Lecture 1

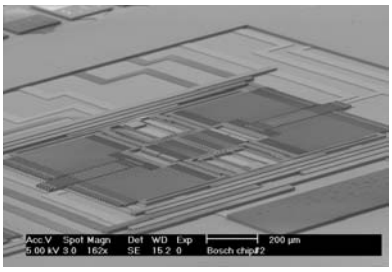
Introduction of MEMS and Microsystem

- What are they?
  - Several Common Features
- How are they made?
  - Integrated Circuit Fabrication
  - Deposition and Etching
  - Surface Modification and Patterning
- What are they made of?
  - Materials for Microfabrication
- How are they designed?
- Markets for Microsystems and MEMS
- Case Studies

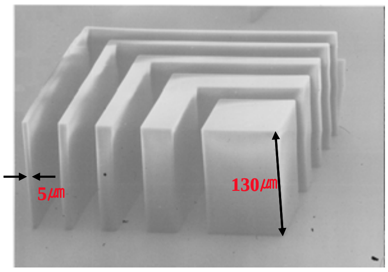
What are they?

MEMS: Microelectromechanical systems in US
Microsystems in Europe

MEMS or Microsystems are “very small systems” or “systems made of very small components”.



Vibrating Micro Gyroscope



Thick PR mold for Electroplating

Several Common Features

1. MEMS involve both electronic and non-electronic elements, and perform functions that can include signal acquisition, signal processing, actuation, display, and control. They can also serve as vehicles for performing chemical and biochemical reactions and assays.

2. MEMS are "systems", which means that important system issues such as packaging, system partitioning into components, calibration, signal-to-noise ratio, stability, and reliability must be confronted.

(continued)

Several Common Features

3. The most successful MEMS have been those which involve paradigm shifts from the "macro" way of doing things, more than simply reducing the size scale. Examples: ink-jet print head, thin-film magnetic disk heads, silicon pressure sensors and silicon and quartz sensors for the measurement of acceleration and rotation. Microfluidic devices are beginning to enable astonishing improvements in the speed of biochemical analysis.

4. Some MEMS involve large arrays of microfabricated elements. Examples: uncooled infrared imaging devices and both reflective and refractive projection devices.

How are they made?

- The batch fabrication offers the potential for great cost reduction when manufacturing in high volume.
- Silicon is often used even when there are no electronic components in the device because the tools and instruments needed for microfabrication are designed to match the characteristics of silicon wafers.
- Lithography offers in-plane sub-micron precision on dimensional scales from micron to millimeter. Thin-sub-micron precision on etching techniques in combination with wafer-bonding techniques allow patterning of the third dimension, making possible the creation of movable parts.

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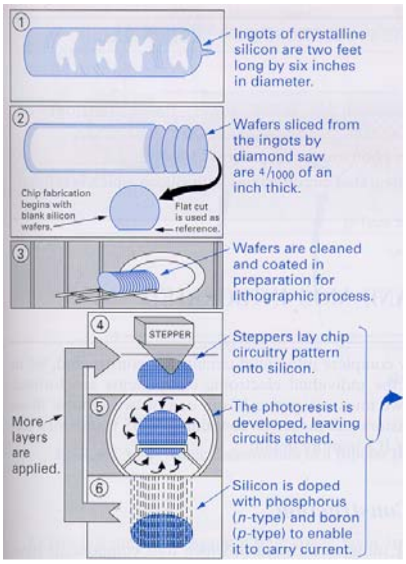
Integrated Circuit Fabrication



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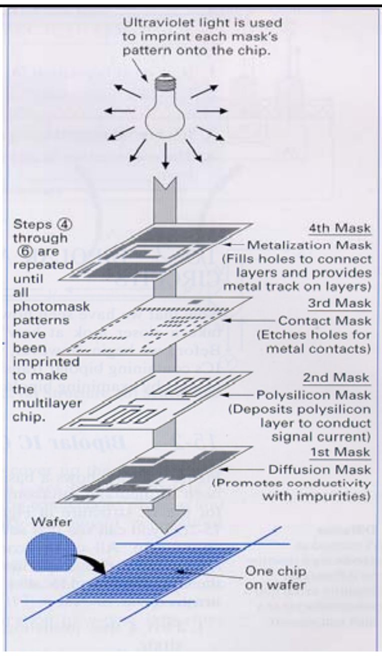
Integrated Circuit Fabrication



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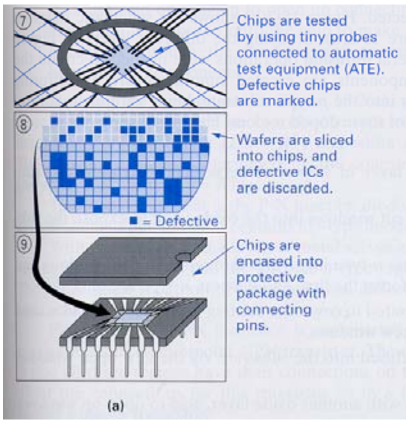
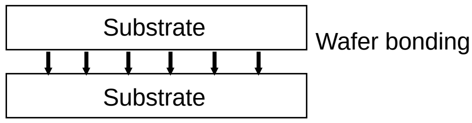
Integrated Circuit Fabrication

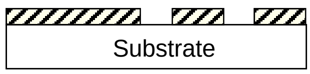


Deposition and Etching

- Deposition and Bonding (Evaporation, Sputtering, CVD, Bonding)

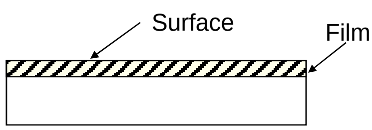


- Etching (Dry etching, Wet etching)

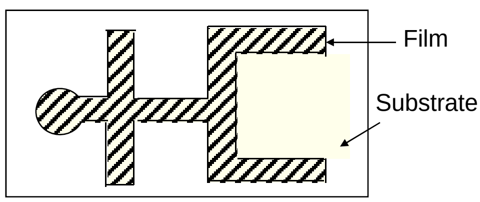


Surface Modification and Patterning

- Surface modification (Annealing, Phase change, Hydrophobic or Hydrophilic)



- Patterning (Photolithography, Laser machining, Electrodischarge, Mechanical machining)

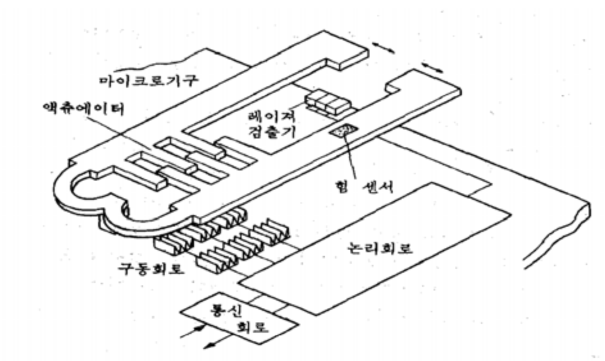


Overview

How are they made?

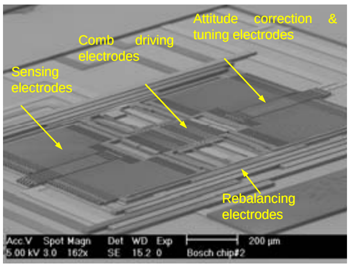
- New fabrication methods provide additional freedom to sculpt more general three-dimensional structures, but these have not yet entered high-volume manufacturing.
- There is an almost reflexive urge to make fully integrated microsystems, *i.e.,* integrated circuits that include mechanical of other non-electronic elements on the silicon chip along with the electronic part of system.
- An alternate strategy is to partition the microsystem into subsystems that are fabricated separately, then assembled into a compact system during the packaging operation.
- It is clear that the system architecture and its partitioning into components have an enormous impact on the details of how the system is built.

Fully Integrated Microsystem

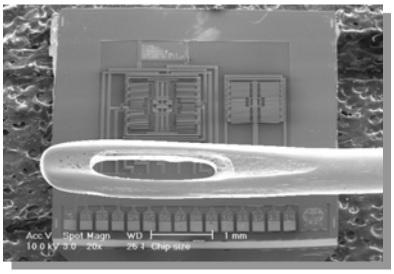


Schematic drawing of fully integrated microsystem

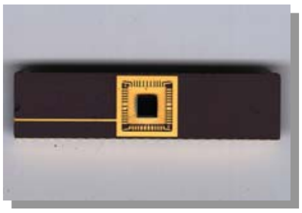
Partitioning into Components



Fabricated microgyroscope



Sensor die with needle's eye



CDIP packaged microgyroscope chip

What are they made of?

- The choice of materials in a microsystem is determined by microfabrication constraints.
- Most IC are inorganic materials (silicon, silicon dioxide, silicon nitride, aluminum, and tungsten), although certain polymers are used well.
- Microfabrication opens up a much broader range of materials and a corresponding set of additional techniques such as electroplating of metals, and molding and embossing of plastics.

(continued)

Materials for Microfabrication

명 칭	용 도	제작 방법	특 징
실리콘	구조재	반도체소자 제조공정	논리회로와 집적화 가능
다결정실리콘	구조재	반도체소자 제조공정	고농도 B 첨가 실리콘 막 사이
실리콘질화막	윤활막	반도체소자 제조공정	절연재
실리콘산화막	희생층	반도체소자 제조공정	실리콘 질화막 사이
PSG (Phospho Silicate Glass)	희생층	반도체소자 제조공정	다결정 실리콘 막 사이, 실리콘 질화막과 실리콘 기판 사이
텅스텐	구조재	반도체소자 제조공정	HF에 녹지않고 연성이 있음
몰리브덴	구조재	반도체소자 제조공정	연성이 있음

(continued)

Materials for Microfabrication

명 칭	용 도	제작 방법	특 징
Ni, Cu, Au	구조재	전해도금, LIGA	전해도금
NiFe	구조재	전해도금	자성 재료
고분자재료	구조재	주물성형	전해도금, LIGA로 제작하는 금속구조물의 몰드로 사용
폴리이미드	구조재	회전 도포	후막 제작 가능, 유연함
Photo Resist	희생층	회전 도포	Lift-off 법 사용
Al	구조, 희생	진공 증착	구조재, 희생층으로 사용
Quartz	기능 재료	이방성 식각	압전성, 절연재
ZnO	기능 재료	반도체소자 제조공정	압전성
PZT	기능 재료	후막 공정	압전성
TiNi	기능 재료	반도체소자 제조공정	형상기억합금

What are they made of?

- Since the performance of MEMS devices depends on the constitutive properties of the materials from which they are made, the increased diversity of material choices carries with it a requirement for measurement and documentation of their properties.
- Many of these materials are used in thin-film form, and it is well known that thin-film properties can differ from bulk properties.
- The elastic modulus or residual stress of a suspended beam, must be monitored in manufacturing to ensure repeatability from device to device.
- This demands new methods of material property measurement, a subject of increasing importance in the microsystems field.

How are they designed?

- The design of microsystem requires several different levels of description and detail.
- On one level, the designer must document the need and specifications for a proposed microsystem, evaluate different methods by which it might be fabricated, and , if the device is to become a commercial product, further evaluate the anticipated manufactured cost.
- At another level, for each proposed approach, one must deal with details of partitioning the system into components, materials selection and the corresponding fabrication sequence for each component, methods for packaging and assembly, and means to assure adequate calibration and device uniformity during manufacture.

(continued)

How are they designed?

- Quantitative models play a key role in the design process by permitting prediction of performance prior to building a device, supporting the troubleshooting of device designs during development, and enabling critical evaluations of failure mechanisms after a device has entered take the form of numerical simulations carried out on high-speed workstations.
- Experience suggests that there is a natural progression from approximate analytical models early in the design cycle to more detailed and comprehensive numerical simulations later in the design cycle, continuing into device development and manufacture.

Markets for Microsystems and MEMS

Table System Planning Corporation Market Survey (1999) with an estimate of 1996 product volume and a forecast of 2003 sales (in millions of US$).

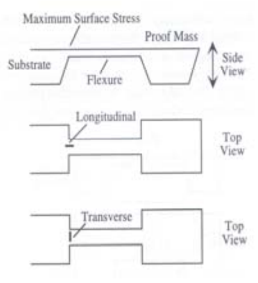
Devices	Applications	1996	2003
Inertial Measurement	Accelerometers and rate gyros	350 - 540	700 - 1,400
Microfluidics	Ink-jet printers, mass-flow sensors, biolab chips	400 - 500	3,000 - 4,450
Optics	Optical switches, displays	25 -40	440 - 950
Pressure Measurement	Automotive, medical, industrial	390 - 760	1,100 - 2,150
RF Devices	Cell phone components, devices for radar	none	40 - 120
Other Devices	Microrelays, sensors, disk heads	510 - 1,050	1,230 - 2,470

Case Studies

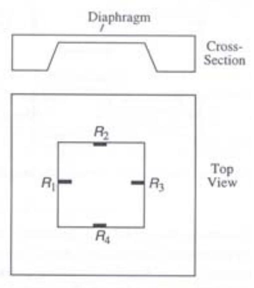
Case Study	Partitioning	Technology	Transduction	Packaging
Pressure sensor	Monolithic	Bulk micromachining with bipolar circuitry plus glass frit wafer bonding	Piezoresistive sensing of diaphragm deflection	Plastic
Accelerometer	Monolithic	Surface micromachining with CMOS circuitry	Capacitive detection of proof-mass motion	Metal can
Resonant rate gyroscope	Hybrid	Bulk micromachined quartz	Piezoelectric sensing of rotation-induced excitation of resonant mode	Metal can
Electrostatically driven display	Hybrid	Surface micromachining using XeF_2 release	Electrostatic actuation of suspended tensile ribbons	Bonded glass device cap plus direct wire bond to ASIC
DNA amplification with PCR	Hybrid	Bonded etched	Pressure-driven flow across temperature-controlled zones	Microcapillaries attached with adhesive
Catalytic combustible gas sensor	Hybrid	Surface micromachined with selective deposition of catalyst	Resistance change due to heat of reaction of combustible gas	Custom mounting for research use

Pressure Sensor

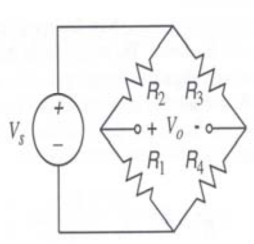
Case Study	Partitioning	Technology	Transduction	Packaging
Pressure sensor	Monolithic	Bulk micromachining with bipolar circuitry plus glass frit wafer bonding	Piezoresistive sensing of diaphragm deflection	Plastic



Illustrating lateral and transverse piezoresistor placements using an accelerometer flexure as an example.



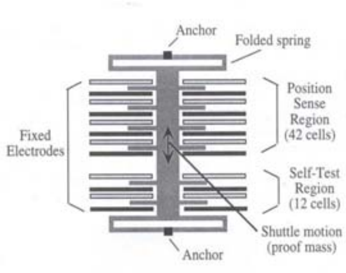
Illustrating the placement of piezoresistors on a micromachined diaphragm pressure sensor.



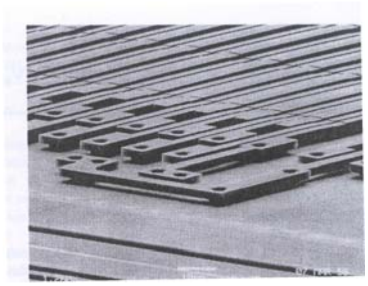
A Wheastone-bridge circuit constructed from resistors.

Accelerometer

Case Study	Partitioning	Technology	Transduction	Packaging
Accelerometer	Monolithic	Surface micromachining with CMOS circuitry	Capacitive detection of proof-mass motion	Metal can



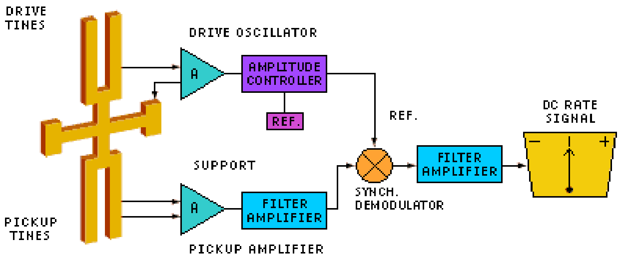
Schematic illustration of the design of the sensor portion of the ADXL 150 accelerometer.



Enlarged view of electrodes on an Analog Devices accelerometer.

Resonant Rate Gyroscope

Case Study	Partitioning	Technology	Transduction	Packaging
Resonant rate gyroscope	Hybrid	Bulk micromachined quartz	Piezoelectric sensing of rotation-induced excitation of resonant mode	Metal can

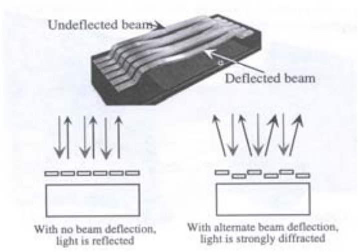


Schematic illustration of the QRS(Quartz Rotation Sensors) rate sensor.

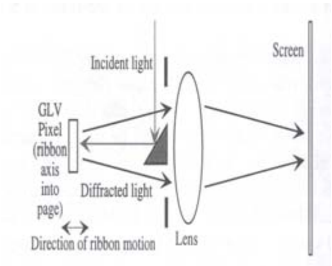
One of commercially available QRS Gyro Chip™

Electrostatically Driven Display

Case Study	Partitioning	Technology	Transduction	Packaing
Electrostatically driven display	Hybrid	Surface micromachining using XeF_2 release	Electrostatic actuation of suspended tensile ribbons	Bonded glass device cap plus direct wire bond to ASIC



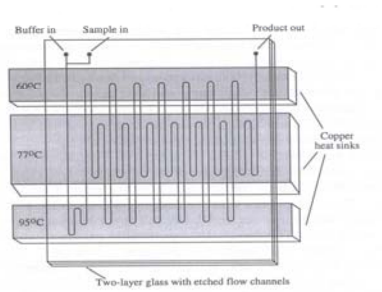
Schematic illustration of the pixel design for a grating-light-valve (GLV) display.



Illustrating how the diffractive projection from a single pixel is achieved.

DNA Amplification with PCR

Case Study	Partitioning	Technology	Transduction	Packaing
DNA amplification with PCR	Hybrid	Bonded etched	Pressure-driven flow across temperature-controlled zones	Microcapillaries attached with adhesive



A continuous-flow PCR(Polymerase Chain Reaction) system. A two-layer glass sample with flow channels etched into it is clamped to a support containing three copper heat sinks, each one controlled to a fixed temperature. As fluid flows through the channel, it encounters a typical PCR temperature cycle.

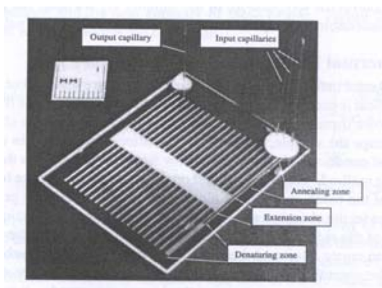
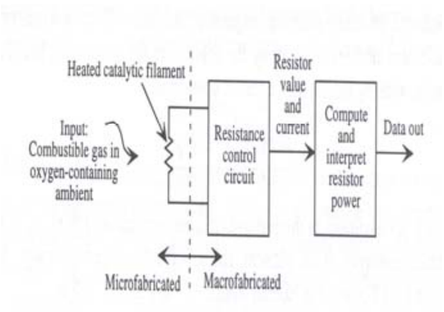


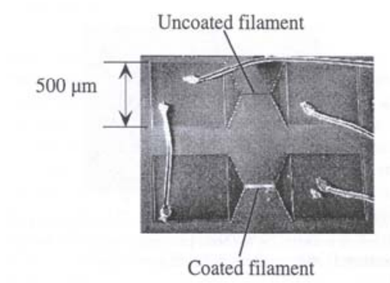
Photo of the continuous-flow PCR cell of Kopp et al.

Catalytic Combustible Gas Sensor

Case Study	Partitioning	Technology	Transduction	Packaing
Catalytic combustible gas sensor	Hybrid	Surface micromachined with selective deposition of catalyst	Resistance change due to heat of reaction of combustible gas	Custom mounting for research use



System architecture for the combustible-gas sensor.



A pair of wire-bonded filaments, in this case, without the high-temperature metallurgy. The lower of the two filaments has been platinum coated using selective CVD.