Lecture 1: MEMS
Motivation

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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

Copyright 1995-2003 Analog Devices, Inc.
MEMS in Sensors
Autonomous airplane

- GPS
- Other sensors
- On-board Micro-controller
- Heading sensor
- Control surface actuators
- MEMS in Sensors

Other sensors

On-board Micro-controller

Heading sensor

Control surface actuators

GPS
MEMS in Sensors

Encoders

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

Deskjet printer

In day to day use:
- Deskjet printer

Two possible ways
- Inkjet
- Bubble jet

Nozzle on printer cartridge
MEMS in Actuators
Optical switch

Micro-Optical Components at Bell Labs
MEMS in Actuators
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

Center for Microelectronic Sensors and MEMS (CMSM)
Micro-actuators

- Comb Drive

www.sensorsmag.com
Micro-actuators

- Comb Drive
Micro-actuators

- Comb Drive
Micro-mirrors

- Comb Drive

Gimbal-less Two-axis MEMS optical scanner

800 um x 800 um actuator element for high fill-factor arrays

Adriatic Research Institute
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

- 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 chips, "lab on chip"
- Micro actuators
  - Comb actuators, micro-motors
  - 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 ($\text{SiO}_2$)
- Silicon nitride ($\text{Si}_3\text{N}_4$)
- 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
- Oxidation
- Sputtering
- Chemical vapor deposition (CVD)
- Electroplating
- 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)
Course outline

Text & References

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 Group, IIT Bombay
- Suman Mashruwala Microengineering 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
- Zywex
Materials for MEMS

- 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