EE C245 – ME C218 Introduction to MEMS Design Fall 2008

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Lecture 1: Definition and Incentives for MEMS

Instructor: Prof. Clark T.-C. Nguyen

UC Berkeley

- *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, from undergraduate to graduate
- *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 2008
- Related courses at UC Berkeley:
  - EE 143: Microfabrication Technology
  - CS 194 (EE 147): 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

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 set for Thursday, Oct. 23
    - Final Exam: Saturday, Dec. 20, 12:30-3:30 p.m.
    - Change this Final Exam time?
    - Project due date TBD (but near semester's end)

Lecture Outline

- Reading: Senturia, Chapter 1
- Lecture Topics:
  - Definitions for MEMS
  - MEMS roadmap
  - Benefits of Miniaturization
  - Examples
    - GHz micromechanical resonators
    - Chip-scale atomic clock
    - Micro gas chromatograph

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

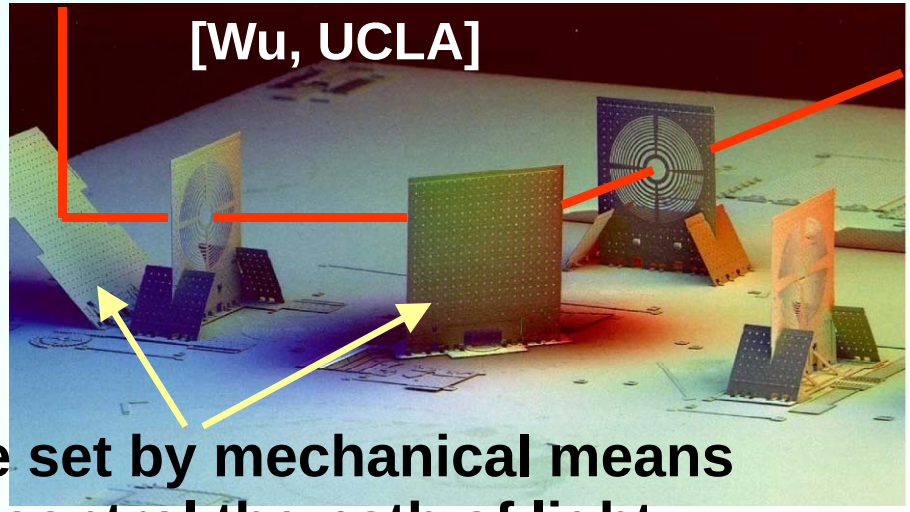
Input:
voltage, current
acceleration, velocity
light, heat …

MEMS

Output:
voltage, current
acceleration, velocity
light, heat, …

Transducer to Convert *Control* to a *Mechanical Variable* (e.g., displacement, velocity, stress, heat, …)

Control:
voltage, current
acceleration
velocity
light, heat, …

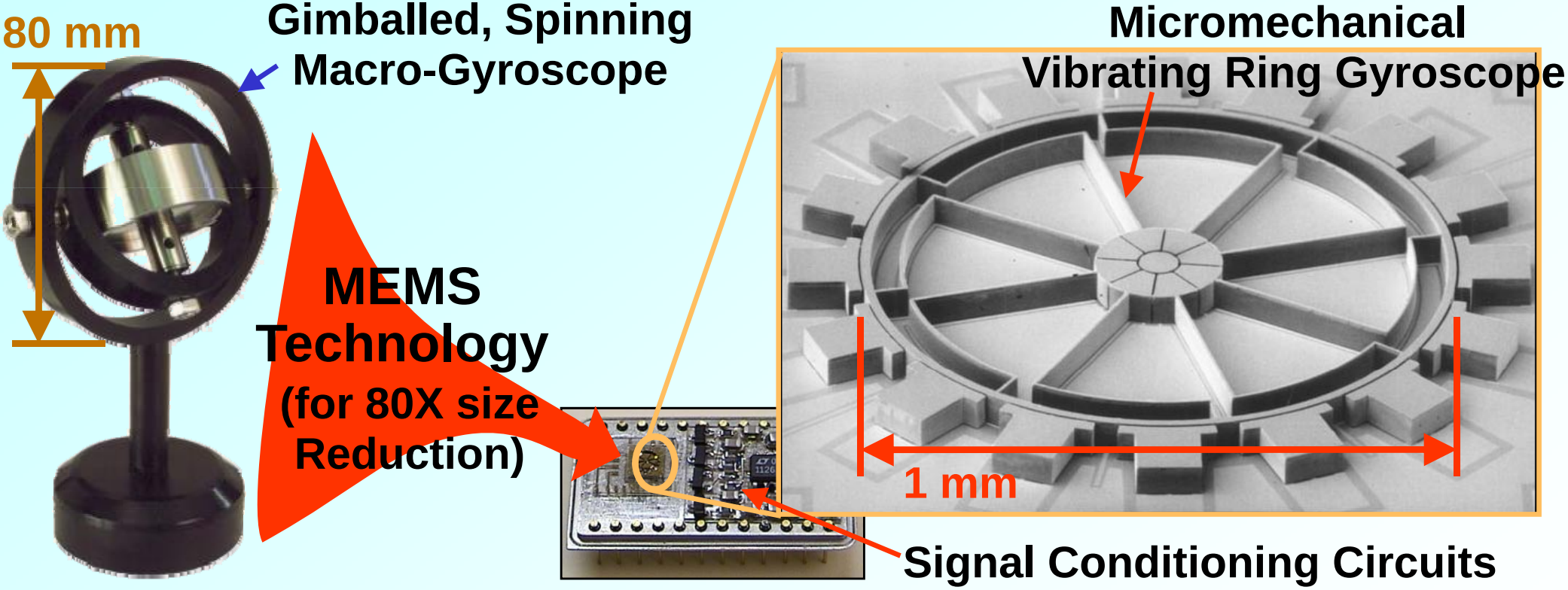


Angle set by mechanical means to control the path of light

Other Common Attributes of MEMS

- Feature sizes measured in microns or less

[Najafi, Michigan]

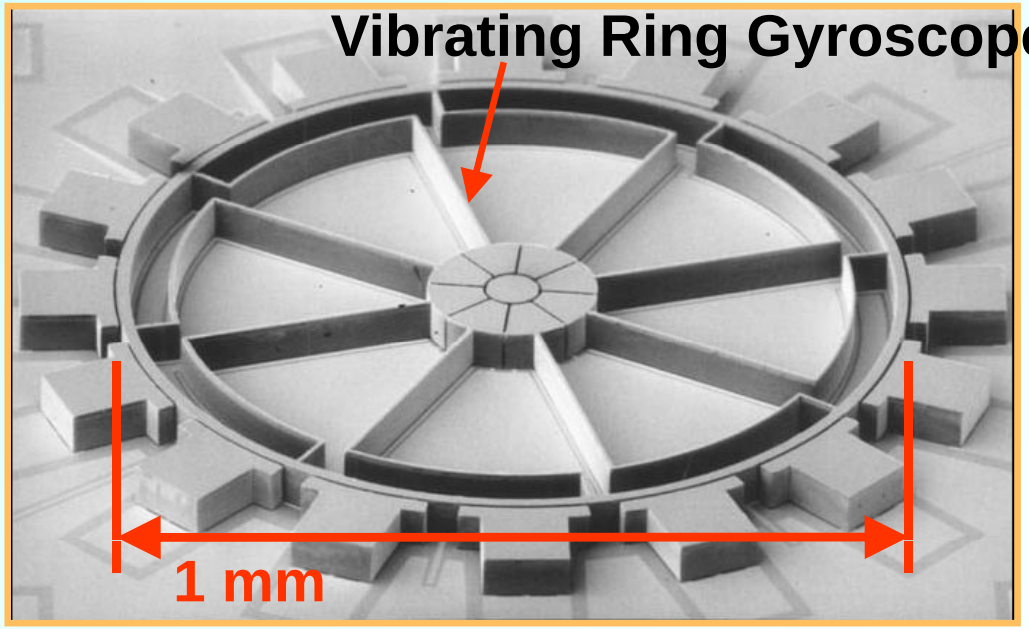


- Merges computation with sensing and actuation to change the way we perceive and control the physical world
- Planar lithographic technology often used for fabrication
  - can use fab equipment identical to those needed for IC's
  - however, some fabrication steps transcend those of conventional IC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

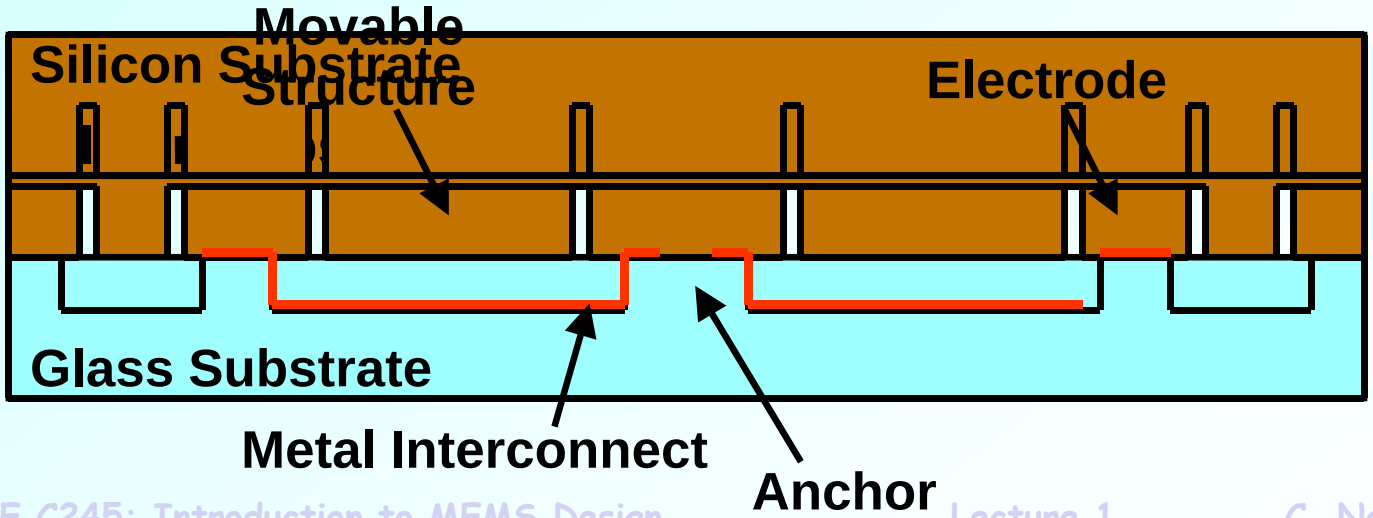
Bulk Micromachining and Bonding

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

Micromechanical Vibrating Ring Gyroscope

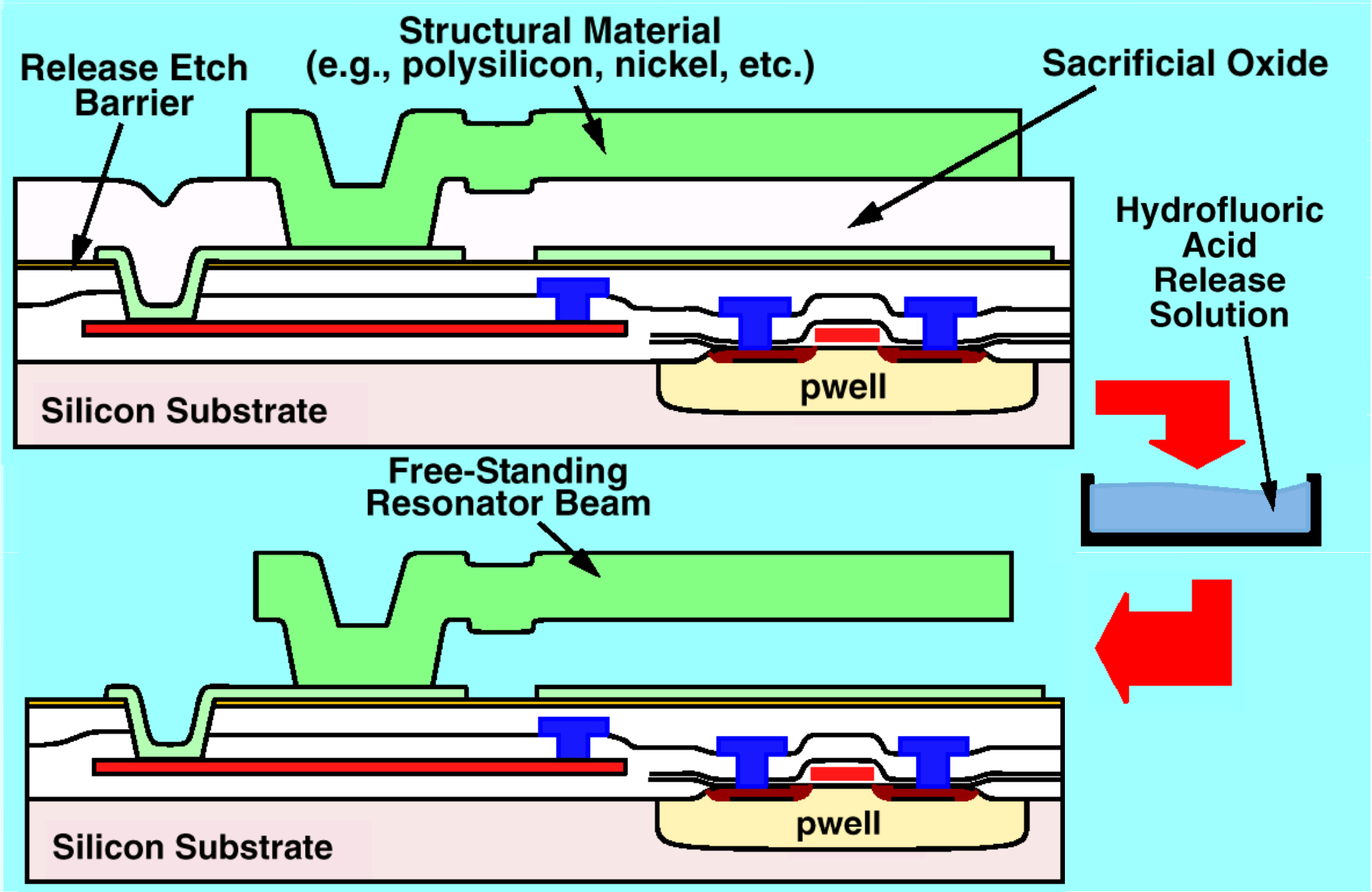


[Najafi, Michigan]



Microrotor (for a microengine)

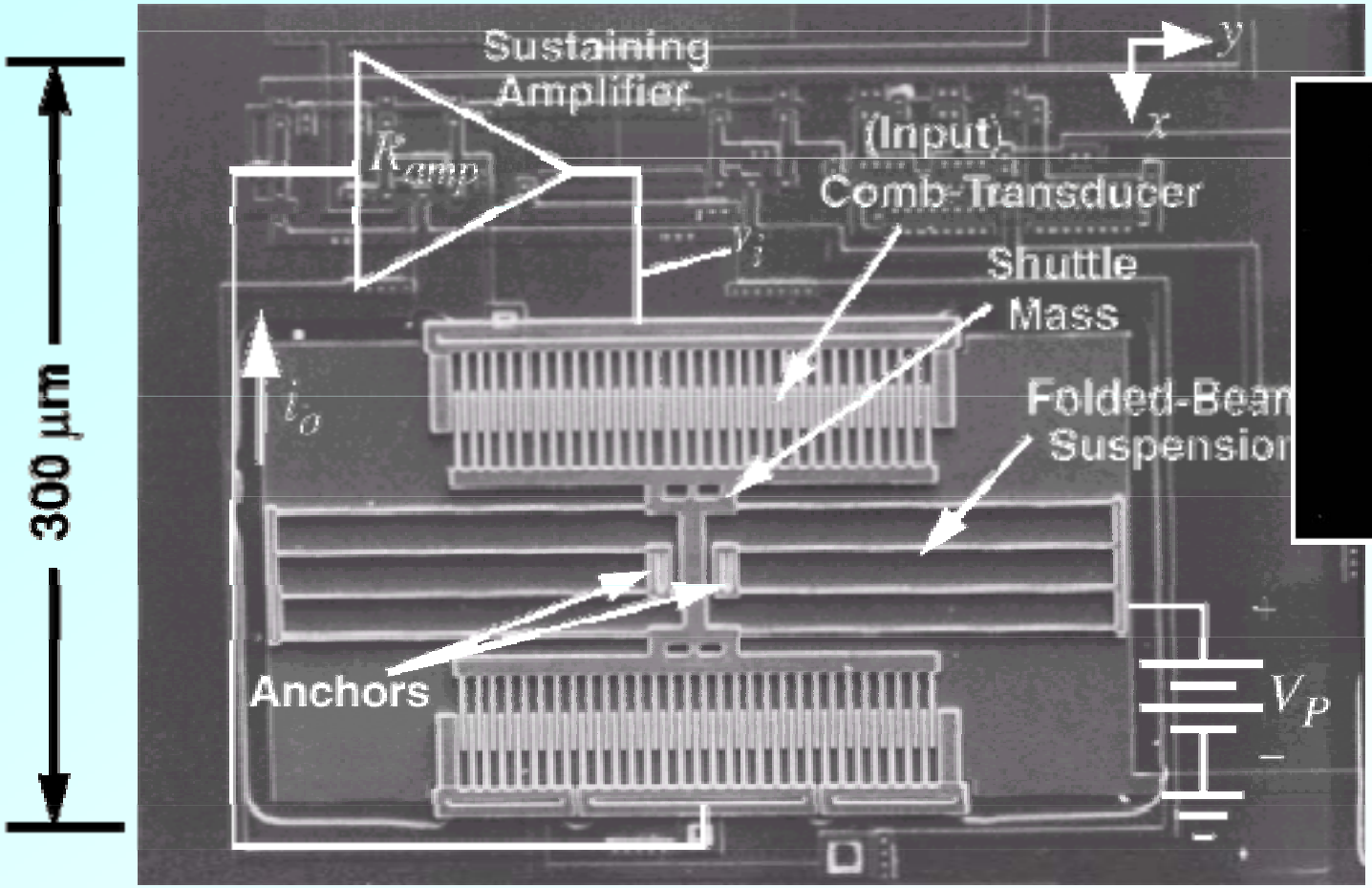
Surface Micromachining

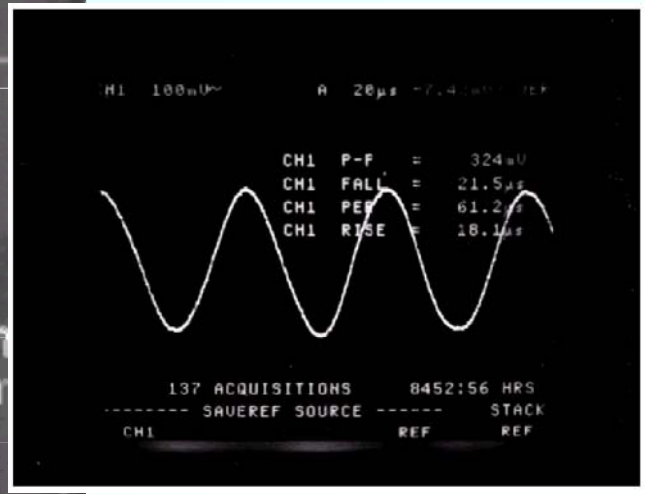


- Fabrication steps compatible with planar IC processing

Single-Chip Ckt/MEMS Integration

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



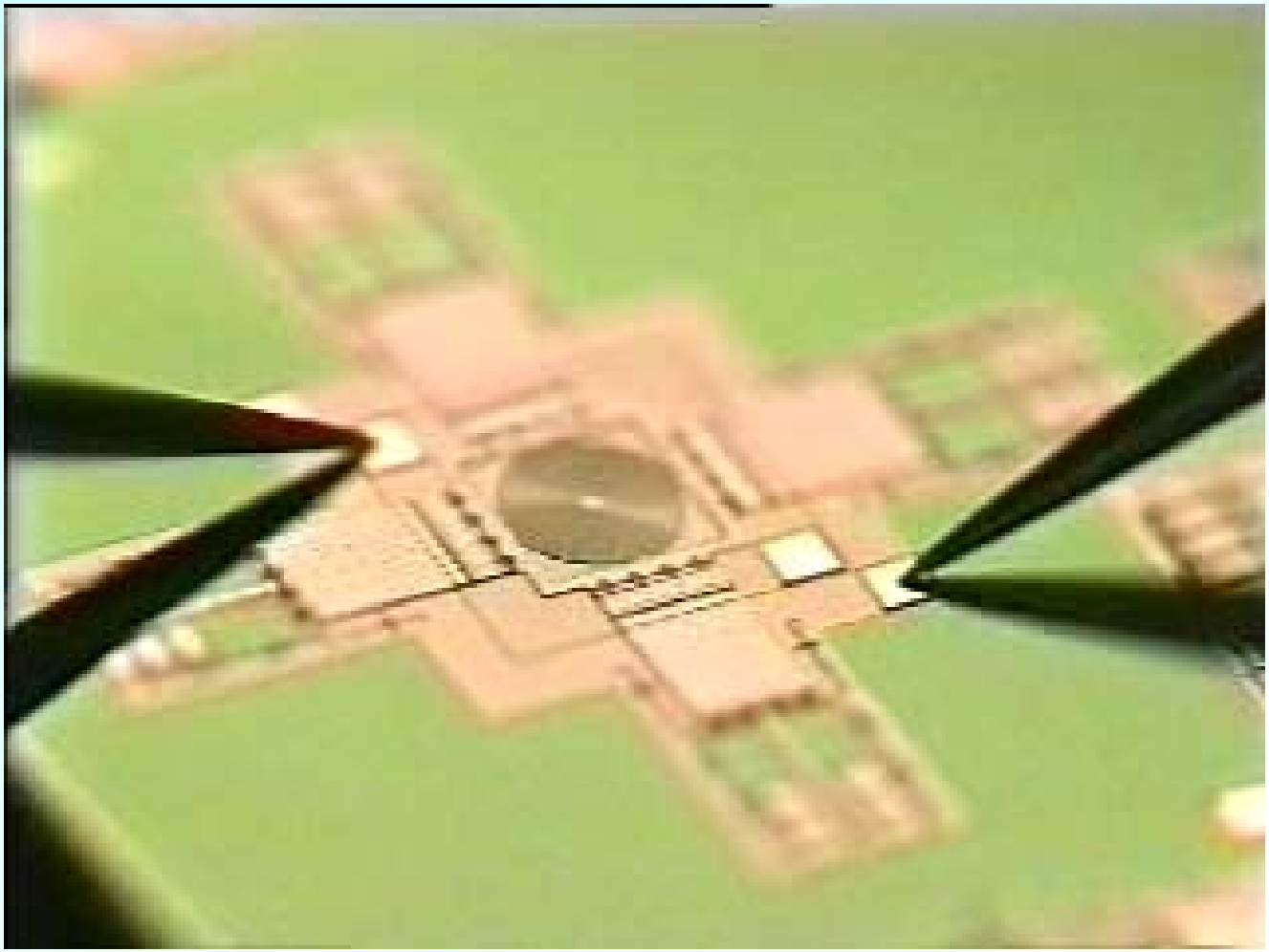


Oscilloscope Output Waveform

[Nguyen, Howe 1993]

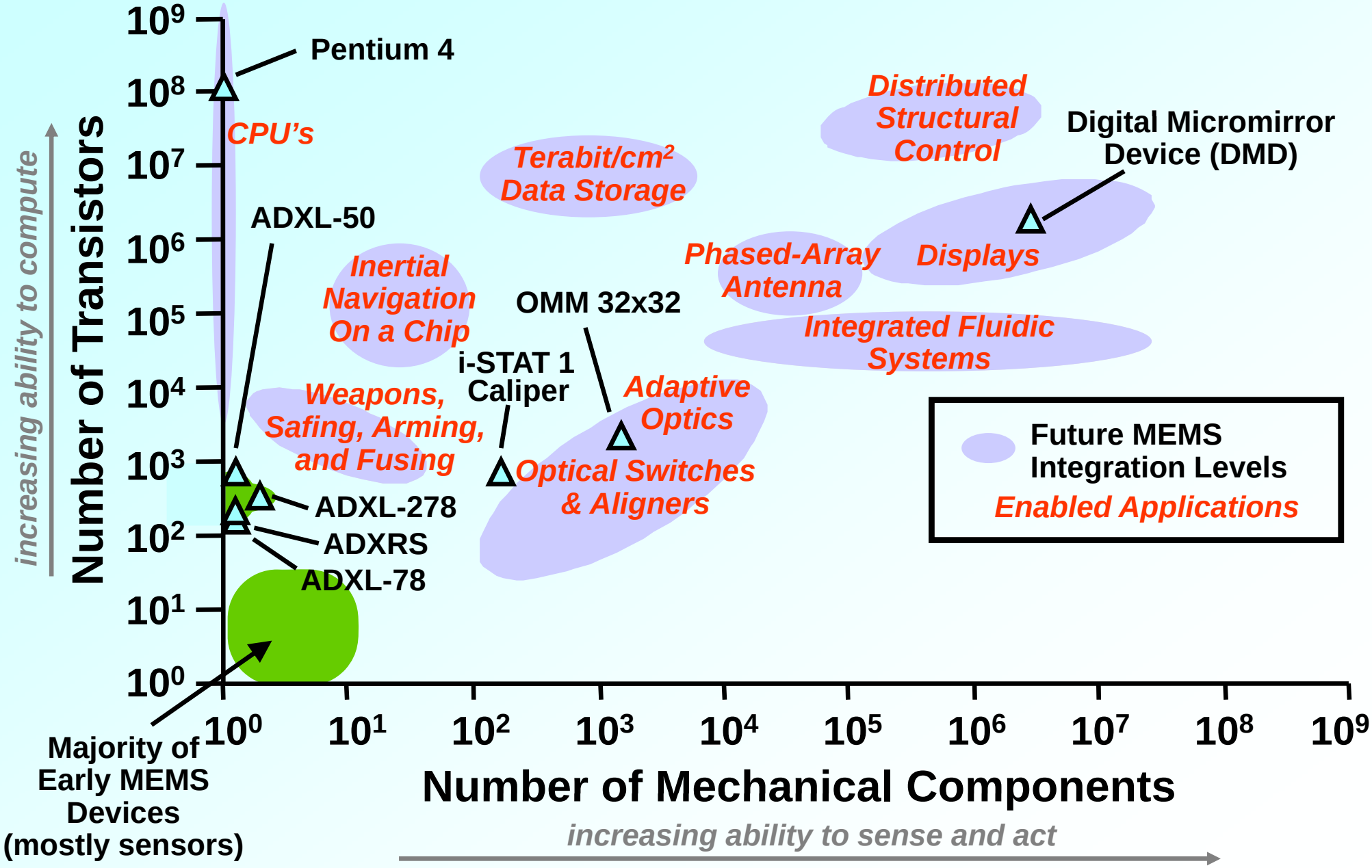
- To allow the use of >600°C processing temperatures, tungsten (instead of aluminum) is used for metallization

3D Direct-Assembled Tunable *L*



[Ming Wu, UCLA]

Technology Trend and Roadmap for MEMS



Benefits of Size Reduction: IC's

- Numerous benefits attained by scaling of transistors:

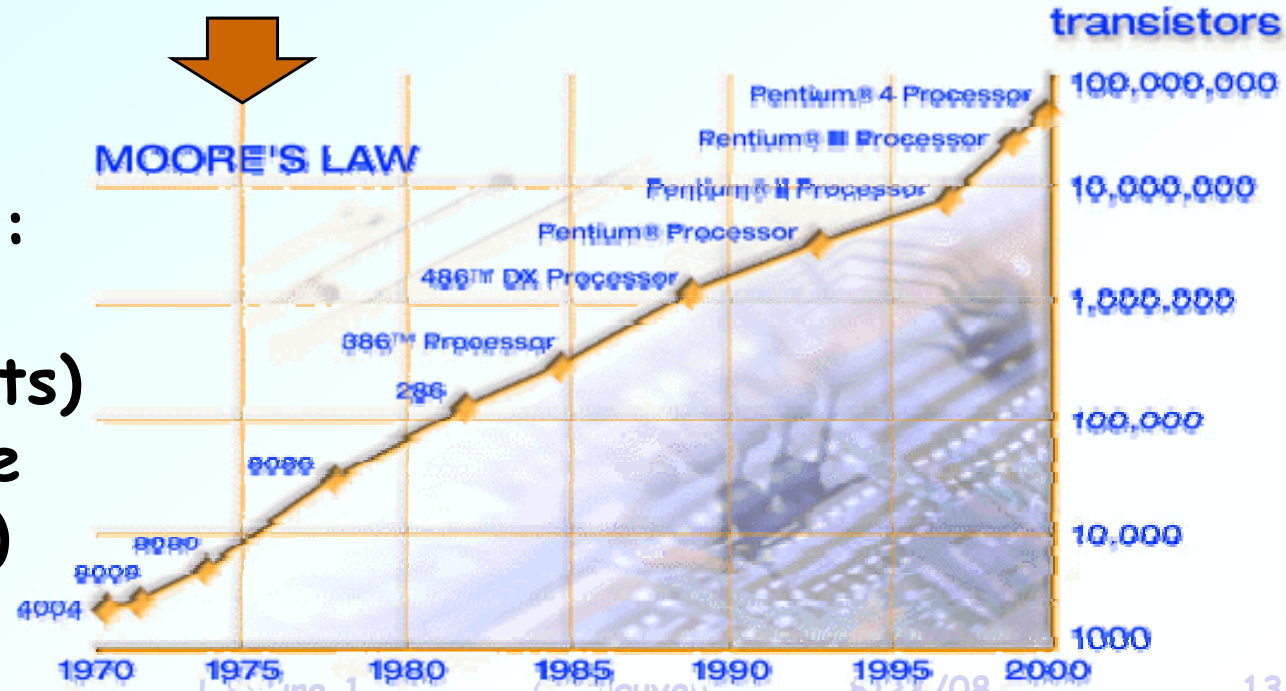
Higher Current Drive
Lower Capacitance
Higher Integration Density
Lower Supply Voltage

→ Faster Speed

→ Lower Power

Higher Circuit Complexity & Economy of Scale

- But … some drawbacks:
  - poorer reliability (e.g., hot e- effects)
  - lower dynamic range (analog ckts suffer)

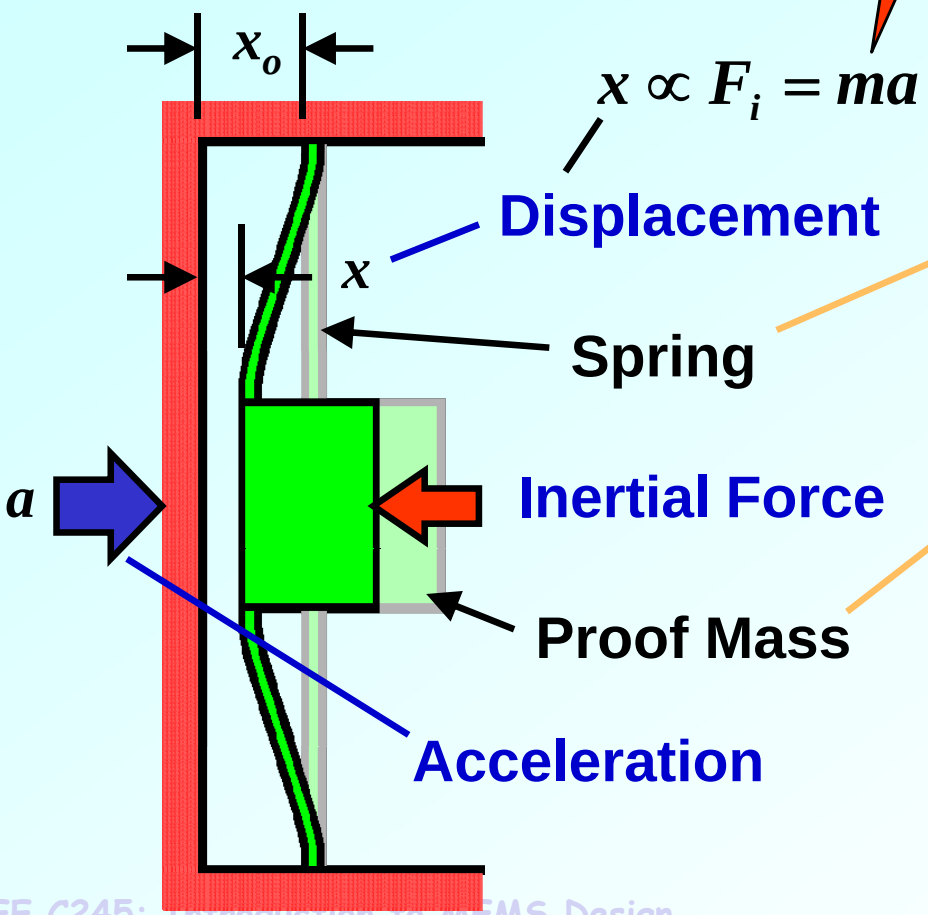


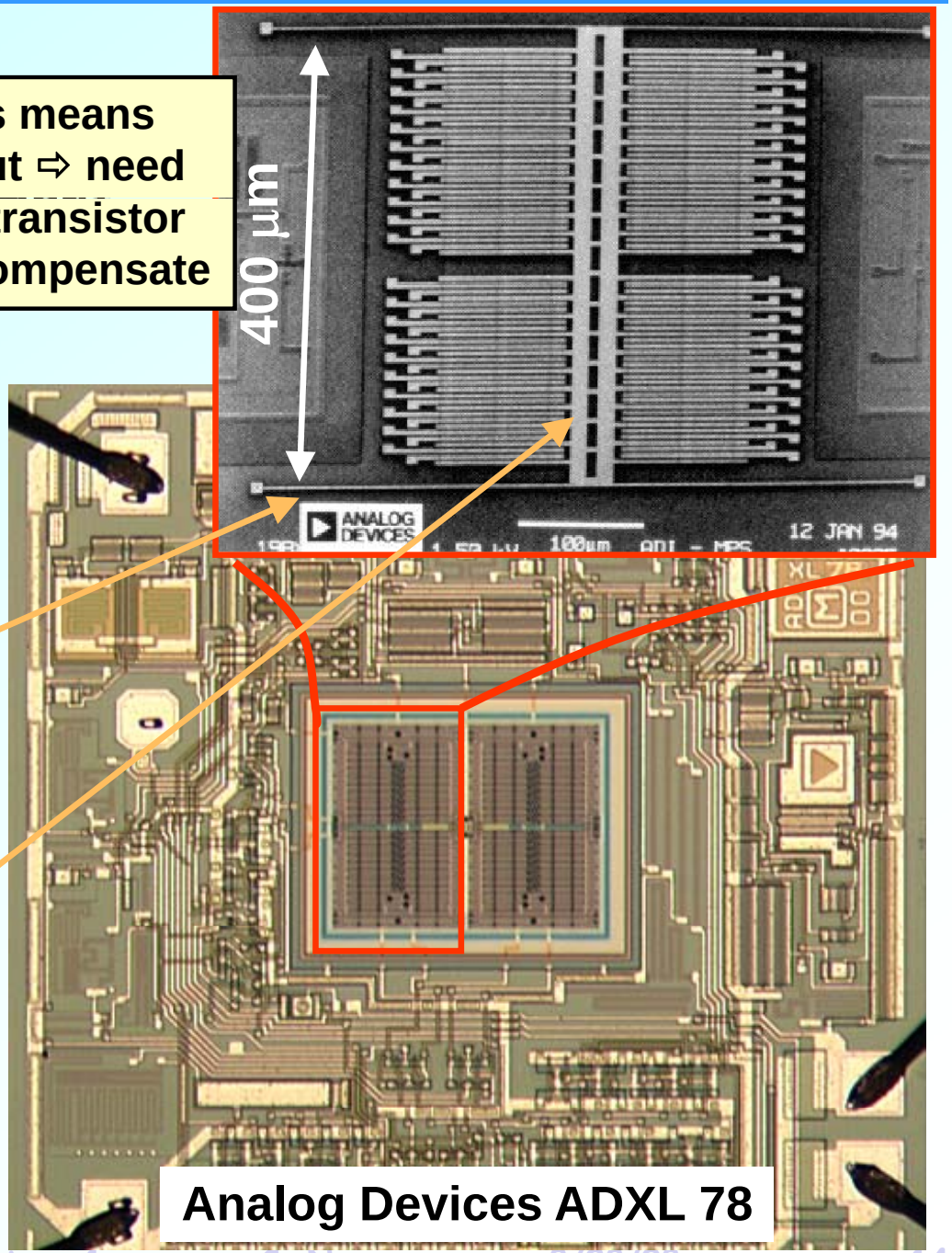
Example: Micromechanical Accelerometer

- *The MEMS Advantage:*
  - ↳ >30X size reductio
    accelerometer mec
  - ↳ allows integration w

Tiny mass means small output ⇨ need integrated transistor circuits to compensate

Basic Operation Principle





Analog Devices ADXL 78