EE C247B – ME C218
Introduction to MEMS Design
Spring 2014

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Lecture Module 1: Admin & Overview

Instructor: Prof. Clark T.-C. Nguyen

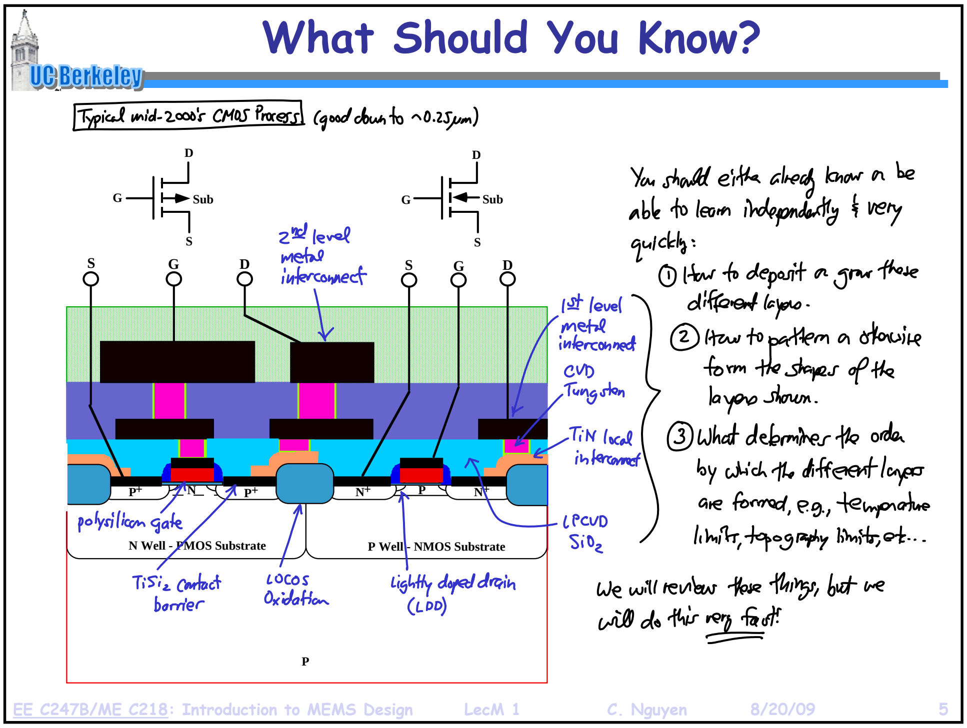
- *Education*: Ph.D., University of California at Berkeley, 1994
- *1995*: joined the faculty of the Dept. of EECS at the University of Michigan
- *2006*: (came back) joined the faculty of the Dept. of EECS at UC Berkeley
- *Research*: exactly the topic of this course, with a heavy emphasis on vibrating RF MEMS
- *Teaching*: (at the UofM) mainly transistor circuit design courses; (UC Berkeley) 140/240A, 143, 243, 245
- *2001*: founded Discera, the first company to commercialize vibrating RF MEMS technology
- *Mid-2002 to 2005*: DARPA MEMS program manager
  - ran 10 different MEMS-based programs
  - *topics*: power generation, chip-scale atomic clock, gas analyzers, nuclear power sources, navigation-grade gyros, on-chip cooling, micro environmental control

Course Overview

- Goals of the course:
  - Accessible to a broad audience (minimal prerequisites)
  - Design emphasis
    - Exposure to the techniques useful in analytical design of structures, transducers, and process flows
  - Perspective on MEMS research and commercialization circa 2013
- Related courses at UC Berkeley:
  - EE 143: Microfabrication Technology
  - EE 147/247A: Introduction to MEMS
  - ME 119: Introduction to MEMS (mainly fabrication)
  - BioEng 121: Introduction to Micro and Nano Biotechnology and BioMEMS
  - ME C219 – EE C246: MEMS Design
- Assumed background for EE C245:
  - graduate standing in engineering or physical/bio sciences
  - may change to require 247A next year

Course Overview

- The mechanics of the course are summarized in the course handouts, given out in lecture today
  - Course Information Sheet
    - Course description
    - Course mechanics
    - Textbooks
    - Grading policy
  - Syllabus
    - Lecture by lecture timeline w/ associated reading sections
    - Midterm Exam: tentatively on Thursday, March 20
    - Final Exam: Friday, May 16, 7-10 p.m. (Group 20)
    - Project due date TBD (but near semester's end)


What Should You Know?
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Typical mid-2000's CMOS Process (good down to ~0.25μm)
2nd level metal interconnect
1st level metal interconnect
CVD Tungsten
TiN local interconnect
LPCVD SiO2
polysilicon gate
TiSi2 contact barrier
LOCOS Oxidation
Lightly doped drain (LDD)
N Well - PMOS Substrate
P Well - NMOS Substrate
You should either already know or be able to learn independently & very quickly:
① How to deposit or grow these different layers.
② How to pattern or otherwise form the shapes of the layers shown.
③ What determines the order by which the different layers are formed, e.g., temperature limits, topography limits, etc...
We will review these things, but we will do this very fast!
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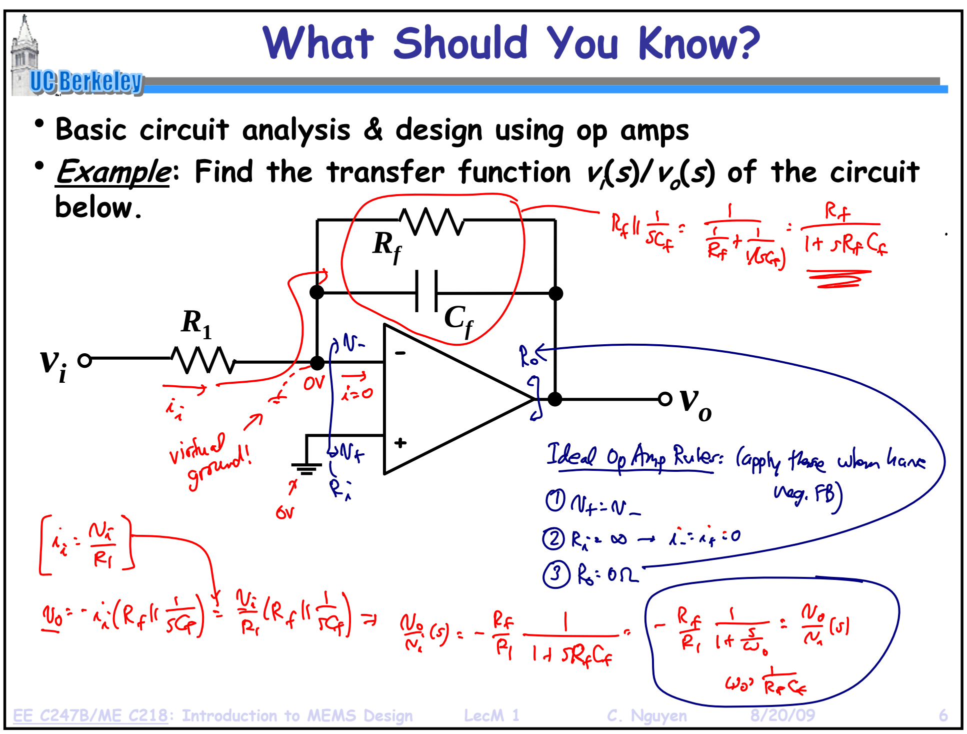
What Should You Know?
UC Berkeley
• Basic circuit analysis & design using op amps
• Example: Find the transfer function $v_i(s)/v_o(s)$ of the circuit below.
R_f
C_f
R_1
v_i
v_o
$R_f \| \frac{1}{sC_f} = \frac{1}{\frac{1}{R_f}+\frac{1}{1/(sC_f)}} = \frac{R_f}{1+sR_fC_f}$
virtual ground!
0V
i=0
Ideal Op Amp Rules: (apply these when have neg. FB)
① $v_+ = v_-$
② $R_i = \infty \rightarrow i_- = i_+ = 0$
③ $R_o = 0\Omega$
$i_i = \frac{v_i}{R_1}$
$v_o = -i_i\left(R_f \| \frac{1}{sC_f}\right) = \frac{v_i}{R_1}\left(R_f \| \frac{1}{sC_f}\right) \Rightarrow \frac{v_o}{v_i}(s) = -\frac{R_f}{R_1}\frac{1}{1+sR_fC_f} = -\frac{R_f}{R_1}\frac{1}{1+\frac{s}{\omega_o}} = \frac{v_o}{v_i}(s)$
$\omega_o = \frac{1}{R_fC_f}$
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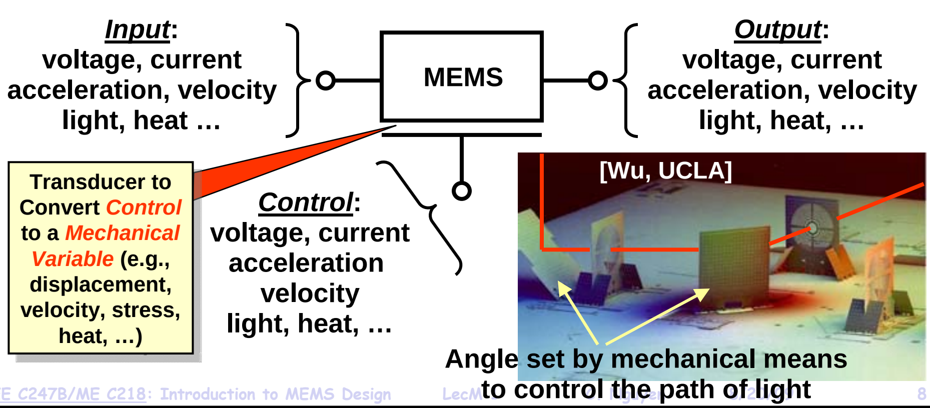
Lecture Outline

- Reading: Senturia, Chapter 1
- Lecture Topics:
  - Definitions for MEMS
  - MEMS roadmap
  - Benefits of Miniaturization

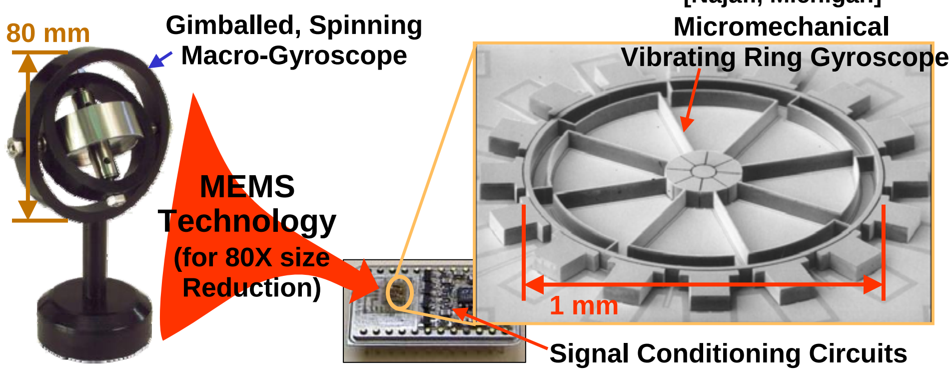
MEMS: Micro Electro Mechanical System

- A device constructed using micromachining (MEMS) tech.
- A micro-scale or smaller device/system that operates mainly via a mechanical or electromechanical means
- At least some of the signals flowing through a MEMS device are best described in terms of mechanical variables, e.g., displacement, velocity, acceleration, temperature, flow



Other Common Attributes of MEMS

- Feature sizes measured in microns or less



- Merges computation with sensing and actuation to change the way we perceive and control the physical world
- Planar lithographic technology often used for fabrication
  - can use fab equipment identical to those needed for IC's
  - however, some fabrication steps transcend those of conventional IC processing

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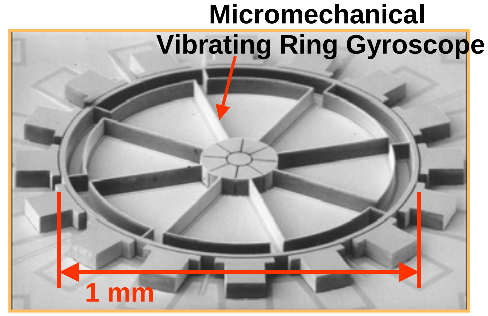
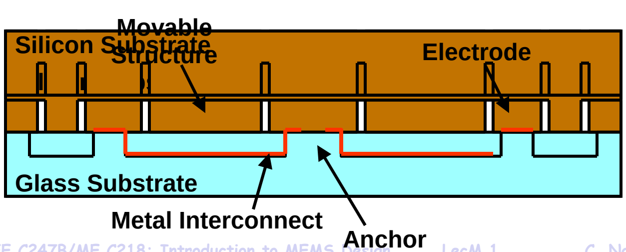
Bulk Micromachining and Bonding

- Use the wafer itself as the structural material
- *Adv*: very large aspect ratios, thick structures
- *Example*: deep etching and wafer bonding



[Najafi, Michigan]



Microrotor
(for a microengine)

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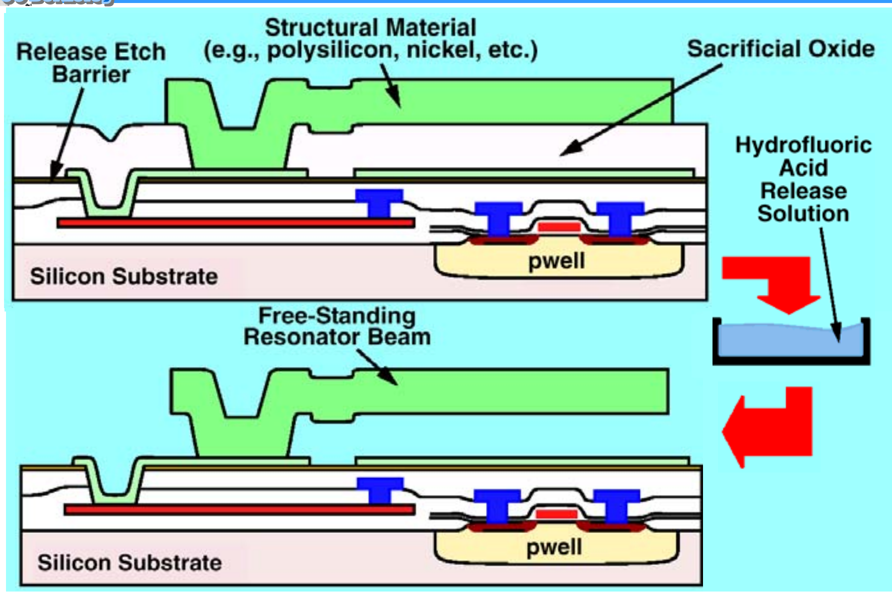
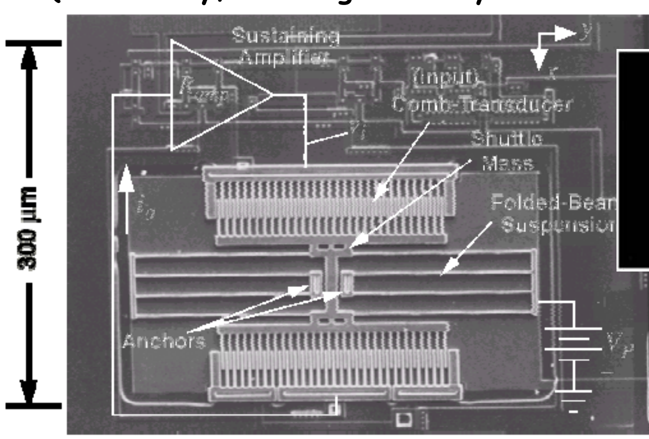
Surface Micromachining



- Fabrication steps compatible with planar IC processing

Single-Chip Ckt/MEMS Integration

- Completely monolithic, low phase noise, high-Q oscillator (effectively, an integrated crystal oscillator)



Oscilloscope Output Waveform

[Nguyen, Howe 1993]

- To allow the use of >600°C processing temperatures, tungsten (instead of aluminum) is used for metallization

3D Direct-Assembled Tunable L

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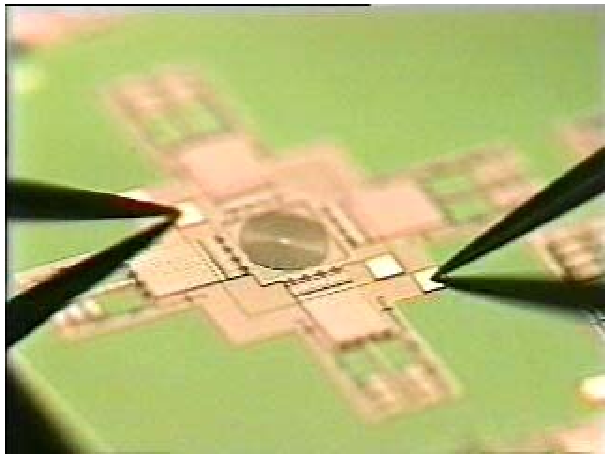

[Ming Wu, UCLA]

Technology Trend and Roadmap for MEMS

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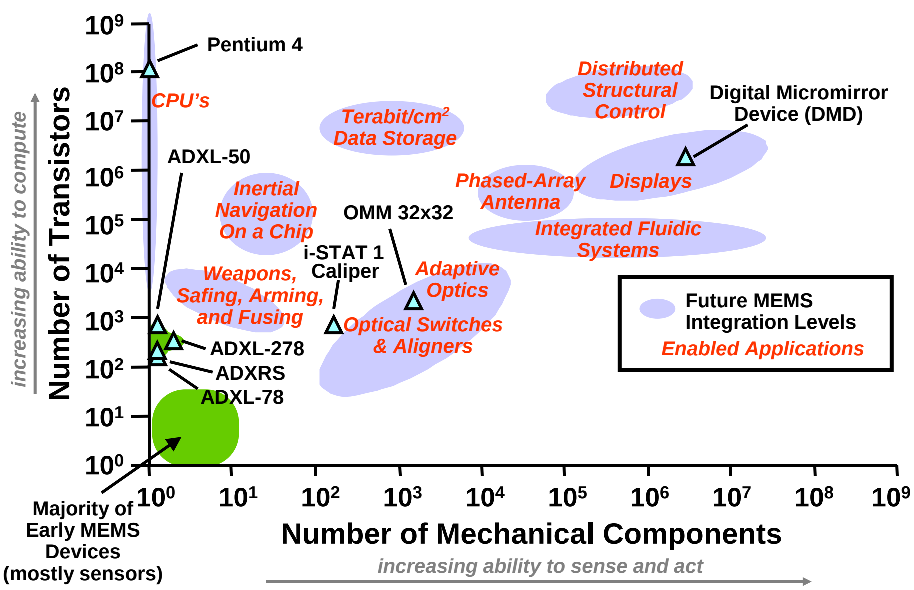

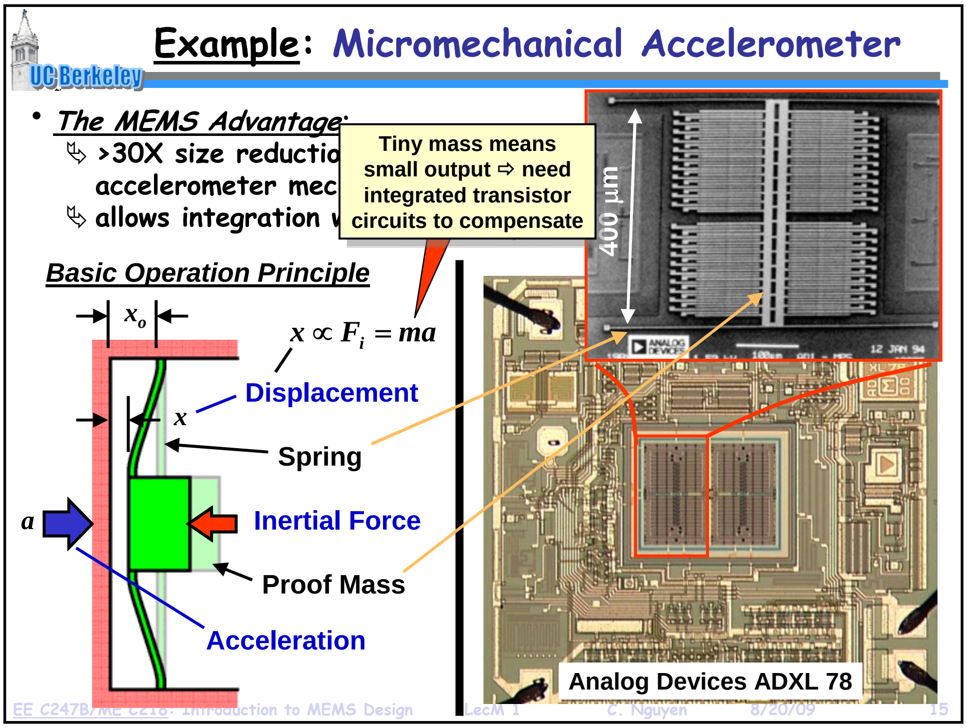
Example: Micromechanical Accelerometer
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The MEMS Advantage:
>30X size reductio
accelerometer mec
allows integration v
Tiny mass means small output ⇨ need integrated transistor circuits to compensate
400 µm
Basic Operation Principle
x_o
$x \propto F_i = ma$
Displacement
x
Spring
a
Inertial Force
Proof Mass
Acceleration
Analog Devices ADXL 78
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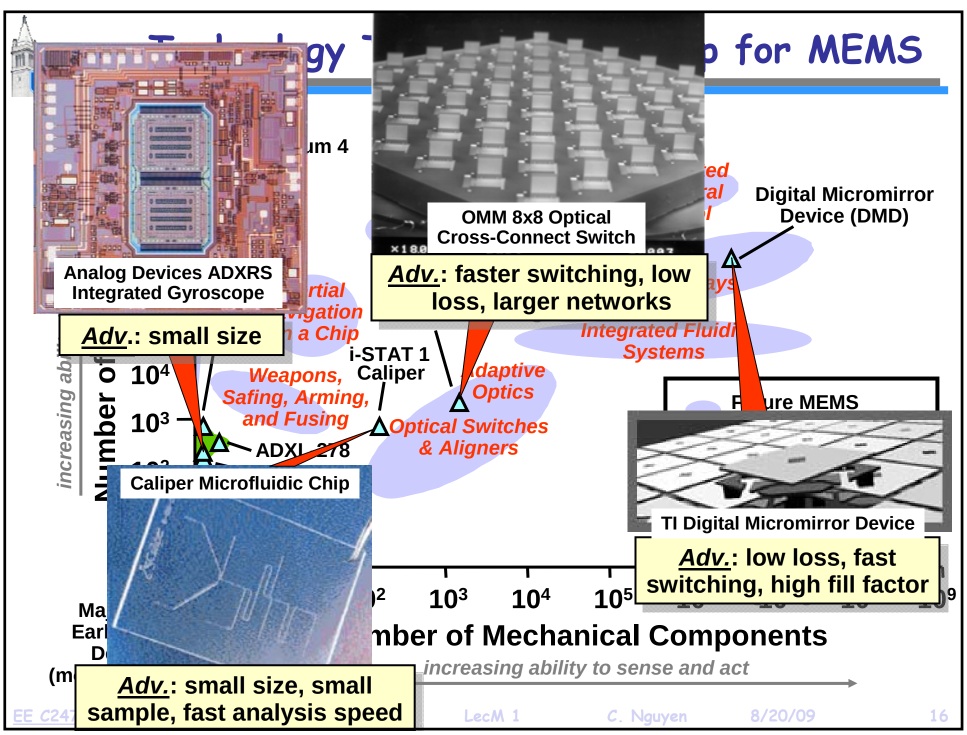
for MEMS
Analog Devices ADXRS Integrated Gyroscope
Adv.: small size
OMM 8x8 Optical Cross-Connect Switch
Adv.: faster switching, low loss, larger networks
Digital Micromirror Device (DMD)
Integrated Fluidi Systems
i-STAT 1 Caliper
Weapons, Safing, Arming, and Fusing
Adaptive Optics
Optical Switches & Aligners
ADXL 278
Future MEMS
Caliper Microfluidic Chip
TI Digital Micromirror Device
Adv.: low loss, fast switching, high fill factor
10^4
10^3
10^3
10^4
10^5
mber of Mechanical Components
increasing ability to sense and act
Adv.: small size, small sample, fast analysis speed
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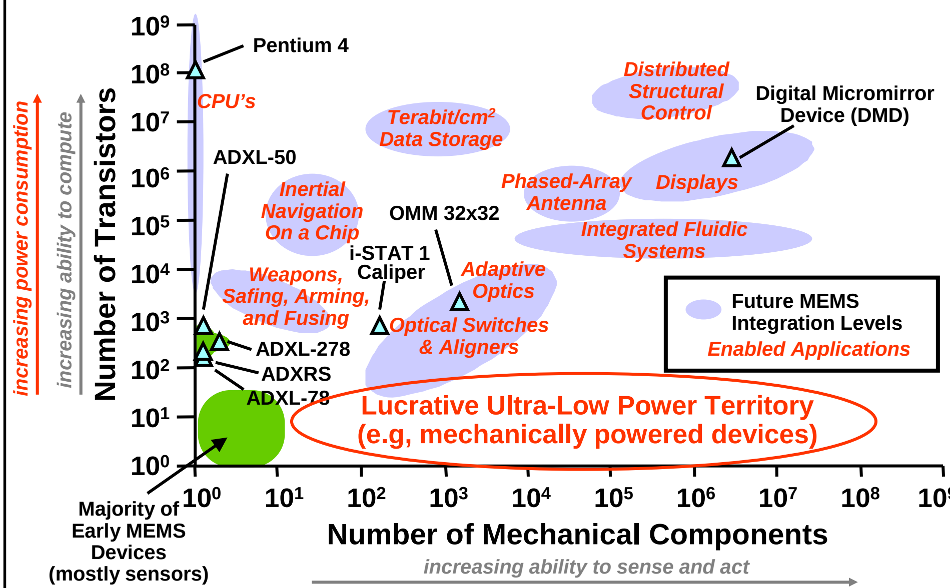
Technology Trend and Roadmap for MEMS



Benefits of Size Reduction: MEMS

- Benefits of size reduction clear for IC's in elect. domain
  - size reduction ⇨ speed, low power, complexity, economy
- MEMS: enables a similar concept, but …

MEMS extends the benefits of size reduction *beyond* the electrical domain

⬇

Performance enhancements for application domains beyond those satisfied by electronics in the same general categories

Speed ➡ Frequency ↑ , Thermal Time Const. ↓

Power Consumption ➡ Actuation Energy ↓ , Heating Power ↓

Complexity ➡ Integration Density ↑ , Functionality ↑

Economy ➡ Batch Fab. Pot. ↑ (esp. for packaging)

Robustness ➡ g-Force Resilience ↑