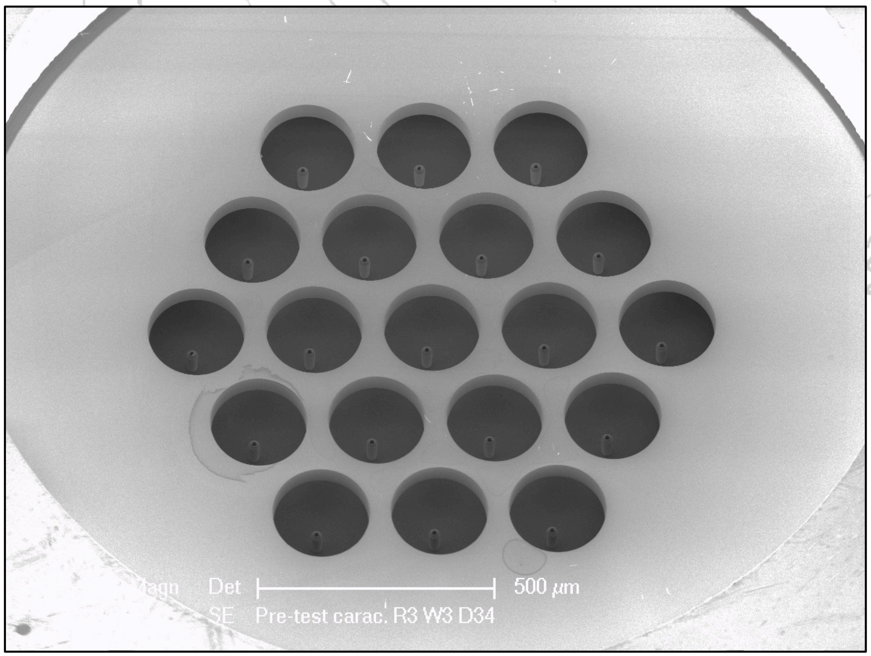
MicroThrust – Microsystems as a solution to enable high ΔV electric propulsion for small spacecraft



19x Emitter array - MicroThrust

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8th ESA Round Table on Micro and Nano Technologies for Space Applications, Noordwijck • Netherlands, October 15-18, 2012

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Queen Mary University of London

Why miniaturized propulsion?

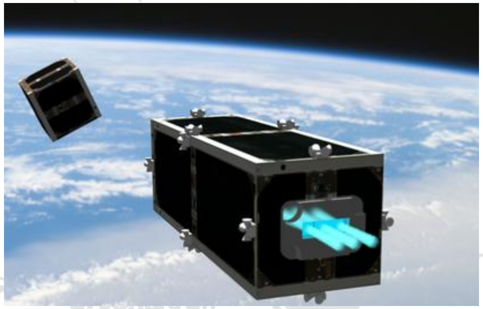
- Electrical propulsion has been around for years!
  - BUT, too large, heavy and power hungry to be applied to small satellites (1-100 kg)

- Small satellites, with efficient propulsion, could enable:
  - Low cost technology demonstrators (e.g. for MEMS in space)
  - Low cost, low risk, science missions
  - Distributed small satellites networks
  - Clean space debris?

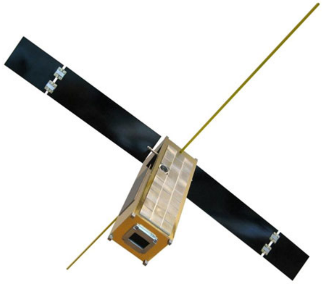
e.g.: 8 cm XIPS® from L-3 communications

http://www2.l-3com.com/eti/product_lines_electric_propulsion.htm

- 2kg (without propellant, HV electronics & high pressure feed)
- 100-300W

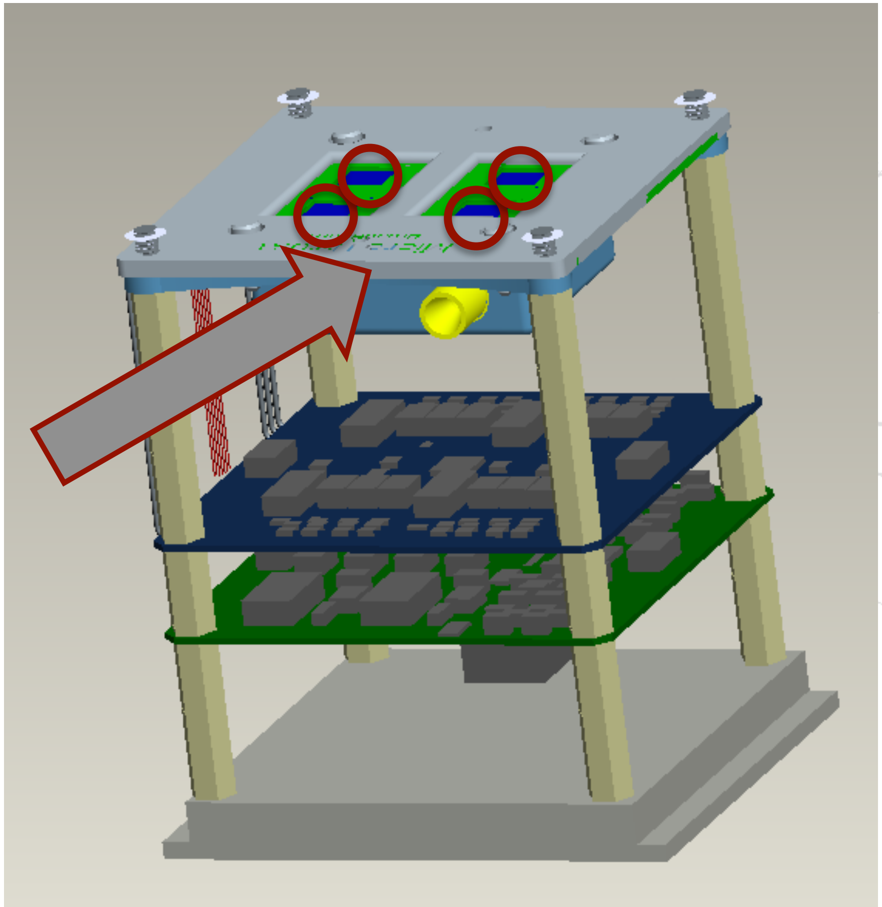


Clean Space One concept – © Swiss Space Center



OLFAR mission

MicroThrust: Developing a thruster system for small spacecraft



Complete module (concept):

- Wet mass: < 300g / kg of launch (30%)
- Power: <5 W @ 3.5 kV
- Dimensions: < 10cm x 10cm x 10cm

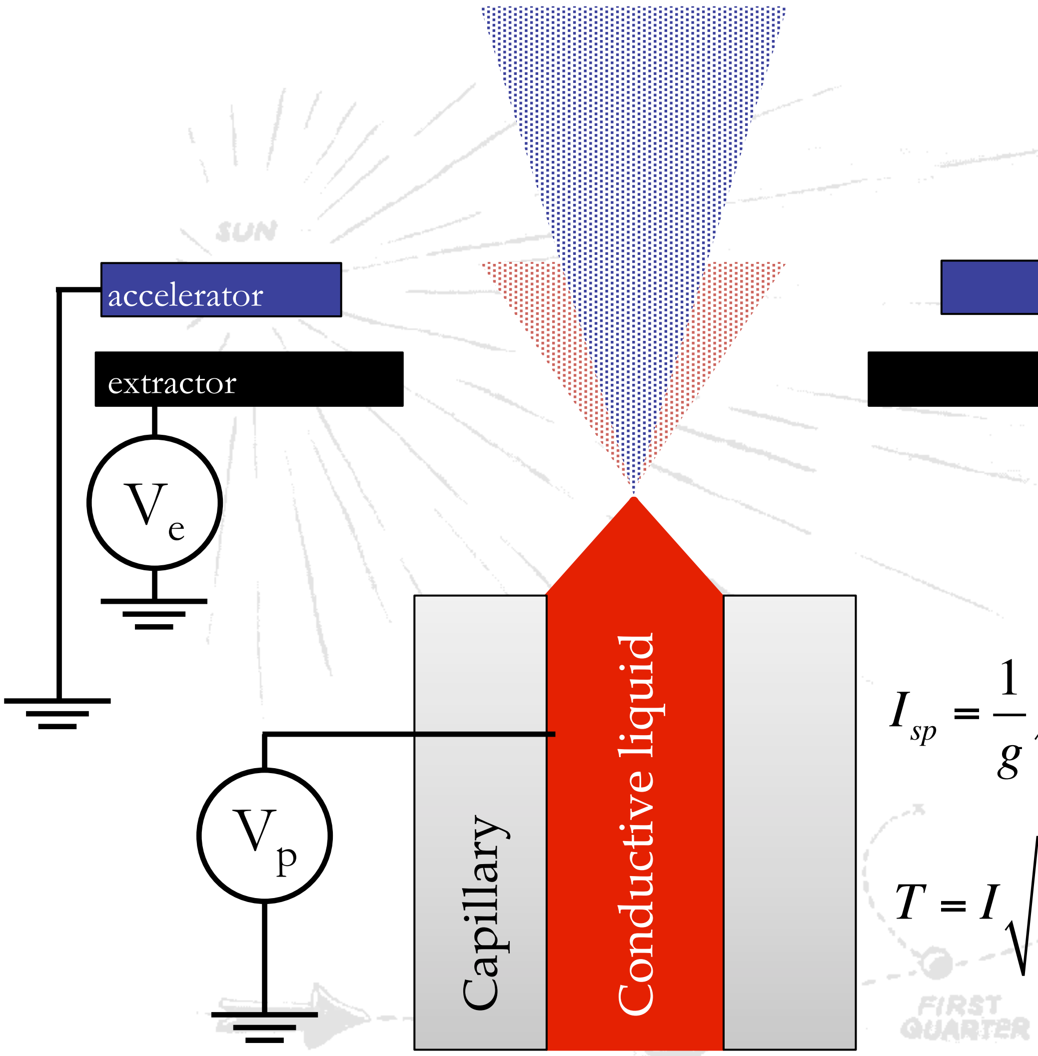
- Isp: > 3000s
- Thrust: 20 μN/W
- **Δ V: 5 km/s**

Partners:

- EPFL (Switzerland)
- Queen Mary University of London (UK)
- Nanospace (Sweden)
- TNO & SystematIC (Netherlands)

http://www.microthrust.eu

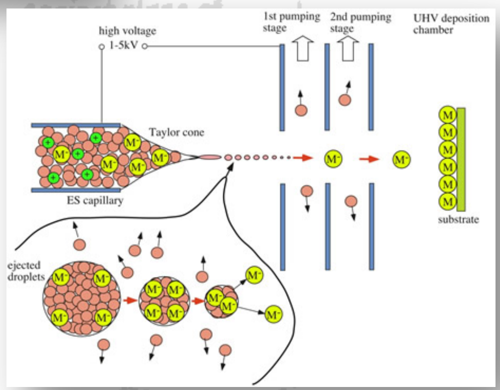
Basic operation of electrosprays



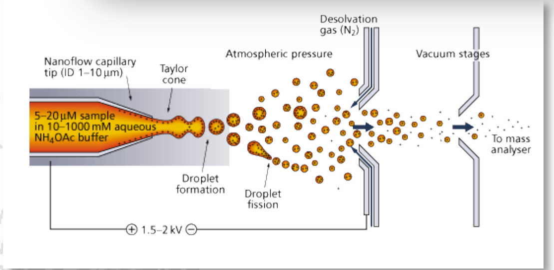
$$I_{sp} = \frac{1}{g}\sqrt{2\Phi_B \frac{q}{m_o}}$$

$$T = I\sqrt{2\Phi_B \frac{m_o}{q}}$$

Industrial painting
http://youtu.be/leapiWpg0Gc



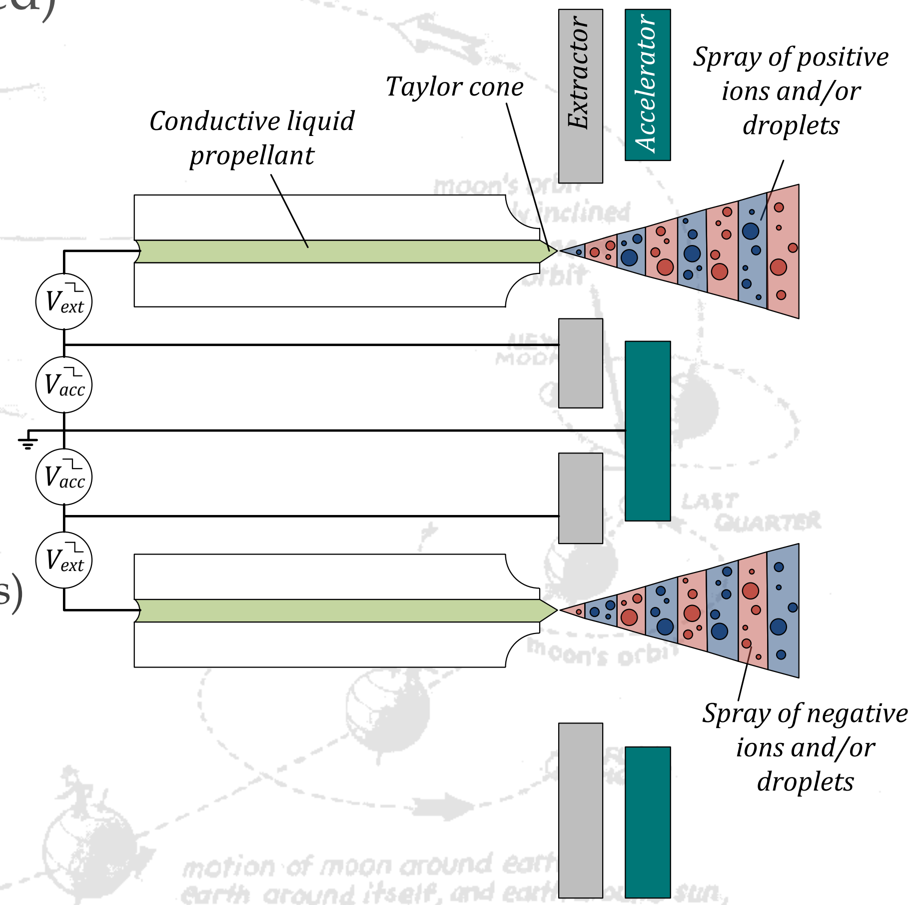
Thin film deposition
http://rsl.eng.usf.edu/Pages/ResearchElectrospray.html



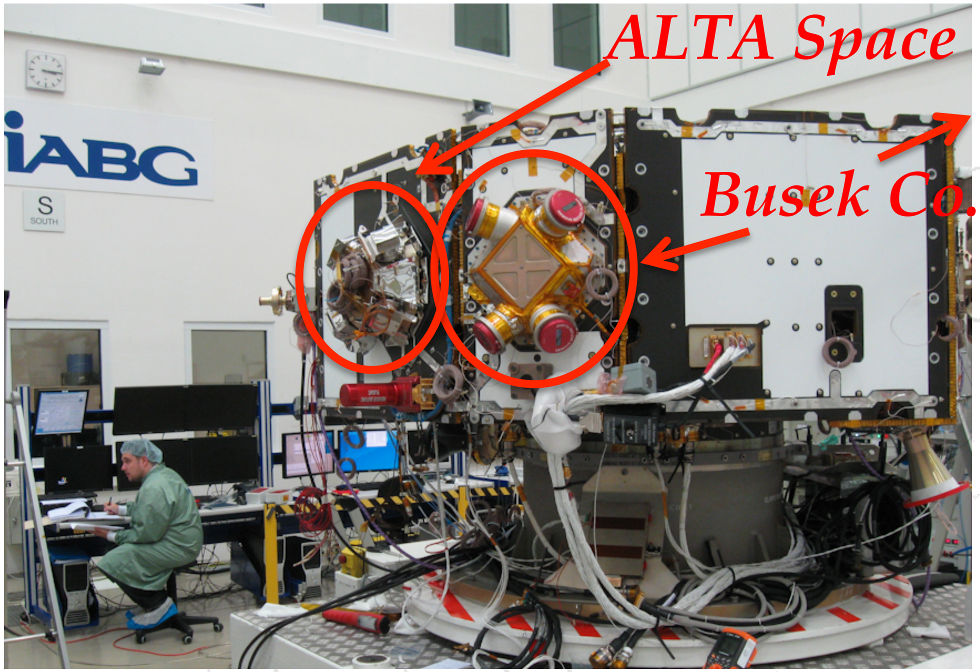
Mass spectroscopy
http://www.rsc.org/chemistryworld/Issues/2003/February/together.asp

Concept of MicroThrust emitters

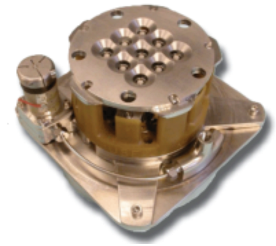
- No pressured tanks/lines (capillary feed)
  - 1.2 bar allowed in CubeSats (*CubeSat Design Specification, Cal. Poly.*)
- No neutralizer
- Variable I_{sp}
  - up to 2 000 – 3 000 s without accelerator
  - "unlimited" with accelerator stage(s) and sufficient power (realistically 5 000 – 10 000 s)
- Variable thrust
  - ~10^{-8} N for individual emitters
  - increased with arrays (realistically ~10^{-4} N)



Miniaturization through microfabrication



Lisa Pathfinder Spacecraft - Thermal-vacuum test in IABG (Germany) - Sep2011 ©ALTA Space

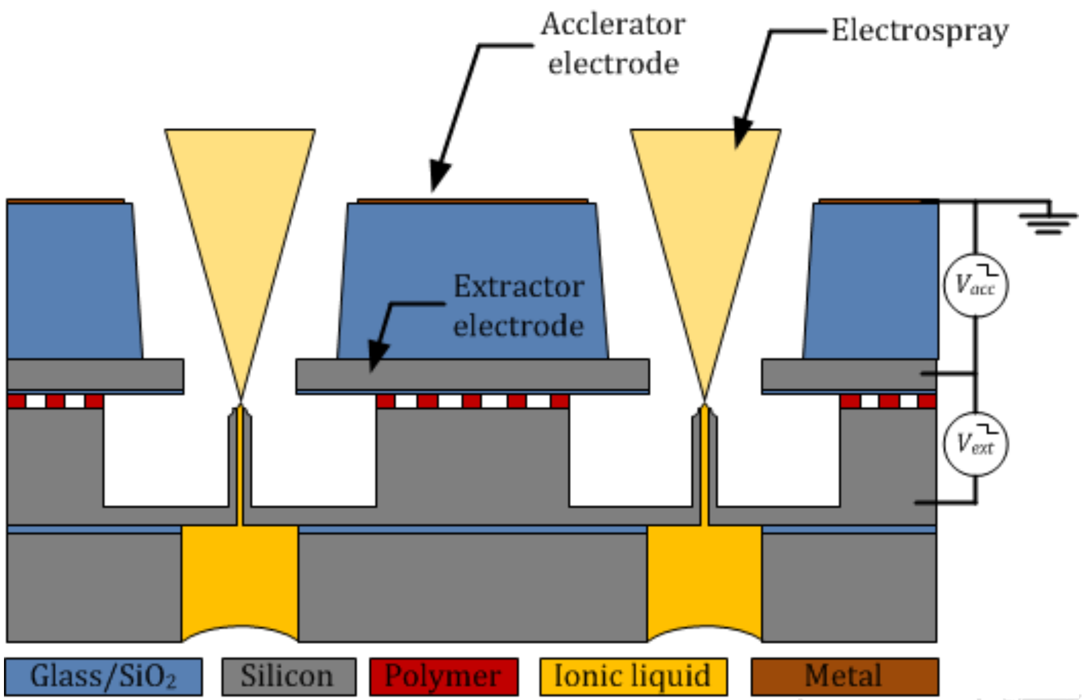


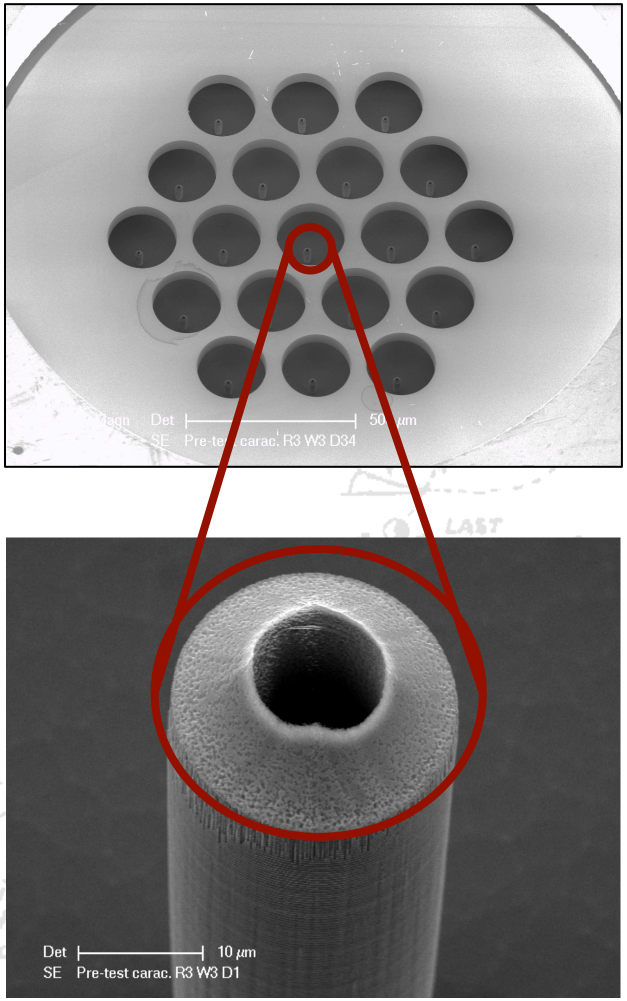
Standard

Microfabricated

Advantages of microfabrication	Disadvantages of microfabrication
Can achieve very high hydraulic impedance	More difficult to make
Possibility to fabricate large, uniform arrays (thousands)	High development costs
Lower mass and footprint	
High level of integration	

Our design of electrospray emitters





Emitter microfabrication process

a. Starting SOI Wafer ¦ 100/2/500 µm

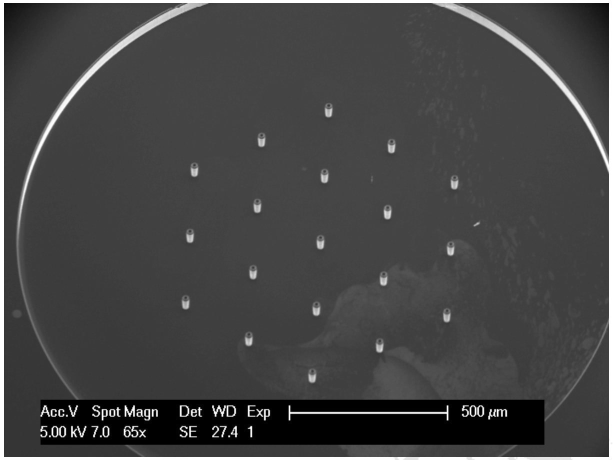
b. DRIE Silicon Etch ¦ Inner Cap. Def.

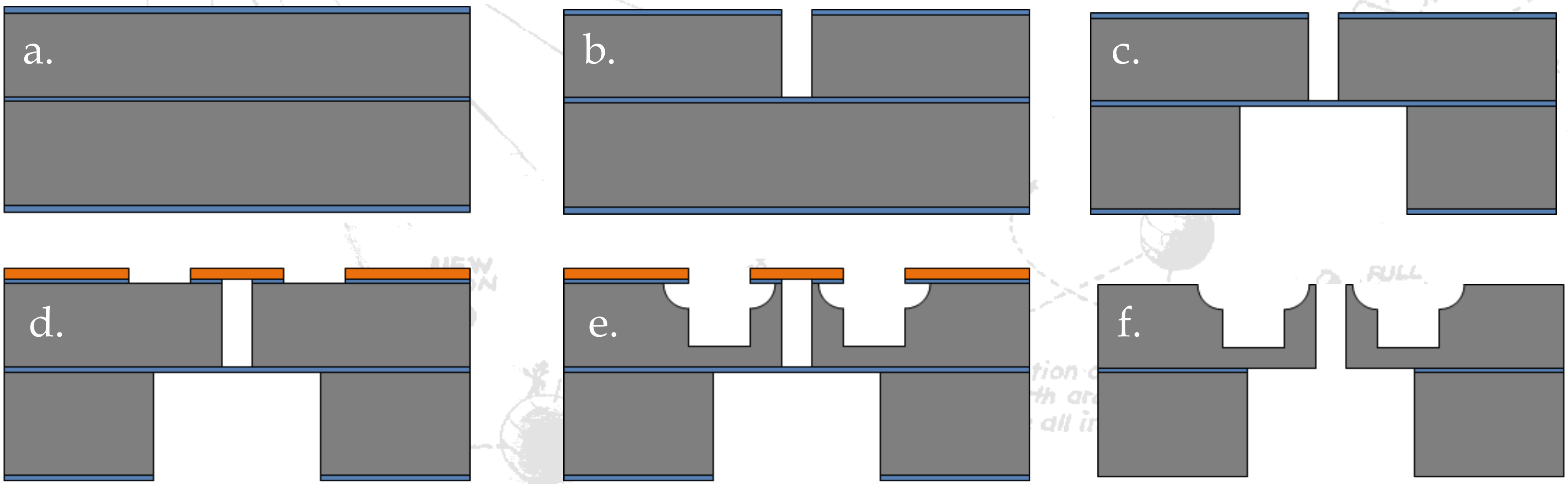
c. DRIE Silicon Etch ¦ Backside

d. Resist lamination & patterning ¦ MX5015

e. DRIE iso. & aniso. silicon Etch ¦ Outer Cap. Def.

f. Oxide etch & Wafer Cleaning → Release





Electrode microfabrication process

300 μm glass ¦ Patterning: HF/Icoflex.ch/APEX™

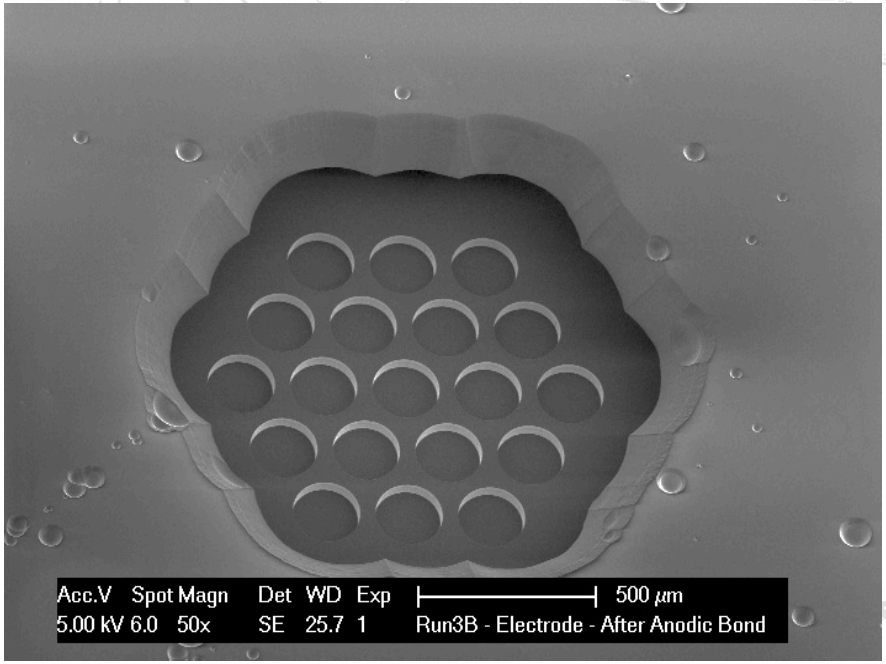
300μm bulk silicon wafer ¦ Patterning: DRIE

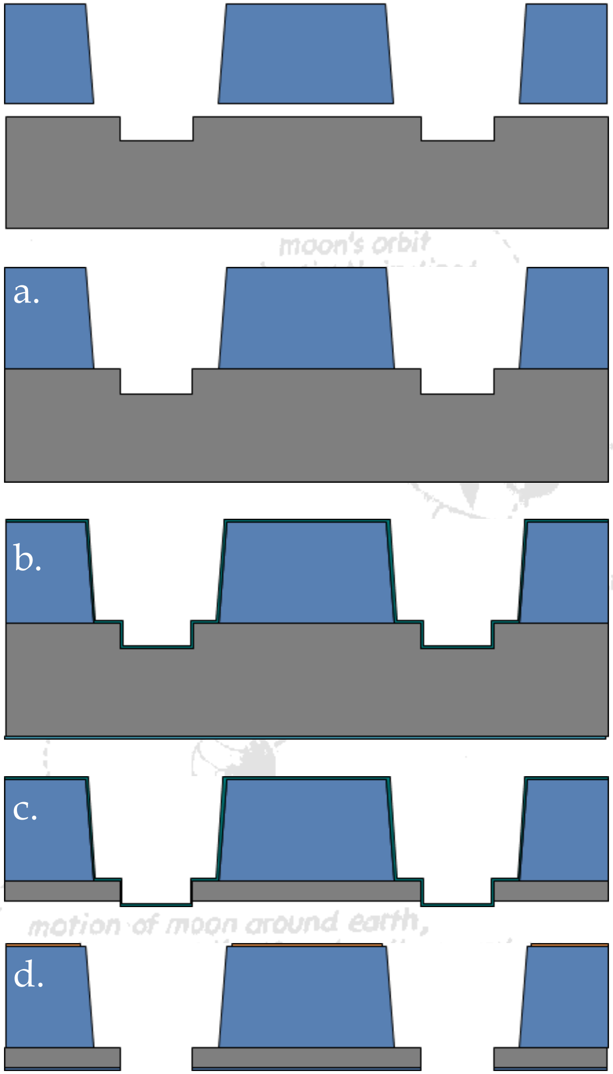
a. Anodic bonding

b. Parylène deposition

c. Backgrind & CMP

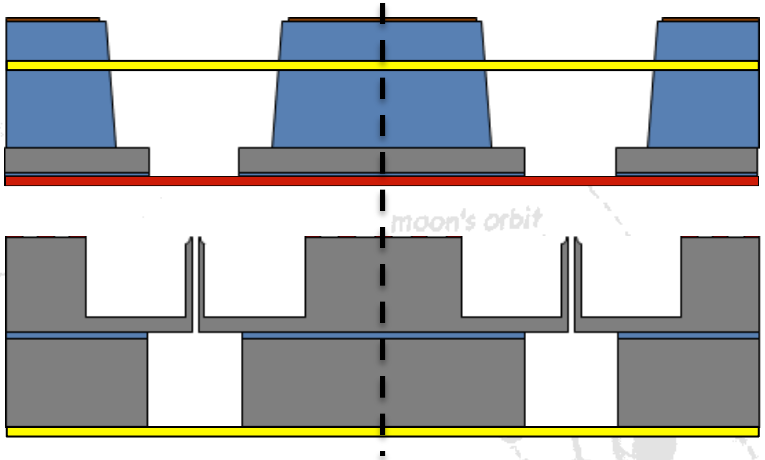
d. SiO2 sputtering & Metallization

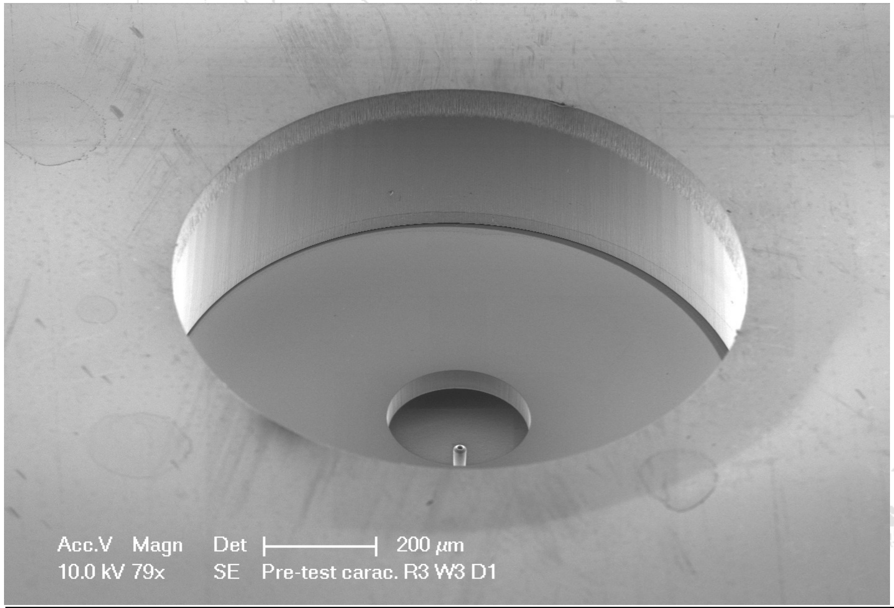


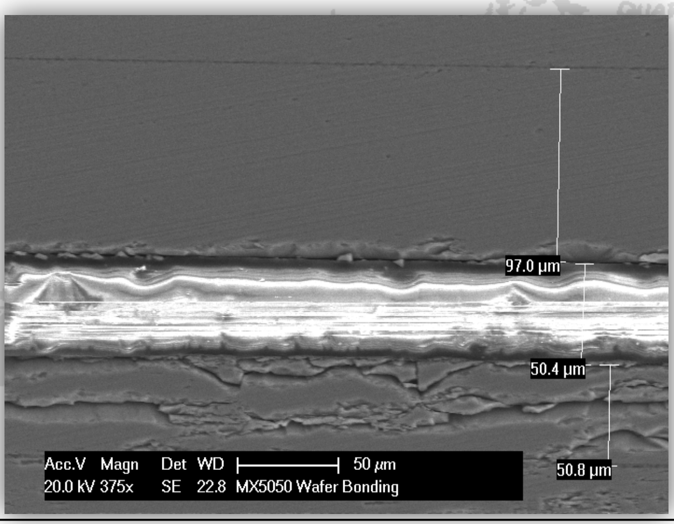


Wafer level assembly

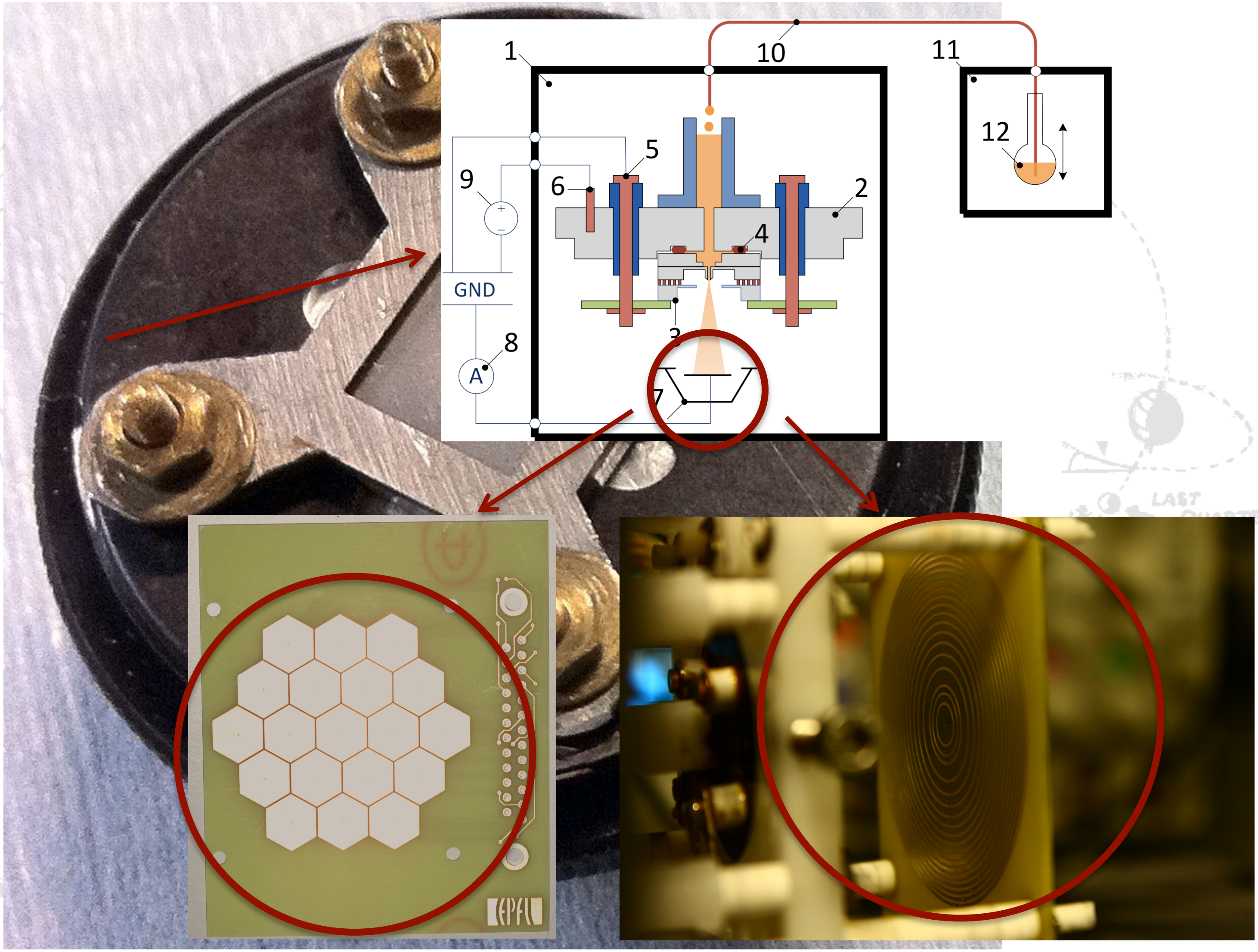
1) Extractor & Emitter Wafers
2) Dry resist lamination & Photolithography
3) Bonding
4) Dicing





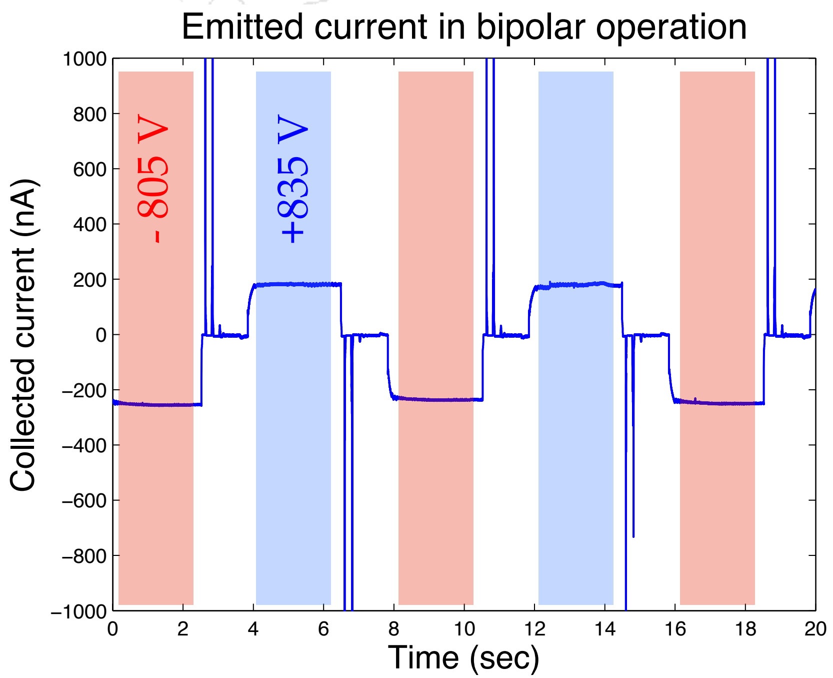


Evaluating the performance

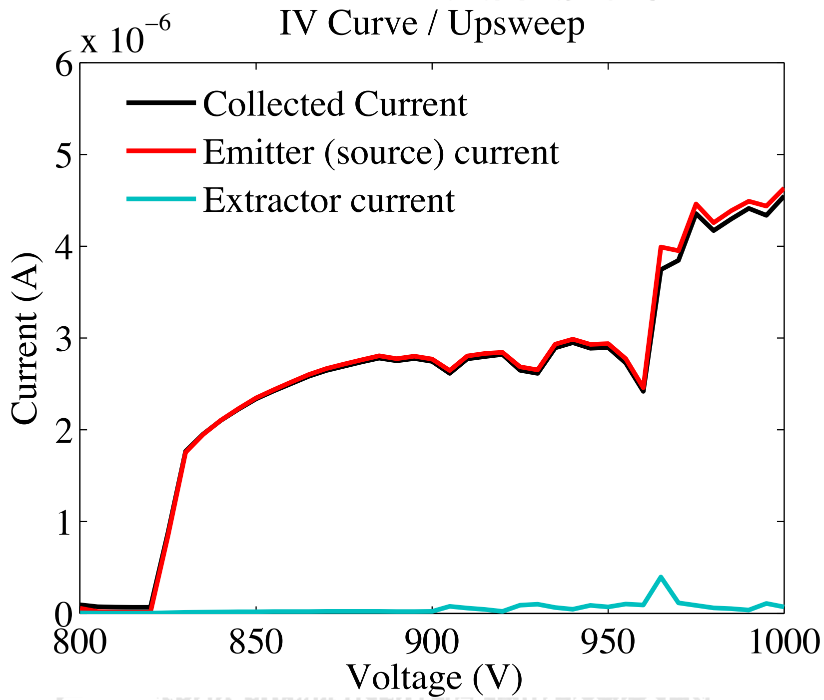


Onset voltage through IV curves

- Onset voltage ~825V
- Current: ~200nA/emitter
- Positive, negative operation



Single emitter, 200μm extractor, after 17 hours bipolar spray with miniature HV supply

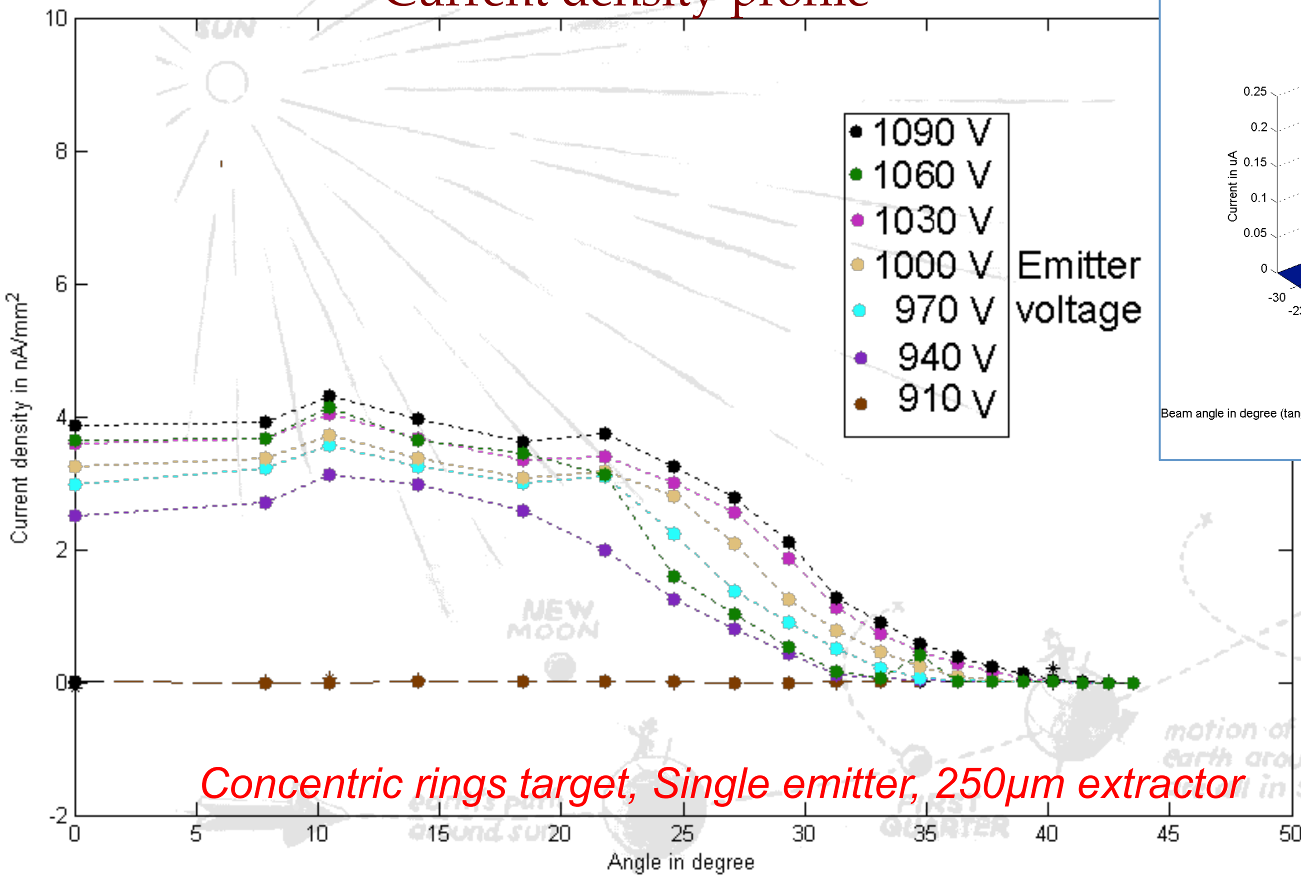


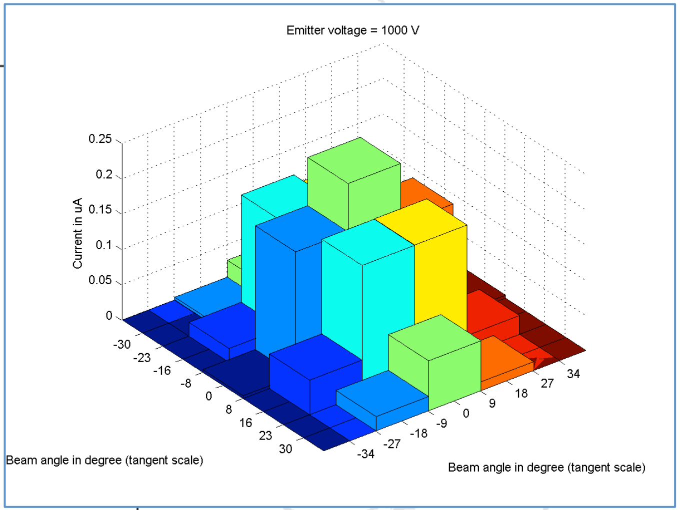
19x array, 200μm extractor

Understanding the beam shape

- Initial characterization: full-angle ~60-80 degrees
  - Beam shape depends on voltage applied (i.e. beam composition)

Current density profile





Hexagonal plates target, single emitter, 200µm extractor

Summary

- Microfabricated electrospray thrusters can be miniaturized to provide propulsion to CubeSats and other small satellites (< 100kg)
- MicroThrust consortium currently building a breadboard to demonstrate the technology
- I_{sp} from ~200s to 2500s reached, but uncontrolled due to low impedance emitters
- Spray up to 20 hours achieved in bi-polar operation
- Next steps will include further reduction of capillary dimensions to access high I_{sp} operation with high repeatability

Acknowledgements

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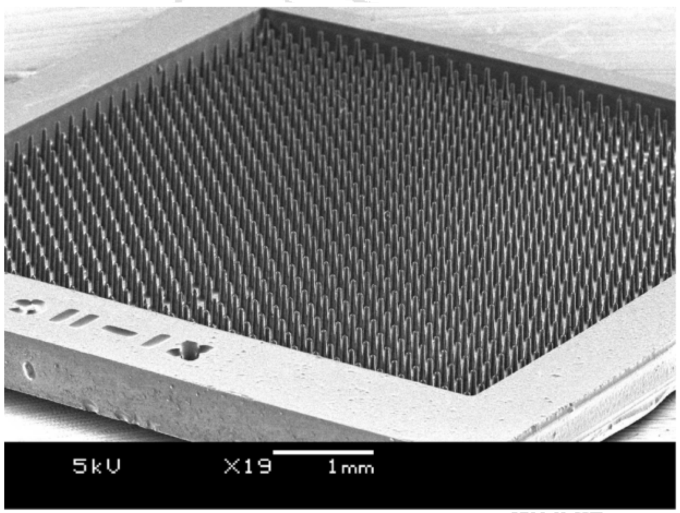
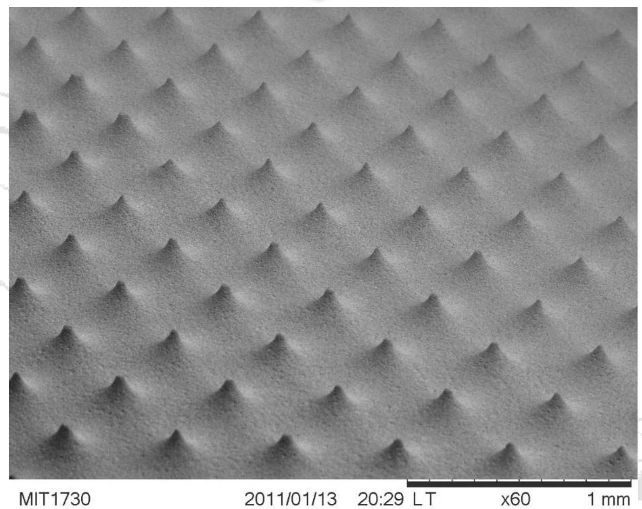
- Authors thank project partners Nanospace, TNO, SystematIC, the Swiss Space Center and the staff of the CSEM and CMI cleanroom

Types of microfabricated emitters

Externally wetted | **Porous material** | **Internally wetted**



Velasquez-Garcia, et al. "A planar array of micro-fabricated electrospray emitters for thruster applications." Journal of Microelectromechanical Systems 15, no. 5 (October 2006): 1272–1280.



Porous emitter array,
Retrieved from MIT Space propulsion Lab. website, Aug 29 2012: http://web.mit.edu/aeroastro/labs/spl/research_ieps.htm