# HISTORY OF MICROELECTOMECHANICAL SYSTEMS (MEMS)

*LIGA-micromachined gear for a mini electromagnetic motor*
*[Sandia National Labs]*

# Unit Overview

The inception of Microelectromechanical Systems (MEMS) devices occurred in many places and through the ideas and endeavors of several individuals. Worldwide, new MEMS technologies and applications are being developed every day.

This unit gives a broad look at some of the milestones which have contributed to the development of MEMS as we know them today.

# Objectives

- Name three major MEMS technology processes which have emerged in MEMS history.
- Name at least three major MEMS milestones which have occurred throughout MEMS history.

# Introduction to MEMS

- Manufactured onto semiconductor material
- Used to make sensors, actuators, accelerometers, switches, and light reflectors
- Used in automobiles, aerospace technology, biomedical applications, ink jet printers, wireless and optical communications
- Range in size from a millionth of a meter (micrometer) to a thousandth of a meter (millimeter.)

*Three MEMS blood pressure sensors on a head of a pin*
*[Photo courtesy of Lucas NovaSensor, Fremont, CA]*

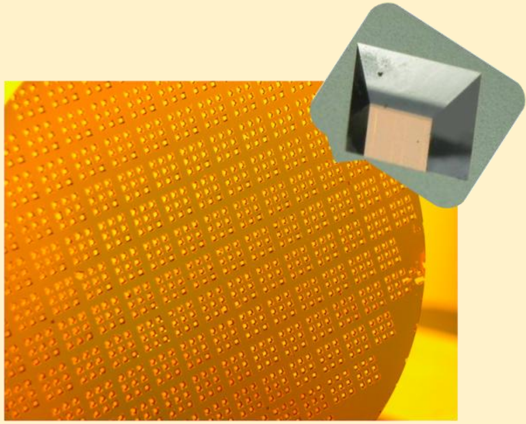
# 1947 Invention of the Point Contact Transistor

- A transistor uses electrical current or a small amount of voltage to control a larger change in current or voltage.
- Transistors are the building blocks of computers, cellular phones, and all other modern electronics.
- In 1947, William Shockley, John Bardeen, and Walter Brattain of Bell Laboratories built the first point-contact transistor.
- The first transistor used germanium, a semiconductive chemical .
- It demonstrated the capability of building transistors with semiconductive materials.

*First Point Contact Transistor and Testing Apparatus (1947)*
*[Photo Courtesy of The Porticus Centre]*

# 1954 Discovery of the Piezoresistive Effect in Silicon and Germanium

- Discovered in 1954 by C.S. Smith.
- The piezoresistive effect of semiconductor can be several magnitudes larger than that in metals.
- This discovery showed that silicon and germanium could sense air or water pressure better than metal
- Many MEMS devices such as strain gauges, pressure sensors, and accelerometers utilize the piezoresistive effect in silicon.
- Strain gauges began to be developed commercially in 1958.
- Kulite was founded in 1959 as the first commercial source of silicon strain gages .



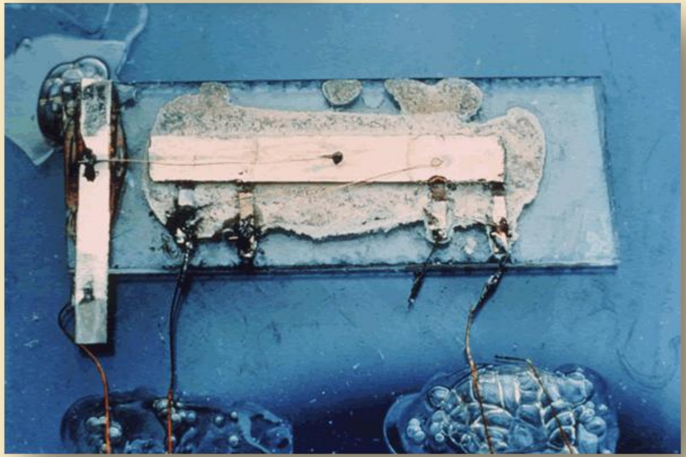
*An Example of a Piezoresistive Pressure Sensor*
*[MTTC Pressure Sensor]*



*Revised 06/02/01*

# 1958 Invention - First Integrated Circuit (IC)

- Prior to the invention of the IC there were limits on the size of transistors. They had to be connected to wires and other electronics.
- An IC includes the transistors, resistors, capacitors, and wires.
- If a circuit could be made all together on one substrate, then the whole device could be made smaller
- In 1958, Jack Kilby from Texas Instruments built a "Solid Circuit“ on one germanium chip: 1 transistor, 3 resistors, and 1 capacitor.
- Shortly after  Robert Noyce from Fairchild Semiconductor made the first "Unitary Circuit“ on a silicon chip.
- The first patent was awarded in 1961 to Robert Noyce.

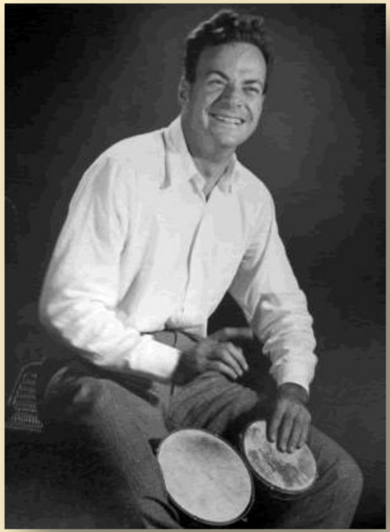


*Texas Instrument's First Integrated Circuit [Photos Courtesy of Texas Instruments]*

# 1959 "There's Plenty of Room at the Bottom"

Richard Feynman's "There's Plenty of Room at the Bottom" was presented at a meeting of the American Physical Society in 1959.

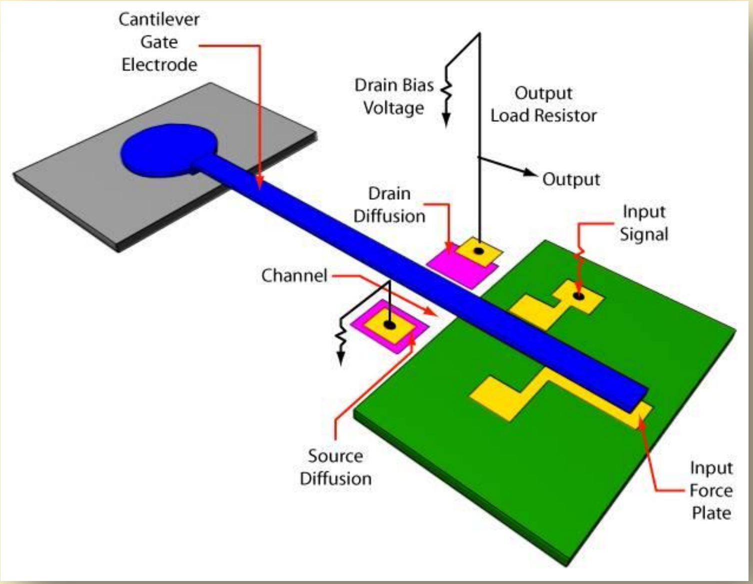
- The talk popularized the growth of micro and nano technology.
- Feynman introduced the possibility of manipulating matter on an atomic scale.
- He was interested in denser computer circuitry, and microscopes which could see things much smaller than is possible with scanning electron microscopes.
- He challenged his audience to design and build a tiny motor or to write the information from a page of a book on a surface 1/25,000.
- For each challenge, he offered prizes of $1000.
- Foresight Nanotech Institute has been issuing the Feynman Prize in Nanotechnology each year since 1997.



*Richard Feynman on his bongos*
*Photo credit: Tom Harvey*

# 1968 The Resonant Gate Transistor Patented

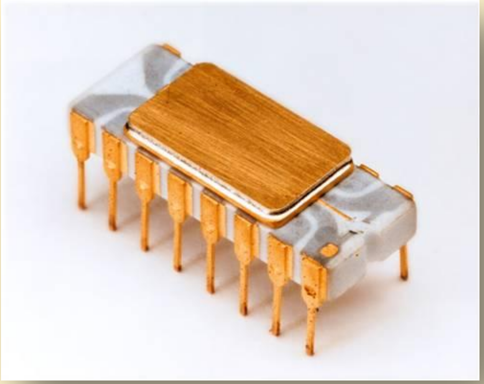
- In 1964, Harvey Nathanson from Westinghouse produced the first batch fabricated MEMS device.
- This device joined a mechanical component with electronic elements and was called a resonant gate transistor (RGT).
- The RGT was a gold resonating MOS gate structure.
- It was approximately one millimeter long and it responded to a very narrow range of electrical input signals.
- It served as a frequency filter for ICs.
- The RGT was the earliest demonstration of micro electrostatic actuators.
- **It was also the first demonstration of surface micromaching techniques.**




*Resonant Gate Transistor*

# 1971 The Invention of the Microprocessor

- In 1971, Intel publicly introduced the world's first single chip microprocessor - The Intel 4004
- It powered the Busicom calculator
- This invention paved the way for the personal computer



*The Intel 4004 Microprocessor*
*[Photo Courtesy of Intel Corporation]*

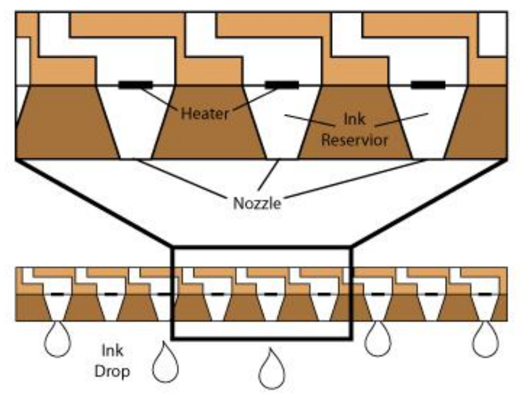
*Busicom calculator*
*[Photo Courtesy of Intel Corporation]*

# 1960's and 1970's Bulk-Etched Silicon Wafers as Pressure Sensors

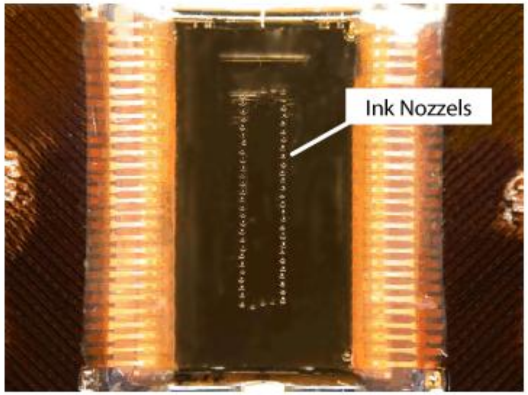
- "Electrochemically Controlled Thinning of Silicon" by H. A. Waggener illustrated anisotropic etching of silicon (removes silicon selectivity).
- This technique is the basis of the bulk micromachining process.
- Bulk micromachining etches away the bulk of the silicon substrate leaving behind the desired geometries.
- Fabricating these micromechanical elements requires selective etching techniques such as bulk etching.
- In the 1970's, a micromachined pressure sensor using a silicon diaphragm was developed by Kurt Peterson from IBM research laboratory.
- Thin diaphragm pressure sensors were proliferated in blood pressure monitoring devices .
- Considered to be one of the earliest commercial successes of microsystems devices.

# 1979 HP Micromachined Inkjet Nozzle

- Hewlett Packard developed the Thermal Inkjet Technology (TIJ).
- The TIJ rapidly heats ink, creating tiny bubbles.
- When the bubbles collapse, the ink squirts through an array of nozzles onto paper and other media.
- MEMS technology is used to manufacture the nozzles.
- The nozzles can be made very small and can be densely packed for high resolution printing.
- New applications using the TIJ have also been developed, such as direct deposition of organic chemicals and biological molecules such as DNA




*Schematic of an array of inkjet nozzles*




*Close-up view of a commercial inkjet printer head illustrating the nozzles [Hewlett Packard]*

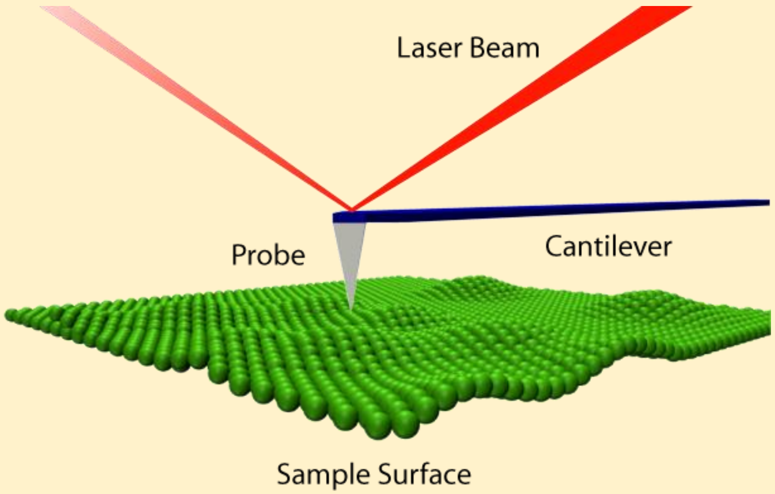
# 1982 LIGA Process Introduced

- LIGA is a German acronym for X-ray lithography (X-ray Lithographie), Electroplating (Galvanoformung), and Molding (Abformung).
- In the early 1980s Karlsruhe Nuclear Research Center in Germany developed LIGA.
- It allows for manufacturing of high aspect ratio microstructures.
- High aspect ratio structures are very skinny and tall.
- LIGA structures have precise dimensions and good surface roughness.

*LIGA-micromachined gear for a mini electromagnetic motor [Courtesy of Sandia National Laboratories]*

# 1986 Invention of the AFM

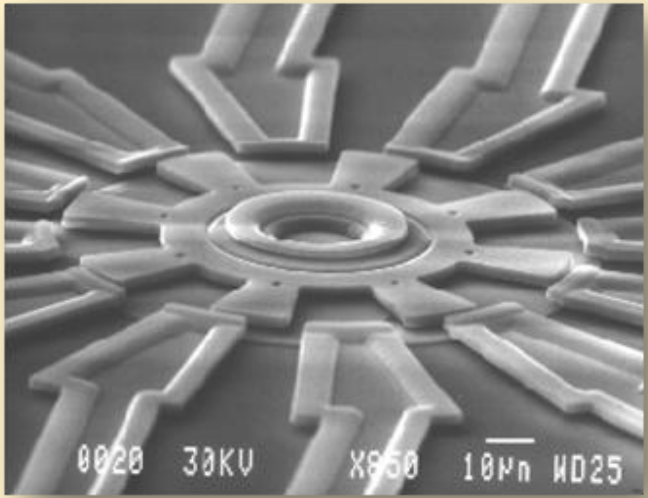
- In 1986 IBM developed a microdevice called the atomic force microscope (AFM).
- The AFM maps the surface of an atomic structure by measuring the force acting on the tip (or probe) of a microscale cantilever.
- The cantilever is usually silicon or silicon nitride.
- It is a very high resolution type of scanning probe microscope with a resolution of fractions of an Angstrom.



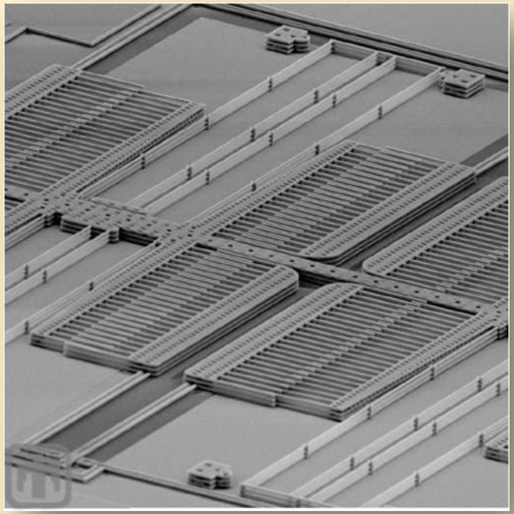

*Cantilever on an Atomic Force Microscope*

# Other Developments in the 1980's

- In 1988 the first rotary electrostatic side drive motors were made at UC Berkley
- In 1989 a lateral comb drive emerged where structures move laterally to the surface



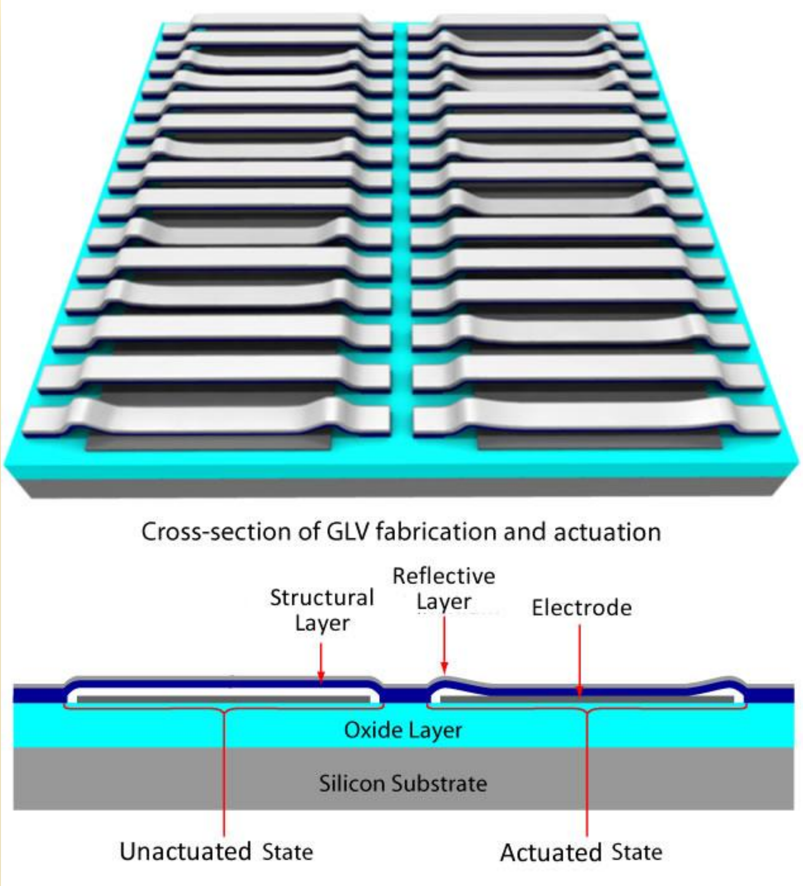

*First Rotary Electrostatic Side Drive Motor*
*[Richard Muller, UC Berkeley]*



*Lateral Comb Drive*
*[Sandia National Laboratories]*

# 1992 Grating Light Modulator

- The deformable grating light modulator (GLM) was introduced by Solgaard in 1992.
- It is a Micro Opto Electro Mechanical System (MOEMS).
- It has been developed for uses in various applications:  Display technology, graphic printing, lithography and optical communications



# 1993 Multi-User MEMS Processes (MUMPs) Emerges

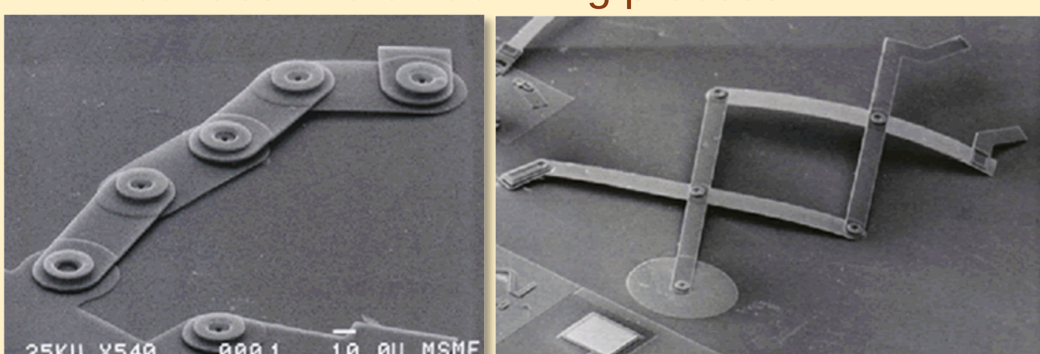
In 1993 Microelectronics Center of North Carolina (MCNC) created MUMPs:

- A foundry meant to make microsystems processing highly accessible and cost effective for a large variety of users
- A three layer polysilicon surface micromachining process

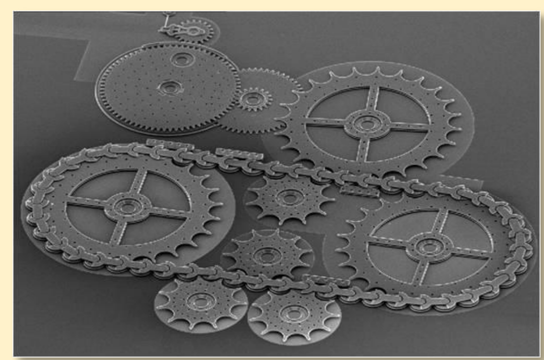
For a nominal cost, MUMPs participants are given a 1 $cm^2$ area to create their own design.

In 1998, Sandia National Labs developed SUMMiT IV (Sandia Ultra-planar, Multi-level MEMS Technology 5)

- This process later evolved into the SUMMiT V, a five-layer polycrystalline silicon surface micromachining process




*Two simple structures using the MUMPs process [MCNC]*



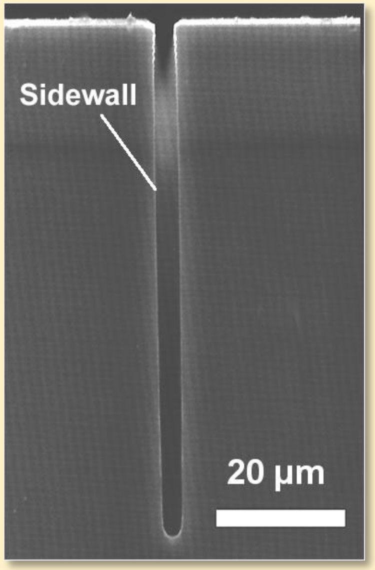
*A MEMS device built using* SUMMiT IV *[Sandia National Laboratories]*

# 1993 First Manufactured Accelerometer

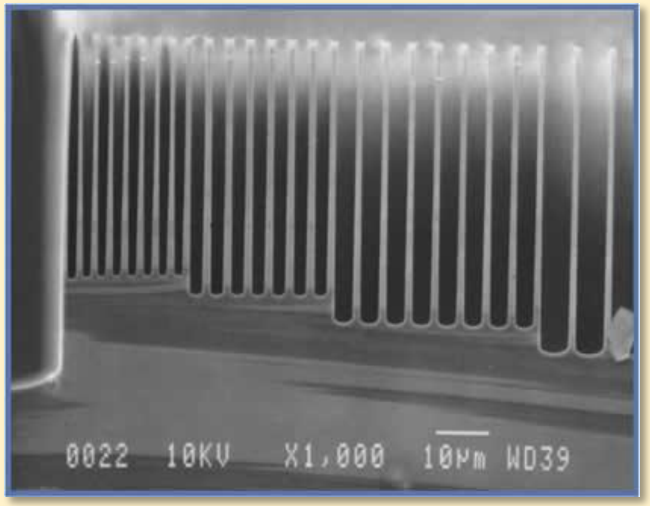
- In 1993 Analog Devices were the first to produce a surface micromachined accelerometer in high volume.
- The automotive industry used this accelerometer in automobiles for airbag deployment sensing.
- It was sold for $5 (previously, TRW macro sensors were being sold for about $20).
- It was highly reliable, very small, and very inexpensive.
- It was sold in record breaking numbers which increased the availability of airbags in automobiles.

# 1994 Deep Reactive Ion Etching is Patented

- In 1994, Bosch, a company from Germany, developed the Deep Reactive-Ion Etching (DRIE) process.
- DRIE is a highly anisotropic etch process used to create deep, steep-sided holes and trenches in wafers.
- It was developed for micro devices which required these features.
- It is also used to excavate trenches for high-density capacitors for DRAM (Dynamic random-access memory).




*Trenches etched with DRIE*
*[SEM images courtesy of Khalil Najafi, University of Michigan]]*

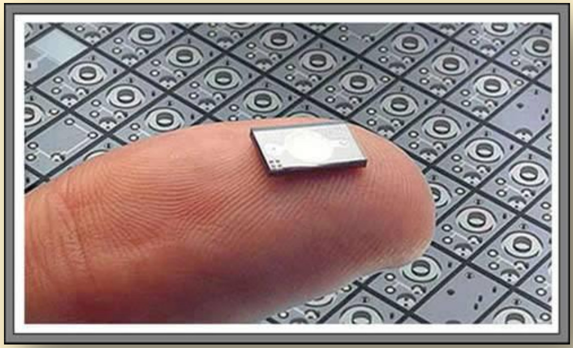


# Late 1990's, Early 2000's Optics

- In 1999 Lucent Technologies developed the first optical network switch.
- Optical switches are optoelectric devices.
- They consist of a light source and a detector that produces a switched output.
- The switch provides a switching function in a data communications network.
- These MEMS optical switches utilize micro mirrors to switch or reflect an optical channel or signal from one location to another.
- There are several different design configurations.
- Growth in this area of technology is still progressing.

# Late 1990's, Early 2000's BioMEMS

- Scientists are combining sensors and actuators with emerging biotechnology.
- Applications include
  - drug delivery systems
  - insulin pumps *(see picture)*
  - DNA arrays
  - lab-on-a-chip (LOC)
  - Glucometers
  - neural probe arrays
  - microfluidics



*Insulin pump [Debiotech, Switzerland]*

# Summary

Since the invention of the transistor, scientists have been trying to improve and develop new micro electro mechanical systems.

The first MEMS devices measured such things as pressure in engines and motion in cars.  Today, MEMS are controlling our communications networks

MEMS are saving lives by inflating automobile air bags and beating hearts.

MEMS are traveling through the human body to monitor blood pressure.

MEMS are even getting smaller.  We now have nano electro mechanical systems (NEMS).

The applications and growth for MEMS and NEMS are endless.

# Major MEMS Milestones

1948 Invention of the Germanium transistor at Bell Labs (William Shockley)

1954 Piezoresistive effect in Germanium and Silicon (C.S. Smith)

1958 First integrated circuit (IC) (J.S. Kilby 1958 / Robert Noyce 1959)

1959 "There's Plenty of Room at the Bottom" (R. Feynman)

1959 First silicon pressure sensor demonstrated (Kulite)

1967 Anisotropic deep silicon etching (H.A. Waggener et al.)

1968 Resonant Gate Transistor Patented (Surface Micromachining Process) (H. Nathanson, et.al.)

1970's Bulk etched silicon wafers used as pressure sensors (Bulk Micromaching Process)

1971 The microprocessor is invented

1979 HP micromachined ink-jet nozzle

# Major MEMS Milestones continued

1982 "Silicon as a Structural Material," K. Petersen

1982 LIGA process (KfK, Germany)

1982 Disposable blood pressure transducer (Honeywell)

1983 Integrated pressure sensor (Honeywell)

1983 "Infinitesimal Machinery," R. Feynman

1985 Sensonor Crash sensor (Airbag)

1985 The "Buckyball" is discovered

1986 The atomic force microscope is invented

1986 Silicon wafer bonding (M. Shimbo)

1988 Batch fabricated pressure sensors via wafer bonding (Nova Sensor)

# Major MEMS Milestones continued

1988 Rotary electrostatic side drive motors (Fan, Tai, Muller)

1991 Polysilicon hinge (Pister, Judy, Burgett, Fearing)

1991 The carbon nanotube is discovered

1992 Grating light modulator (Solgaard, Sandejas, Bloom)

1992 Bulk micromachining (SCREAM process, Cornell)

1993 Digital mirror display (Texas Instruments)

1993 MCNC creates MUMPS foundry service

1993 First surface micromachined accelerometer in high volume production (Analog Devices)

1994 Bosch process for Deep Reactive Ion Etching is patented

1996 Richard Smalley develops a technique for producing carbon nanotubes of uniform diameter

# Major MEMS Milestones continued

1999 Optical network switch (Lucent)

2000s Optical MEMS boom

2000s BioMEMS proliferate

2000s The number of MEMS devices and applications continually increases

2000s NEMS applications and technology grows

# Acknowledgements



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