MEMS Microthruster Digital Propulsion System

June, 1998 MEMS Principal Investigator's Meeting

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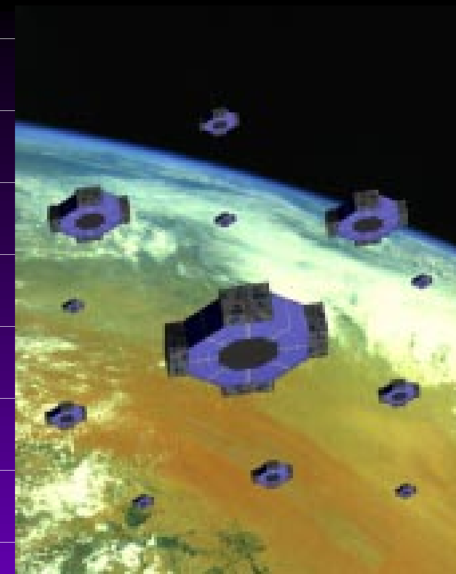
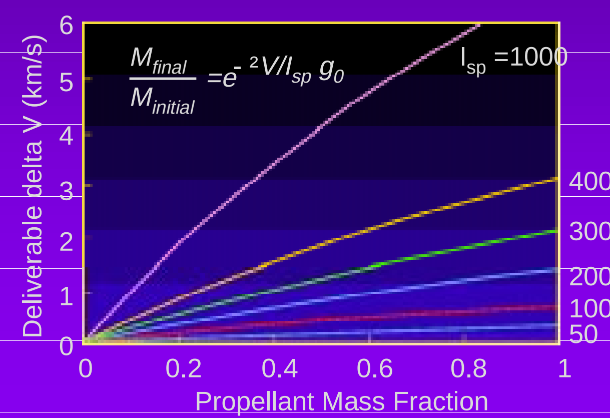
MEMS Technologies Support Future Space Systems

- Distributed proliferated systems have multiple applications
  - Large appperture
  - Long baseline
  - Communication
  - Interceptors
- Low mass nanosats combined with MEMS Digital Propulsion has system advantages
  - Several MEMS Digital Propusion implementations can be identified
    - I_{sp}:<250 sec, resistojet
    - I_{sp}:<250-300 sec, solid propellant
    - I_{sp}:300^{+}-450 sec, bi-propellant
    - I_{sp}:1,000^{+} sec, PPT's
  - Efficient packaging - no valves, lines or structure

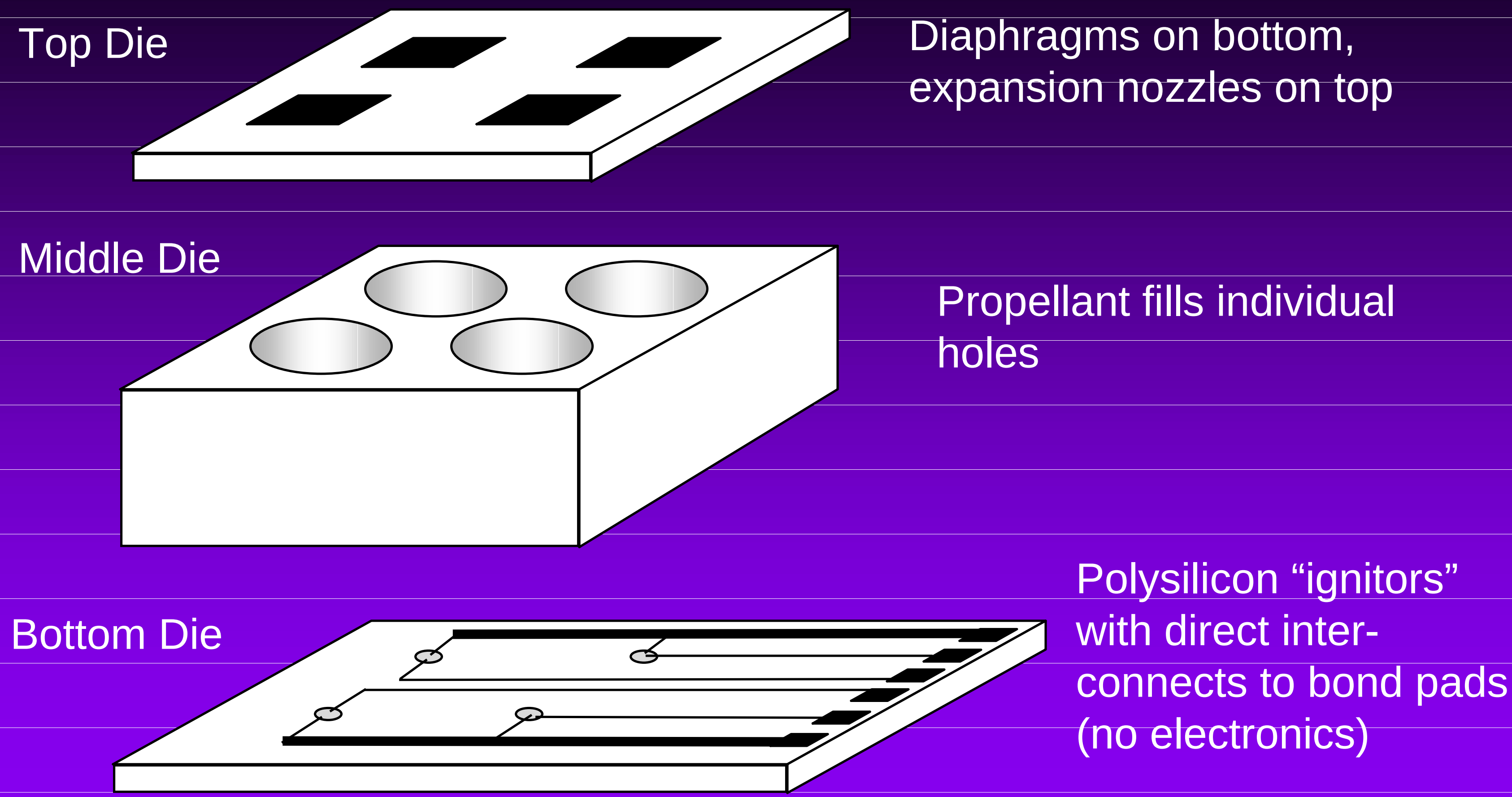


Concept Sketch of Microsatellite Constellation

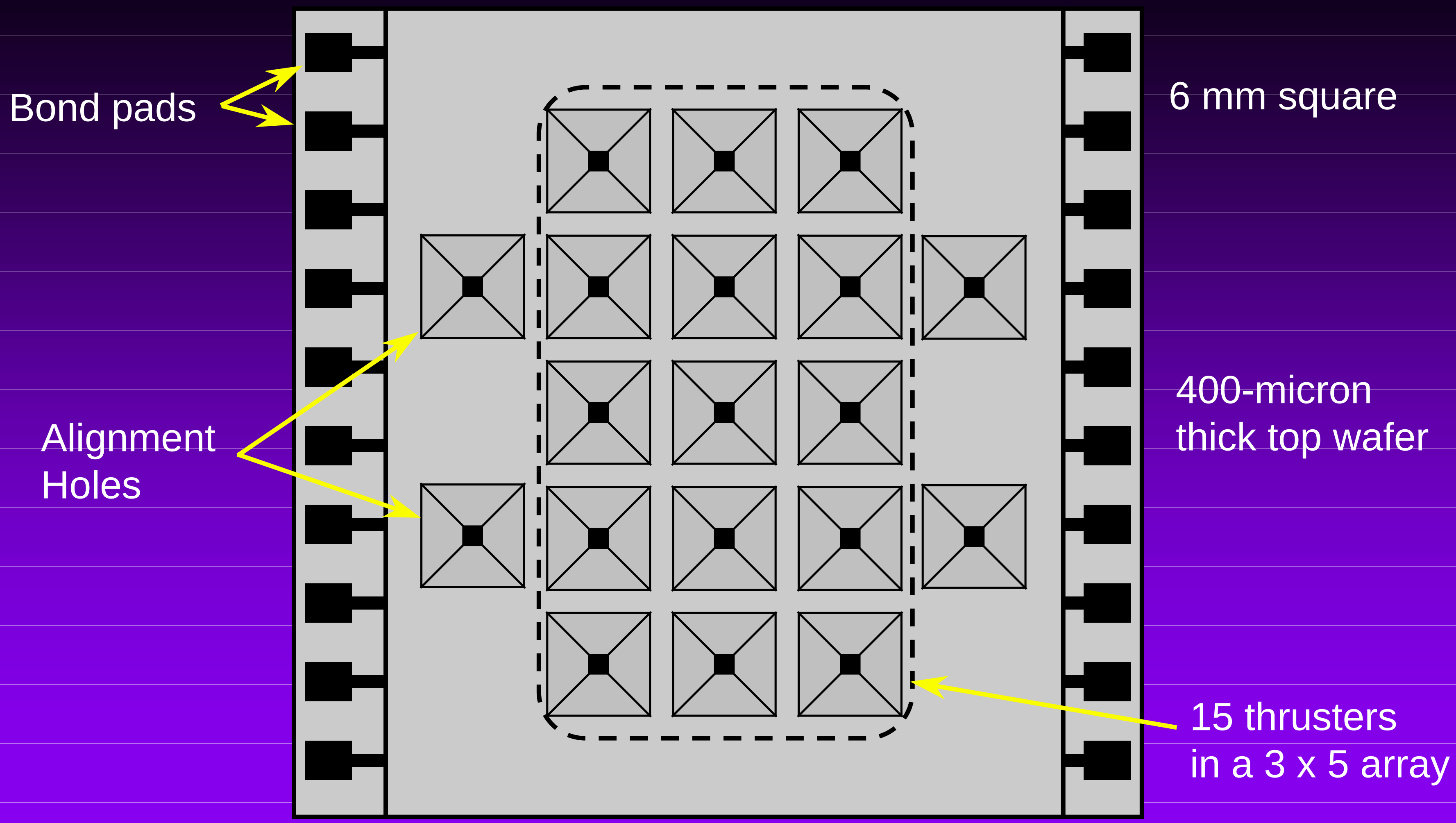


Interceptor ²V Increase Improves as I_{sp} Increases

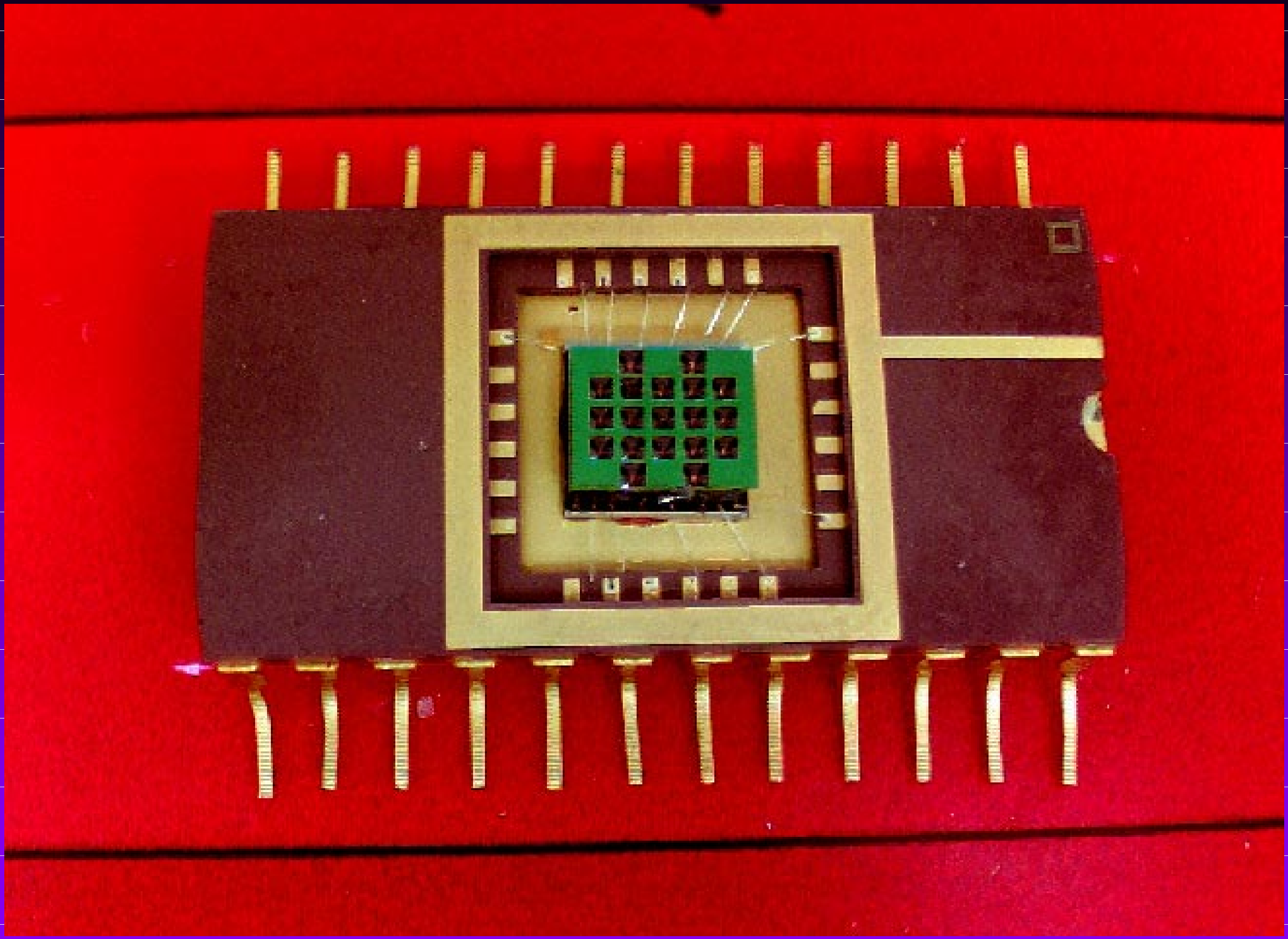
Exploded View of Digital Microthruster Array



Top View of Phase 1 Thruster Stack



Assembled Phase 1 "Thruster Chip"



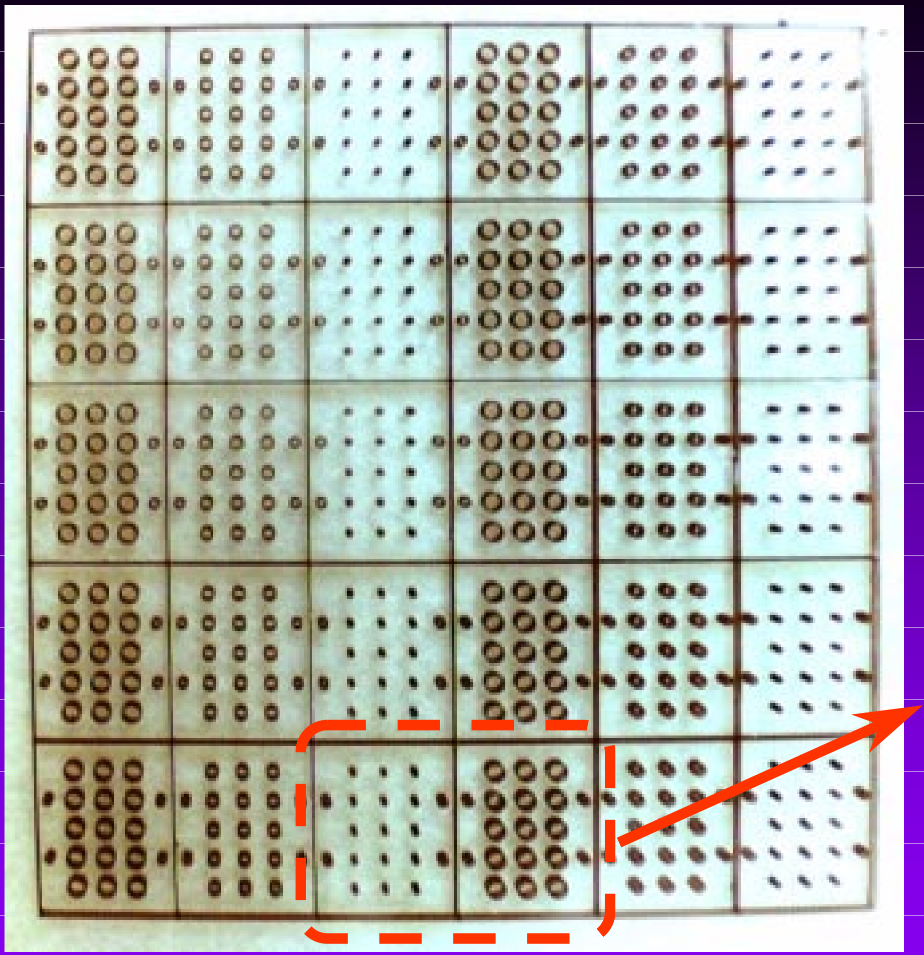
Fabrication Issues

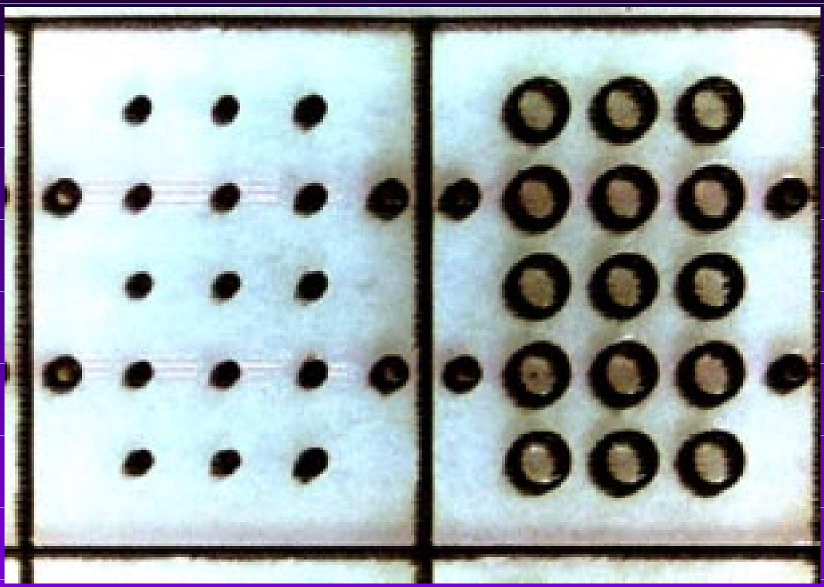
- Combustible solid:
  - Ignitor design; 20 x 400 µ resistors required for lead styphnate
  - Resistors must be thermally-isolated from substrate yet be mechanically robust
  - Bonds must withstand high transient pressure
- Resistojet:
  - No inter-chamber leaks
  - Bonds must withstand ~ 600 K temperature
- Electrolysis rocket:
  - No inter-chamber leaks

Fabrication Issues

- Nozzle array:
  - Mechanical dicing requires diaphragm protection
- Propellant die:
  - Planarity of baked FOTURAN
  - CTE mismatch to silicon; bonding agent required
  - Filling die with propellant; use solids if possible
- Electronics die:
  - Thermal isolation of resistors using standard CMOS SiO_2 layer thickness; reduce power requirements
  - High voltage (>100 V) for spark generation
- Bonding die:
  - Cyanoacrylate cannot tolerate high temperatures
  - Epoxies require controlled deposition (screen printing)

Laser Exposure of Glass Spacer Dice





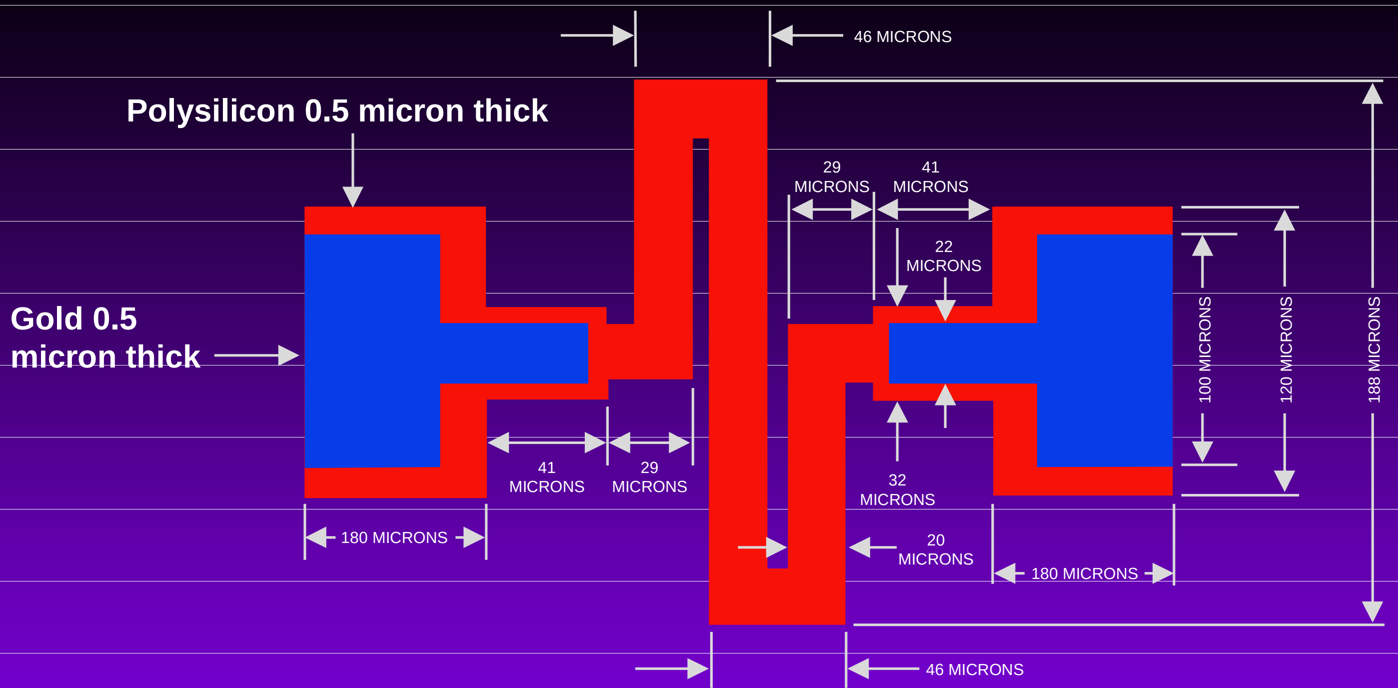
Individual die separate
during the HF etch

DARPA

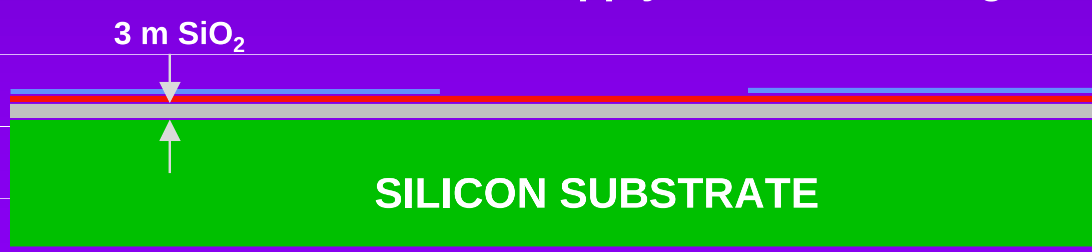
20 x 400 Resistor

TRW

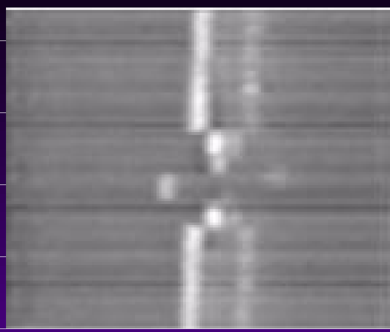
THE AEROSPACE CORPORATION



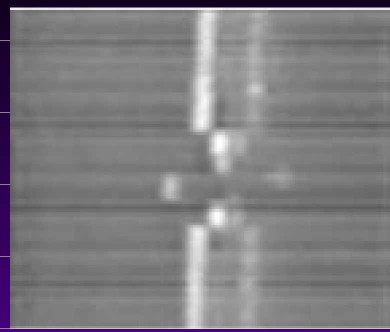
The polysilicon heater element is 20 microns wide, 0.5 microns thick, and has a resistance of 210 Ohms. We apply 30 Volts and it glows red.



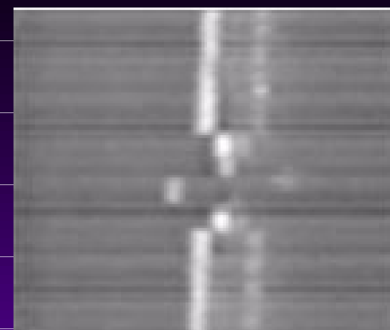
High Speed Video Images of Polysilicon Resistor Firing



t = 0 msec



t = 25 msec



t = 49 msec

t = 74 msec

t = 98 msec

t = 123 msec

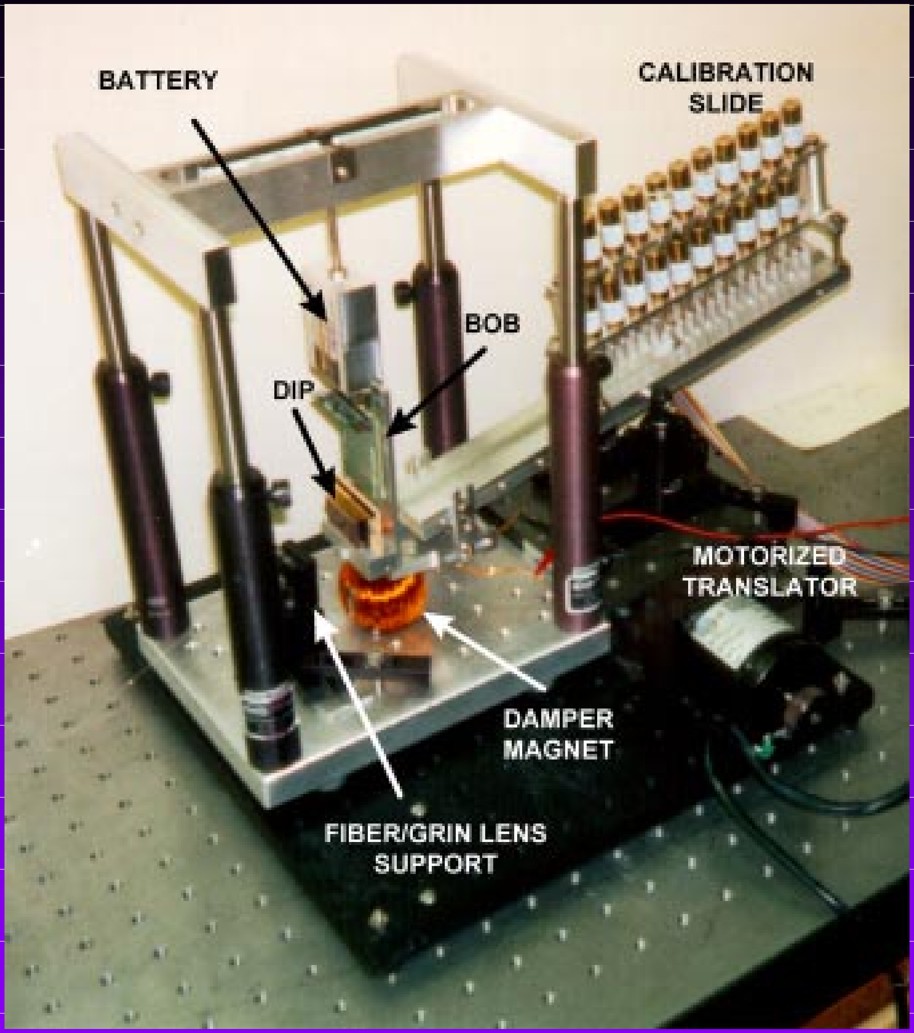
t = 148 msec

t = 173 msec

- With 60 volts input, the 20 x 400 resistor fires for ~50 msec

Thrust Stand

- Ballistic pendulum thrust stand of 240 gram mass
- Impulse range: 10^{-6} to 10^{-3} N-s
- Laser interferometric position measurement
- Active magnetic damping
- Basic Stamp microcontroller
- In-vacuum calibration



Videotapes

- Resistor glow
- Ignition of thin propellant layers
  – Nitrocellulose using kilovolt AC in resistors
  – Lead styphnate using 32 V DC in resistor
- Electrolysis
- Solid thruster ignition
- Thrust stand firing

Summary

- Combustible solid, resistojet, and electrolysis microthrusters demonstrated
  - All three viable with specific propellants
- Initial problems:
  - Poor ignition of typical solid propellants
  - Weak bond strength at high temperatures
  - Inter-chamber leaks for glue-bonded layers
- Thrust stand is ready
  - Customize power drivers for different power requirements (solid, resistojet, electrolysis)

Digital Propulsion Concept is Refined Through Three Hardware Builds