Recent Advances in the Development of Reliable and Simple Solid-Propellant Thrusters and Balloon Actuators

Danick Briand, Ulrich Bley, Laurent Guillot, Nico F. de Rooij

Sensors, Actuators and Microsystems Laboratory

Institute of Microtechnology

University of Neuchâtel, Switzerland

Ruag Ammotec: Ulrich Bley, Sascha Danninger, Erich Muskat

Ruag Aerospace: Volker Gass

LMTS / EPFL : Philippe Dubois, Lysandre-Ed Bonjour, Herbert Shea

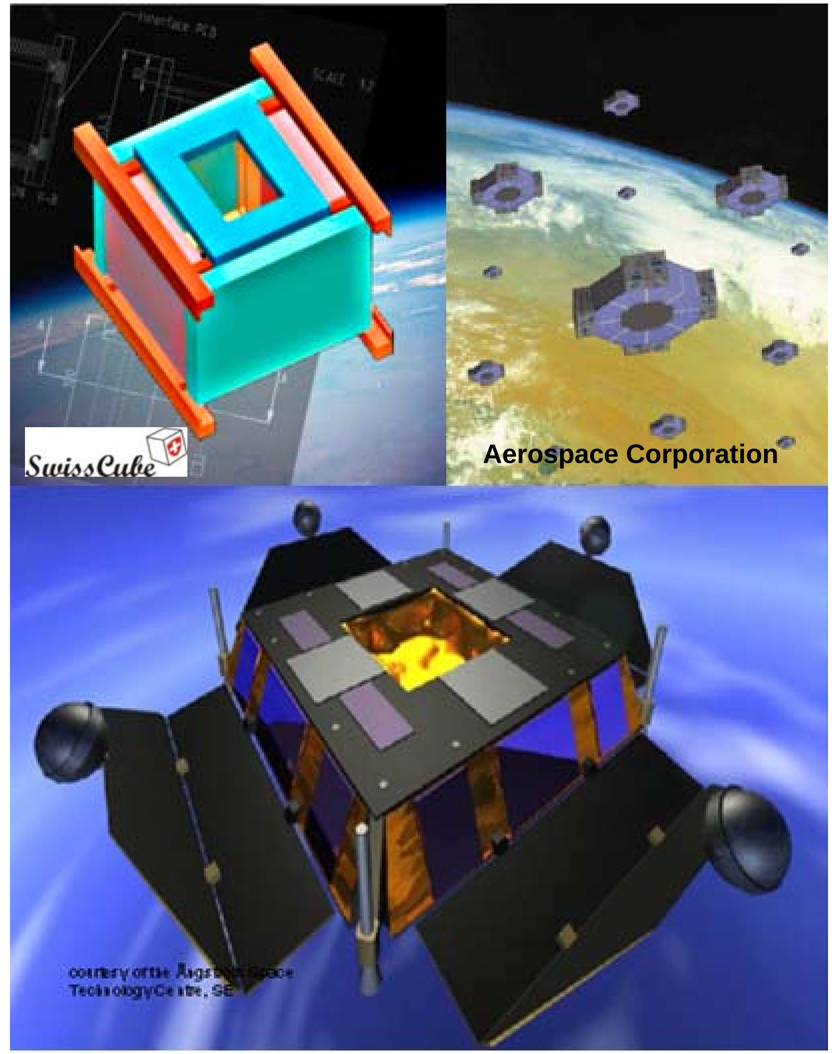
EPFL Space Center project: 009/2005

Outline

- Introduction
- Concept and design
- Propellant
- Characterisation of the ignition
- Micro-thrusters and balloon actuators
- Conclusion and outlook

Introduction

- MEMS in Space
  - Can start replacing larger components
  - Stacked MEMS wafers for self-contained mass produced 1kg satellite
    - Arrays of pico-satellites for weather prediction, or communication, space science…
    - “Inspector” satellites piggy-backed on larger satellites



Introduction

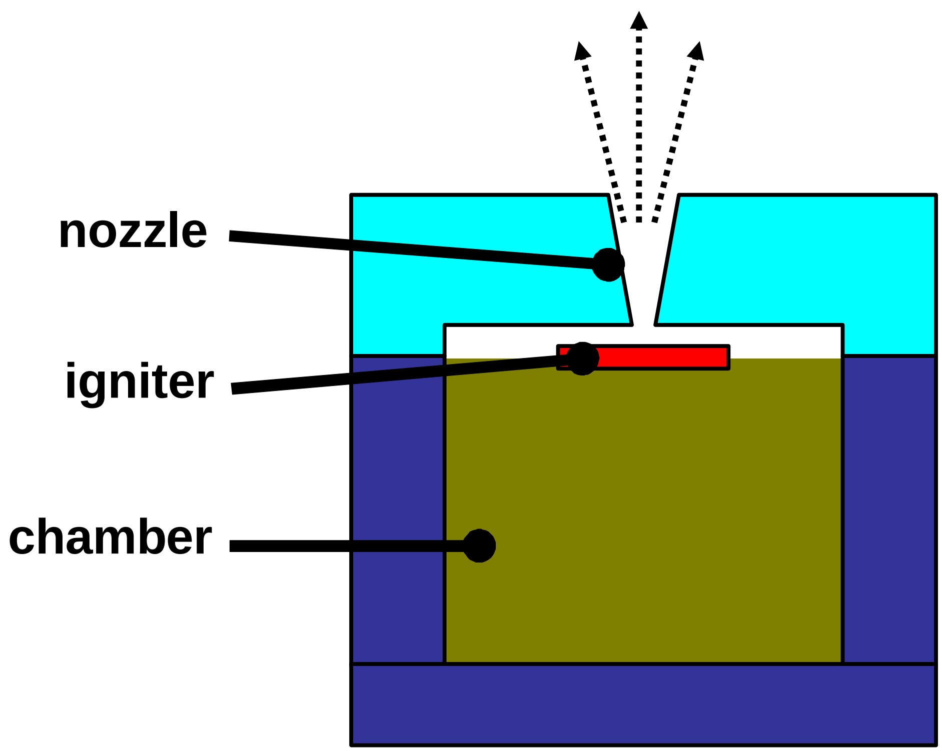
- **Micro propulsion**

Technology	Isp	Thrust range		Efficiency	Typ. Power	Power-to-Thrust
	sec	min	max		W	W/mN
FEEP thrusters	4'000-8'000	1µN	2-4 mN	30-90%	10-150	40-75
Ion thrusters	2'000-3'500	10µN	500mN	50-75%	200-3'000	25-40
Hall-effect thrusters	800-3'000	5µN	200mN	50%	400-5'000	15-20
Colloid thrusters	500-1'500	1µN	50 mN	70-55%	5-50	10
Conventional Resistojets	150-1'000	5mN	500mN	65-90%	500-1'500	1-3
Arcjets	450-2'000	50mN	5N	30-50%	300-10'000	7-9
Pulsed Plasma Thrusters	200-5'000	1µN	0.5-5mN	N/A	1-200	50-90
Cold gas microthrusters	80-120	1-5µN	0.5-5mN	N/A	1.5-3	N/A
Solid prop. microthrusters	100	1mN	300mN	N/A	1	N/A

From: Mikael Kilter, Micropropulsion technology assessment for Darwin,
Master thesis, Luleå University of Technology, 2004.

Introduction

- **Solid propellant concept**
  - Combustion of a solid propellant stored in a micromachined chamber

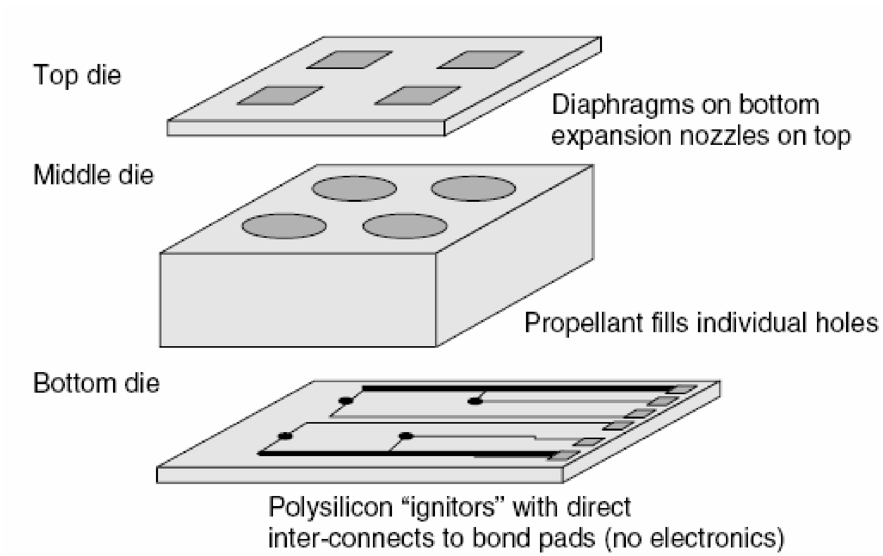


Introduction

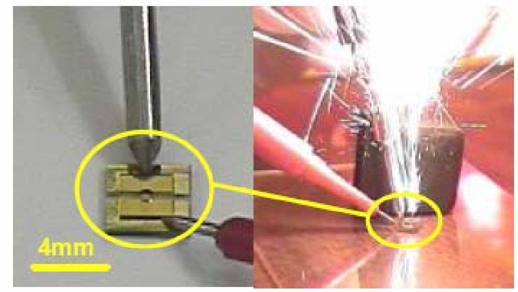
- **Solid propellant technology**
  - Combustion : large quantity of energy from small volume
  - Solid fuel : no leakage, stability in time
  - No moving parts, eliminating frictional force and making technological fabrication easier
  - The chamber is not pressurised, the reservoir does not need to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

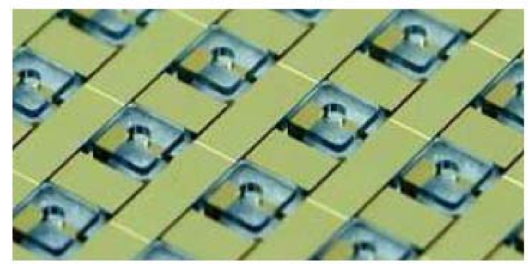
Introduction

- Solid-propellant micro-thrusters around the world



Lewis et al. Caltech USA



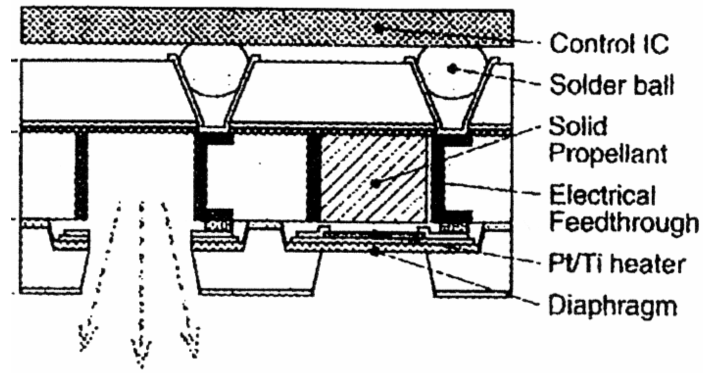


Mass fabricated array concept demonstrated in Phase I

Introduction

- Solid-propellant micro-thrusters around the world

Tanaka et al., Japan



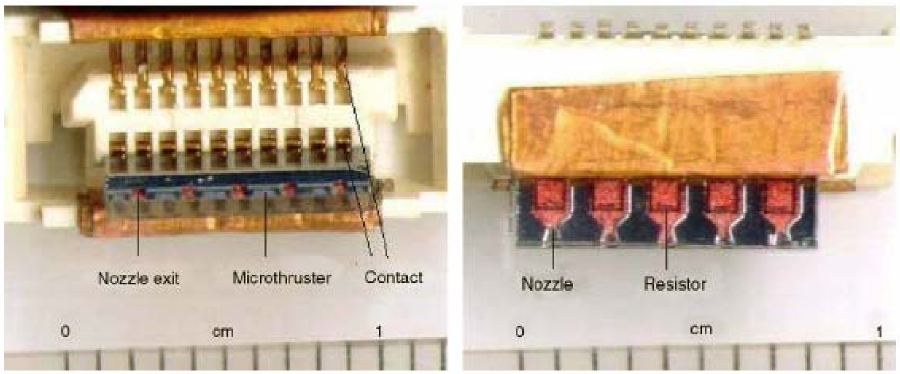
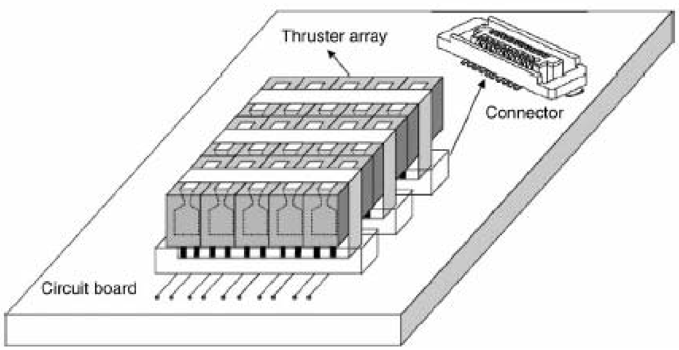
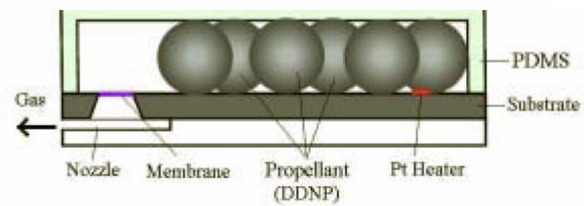


Fig. 9. Front and side views of the microthrusters installed a micro-connector.

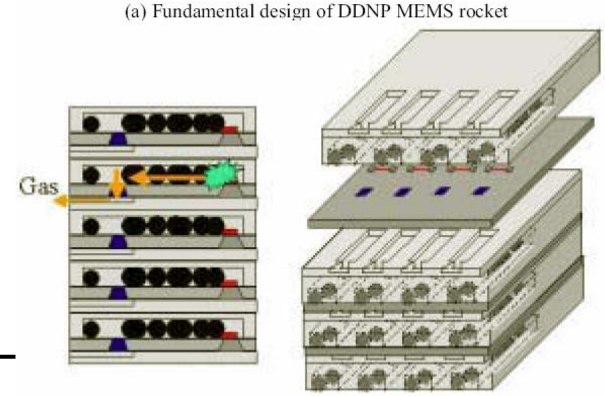


Zhang et al., Singapore



(a) Fundamental design of DDNP MEMS rocket

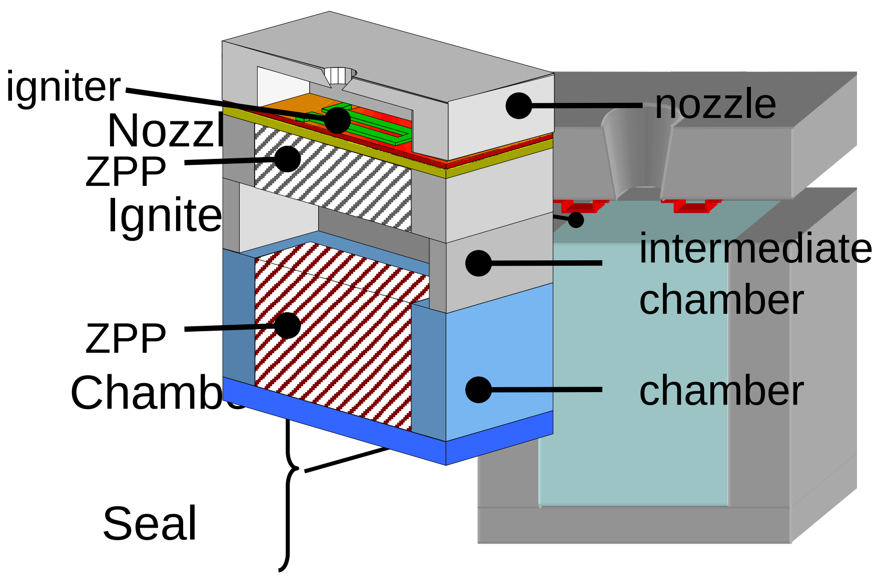
Takahashi et al., Japan

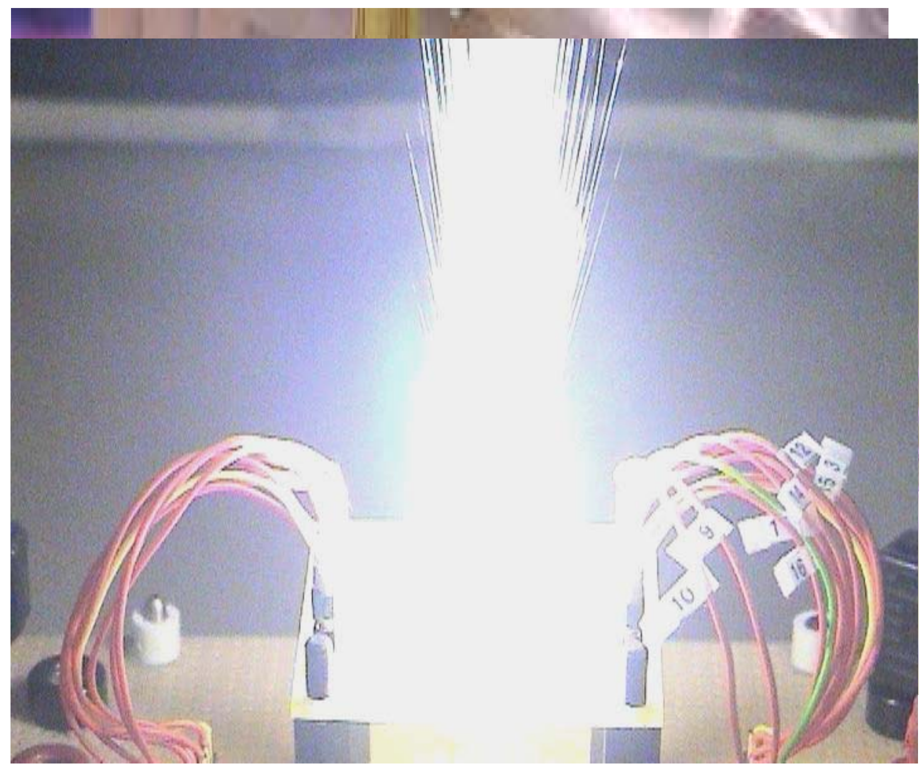


(b)Schematic of firing operation and three dimensional view of rocket array

Introduction

- European MicroPyros project





Introduction

- **Drawbacks**
  - Low ignition yield (bad contact between igniter and propellant)
  - Unsustained combustion in small dimensions (quenching)
  - Particules generation
  - Filling procedure not reproducible
  - Propellant and igniter not adapted to each other

➢ The propellant and ignition technologies were not developped for MicroPyrotechnical Systems

Objectives

Validation of the technology in a space mission

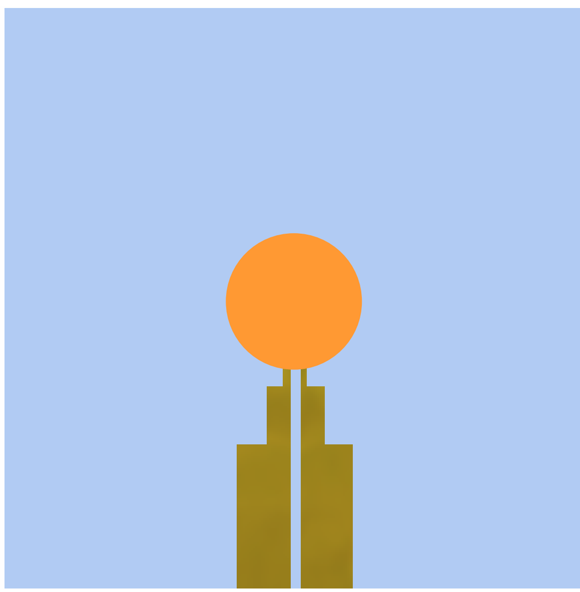
- Specific propellant and supplier needed

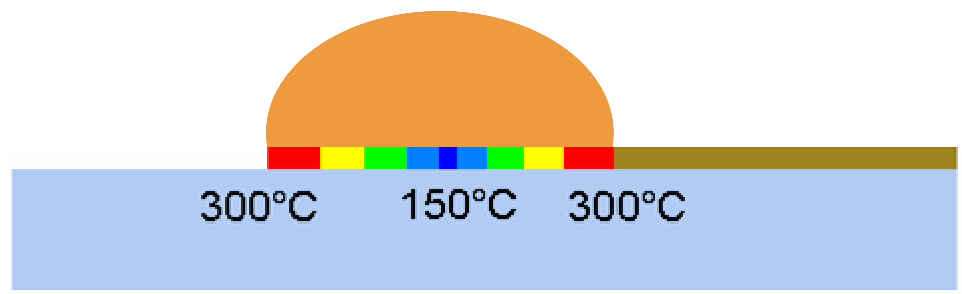
- Develop a propellant adapted for combustion in micromachined chambers (Ruag)
  - Composition
  - Filling procedure
- Develop igniters adapted to the propellant technology (IMT)

- To obtain reproducible ignition and combustion characteristics

Concept and design

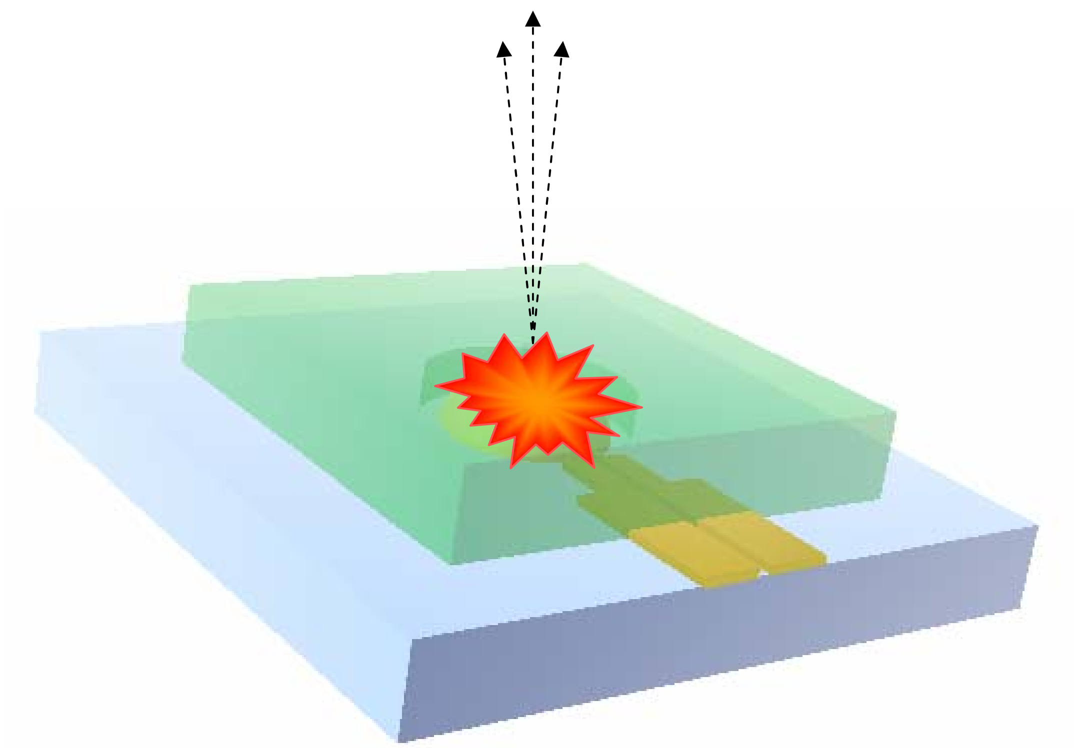
- **Ignition concept**





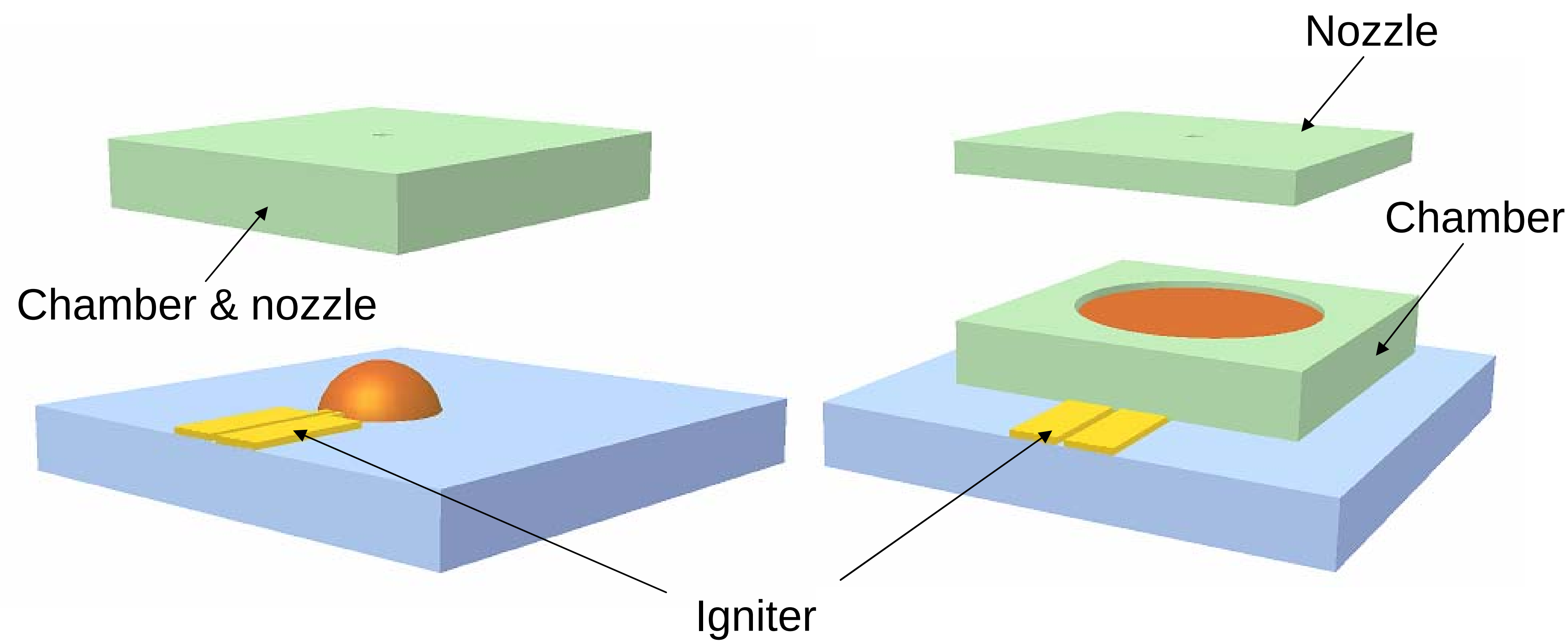
Concept and design

- **Microthrusters**



Concept and design

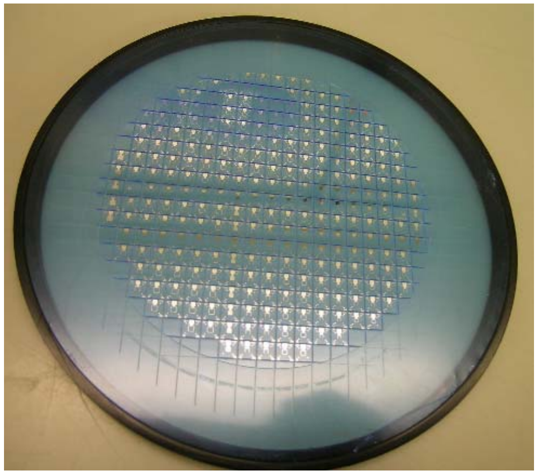
- **Two different assembling procedures**

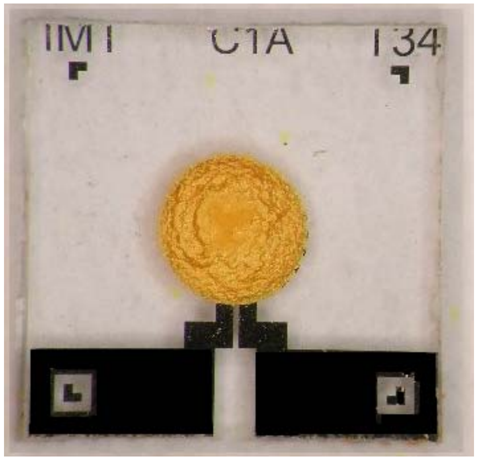


Propellant

- **Demands on propellant**
  - ✓ safe
  - ✓ fast reaction
  - ✓ easy to ignite
  - ✓ extensive gas production
  - ✓ appropriate ignition temperature
  - ✓ micrometric grain size

Propellant

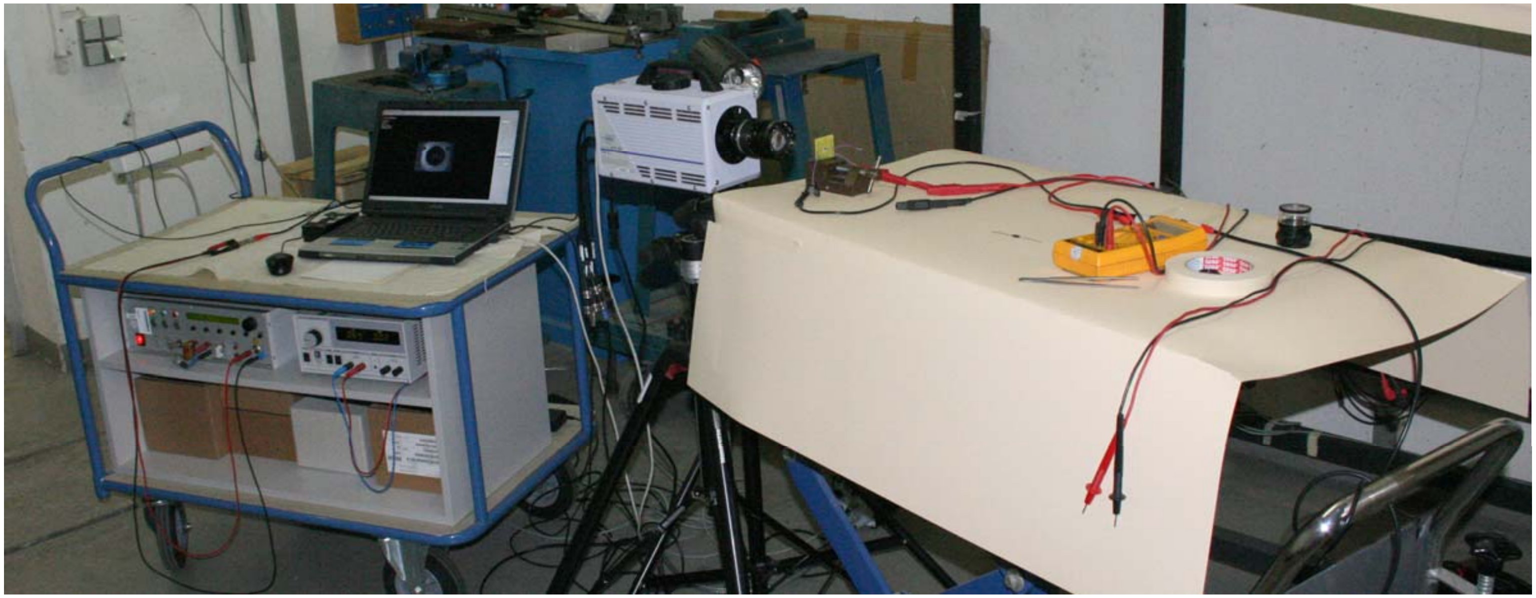


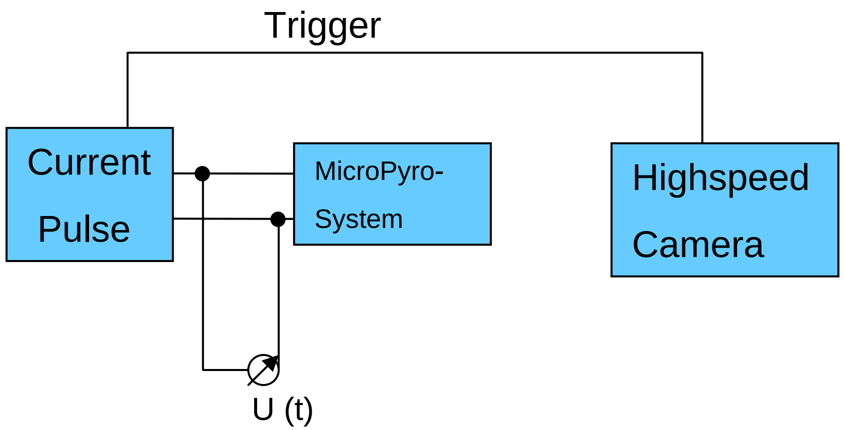


0.18 ± 0.03 mg of propellant coated on igniter

0.98 ± 0.07 mg of propellant deposit in chambers

Pulse set-up





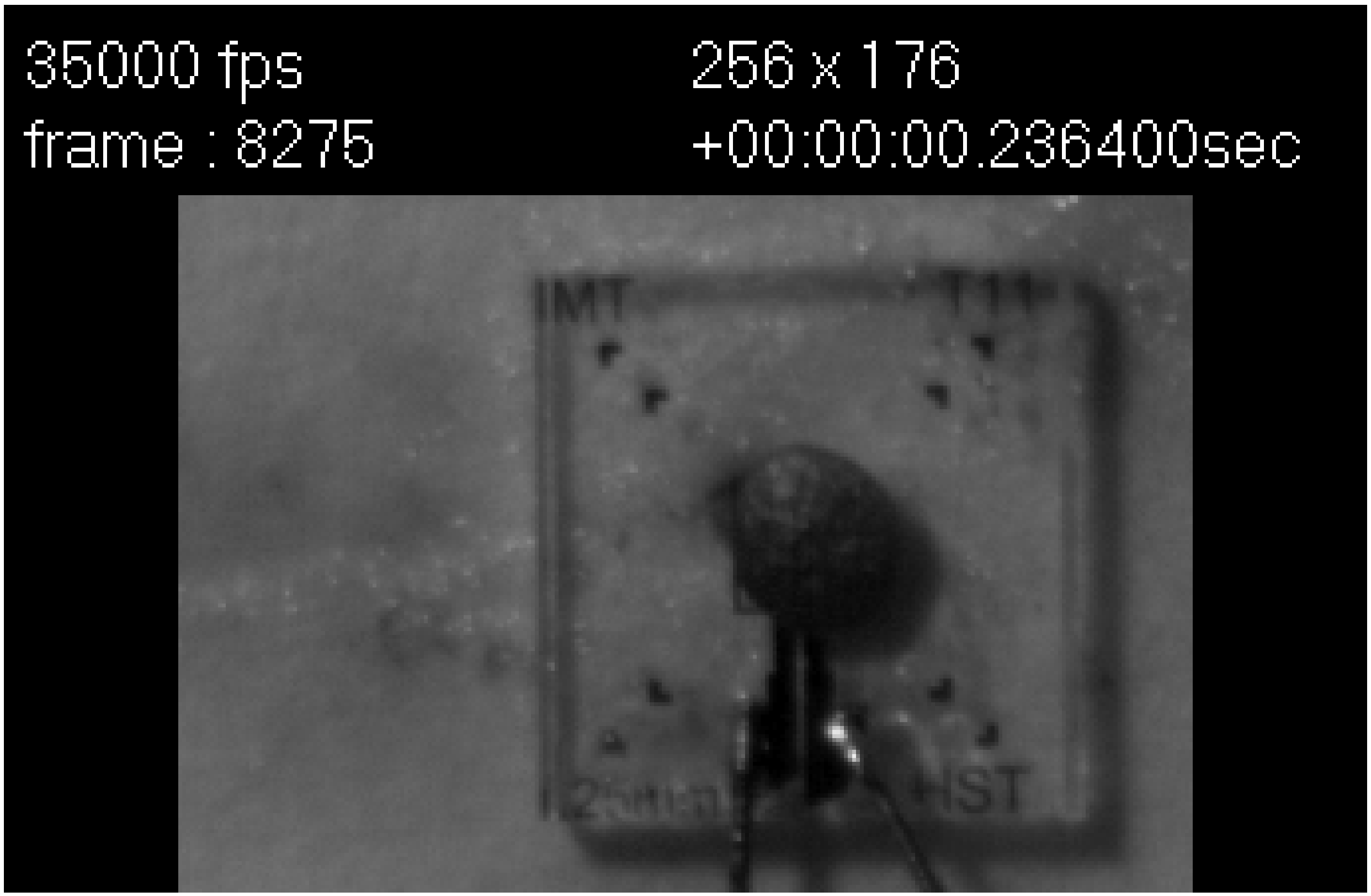
t ca. 1s

I ca. 150 mA

U ca. 50 V

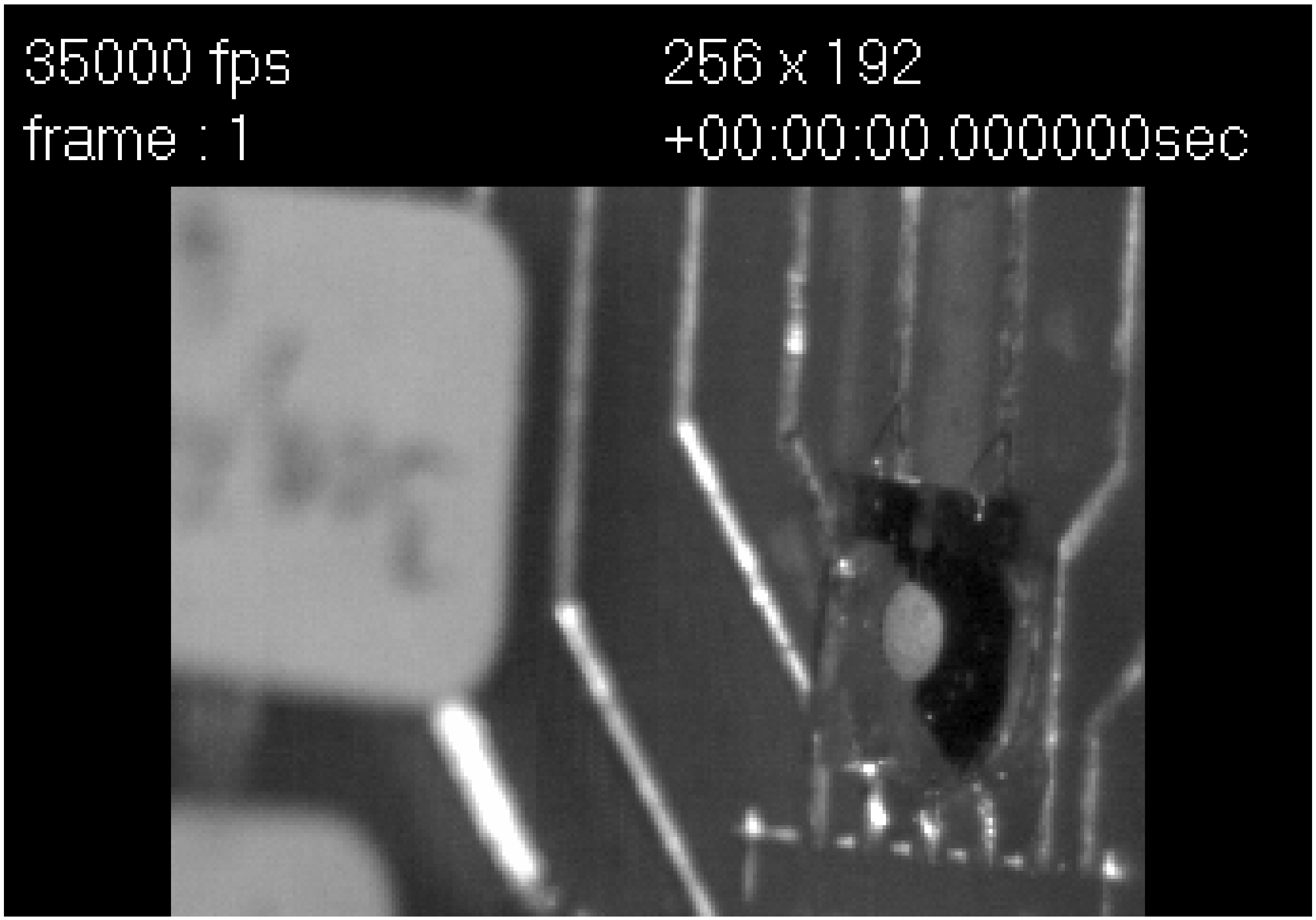
Ignition experiments

- Typical movie of an ignition test not optimised



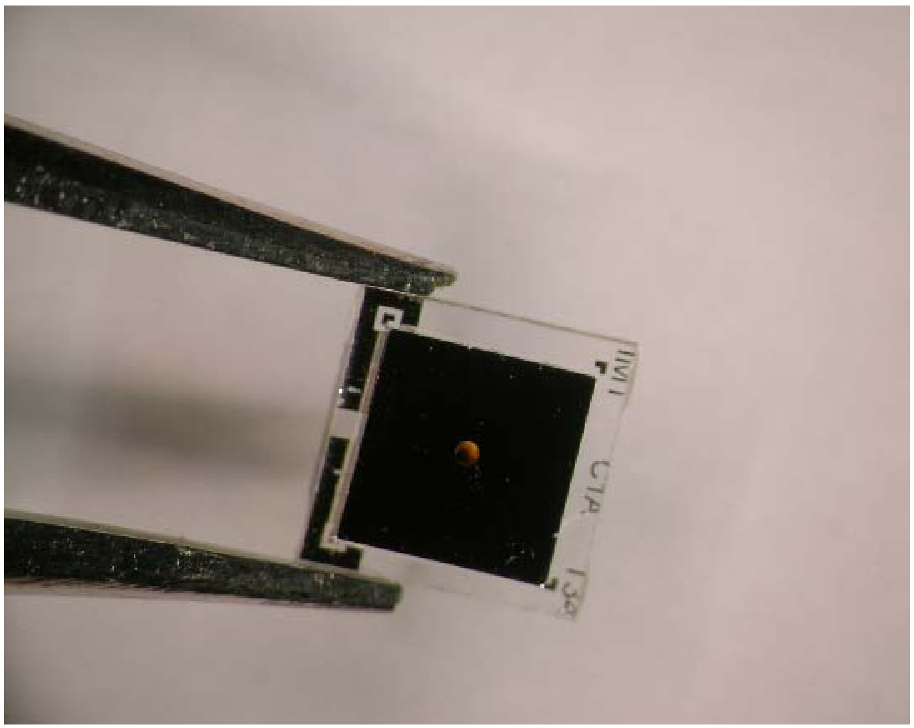
Ignition experiments

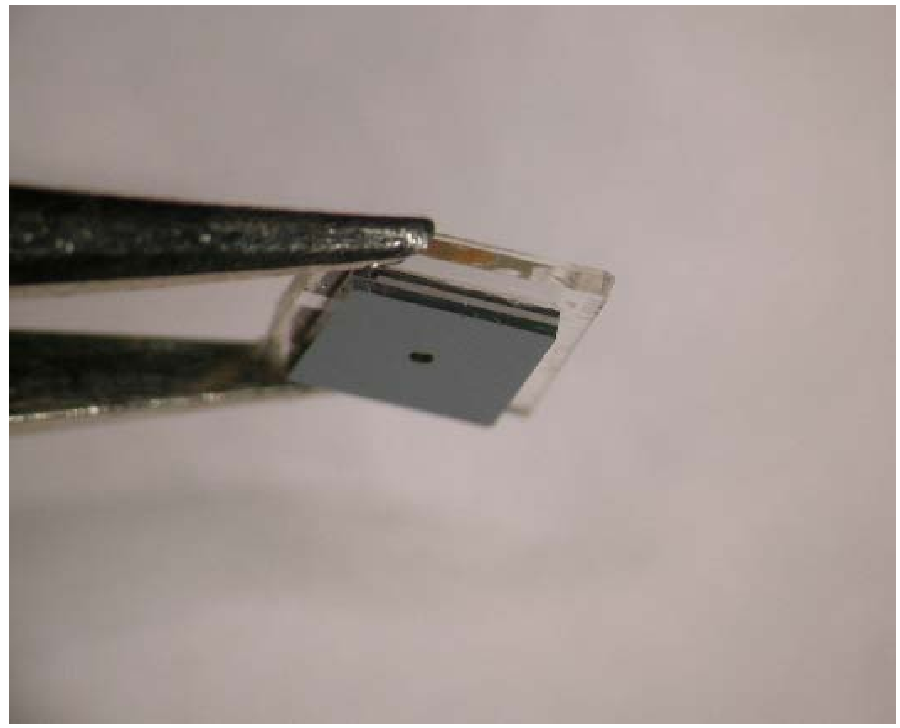
- Typical movie of ignition tests, I= 100 mA



Micro-thrusters

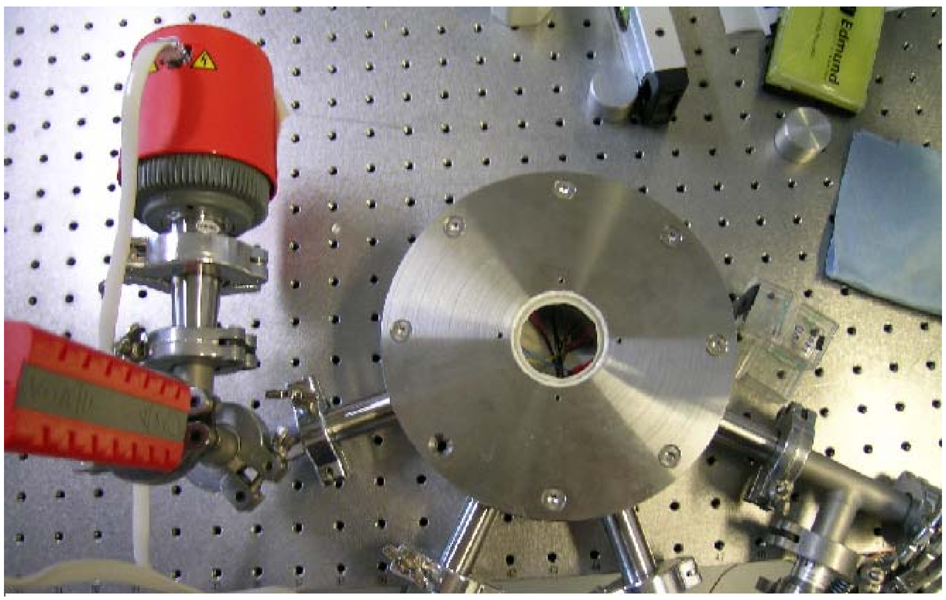
- Assembled chips





Micro-thrusters

- **Study in spatial conditions**
  - Under vacuum (1e-2 mBar) between -20°C to 100°C

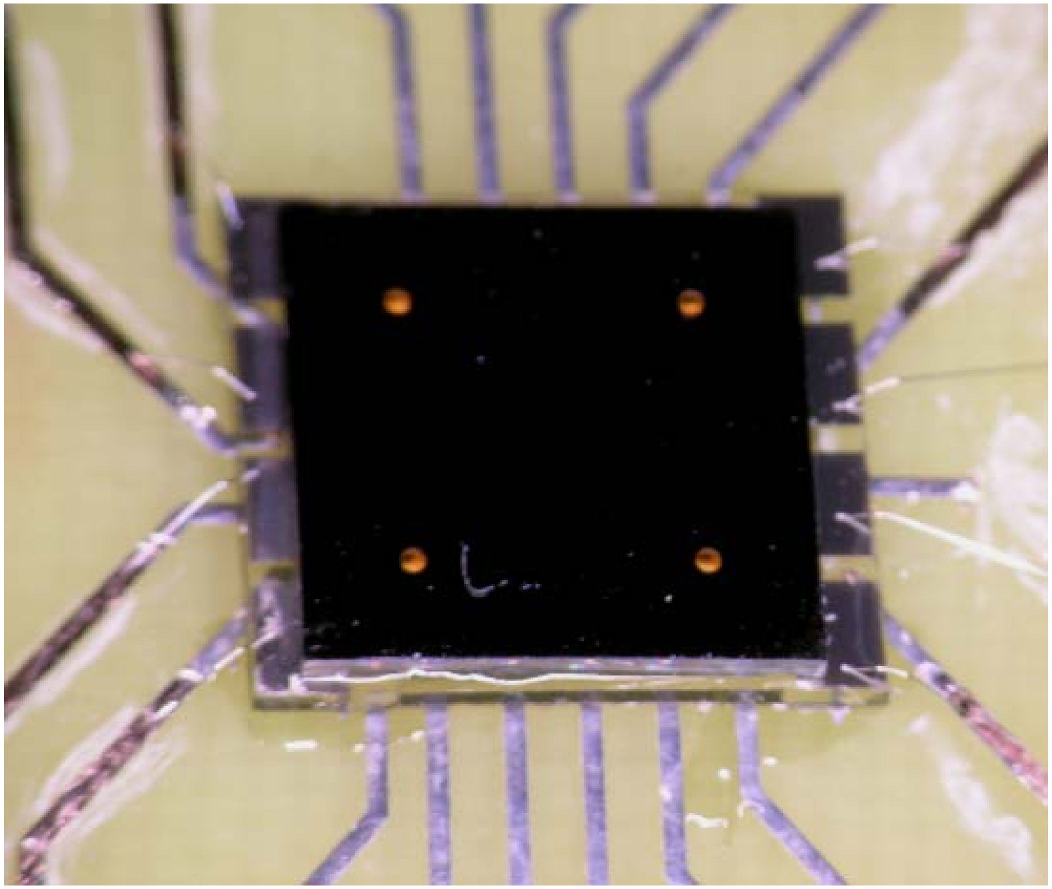


Chamber under vacuum

Oven (heating and cooling)

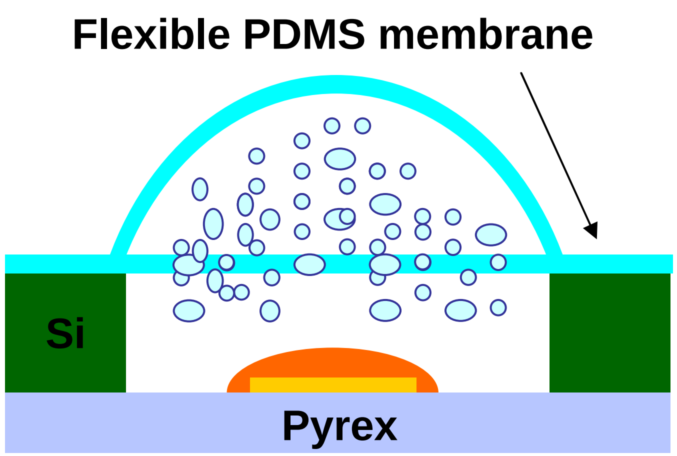
Demonstrator

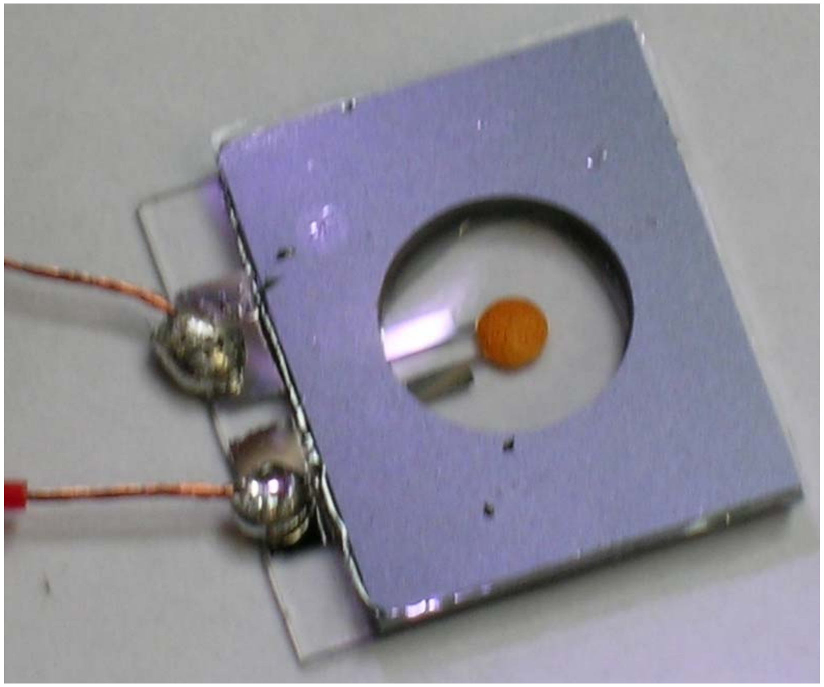
- 2x2 Microthrusters array



Balloon Actuator

- **Large deformation micro balloon actuator**
  - To release structures
  - To move chips
  - Micro « air bag »
  - Hot air balloons

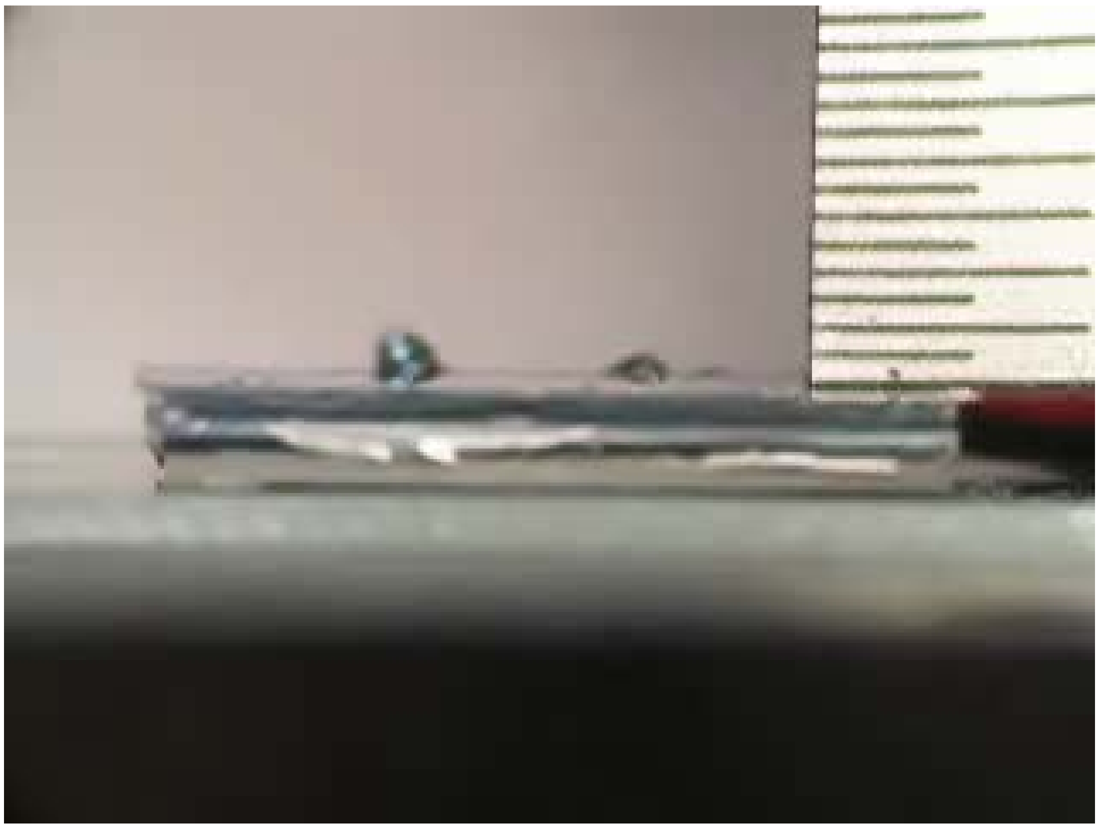




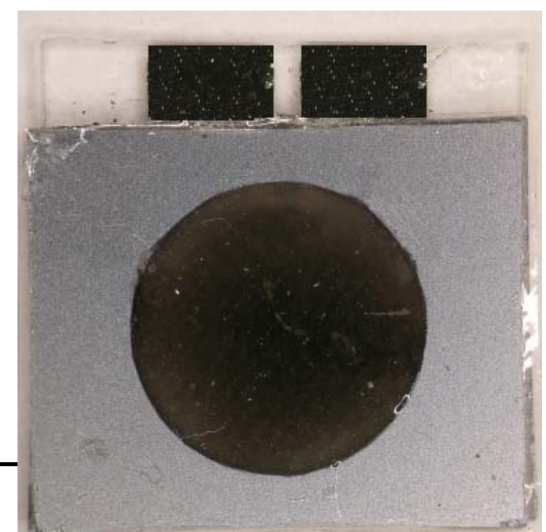
Height: 1 mm,
Chamber width: 7.5 mm
PDMS: 20 to 50 µm -thick

Balloon Actuator

- Typical movie from inflation tests, I= 150 mA



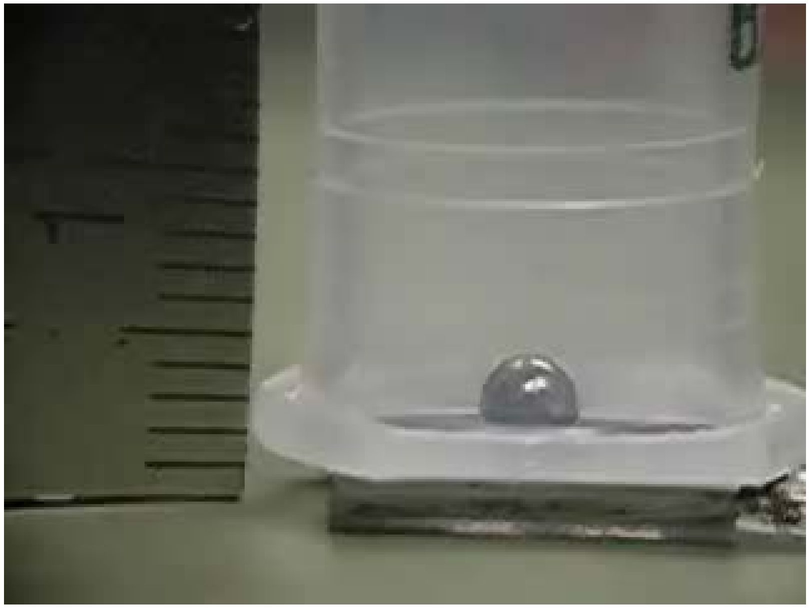
5 mm
4 mm
3 mm
2 mm
1 mm
0



H=1 mm, D=9 mm, m=0.60mg

Balloon Actuator

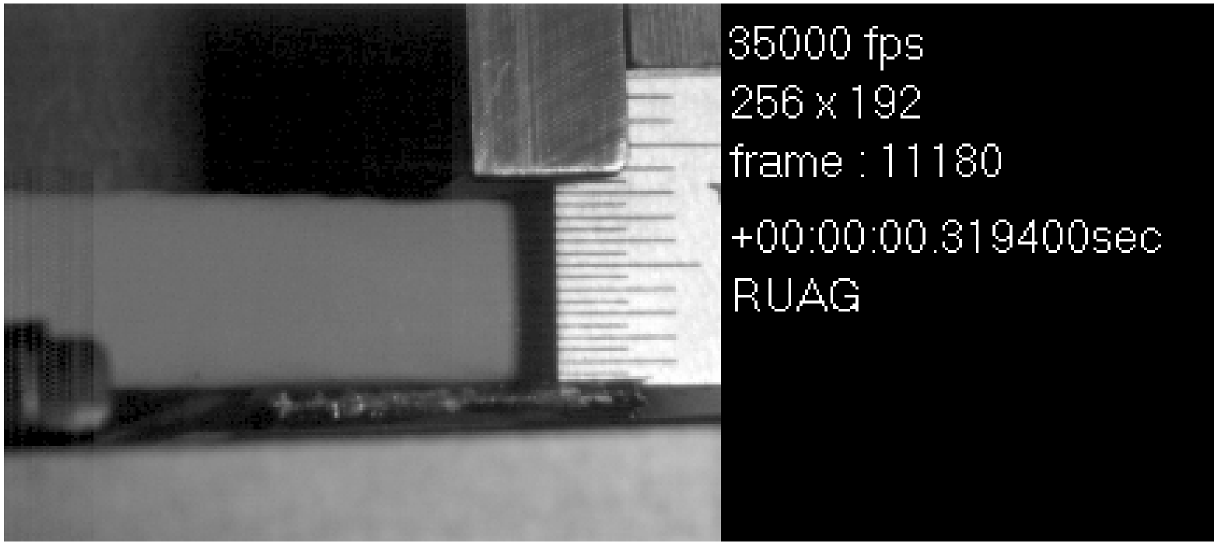
- Deformation up to 6 mm
- Energy estimation by measuring the displacement of a ball



Ball weight	Displacement	Energy
130.4 g	1.04 m	1.33 mJ

Balloon Actuator

- Actuation filmed with a high speed camera



Ignition at	Max deformation obtain in	Maximum deformation
321.3 ms	**3.4 ms**	**8 mm**

Conclusion

- Ignition principle has been validated
- Low power suspended igniters were realised
- Successful controled combustion of propellant
  - Large volume of gas generated
  - Significant reduction of ejected particles
  - Variation of volume via assembling scheme
  - Tuning of the combustion rate via the binder percentage
- Demonstration of the technology with a 2x2 micro-thruster array

Outlook

- **Testing at IMT and LMTS**
  - Complete the ignition test in space conditions to get more information and and statistics on performances
- **Testing of the thrust characteristics**
  - Contact with ESA Propulsion Laboratory (EPL), ESTEC (NL)
    - Stabilisation time of the balance too long (2-3 s)
  - Contact with LAAS-CNRS
    - Incompatibility with the electronics piloting the thrust balance

Evaluation of the thrust force, combustion time, impulse and ISP

Next phase

- **Validation of reproducibility and industrialization**
  - Objectives
    - Validate the solid-propellant technology developed in terms of reproducibility and production.
    - Address the level of performance that could be reached at a production level.
    - Evaluate the cost of production.
  - Description of work
    - Reproducibility of the filling procedure
    - Reproducibility of the ignition and thrust
    - Feasibility of industrialization

Next phase

- Go to an higher TRL

TRL1	Basic principles observed and reported	
TRL2	Technology concept and/or application formulated	Low
TRL3	Analytical and experimental critical function and/or characteristic proof-of-concept	
TRL4	Component and/or breadboard validation in the laboratory environment	
TRL5	Component and/or breadboard validation in the relevant environment	Medium
TRL6	System/subsystem model or prototype demonstration in the relevant environment (ground or space)	
TRL7	System prototype demonstration in a space environment	
TRL8	Actual system completed and flight-qualified through test and demonstration (ground or flight)	High
TRL9	Actual system "flight-proven" through successful mission operations	

Next phase

- ESA GSTP or TRP programs
  - Validation in space based on a application with a strong potential for commercialisation
  - Application must be known before validation of the technology
  - Linked to a mission if possible

Application will determine:

- The design of the thrusters arrays (number of cells, volume of propellant and chamber, ratio chamber / nozzle)
- The packaging
- The control electronics and data acquisition