MEMS Accelerometers

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Outline

- **Accelerometer Quick Study**
  - Background and device market
  - Purpose and function
  - Control variables
- **Proposed Modification**
  - Impacting performance by process modification
  - Preventing failure modes
- **Economic Model**
  - Drivers of cost structure
  - Impact of proposal

Quick-Study: Background

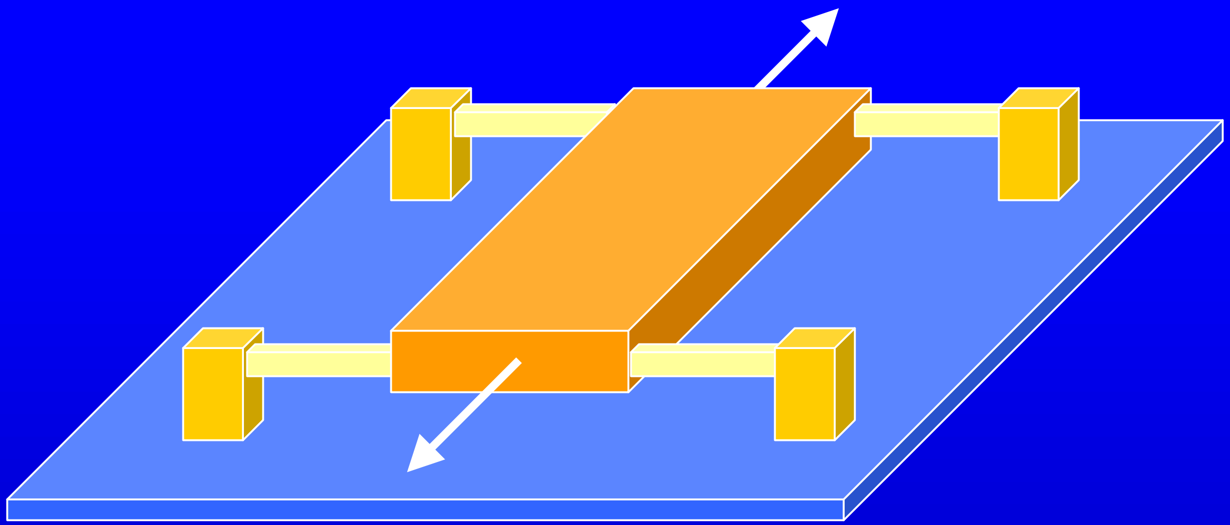
- **MEMS**
  - Micro ElectroMechanical Systems
  - Small devices that perform the same function as larger mechanical systems
  - Usually “machined” out of silicon
- **Accelerometers**
  - Devices that are used to measure acceleration
  - Used for airbag sensors, etc.
  - MEMS version is smaller, lighter, and cheaper than traditional alternatives

Quick-Study: Accelerometer Market

- **Primary Market**
  - Automobile Airbag Sensors
  - Approximately 50 million sensors/year
  - Sensors sell for approximately $10 each
- **Secondary Markets**
  - Computer Joysticks
  - Military Applications
  - Amusement Park Technology

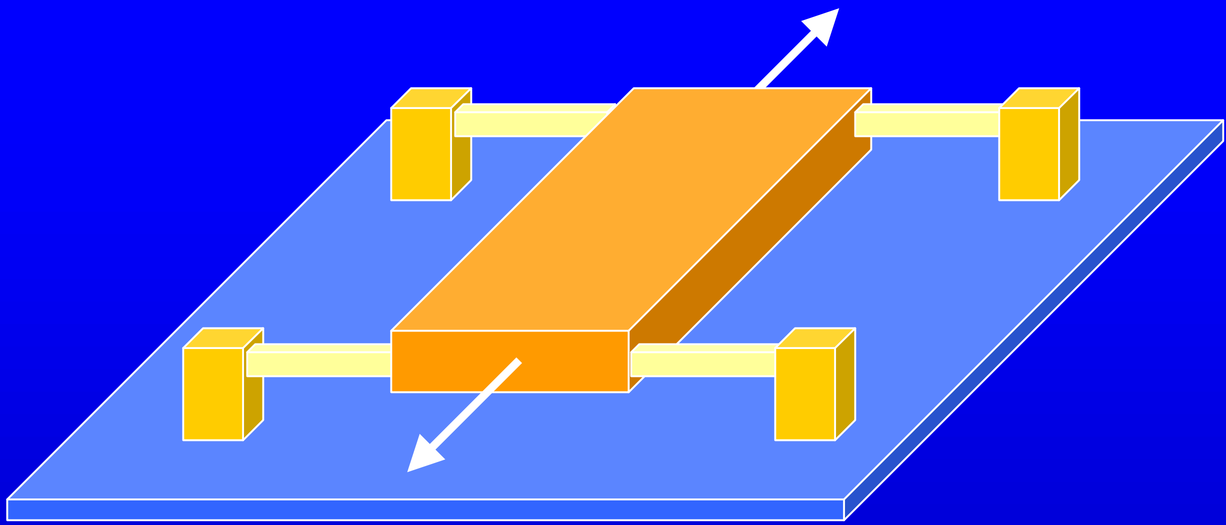
Quick-Study: Purpose and Function

- **Purpose: microchip sensor to detect acceleration**



Quick-Study: Purpose and Function

- **Purpose: microchip sensor to detect acceleration**
- **Functional Features:**



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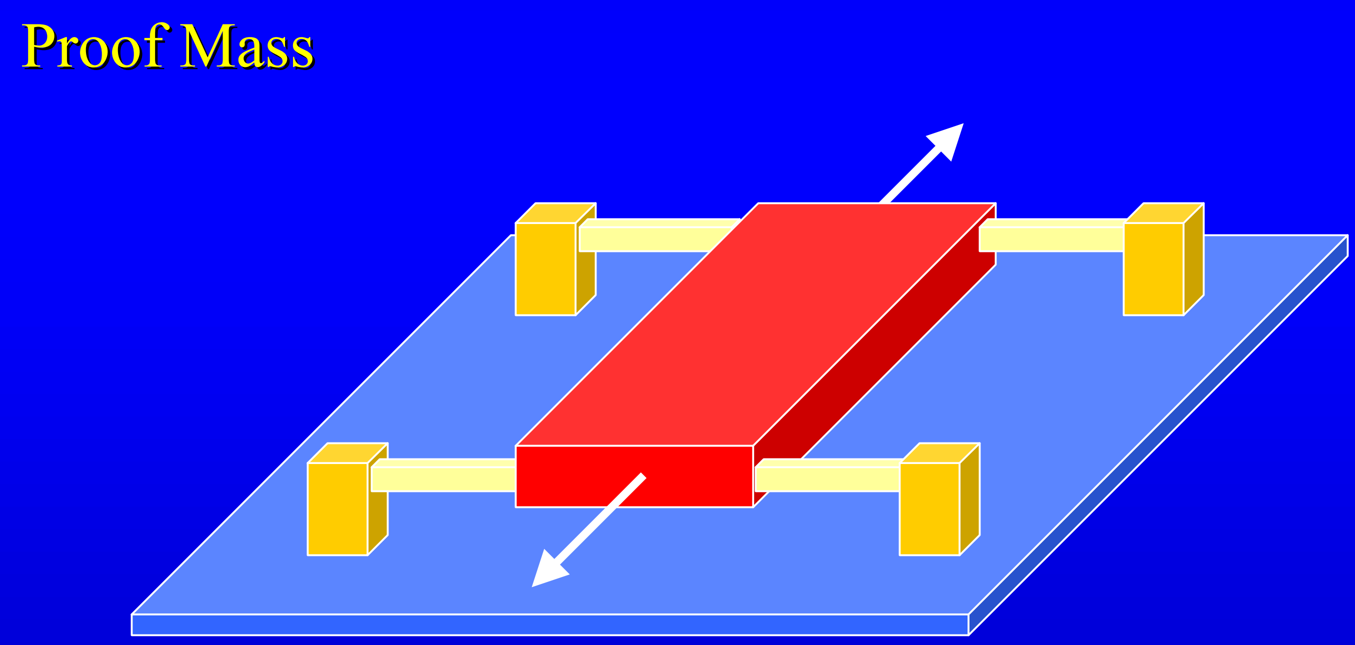
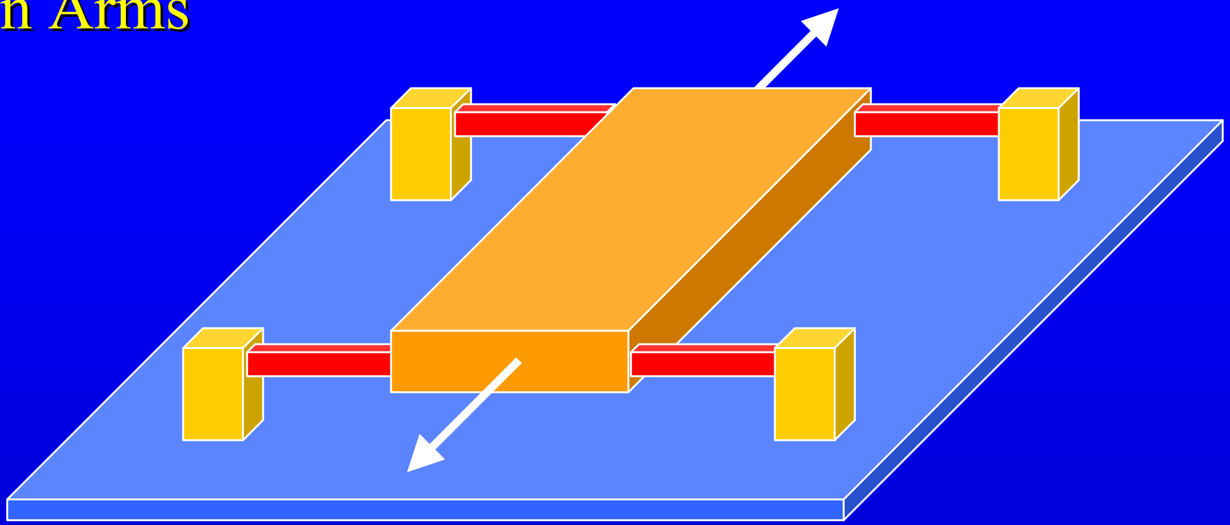


Quick-Study: Purpose and Function

- **Purpose: microchip sensor to detect acceleration**
- **Functional Features:**

Proof Mass

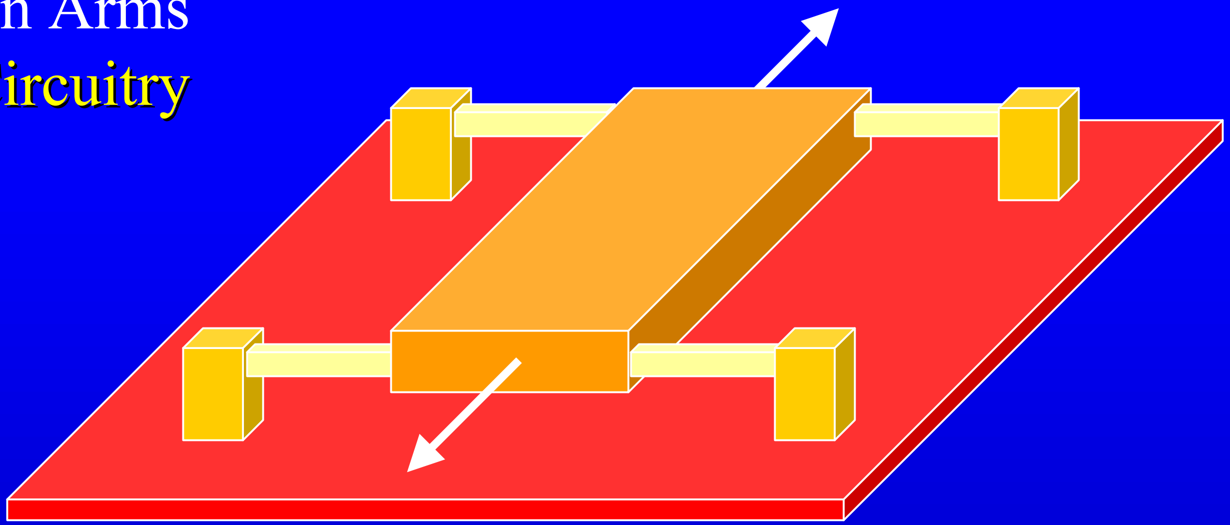
Suspension Arms



Quick-Study: Purpose and Function

- **Purpose: microchip sensor to detect acceleration**
- **Functional Features:**

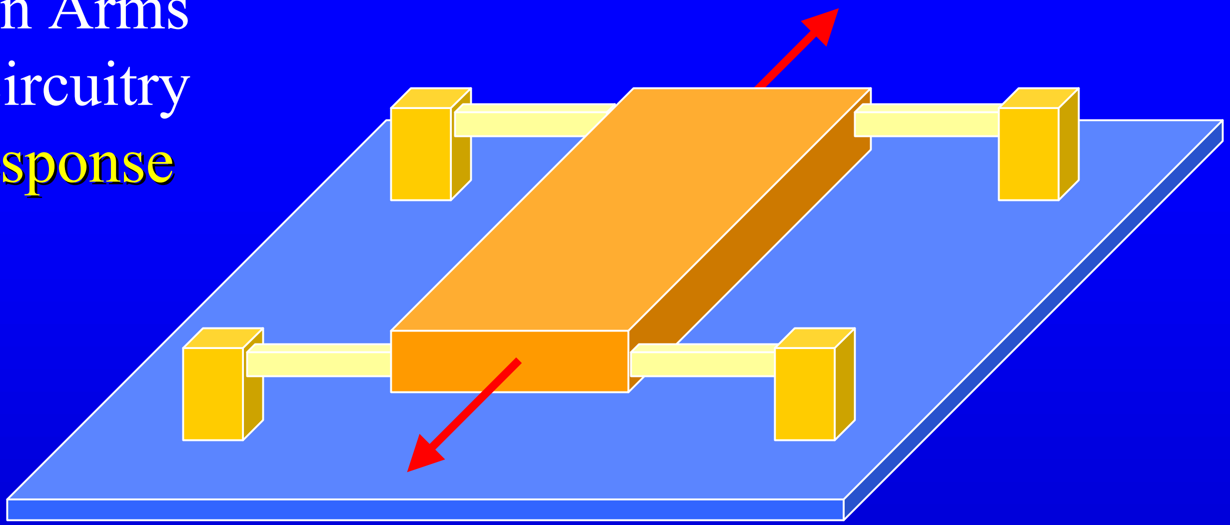
Proof Mass
Suspension Arms
Substrate with Circuitry



Quick-Study: Purpose and Function

- **Purpose: microchip sensor to detect acceleration**
- **Functional Features:**

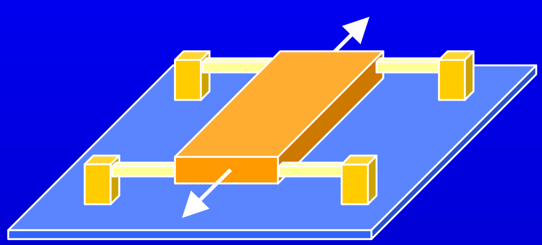
Proof Mass
Suspension Arms
Substrate with Circuitry
Axis of Response



Quick-Study: Purpose and Function

- **Purpose: microchip sensor to detect acceleration**
- **Functional Features:**

Proof Mass
Suspension Arms
Substrate with Circuitry
Axis of Response
Sensing Function



Quick-Study: Purpose and Function

- **Purpose: microchip sensor to detect acceleration**
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Proof Mass
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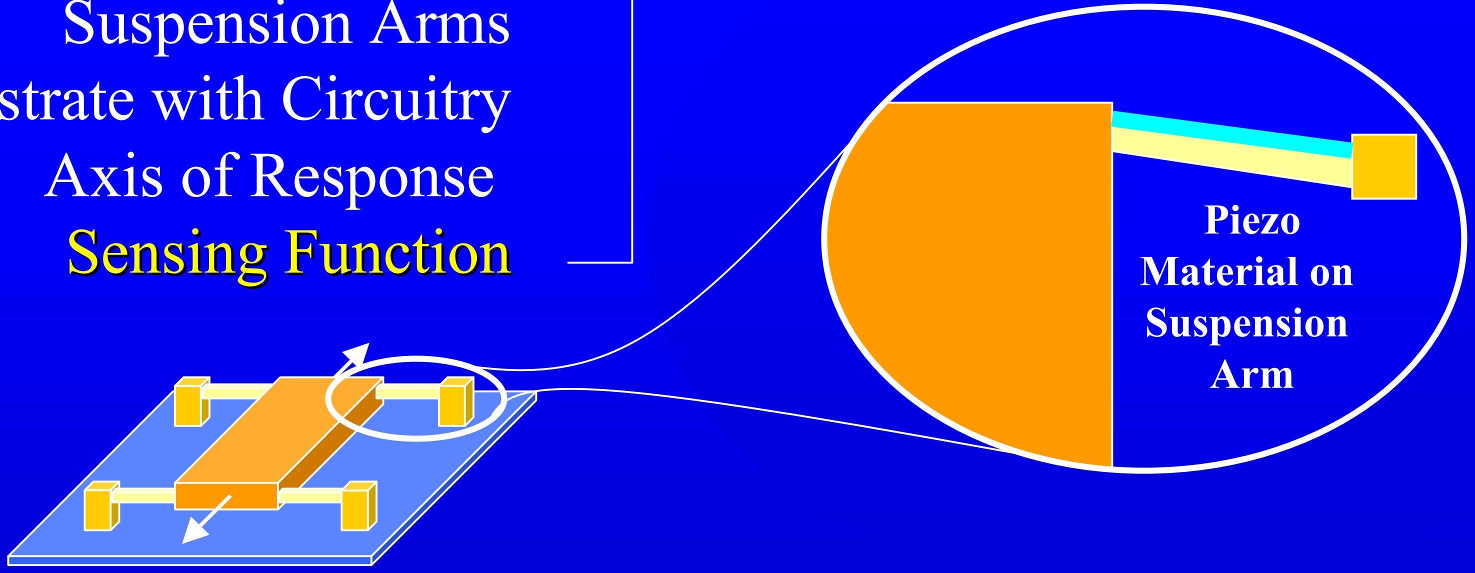
Axis of Response
Sensing Function

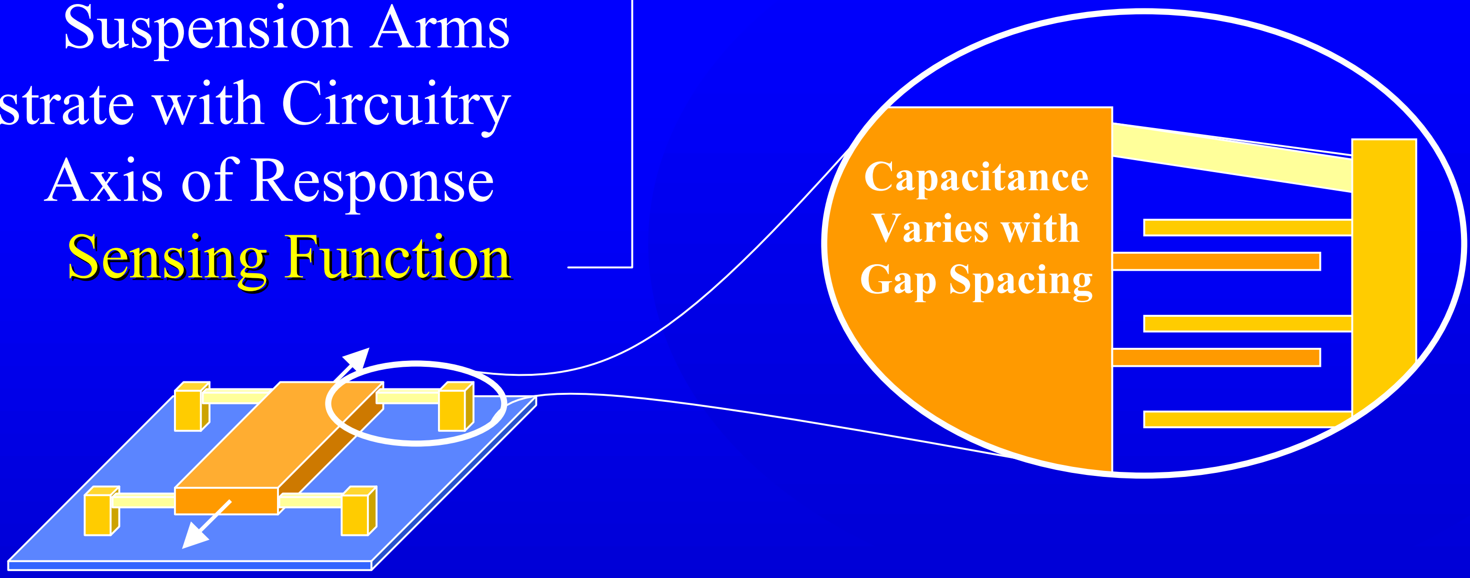
Piezoresistive Strain Gauge



Quick-Study: Purpose and Function

- **Purpose: microchip sensor to detect acceleration**
- **Functional Features:**

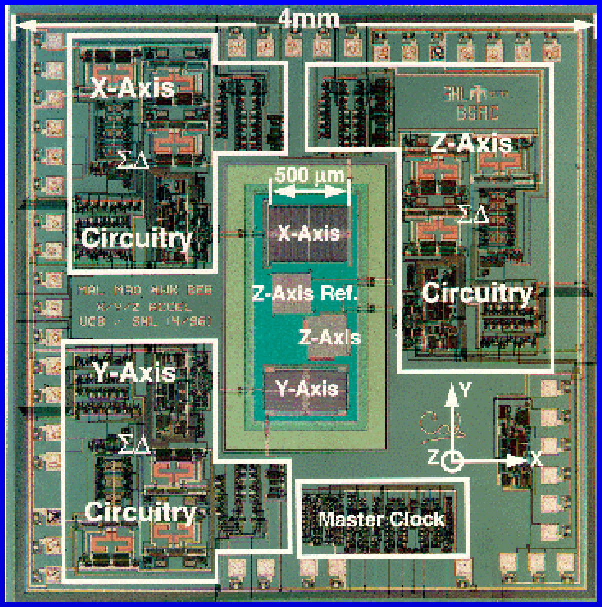
Proof Mass
Suspension Arms
Substrate with Circuitry
Axis of Response
Sensing Function → Capacitive



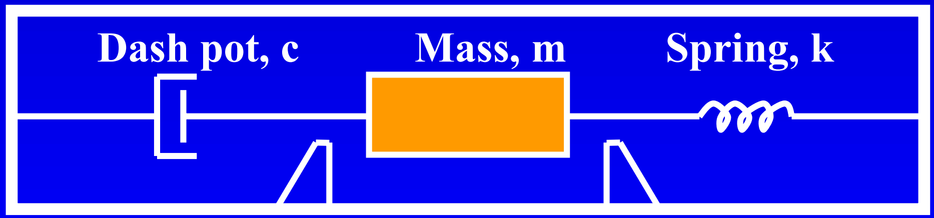
Quick-Study: Purpose and Function

- **Purpose: microchip sensor to detect acceleration**
- **Functional Features:**

Proof Mass
Suspension Arms
Substrate with Circuitry
Axis of Response
Sensing Function → Capacitive (Analog Devices)



Quick Study: Control Variables



Motion Limiters

Modeled as a spring/dashpot: $F = ma = kx + c\dot{x}$

Model gives control relationships...

1. **Static sensitivity**: $$\frac{x_{static}(s)}{a(s)} = \frac{M}{K} = \frac{1}{\omega_r^{\ 2}}$$

$\omega_r = (K / M)^{1/2}$ = Natural Resonance Frequency

2. **Total Noise**: $$TN = \frac{(4KTc)^{1/2}}{M}$$

Increased mass → ***more sensitive, less noise***

Proposed Modification: Economics

Increased mass → ***more sensitive, less noise***

- **Increase the density**
- **Decrease the size of the proof mass**
- **Increase the number of devices per wafer**
- **Obtain greater throughput or decreased material input.**

Techniques to Add Mass

- Ion Implanting of Metal
- CVD of Metal
- Sputtering of Metal

Ion Implanting

- **Benefits**
  - No masking and post-mask etching required.
  - Sensitive control of deposited quantities
- **Problems**
  - Causes high stress, therefore annealing is required.
  - Damages the underlying silicon crystal structure, I.e. fracture points that may remain after the anneal.
  - Sputter some of the surface silicon.
  - Most expensive equipment
  - **Only small gains in densification**
    - (+2%) w/annealing
    - (+0.4%) w/heavy metal doping

CVD of Metal

- **Benefits**
  - Rich history of use for metal interconnects (Al/Cu, or W)
    - i.e. $WF_6(g) + 3H_2(s) = W(s) + 6HF(g)$
  - Relatively low stress application (no annealing required)
  - Equipment is already used by MEMS Accelerometer manufacturers (although not for metallization).
- **Problems**
  - HF formation causes “worm-holes.”
  - Impurities in metal cause “encroachment”, where Si and SiO_2 layers separate.
  - Pure tungsten layers de-laminate at the edges.
  - CVD metallization is new for MEMS accelerometer manufacturers
  - sputtered metal film pretreatment is required for adhesion of metal.

Sputtering Metal

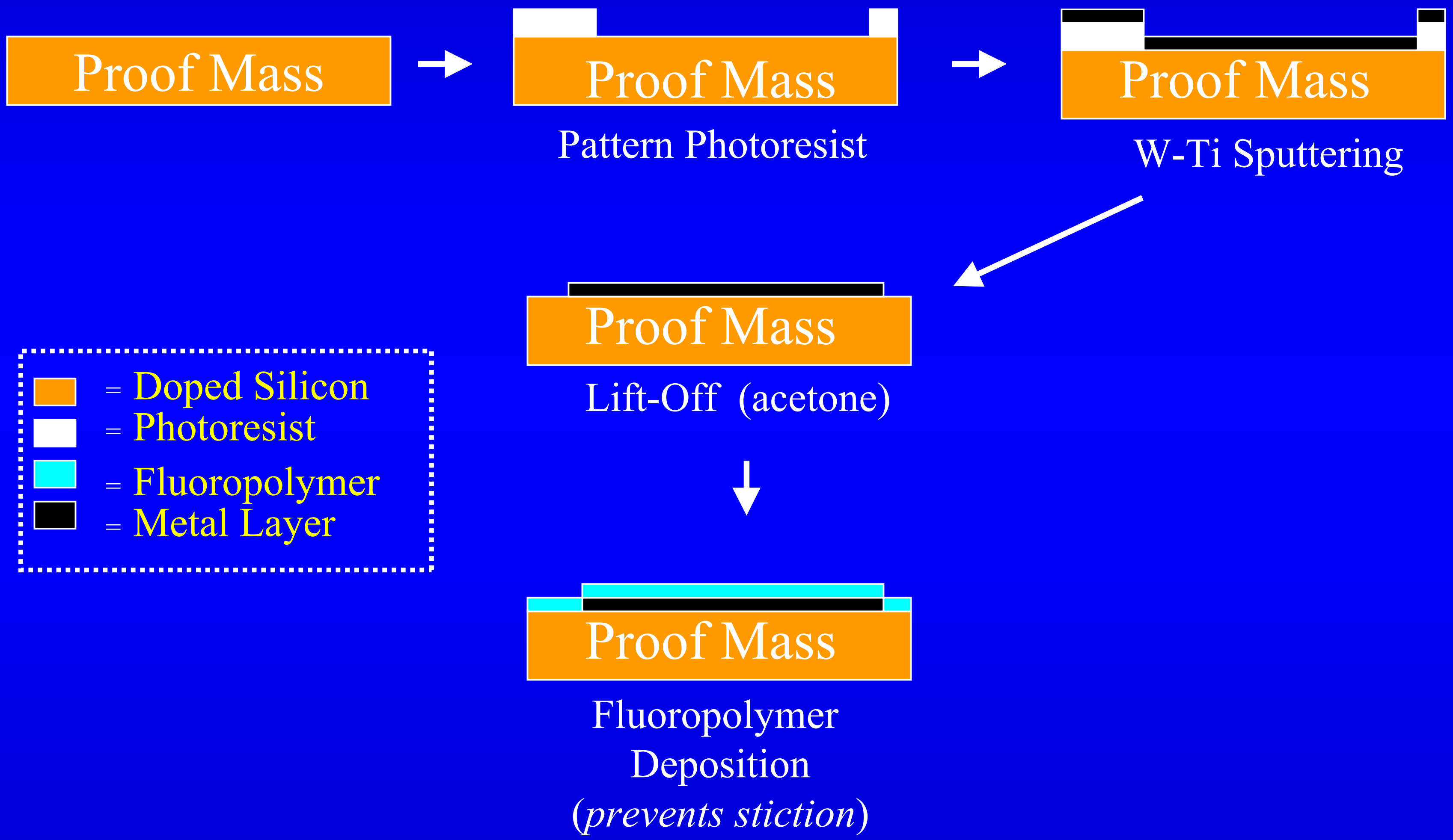
The Best Choice

- **Problems**
  - Annealing is required after application.
  - High sputter rates lead to non-uniform coverage (cosine law).
  - Typically lower growth rate than CVD.
  - Plasma energy must be optimized.
- **Benefits**
  - Rich history of use.
  - This is “line-of-sight.”
  - Alloy concentrations can be carefully controlled.
  - This equipment is already used for metallization of MEMS!!
    - Adding W-Ti alloy is recommended

Best Choice

- **Sputtering**
  - Problems with the other technologies
    - CVD has “worm-holes” and encroachment, **and requires sputtering pretreatment.**
    - Ion Implanting causes damage and has expensive equipment.

The Process of Adding Mass

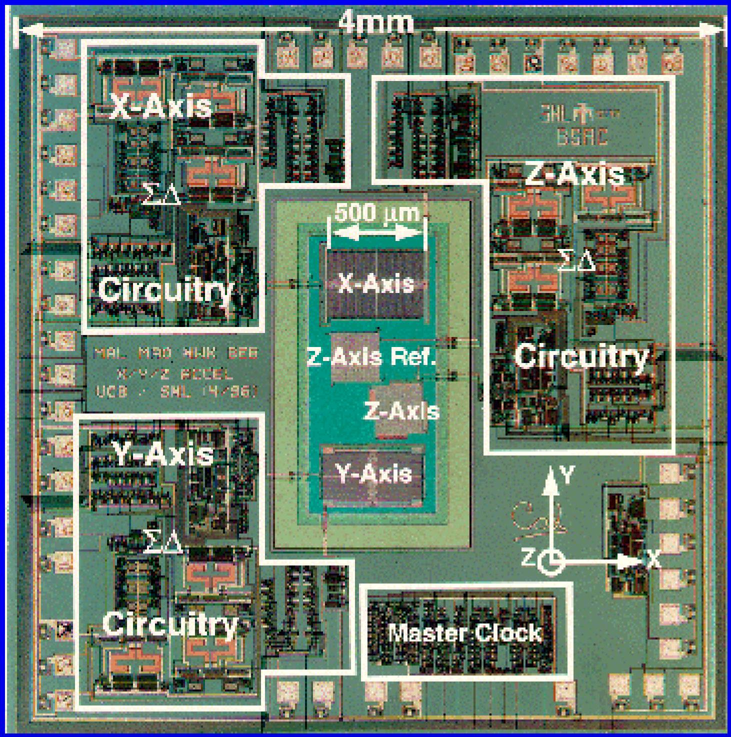


Modes of Failure

- **Stiction**
  - 2 clean Si surfaces stuck together by Van der Waals forces
  - prevent with fluoropolymer and motion stops
- **Adhesion**
  - metal layer delamination
  - prevent with Ti “glue” layer which creates strong W/Ti/Si bond
- **Dirt/junk/dust in capacitive gaps**
  - stops motion of proof mass; obscures signal
  - prevented with careful packaging of device

Economic Justification

- **It is possible to add a layer with a density of 16.6 g/cm^3.**
  - Assume this layer is 0.5 microns thick
- **This makes the density of the proof mass 5.2 g/cm^3**
  - (Silicon [ρ=2.3g/cm^3] is 2 microns thick, 80% of volume, rest is metal layer)



Economic Justification

- **Given that the proof mass is 1μg**
  - And assuming Length = 2 Width, thickness = 2 micron
  - The original proof mass is 660 by 330 microns.
- **With the new density and thickness**
  - The new proof mass is 200 by 400 microns.
- **Assuming that the device can be scaled based on the longer dimension.**
  - This gives 15% additional devices per wafer = 9 M additional devices per year - without changing throughput!

Conclusion

- Sensitivity directly varies with mass; noise decreases with increasing mass
- Can make more sensitive devices of same size or smaller devices of same sensitivity
- Evaluation of processing options shows sputtering with W/Ti is optimal and economically viable
- Modes of failure preventable ensuring continued reliable devices with new process

QUESTIONS?