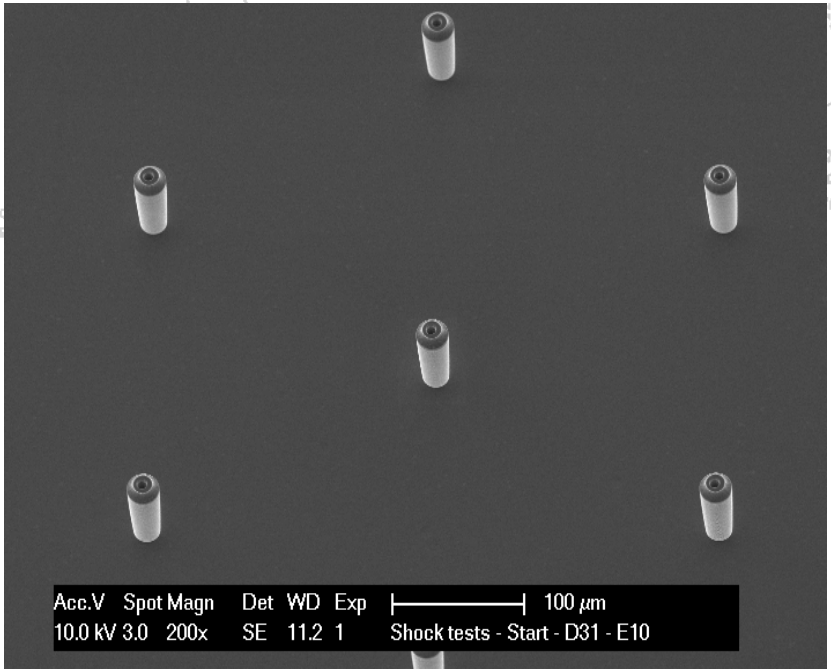
Evaluation of propellant containment under acceleration, shock and vibration for the MicroThrust electrospray thruster system



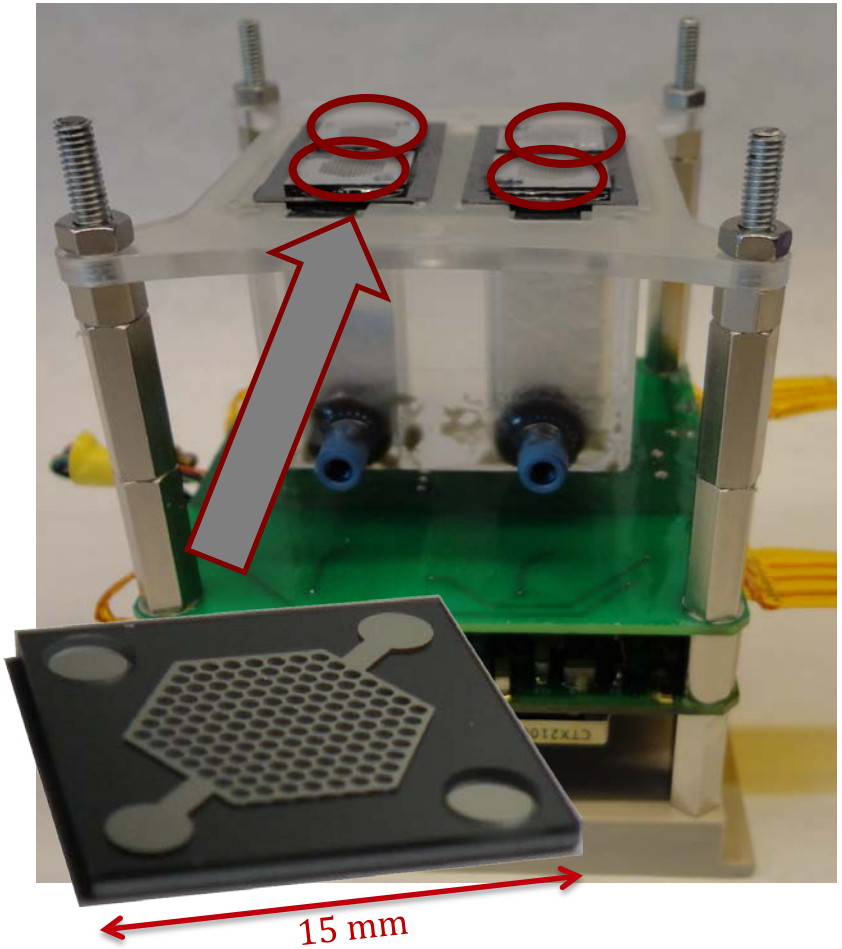
S. Dandavino, C. Ataman, B. Huber, D. Courtney, S. Chakraborty and H. Shea

EPFL, Switzerland

9th ESA Round Table on Micro and Nano Technologies for Space Applications, Lausanne • Switzerland, June 12-15, 2014

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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

- Isp: > 3000s (~1070s demonstrated[1])
- Thrust: 20 µN/W (~70 µN/W demonstrated[1])
- **ΔV: 5 km/s**

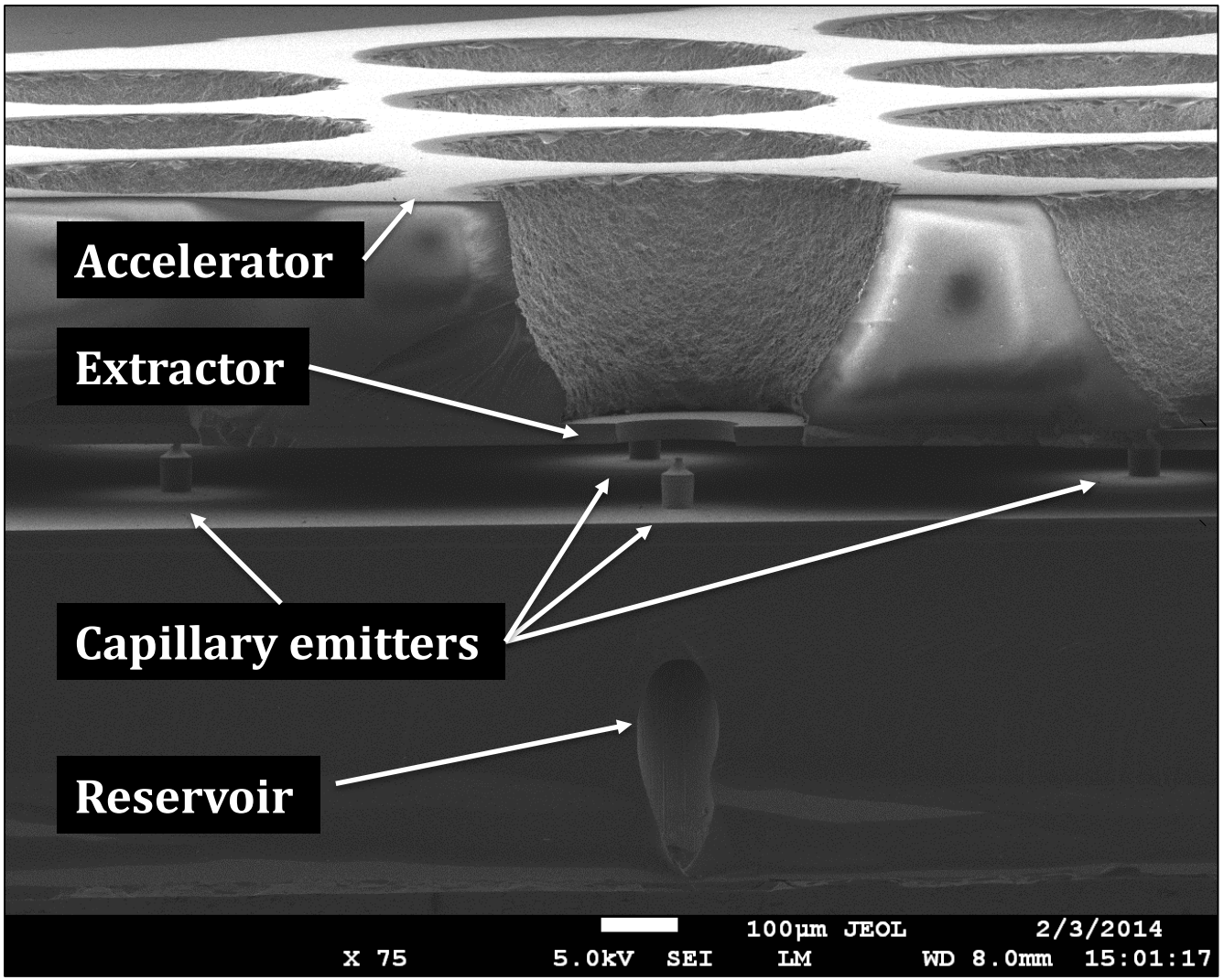
Partners:

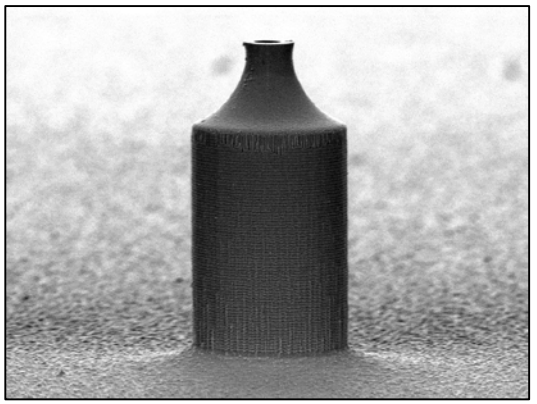
- EPFL (Switzerland)
- Queen Mary University of London (UK)
- Nanospace (Sweden)
- TNO (Netherlands)
- SystematIC (Netherlands)

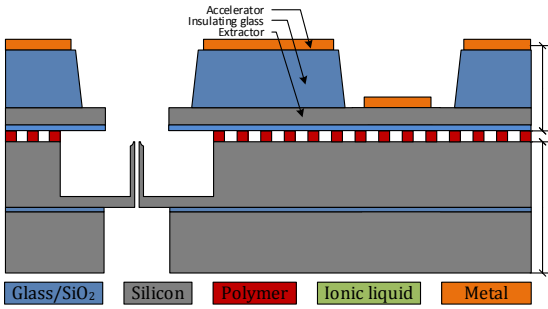
http://www.microthrust.eu

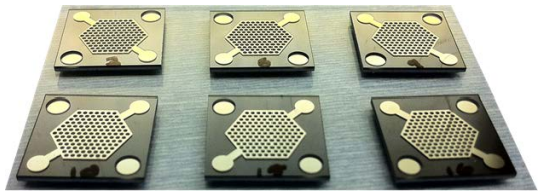
[1]*Ryan, C., et al. (2013). Experimental progress towards the MicroThrust MEMS electrospray electric propulsion system. In 33rd International Electric Propulsion Conference (pp. 1–10). Washington, D.C.*

Microfabrication for advanced integration and reduced footprint

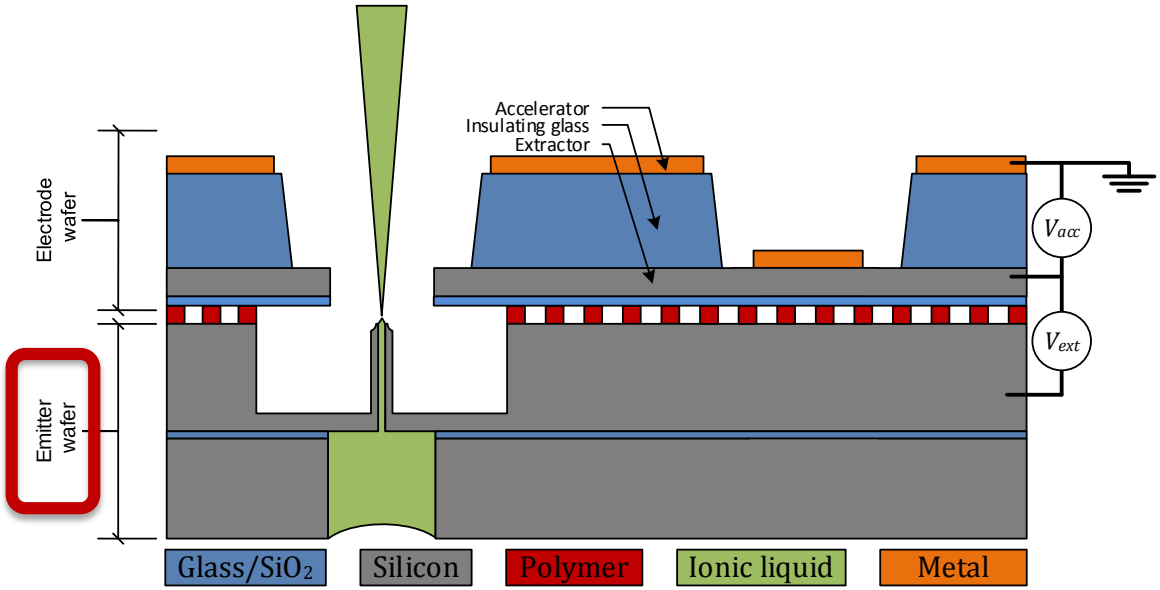


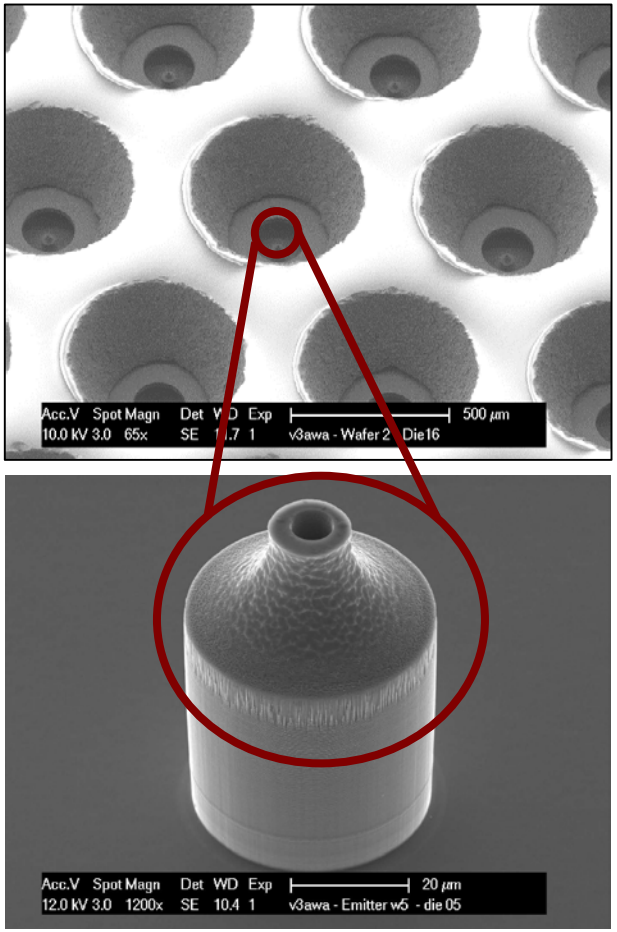






Our design of electrospray thrusters





MicroThrust thruster features

- No pressured tanks/lines (capillary feed)
- Very high fluidic impedance and low propellant flow rates
- Good electrical isolation
- No neutralizer (Ionic liquids can emit in both polarities)
- Large arrays (tens of thousands of emitters) can be fabricated
- Excellent alignment of electrodes (<5um)

Dandavino, S., et al. (2014). Journal of Micromechanics and Microengineering, 24(7), 075011.

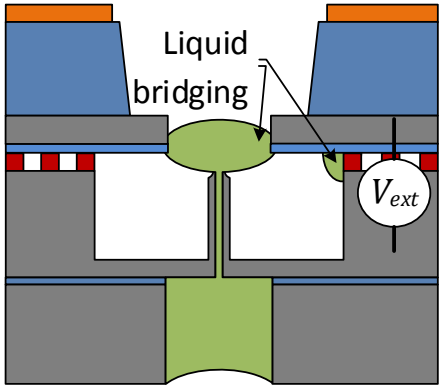
Motivation: Can the emitters contain the propellant?

- Liquid spillage from the emitters is a principal source of device failure.

- We are interested in the ability of the capillaries to contain liquid under different environmental constraints (acceleration, vibration and shock).
  - Worst case: emitters filled during launch

- We make no assumption on the added retention capabilities of propellant reservoirs (e.g. porous reservoirs), using bare emitters as test samples.

- We will present results on three aspects:
  - Static acceleration
  - Sinusoidal vibration
  - Shock

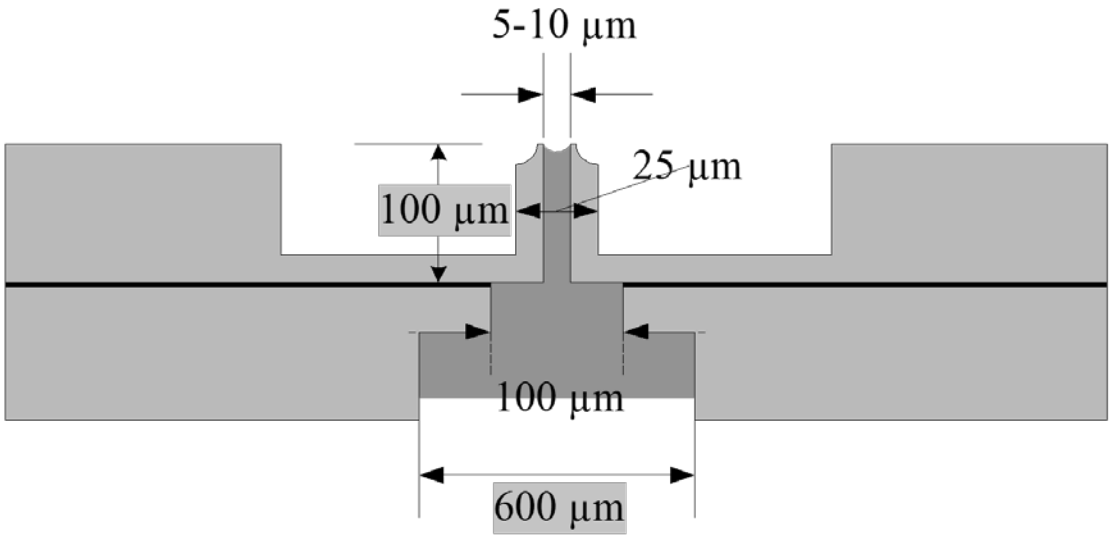


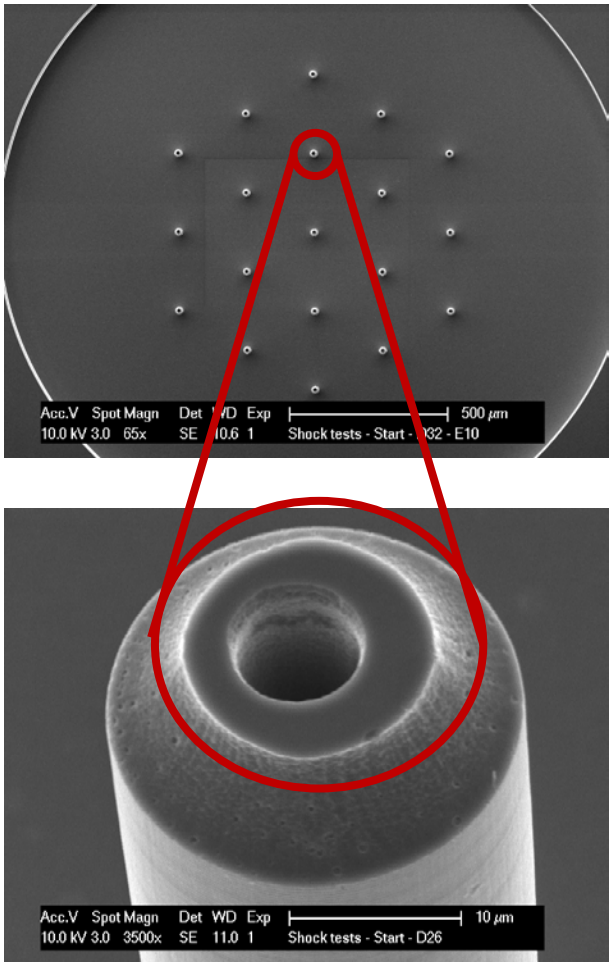
Ariane 5 launch, Credit: ESA

Electrospray emitter test samples

- Test samples are 1x1cm chips containing 1 to 19 microfabricated emitters.

- The inner diameters of the capillaries range from 5 to 10µm.

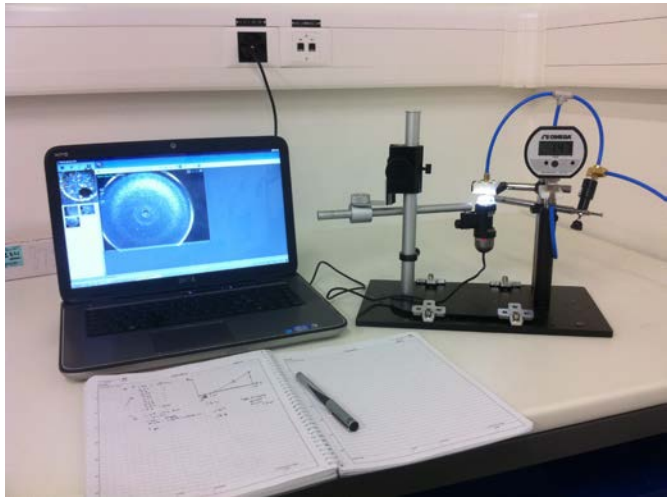




Using pressure to simulate static acceleration

- The holding pressure of liquid inside a capillary is (γ = *surface tension*, θ_c = *contact angle, D = capillary inner diameter*) :

$$P_{holding} = -\frac{4\gamma_{la}\sin\theta_c}{D}$$



- We validated this model with a pressure feeding setup and tested the propellant EMI-BF_4.

Propellant	ρ (kg/m³)	γ (N/m)	θ_c
EMI-BF_4	1.29E3	44.3	72 ± 2°

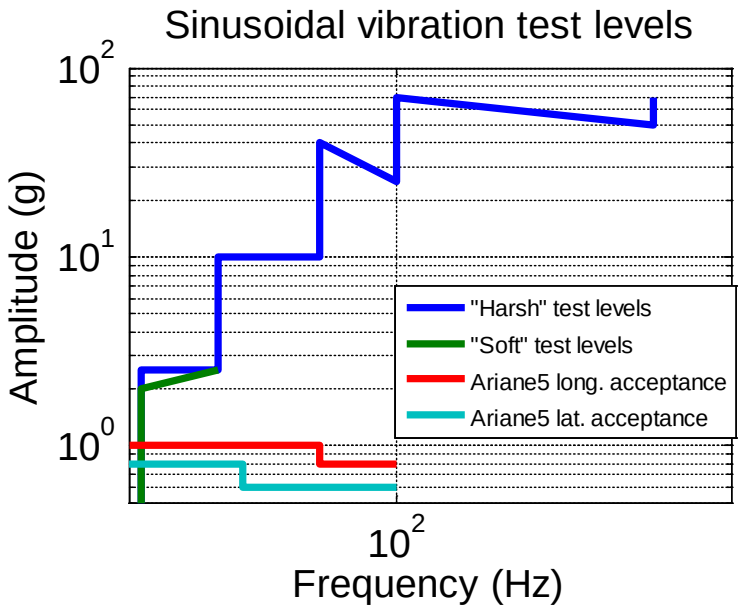
- We measured approximately 330 mBar holding pressure exerted by the capillary, enough to hold a 10cm liquid column up to 26g.

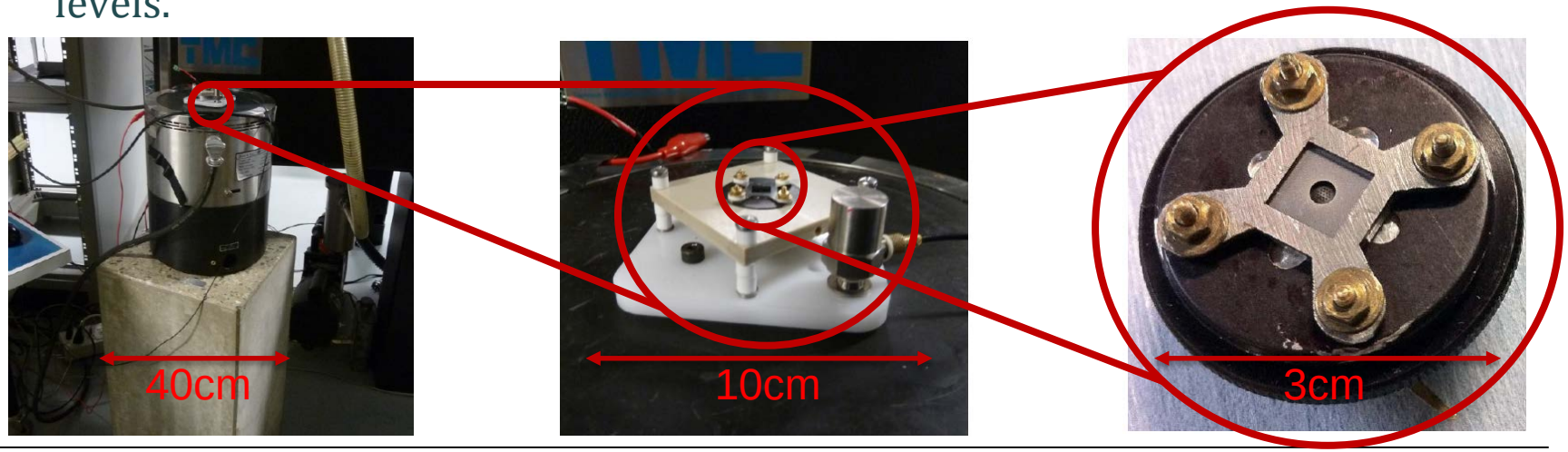
	Holding pressure
Modelled	369 ± 8 mBar
Measured	**332 ± 62 mBar (26g)**

Sinusoidal vibration tests setup

- Samples were mounted on a magnetically actuated shaker table (Vibration Exciter System V (body 4805, head4811) of Brüel & Kjær)

- Soft and harsh tests were performed on two sets of emitters.
  - Compared to Ariane 5 acceptance test levels.



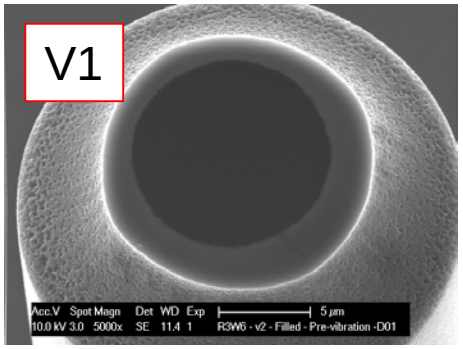


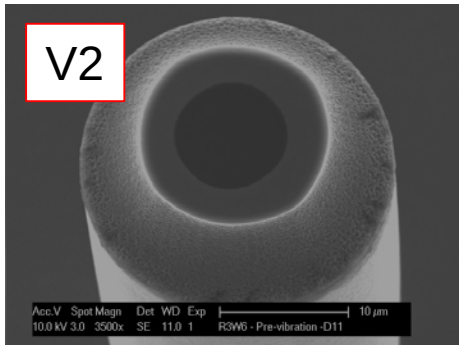
Results: Vibration tests

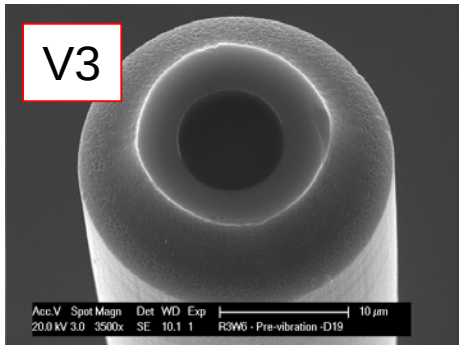
- No damage on any device
- No evidence of liquid spillage was found from any emitter (21 total)

Test #	*Die id*	*Number of emitters*	*Test levels*
V1	01	1	Soft
V2	11	19	Harsh
V3	19	1	Harsh

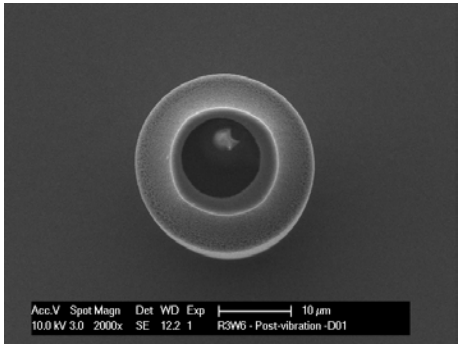
Before

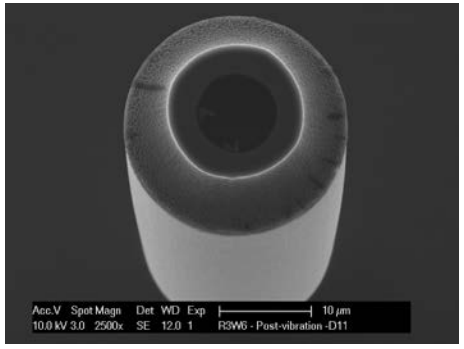


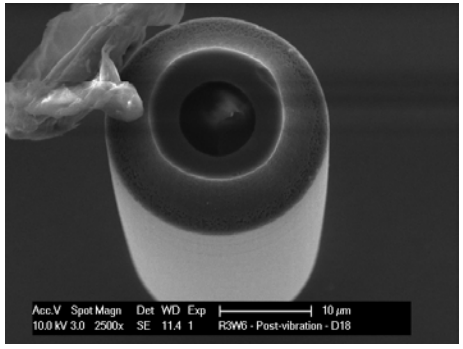




After



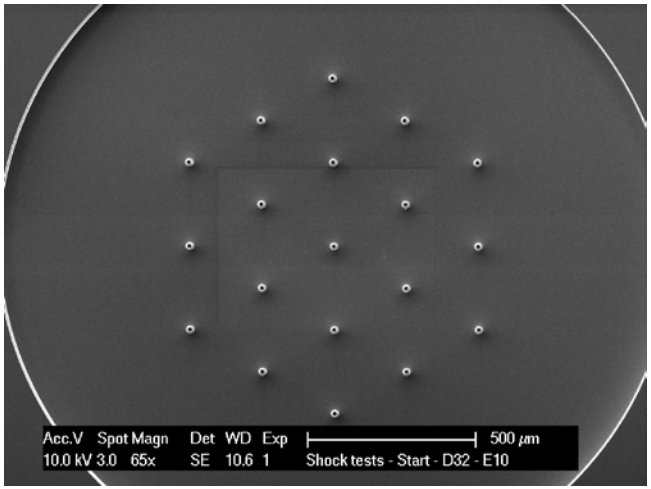


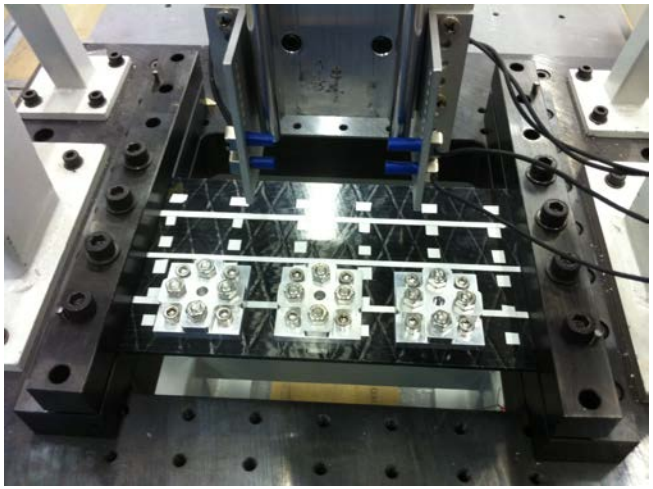


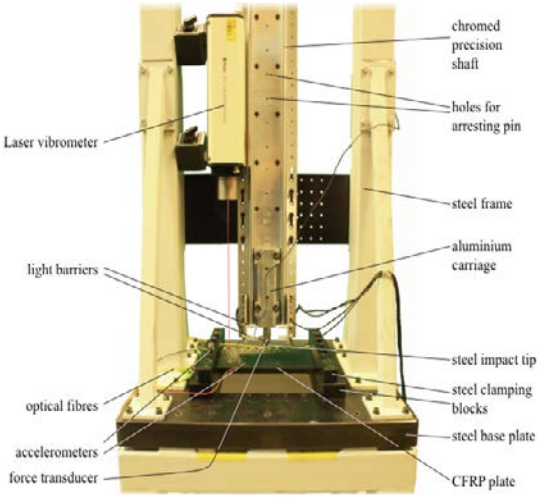
Shock test setup

- Samples were mounted on a CFRP plate installed in a drop test tower (LMAF lab. at EPFL, Jeannot Frieden)

- Longitudinal and lateral shocks were generated and compared to Lisa Pathfinder qualification test levels



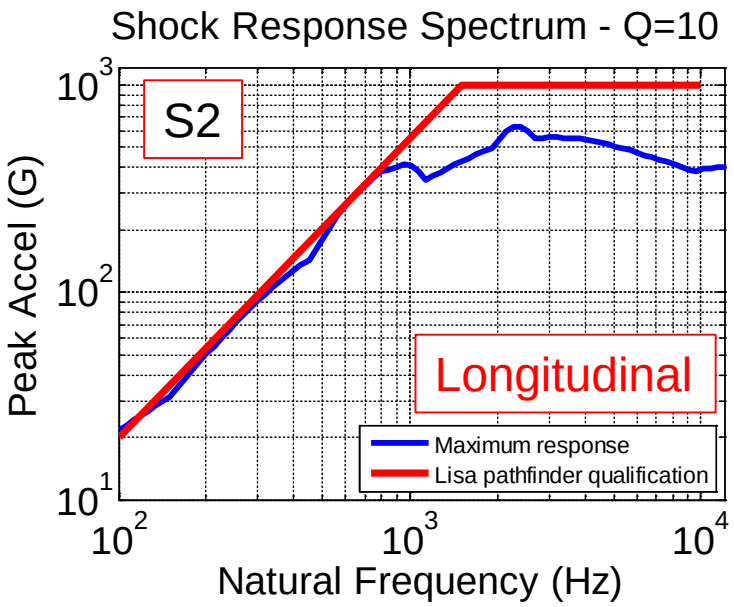


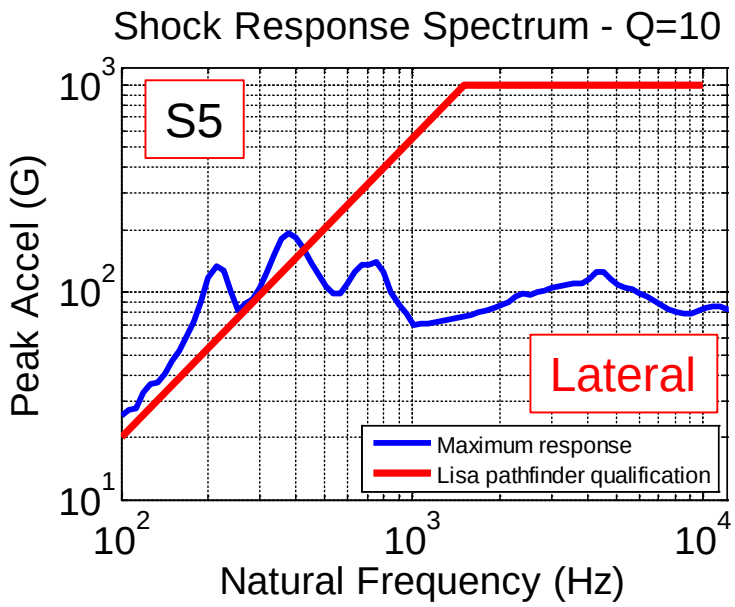


Results: Shock tests

- No evidence of damage on any sample (42 emitters)
- No evidence of spillage from 41/42 emitters
  - One drop found on sample S2

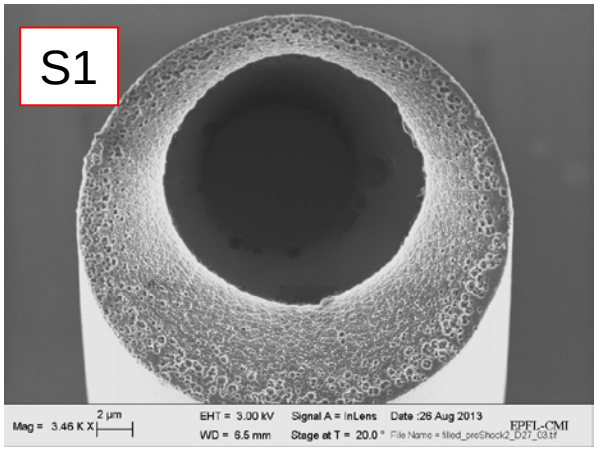
#	*Type*	*Drop height h (mm)*	*Mounting*
S1	Single emitter	500	Longitudinal
S2	Single emitter	750	Longitudinal
S3	Single emitter	750	Longitudinal
S4	Array	750	Longitudinal
S5	Single emitter	750	Lateral
S6	Array	750	Lateral

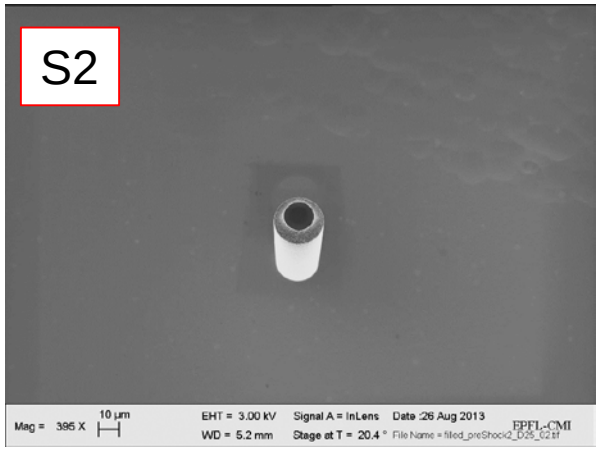


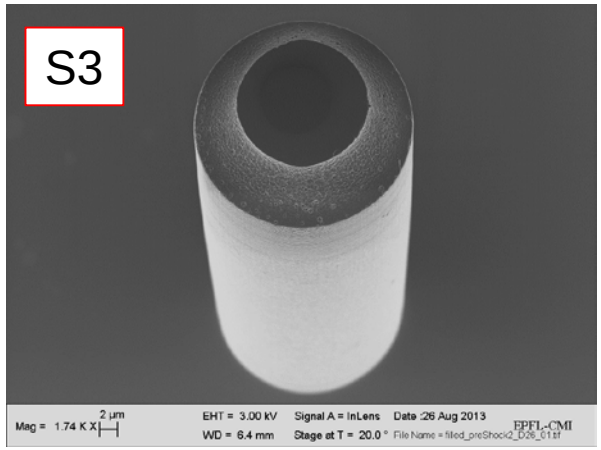


SEM images before and after shock

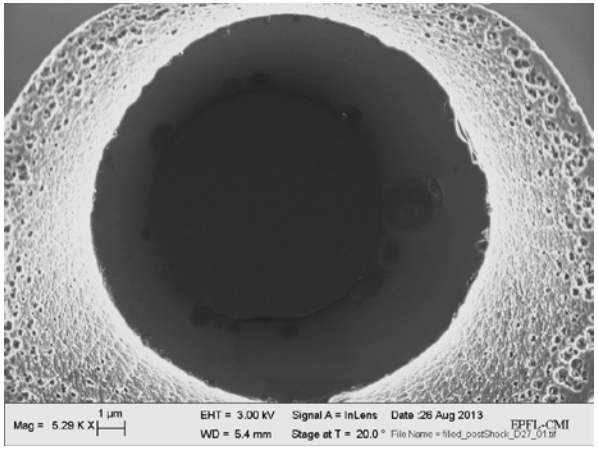
Before

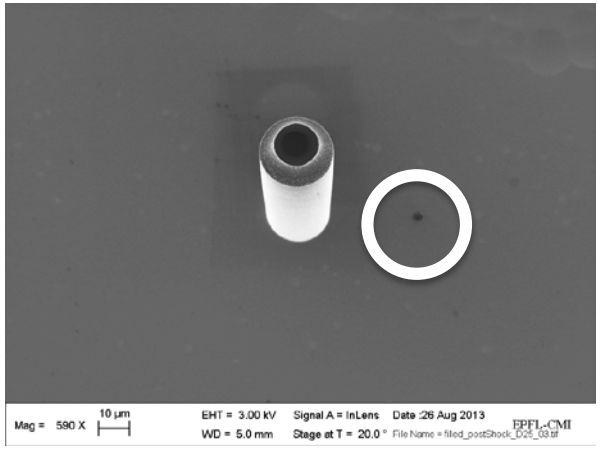


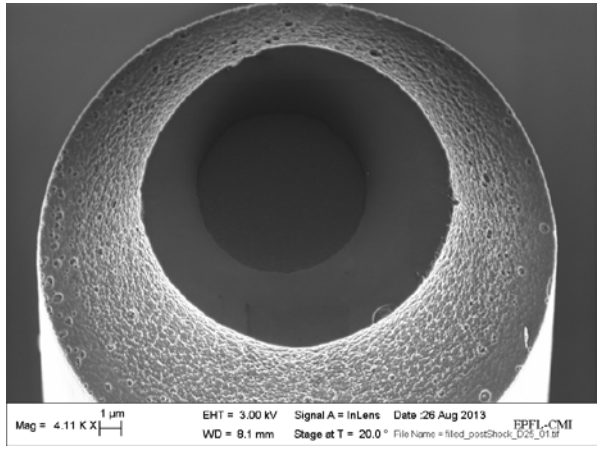




After







Conclusion

- We evaluated the ability of the microfabricated capillary emitters to contain liquid under different launch conditions:
  - Static acceleration
    - Model (which was validated) shows that approximately 26g of acceleration could be supported without spillage.
  - Sinusoidal vibration tests
    - No evidence of spillage under conditions harsher than the acceptance requirements of Ariane5 (3 samples)
  - Shock tests
    - Possible evidence of spillage from 1/41 emitters, with conditions close to the requirements of Lisa Pathfinder qualification

- Under no condition did we find any evidence of structural damage or device degradation

Acknowledgements

- This work has been supported by the MicroThrust project, grant agreement number 263035, funded by the EC Seventh Framework Programme theme FP7-SPACE-2010 (www.microthrust.net) and by the Swiss National Science Foundation grant 200021-146365

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

- Special thanks to EPFL laboratories SAMLAB for the magnetic shaker installations and LMAF for access to the shock test setup.