Solid Propellant thruster for Space application

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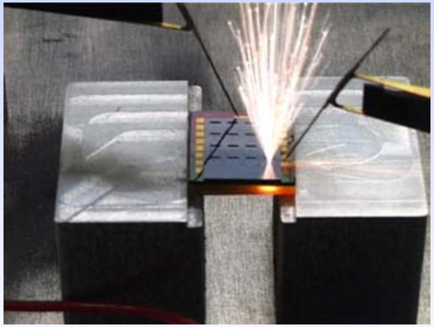


Introduction

- LAAS's MEMS solid propellant microthruster is part of a field of research into pyrotechnical microsystems as POWER MEMS.
- Pyrotechnical microsystems is mainly funded by an E project of IST program : « Micropyros »

Micropyros

Partners :

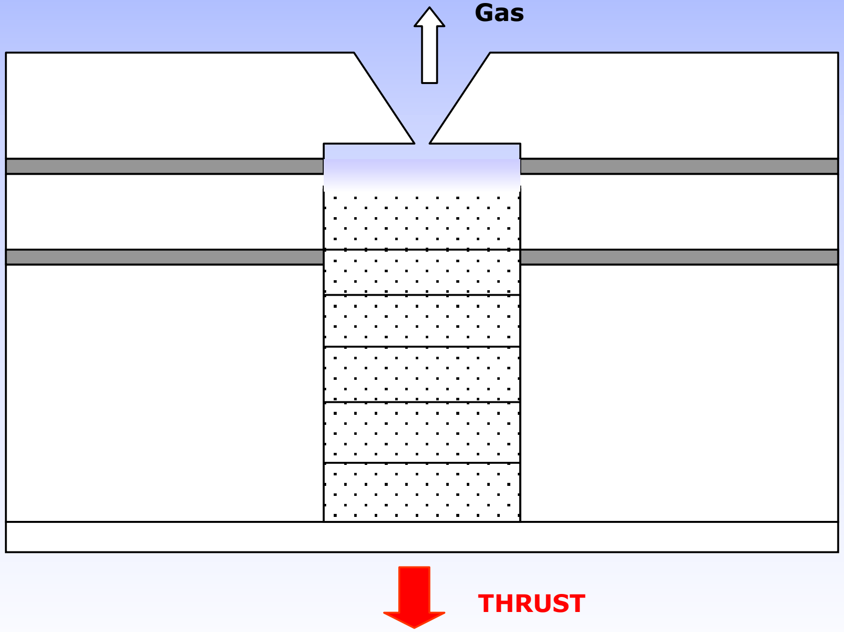
Program funded by the European Commission

Outline

- Principle of pyrotechnical power MEMS
- Design and Fabrication of thrusters
- Characterization Methods and first results
- Application to space
  - For station keeping need
  - For some de orbiting scenari
  - For other mechanical operation (panel deployment, spacecraft separation…)

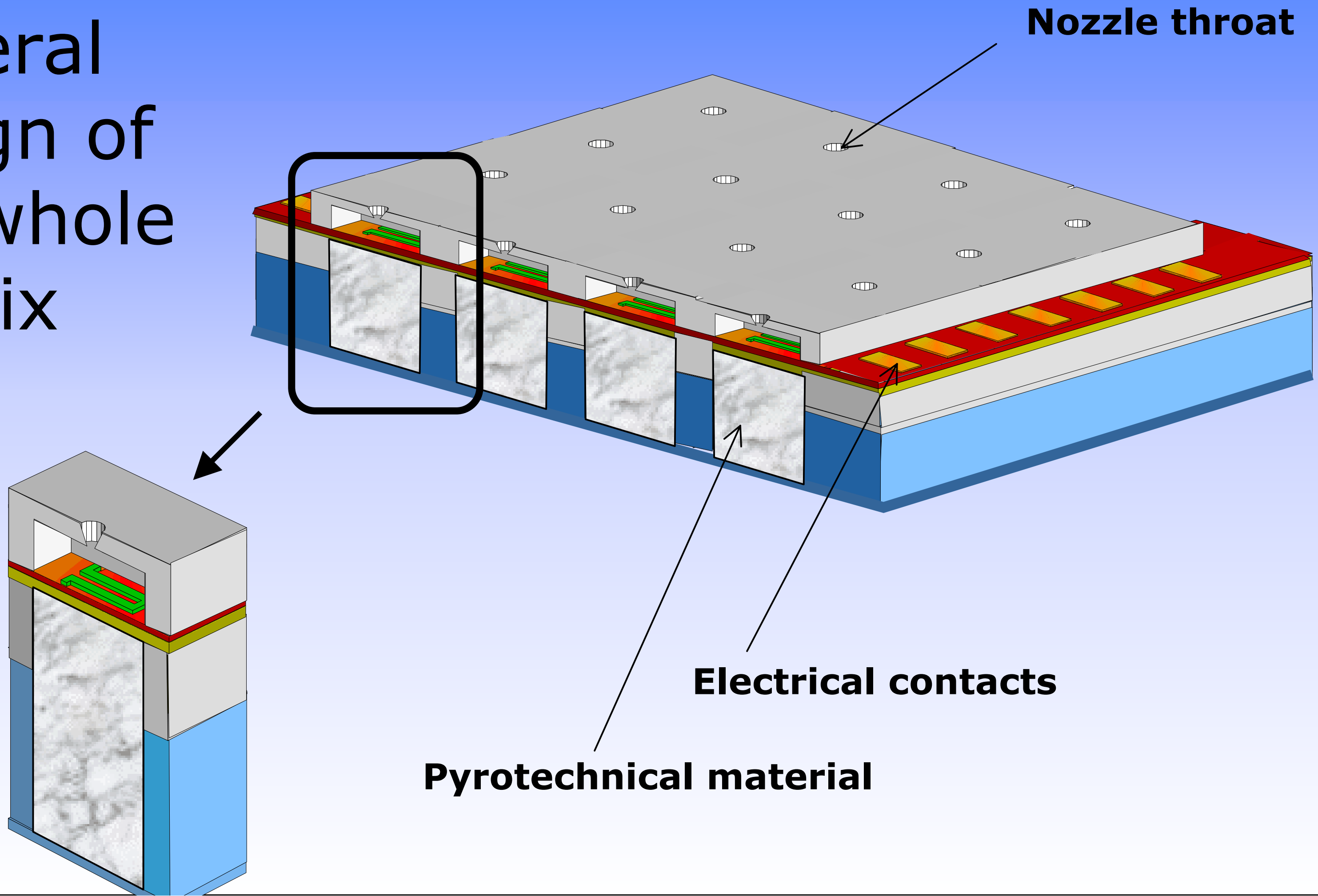
Pyrotechnical Power MEMS

- Its principle of operation is based on the combustion of an energetic solid-state propellant.



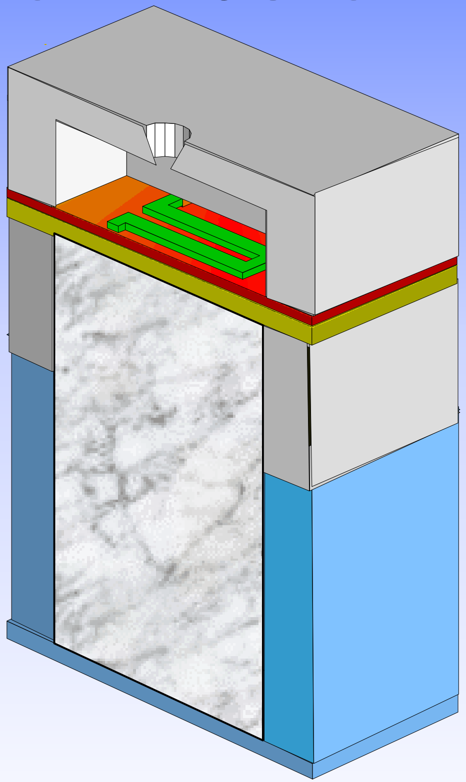
Design and Fabrication

- General design of the whole matrix



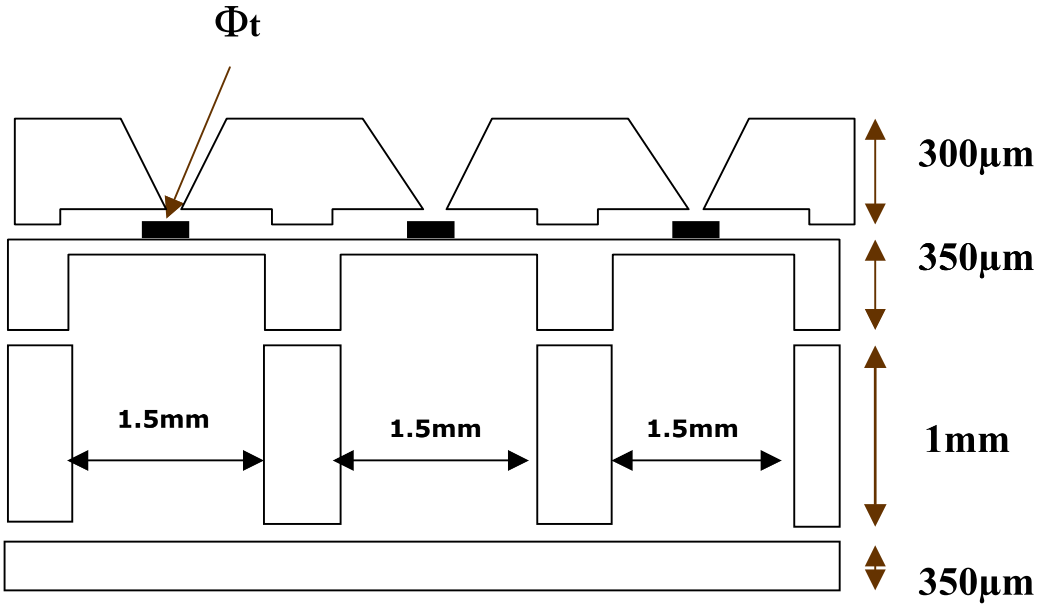
Design and Fabrication

- General design of 1 single thruster
  - Three / Four assembled parts
    - Nozzle (optional)
    - Igniter
    - Chamber
    - Seal
  - Silicon, glass materials
  - Thin film processing, 3D micromachining



Choice of variable

- Propellant
  - *primary explosives offer best chemical property for ignition and combustion at low dimension*
  - GAP based mixture offer best physical property for filling
- Chamber diameter
  - Order of magnitude calculations of required thrust for control of a nanosatellite station keeping
  - Size to have ignition and combustion characteristics success
- Diaphragm thickness
  - filling pressure vs. thermal insulation
- Heater profile
  - previous experience in pyrotechnical igniter
- Nozzle
  - Nozzle theory breaks down as size and Reynolds number decrease. Lack of knowledge of propellant behaviour in small quatities

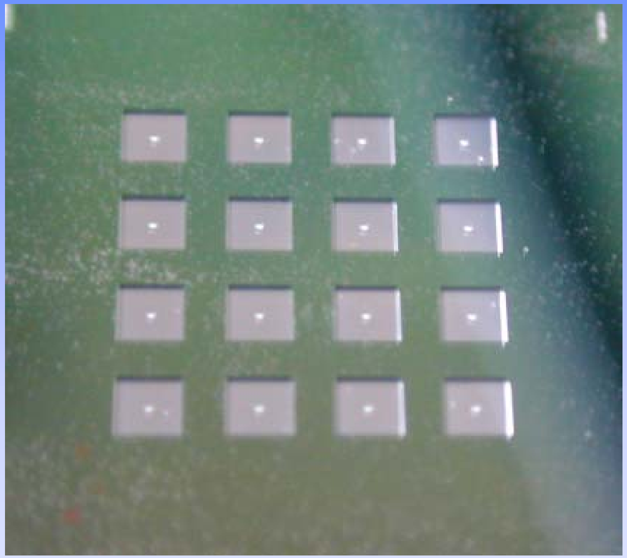


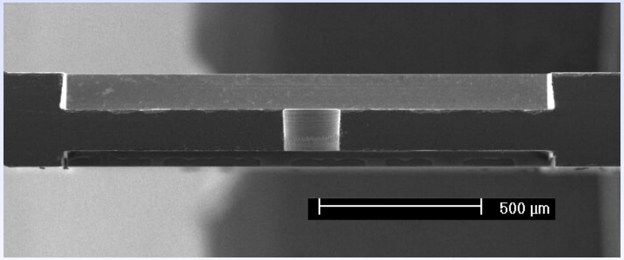
NOZZLE CHARACTERISTICS :

Throat section Φ_t	250µm	150µm
Ac/At	36	100
H_c	150 µm	
H_d	200µm	

Design and Fabrication

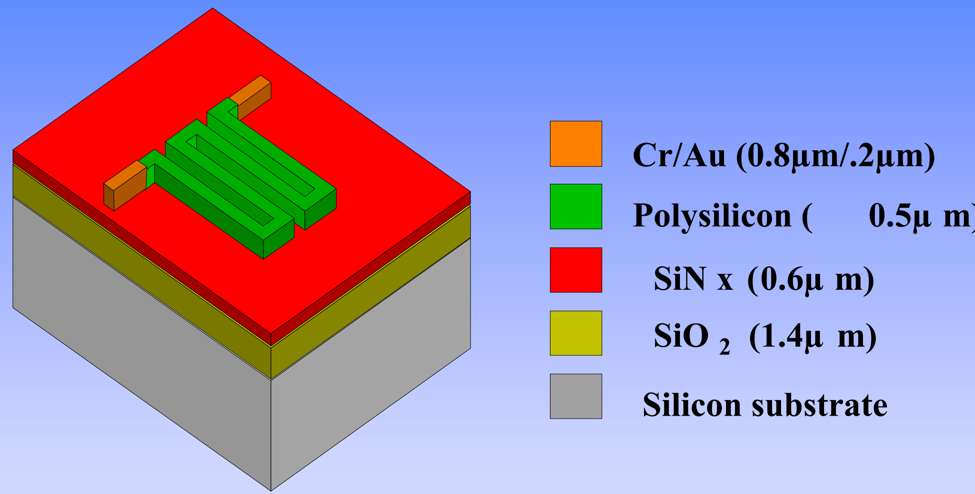
- Main process steps :
  - dry etching on standard 300µm Si wafer to create the gap between igniter and nozzle
  - dry etching to create the throat
  - Diverging part is realized by over etching the silicon

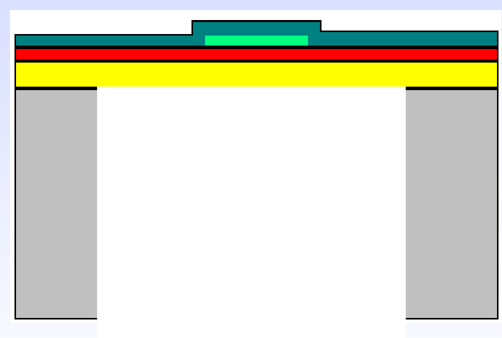




Design and Fabrication

- Main process steps :
  - LPCVD Polysilicon on Thermal oxide + LPCVD Nitride
  - Dry etching to pattern the polysilicon resistor
  - Dry etching on standard 350µm Si wafer to create resistor on thin membrane

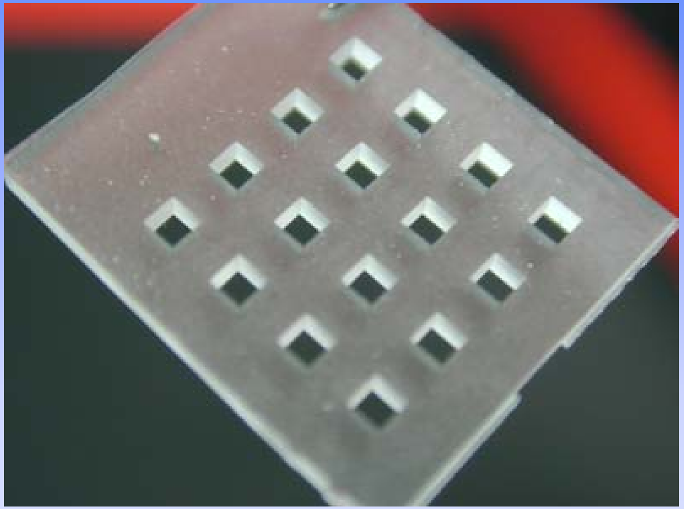


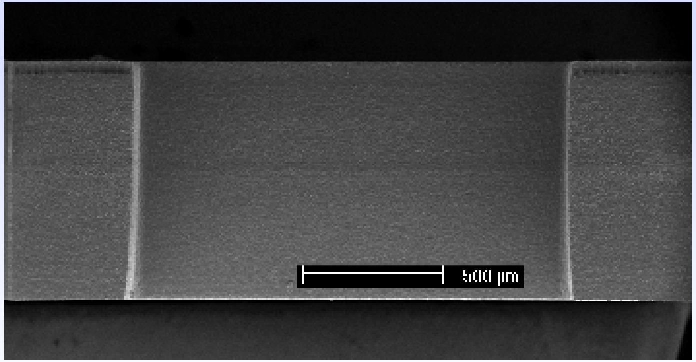


Design and Fabrication

- Carry out wet chemical etching on standard 1mm Foturan wafer to create reservoir

OR



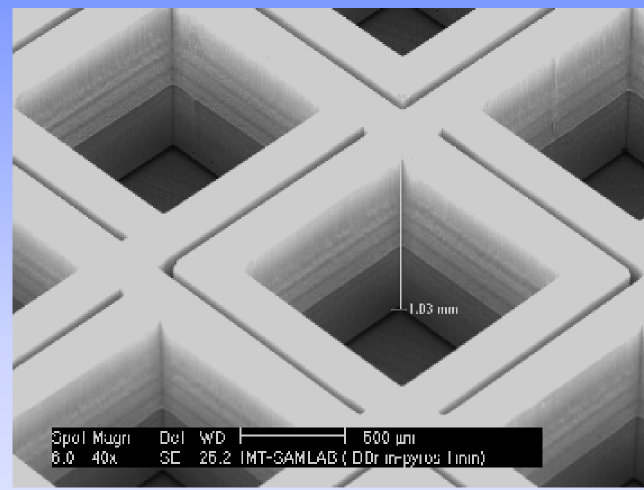


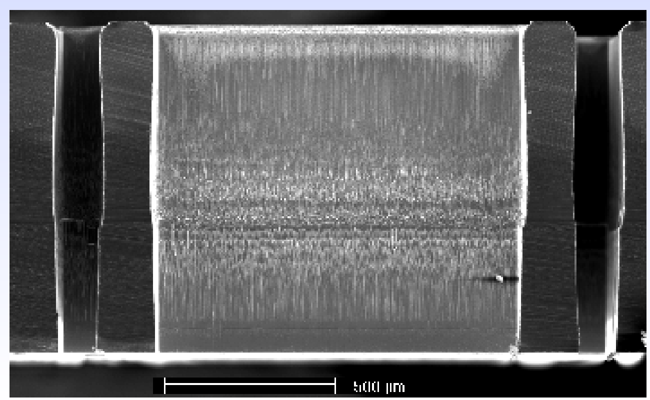
Design and Fabrication

- Carry out wet chemical etching on standard 1mm Foturan wafer to create reservoir

OR

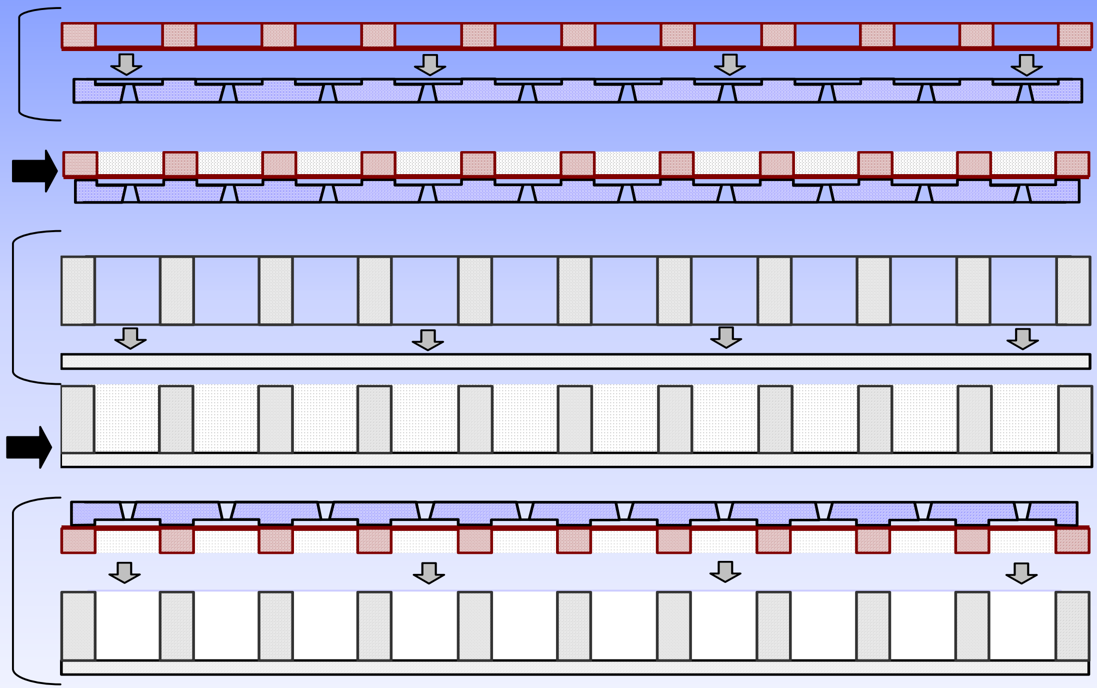
- Carry out dry etching on standard 1mm Si wafer to create reservoir surrounded with air grooves



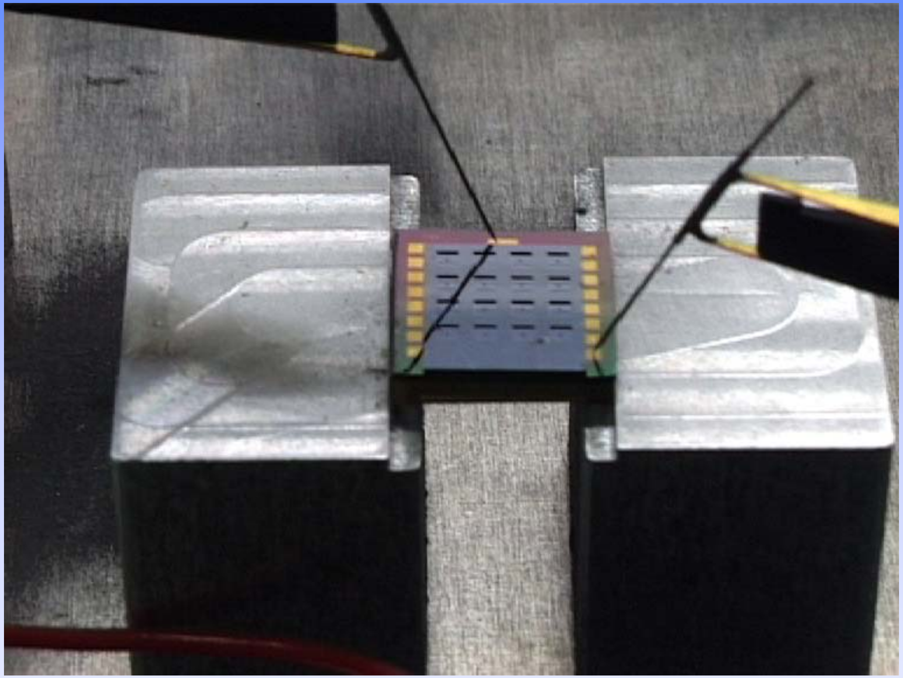


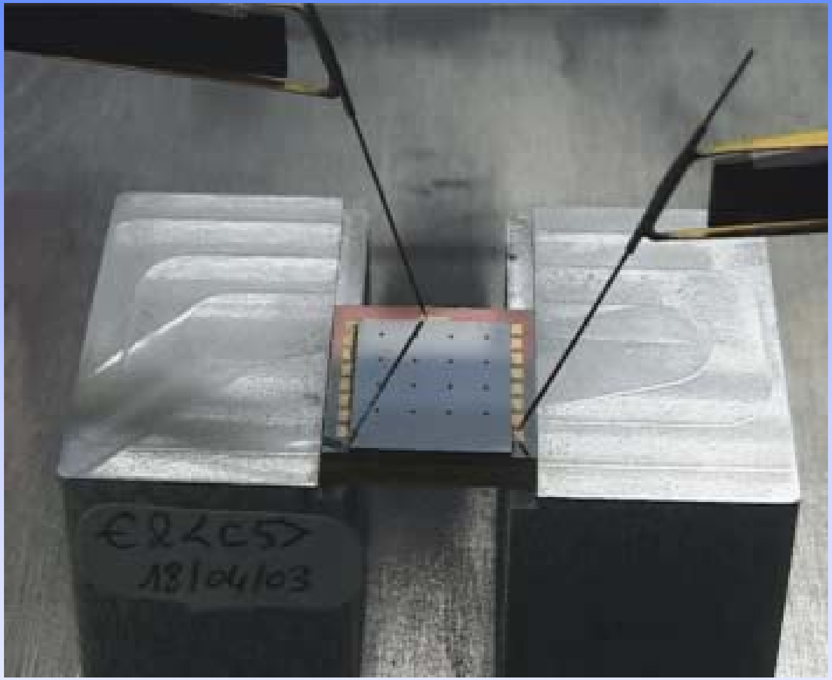
Design and Fabrication

- Carry out :
  - Anodic bonding to seal chamber to rear wafer
  - Low T bonding
  - Low T gluing with Epoxy glue



Some photos of realization





Assembling with nozzle throat of 160µm **Assembling with nozzle throat of 250µm**

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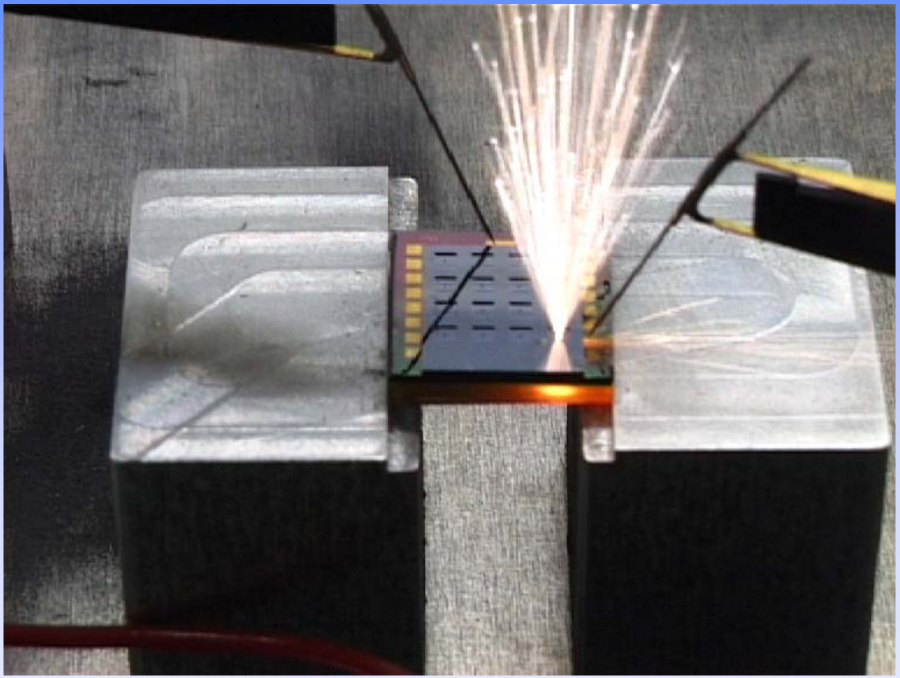
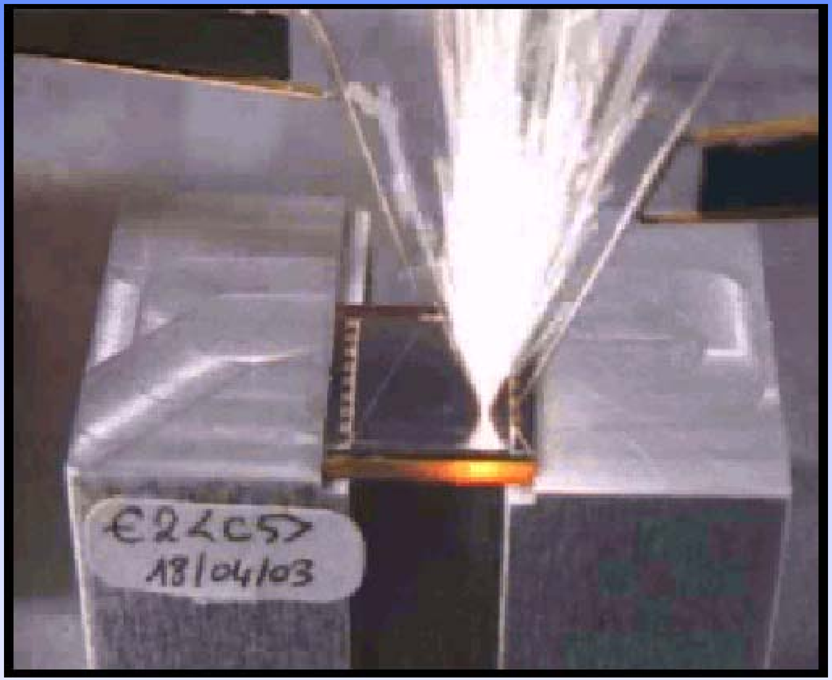
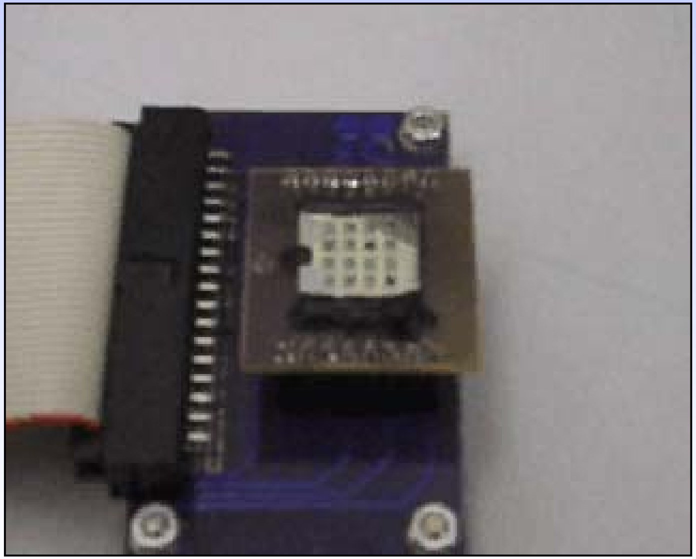




Assembling with nozzle throat of 160µm **Assembling with nozzle throat of 250µm**

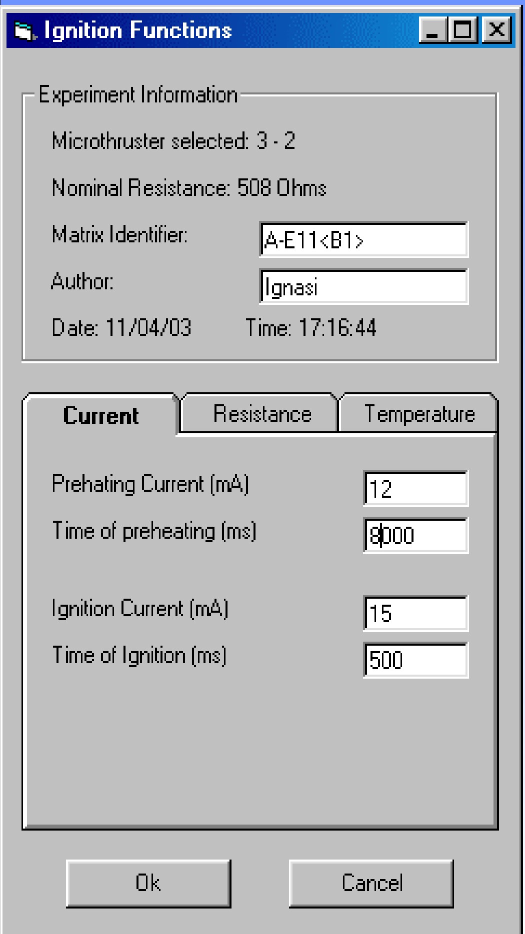
Characterisation method

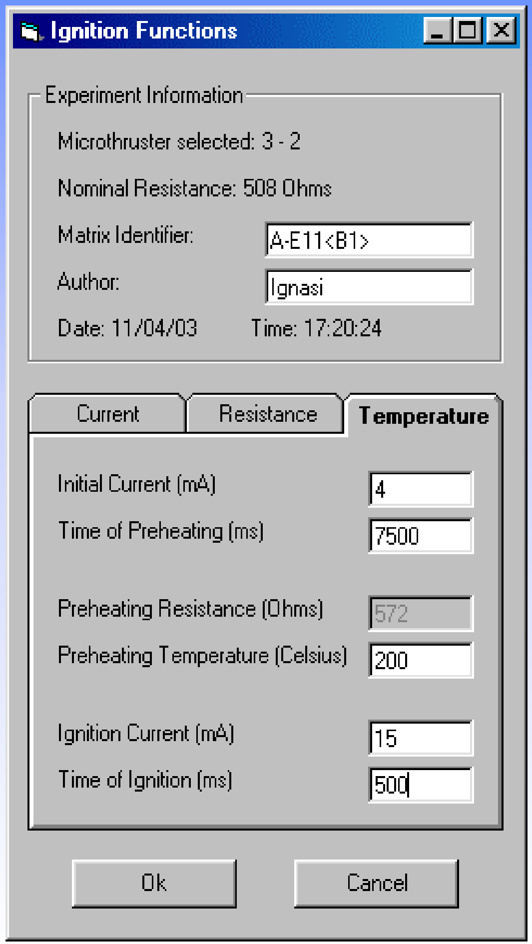
- Ignition characterization done with an electronic
  - Ignition test performed via an electronic interface in closed-loop or open-loop process
  - Ignition test with an input current impulse
  - Possibility of adding a preheating phase
  - Possibility of controlling the Temperature during the preheating

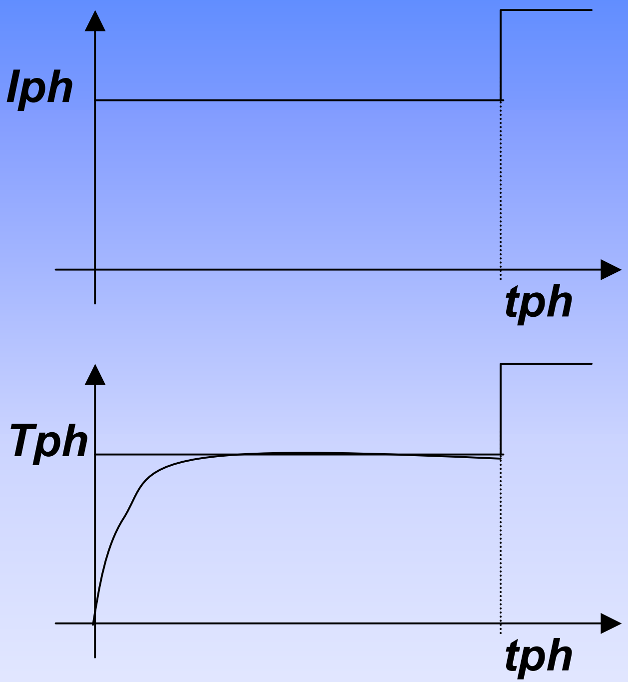


Characterisation method

EXAMPLE WITH A PREHEATING PHASE



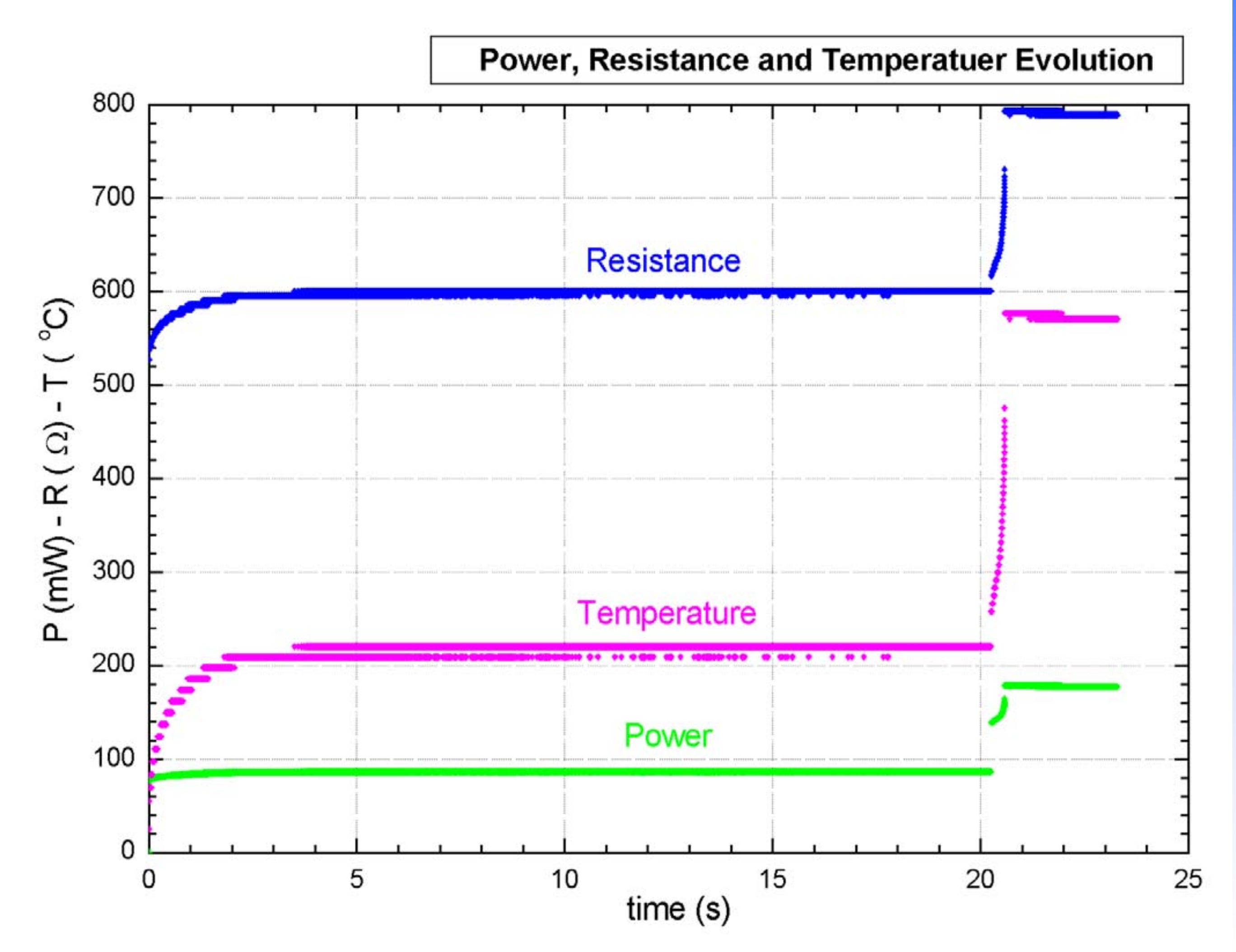




<u>Optimization parameters:</u>

Iph, tph
Tph, tph

EXAMPLE of IGNITION CURVES WITH PREHEATING PHASE



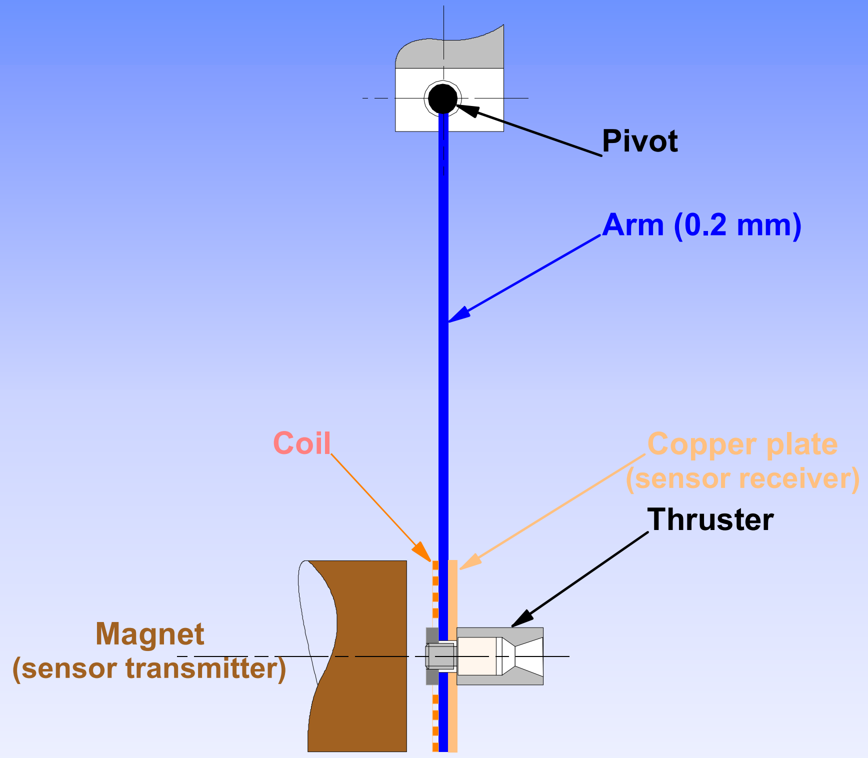
Ignition characteristic

WITHOUT PREHEATING PHASE

Type of propellant tested	Ignition power	Ignition energy	Percentage of ignition success
Compo 1 *GAP based*	**225mW**	**105mJ**	**50%**
Compo 2 *GAP based*	**150mW**	**60mJ**	**70%**
Compo 3 ZPP based	**100mW**	**10mJ**	**100%**

Characterisation method

- Thrust measurement
  - Problem : Low thrust and short period
  - Choice of design : close loop controlled torsion balance



Characterisation method

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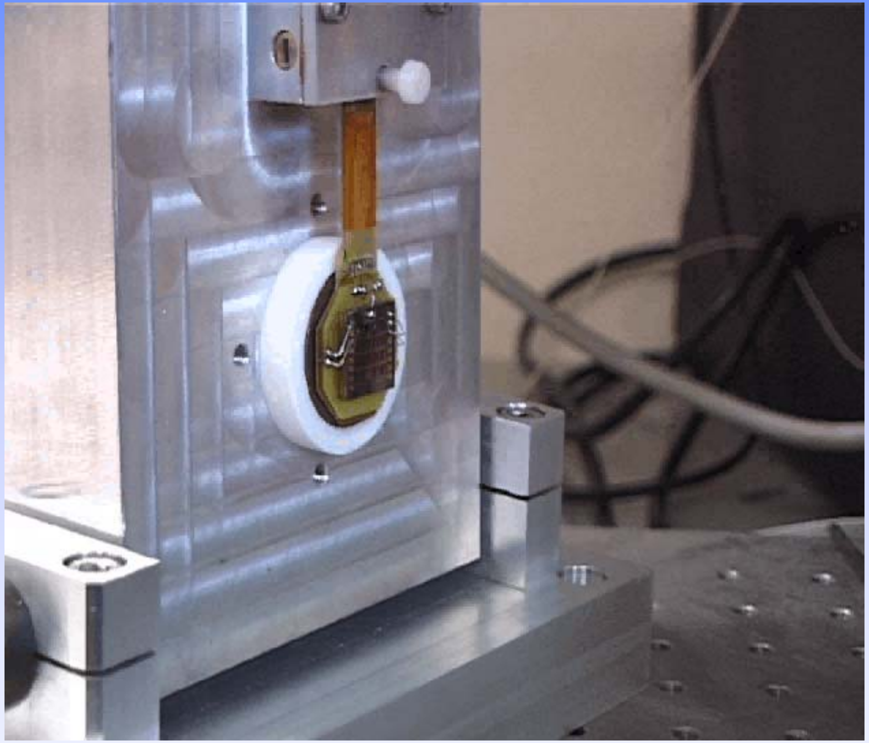
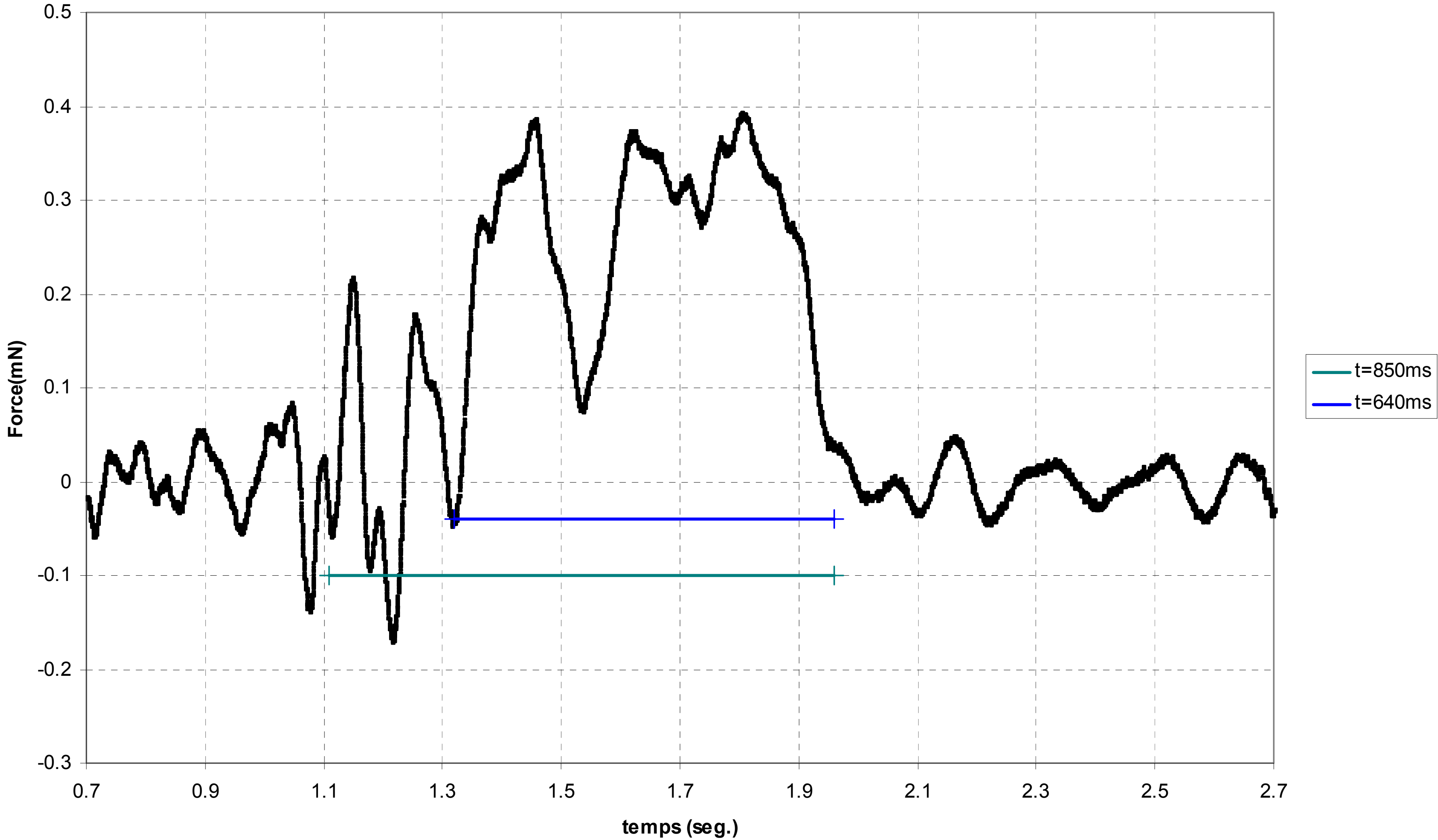


Characterisation method

- Balance characteristics

•Measurement range :	0 – 2g (0 – 19mN)
•Sensibility :	20mg (196µN)
•Noise:	8mg (80µN) direct output
	2mg (19µN) filtered output
•Response delay :	540µS direct output
	1.15ms filtered output

■Example of results : thruster without nozzle



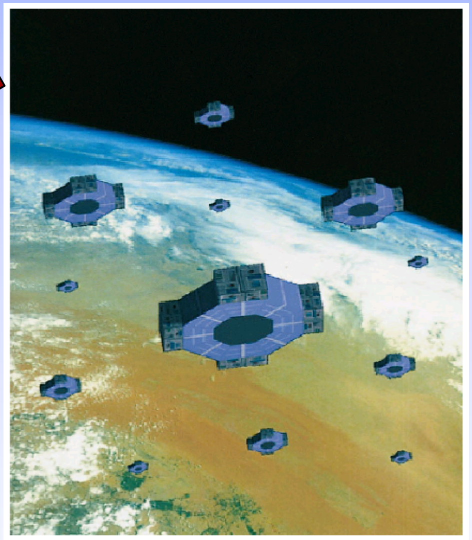
Application to Space

Assessment study on the Application of Solid Propellant thrusters to nanosat.

Why?

Nanosats would need very small and very accurate force to realize the stabilization, the pointing, the station keeping, on-orbit operation…

Micropropulsion module
is a key module for the development of nanosat



Asessment study

- Choose a simple mission scenario
- Calculate the velocity decrement due to the atmospheric drag
- From the performances of our DEMO thrusters calculate the number of shots required to compensate the velocity decrement
- Dimension the array for one year mission
- Conclude on the feasibility

Main assumptions

- Cubic satellite from 20kg-100kg
- Operating above 1000km
- Orbits are only circular
- Perturbations are only atmospheric drag
- Each thruster fire is a pulse
- Delay between 2 shots is identical during the mission
- Two types of thrusters : SMALL (Dc=1.5mm and L=1.7mm), BIG (Dc=1.5mm and L=5mm)

Main results

- Solid Propellant Technology can respond to the station keeping requirement for nanosat operating at altitude above 400km and below 1000km.

- In this range of altitude and for one year mission duration, the micropropulsion module sizes less than 11% of one face of the cube (if we consider the cubic satellite). Its weight is below 5% of the satellite mass.

Example of results for Ms=50kg

Altitude loss Tolerance	**$\Delta h/h=0.001\%$** **(6m et 10m)**
600km	Prop Module would contain : **1304 thrusters** 1 shot every 1.01 day Propulsion module Surf. 81.5cm² Propulsion module Mass : 67.5g
1000km	Prop Module would contain : **24 thrusters** Propulsion module Surf. 1.5cm² Propulsion module Mass :1.28g 1 shot every 1.21 day

Conclusions

- The Solid Propellant technology has been demonstrated for mm scale device
- Ignition energy ∈ [10 – 100mJ]
- Force impulse ∈ [1e-4 – 4e-3 N.s]
- Isp ∈ [65s (without nozzle) – 100s (without nozzle)]

Conclusions

- Composite propellant has been preferred for filling convenience: GAP based propellant
- Chamber sizes from 1mm-2.5mm (1.5mm has been demonstrated – tolerance of fabrication +/-30µm)
- thrust performance in chambers of this size is not really known but ignition and combustion characteristics are promising

Perspectives

- Ignition and combustion reliability must be improved
  - Pyrotechnical material & electronic control
- Nozzle theory must be studied because classical theory breaks down as size and Reynolds number decrease
- Solid propellant chemical property are limitative when dimensions decrease
  - Open the technology to explosive material

Perspectives

- Validate the technology in space environment by participating in a nanosat mission demo
- Make an analysis of the real capacity of SPT for nanosat application
  - Station keeping, de orbiting function….
- Increase the level of integration