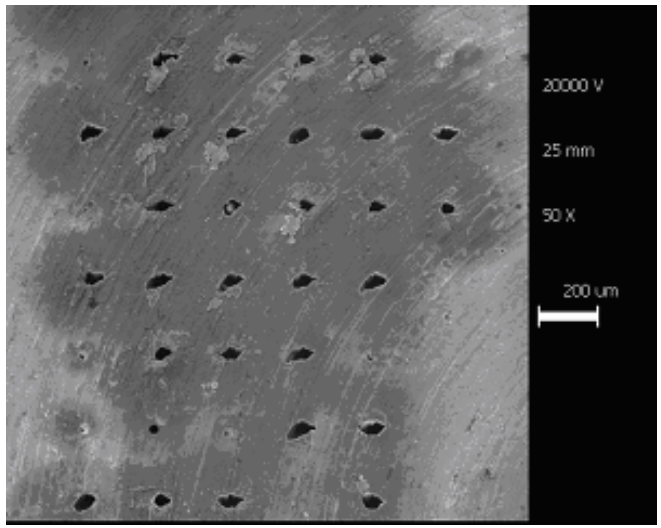


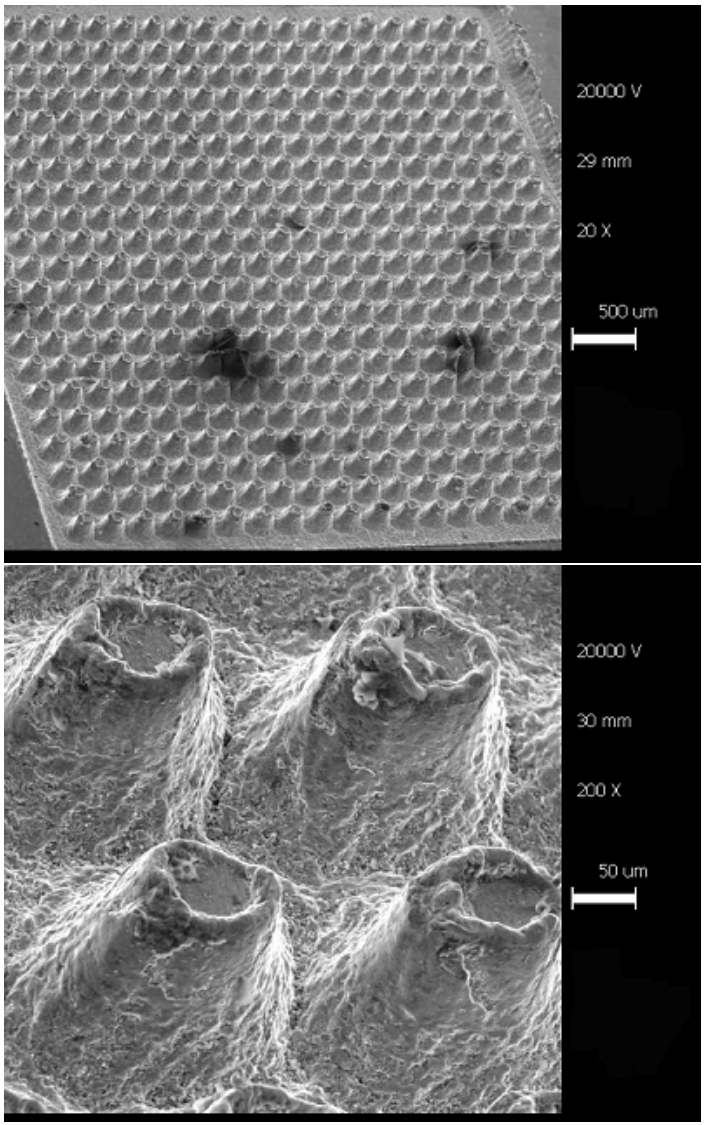
Laser-Zentrum-Hannover

- Femto-second laser
- No purge gas was used

- Hole structure in steel was good
- Holes in Tantalum were asymmetric







FOBA

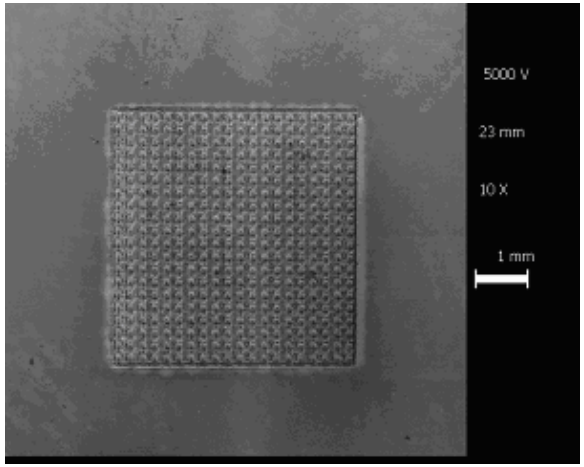
- NeYAg-UV (355nm) Laser in stainless steel

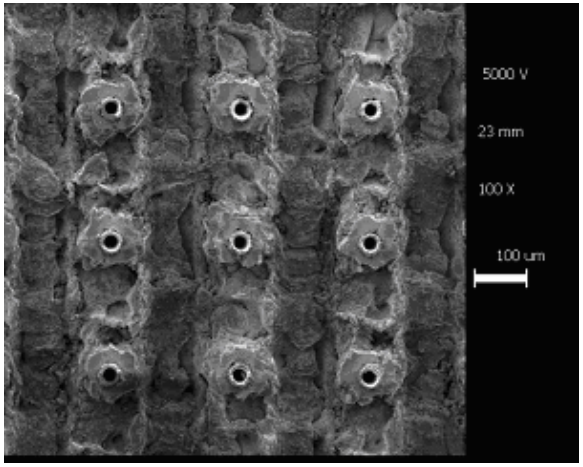
- Structure has a better shape, than previous results, but it lacks accuracy.
- Drilling a hole in the structure was tried, but none was visible under microscope.

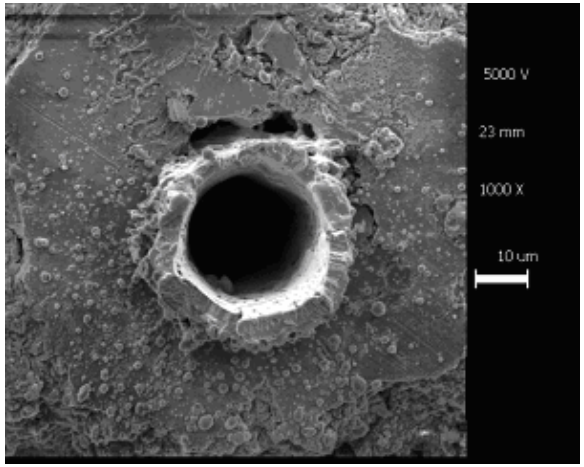
Feigl KG

- Excimer laser with purge gas and high accuracy positioning
- Special software for capillary manufacturing
- Stainless steel prototypes with 21x21 emitters on 5x5mm area

- Resulting capillary height 90µm, hole diameter 10µm

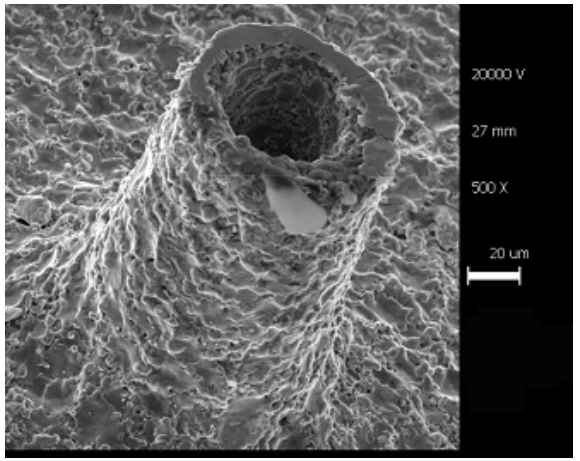


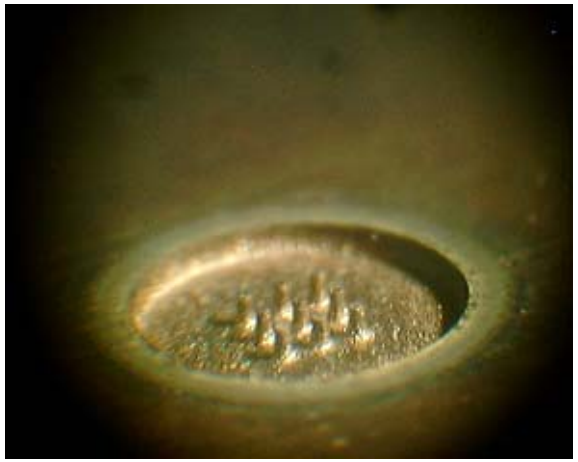


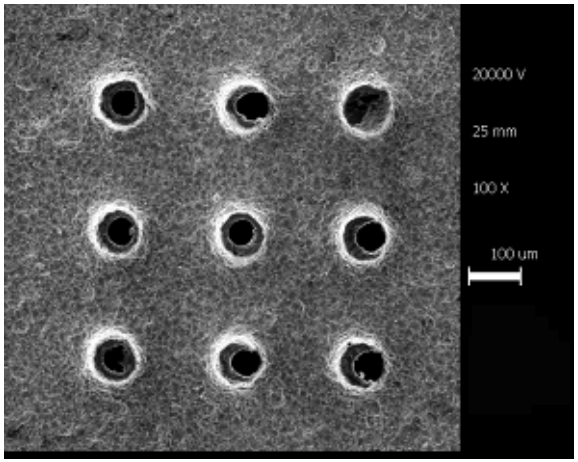


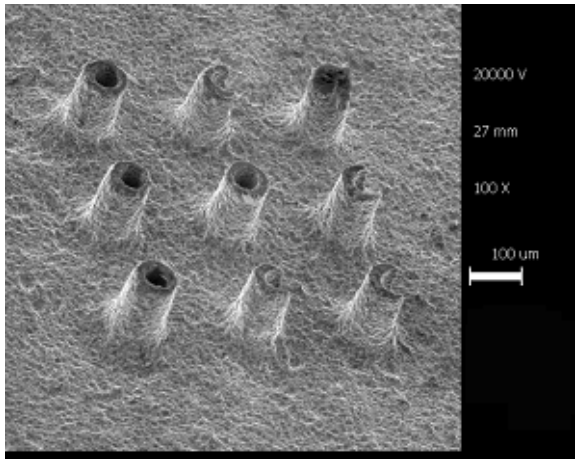
Koese Engineering

- Micro-spark erosion prototyping in stainless steel
- 3x3 capillaries 100µm height, 50µm hole diameter
- Clear structures, but wire positioning system needs to be more accurate→ holes off-center
- Best result, but slow and expensive









Photochemical etching

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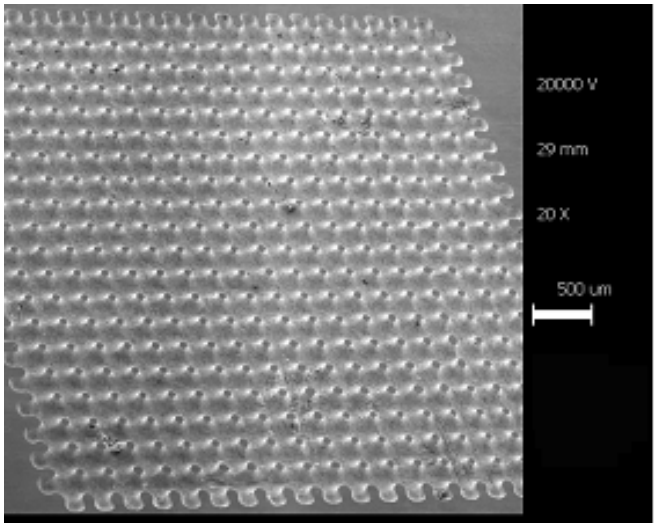
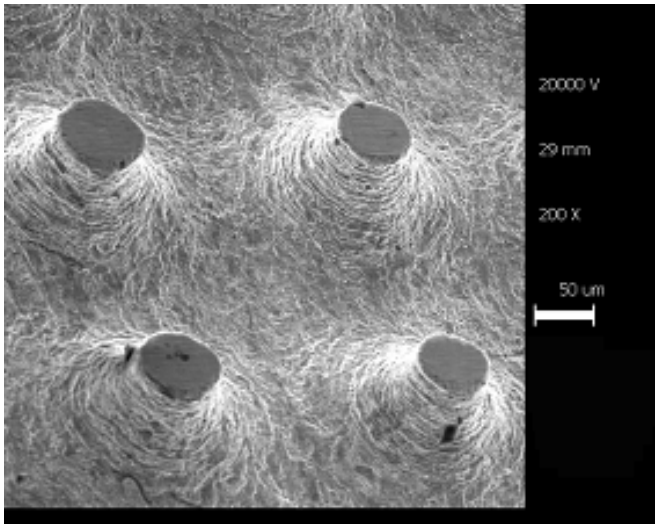
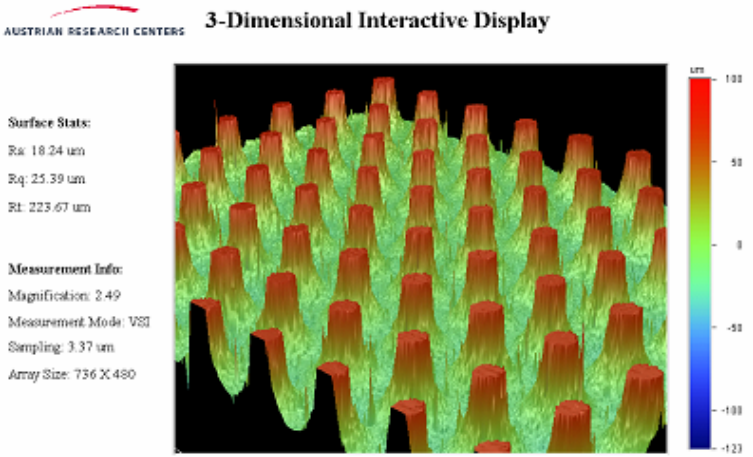




Etchform



- Prototyping in 2 stainless steel samples, 20x20 emitters in 5x5mm area
- Main difficult is producing a film on the metal that withstands the etching
- Low aspect ratio (1:1)
- Structure height ~80µm
- No holes could be etched, requires a 2-step process
- Accuracy achieved was ±5µm
- Etching of Tantalum not possible

Silicon Etching

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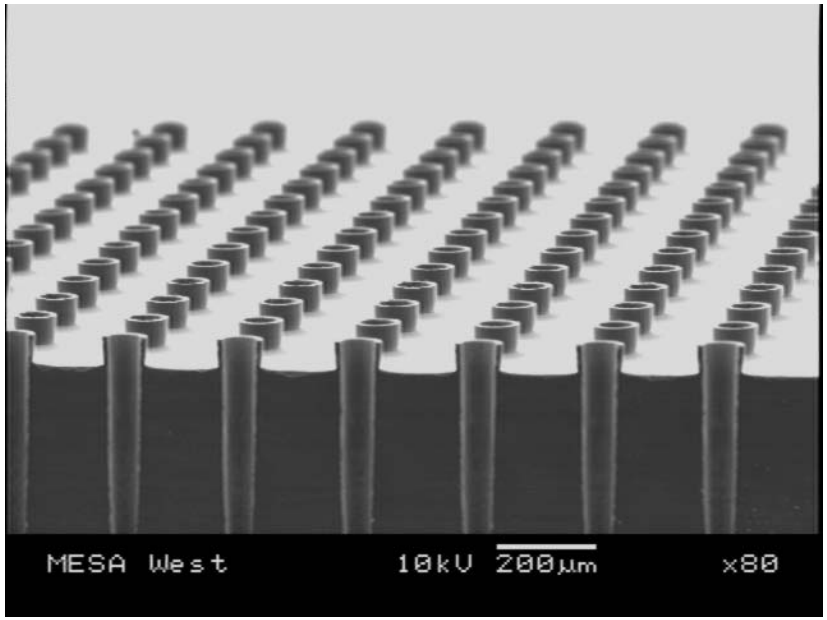
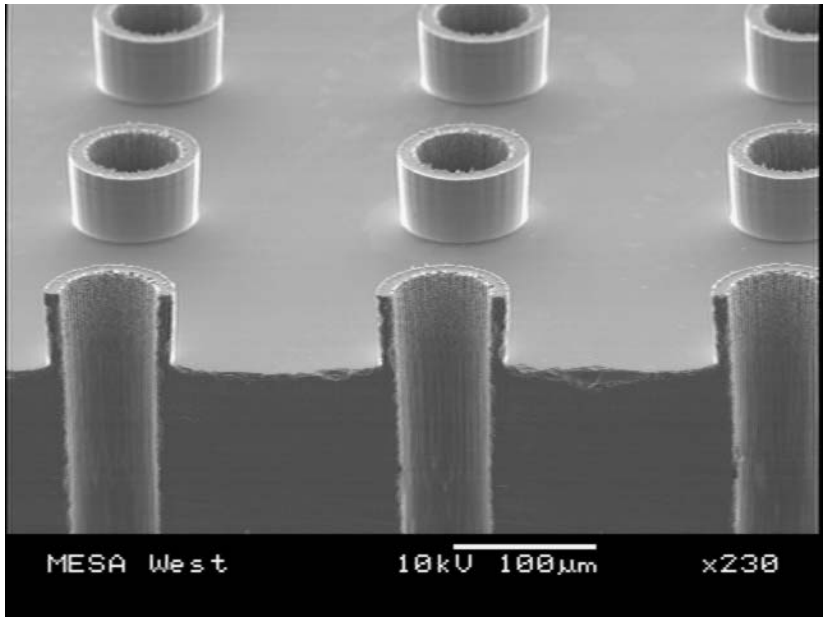
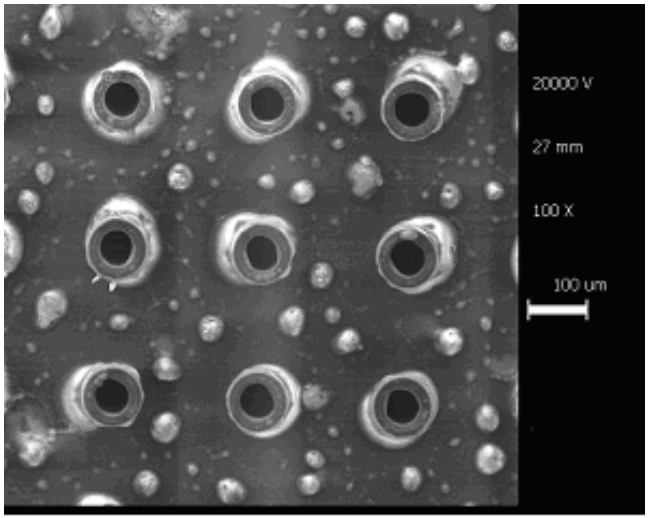




Sandia



- Silicon Deep Reactive Ion Etching (DRIE)
- Excellent accuracy
- Structure needs coating for wetting

µFEEP Assembly

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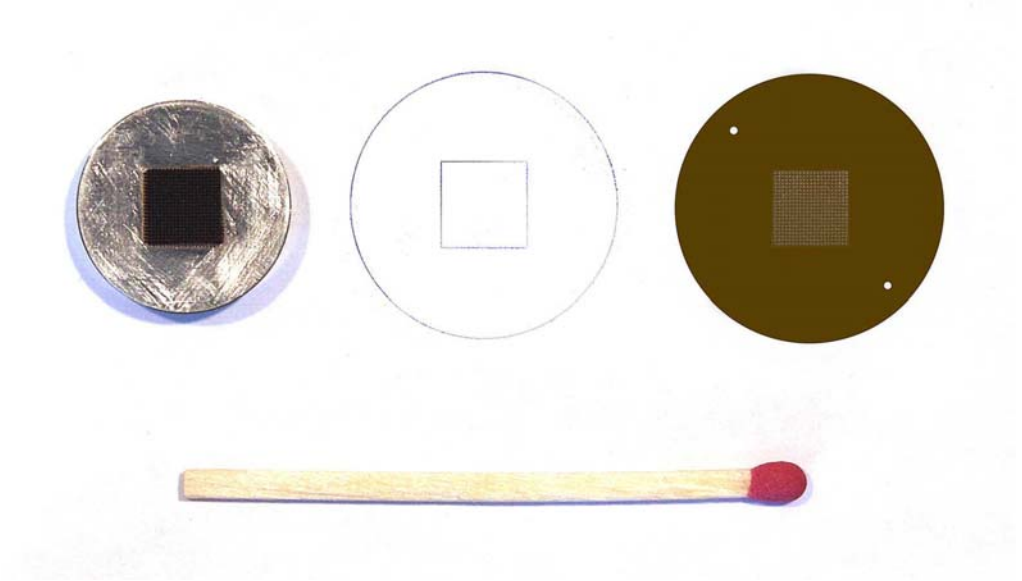

- Glass spacer layered between emitter and a doped Silicon extractor
- The Silicon extractor was sputtered with gold to reduce the resistivity
- A module housing complete with heaters, wiring, thermal and electric insulation was made for the laser manufactured prototypes

µFEEP Assembly

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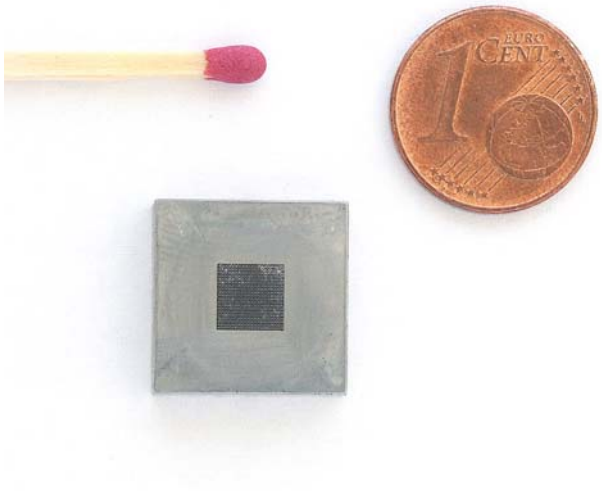
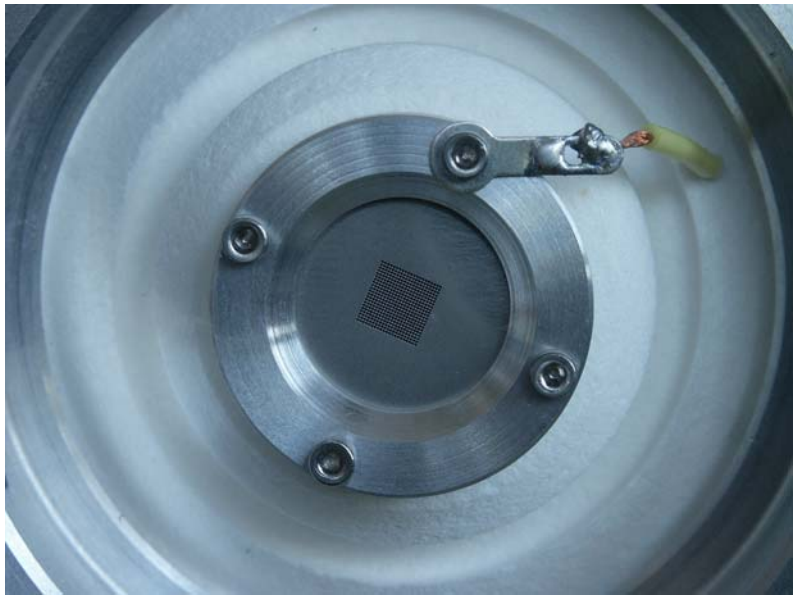
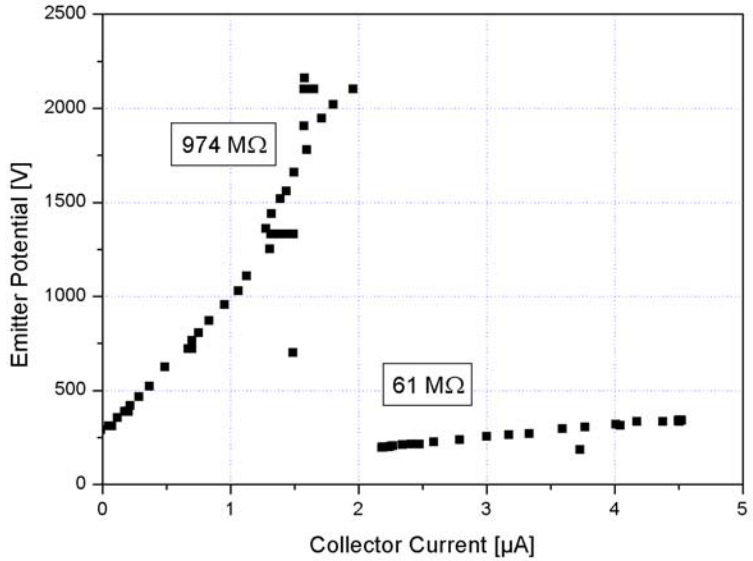




- Wetting of the FEIGL Excimer Laser prototype with liquid Indium was successfully performed at 800°C
- Investigation showed that capillaries were entirely filled with Indium
- Prototype was mounted in a breadboard module and heated to operation temperatures

Firing



- A collector electrode was placed opposite the µFEEP thruster to register emitted ions.
- At a threshold voltage of 300V, a small current appeared on the collector, proving that ions are indeed emitted.
- The current-voltage slope was steep up to 2kV but suddenly dropped from 974MΩ to 61MΩ, indicating that 16 times as many capillaries started to fire at this voltage.

Conclusion

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A prototype of a microstructured FEEP thruster was fired successfully with Indium as propellant!

MicroEDM appears to give the best results in bulk metal, but needs better accuracy.

Laser manufacturing in steel resulted in an operative thruster.

Silicon etching yielded excellent structures but the required coating, especially on the inner surfaces of the capillaries, is very difficult.

The method of alignment of the extractor and emitter needs improvement.

Development continues, larger clusters, different propellants and substrate materials, improved electrode geometry…