7th ESA Round-Table on MNT for Space Applications
9-2010

Electric Propulsion on a Chip: Micromachined Thrusters for Nanosatellites

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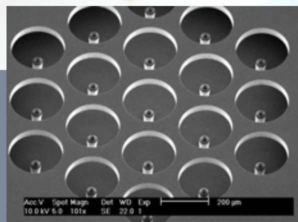
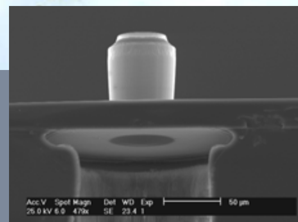
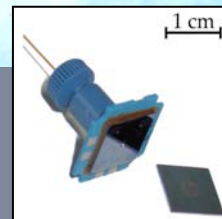
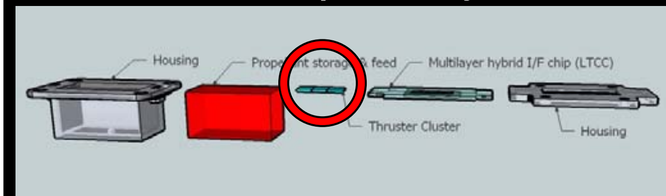




Overview

- We have fabricated a miniaturized colloid thruster chip, using ionic liquids as propellant
  - Emits ions at up 40 km/s (specific impulse of 4000s at 1.5 kV)
  - Very efficient use of propellant mass
- Thruster is batch fabricated from silicon wafers, to provide sufficient thrust (µN to mN) for a wide variety of missions for satellites of mass 1-100 kg
- Now working with European consortium (FP7) to
  - build full thruster system (including power supply, interfaces, etc), and
  - increase maturity of thruster and www.microthrust.net
- This talk focuses on the chip design and fabrication
- Next talk by TNO addresses some system aspects from an ESA funded study on MEMS-based Electric Propulsion

MicroThrust Consortium

MEMS Electric Propulsion System – Full system



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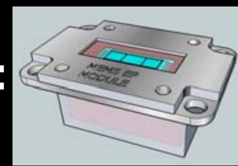


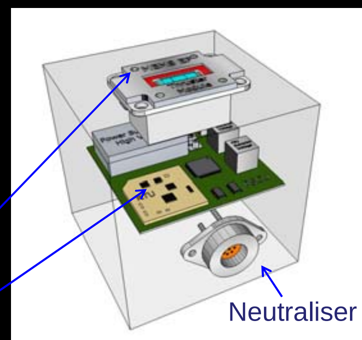
60 g

4 country consortium developing miniaturized MEMS electric propulsion in an FP7 Space project: MicroThrust

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

MEMS EP module
60g, incl. 20g propellant

Power and control board



http://www.microthrust.net

150 g, fits in a cubesat

Performance goals

- Thrust range: 1 µN – 1 mN
- Lifetime: > 10'000 hours
- Specific Impulse 1500 s to 3000 s (i.e., exit velocity 15 to 30 km/s)

for pico/nanosatellites:

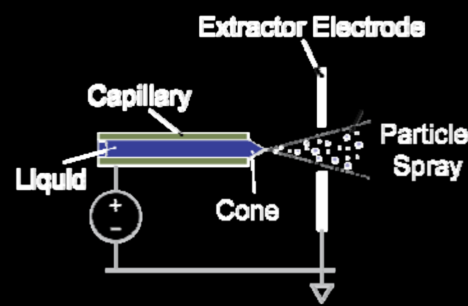
-Total mass and power are key

-Missions include:

- •deorbiting,
- •debris clean-up,
- •orbital transfer,
- •formation flying
- •Attitude control

Electrospray Principle of operation

1. Capillary filled with conductive liquid
2. Voltage applied between liquid & extractor electrode
3. After threshold voltage is reached spray of ions or droplets is emitted



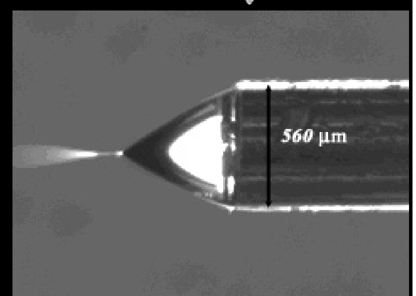


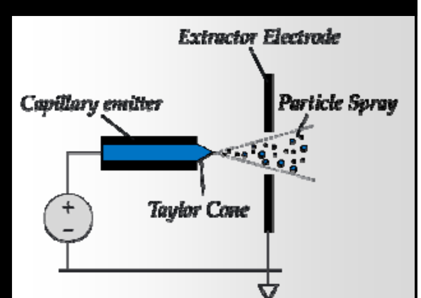
Image courtesy of M. Alexander, QMUL

Electrospray – Principle of operation

- If the liquid's conductivity is low or flow rate is high, the spray consists of **droplets** (colloid thrusters). Large m/q
- If the liquid's conductivity of the liquid is sufficiently high, the charged spray consists of **ions** for low flow rates. Small m/q

$$Isp = \frac{1}{g}\sqrt{2V_a \frac{q}{m}} \qquad T = I\sqrt{2V_a \frac{m}{q}}$$

q charge
V_a applied voltage
g 9.8 m/s^2
m particle mass
I current
T thrust

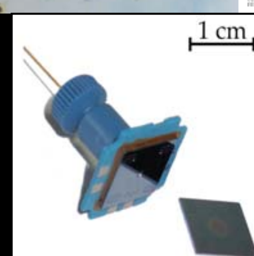


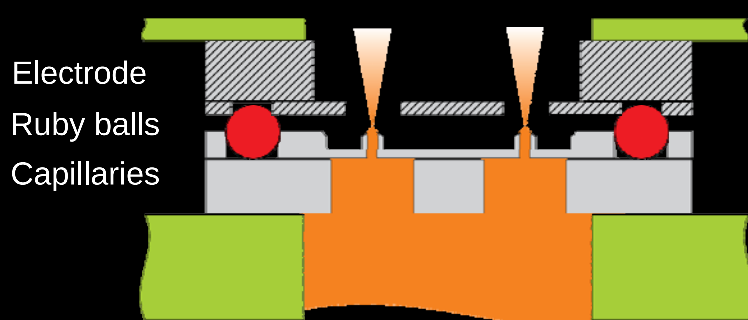
For typical liquids, get 1 ∝N/emitter, using about 3 mW power…
so need arrays to get useful thrust range (∝N to mN)

Microfabricated solution

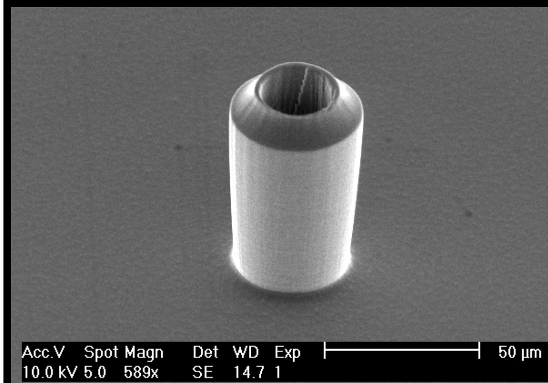
- **Arrays** of thrusters with individual extraction electrodes enable:
  - Large thrust range (∝N to mN)
  - Redundancy
  - Lower operation voltage
  - High ISP (by operating in ion regime)
  - Simple operation (no active pumping)

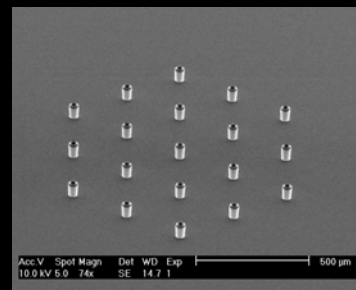
Thruster schematic cross-section

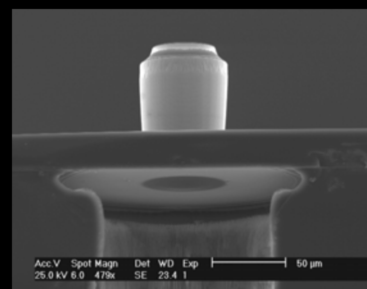




Silicon Capillaries

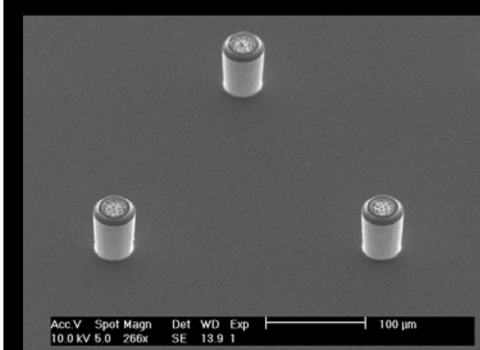


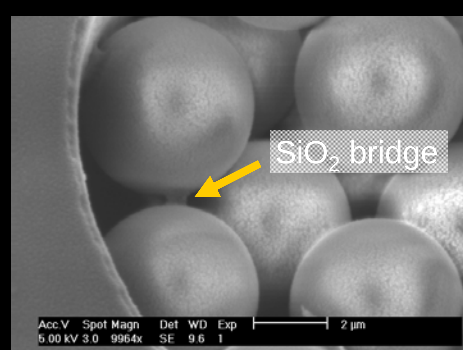




"Integrated out-of-plane nanoelectrospray thruster arrays for spacecraft propulsion", R. Krpoun and H. Shea, Journal of Micromechanics and Microengineering, 19, p. 045019, 2009

Tailoring the flow impedance

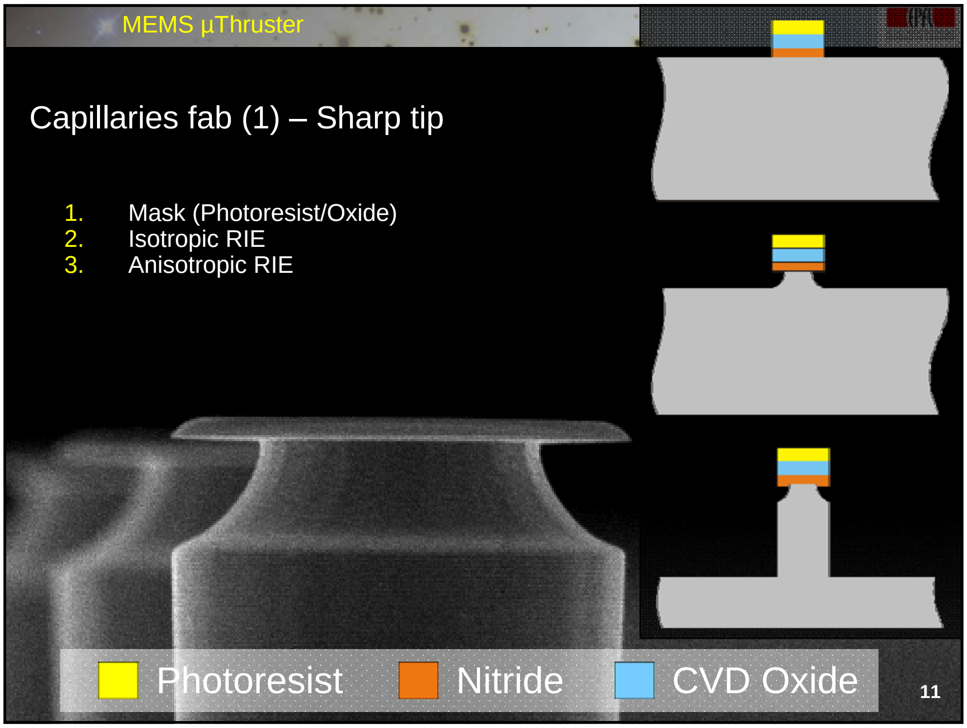


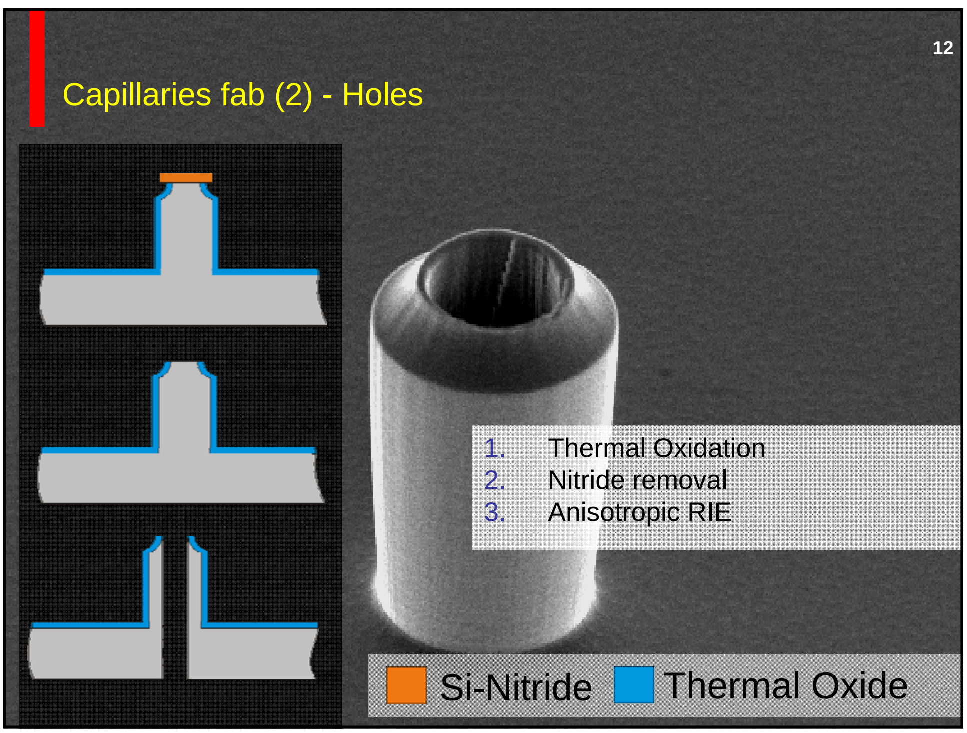


- Introduced 5 µm diameter silica microbeads
- Fixed inside the capillary using $SiCl_4$ gas

$$SiCl_4 + 2 \cdot H_2O \rightarrow SiO_2 + 4 \cdot HCl$$

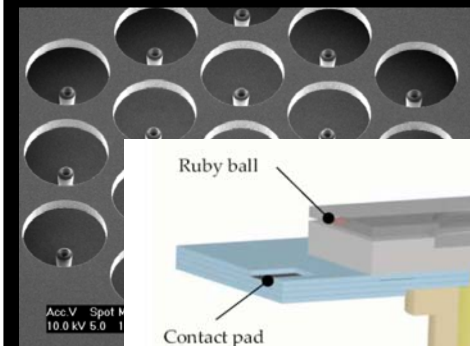
Tailoring the hydraulic impedance of out-of-plane micromachined electrospray sources with integrated electrodes."' R. Krpoun *et al*, , Applied Physics Letters, 94 p. 163502, 2009

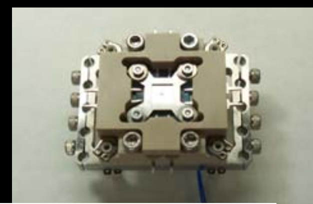

MEMS µThruster
Capillaries fab (1) – Sharp tip
1. Mask (Photoresist/Oxide)
2. Isotropic RIE
3. Anisotropic RIE
Photoresist
Nitride
CVD Oxide
11

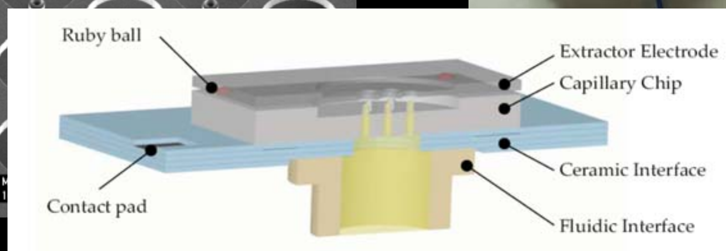

12
Capillaries fab (2) - Holes
1. Thermal Oxidation
2. Nitride removal
3. Anisotropic RIE
Si-Nitride
Thermal Oxide

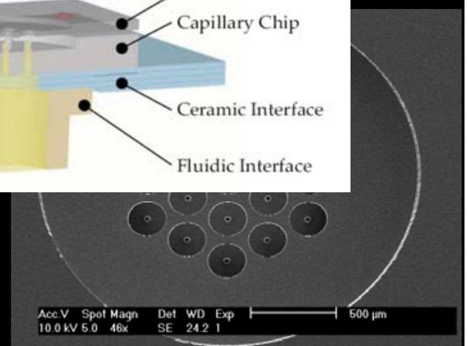
MEMS µThruster

Assembled thruster









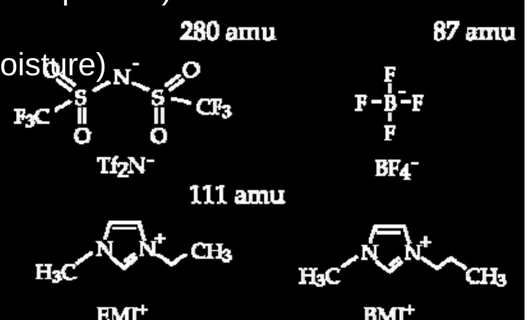
"Integrated out-of-plane nanoelectrospray thruster arrays for spacecraft propulsion", R. Krpoun and H. Shea, Journal of Micromechanics and Microengineering, 19, p. 045019, 2009

MEMS µThruster

Ionic Liquids (Room temperature molten salts)

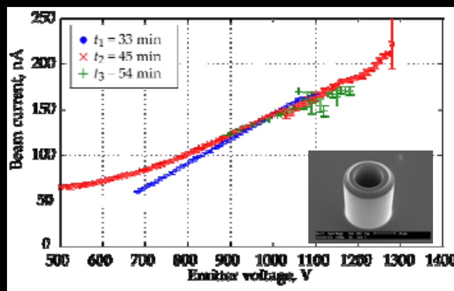
+ Composed solely of anions & cations
+ No measurable vapor pressure
+ High conductivities
+ Tailoring of ionic liquids possible
+ Radiation tolerant
+ Stable (non-flammable, non-explosive)

− Contamination (Absorbs moisture)

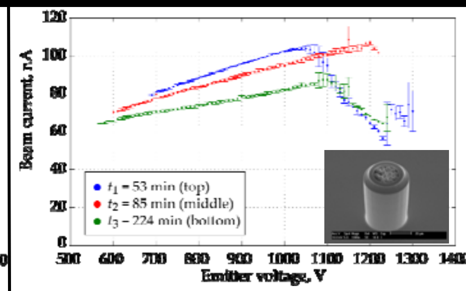


EMI-BF4
EMI-Im (=EMI- Tf_2N)

I-V characteristics: operation in ion and mixed (droplet/ion) modes



no µ-beads
(droplet & ion mode)

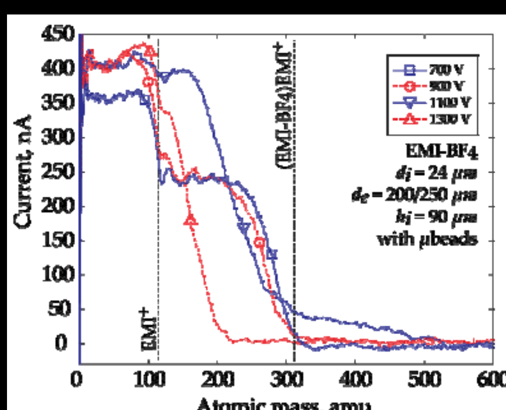


with µ-beads
(pure ion mode <1100V)

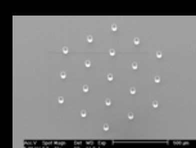
- Sprayed liquid: EMI-Tf_2N (aka EMI-Im)
- Configuration: single capillary

$$T = I\sqrt{2V_a \frac{m}{q}}$$

Time of Flight data demonstrates ion mode operation



data taken by K. Smith & J. Stark, QMUL



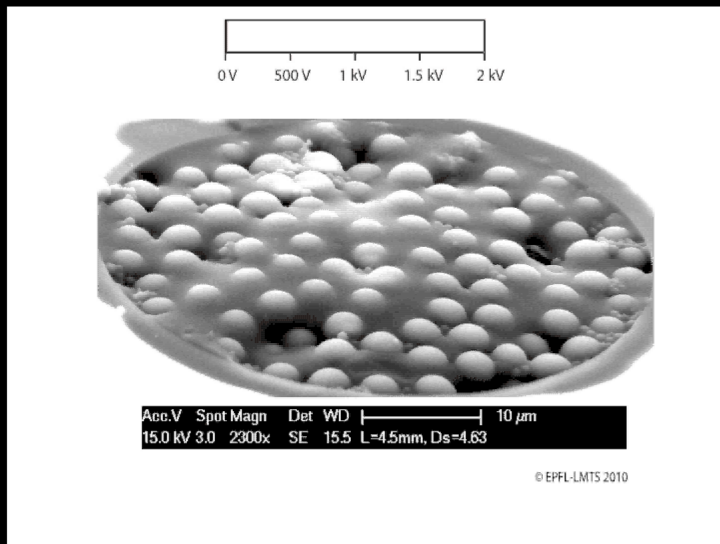
- Sprayed liquid: EMI-BF_4
- Specific impulse: 4000 s   40 km/s
- Thrust for 5x5 cm^2 = 100 ∝N

Tailoring the hydraulic impedance of out-of-plane micromachined electrospray sources with integrated electrodes."' R. Krpoun *et al*, , Applied Physics Letters, 94 p. 163502, 2009

Flow impedance (beads) and voltage enables tunable operation between ion mode and droplet mode.

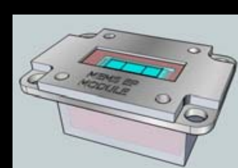
Electrospray from capillary

Use SEM to image ionic liquid when apply up to 2 kV

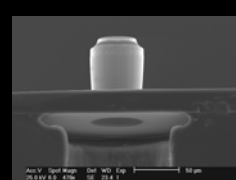


MEMS µThruster

Conclusions on our micromachined electric propulsion system



- Small satellites need micropropulsion !
- High yield microfabrication process validated
- Thruster operation demonstrated for small arrays
  - Ion and droplet mode both achievable: variable Specific Impulse, 500 s to 4000 s at 1.4 kV
- Open issues: lifetime, complete system integration, physics of emission



- FP7 EU project starting with 5 partners to address system aspects and increase maturity

We intend to fly this within 4 years !

Financial Support from:

- European Space Agency
- European Commission
- EPFL

Thanks to the ESA Electric Propulsion team, in particular:
- Jose Gonzalez del Amo
- Davina di Cara
- Alexandra Bulit

Thanks to John Stark, Kate Smith and colleagues at QMUL, UK

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