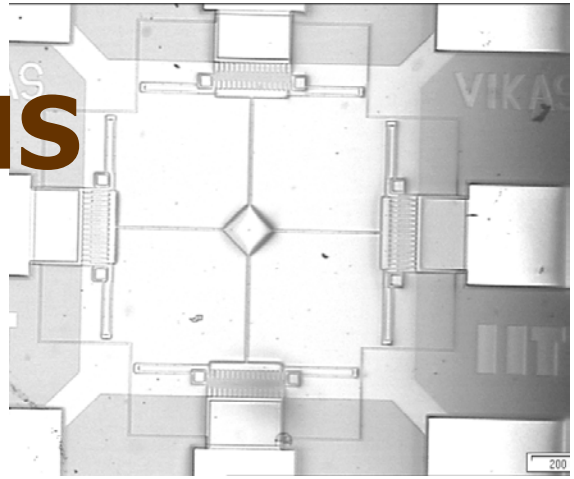
Lecture 1: MEMS Motivation



Prasanna S. Gandhi
Assistant Professor,
Department of Mechanical Engineering,
Indian Institute of Technology, Bombay,

Today's Class

- What are MEMS? Importance
  - Sense of scale
  - Day-to-day use airbag/dj printers
  - Sensors of various kinds
  - Industrial and research products
- Contents of the course
  - Fabrication: VLSI-based, nonconventional laser
  - Design and analysis
  - Characterization

What are MEMS?

- MEMS refer to miniature mechatronic systems bulk fabricated using VLSI technology
- Techniques and processes to design and create miniature systems
- Miniature embedded systems

Motivation

Why study MEMS??

MEMS benefits

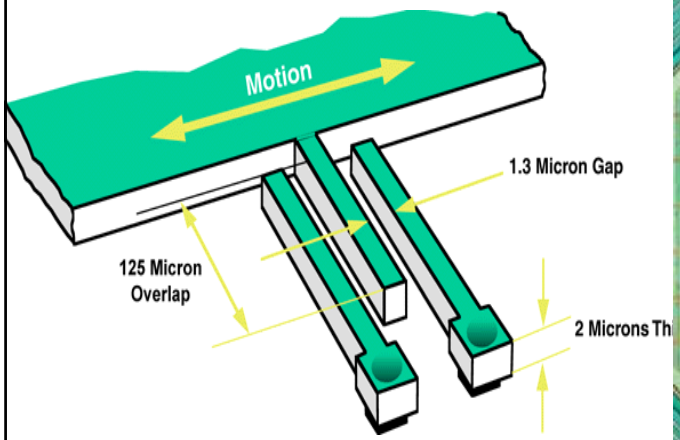
- Micro size sensors and actuators: Integration with electronics on single chip (system or lab on chip)
- Decreased cost of production: bulk processing
- Many new features and products previously unthought can be possible.
- Combination of MEMS with other branches: Example optical MEMS, Bio-MEMS → futuristic devices

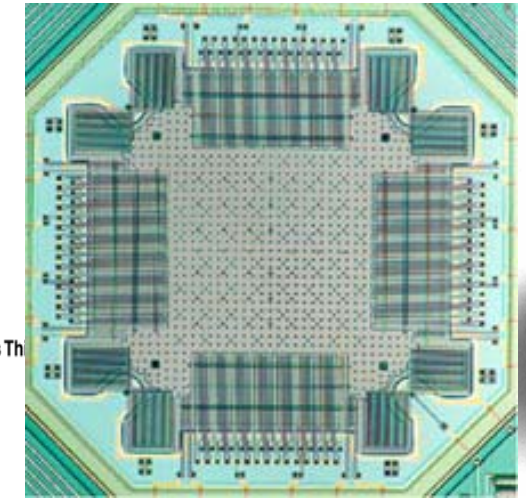
MEMS in Sensors

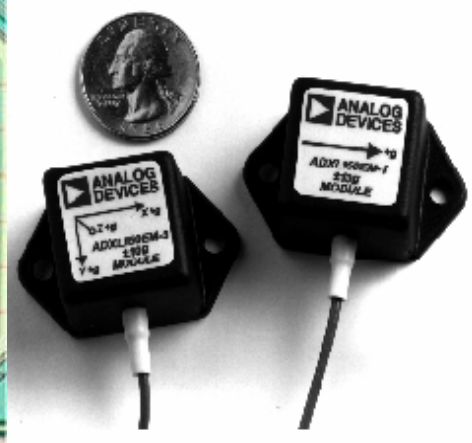
Accelerometers and Gyroscopes

-In day to day use:

Automobile accelerometers (air bag)



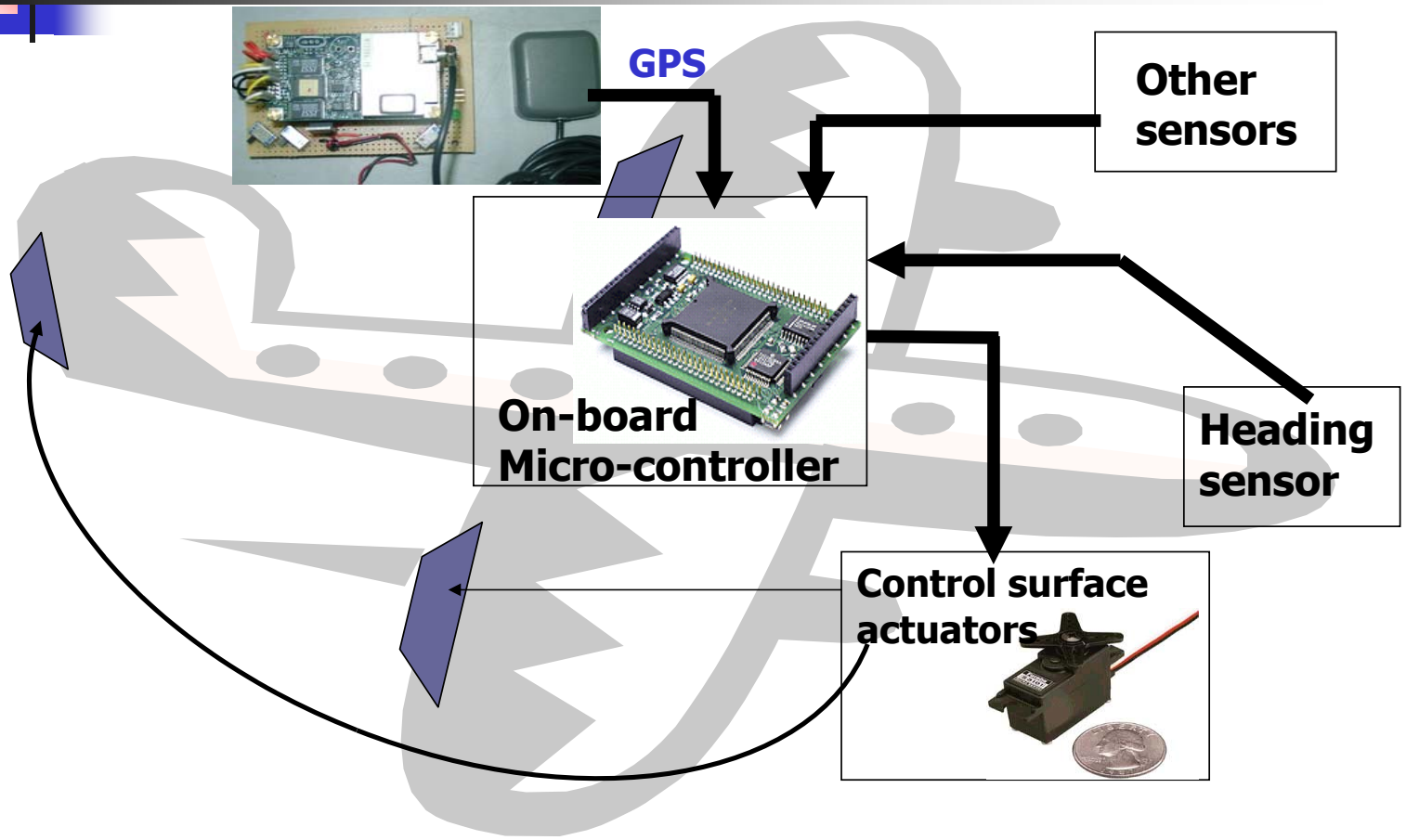




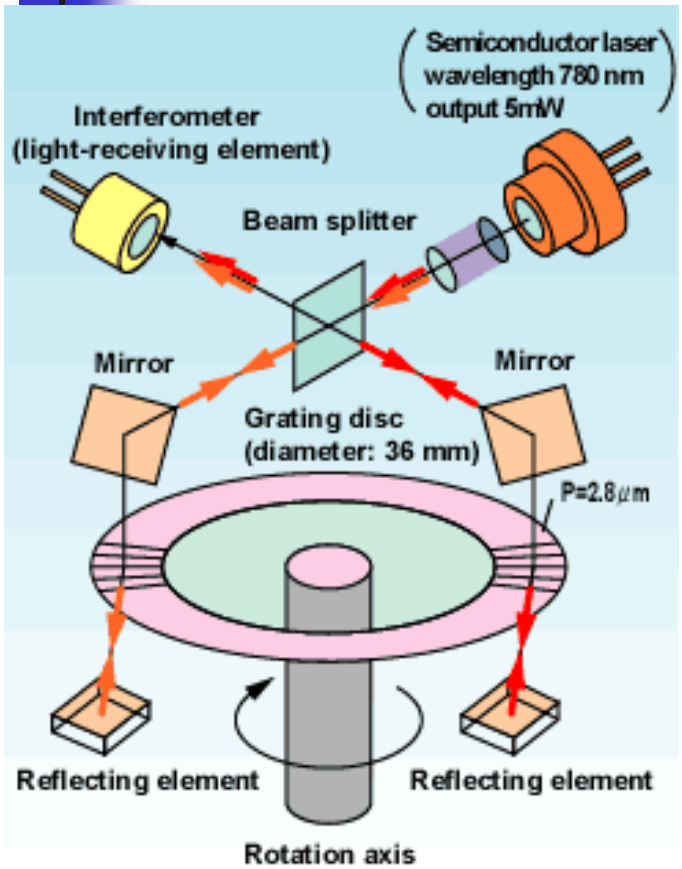
ADXL202 dual axis accelerometer

MEMS in Sensors

Autonomous airplane



MEMS in Sensors
Encoders



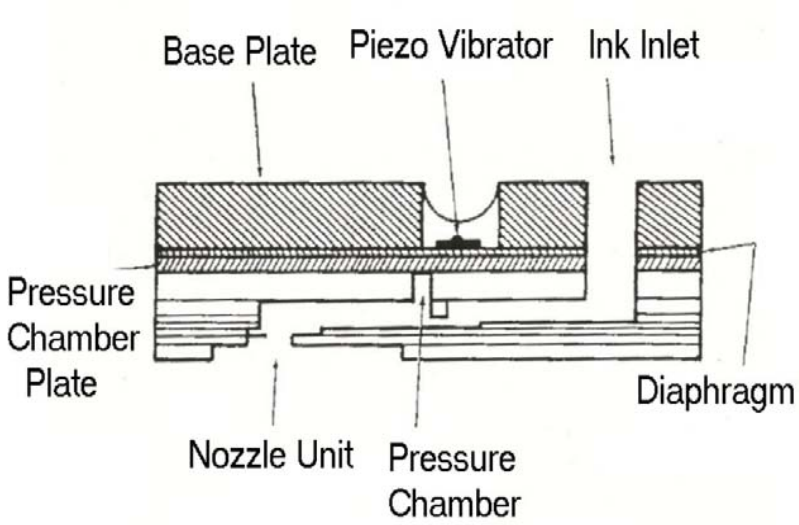
- 81,000 grating lines
- 36-mm grating disc
- Diffraction of light
- Interference to produce detection signal

MEMS in Acuators

Deskjet printer

In day to day use:

- Deskjet printer

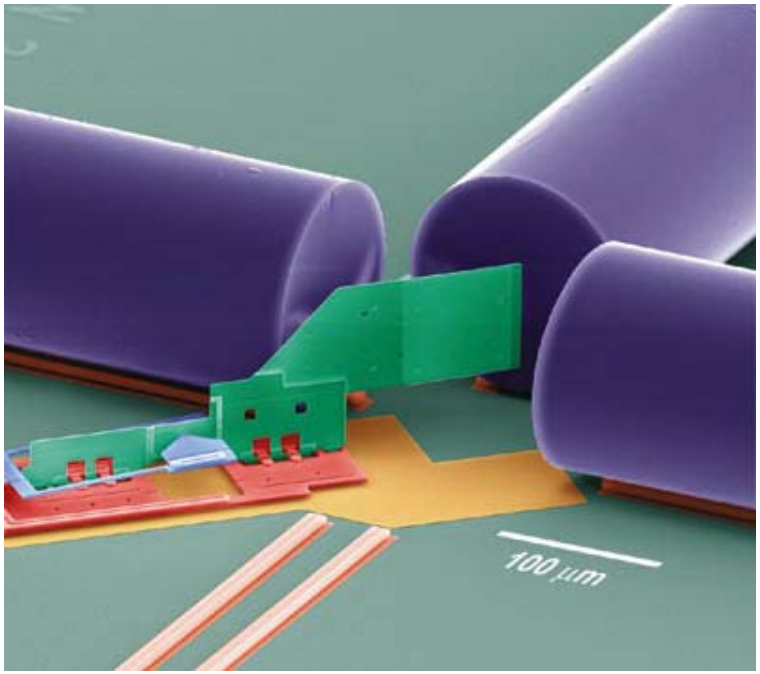


Two possible ways
-Inkjet
-Bubble jet

Nozzle on printer cartridge

MEMS in Acuators

Optical switch

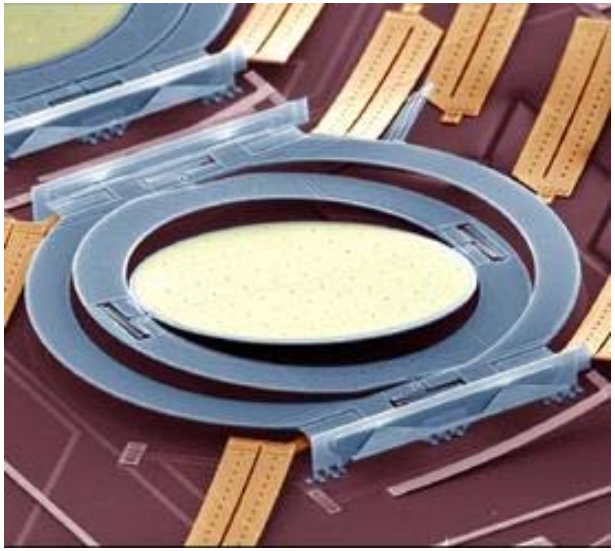


Micro-Optical Components at Bell Labs

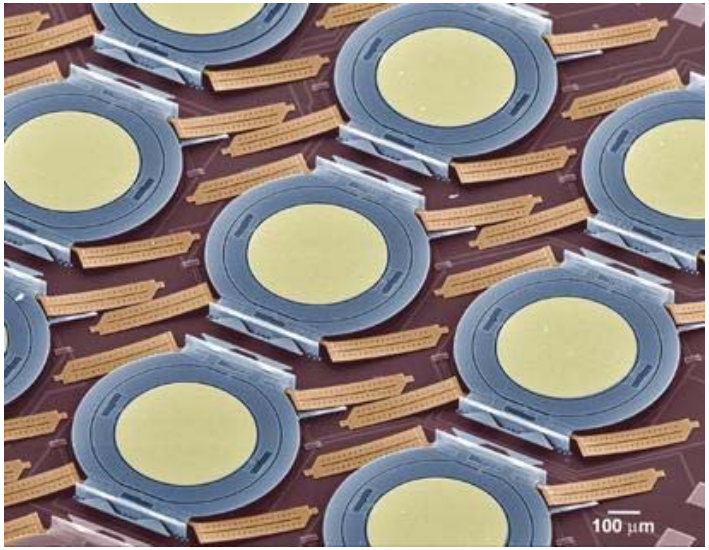
MEMS in Acuators

Actuated mirrors

- Micro-optical elements: **(reflective)**
  - **Micro-mirrors for fiber-to-fiber switching**



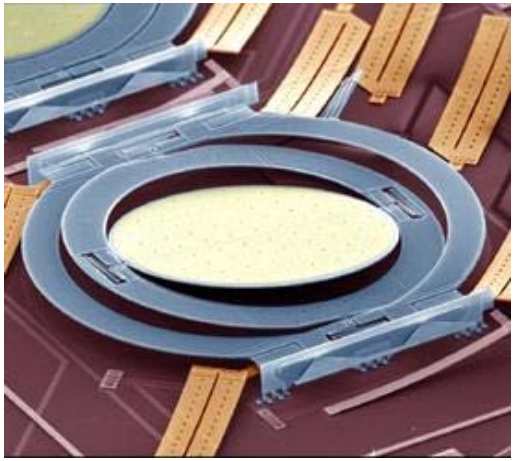
Bell Lab single-color Mirror

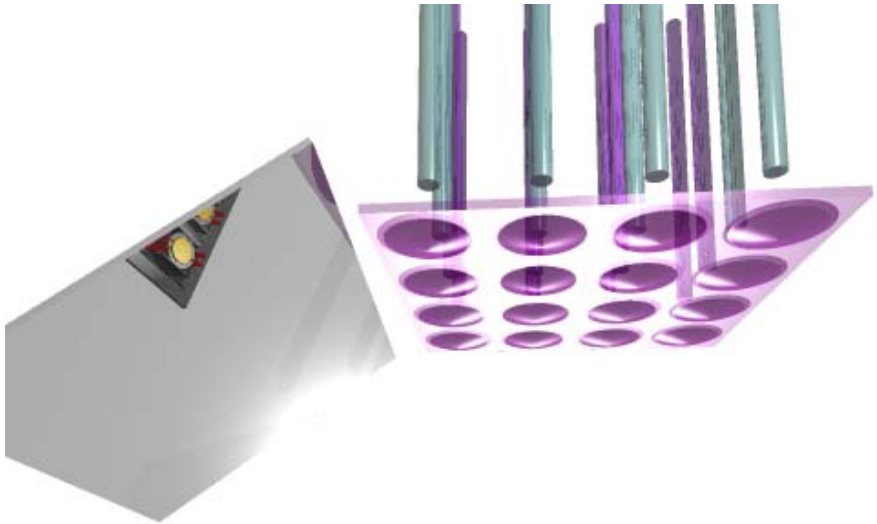


Bell Lab cross-color Mirrors

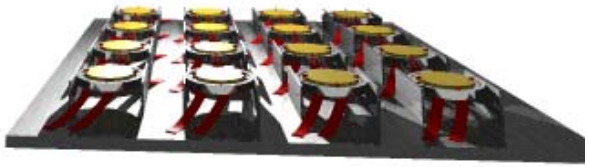
MEMS in Acuators

Actuated mirrors





Fiber, Lenses and Mirrors
4 x 4 Optical Switch

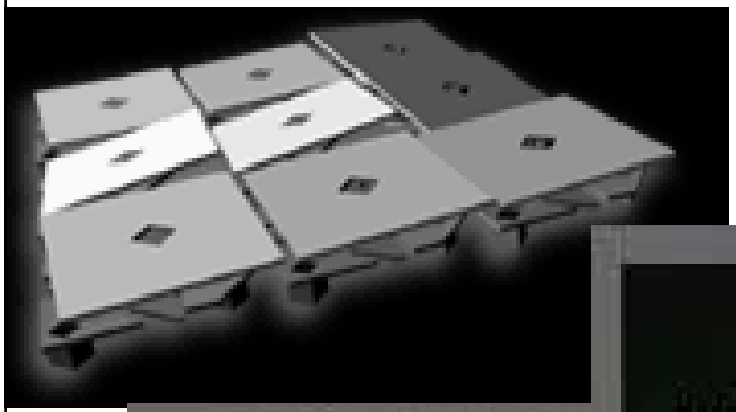


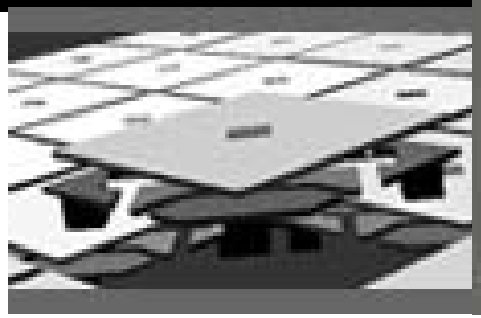
MEMS in Acuators

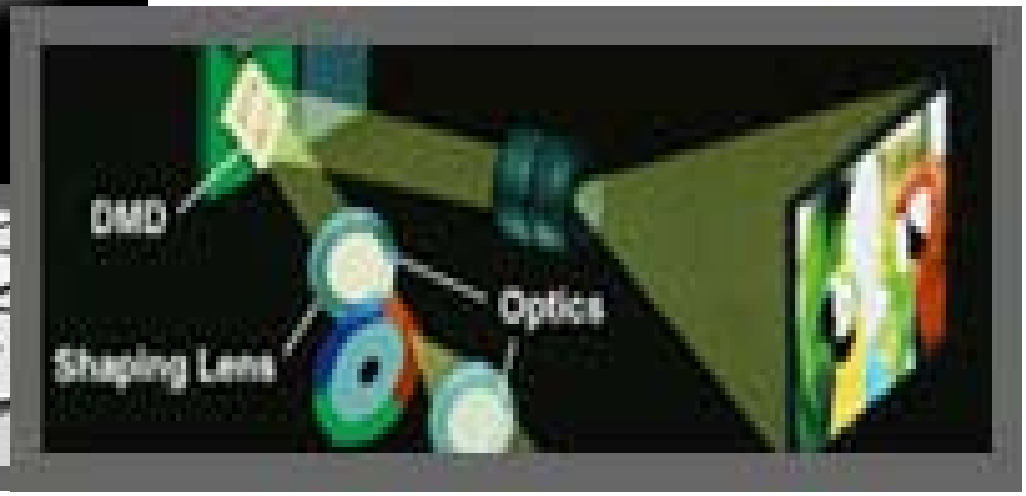
Actuated mirrors

DLP Technology

- Array of micromirrors on chip
- Applications: projection TV etc.







http://www.dlp.com/dlp_technology/dlp_technology_overview.asp

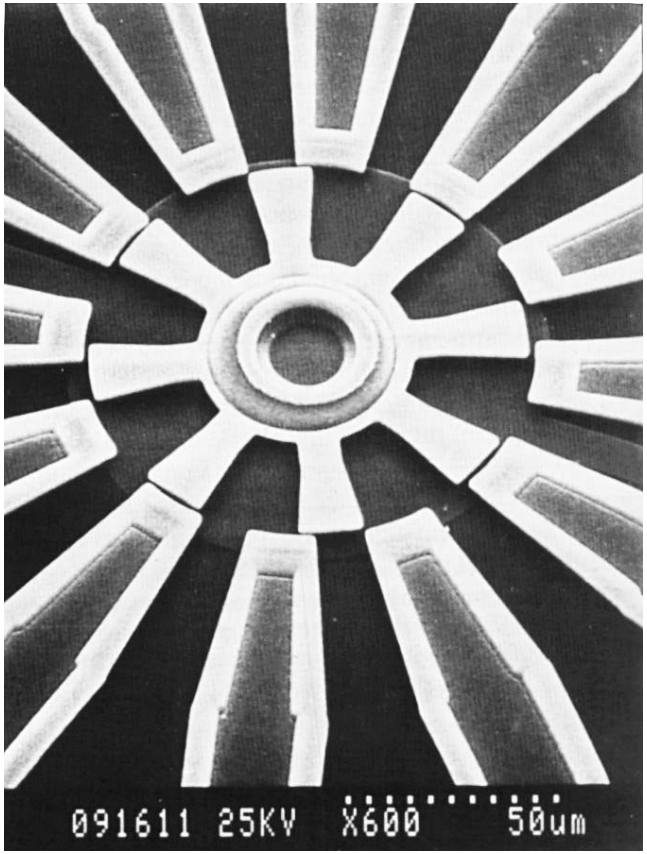
MEMS in Actuator

Micromotor

A micro-motor

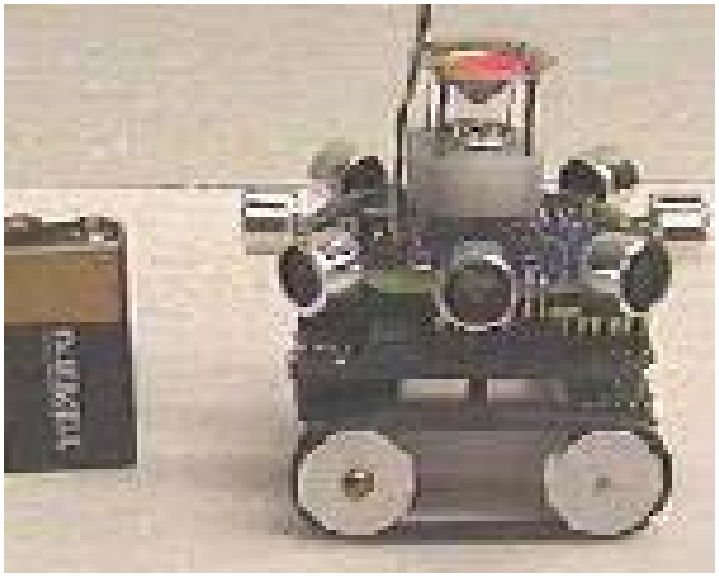
First one was made by

Mehergany at MIT

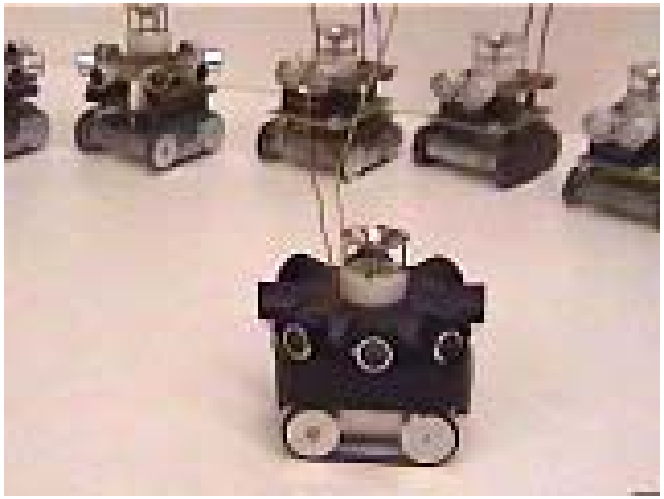


MEMS System
Millibot

- Millibots (CMU)



Millibot fleet



- Gyrover: Single wheeled robot uses gyroscope for stabilization

www-bsac.eecs.berkeley.edu

MEMS System

Capsule camera

- 240° viewing angle
- Images at rate of 2 per second
- Unit on belt to receive images
- 2-6 hr journey through intesting
- 0.4 X 1 in size
- FDA approved

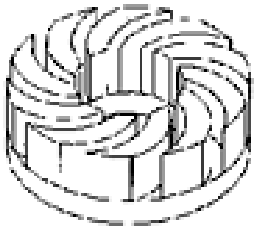
MEMS System

University of Cincinnati

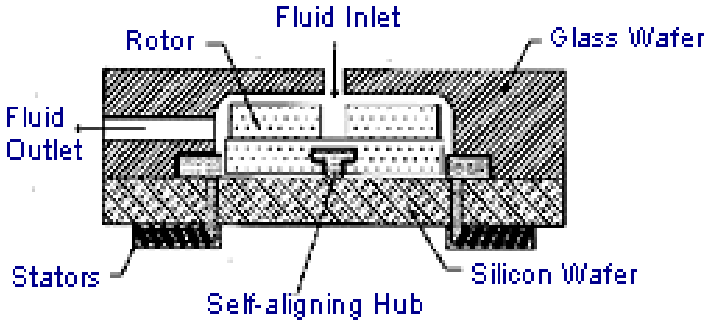
Rotary Microfans and Micropumps

- Diffusion type-pump
- Self-aligned rotors and gears
- High air flow

Application: cooling of ICs



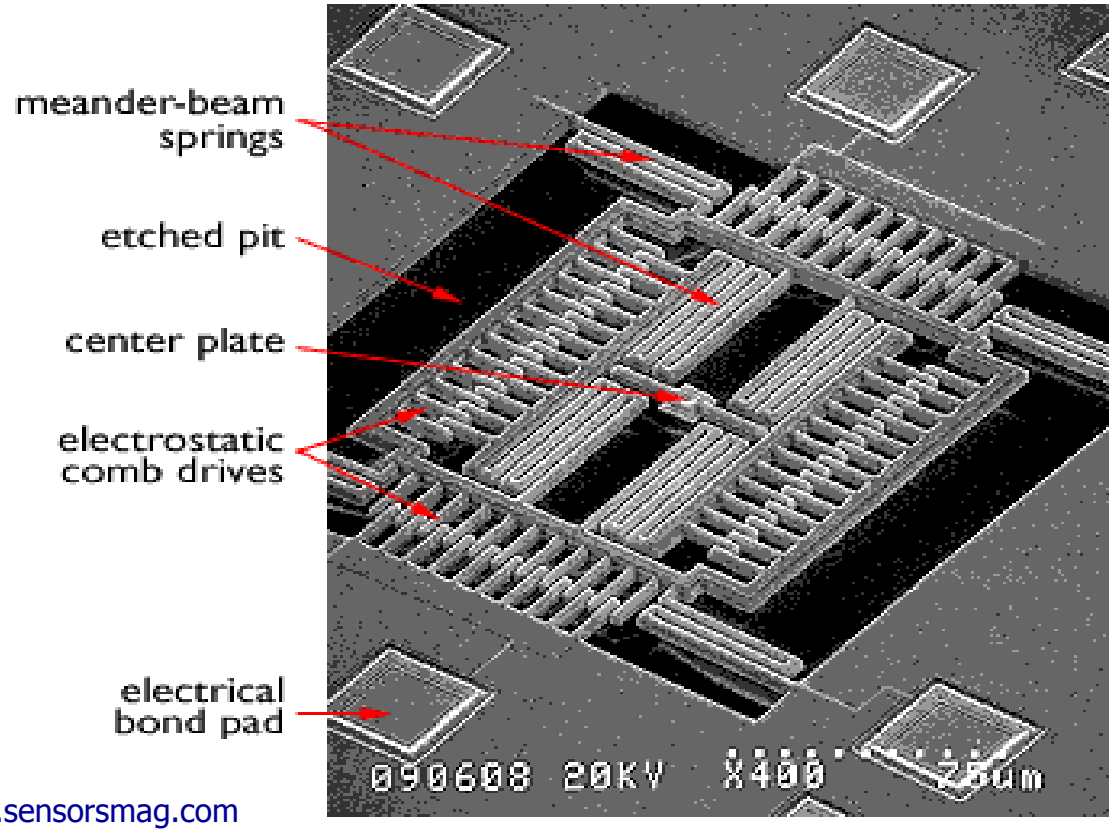
Impeller and Structures



Schematic Diagram

Micro-actuators

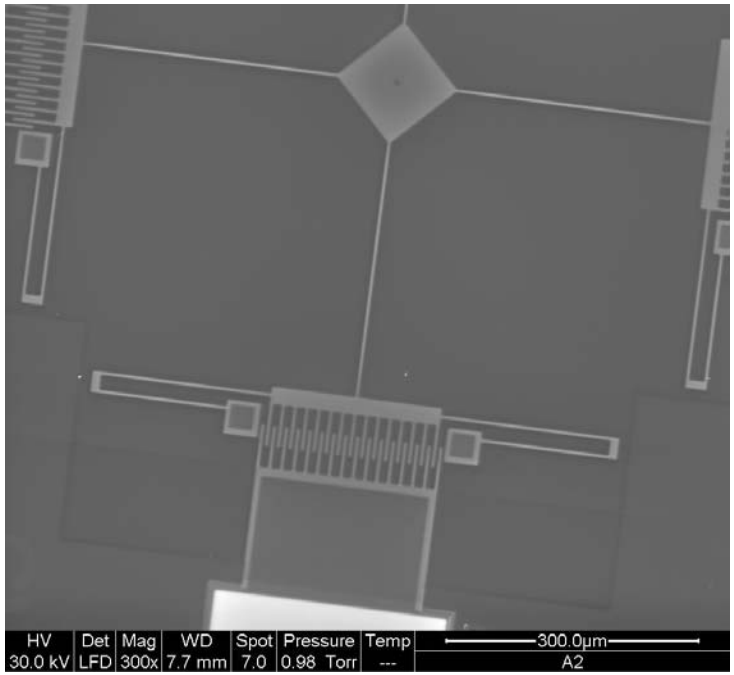
- Comb Drive

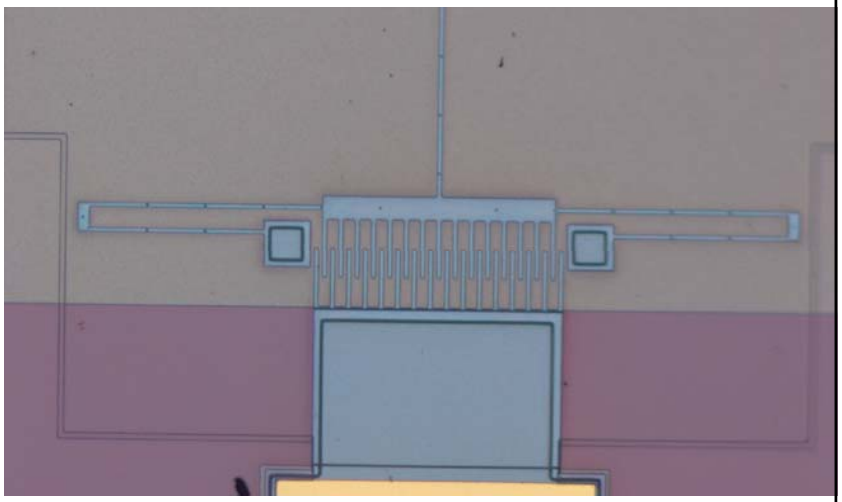


www.sensorsmag.com

Micro-actuators

- Comb Drive





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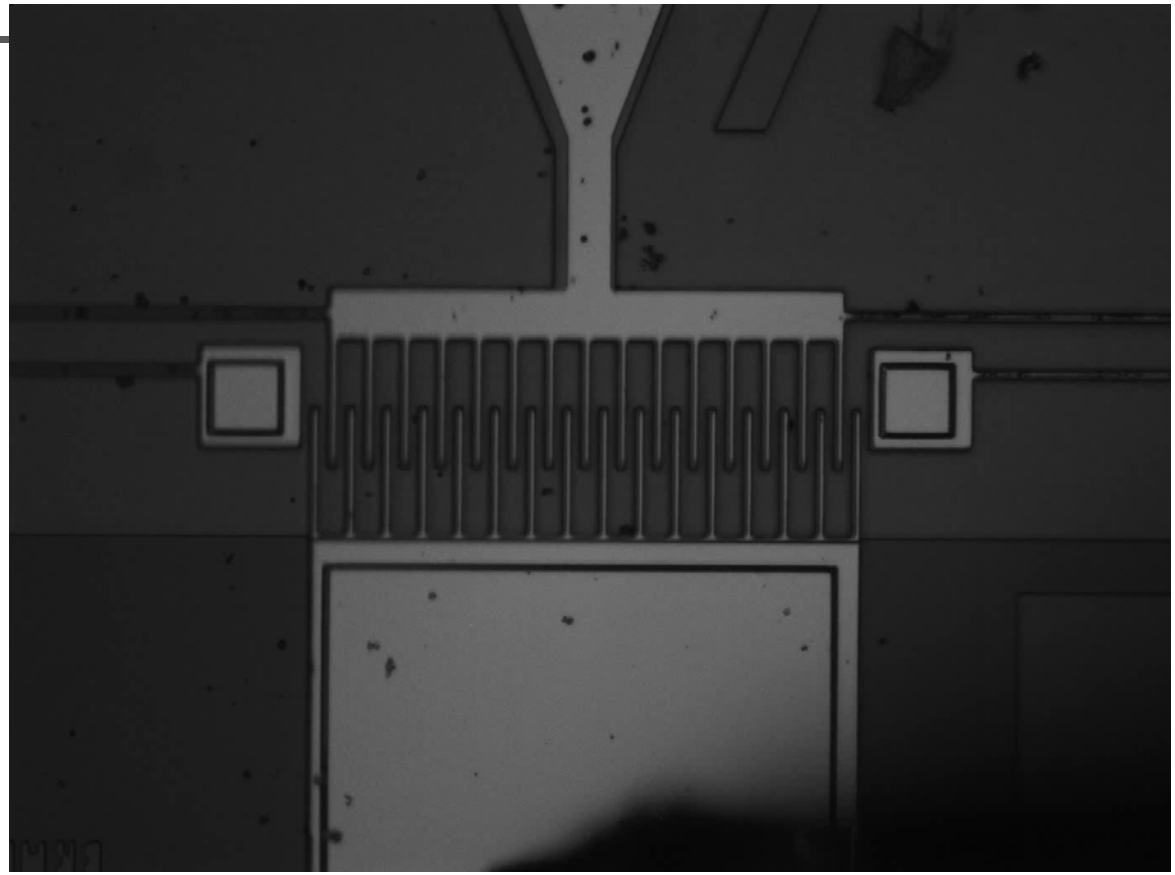
Micro-actuators

- Comb Drive



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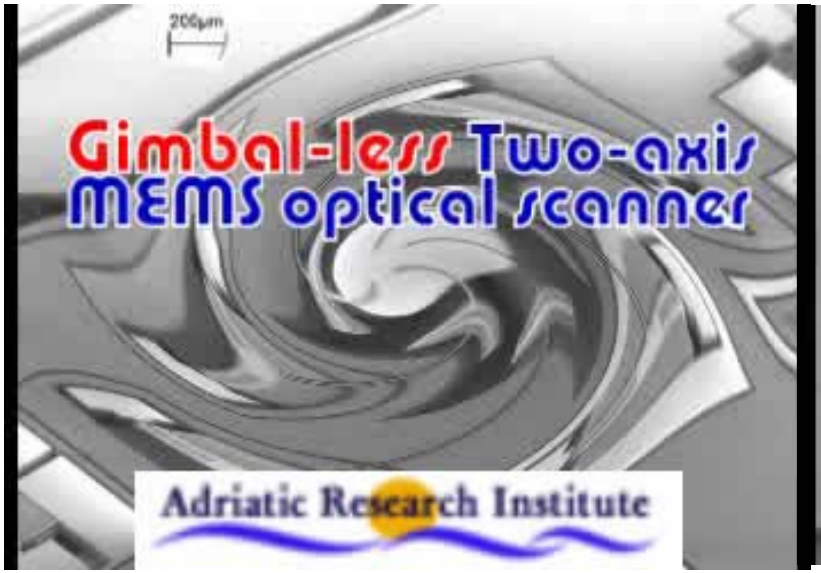
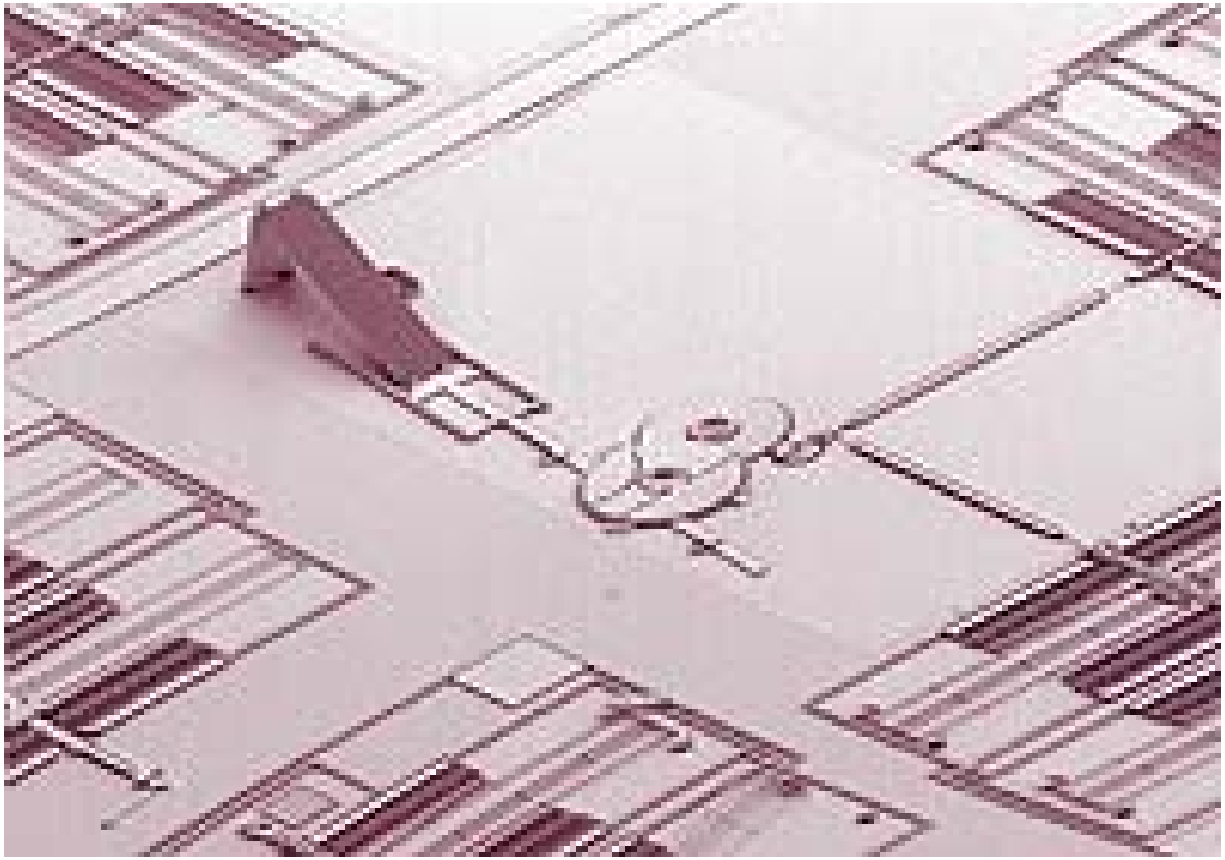
Micro-mirrors

- Comb Drive



Micro-actuators

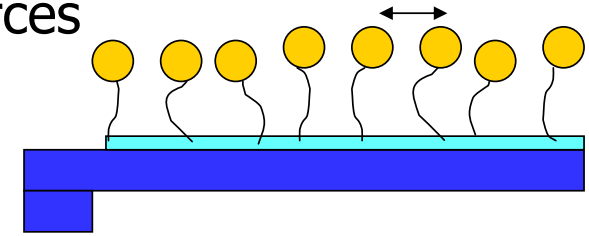
Comb drive operating gears



Bio-MEMS Sensor

Cantilever based

- Concept: cantilever structure with antigen
- Effects:
  - Change in mass
  - Deflection due to repulsive forces
- Detection of bacteria by
  - Optical
  - Capacitive
  - Other techniques like resonance freq.



Walking Micro-Robots

load500mg

- Silicon microrobot
  - High load capacity
  - Heatuator
  - Principle of operation
  - Arraying
  - Steering concept

More MEMS devices

- Other micro-sensors:
  - Pressure sensor
  - Vibrating gyroscope
  - Bio-MEMS sensors: DNA c
- Micro actuators
  - Comb actuators, micro-mo
  - Thermal actuators
  - Piezo-actuators
- Micro-gears, micro-engines
- Micro-fluidic systems: drug delivery: smart pill
- Grating light valve (GLV display)
- Digital optical switches

And many more
Yet to come…

Course Contents

- Introduction to MEMS: Motivation, history and current status
- MEMS: Fabrication
  - Conventional MEMS fabrication using VLSI technology
  - Nonconventional fabrication

Materials for MEMS

Other materials

- Polycrystalline silicon (polysilicon)
- Silicon dioxide (SiO_2)
- Silicon nitride (Si_3N_4)
- Aluminum (thin film)
- Gold (thin film)
- Many more including polymers now a days

- Doping of silicon

Conventional (VLSI) Fabrication processes

- Lithography: patterning
- Chemical etching
  - Isotropic
  - Anisotropic
- Plasma etching: RIE

Material removal

- Oxidation
- Sputtering
- Chemical vapor deposition (CVD)
- Electroplating

Material deposition

- Surface micromachining
- LIGA

Nonconventional Microfabrication

- Laser micromachining and welding, processing of metals and nonmetals with laser
- Electro Discharge and Electro Chemical micromachining (EDM and ECM)
- Microstereolithography: scanning process, dynamic mask process
- Electronic packaging

MEMS: Design and Analysis

- Basic concepts of design of MEMS devices and processes.
- Design for fabrication, other design considerations
- MEM systems theoretic analysis
- Analysis of MEMS devices: FEM and Multiphysics analysis in continuum domain, Modeling and simulation
- Statistical methods
- Molecular dynamics

MEMS: Characterization

- Technologies for MEMS characterization: Scanning Probe Microscopy (SPM)
  - Atomic Force Microscopy (AFM)
  - Scanning Tunneling microscopy (STM)
  - Magnetic Force Microscopy (MFM)
- Scanning Electron Microscope (SEM)
- Laser Doppler Vibrometer
- Electronic Speckle Interference Pattern technology (ESPI)

Text & References

- Nadim Maluf, "An Introduction to Microelectromechanical Systems Engineering," Artech House, Boston, 2000.
- Stephen D. Senturia, "Microsystems Design," Kluwer Academic Publishers, New York, November 2000
- S. M. Sze, "VLSI Technology," McGraw-Hill International Editions, Singapore, 1988.
- M.Elwenspoek and H. Jansen, "Silicon Micromachining," Cambridge University Press, Cambridge, UK, 1998.
- Norio Taniguchi, editor "Nanotechnology," Oxford University Press, Oxford, UK, 2003.
- Joseph McGeough, editor "Micromachining of Engineering Materials," Marcel Dekker, Inc., New York, 2002.
- Marc Madou, "Fundamentals of Microfabrication: The science of miniaturization," CRC Press, LLC, 2002.

Demonstration of Practical Samples

- Deskjet printer cartridge
- Accelerometer chips
- Microcantilevers
- CD ROM technology

MEMS Journals

- Applied Physics Letters
- International Frequency Sensor Association (IFSA) Newsletter
- Journal of Applied Physics
- Journal of Lightwave Technology
- Journal of MEMS
- Journal of Microlithography, Microfabrication and Microsystems
- Journal of Micromechanics and Microengineering
- Journal of Selected topics in Quantum Electronics
- MicroTAS (Micro Total Analysis Systems) Journal
- Sensors and Actuators A (Physical)
- Sensors and Actuators B (Chemical)

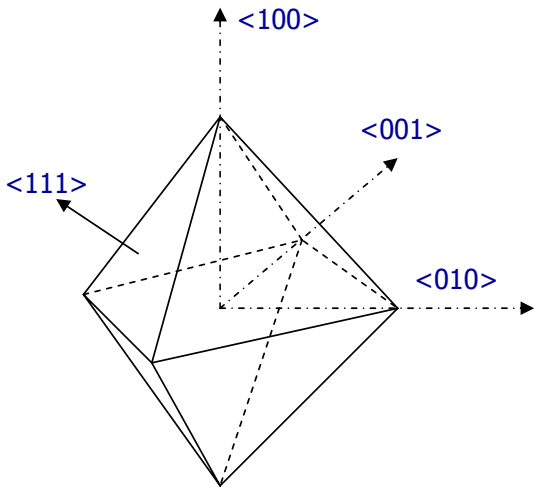
MEMS Laboratories

- Microelectronics Gruop, IIT Bombay
- Suman Mashruwala Micoengineering Lab, IIT Bombay
- Berkeley Sensor & Actuator Center (BSAC)
- Center for Applied Microtechnology (CAM)
- Center for MEMS and Microsystems Technologies @ Georgia Tech
- Center for MicroElectronic Sensors and MEMS @ University of Cincinnati
- Center for NanoTechnology @ University of Wisconsin, Madison
- Center for Wireless Integrated Microsystems @ University of Michigan
- Laboratory for Physical Sciences @ University of Maryland
- MEMS Laboratory @ CMU
- Microsystems Technology Laboratories @ MIT
- Microfabrication Lab @ UC Berkeley
- Micromachining Lab @ Caltech
- Micro Structures and Sensors Lab @ Stanford
- Transducers Lab @ Stanford

MEMS Industries

- Aclara Biosciences
- Analog Devices, Inc.
- Caliper Technology
- Cepheid
- Coventor, Inc.
- Cronos Integrated Microsystems, Inc.
- Draper Laboratories
- IMEC
- Integrated Sensing Systems Inc.(ISSYS)
- Intellisense (Corning)
- Northrop Grumman Corporation
- Orchid BioSciences, Inc.
- Redwood Microsystems
- Surface Technology Systems, Ltd. (STS)
- TRW NovaSensor Online
- Zyvex

Materials for MEMS



Silicon crystal orientation

- Silicon
  - Stronger than steel
  - Light as Aluminum
  - Can be coated with varieties of materials
- Available in form of wafers 2”, 4”, 8”, 12” dia
- Other materials