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MEMS Microthruster Digital Propulsion System

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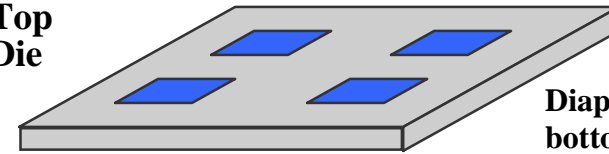
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MEMS Digital Propulsion Microthrusters Have Advantages



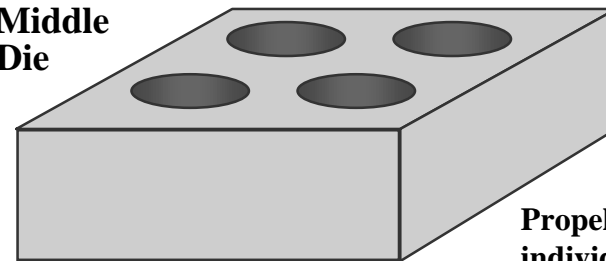
- Physics of operation is straightforward
 - Individual plenums can be loaded with many types of propellants
 - Heating increases plenum pressure-ruptures MEMS fabricated blowout disk which delivers impulse to microsatellite
- Digital propulsion has advantages
 - Can deliver precise impulse bit for microsatellite 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 $\sim 10^6$ engines or more per 10 cm. wafer
- Design scales directly to Meso- and Macroscale

Top Die



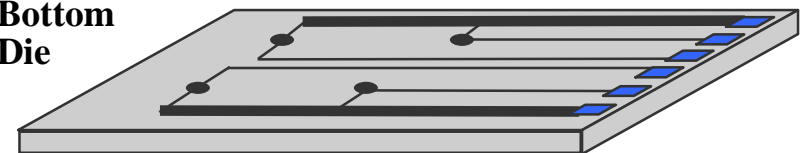
Diaphragms on bottom, expansion nozzles on top

Middle Die



Propellant fills individual holes

Bottom Die



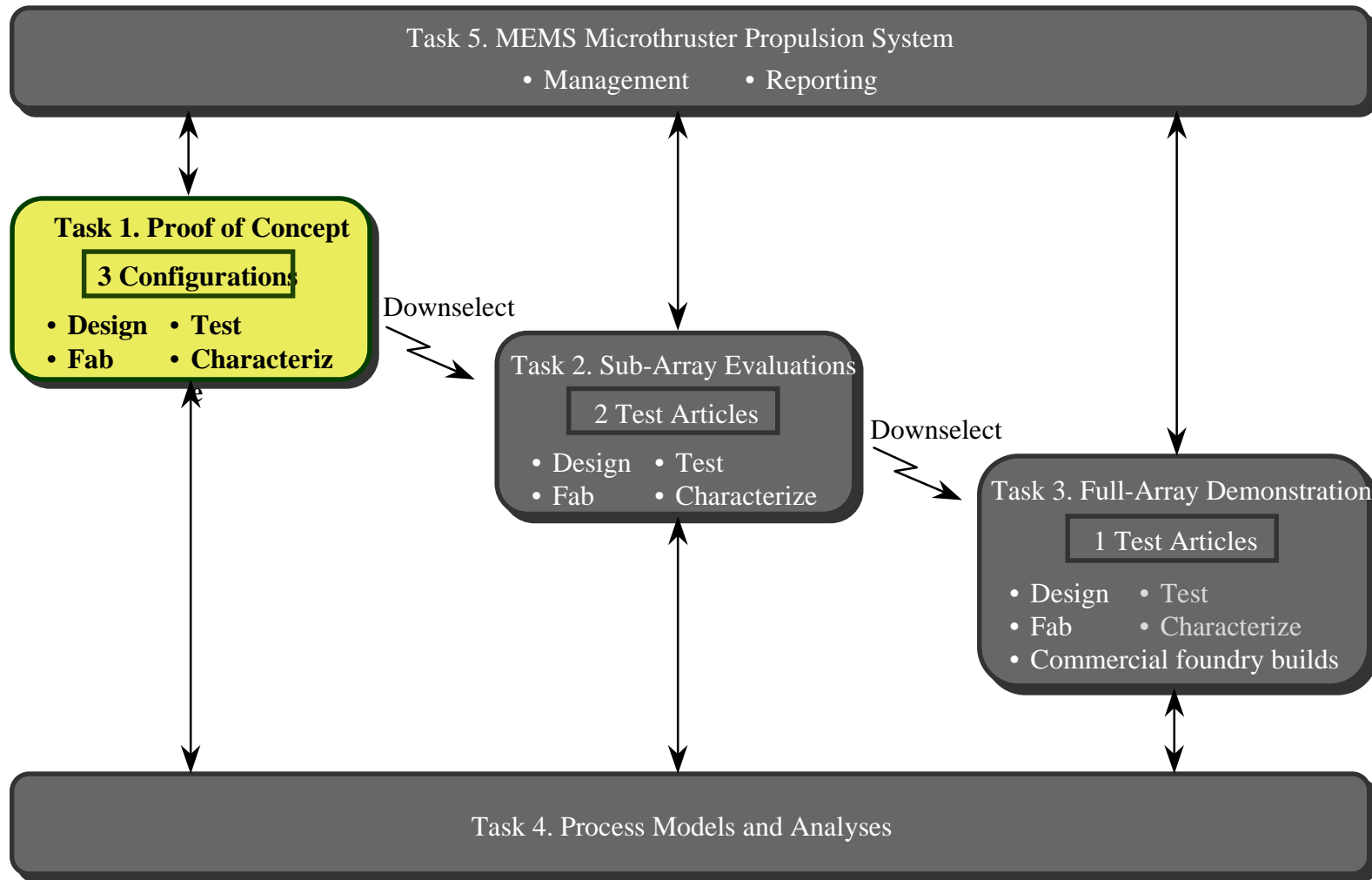
Polysilicon "ignitors" with direct inter-connects to bond pads (no electronics)



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Digital Propulsion Concept is Refined Through Three Hardware Builds





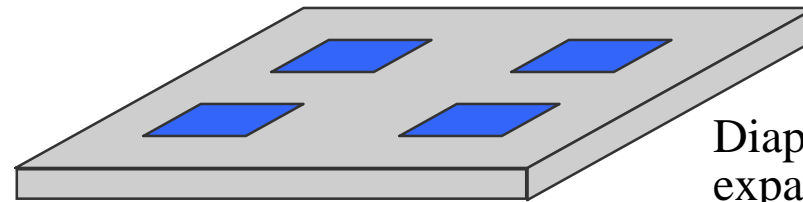
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MEMS Digital Propulsion Microthrusters Prototype Have Modular Design

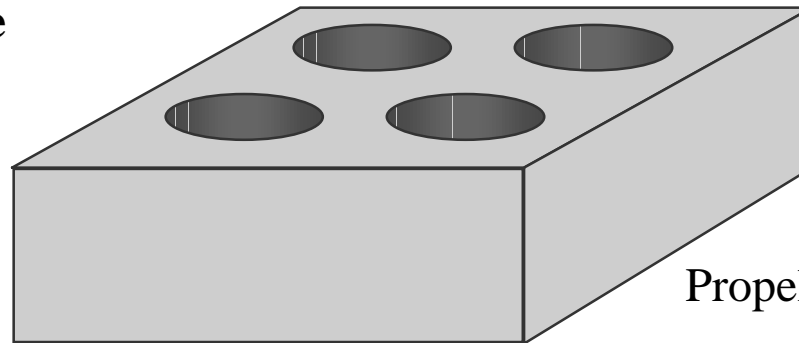


Top Die



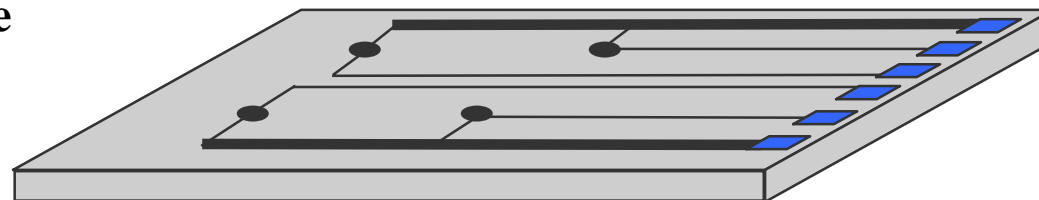
Diaphragms on bottom,
expansion nozzles on top

Middle Die



Propellant fills individual holes

Bottom Die



Polysilicon "ignitors" with direct
inter-connects to bond pads (no electronics)



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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



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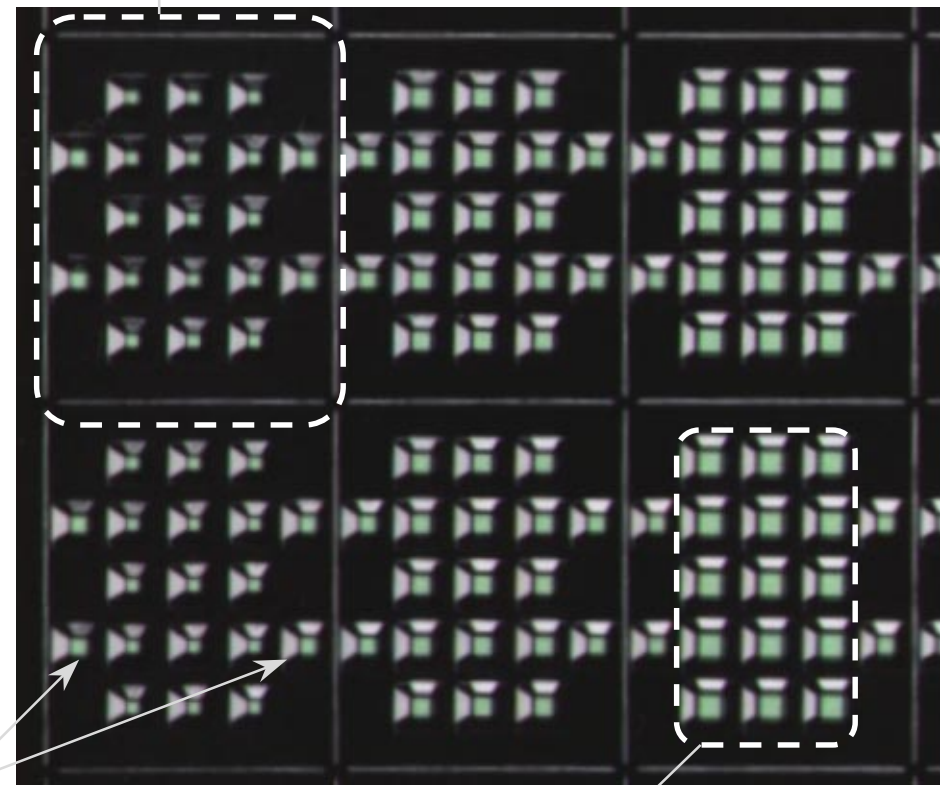
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Top Dice Contains Diaphragms and Nozzles



- 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

Single die



Alignment holes

3 x 5 Thruster array



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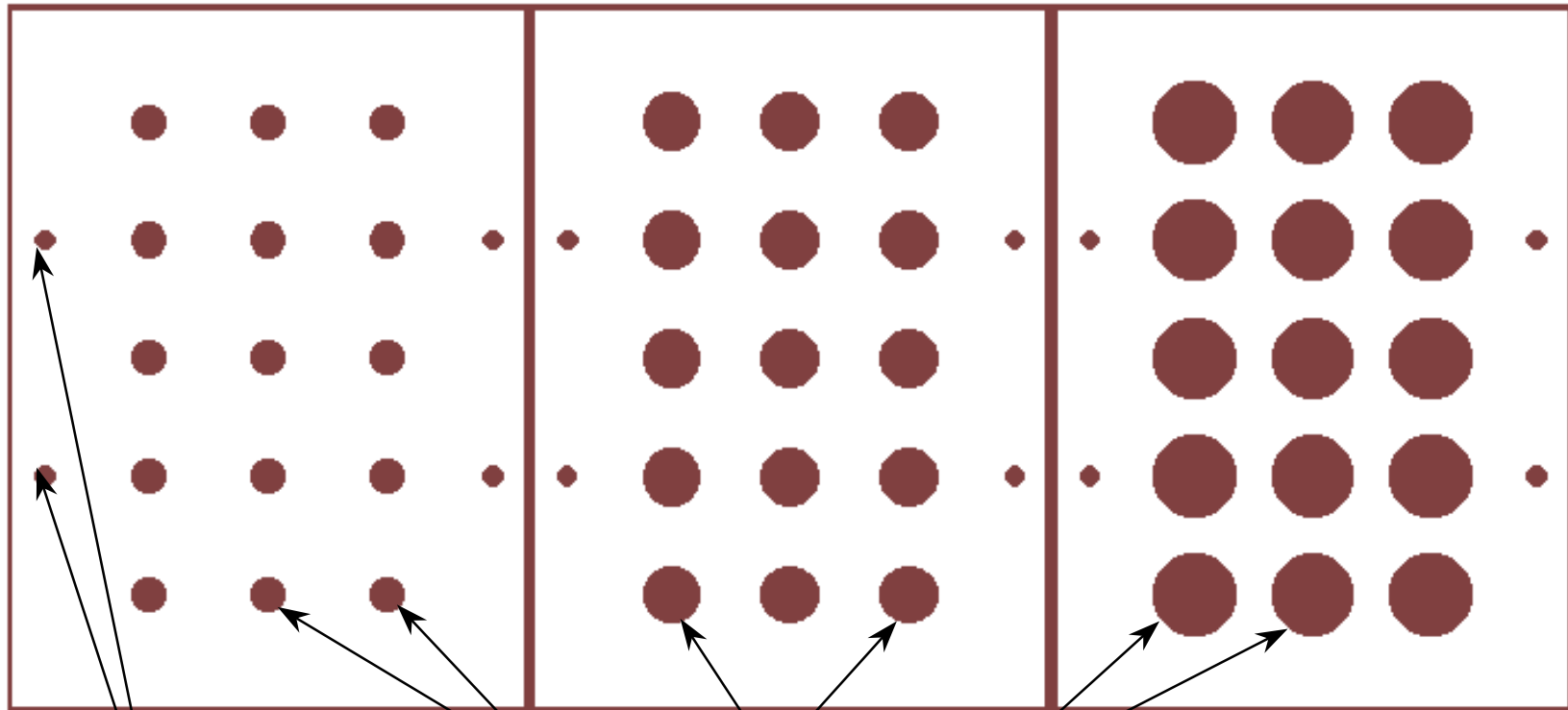
Middle Dice Contains Propellant Plenum



300 micron dia.

500 micron dia.

700 micron dia.



Propellant cavities

Alignment holes



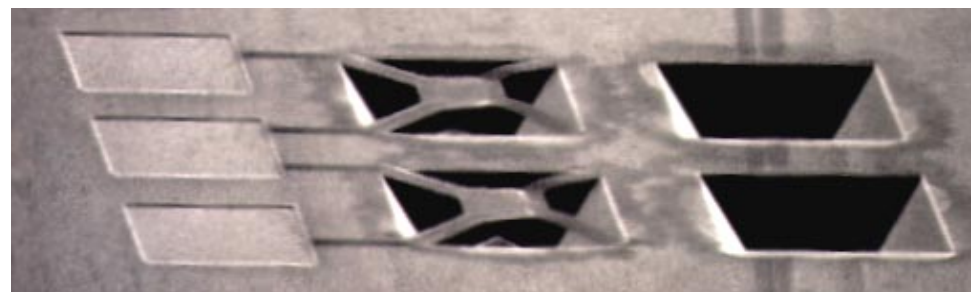
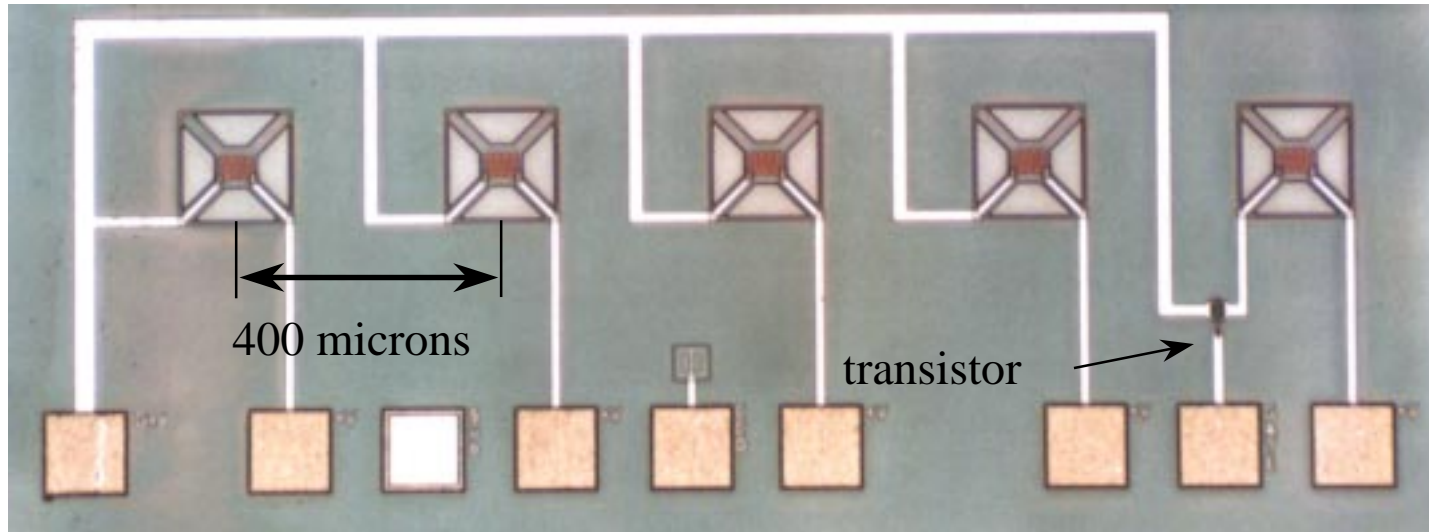
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Bottom Dice Contains Several Heater/Ignitor Variants – 1A



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



SEM of Run N76L Etched in EDP



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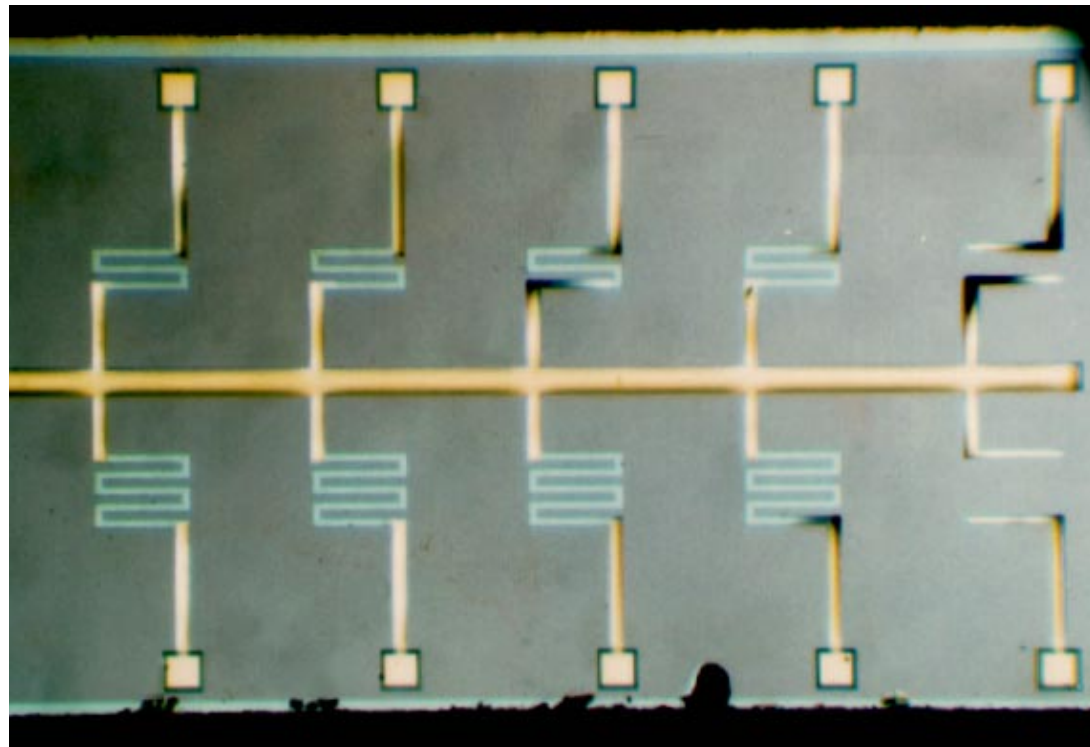
Bottom Dice Contains Several Heater/Ignitor Variants – 1B



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THE AEROSPACE CORPORATION

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





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Bottom Dice Contains Several Heater/Ignitor Variants – 1C

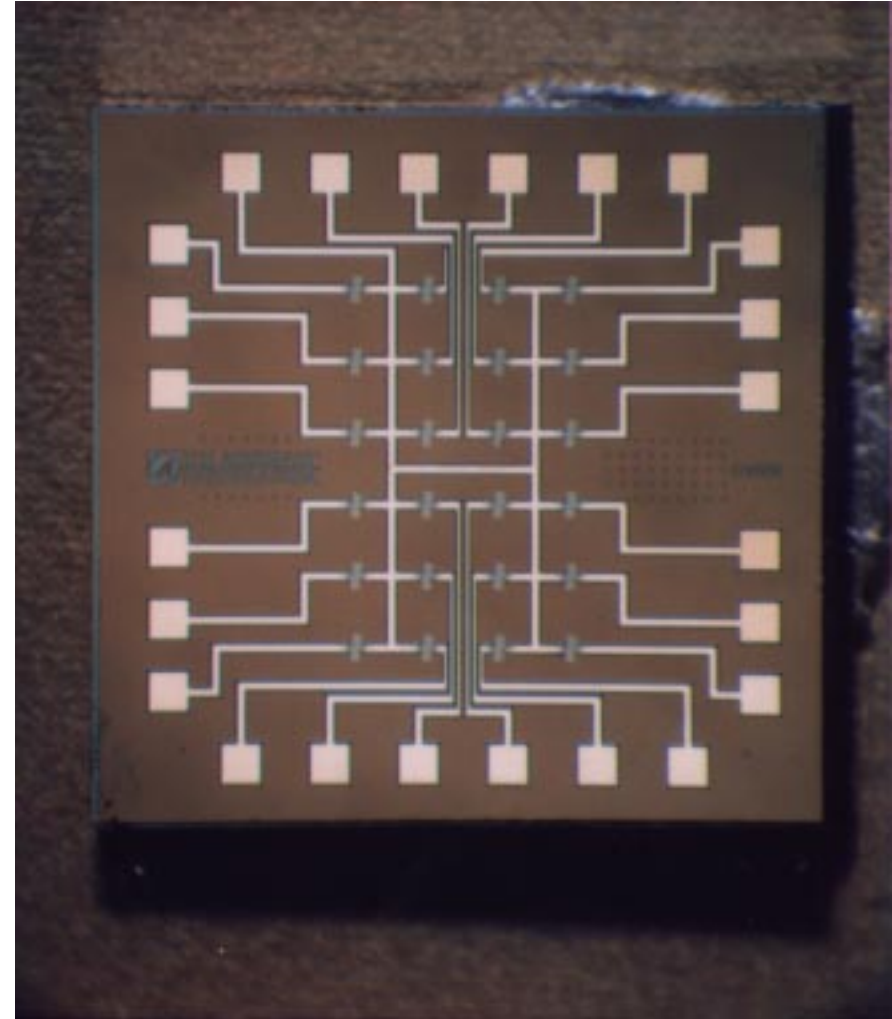


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THE AEROSPACE CORPORATION

Example sub-die:

- 10-micron-wide heater
- 1500-Ohms





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Bottom Dice Contains Several Heater/Ignitor Variants – 1D



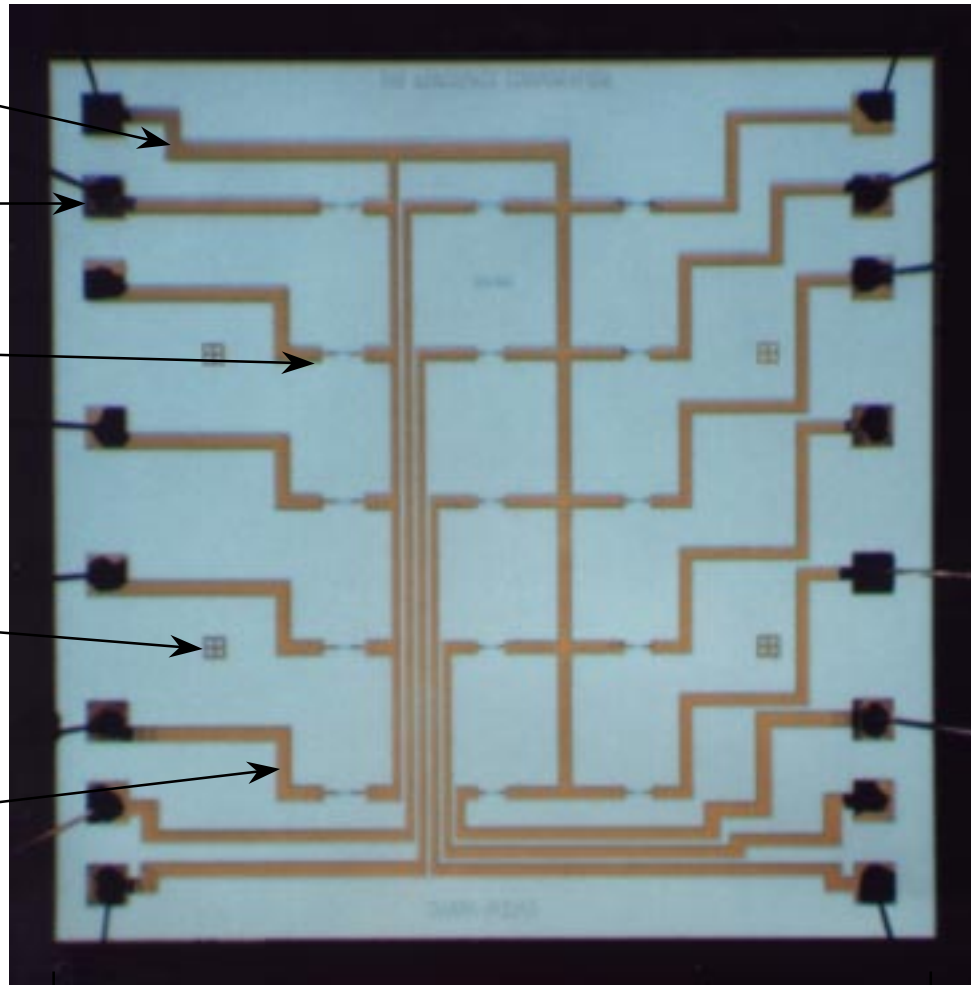
Common Ground

Bond Pad

Polysilicon Resistor

Alignment Target

Metal-on-poly Conductor



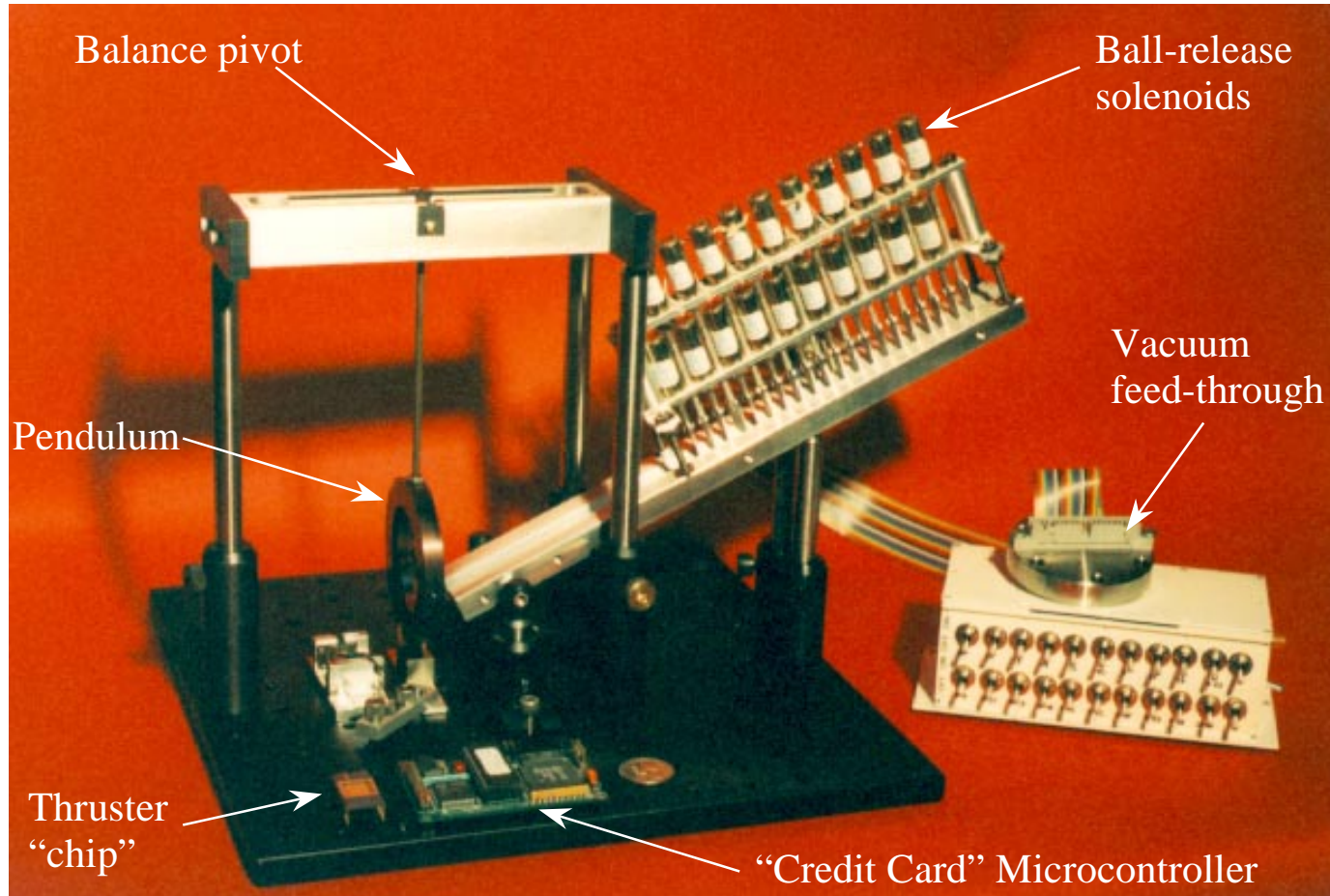
6 mm



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Thrust Stand Components Have Been Fabricated





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Prototype Digital Propulsion System Has No Umbilicals

