# WORCESTER POLYTECHNIC INSTITUTE

## MECHANICAL ENGINEERING DEPARTMENT

Engineering Experimentation
ME-3901, D'2012

Lecture 12

25 April 2012

# General information

## Office hours

**Instructors**: Cosme Furlong

Office: HL-151

Everyday:

9:00 to 9:50 am

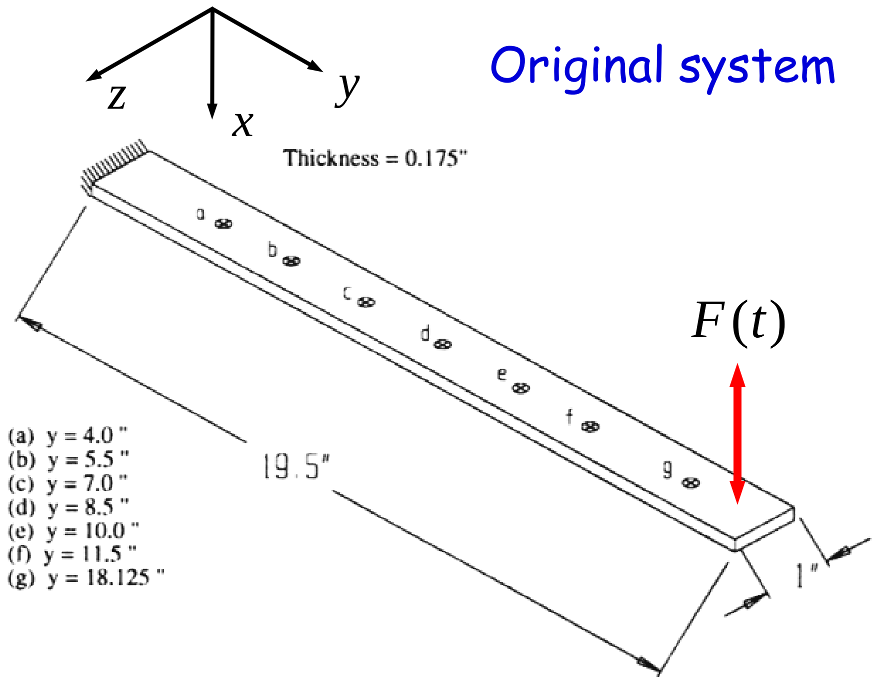
Christopher Scarpino

Office: HL-153

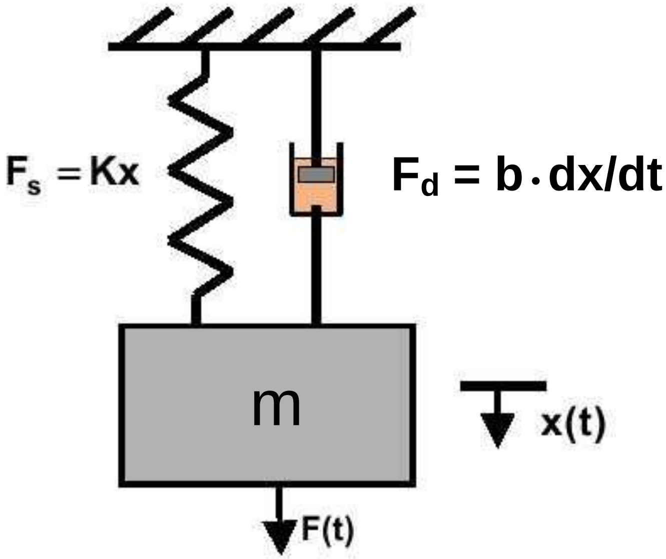
During laboratory sessions

Teaching Assistants: During laboratory sessions

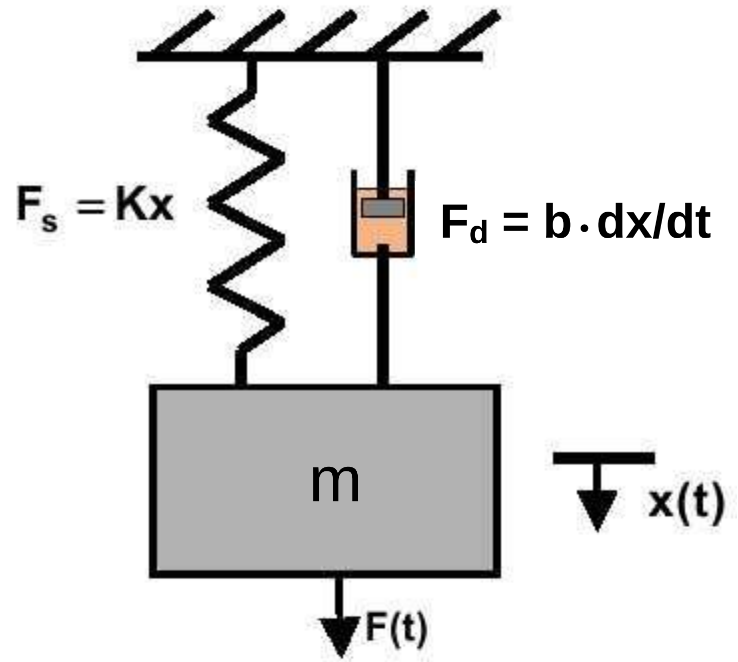
# Equivalent systems




Original system → Equivalent system



# Analysis of a single degree of freedom system




Governing equation: $$m\frac{d^2x}{dt^2} = \sum_i F_i$$

$$m\frac{d^2x}{dt^2} = -kx - b\frac{dx}{dt} + F(t)$$

External force

# Analysis of a single degree of freedom system

## First case: $F(t) \neq 0$ – Forced vibrations

Governing equation: $$m\frac{d^2x}{dt^2} + b\frac{dx}{dt} + kx = F(t)$$

Governing equation can be written as:

$$\frac{d^2x}{dt^2} + \frac{b}{m}\frac{dx}{dt} + \frac{k}{m}x = \frac{F(t)}{m} \rightarrow \frac{d^2x}{dt^2} + 2\lambda\frac{dx}{dt} + \omega^2 x = F'(t)$$

Solution has the form:

$$x(t) = x_c(t) + x_p(t)$$

$x_c(t)$ Complementary solution

$x_p(t)$ Particular solution

Solution requires the method of *undetermined coefficients*

# Analysis of a single degree of freedom system

## First case: $F(t) \neq 0$ – Forced vibrations

Governing equation: $$\frac{d^2x}{dt^2} + 2\lambda\frac{dx}{dt} + \omega^2 x = F_o \sin(\gamma t)$$

Solution has the form: $$x(t) = x_c(t) + x_p(t)$$

$$x(t) = \underbrace{Ae^{-\lambda t}\sin(\sqrt{\omega^2 - \lambda^2}\,t + \phi)}_{transient} + \underbrace{\frac{F_o}{\sqrt{(\omega^2 - \lambda^2)^2 + 4\lambda^2\gamma^2}}\sin(\gamma t + \theta)}_{steady\ state}$$

with: $$\sin(\phi) = \frac{C_1}{A}; \qquad \sin(\theta) = \frac{-2\lambda\gamma}{\sqrt{(\omega^2 - \lambda^2)^2 + 4\lambda^2\gamma^2}}$$

$$\cos(\phi) = \frac{C_2}{A}; \qquad \cos(\theta) = \frac{\omega^2 - \lambda^2}{\sqrt{(\omega^2 - \lambda^2)^2 + 4\lambda^2\gamma^2}}$$

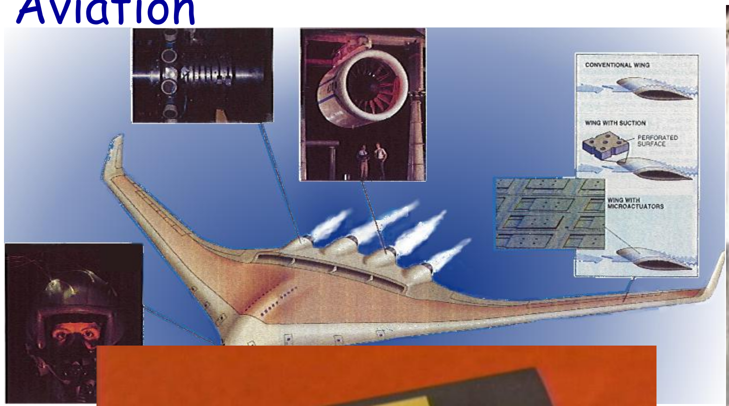
# Analysis of a single degree of freedom system

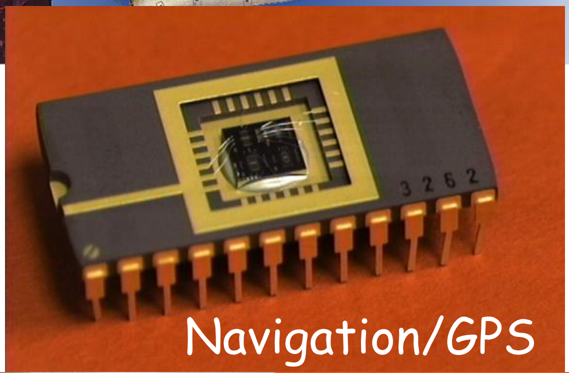
First case: $F(t) \neq 0$ – Forced vibrations

**REVIEW - Lecture 10: section on accelerometers**

# MEMS sensors & actuators: some applications

Aviation

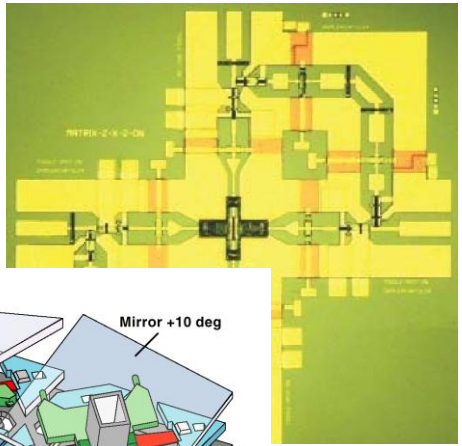


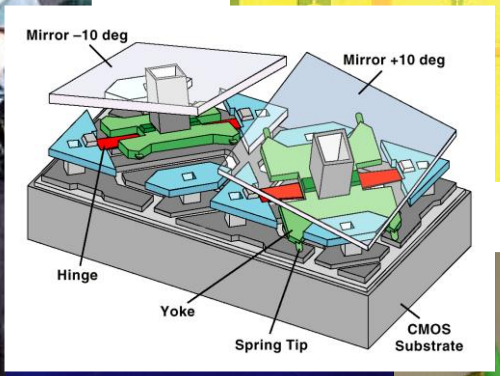




Navigation/GPS

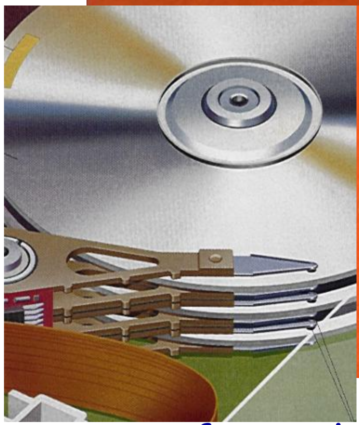
Segway: sensors

Microelectronics: RF MEMS

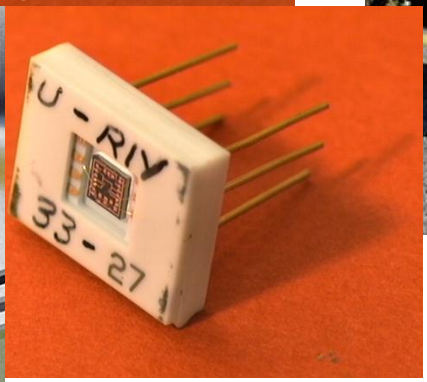




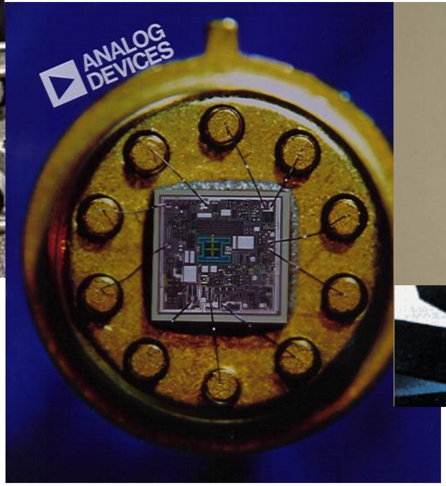

Photonics



Info-tech



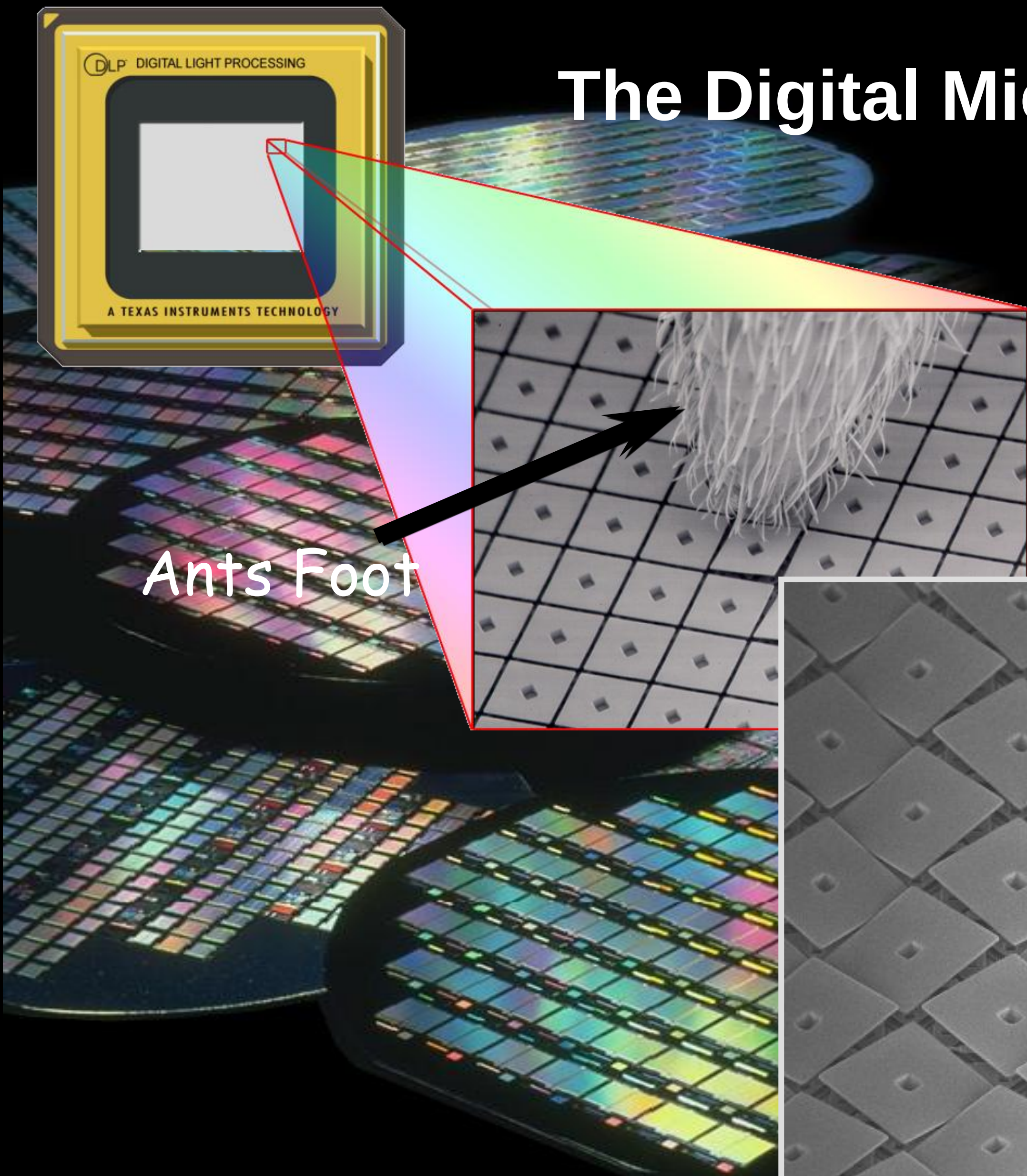

Controls



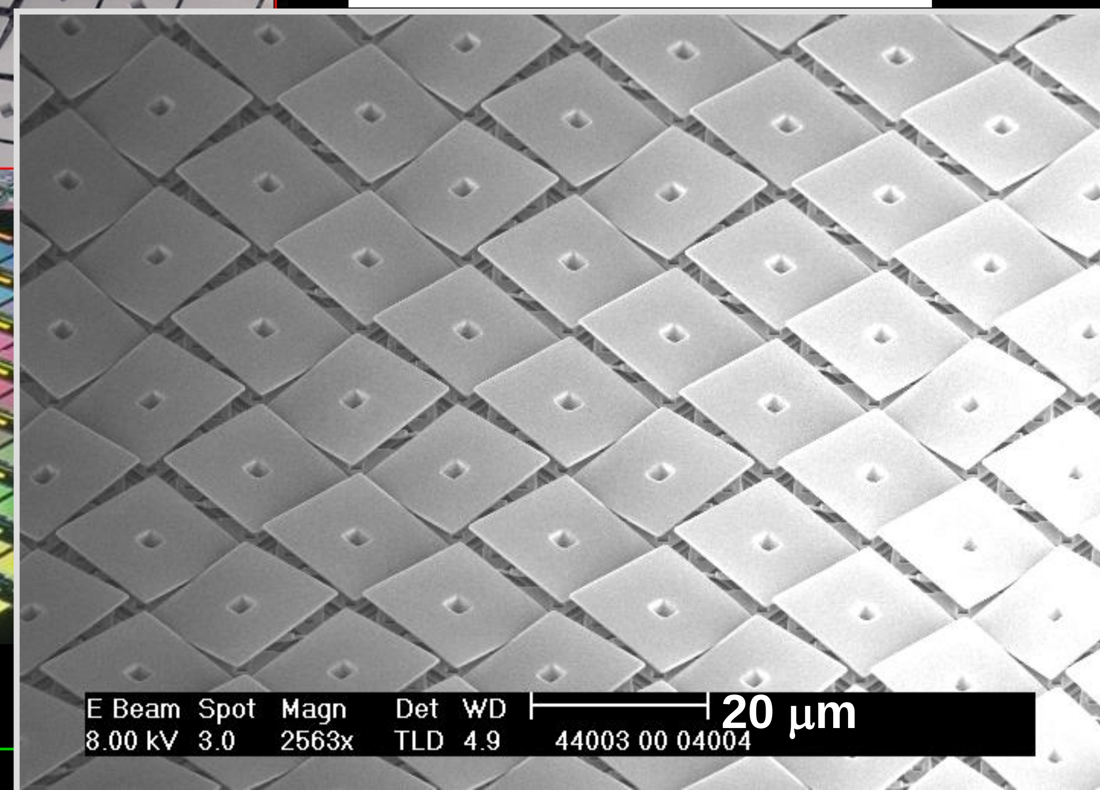

Automotive


Tele-com

# The Digital Micromirror Device

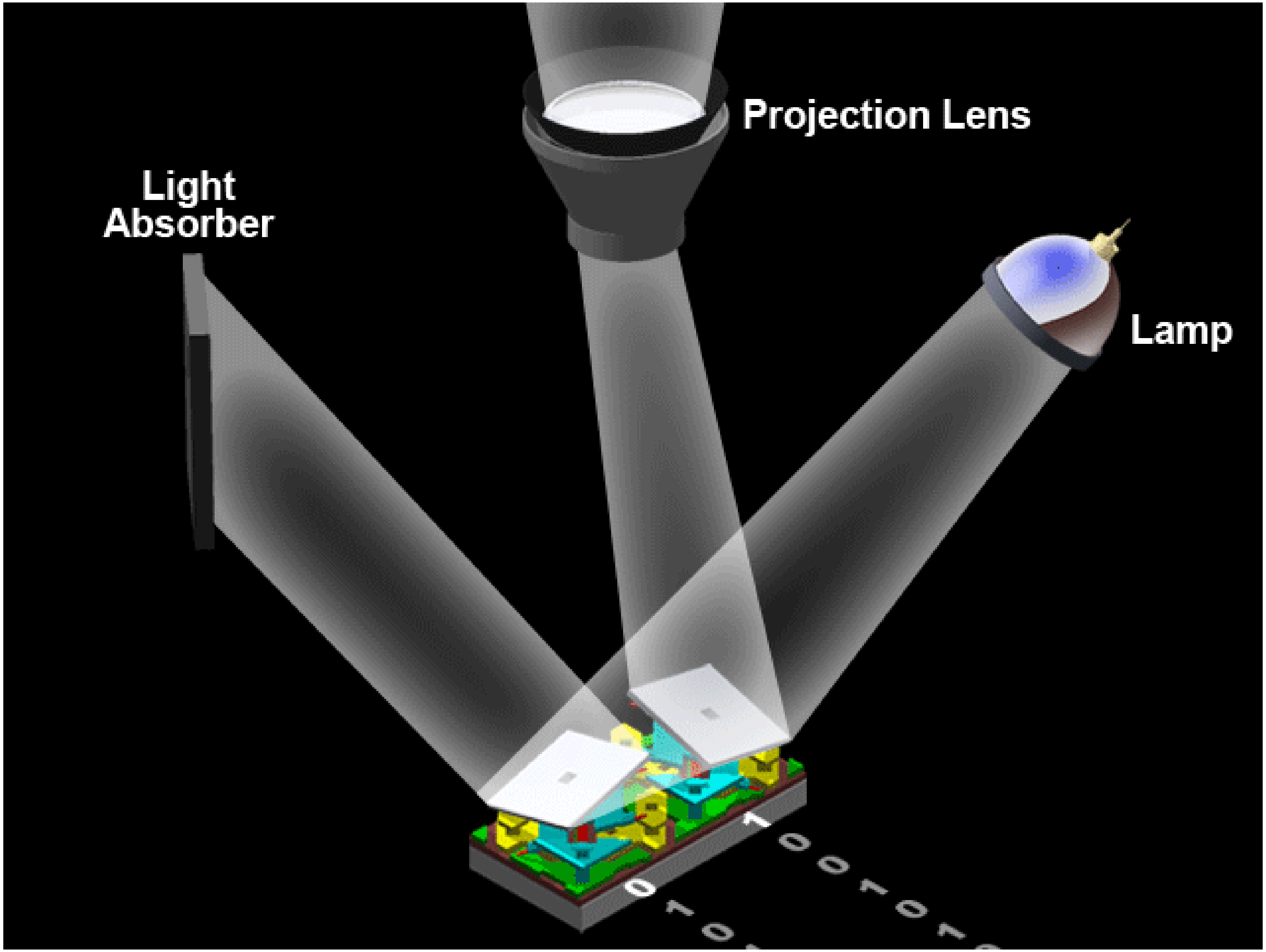



Close-up of Chip Surface



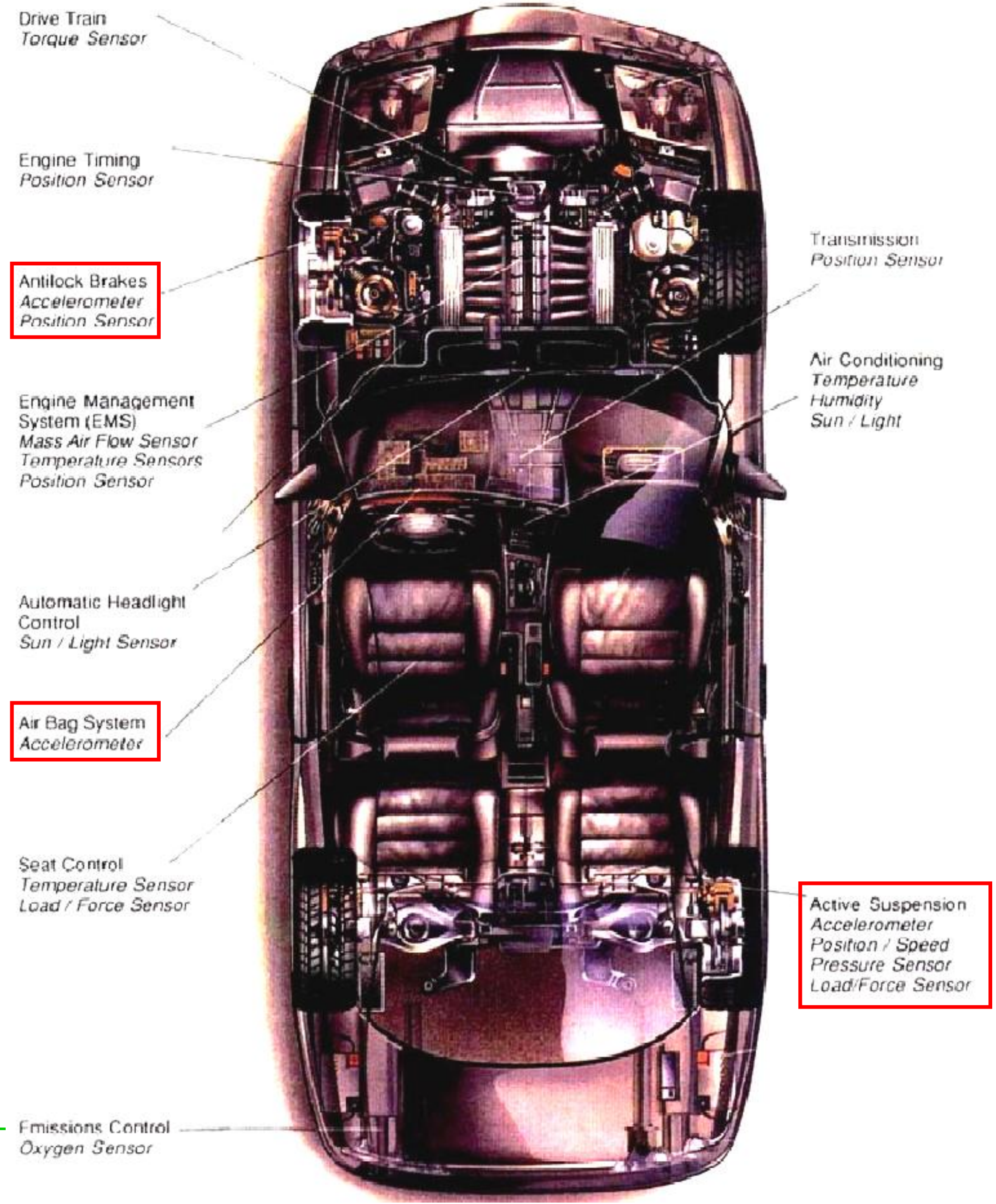

http://www.dlp.com/

# How DMD™ Technology works




http://www.dlp.com/

# MEMS sensors: some applications
(MEMS – Microelectromechanical Systems)

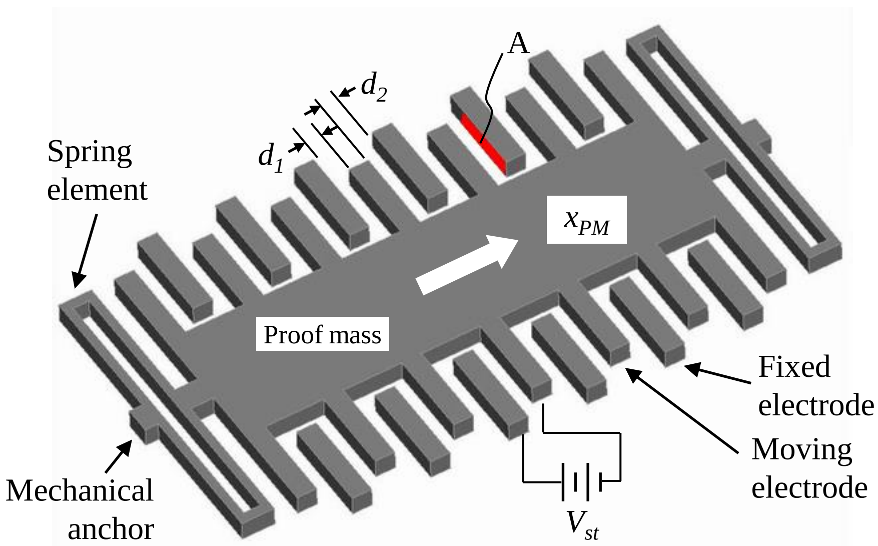


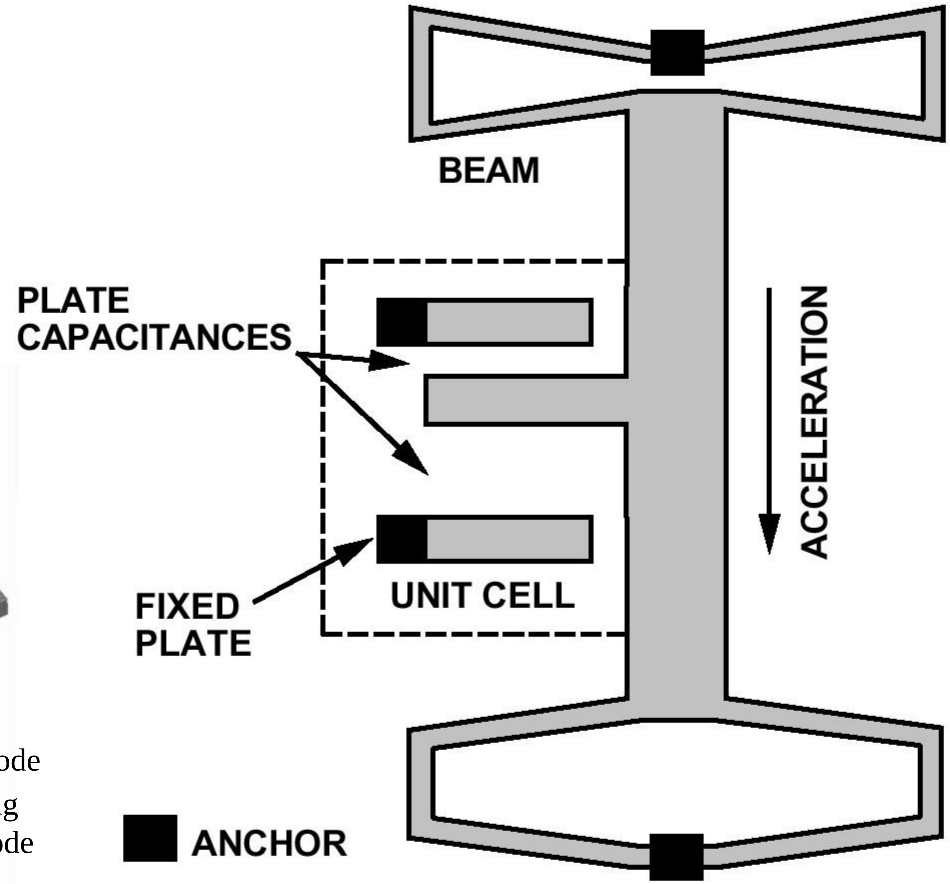
# MEMS accelerometers

## Simplified view of a sensor subjected to acceleration

Capacitance → $C = \varepsilon_r \varepsilon_o \dfrac{A}{d}$

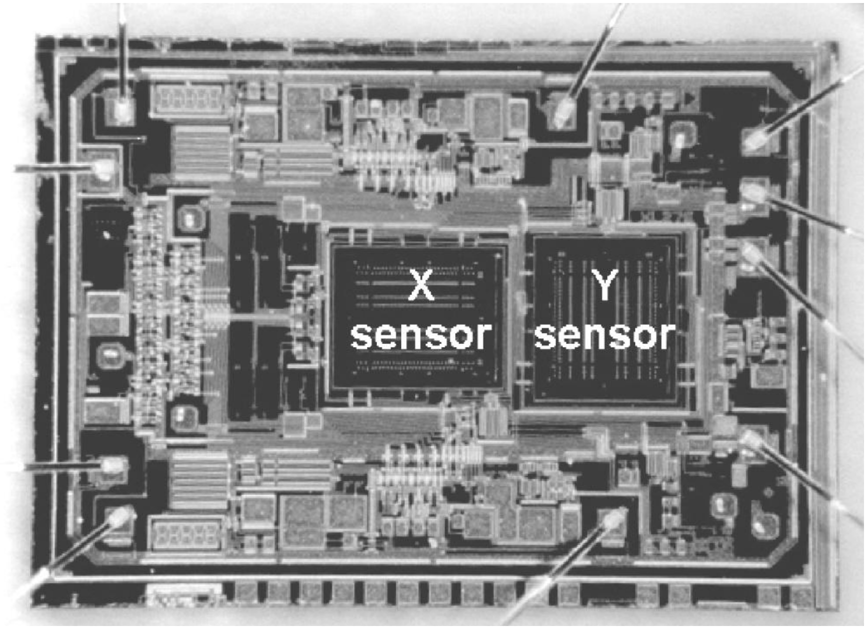
Single axis capacitive MEMS inertial sensor

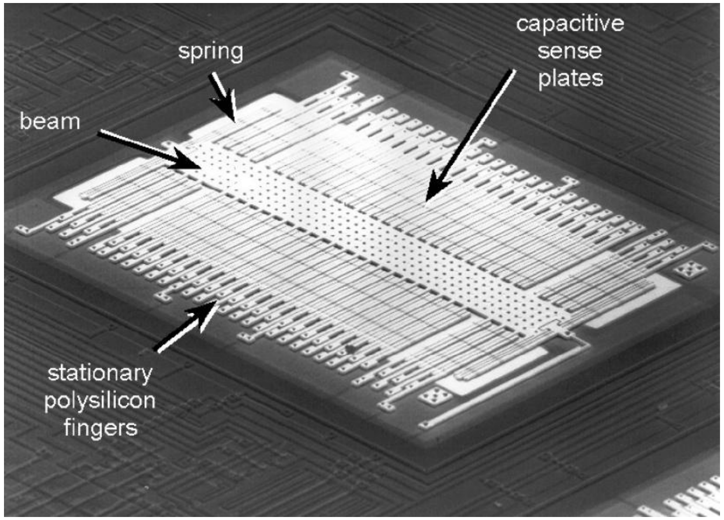


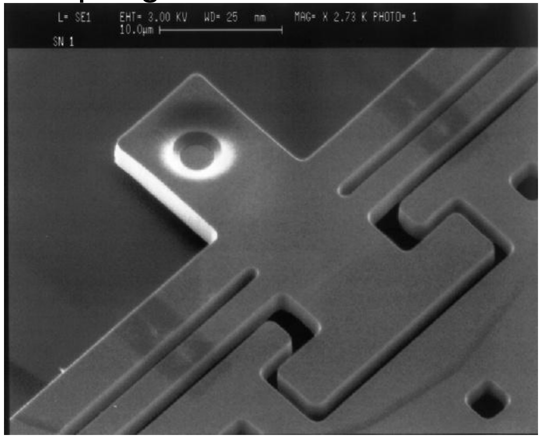
# MEMS accelerometers: ADXL 150

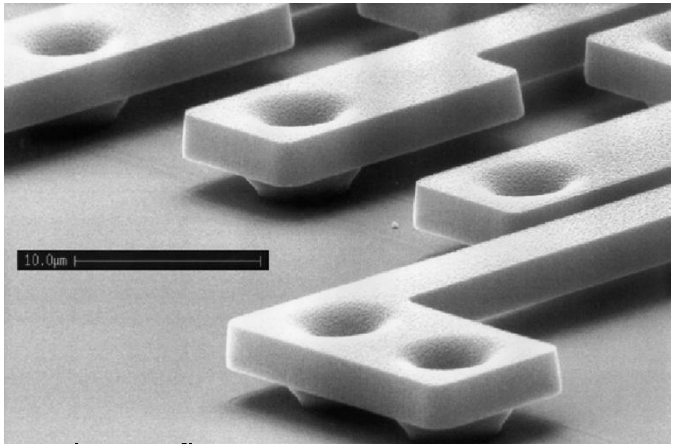
## Dual-axes accelerometers




Spring attachment: anchor

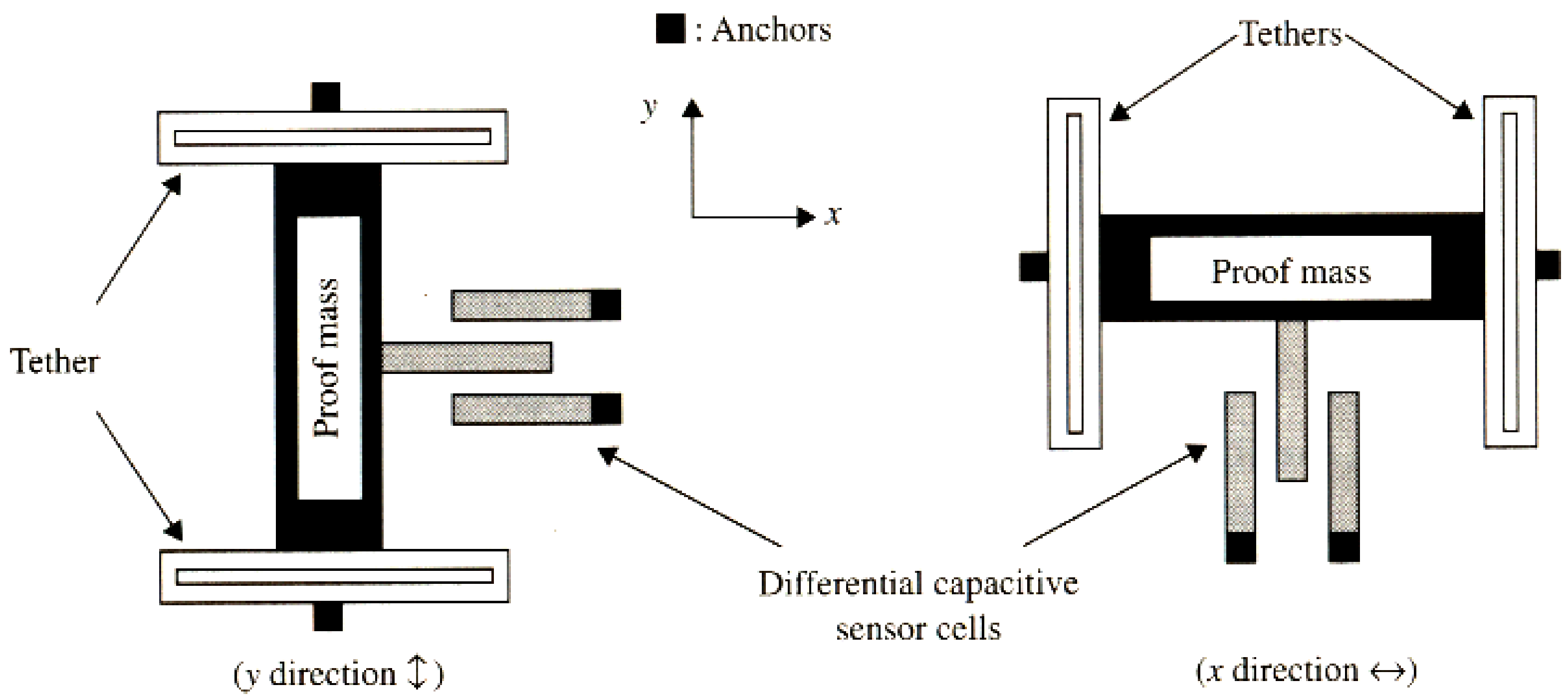





Stationary fingers

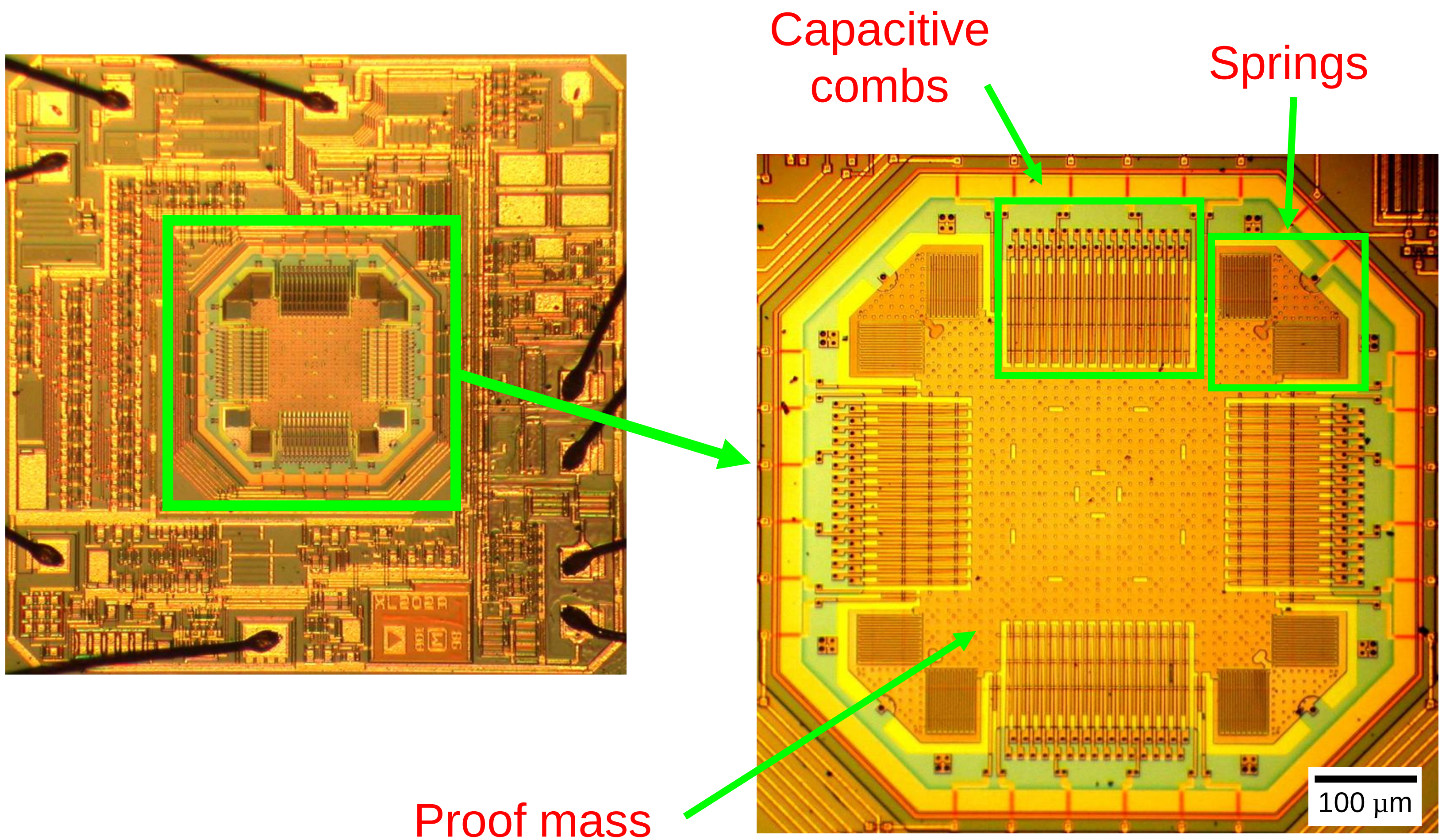
# MEMS accelerometers: ADXL 150

## Dual-axes accelerometers



# MEMS accelerometers: ADXL 202

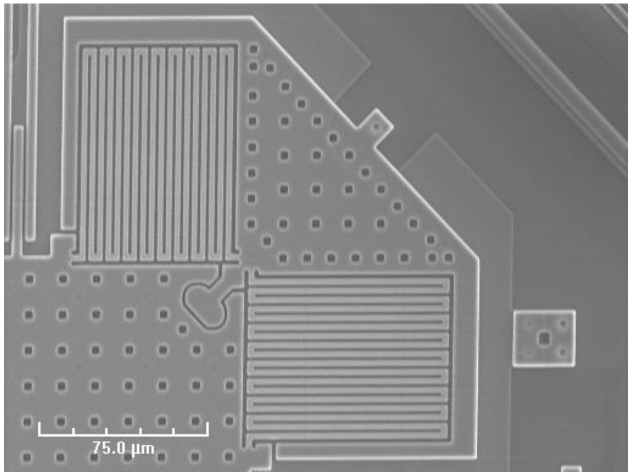
## Dual-axes accelerometers

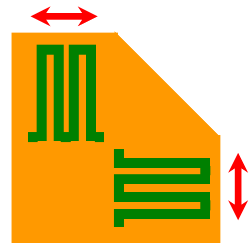


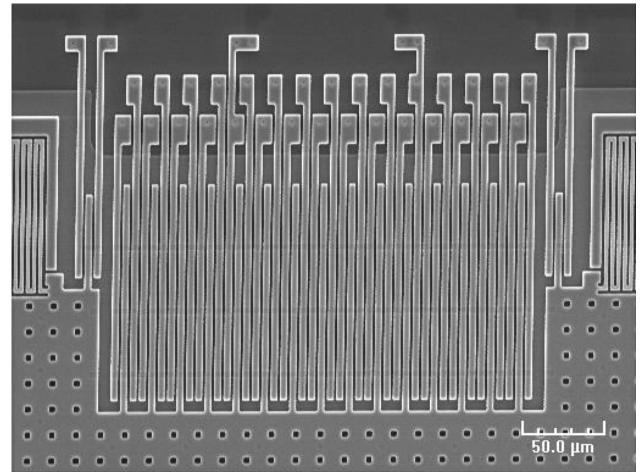

ADXL202 micromechanical sensor

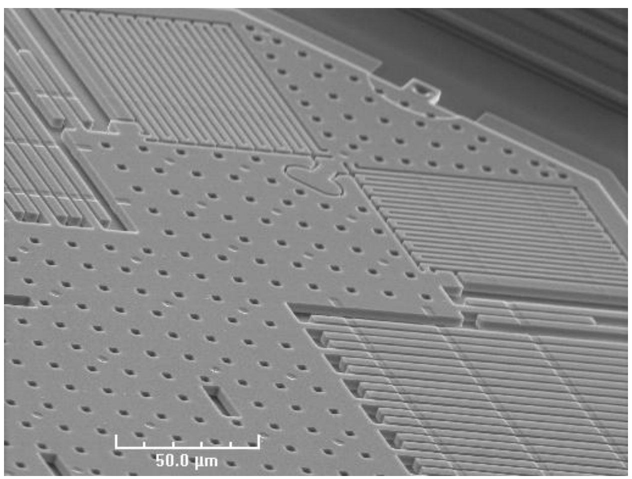
# MEMS accelerometers: ADXL 202

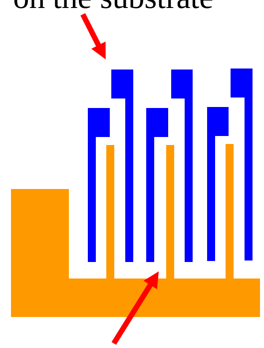
Proof mass has dimensions of 600 × 600 × 3 $\mu m^3$

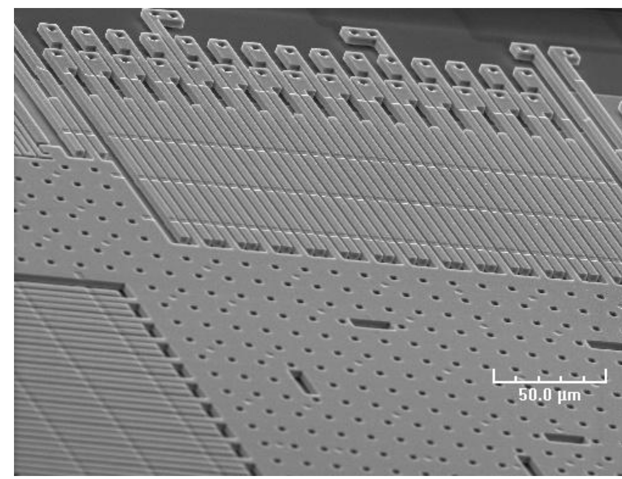




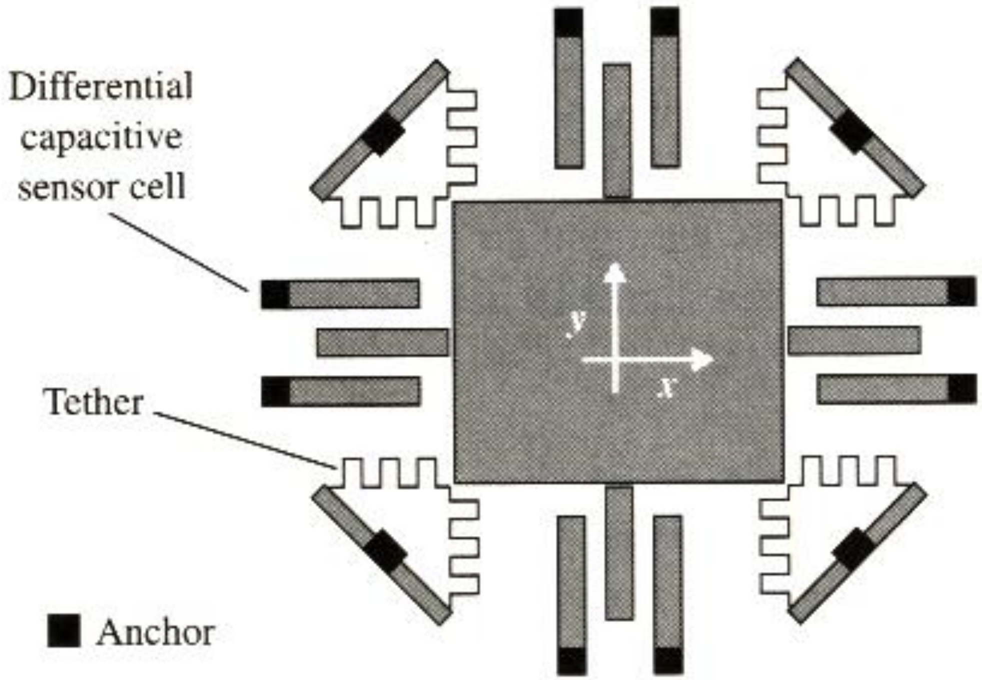




One set of spring elements

One set of capacitive combs

# MEMS accelerometers: ADXL 202

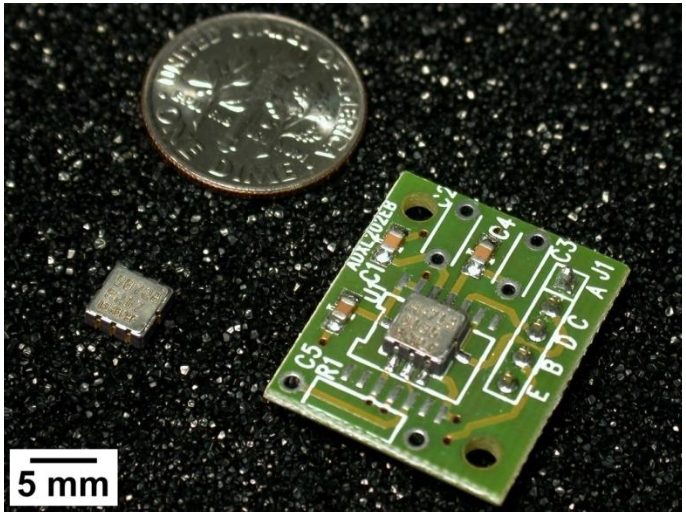
## Dual-axes accelerometers




(Courtesy of Analog Devices Inc., Norwood, Massachusetts.)

# MEMS accelerometers: ADXL 202

- Provide optimum substitution for typical piezoelectric accelerometers because of their
  - high resonance frequency
  - light weight, small size, low power use
- Some properties of the Analog Devices' *ADXL202* dual-axes accelerometer include



ADXL202 packages

| Specifications of Analog Devices ADXL202 | | | |
|---|---|---|---|
| Measurement range | ± 2 g | Operating voltage | 3.0-5.25 V |
| Sensitivity | 312 mV/ g | Mass | 160 ± 10 mgr |
| Resonance frequency | 10 kHz | Operating temperature | [-40,85] °C |