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MEMS Microthruster Digital Propulsion System

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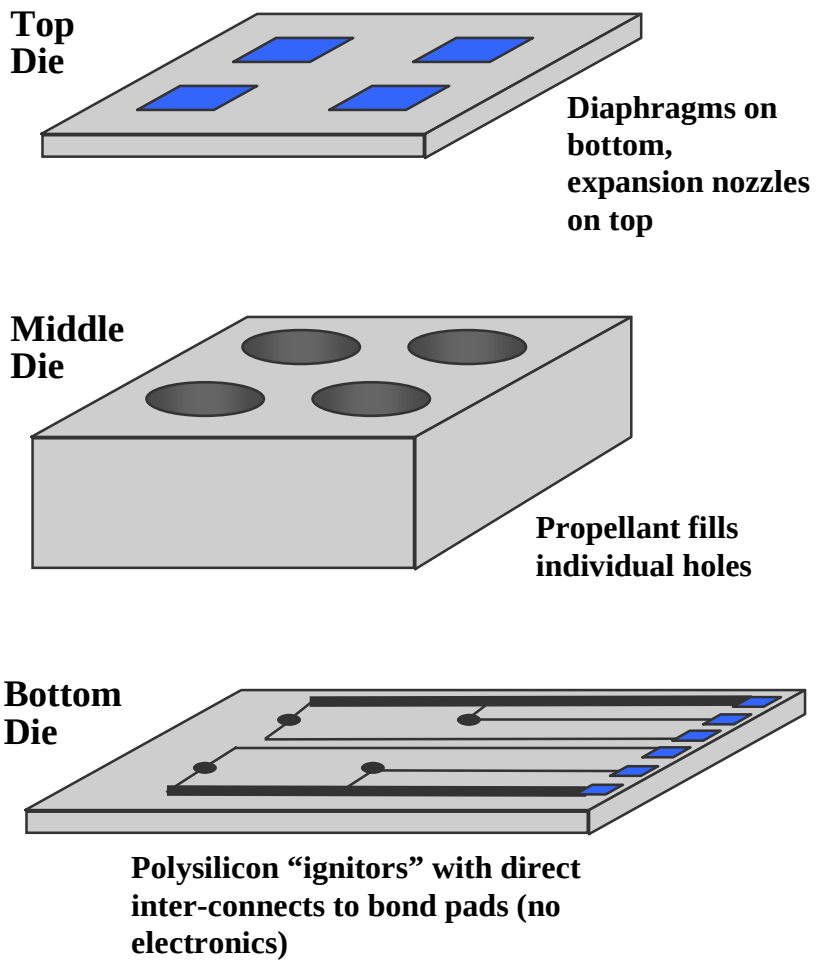
MEMS Digital Propulsion Microthrusters Have Advantages

- 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



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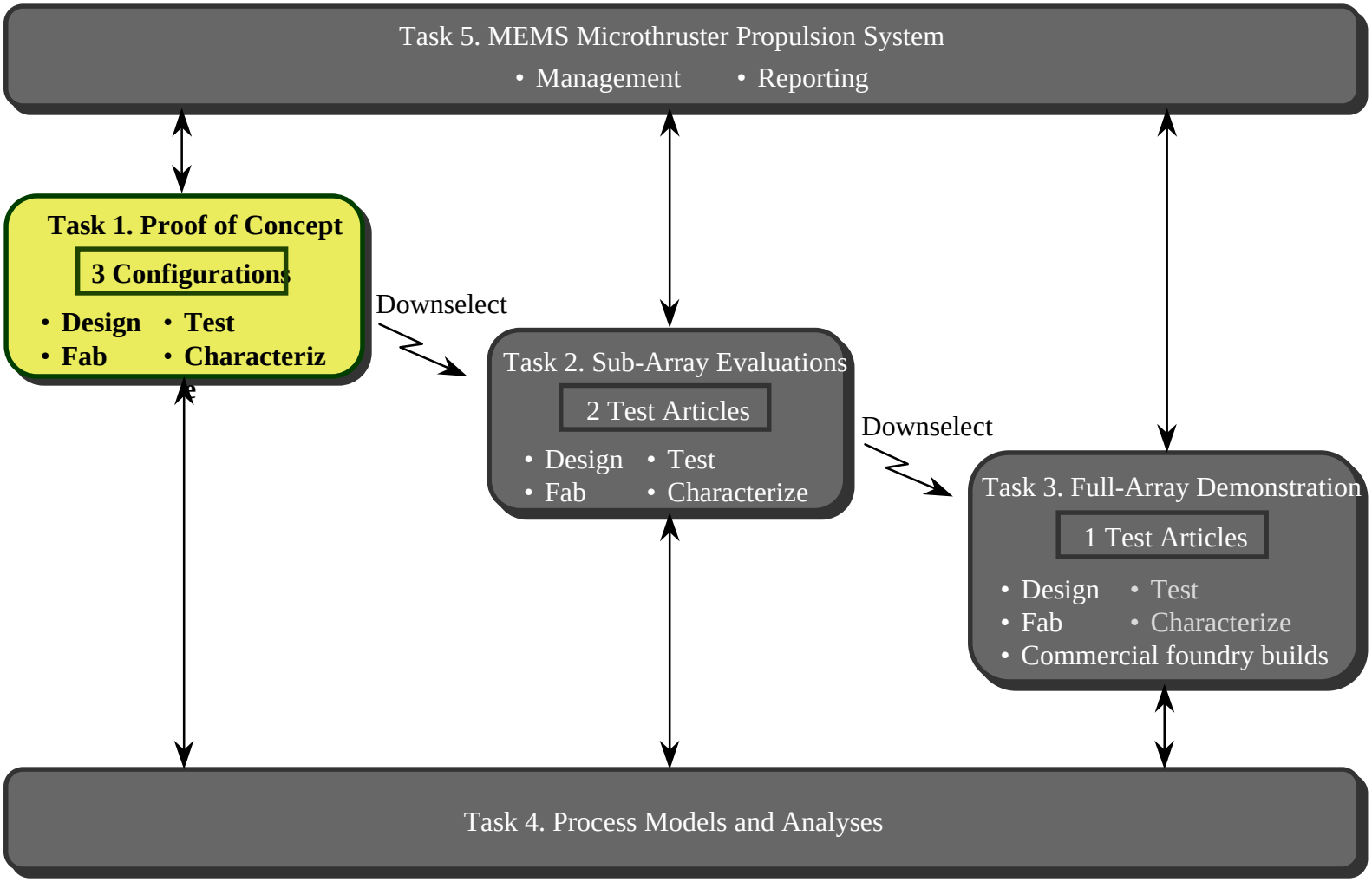
Digital Propulsion Concept is Refined Through Three Hardware Builds



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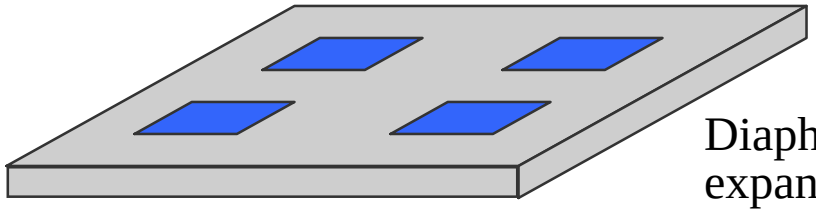
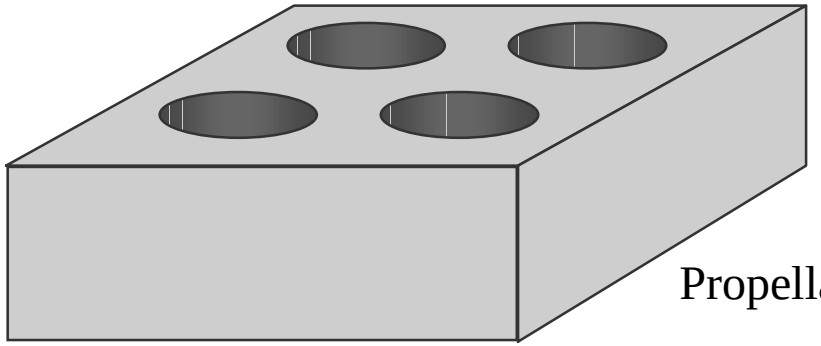
MEMS Digital Propulsion Microthrusters Prototype Have Modular Design

Top Die



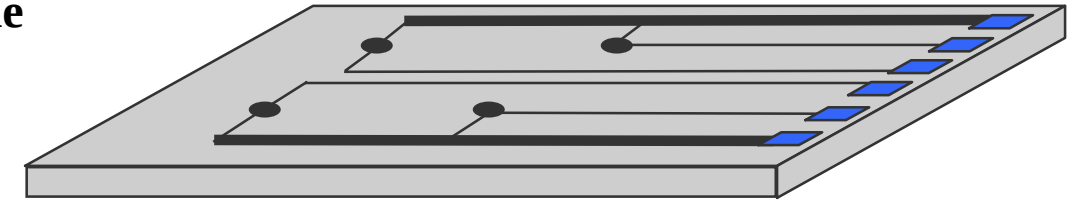
Diaphragms on bottom, expansion nozzles on top

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

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- 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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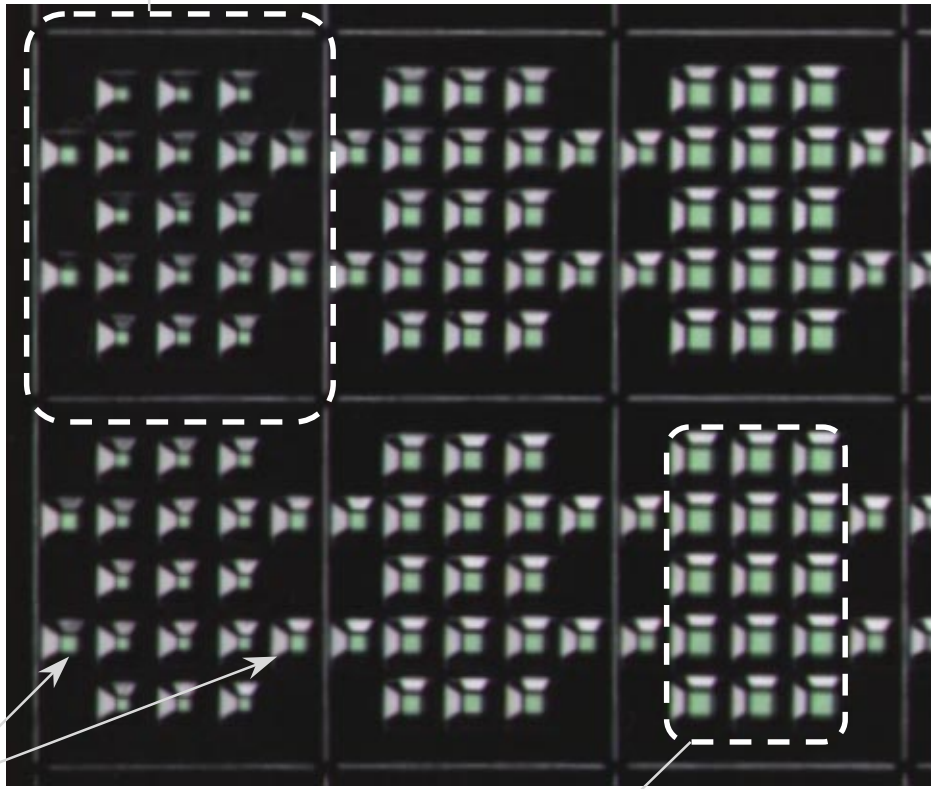
Top Dice Contains Diaphragms and Nozzles

- 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



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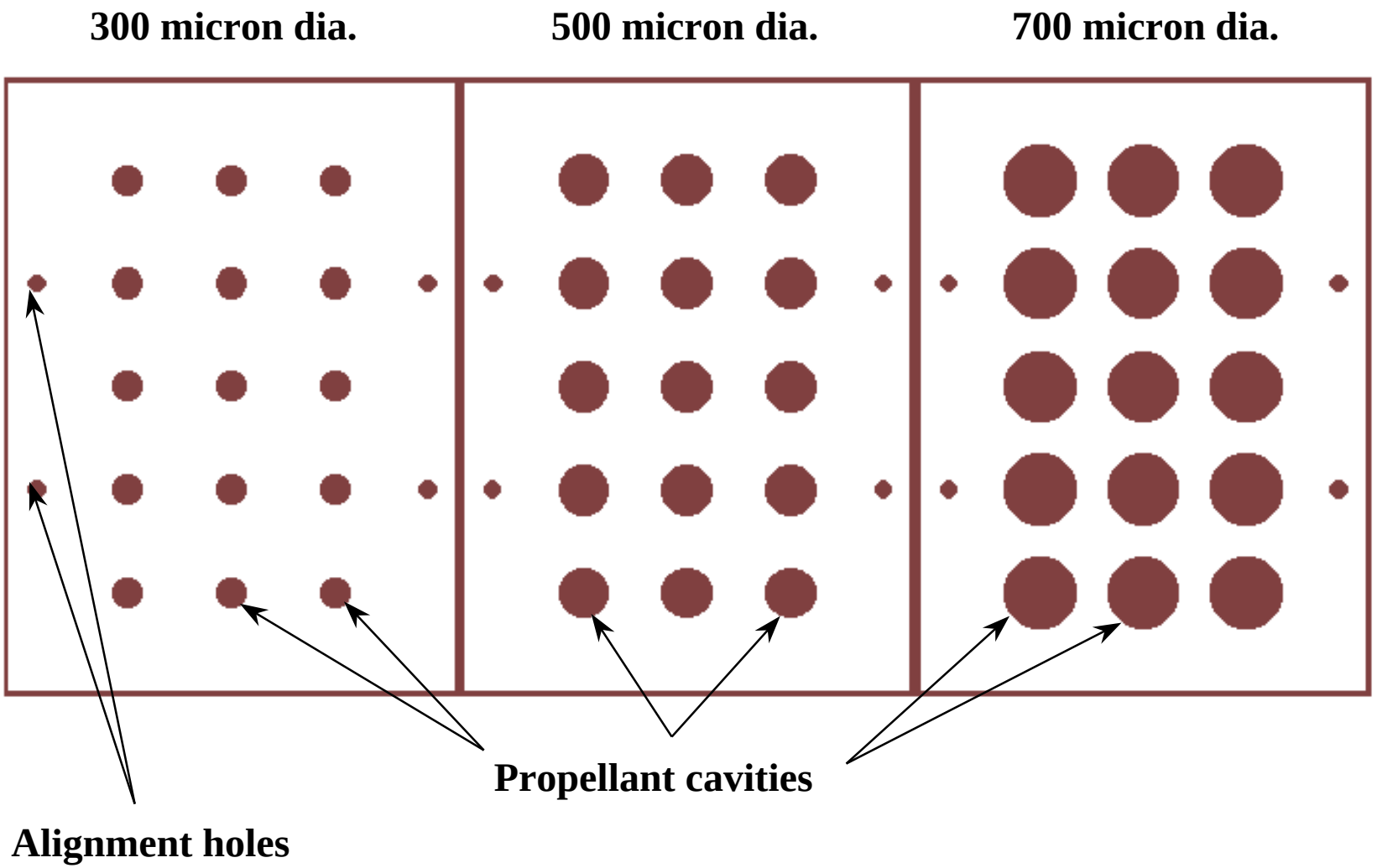
Middle Dice Contains Propellant Plenum



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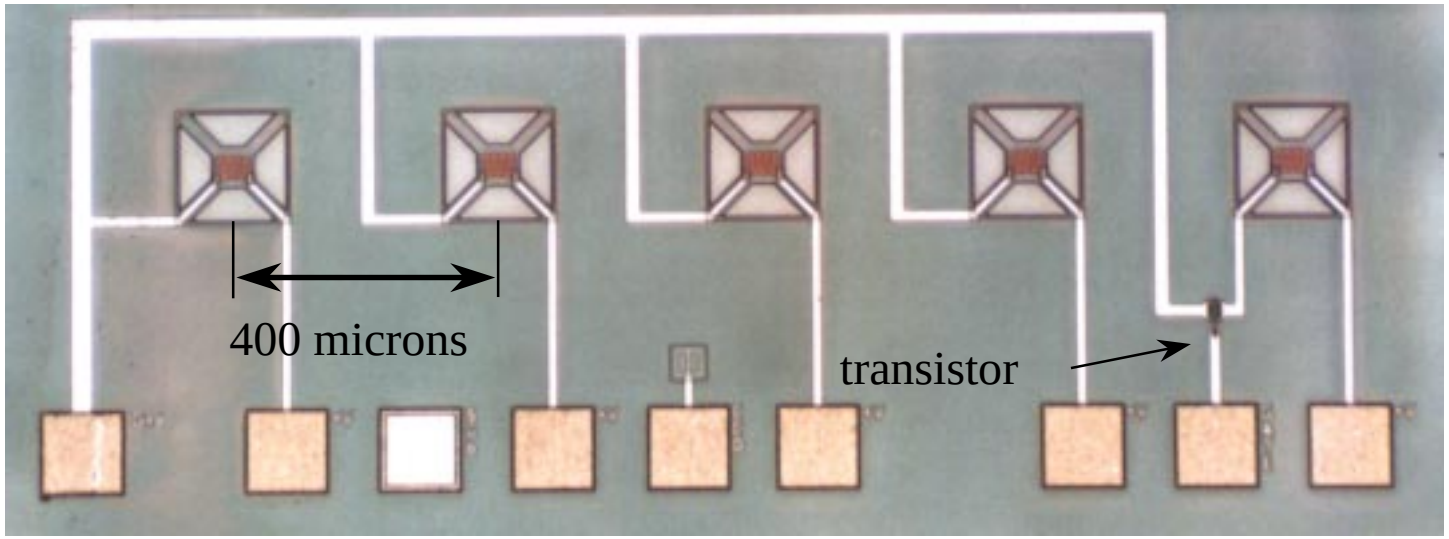
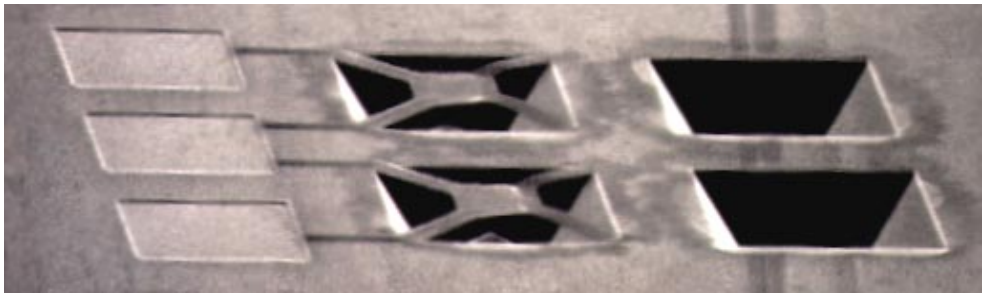
Bottom Dice Contains Several Heater/Ignitor Variants – 1A

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



Run N76Y as Received



SEM of Run N76L Etched in EDP

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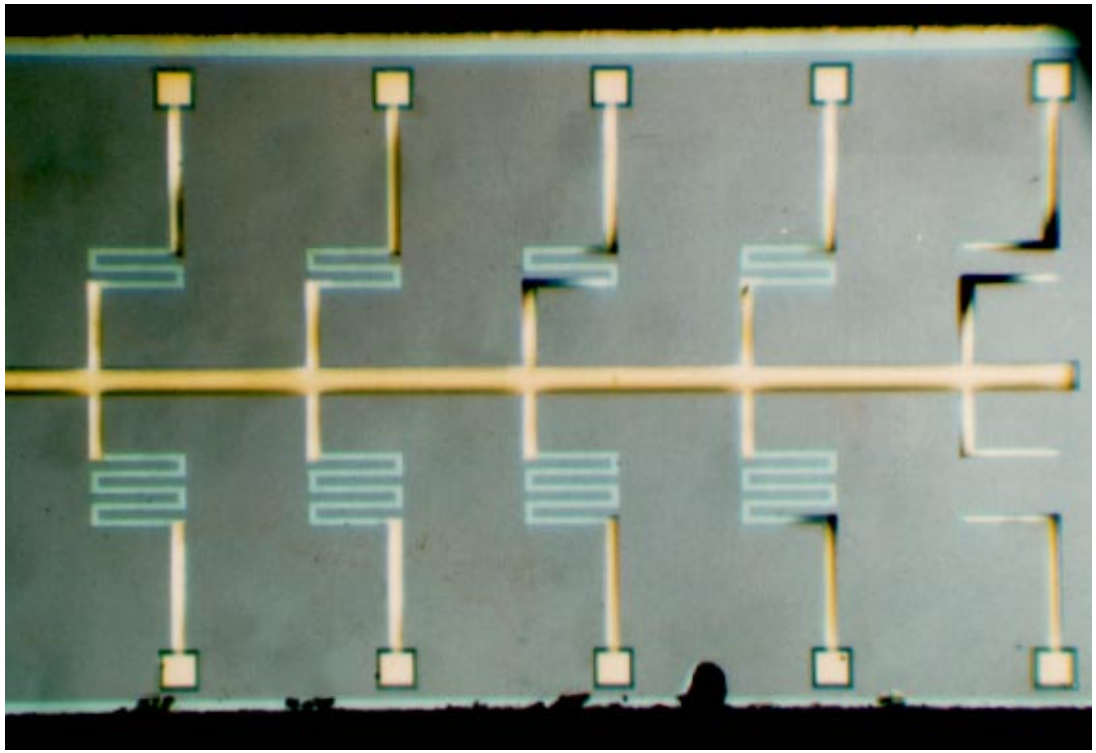
Bottom Dice Contains Several Heater/Ignitor Variants – 1B

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



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Bottom Dice Contains Several Heater/Ignitor Variants – 1C

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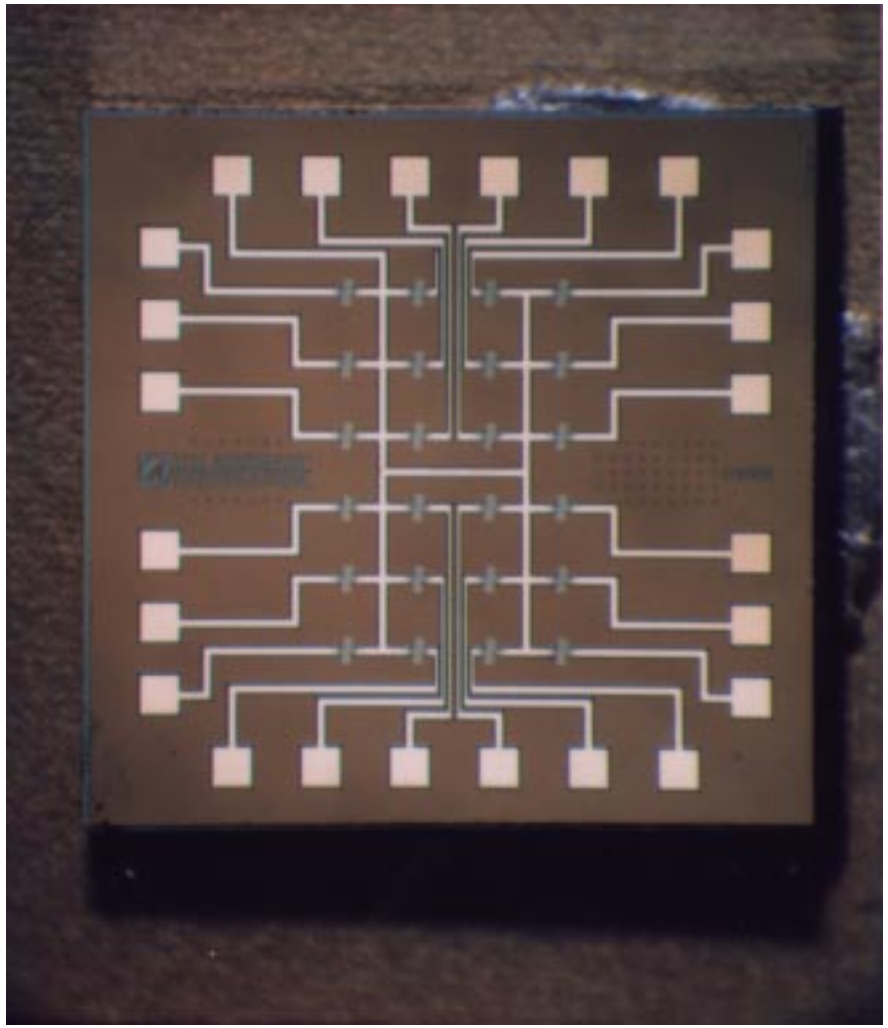
Example sub-die:

- 10-micron-wide heater
- 1500-Ohms



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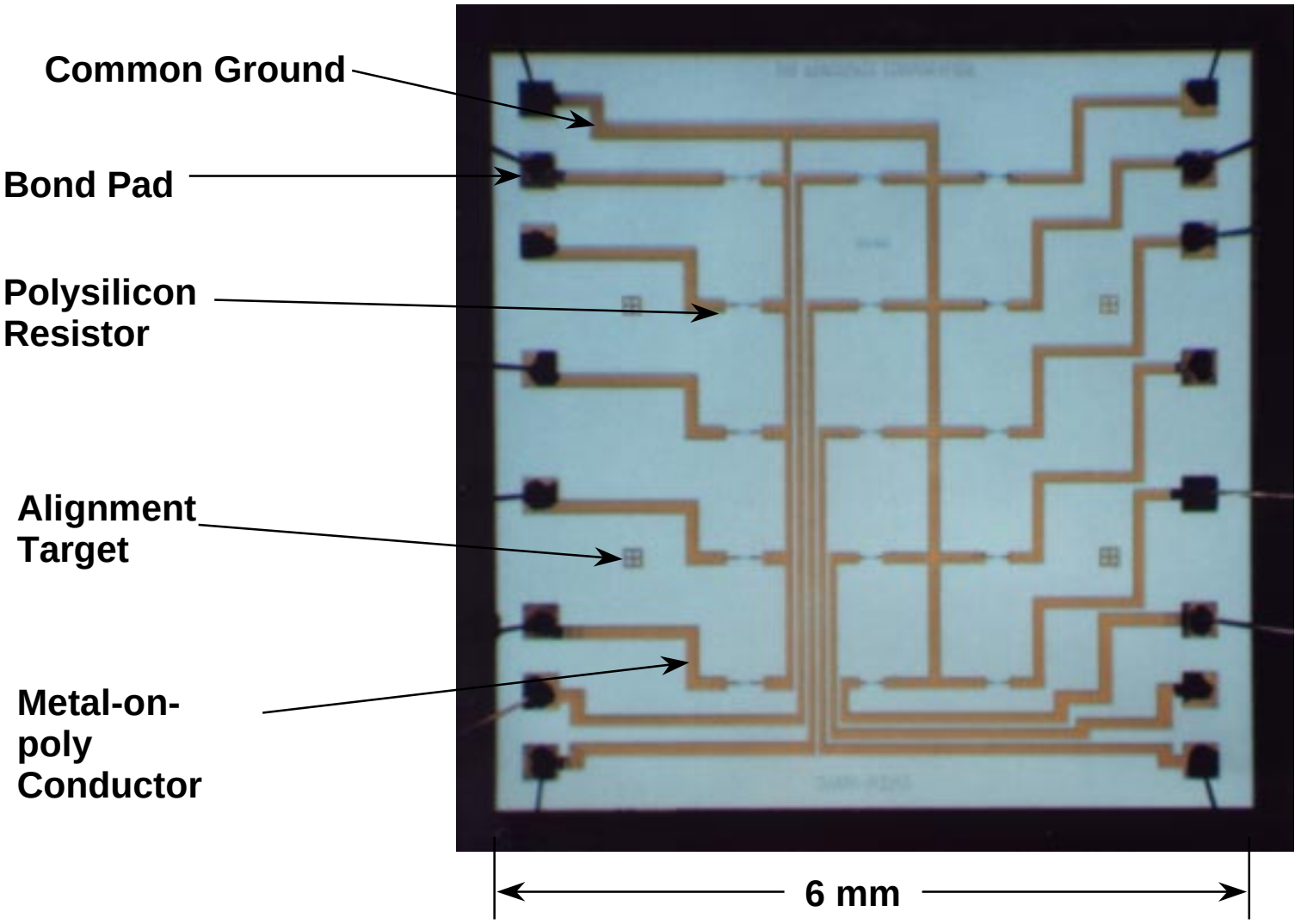
Bottom Dice Contains Several Heater/Ignitor Variants – 1D



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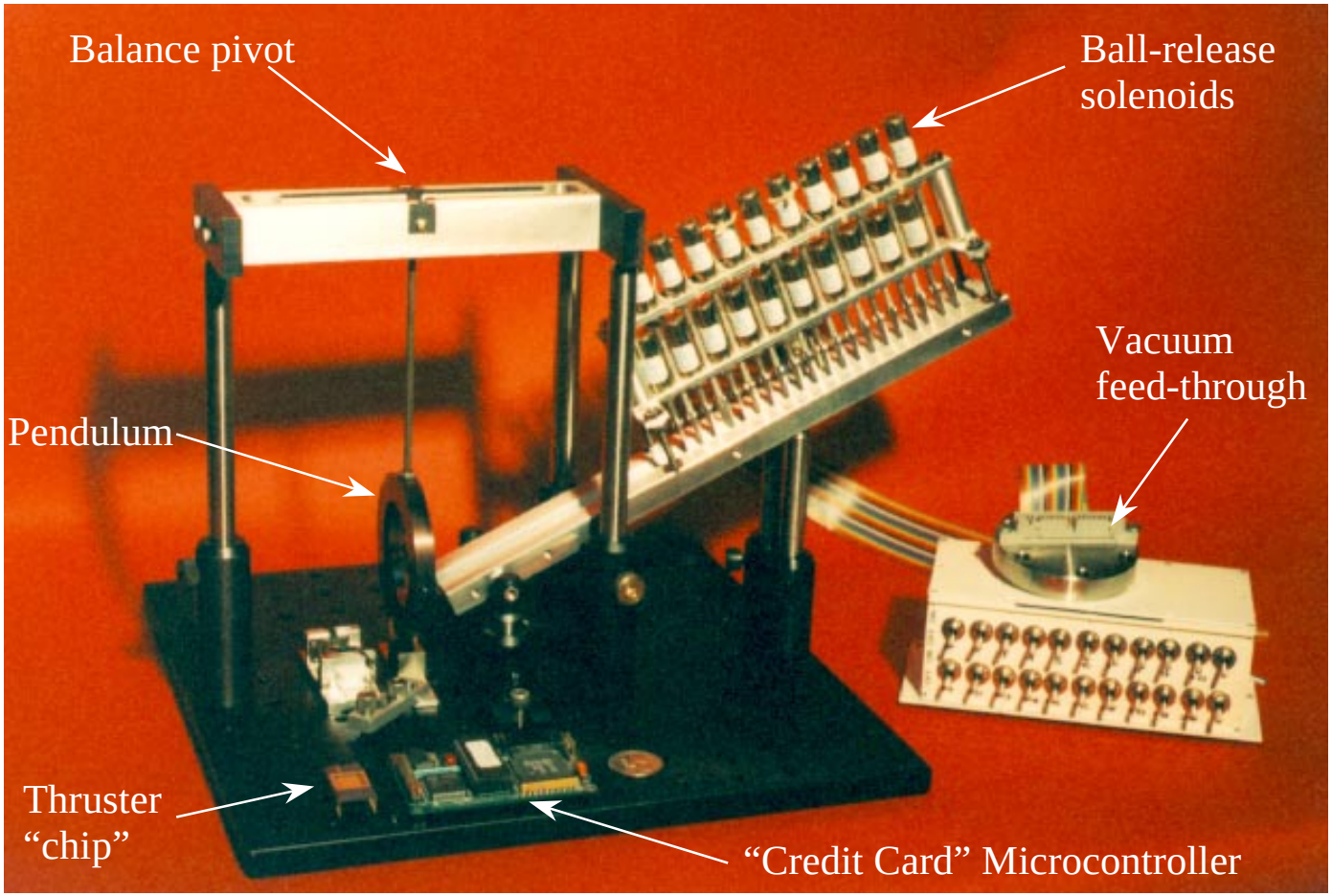
Thrust Stand Components Have Been Fabricated



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Prototype Digital Propulsion System Has No Umbilicals