MEMS Microthruster
Digital Propulsion System

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MEMS Digital Propulsion
Microthrusters Have Advantages

- Physics of operation is straightforward
  - Individual plenums can be loaded with many types of propellants
  - Heating increases plenum pressure-ruptures MEMS fabricated blowout disk which delivers impulse to microsatellite

- Digital propulsion has advantages
  - Can deliver precise impulse bit for microsatellite applications for insertion, station keeping, attitude control, disposal
  - Pulsed design has operational advantages
    - No moving parts
    - Multiple propellant options
    - Variable plenum and throat dimensions for programmable thrust and impulse delivery
    - Up to ~10^6 engines or more per 10 cm. wafer

- Design scales directly to Meso- and Macroscale
Digital Propulsion Concept is Refined Through Three Hardware Builds

Task 5. MEMS Microthruster Propulsion System
- Management
- Reporting

Task 1. Proof of Concept
3 Configurations
- Design
- Test
- Fab
- Characterize

Task 2. Sub-Array Evaluations
2 Test Articles
- Design
- Test
- Fab
- Characterize

Downselect

Task 3. Full-Array Demonstration
1 Test Articles
- Design
- Test
- Fab
- Characterize
- Commercial foundry builds

Downselect

Task 4. Process Models and Analyses
MEMS Digital Propulsion
Microthrusters Prototype Have
Modular Design

Top Die
- Diaphragms on bottom, expansion nozzles on top

Middle Die
- Propellant fills individual holes

Bottom Die
- Polysilicon “ignitors” with direct inter-connects to bond pads (no electronics)
MEMS Digital Propulsion
Microthrusters Prototype Have Modular Design

- We have potentially 90 different bottom-middle-top combinations for configuration 1D alone.

- Top (diaphragm and nozzle) dice:
  - Silicon nitride (0.5 microns thick) on silicon (both sides)
  - One side forms mask
    - Laser-patterning exposes silicon
  - Other side forms diaphragm
    - KOH etch through wafer forms nozzle with diaphragm
    - 190, 290, and 390-micron square silicon nitride diaphragms

- Middle (propellant storage) dice:
  - FOTURAN (photosensitive glass by Schott) wafer, 1.5-mm-thick
    - Laser-patterning exposes 300, 500, and 700-micron diameter holes for propellant storage.

- Bottom (heater or ignitor) dice:
  - 1A: MOSIS fabrication  Test suspended heater designs
  - 1B: MUMPS fabrication  Test unsuspended polysilicon heaters
  - 1C: MUMPS fabrication  Test bridge polysilicon heaters
  - 1D: In-house fabrication  Test unsuspended and bridge-type polysilicon heaters
Top Dice Contains Diaphragms and Nozzles

- 400-micron-thick silicon wafer
- 0.5-micron-thick silicon nitride (both sides; from MCNC)
- Laser-patterned on top surface
- KOH etched down to bottom silicon nitride layer
- 190, 290, and 390-micron-square diaphragms
### Middle Dice Contains Propellant Plenum

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<th>300 micron dia.</th>
<th>500 micron dia.</th>
<th>700 micron dia.</th>
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- **Alignment holes**
- **Propellant cavities**
Bottom Dice Contains Several Heater/Ignitor Variants – 1A

MOSIS: 2-micron ORBIT Semiconductor Tiny Chips NIST Microheater Design

Run N76Y as Received

SEM of Run N76L Etched in EDP
Bottom Dice Contains Several Heater/Ignitor Variants – 1B

- MUMPS fabrication
- 2 resistor designs
- 2 spark gap designs
- 800-micron centers
- 10 “heaters” per sub-die
Example sub-die:

- 10-micron-wide heater
- 1500-Ohms
Bottom Dice Contains Several Heater/Ignitor Variants – 1D

- Common Ground
- Bond Pad
- Polysilicon Resistor
- Alignment Target
- Metal-on-poly Conductor

6 mm
Thrust Stand Components Have Been Fabricated

Balance pivot

Ball-release solenoids

Pendulum

Vacuum feed-through

Thruster “chip”

“Credit Card” Microcontroller
Prototype Digital Propulsion System
Has No Umbilicals

Infra-Red Serial Data Link

Microcontroller With Accelerometer
(Parallax “Basic Stamp” with Kistler 8303A1M2 MEMS accelerometer)

Batteries
(Two 9V batteries)

Mirror

10-cm Moment Arm

Microthrusters Mounted in DIP carrier

“poof!”

Optical Fiber to Laser Interferometer
(Precision Dynamics PD-1000; 10-nm accuracy with 2-mm travel)