PROPULSION SYSTEMS

Micro-Propulsion: A limited Introduction

FAMU/FSU College of Engineering

Mechanical Engineering Dept

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December 05, 2001

Outline

- μ-Spacecraft view point
  - Classification and Applications
- Propulsion Using MEMS
  - MEMS Overview
  - Electro-Thermal Propulsion
  - Chemical Propulsion
  - Digital Micro-Thruster
- Non-MEMS Options
  - Chemical
  - Electro-Thermal
- μ-Propulsion Issues

Starting Line

- Massive Field (opportunity)
  - Various applications
  - Numerous Works
- Limit Scope
  - Gives a reference
  - Exclude earth-bound applications
  - Exclude landing and take-off
  - Low thrust
  - μ-Spacecraft!!

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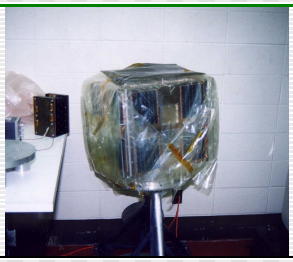
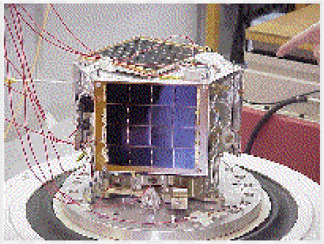
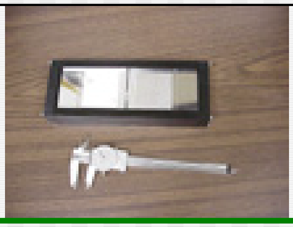
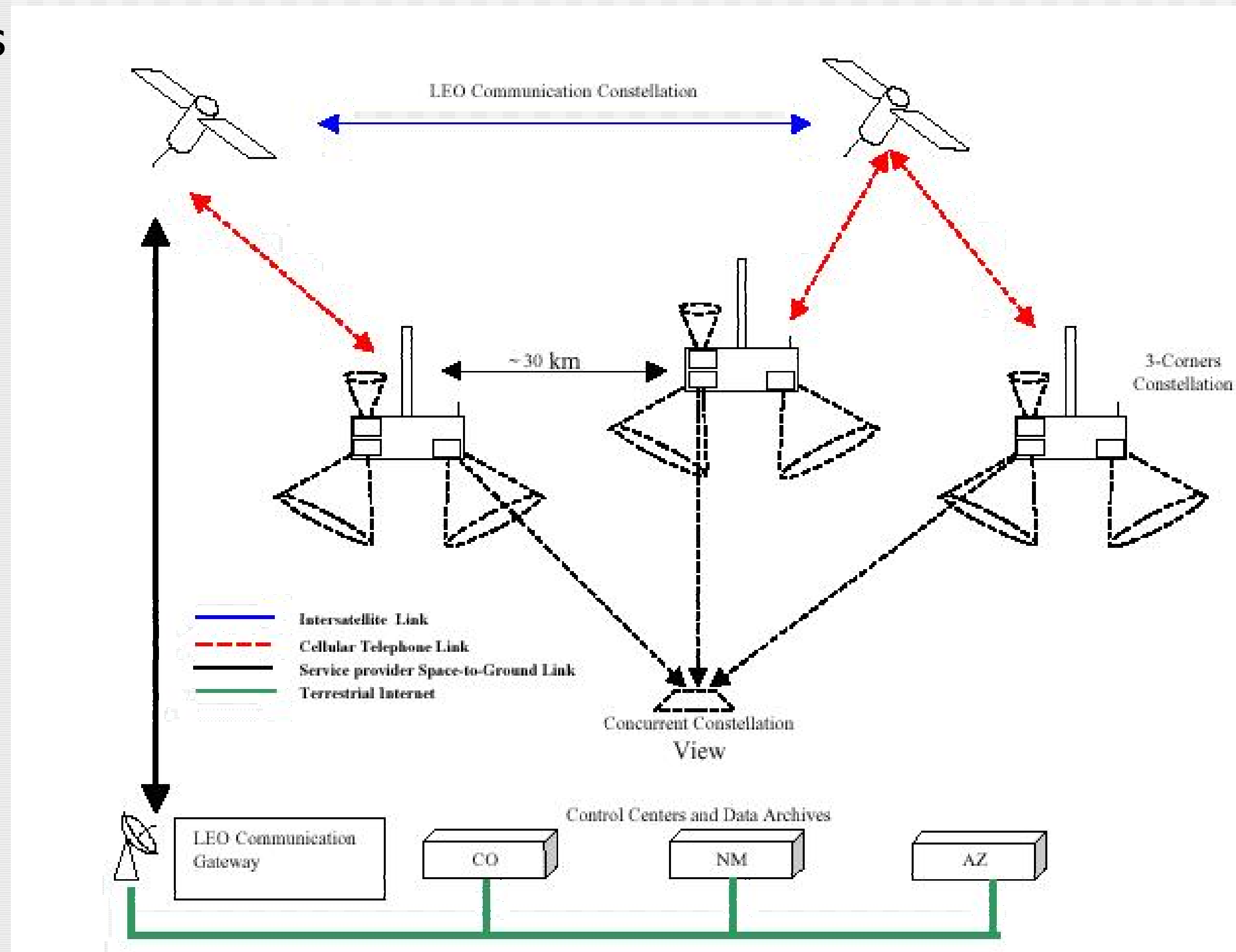
Categorizing μ-Spacecraft

Designation	Mass (kg)	Power (W)	Dimension (m)	Comment/Picture
Micro-spacecraft	10-100	10-100	0.3-1	
Class I micro-spacecraft	5-20	5-20	0.2-0.4	
Class II micro-spacecraft	1-5	1-5	0.1-0.2	
Class III micro-spacecraft	<1	<1	<0.1	

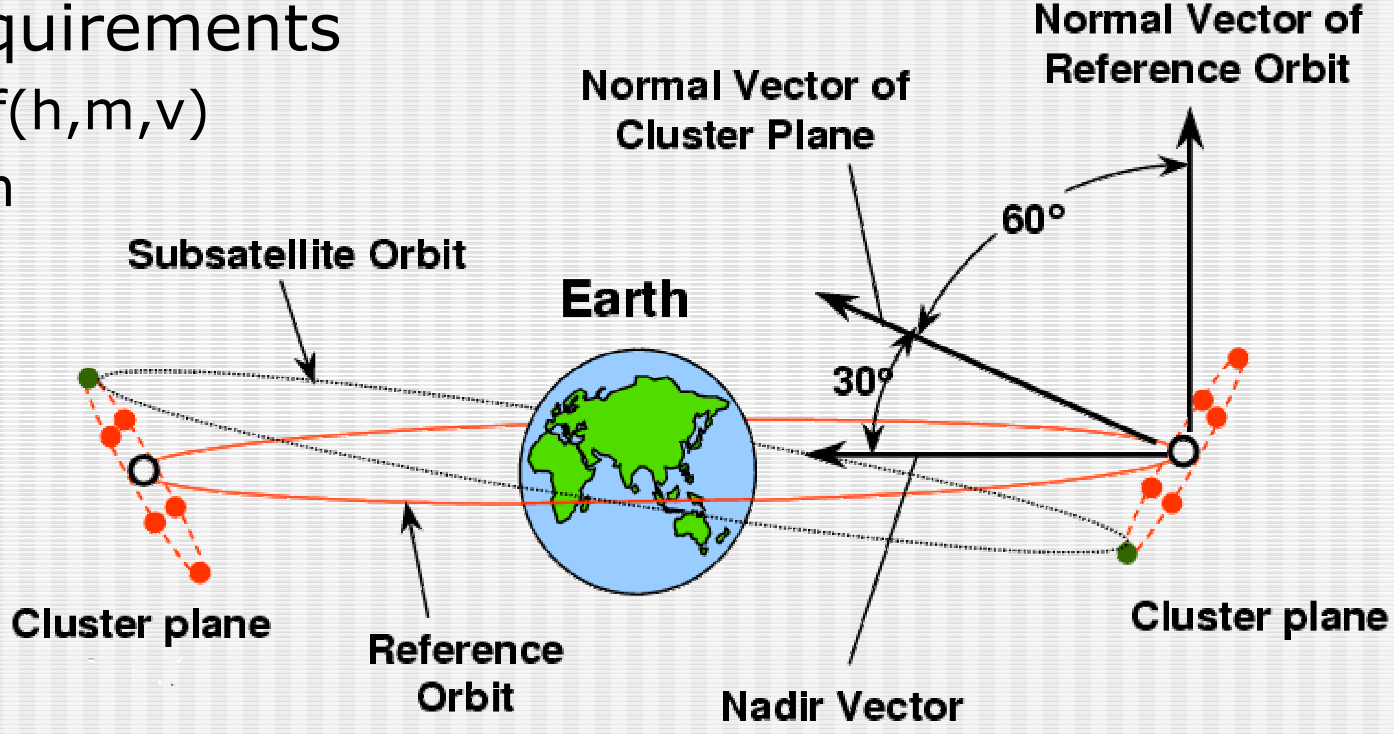
Constellations

- 10-1000m formations
- Parallel or individual
- Direct/LEO Comm.
- 3CS
- Stereoscopic Imaging
- Closed Loop Control



Constellations

- Rigid body rotation
- Orbit Correction Burns: 3/orbit
- ΔV Requirements
  - $\Delta V = f(h,m,v)$
  - $\Delta V \propto h$



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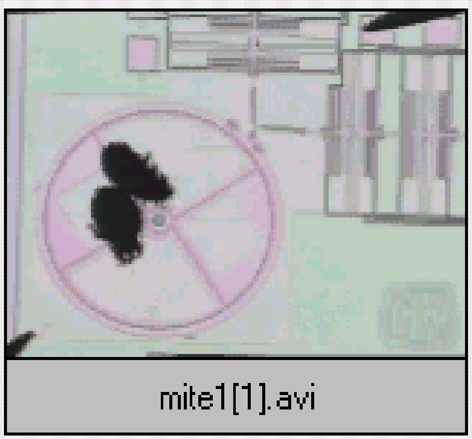
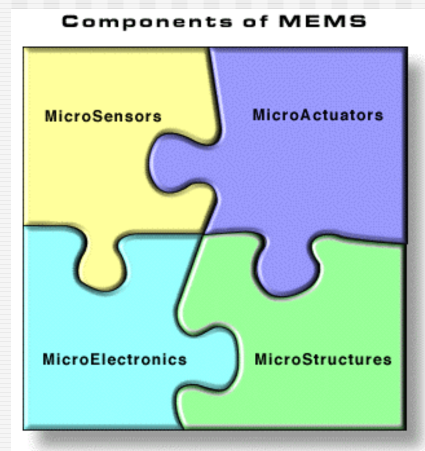
MEMS

- Micro-Electro-Mechanical Systems
  - Micron-scale
  - Adapted IC technology
  - Systems on chip



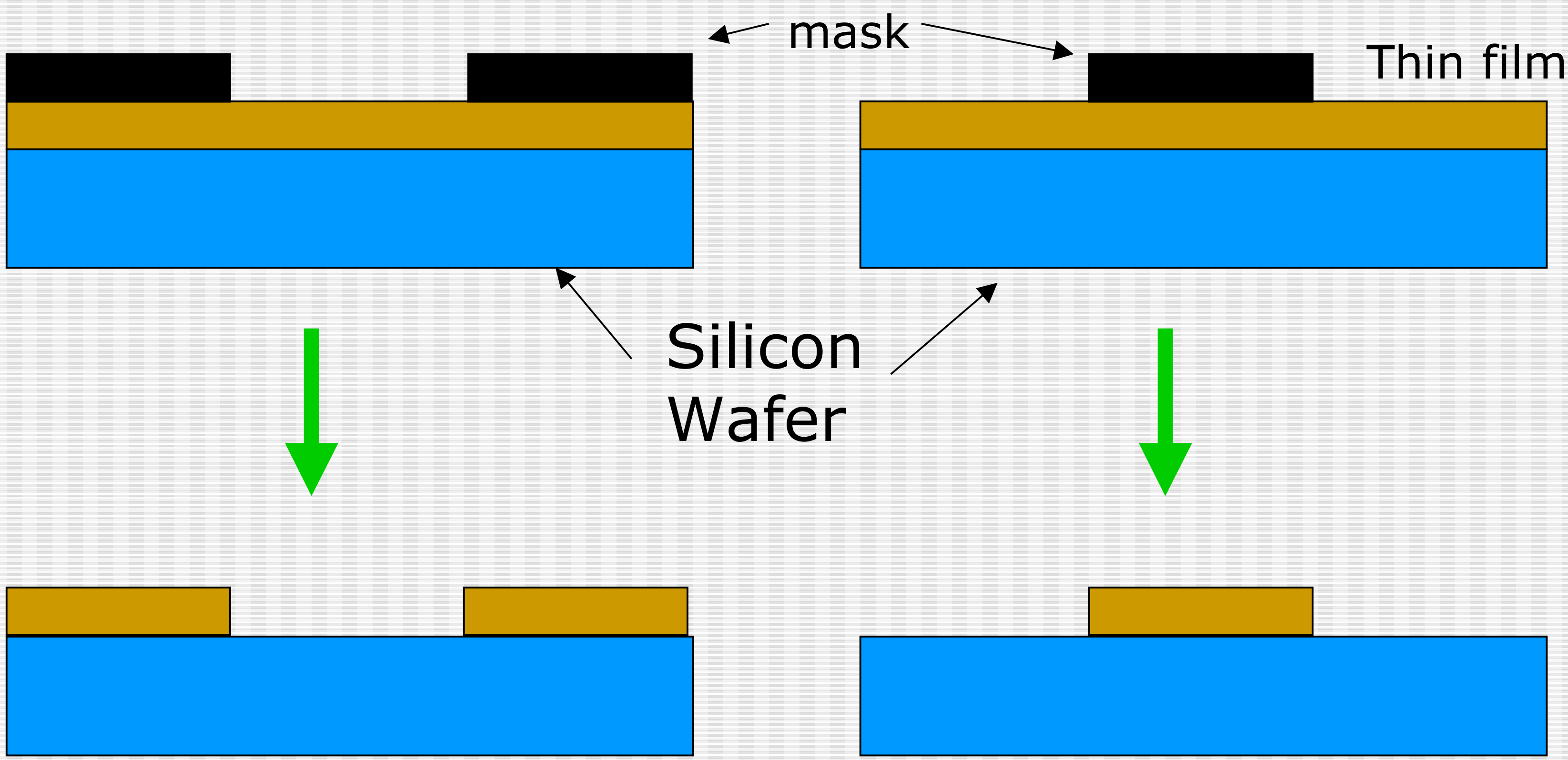


MEMS

- Silicon
  - Sacrificial surface μ-machining or etching
  - Numerous techniques
- Non-Silicon Fabrication
  - New and under development
  - Stronger materials
  - Polymers

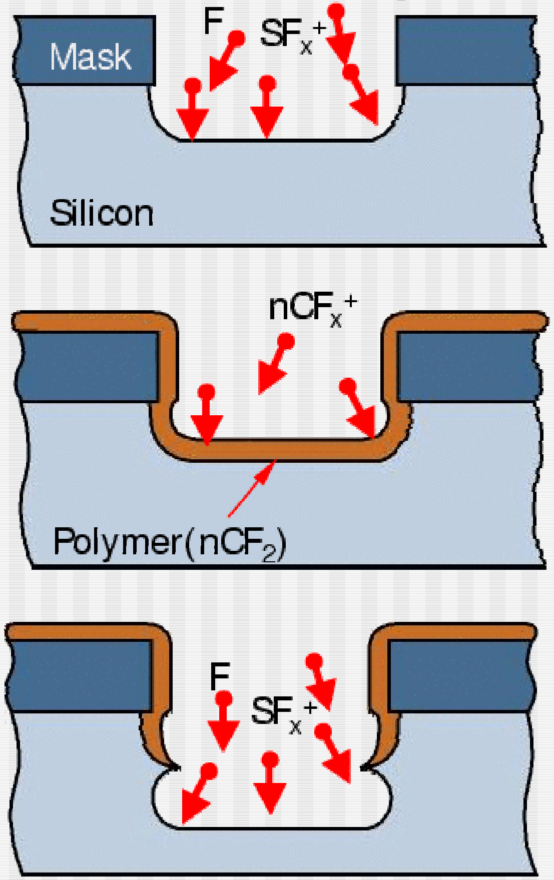
MEMS

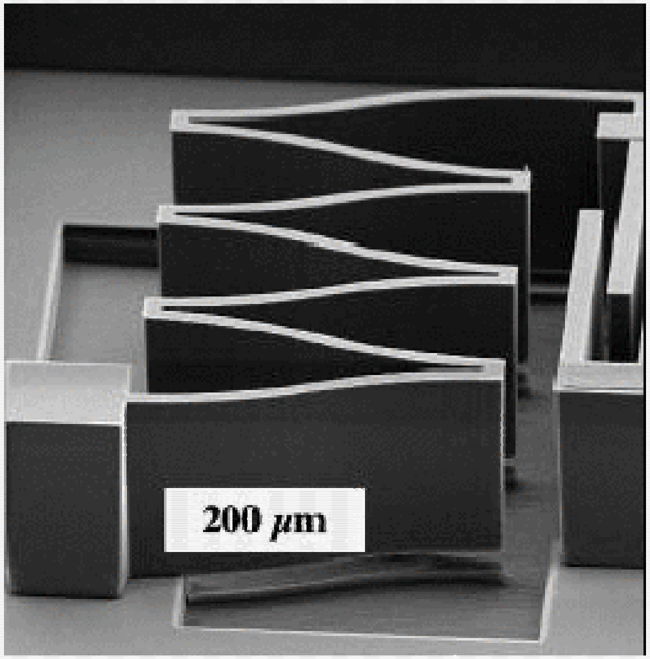
- Anisotropic Wet Etching



MEMS

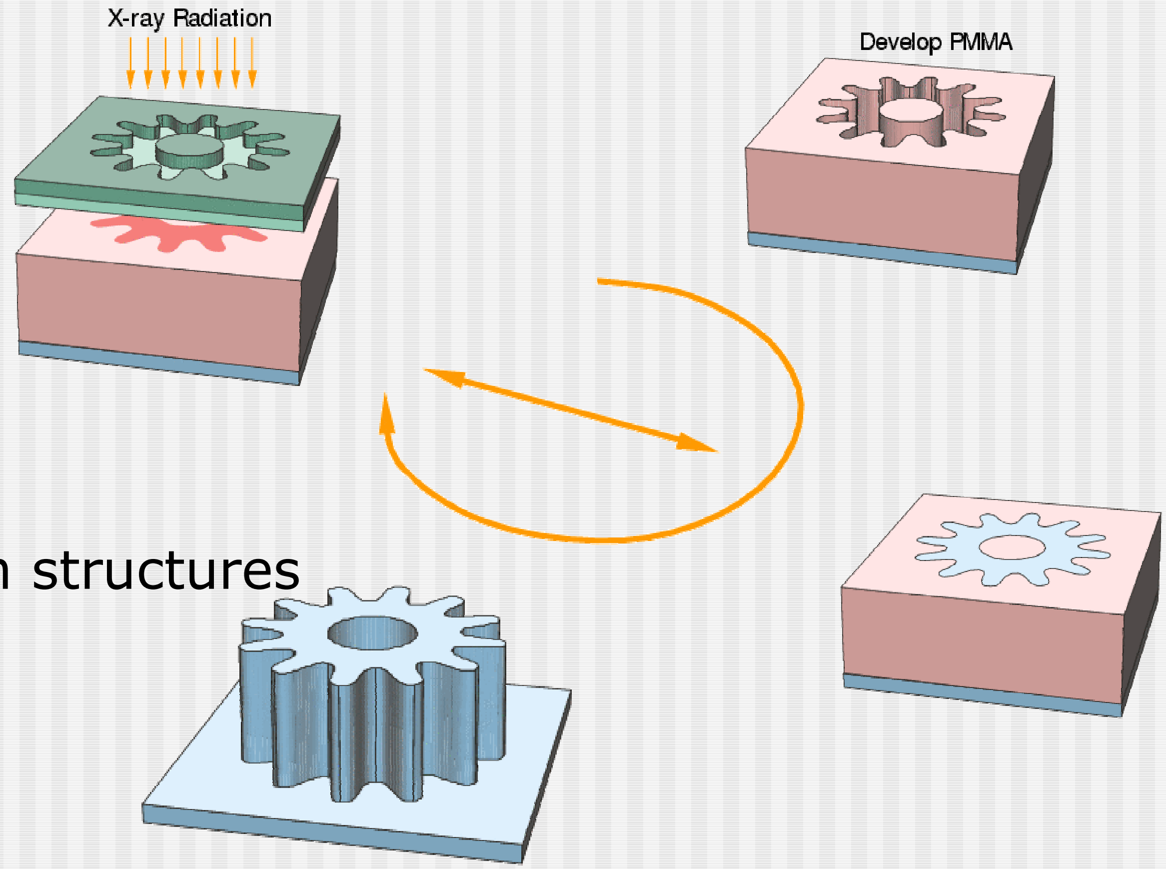
- Anisotropic Dry Etching (RIE)





MEMS

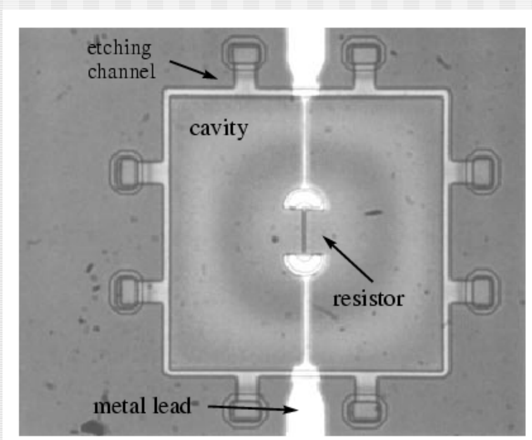
- Lithographie Galvanoformung Adformung(LIGA)
- Synchrotron x-ray source (expensive)

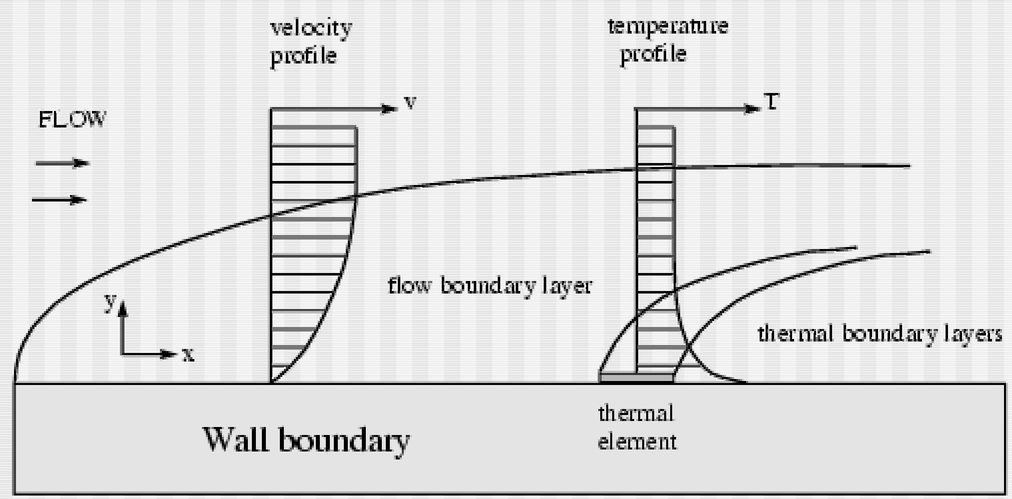


- 1000µm structures

MEMS

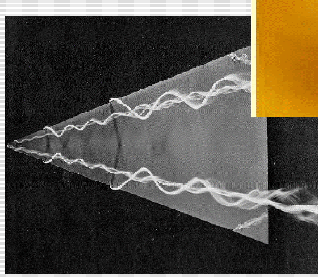
- Tools (Shear Stress Sensor)
  - Determine wall shear stress
  - Flush mounted
  - Assumptions allow modeling

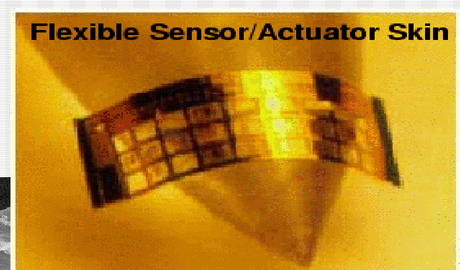


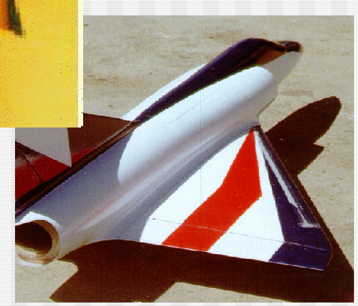


MEMS

- Research (Vortex-Control: Delta Wing)
  - MEMS actuators and sensors
  - μ-flaps properly located
  - Induce moments for maneuvering

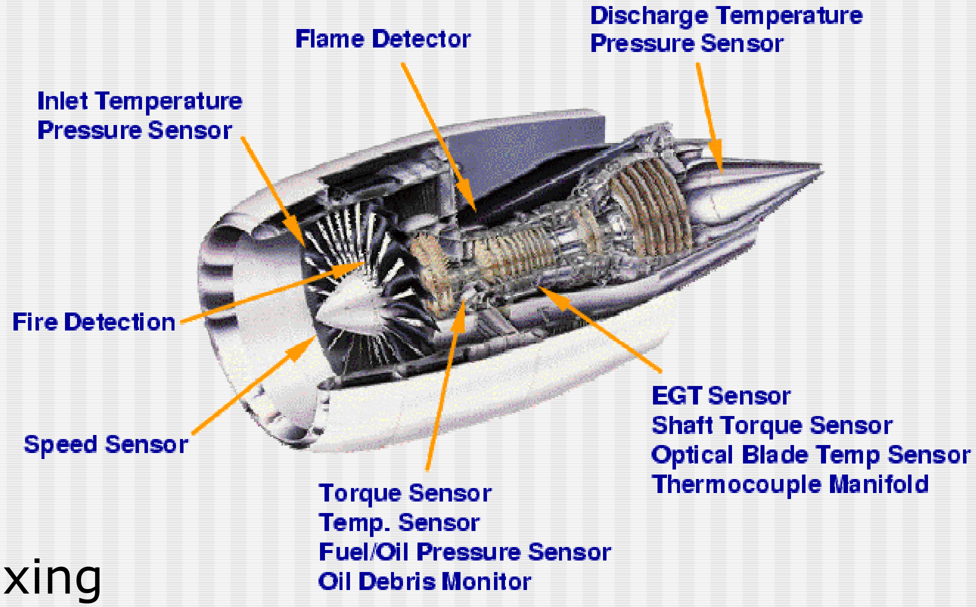




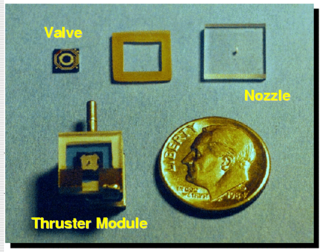


MEMS

- Propulsion (non-propulsive)
  - Measurements
  - Combustion
    - Enhance mixing
    - Improve combustion



Outline



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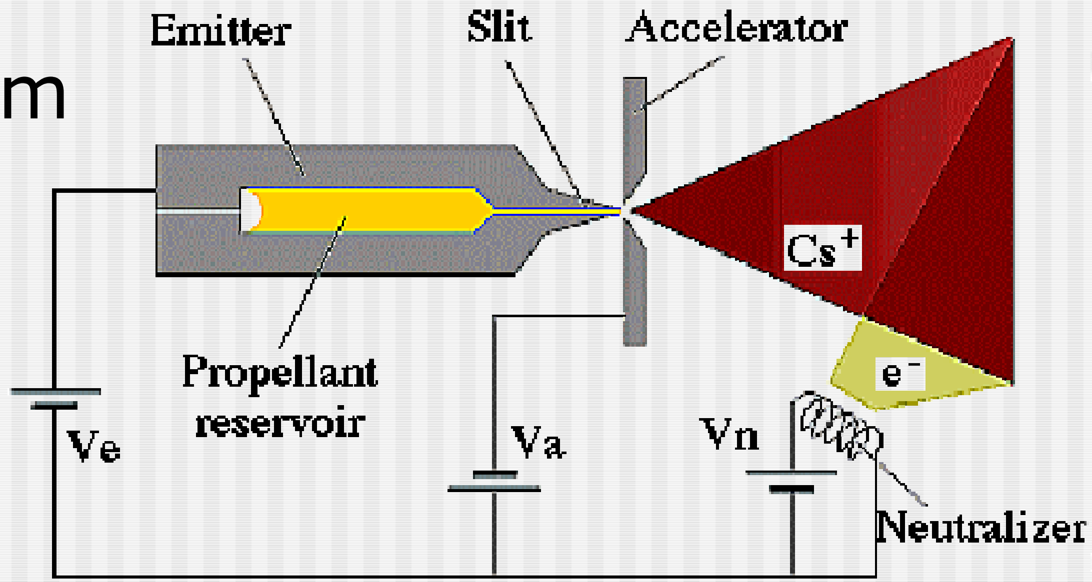
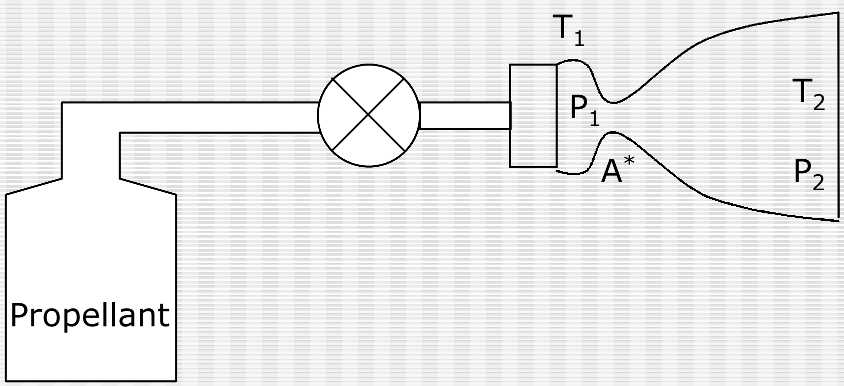
Electro-Thermal (Ion)

- FEEP and Colloid Thrusters
  - 1μN – 1mN Thrust
  - Driven by capillary forces
  - Ion jet
  - $\Delta V = 10^9$ V/m
  - Low $\dot{m}$



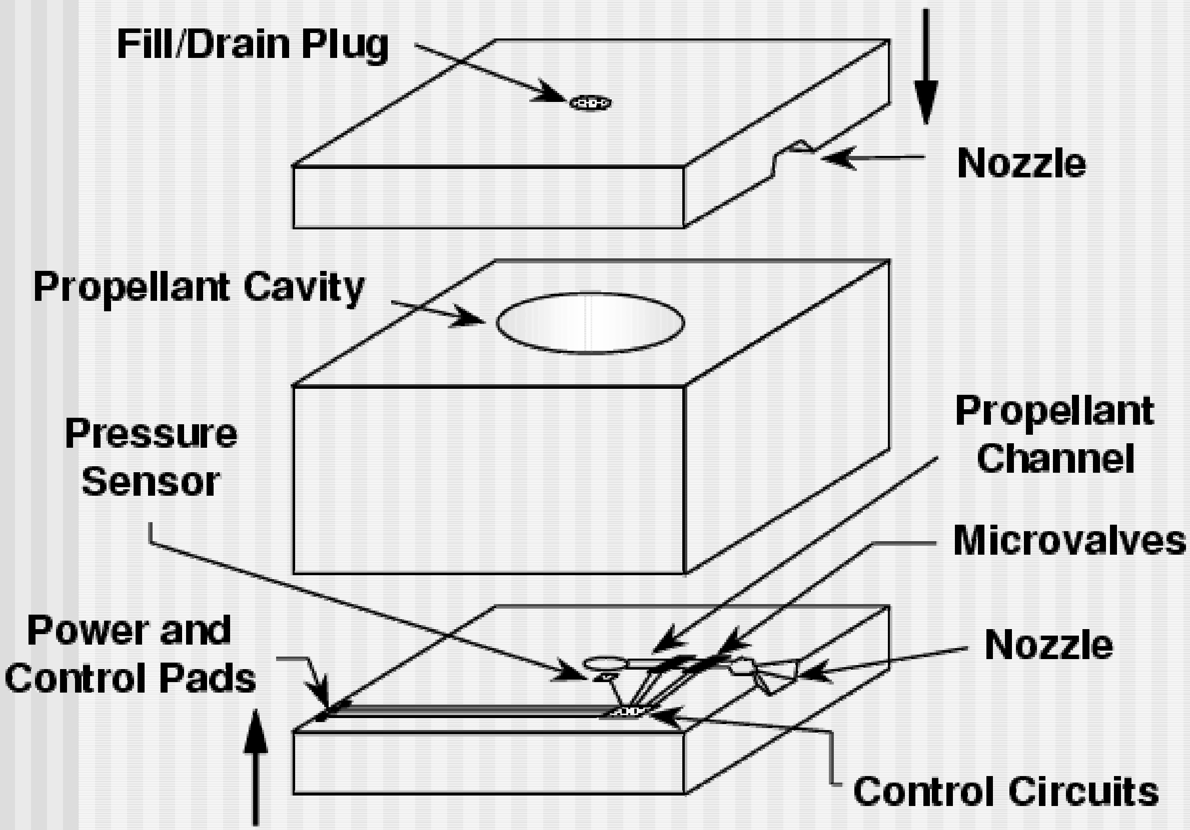
Chemical

- Cold Gas
  - Smallest rocket engines
  - Simple: $v = f(T, P, \gamma)$
  - 0.1mN thrust
  - Scaling Concerns only



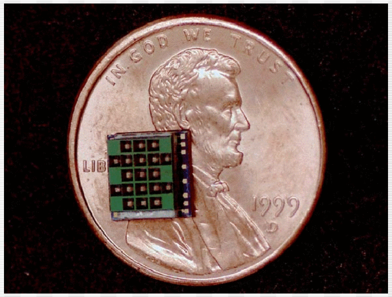
Chemical

- Cold Gas – Aerospace Corp Version



- Valve leakage
  - High rate
- Choking at valve
  - 10x τ reduction
  - 27s I_{bit}

Outline



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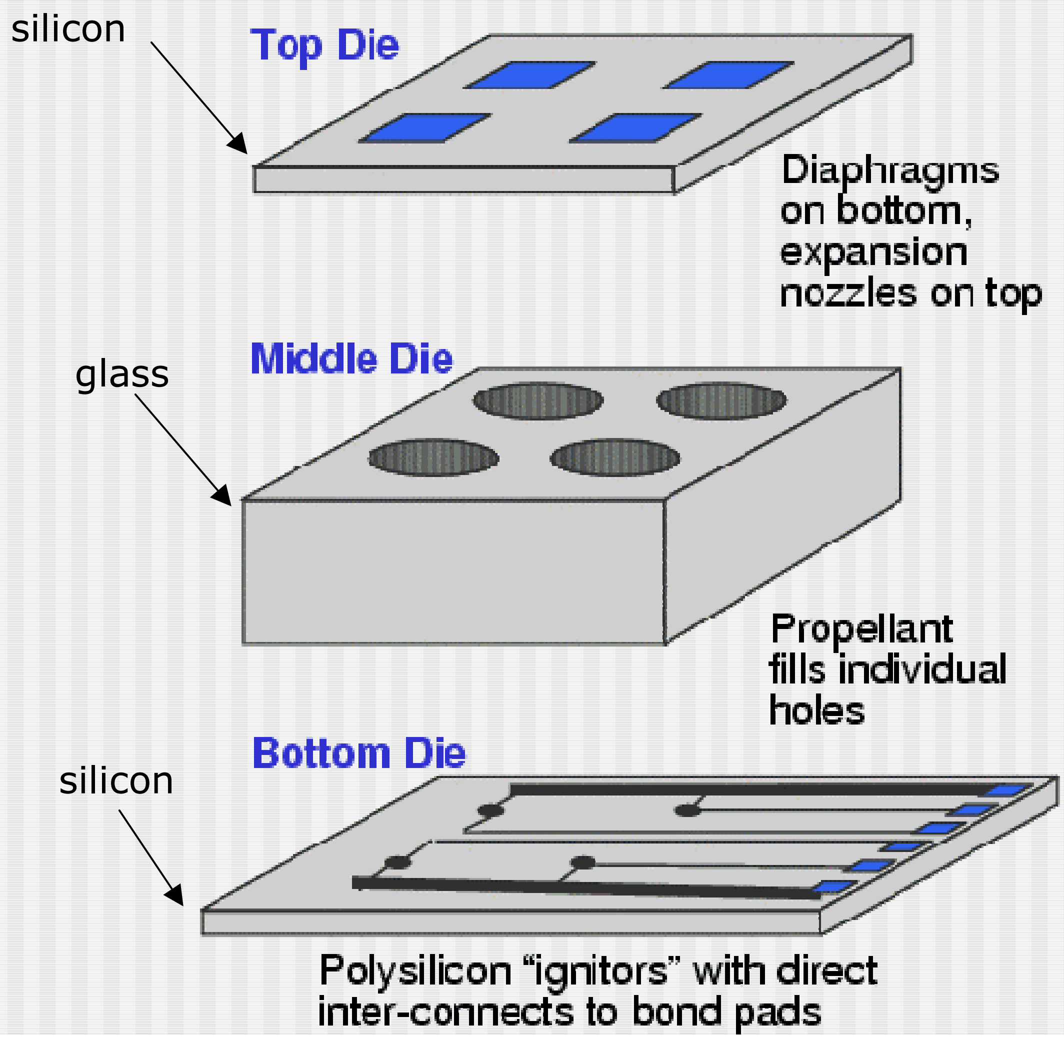
Digital Micro-thruster

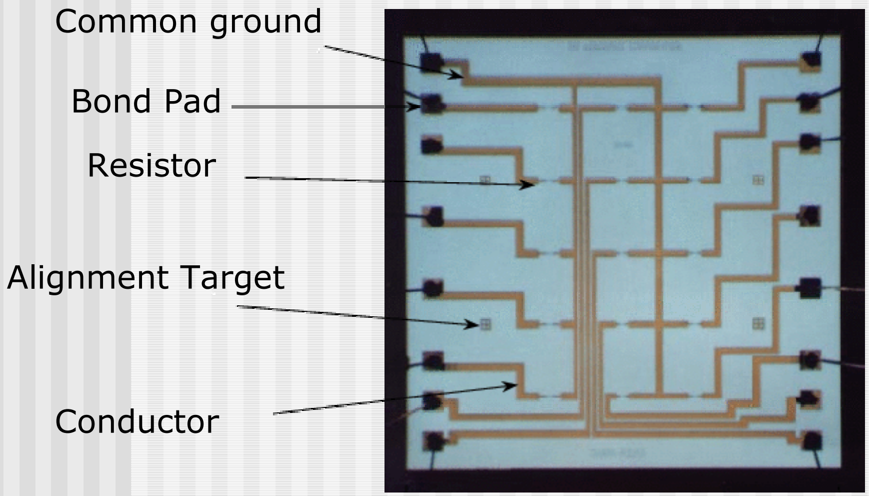
- Multitude of single shot μ-thrusters (10^{-4} to 10^{-6} per 10 cm wafer)
- 10^{-4} to 10^{-6} N-s Impulse bits
- KOH wet etching & wafer bonding
- Class I and II applicability
- Attitude control
- Several Versions
  - TRW/Aerospace Corp
  - French (LAAS at CNRS)
  - Honeywell
  - NASA Glenn

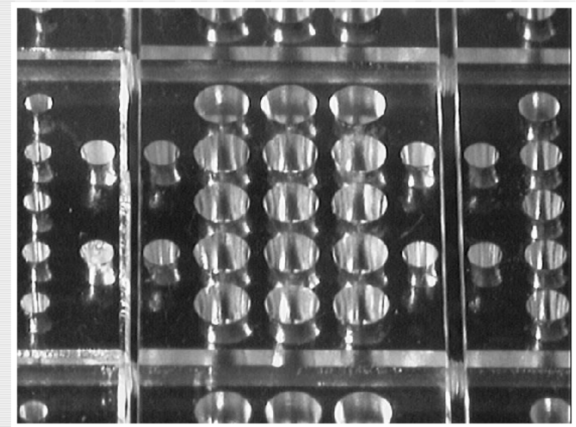
Digital Micro-thruster

- No tanks, fuel lines, valves
- Integrated with structure
- Propellant: inert or combustible
- No electronics



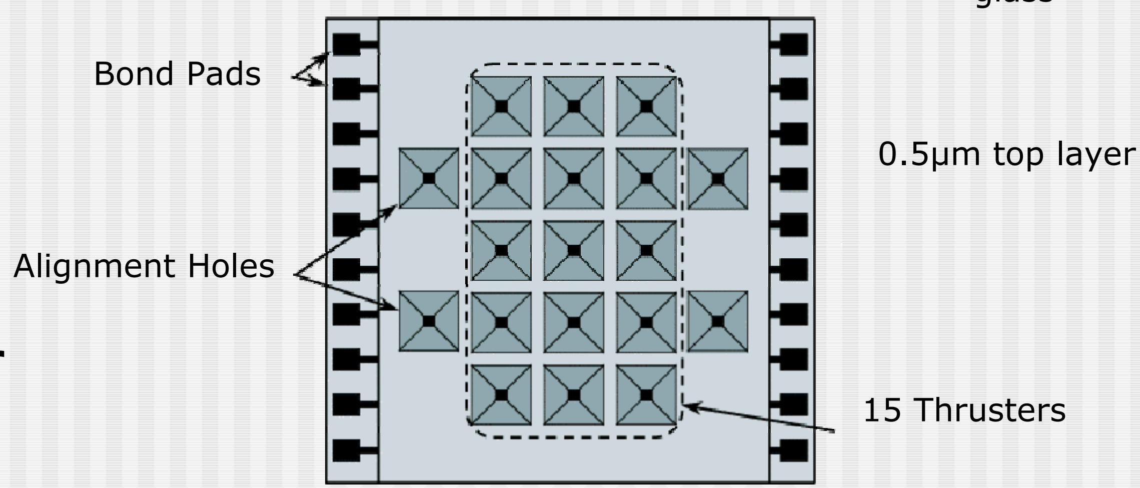
Digital Micro-thruster





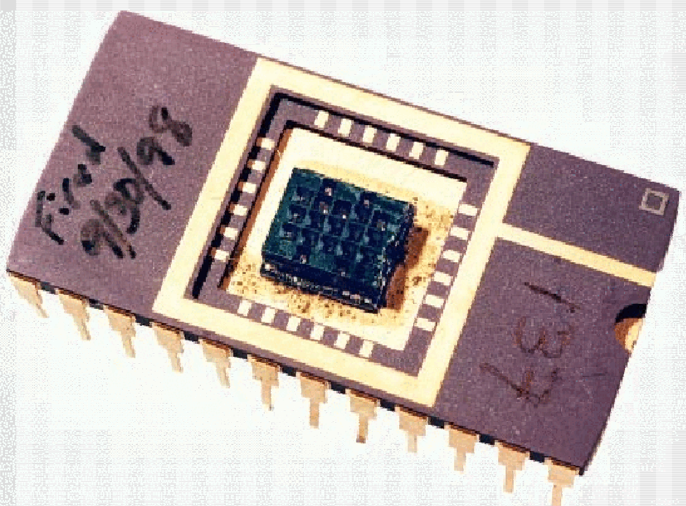
1.5mm Photosensitive glass

- KOH wet etched
- Three layered wafer



Digital Micro-thruster

- 10^{-4} N-s with Lead Styphnate
- 1ms impulse duration
- Relatively low ΔV missions
- Ideal for attitude control
- Scales to Meso/Macro



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Non-MEMS Options

CHEMICAL

- **Bipropellant**
- **Monopropellant**
  - **HAN**
  - **Hydrazine**
  - **H_2O_2**
- **Cold Gas**
- **Solid**

Generally Applicable to Class I Primary Propulsion

ELECTRIC (ION)

- **Ion Engine**
- **Hall**
- **FEEP/Colloid**
- **PPT**
- **Resistojets**

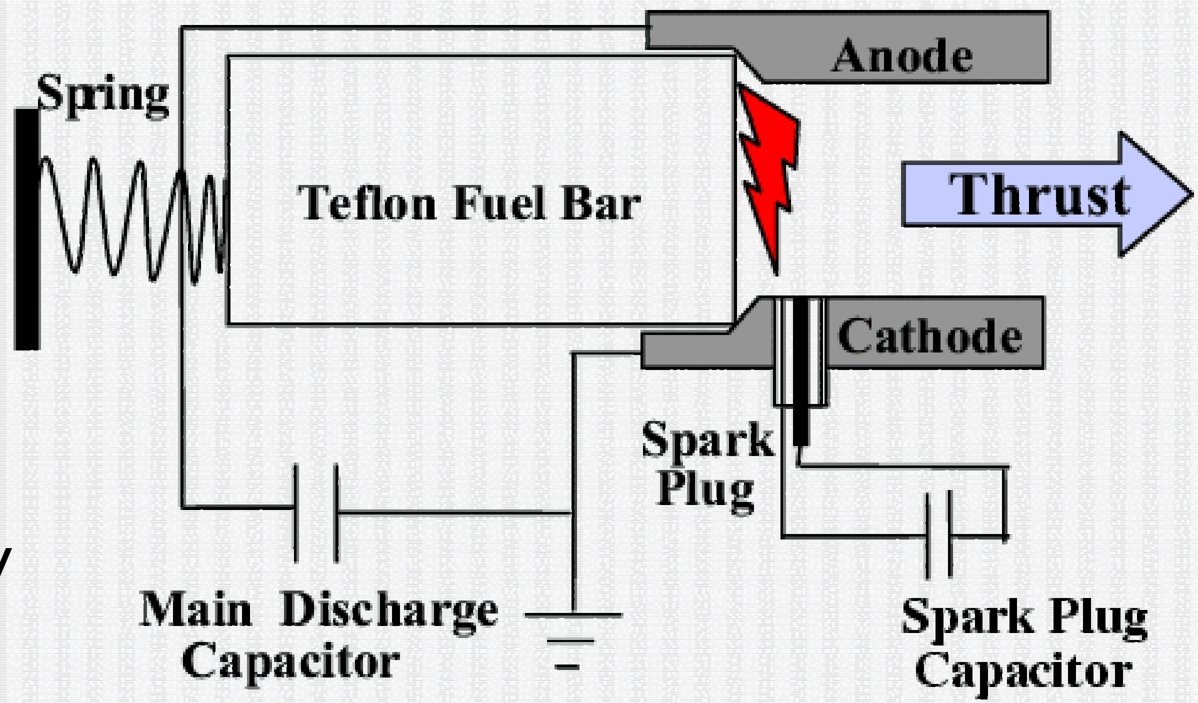
MEMS Extendible
(current developments)

- **FEEP/Colloid**
- **Ion Engine**
- **Resistojet**
- **Solid**
- **Cold Gas**
- **Bipropellant**

Non-MEMS Options

- Pulsed Plasma Thruster (PPT)

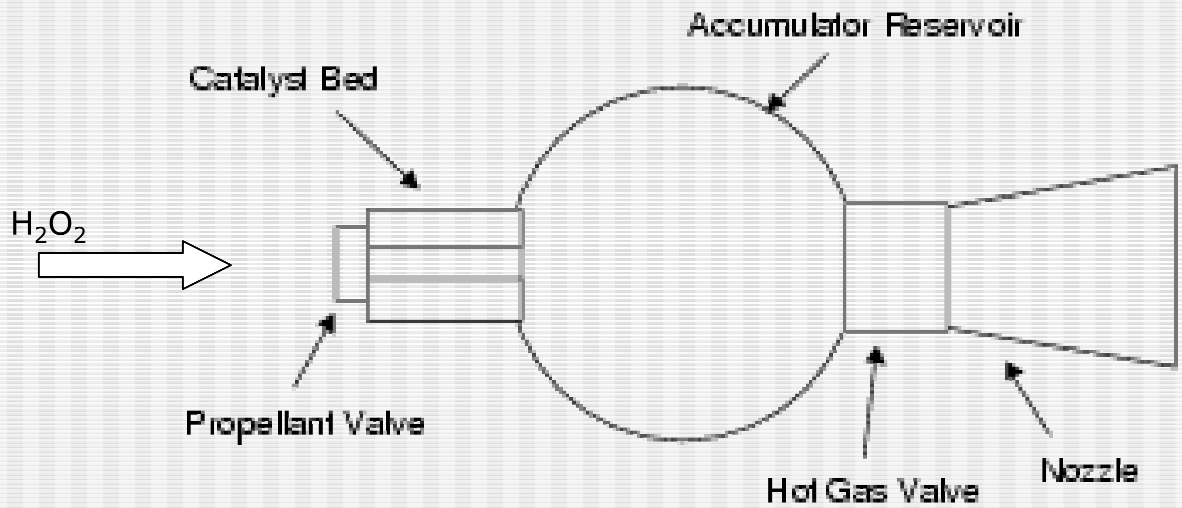
Teflon "Plasmarized" by high current



Plasma accelerated by B field

Non-MEMS Options

- Hydrogen Peroxide (H_2O_2)
  - At 90% concentration
  - Silver-wire mesh as catalyst
  - Products: H_2O and heat = steam



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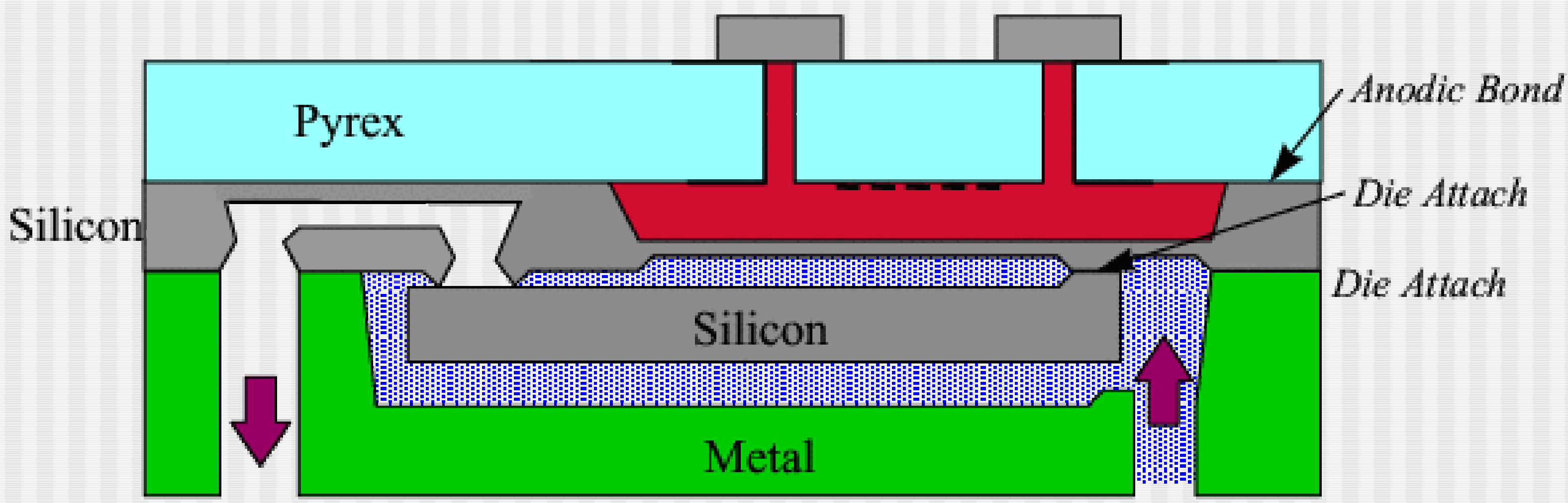
μ-Propulsion Issues

- Surface effects are dominant
  - BC's change in momentum (gas flows)
- Flows become highly dissipative
- μ-Nozzles
  - ΔP underestimated
  - Currently Several Investigations
- μ-Combustion
  - Incomplete Burn = clogged systems
  - Temps (700 to 1800 K) to high for Silicon
- μ-Heat Effects
  - Thermal Expansion and modeling

μ-Propulsion Issues

- μ-Valves
  - High leak rates
  - Incomplete flow characterizations



Summary

		I_{sp} (sec)	I_{bit} (N-s)	Thrust (N)	Power (W)	µ-Craft	Class I	Class II	Class III
MEMS							✓	✓	
	FEEP/Colloid		$5x10^{-9}$	$(1 – 1000)x10^{-6}$	2		✓	✓	
	Ion Engine						✓	✓	
	Resistojet	48 - 70	Expected arbitrarily small				✓		
	Solid	----	-----	-----	------		✓		
	Cold Gas			$0.1x10^{-3}$			✓	✓	
	Bipropellant						✓	✓	
	Digital		$10^{-4} – 10^{-6}$		100		✓	✓	
Non-MEMS									
	Bipropellant	280 - 300		5 - 156		✓			
	Monopropellant								
	***HAN					✓	✓		
	***Hydrazine	~220		0.9 - 18			✓		
	***H_2O_2	65 - 150	0.1	10 - 45		✓			
	Cold Gas	65 - 296	10^{-4} – 0.044	0.0045 – 4.5	2.4 - 30	✓	✓		
	Solid	199 - 273		157 - 2500			✓		
	Ion Engine	1700 - 3700		0.001 – 0.031	50 - 600	✓	✓		
	Hall	830 - 1740		0.0018 – 0.035	70 - 540	✓			
	FEEP/Colloid	450 - 9000		$7x10^{-6}$ – 0.0056		✓			
	PPT	400 - 5000	$(2 – 860)x10^{-6}$	$(0.002 – 2)x10^{-3}$	1 - 25	✓	✓		
	Resistojets	----	----	----	----		✓		

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