Miniaturisation of Solid Propellant Thrusters for Space Application

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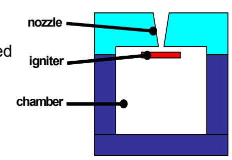
Outline

- Introduction – MicroPyros project
- MicroPyros demonstrator
  - Millimeter-scale DEMO
- Microscale device
  - Design, fabrication, assembling
  - Characterisation
- Conclusion & outlook

Introduction

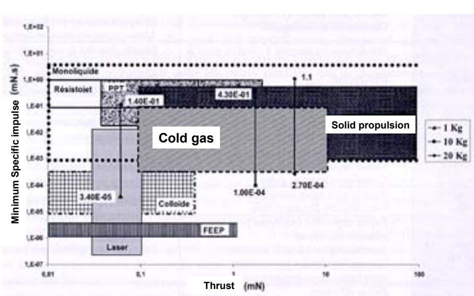
- MicroPyros project objectives (2000-2003)
  - Integration of energetic material, MEMS device and electronics to realise new performing PowerMEMS
  - Application of Micropyrosystems to propulsion
    - Nanosatellite: micropropulsion for station keeping
- Solid propellant concept
  - Combustion of a solid material stored in a micromachined chamber



Introduction

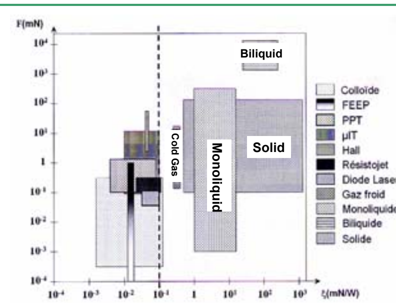
- Solid propellant technology
  - Combustion : large quantity of energy from small volume
  - Solid fuel : no leakage, stability in time
  - No moving parts, eliminating frictional force and making technological fabrication easier
  - The chamber is not pressurised, the reservoir does not need to be massive

Introduction



From B. Larangot, Conception, fabrication, caractérisation de matrices de micropropulseurs pyrotechniques sur silicium, Thesis, LAAS/CNRS, 2004

Introduction



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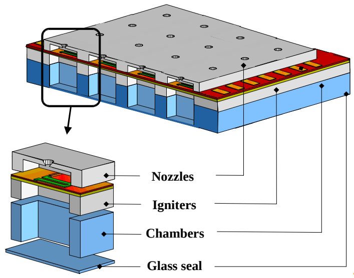
Microthrusters : mm-scale DEMO

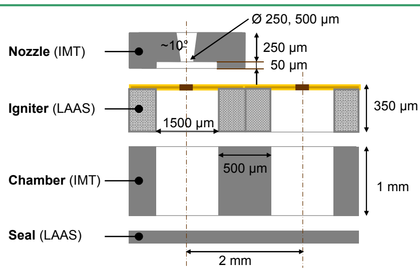
- Single shot microthruster
  - ► Array of 4 x 4 microthrusters (16 thrusters)



Challenges

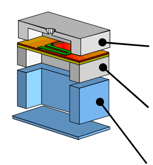
- Compromises between the reduction of the dimensional features and combustion process considerations
- Management in a very small volume of high temperature and pressure that could lead to mechanical failure
- Limits of silicon and the introduction of best appropriate materials implying to bond different materials together
- Compatibility of processing and assembling with the propellant

DEMO Design



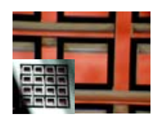
- Array of 4 x 4 microthrusters
- Chip size : 14.65 mm x 14.65 mm

DEMO Fabrication Technology



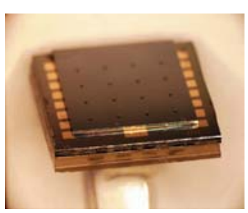
	Material	Technology
Nozzle *(IMT)*	Si	Diverging angle : conic DRIE Cavity : KOH
Igniter *(LAAS)*	Si, polySi	RIE, DRIE
Chamber *(IMT)*	Si	DRIE
	Foturan	HF10%






DEMO Assembling

- Filling of the parts with propellant
  - Igniter
  - Sealed chamber

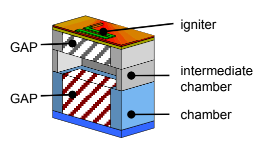


- Assembling
  - Anodic bonding
  - Thermal gluing (epoxy glue)

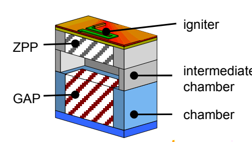
DEMO: Tests

- Set-up
  - Source I, measure V(t) => power, energy calculated
  - Thrust balance : thrust force measurement (LAAS)

- **Ignition tests** (GAP / GAP)
  - Ignition power : 100–150 mW
  - Ignition time : 20–130 ms
  - Combustion time : ~ 320 ms

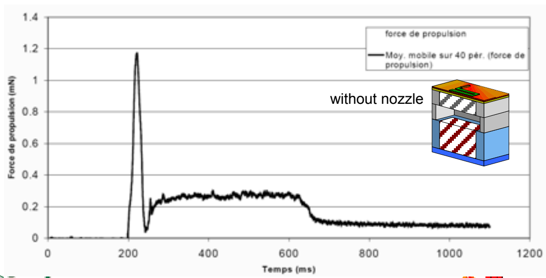


- **Ignition tests** (ZPP / GAP)
  - Ignition power 150–200 mW
  - Ignition time : 80–130 ms
  - Combustion time : ~ 270 ms



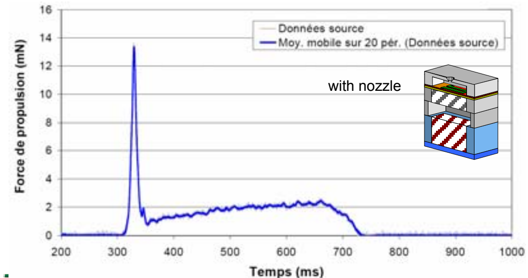
DEMO: Thrust Force

– Force without nozzle :
  - ZPP : 1.2 mN
  - GAP : 0.28 mN



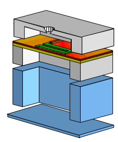
DEMO: Thrust Force

– Force with nozzle (Ø500 µm)
  - ZPP : 13.5 mN
  - GAP : 2.3 mN



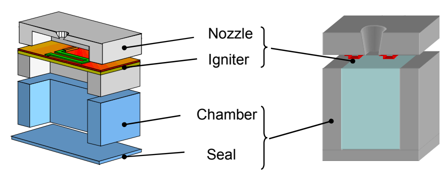
Microscale Device

- Objective
  – Investigation of the limit of integration
  – Miniaturisation
  – Reduction of the number of parts



- Microthruster dimensions
  – MicroPyros DEMO (macro-scale device)
    → 1500 µm x 1500 µm
  – Microscale device
    → 1040 µm x 1040 µm and 500 µm x 500 µm (275 µm x 275 µm)

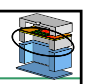
Microscale Device Design



– **Igniter on membrane** *(Design 1)*
  - Same design than MicroPyros with smaller dimensions

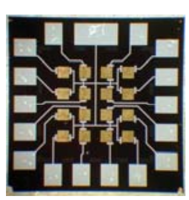
– **« Free standing » igniter** *(Design 2)*
  - New design

Igniters

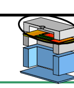


- Heaters characteristics:

Area	1 mm	500 µm
180 x 180 µm²	1020 Ω	830 Ω
390 x 390 µm²	1975 Ω	1730 Ω
720 x 720 µm²	3340 Ω	–

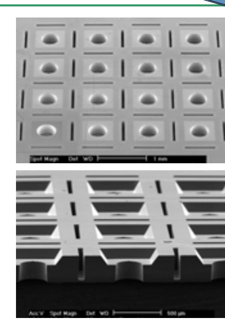


Nozzles



- Throat diameters

Diameter	1 mm	500 µm
275 µm	–	X
375 µm	X	X
500 µm	X	–

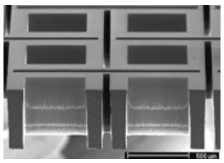


- Silicon bulk micromachining: DRIE and KOH

Chamber Fabrication

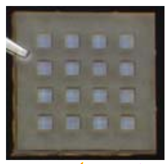
- Technology developped for the mm scale design
  - DRIE of silicon wafers
  - Wet etching of Foturan glass wafers

Si: 500 µm chambers 50 µm grooves

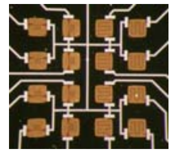
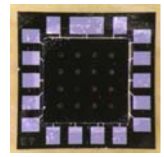
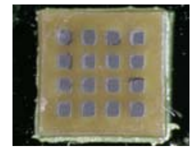


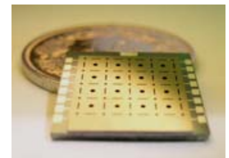
Si: 500 µm chambers 250 µm grooves

Foturan: 500 µm chambers



Assembling

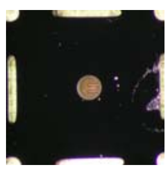
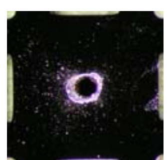






Ignition and Combustion

- Constant current of 7.0 to 7.75 mA

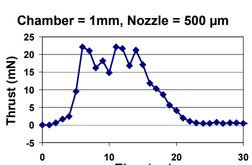
Area	1 mm	500 µm
180 x 180 µm²	60-90 mW	65 to 105 mW
390 x 390 µm²	130-200 mW	125-200 mW
720 x 720 µm²	200-375 mW	–

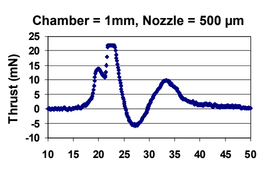



Ignition and Combustion

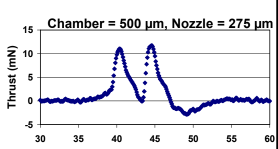
- Ignition time: 27 to 37 ms
- Ignition energy: 4.9 to 7.9 mJ

Ignition and Combustion

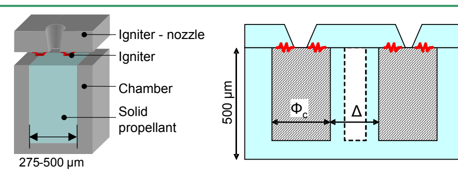




- Combustion time: 10 to 15 ms
- Thrust force: 12 to 23 mN



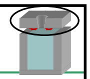
Microscale Device: Compact design



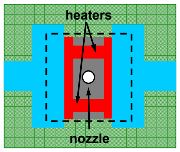
Φ_c [µm]	Δ [µm]	groove [µm]	nozzle diameter [µm]
500	250	50	180- 240
	500	200	
275	225	50	100 - 130
	475	175	

– **Array of 4 x 4 microthrusters, chip dimension of 8 x 8 mm²**

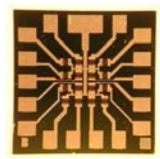
SOI Igniters Fabrication

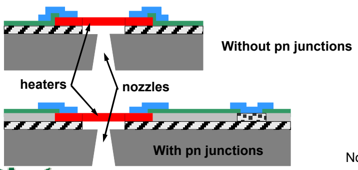


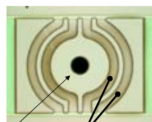
- SOI igniters



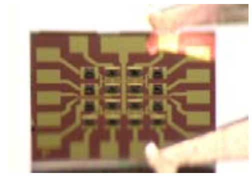
- SOI
- Si doping
- Si DRIE
- LPCVD Si_3N_4
- conic DRIE
- release : HF 50%
- Al contacts

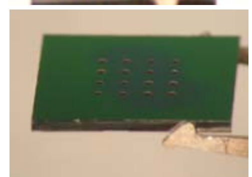


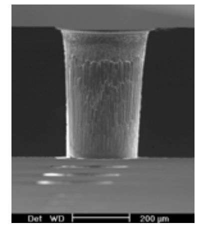




SOI Igniters

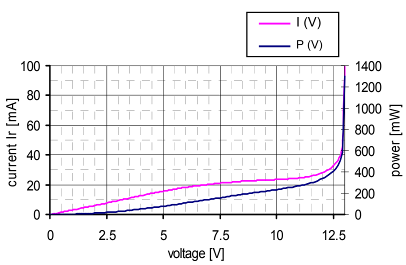


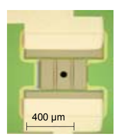




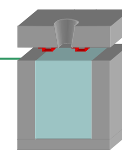
SOI Igniter Characterisation

– Maximum electrical power controlled by a limitation on the current delivered

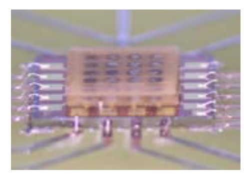




Assembled SOI Thrusters



- One step filling procedure
- One bonding step (epoxy gluing)



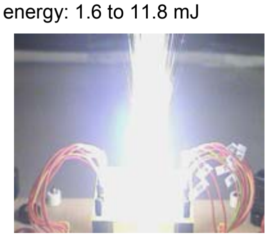
- Heater: 200 to 400 ohms

  2 x 1 or 2 x 2 beams

Ignition SOI Thrusters

Constant Current of 10 to 24 mA / beam

- Ignition time: 6 to 24 ms
- Ignition power: 225 to 400 mW
- Ignition energy: 1.6 to 11.8 mJ



Conclusion

- Micrometer scale device
  - Design and specification of a micrometer scale device
  - Processing development to fabricate smaller igniters with integrated nozzles
  - Successful ignition of ZPP stored in sub-mm cavities
  - Key points:
    - reproducibility of the propellant filling
    - Development of propellant, igniters, filling and assembling are strongly linked

Outlook

- Complete the characterisation of the ignition and combustion in smaller dimensions
- Optimised designs and fabrication processes
  - Nozzles
  - Igniters
  - Assembling

➢ **Validation of the technology in a space mission**

MicroPyros

- Project funded by the European Commission
- Involved partners:

CNRS LAAS
Groupe Lacroix
Albert-Ludwigs-Universität Freiburg
IMTEK
Universitat de Barcelona
Uppsala University
The Ångström Space Technology Centre