Micropropulsion for NanoSatellites

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Tor-Arne Grönland
President

www.sscspace.com/nanospace
Point of contact

Tor-Arne Grönland
President
NanoSpace AB
Uppsala Science Park
SE-751 83 Uppsala
SWEDEN

Tel: +46 8 627 62 00
Direct: +46 70 424 41 04
Fax: +46 18 55 13 01
Http: www.sscspace.com/nanospace
Email: tor-arne.gronland@sscspace.com
Outline

• First generation MEMS micropropulsion:
  – *Miniaturised and proportional thrust*

• Second generation MEMS micropropulsion:
  – *Closed loop thrust control*

• Other scientific missions

• Components
Core technology developed for Prisma

- **2005:** NanoSpace starts operation
  - NanoSpace phase B contract
- **2006:** First test of MEMS thruster module
- **2007:** 1st complete thruster module
  - 1st delivery of flight H/W
- **2008:** Final delivery to Prisma
- **2009:** End-to-end testing on S/C
- **2010:** Launch!

NanoSpace

Core technology developed for Prisma

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Thruster Pod Assembly – Plenty of MEMS inside

$\varnothing = 44 \text{ mm (1.73")}$

Four thrusters per pod

10 $\mu$N – 1 mN

Mass: 115 g

Six-wafer-stack MEMS Thruster Chip
MEMS Thruster Chip – Valve package

- 4 valves/chip
- 2-way, normally-closed
- 0 – 2 mg/s GN2
- MEOP 6 bar (87 psi)
- 22x22 mm (0.9”)
- 1.2 mm thick
Next generation – Closed-Loop Thrust Control

Integrated mass flow sensor provides closed loop control signal to the proportional flow control valve

=> Unique performance, enabling new mission scenarios

Figure: Schematic view of a complete closed loop control thruster. ON/OFF valve in conventional technology, the rest in MEMS.

Key component: Integrated MEMS flow control valve and mass flow sensor
Key capabilities – Like any other

Figure: Test result of MEMS thruster operating in ON/OFF mode (open loop, using solenoid valve only) to show thrust range. Full thrust can be set in the range **50 micro-Newton** to **5 milli-Newton**.
Key capabilities – Unlike any other

Low thrust regime step response: 5µN steps

Figure: Test result of a MEMS valve operating in closed loop control mode showing the thrust response to commanded steps of 5 µN.
Unique performance

Figure: Test result of a MEMS valve operating in closed loop control mode responding to the commanded steps of 0.1 μN.
MISSION ENABLING NEEDS

- 16 closed loop thrust control μ-thrusters:
  - 0 – 300 μN thrust
  - 0.2 μN resolution
  - 250 ms response time
  - 120 million cycles
QB50: The major European nanosat project

Mission Objectives
QB50 has the scientific objective to study in situ the temporal and spatial variations in the lower thermosphere (90-320 km) with a network of 50 double CubeSats carrying identical sensors. QB50 will also study the re-entry process by measuring a number of key parameters during re-entry and by comparing predicted and actual CubeSat trajectories and orbital lifetimes.

Teaming
University of Tartu (Estonia), SI-SPACE (Slovenia) and NanoSpace is teaming up for a joint CubeSat for the QB50 project. NanoSpace will provide a propulsion module, SI-SPACE will develop the control electronics and algorithms and University of Tartu will integrate the satellite.

Objective of technology demonstration
The objective of the joint CubeSat effort is to demonstrate orbit control capability with a CubeSat. Being launched together with 49 other CubeSats does also provide the possibility of doing proximity operations around another satellite.

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The CubeSat propulsion module

General specification:

- Four 1mN thrusters with closed loop thrust control
- Thrust resolution: <10µN
- Propellant: Butane
- Total impulse: 40Ns
- Size: 10*10*3cm
- Weight: 220g (including propellant)
- Operating pressure: 2-5 bar
- Power consumption: 2 W (average, operating)
- Mechanical interface: CubeSat payload I/F
- Electrical interface: 52 pins analog (0-12V) and digital (SPI)
Low Flow Control Module - Mini-Ion engines

Precise control of Xenon flow rate in the range 5 – 50 µg/s (one µN-RIT)

<table>
<thead>
<tr>
<th>Specification</th>
<th></th>
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<tbody>
<tr>
<td>Operating media</td>
<td>Xenon</td>
</tr>
<tr>
<td>Flow Range</td>
<td>5-50 µg/s</td>
</tr>
<tr>
<td>Flow rate resolution</td>
<td>± 0.5 µg/s</td>
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<tr>
<td>Mass</td>
<td>65 g</td>
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<tr>
<td>Power</td>
<td>&lt;1 W</td>
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</tbody>
</table>
| Dimensions             | Module: Ø=43 mm  
|                        | Chip: 8x20 mm |
LISA Pathfinder

Needed technology:
Low thrust, low noise, high accuracy, high resolution, short response time, high Isp

2 year delay due to:
- Change of microthruster
- Faulty mechanism

Consequence:
- New thruster
- Requires new feed system with precise flow rate < 10 μg/s

-Budget implications:
- 185 Meuro 2006
- 350 Meuro 2011
Components

- Isolation valve
- Pressure relief valve
- Filters
- Pressure sensors
MEMS isolation valve

An isolation valve near the propellant tank to ensure “No leak” before the system is operated (similar to a pyro-valve)
- A 2 micron filter included
- Redundant (2 inlets, 9 outlets)

Chip mass: < 1 g
Pressure Relief Valve

**MEMS devices provides multiple functionality**

To act as passive burst membrane (redundant)
To act as active single shot valve if pressure builds up in system (redundant)
To act as check valve system if opened (actively or passively) and thus prevent loosing all propellant
To filter the gas passing the check valve

*Chip mass: < 1 g*
MEMS Filters

Etched disk technology:
- Filtration rate: 2, 10, 20 micron
- Scalable design
- High flow rate/low pressure drop

10µm Filter Assembly #1
@ 1.9 Bar and 293 K

![Graph showing mass flow vs. pressure drop for 10µm Filter Assembly #1 (8 Filter Networks)](Graph.png)
MEMS technology in sensing element

Developed by Presens (N)

Unique sensing element

- Tubular silicon structure
- Compressive stress
- Piezoresistive Wheatstone bridge
  - P and T measured by same resistors

Key properties

- Full-scale up to 10000 bar (100 000 psi)
- Accuracy down to 0.01% of FS
- Inherent over-pressure protection
-Insensitive to mounting stress