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# **MEMS Accelerometers**

**Constantine, Friedman & Goldberg, LLP**

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*MEMS Accelerometer*

# Outline

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- **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

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- **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

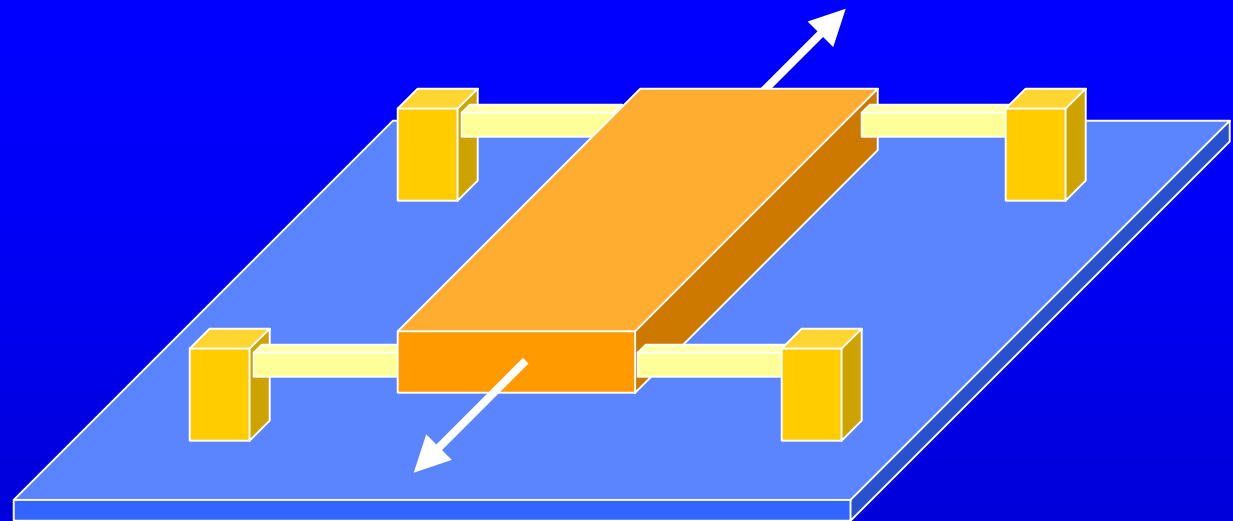
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- **Primary Market**
  - Automobile Airbag Sensors
  - Approximately 50 million sensors/year
  - Sensors sell for approximately \$10 each
- **Secondary Markets**
  - Computer Joysticks
  - Military Applications
  - Amusement Park Technology

## Quick-Study: Purpose and Function

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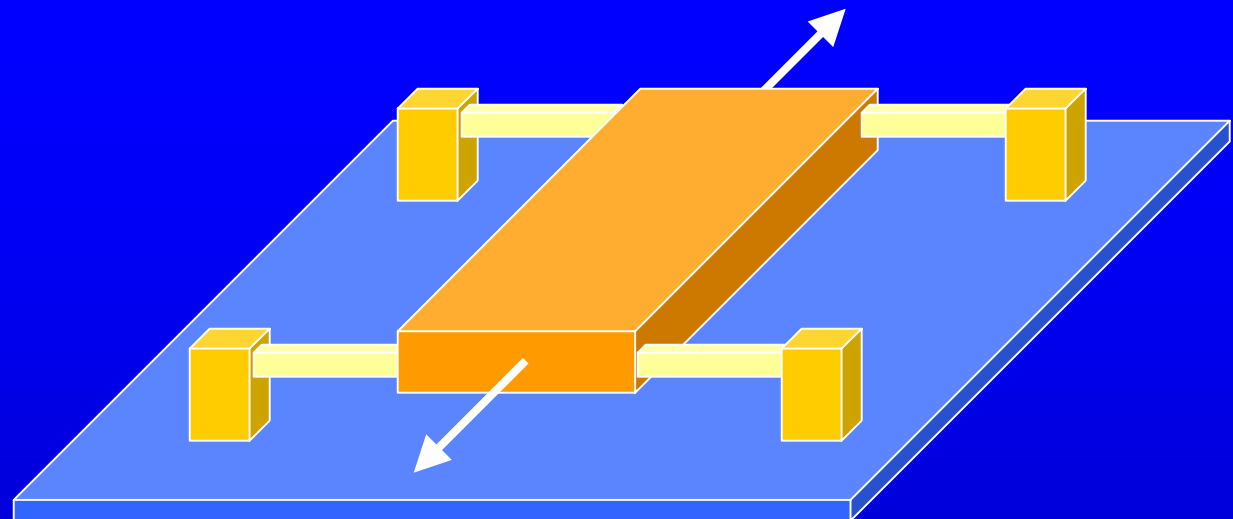
- **Purpose: microchip sensor to detect acceleration**



## Quick-Study: Purpose and Function

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

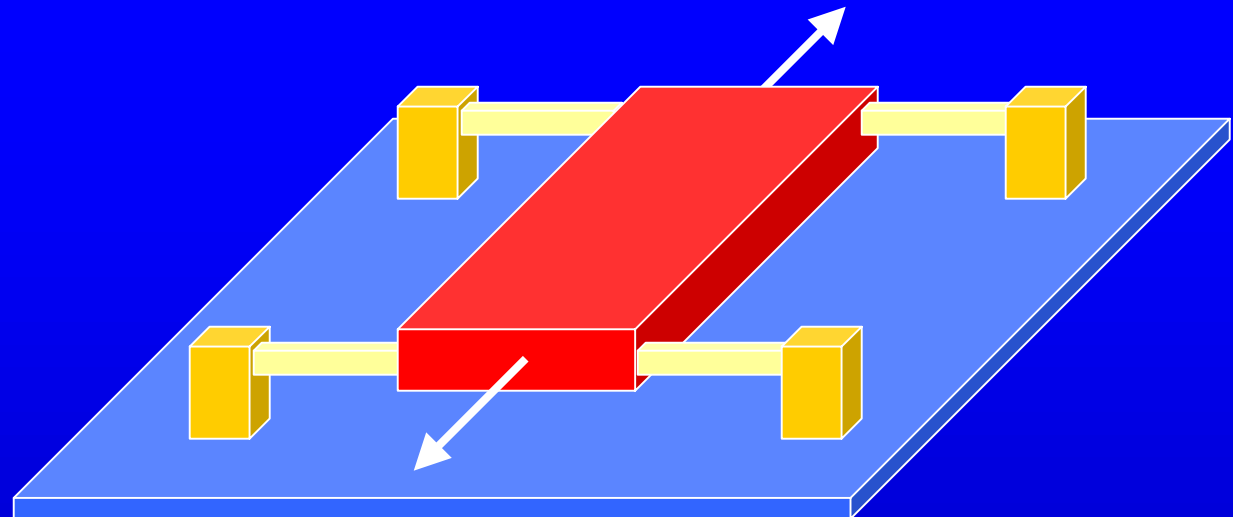


# Quick-Study: Purpose and Function

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

Proof Mass

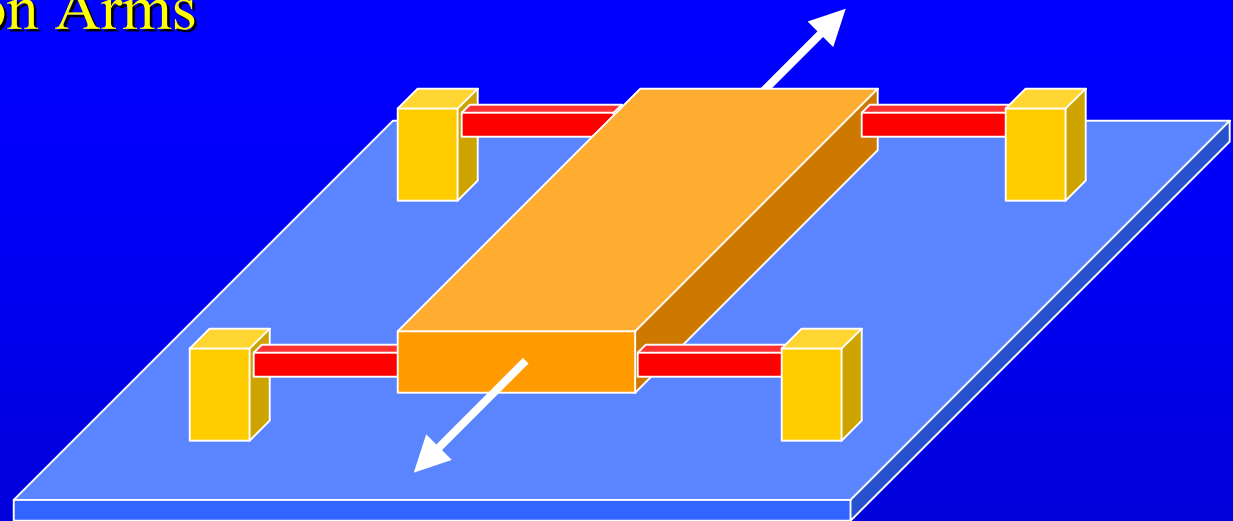


# Quick-Study: Purpose and Function

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

Proof Mass  
Suspension Arms

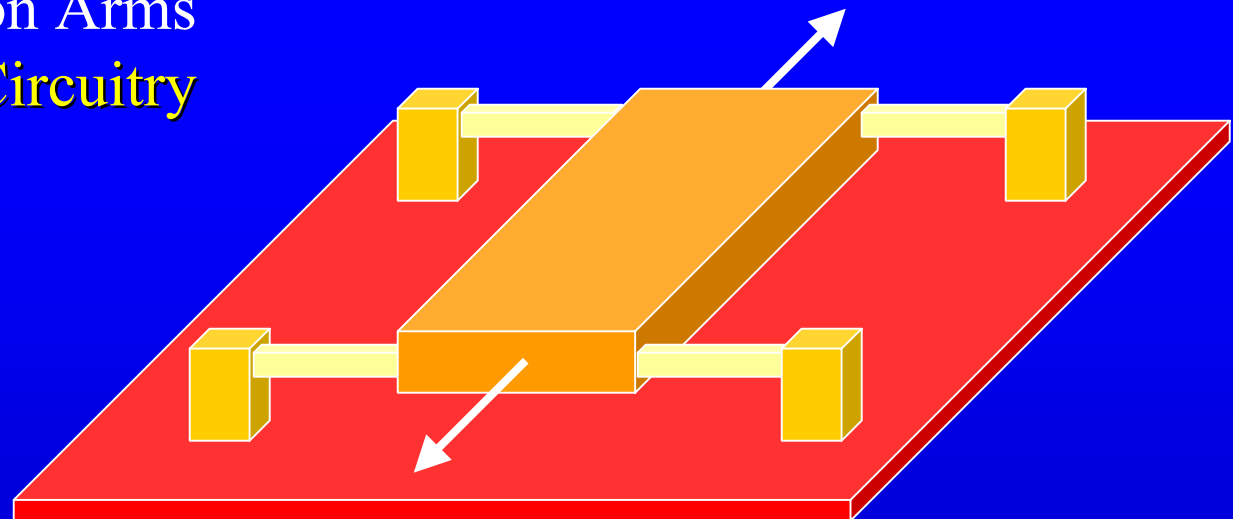


# Quick-Study: Purpose and Function

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

Proof Mass  
Suspension Arms  
Substrate with Circuitry

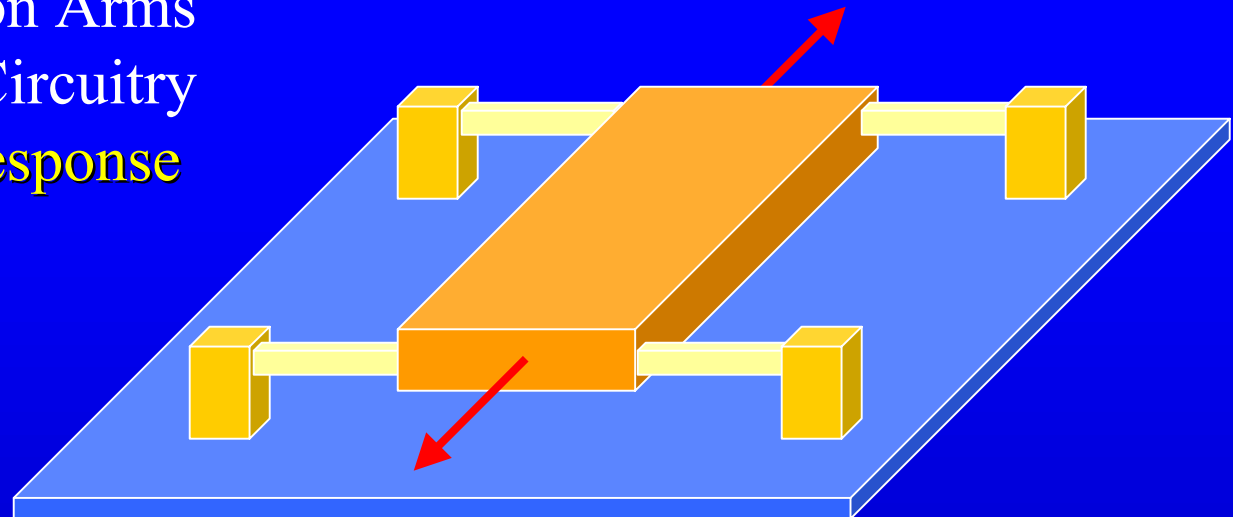


# Quick-Study: Purpose and Function

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

Proof Mass  
Suspension Arms  
Substrate with Circuitry  
*Axis of Response*

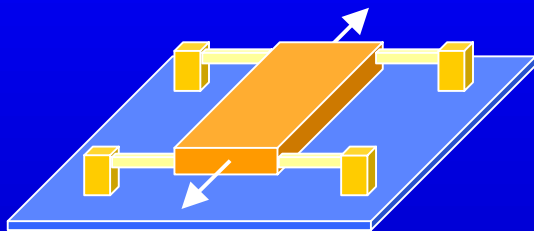


# Quick-Study: Purpose and Function

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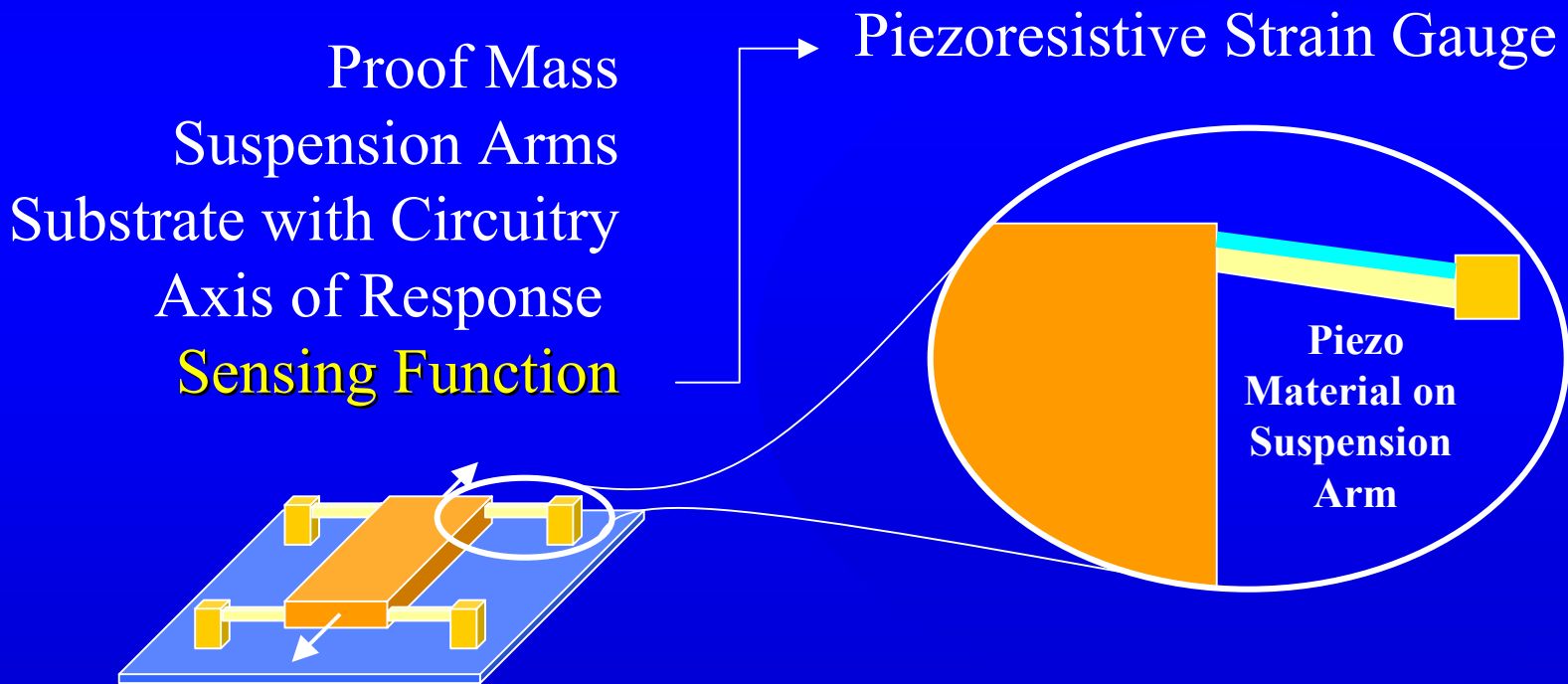
Proof Mass  
Suspension Arms  
Substrate with Circuitry  
Axis of Response  
Sensing Function



# Quick-Study: Purpose and Function

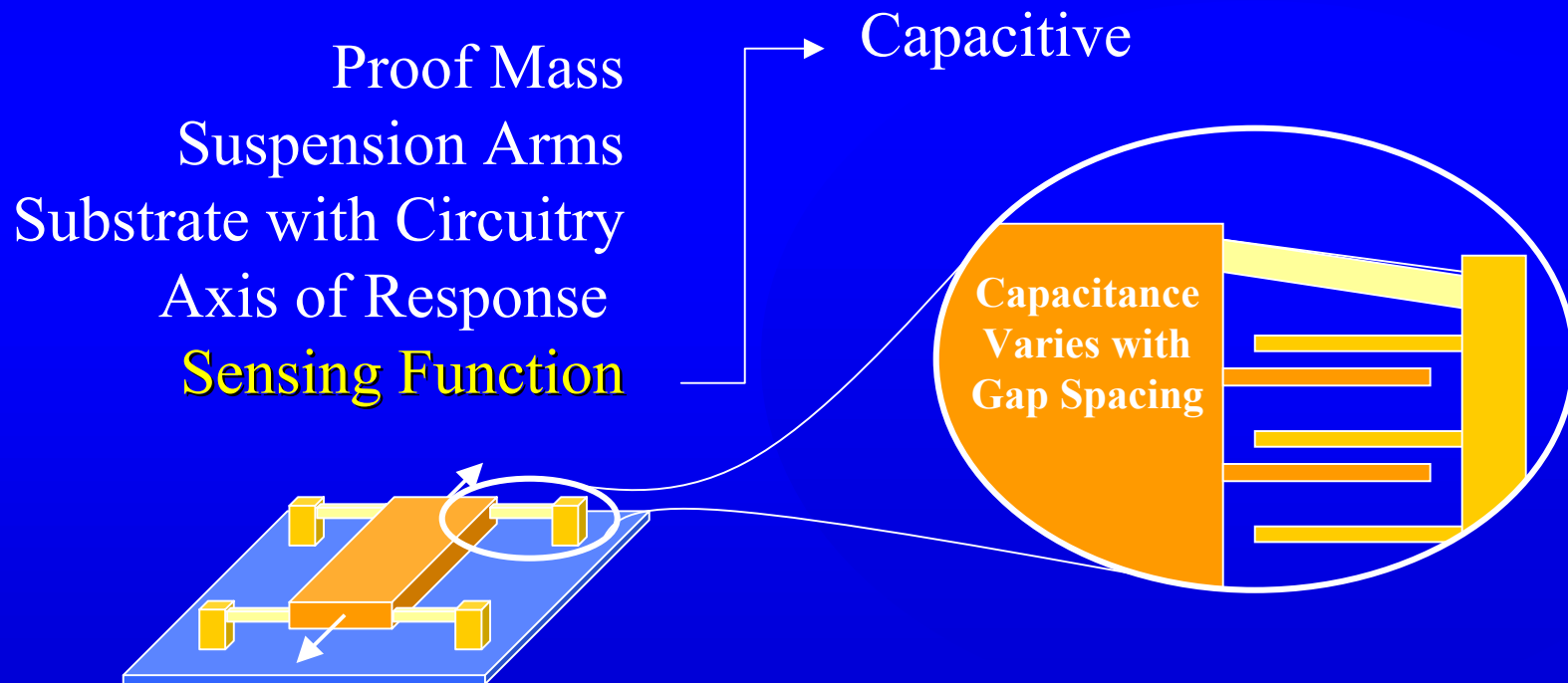
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# Quick-Study: Purpose and Function

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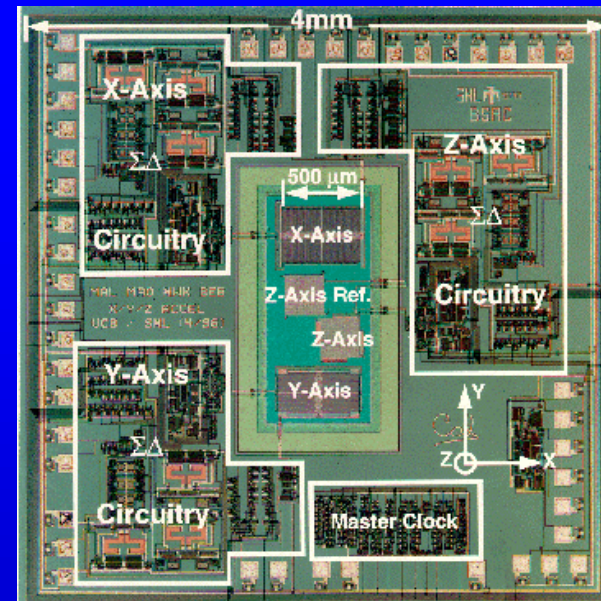


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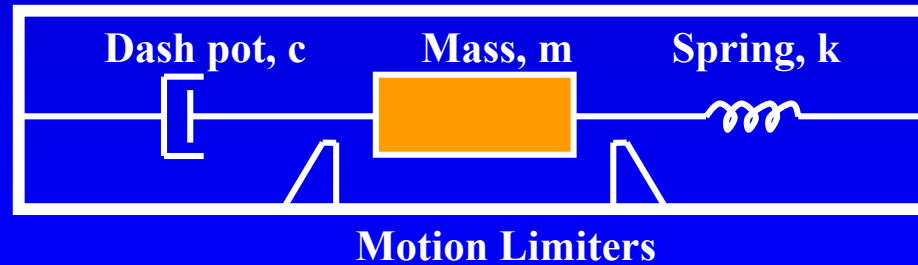
- **Purpose: microchip sensor to detect acceleration**
- **Functional Features:**

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

Capacitive (Analog Devices)



# Quick Study: Control Variables



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

**Model gives control relationships...**

**1. Static sensitivity:**

$$\frac{x_{\text{static}}(s)}{a(s)} = \frac{M}{K} = \frac{1}{\omega_r^2}$$

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

**2. Total Noise:**

$$TN = \frac{(4KTc)^{1/2}}{M}$$

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

## **Proposed Modification: Economics**

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**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

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

# Ion Implanting

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- **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

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- **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<sub>2</sub> 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

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- **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

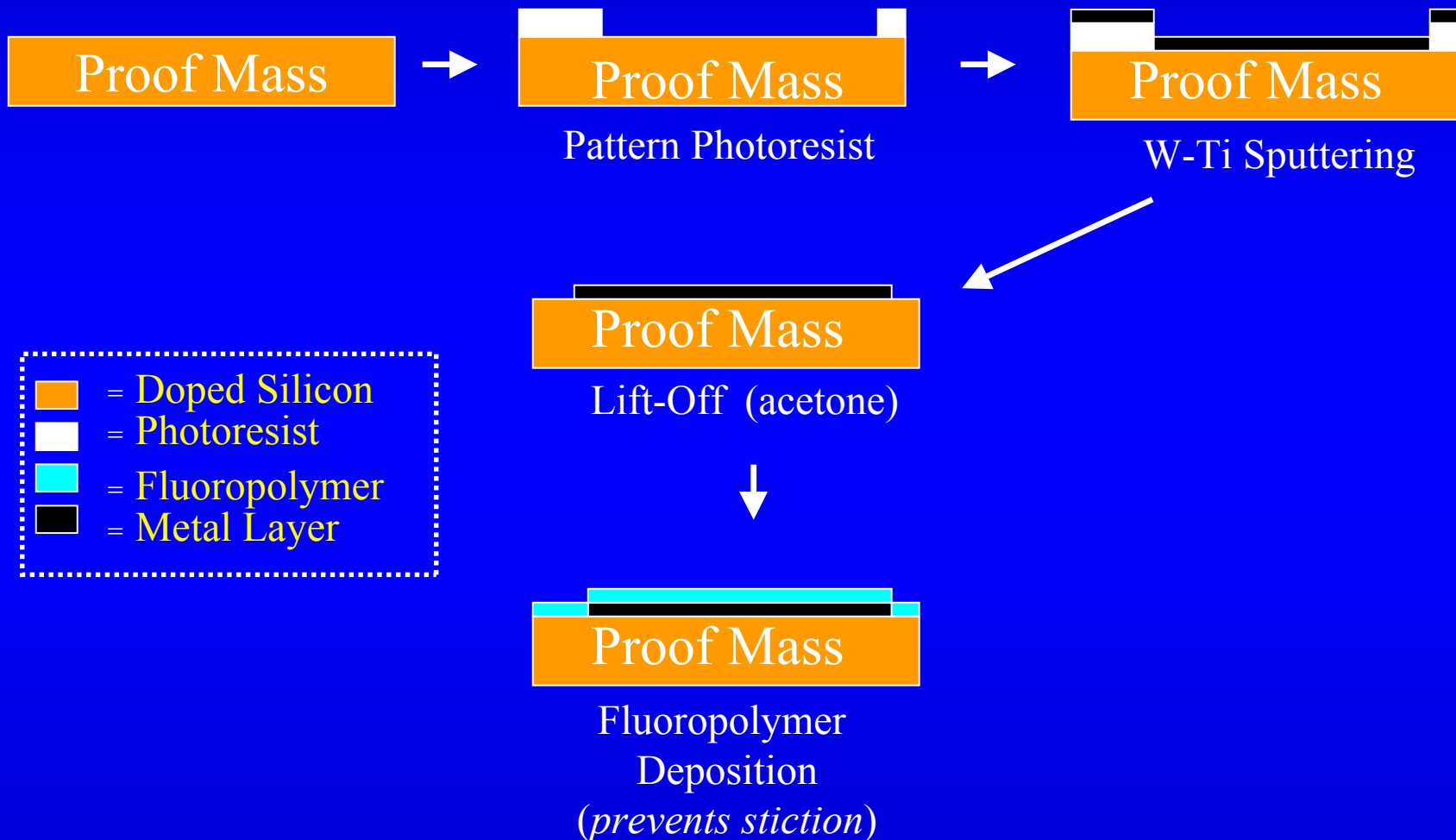
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- **Sputtering**

- 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



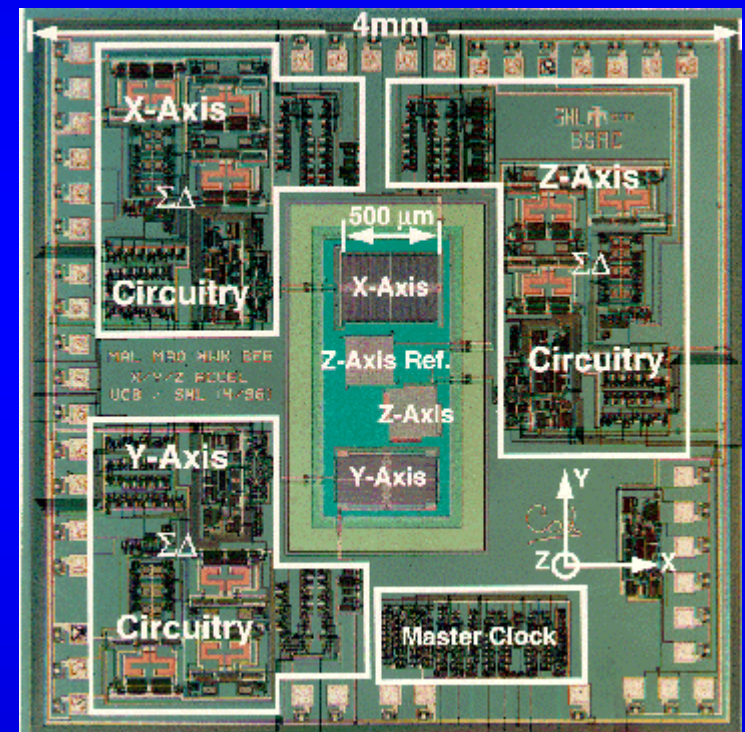
# Modes of Failure

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- **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  $16.6 \text{ g/cm}^3$ .**
  - Assume this layer is 0.5 microns thick
- **This makes the density of the proof mass  $5.2 \text{ g/cm}^3$** 
  - (Silicon [ $\rho=2.3\text{g/cm}^3$ ] is 2 microns thick, 80% of volume, rest is metal layer)



# Economic Justification

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- **Given that the proof mass is  $1\mu\text{g}$** 
  - 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**

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- **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**

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**QUESTIONS?**