UNIT-1

MEMS & MICROSYSTEMS

INTRODUCTION TO MEMS & MICROSYSTEMS:

- MEMS the full name is microelectromechanical systems and this is a very emerging area today and lot of work is going on around the globe on MEMS and Microsystems and it has got enormous applications.

HISTORY OF MICROELECTRONICS:

- The three scientists who are the Bardeen, Brattain and Schokly from the Bell Laboratories discovered the Point Contact Transistor which is in 1947.
- For that discovery they got Nobel Prize in 1956 and that was the first time Nobel Prize was awarded for an engineering device.
- Jack Kilby invented integrated circuit in 1958 and he got again Nobel Prize for this particular device in the year 2000.
- So, from that time onwards people are not seeing back and they are procee ding forward, particularly in the context of miniaturization of different components and making the integrated circuits.

SILICON IC'S- STATUS & TRENDS:

- The below figure where this has been obtained from CR route map and here in one side you can see the minimum feature size of the transistor starting from 1970 to 2020 and on the other side you can see the number of transistors for DRAM chip.
- So now look at this figure, here in 1980 where these minimum feature sizes was nearly say 2000 nanometer and then if you go, at present this is the present line 2004 and there you can see the feature size is nearly 100 nanometer.

MOORES LAW:

- It is defined as the no of transistors in a dense integrated circuit is doubles for every two years.
- That means year to year how the integration is taking place, you can see from here the model CMOS in 1980 which is nearly one micron technology and then at present in 2004, the transistor size has come down to 19 nanometer only.
- Earlier this generation is nearly 2.9 years but later on the progress is so fast that has been changed to 2 years recently every two year they are speculating something.

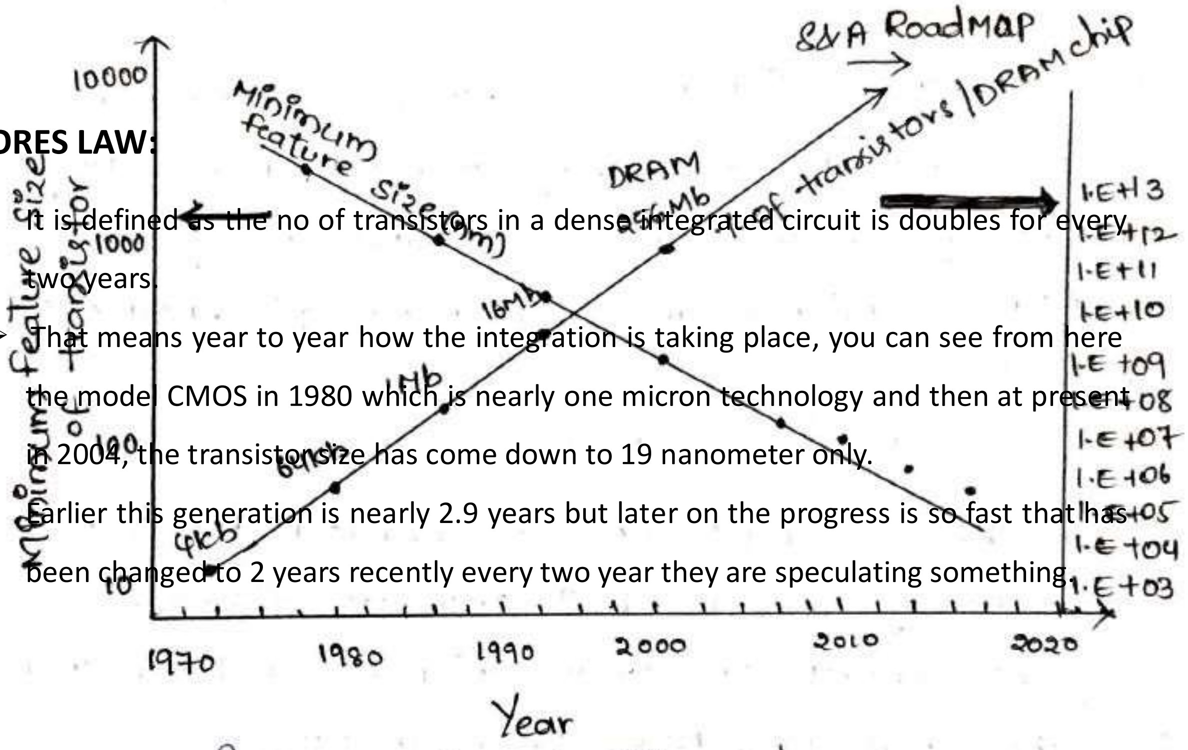
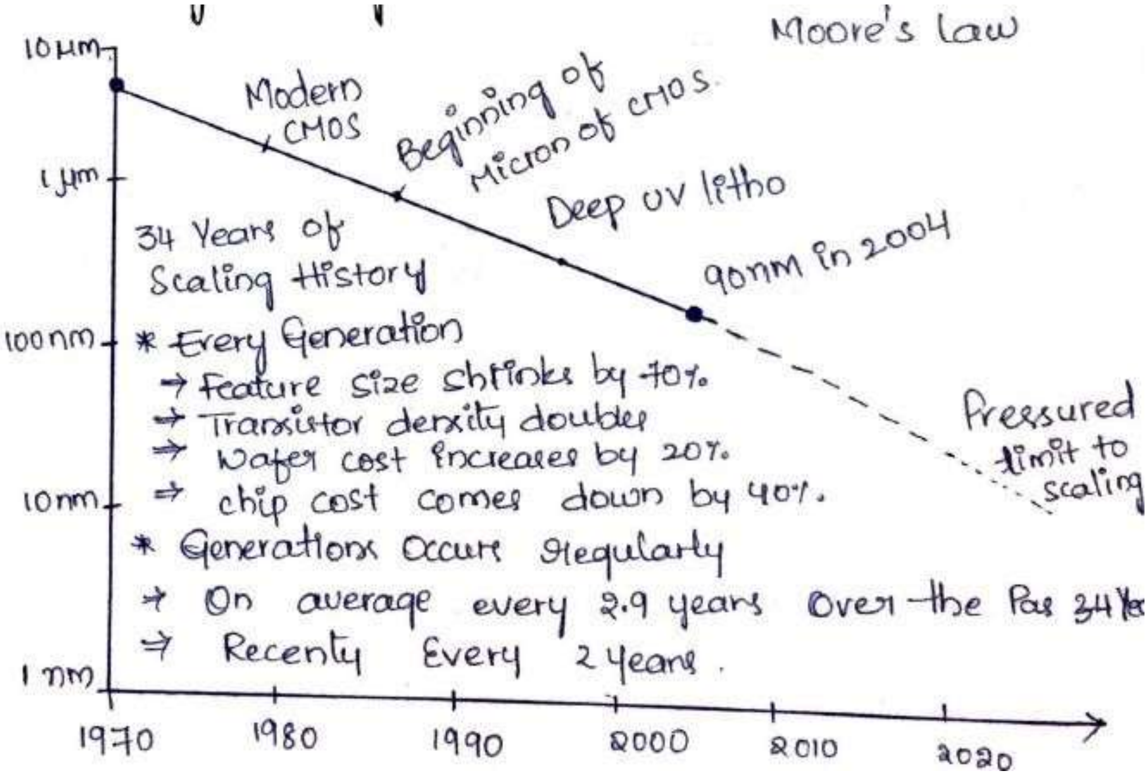
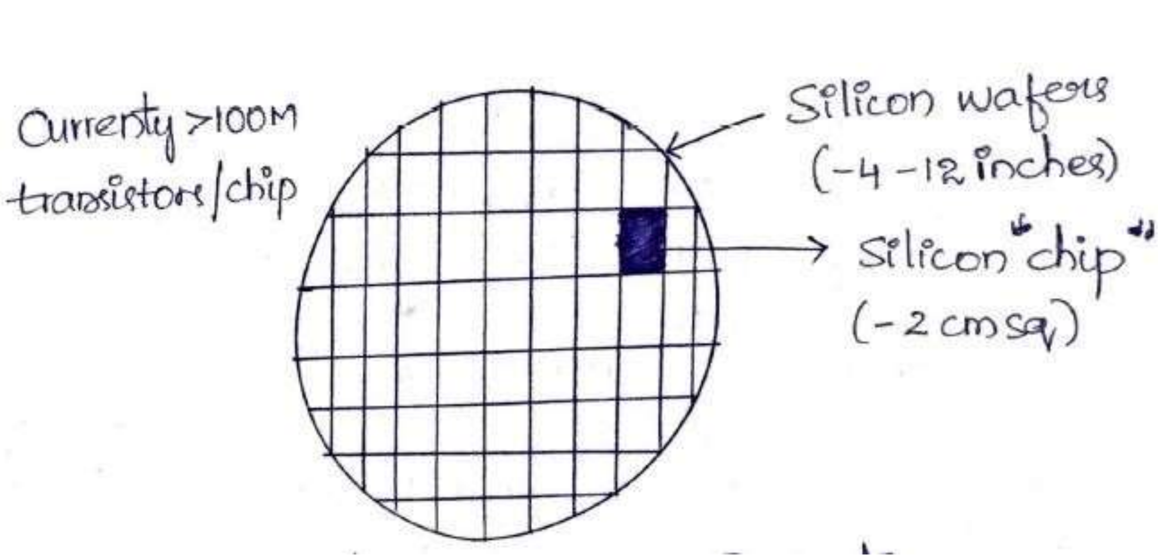


fig:- Trends of silicon IC's.

SILICON MICROELECTRONICS:

- But now the silicon microelectronics basically if you see, that is the silicon wafer is 1 0 0 crystal orientation wafer.
- Now, at present the standard size of the silicon wafer in industry is nearly 12 inches. Normally in some cases the 4 inch or 6 inch and 8 inch wafers are also used in some of the small fabs but in big fabs they are working on 8 to 12 inches.
- Now, you know the lots of circuits are made on silicon wafer and individual single chip and that is of the order of 2 centimeter square.





HISTORICAL FUTURE AND FUTURE PROJECTION:

- In the below figure you can see the feature size goes down, so if you look into the integrated circuit history, below this is a 0.1 micrometer and this is 10 nanometer range, this is the one transition 0.1 to 10 nanometer.

FUTURE PROJECTION OF SILICON TECHNOLOGY:

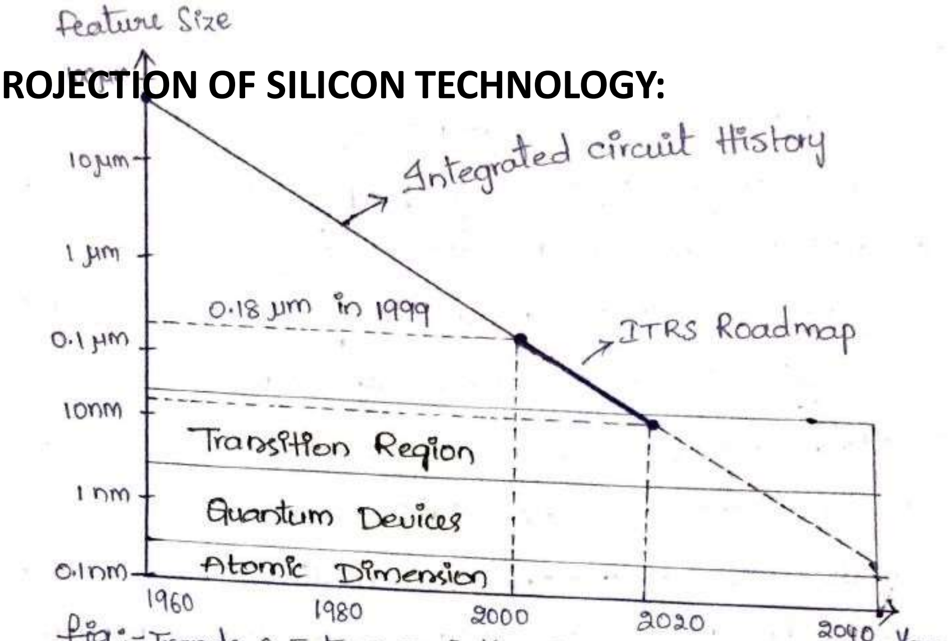
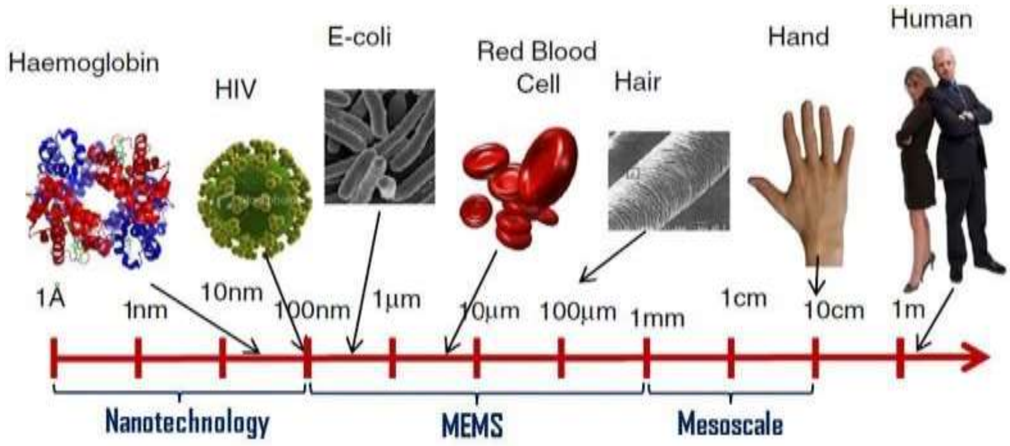


fig:- Trends & Future projection for min feature Size in IC

Year of first DRAM Shipment	1997	1999	2003	2006	2009	2012
Minimum feature Size	250nm	180nm	130 nm	100nm	70nm	50 nm
DRAM Bits/chip	256M	1G	4G	16 G	64 G	256G
DRAM Chip Size (mm2)	280	400	560	790	1120	1580
Microprocessor Transistor/chip	11M	21 M	76 M	200M	520M	1.40 B
Maximum Wiring Levels	6	6-7	7	7-8	8-9	9
Maximum Mask count	22	22-24	24	24-26	26-28	28
Maximum Supply Voltage (volts)	1.8 - 2.5	1.58 - 1.8	1.2 - 1.5	0.9-1.2	0.6-0.9	0.5-0.6

SIZE MATTERS:

- So, this is the area of the micromachining and this Nano machining. So another word you are coming across now is machining.
- So machining, the terminology initially it was in mechanical engineering, people they used to point machining, that means from a huge bulk steel or any of the metal beam they used to machine it to get small miniature structures
- The size does matters because the with the reduction of the size and minimum feature size all the technology is going to change and at the same time the equipments are going to change



MEMS- MICROELECTROMECHANICAL SYSTEMS

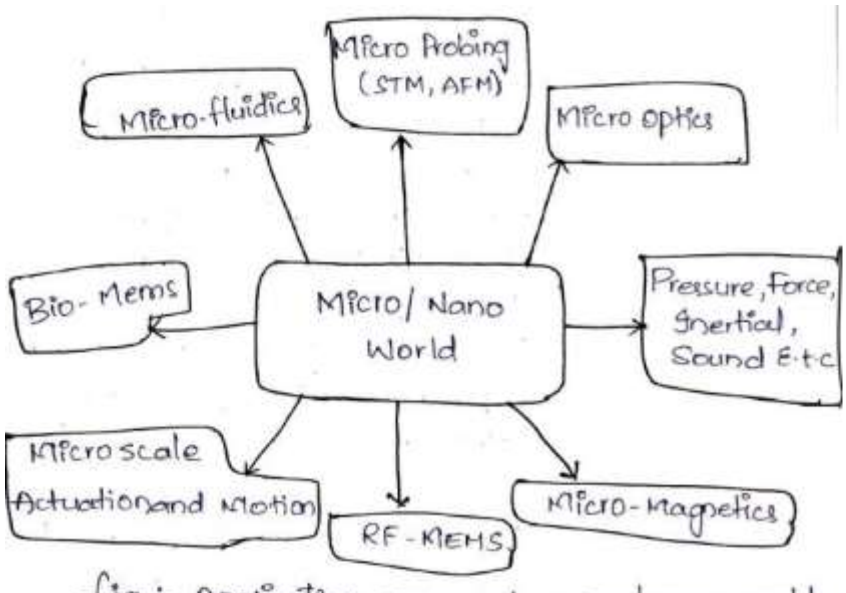


fig :- Application areas of Micro|Nano world.

- Physical MEMS or physical sensors which deals with pressure sensor, force, inertial, sound means that these are the area where MEMS devices are made.
- Other area is micro-optics, optical areas which we call it as MOEMS Micro-Optical Electromechanical Systems. So there is the optical domain, there are lots of devices made using micromachining technology.
- Then another is micro-probing, the STM and AFM. The AFM components are being made using the MEMS.
- Micro-fluidics is a major application in the biology and not only the biological application, there are others in flow of gas and flow of fluid in a micro channel, that dynamics is a is a very interesting and there lot of devices are being made now. This is another area of micro-fluidics.
- In Bio-MEMS, lot of work is going and one emerging area of research at present Bio-MEMS area.
- And by the actuation and motion that is basically the actuators are also very important. If you want to make a micro system, you need the sensor, you need actuator and you need the signal conditioning circuits or processing circuits. So actuator is one part of the micro system.

MEMS HISTORY:

1959 → 1969 Nobel literate Richard Feynman - vision- "The plenty of Room at the bottom". Silicon inside you can make lot of small miniature devices.

1967 → Resonant Gate Transistor came from Wasting house

1989 → MEMS Micromotor has been devoloped in UC Berkeley.

1991 → Texas Instrument, MEMS device- is one Digital Light processing chip used in DLP Projector machine.

1993 → Commercial MEMS based accelerometer. coming from analog devices. ADXL Series accelerometers (actually a chip inside).

2001 → MOEMS - Commercial optical cross-connect and switches as coming to the market.

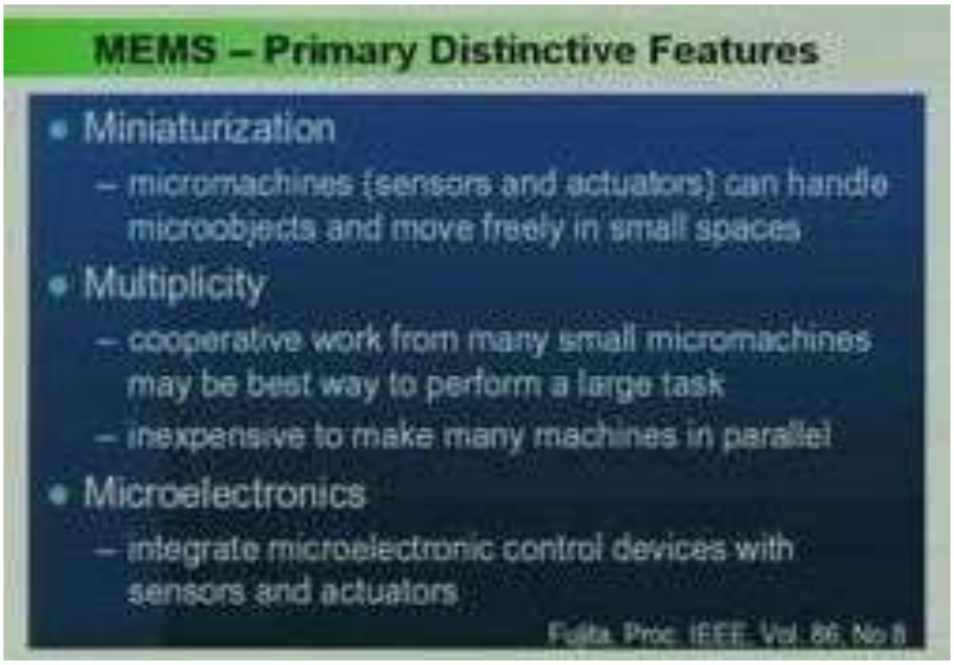
MEMS & MICROSENSOR:

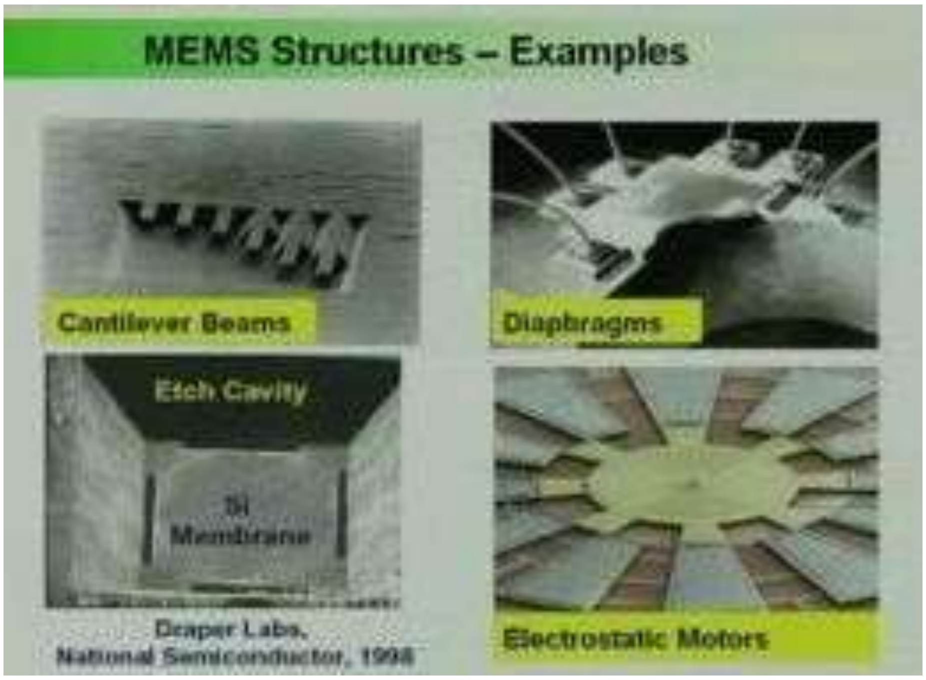
- At present, if you see the micro structures made out of the silicon and other materials, some of the structures are shown: the hinge slider, and this is the one gear, this is a pin joint, so this is all this made using the micromachining technology.

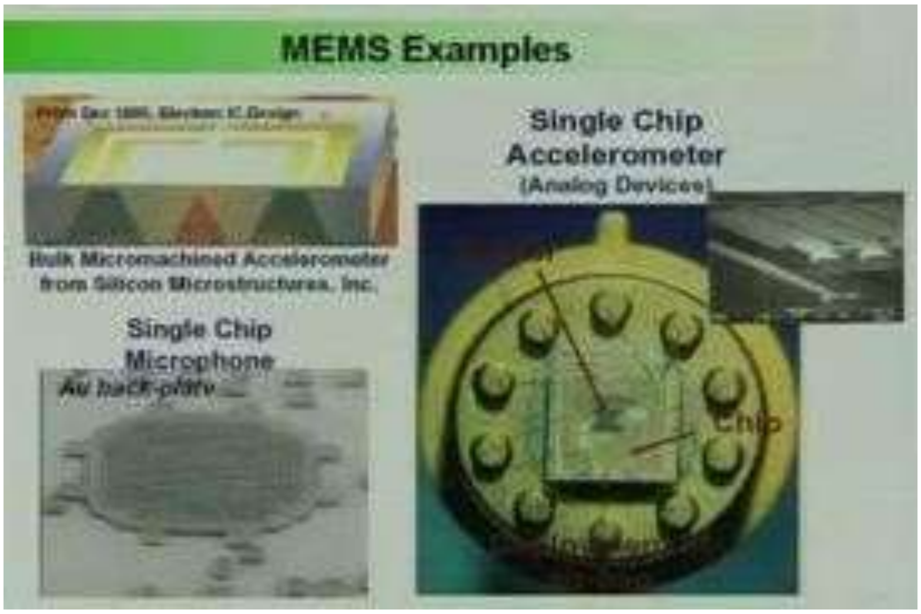
- Now-a-days, no system can be made without use of sensor. Lot of sensors is there in any of these microsystems.
- So that is basically the difference between sensor and micro is nothing but, the physical dimension is very very small in case micro sensor and in the range of the sub-millimeter level.
- The M E M S or MEMS microelectromechanical system is a device where microsensors and mechanical parts, along with signal processing circuits are integrated on a small piece of silicon.
- In earlier days, sensors and circuits are not integrated on silicon.
- But if you integrate both the devices, then it is known as the microelectromechanical system.
- Mechanical means they are basically the mechanical part which means actuation parts.
- Actuators will be there, as well as the sensor parts along with the circuits, that is the MEMS.

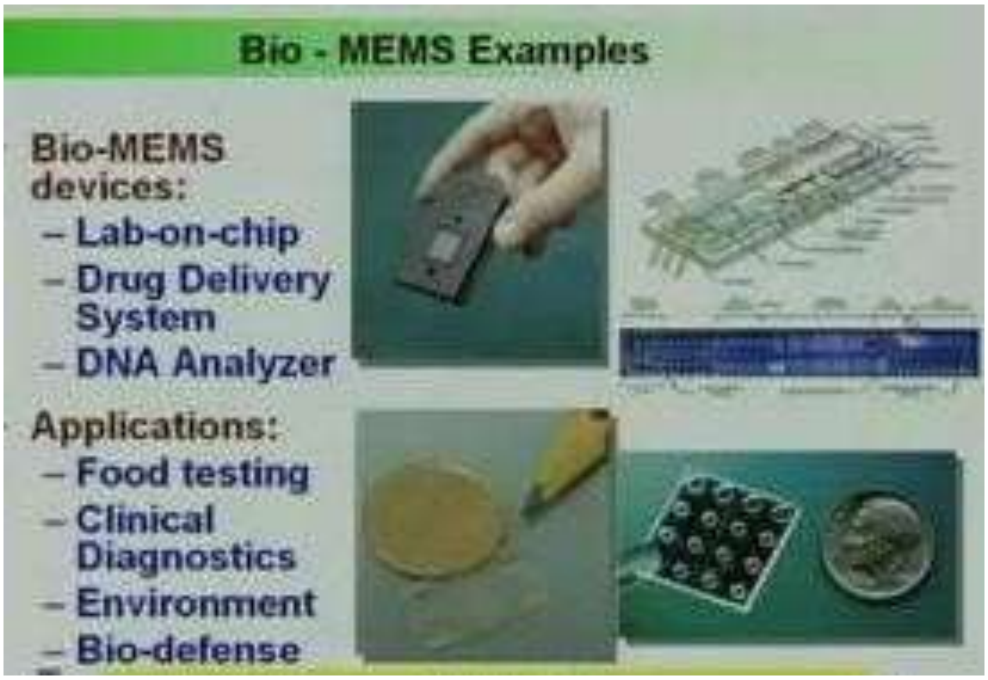
MEMS "touch "PHYSICAL WORLD:

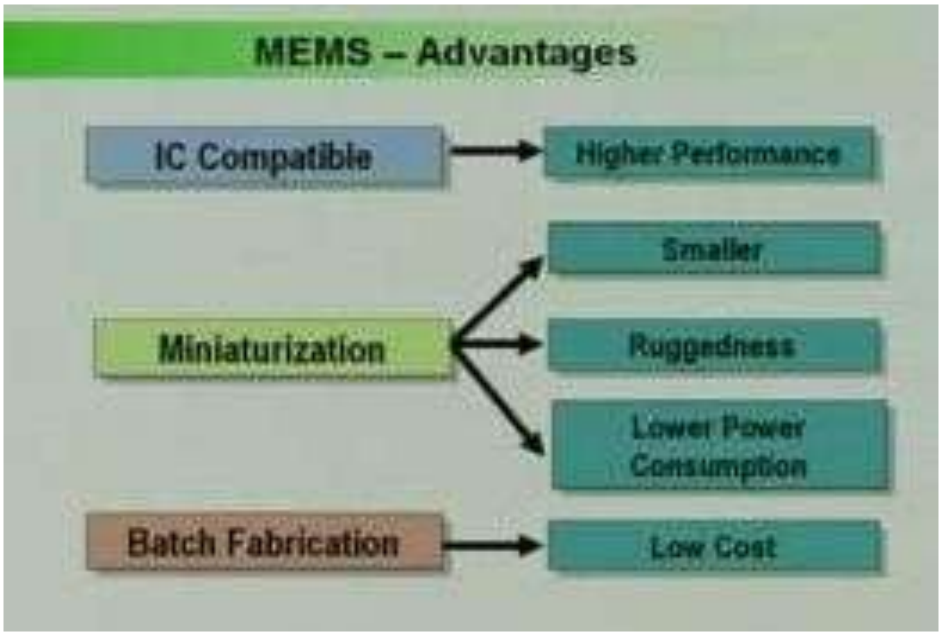
- Now, as the computing power increases, the information systems also move into the physical world.
- MEMS is playing a major role, that is in particular in case of I/O of input output device of any of the information system.
- And they can sense and create motion, velocity, acceleration they can produce and at the same time in the optical side these devices can reflect or refract light or radio waves also.
- And at the moment, the pumps and control fluids gases reactions gases and reactions are also done with the help of MEMS devices and these are integrated any of the information system now a days.




MEMS Structures – Examples
Cantilever Beams
Diaphragms
Etch Cavity
Si
Membrane
Draper Labs,
National Semiconductor, 1998
Electrostatic Motors


MEMS Examples
Single Chip
Accelerometer
(Analog Devices)
Bulk Micromachined Accelerometer
from Silicon Microstructures, Inc.
Single Chip
Microphone
Au back-plate
Chip


Bio - MEMS Examples
Bio-MEMS devices:
– Lab-on-chip
– Drug Delivery System
– DNA Analyzer
Applications:
– Food testing
– Clinical Diagnostics
– Environment
– Bio-defense


MEMS – Advantages
IC Compatible
Higher Performance
Smaller
Miniaturization
Ruggedness
Lower Power Consumption
Batch Fabrication
Low Cost

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INTRODUCTION TO MICROSENSORS

- Sensor basically is a word coming from a Latin word sentire that means to perceive.
- Basically it gives information about the physical and chemical signals which could not otherwise be directly perceived by our senses.
- Sensor is a device that responds to a physical or chemical, some stimulus and is transmit a resulting impulse as per measurement.
- In general a sensor is device which takes non electrical form as a input and converts it into electrical form.

SEMICONDUCTOR SENSOR:

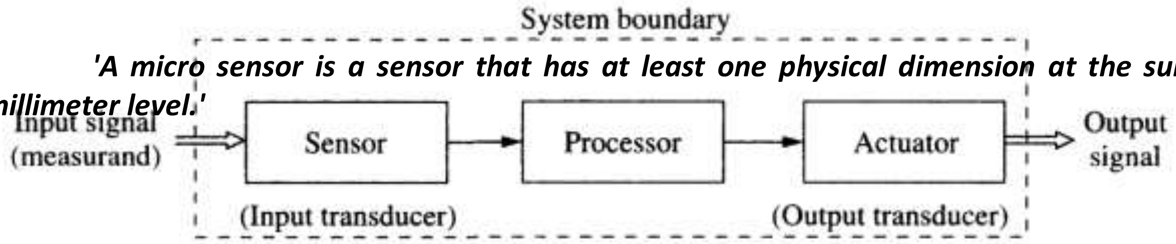
- Small in size and low cost.
- They use fabrication processes of integrated circuits or VLSI.
- Batch processing improves performance as well as cost ratio
- It integrates with microelectronic circuit.

TRANSDUCER:

- Basically both sensor and transducer are synonymous form.
- Transducer word is again derived from another Latin word which is known as transducere and that means to lead across, a device that converts energy from some system to another in the same or in different form.
- So you see transducer normally transfer the energy from one form to the same form or in another form.
- That means if the sound, if we apply at the input energy as a sound energy, then transducer output will also be sound energy.
- Then it is called sound energy of this different magnitude so that we don't call a sensor.

INFORMATION PROCESSING SYSTEM:

'A micro sensor is a sensor that has at least one physical dimension at the sub millimeter level.'

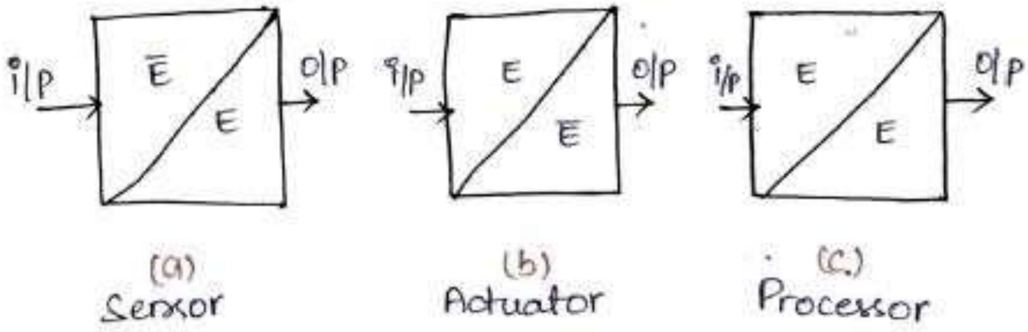


- Then a information processing system where sensors are used.
- So in information processing system, there are three blocks and they are known as sensor, processor and actuator.
- So input signal which is a measuring quantity, so that is coming to the sensor and that is the input transducer and then the sensor converts the input signal into another form which can bet then convert non electrical energy into the electrical energy.
- So that in the next block which is a processor block and that block can process the output of the sensor signal.
- And the other block after processor is the actuator. So actuator is a device that converts an electrical signal into non electrical signal.
- For example, if the acoustic energy is transmitted in a PS system, then at the end of it you have to get back the acoustic energy.

MICROSENSOR:

- Now the microsensors, if you look into the building block of micro sensor we have sensor input and output, there are two parts.

fig:- Basic i/p - o/p representation



E - ~~Non~~ electrical Quantity

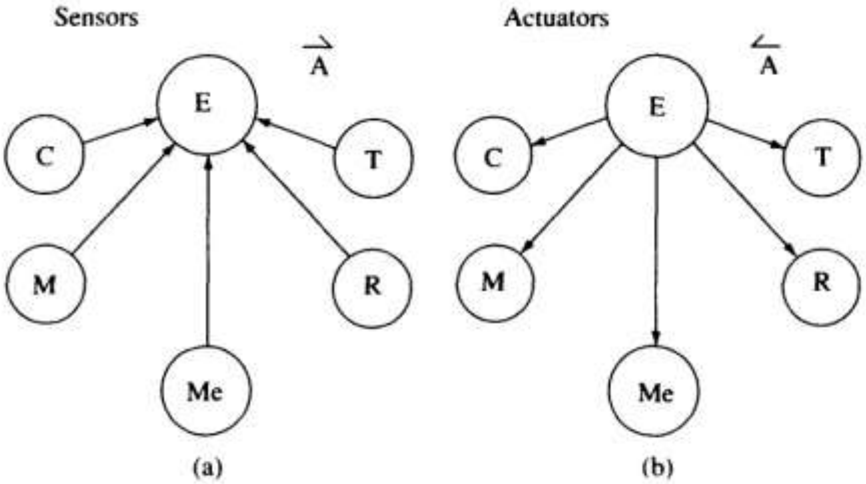
E - Non electrical Quantity.

- Here you can see the E, is the energy one form of energy, E bar is another form of energy and E bar represents the electrical quantity and E bar represents the non electrical quantity and E represents the electrical quantity.
- So the sensor basically converts the non electrical quantity into its electrical quantity. Then another block is actuator.
- The actuator input is electrical again and output may be non-electrical. Non electrical means it may be mechanical energy, it may be acoustical energy, it may be optical energy, it may magnetic energy.
- So input is electrical, that is the actuator block and the other one you see here is the processor block. There you can see the input is also electrical and output is also electrical.
- So a processor changes input which is electrical form to output which is also in electrical form, but, may be the amplitude or may the frequency change at the output.
- Depending on the block which you are going to use it, so these are the three blocks we transform some quantity of energy into other form of energy.

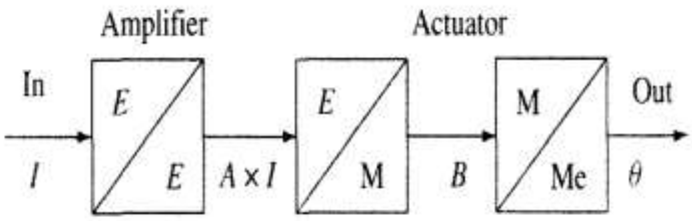
ENERGY DOMAINS OF CONVENTIONAL SENSOR AND ACTUATORS:

- The different forms of energy, the sensors and actuator deals are mainly the electrical, thermal radiation, mechanical, magnetic and biochemical energy.
- Now the electrical, here is denoted by the word E, thermal is a T and R is a radiant energy, Me is a mechanical energy, M is magnetic energy and C is biochemical energy.
- So all these energy is at input and they transformed into electrical energy that is the job of the sensor.
- Now on the other hand here, vectorial representation of actuators is shown in the figure below.
- So here, the actuators get electrical energy then it converts it into either chemical energy or you see magnetic energy or mechanical energy or radiation energy or thermal energy. This is the vectorial representation of sensors and actuators.

ACTUATOR SYSTEM:



- So in the actuator system, the actuation means it will act something, some either mechanical or some motion or movement or some colour change or light intensity change something will happen there.
- So for that first the whole system is again can be sub divided by different blocks.
- For example, first block is an amplifier where the input is also electrical energy and output is electrical energy.
- If I is the input so output you are getting A* I. A is the amplification or gain. So now this is fed into another block which A * 1 is basically electrical quantity, so the electrical quantity is getting but output is getting magnetic energy. So electrical to magnetic, it changes.
- Now these magnetic energy is fed, that is the B is the magnetic flux so that is fed into another block which takes it to the magnetic energy. But its output is a mechanical energy with vibration or motion or displacement or whatever it is.



Block-diagram representation of the transduction processes within a magnetic actuator

- That means from electrical to basically the mechanical motion displacement from vibration, that conversion sometimes it needs another block which changes from electrical to magnetic energy.
- In some cases, there are certain materials which directly from electrical can be converted into mechanical vibration and most on those you know is a piezoelectric material.
- So input if you apply the electrical energy, electrical field and output you will get the mechanical motion or vibration and in this short of crystal, but not always.

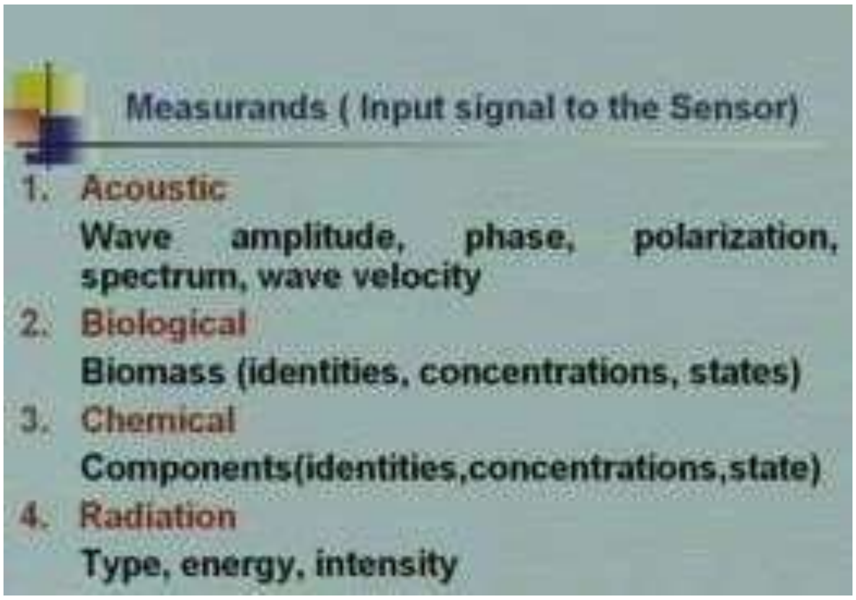
FORMS OF ENERGY CONVERTED BY A SENSOR:

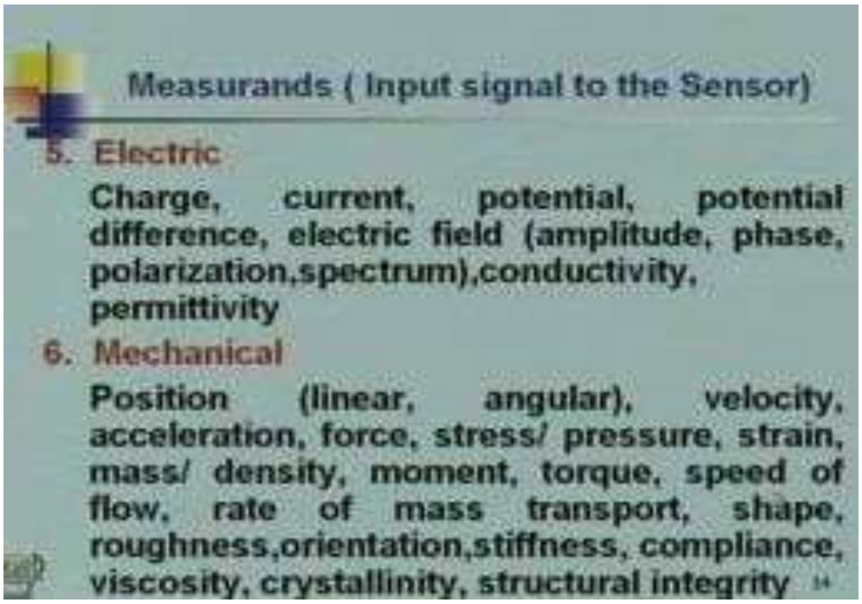
- Those forms of energy are many.
- One is atomic energy, electrical energy, gravitational energy, magnetic energy, mass energy, mechanical energy, molecular energy, nuclear energy, radiant energy and thermal energy and so on.
- So **atomic energy** relates the force between nuclei and electrons. So, that is the atomic energy.
- **Electrical energy** pertains to electrical field current or voltage.
- **Gravitational energy** it is related to the gravitational attraction between a mass and the earth.
- Similarly **magnetic energy** deals with magnetic field.
- So **mass energy** described by Einstein and you know if mass is m, so energy equivalent of m is mc square, where c is the velocity of light is the same as Einstein equation E equal to mc square.
- **Mechanical energy** pertains specifically to the motion, displacement and force. So those are mechanical energy.
- **Molecular energy** is basically the binding energy between the molecules is known as the molecular energy.
- So **nuclear energy** is the binding energy between two nuclei. So you can get the distinction between molecular energy and the nuclear energy. So molecule to molecule, that binding energy is molecular energy. And nucleus to nucleus, that binding energy is called nuclear energy.
- And **atomic energy** is electrons with the nucleus. So those three energies little bit slight difference, all are related to the molecule structures, means atoms, nucleus or molecules.

- **Radiant energy** related to the electromagnetic radio waves, microwaves, infrared visible light, ultraviolet, X-rays and gamma rays, those are radiant energy.
- **Thermal energy** related basically to kinetic energy of atoms and molecules.

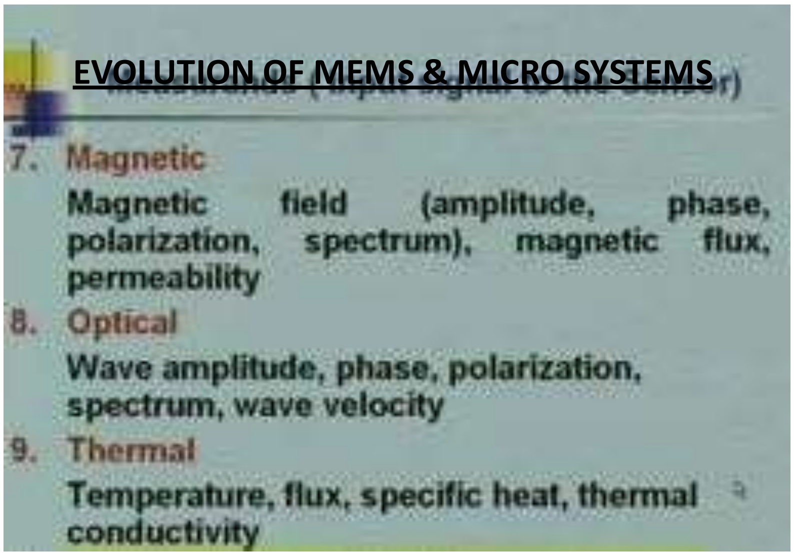
TYPES OF SIGNALS:

- Each form of energy has a corresponding signal associated with it. And those are chemical signal that is basically atomic and molecular energy, electrical signal, magnetic signal, mechanical signal which are gravitational and mechanical, radiant signal, thermal signal.
- So these are different signals we are getting and those signals are fed into your sensor system.





EVOLUTION OF MEMS & MICRO SYSTEMS



- Feynman visionary is a great visionary and he told us that there is a plenty of room at the bottom.
- At the same time he predicted that the entire encyclopaedia could be written on the head of a pin. And his vision in 1959 is close to the reality in 2004.
- Because of the miniaturization of the devices, miniaturization of the systems, at the same time the miniaturization of the sensors has made successful of the dream of Feynman which was published in 1959 in a famous paper by Feynman.
- And at that time he also predicted that it is possible to fabricate a motor with a

th

Table 8.1 Classification of transducers by electrical property or signal type

Property/signal	Descriptor	Example of sensor	Example of actuator
Property:			
Resistance, R	Resistive	Magnetoresistor	Piezoresistor
Capacitance, C	Capacitive	Chemical capacitor	Electrostatic motor
Inductance, L	Inductive	Inductive proximity sensor	Induction motor
Signal:			
Voltage, V	Potentiometric	Thermocouple	Electrical valve
Current, I	Amperometric	Fuel cell	Solenoid valve
Charge, q	Coulombic or electrostatic	Piezoelectric pressure	Electrostatic resonator
Frequency, f	–	Acoustic wave	Stepper motor[a]

[a]Operated with a pulsed rather than alternating current (AC) actuating signal

volume less than 164 of an inch.

- That mean at that time one could not foresee the mechanical things can be miniaturized. But now it is also possible because of the evolution of the MEMS.
- Now micromotors are available whose dimension are few millimeter by few millimeter and obviously it can be reduce still further with innovations of new technologies new processes new materials.
- And then Sir Feynman's vision will be successful obviously in the near future and is close to the reality.

MINIATURIZATION AND BATCH PROCESSING:

- Now, if we look back from the transistor discovery which is 1947, then comes planar silicon technologies 1950 then comes integrated circuits 1960 and after that there are two areas; one area is meant for the silicon VLSI and another area is micromechanics or micromachining and on the other hand MEMS. So it has basically got importance in 1970 and from there in 1982 when Peterson paper came and people thought extensively and how to improve, how to progress with that particular area, that is MEMS or micromachining area.

MICROMACHINIG/MEMS/MICROSYSTEMS:

- Then in 1980, the micromachining technology evolved and photolithography etching recognized as a tool of micromachining.
- Because all the other photolithography etching was used in case of patterning of VLSI, VLSI components or VLSI fabrication photolithography technique and etching technique was used.
- And in a micromachining means, here the same technology but little bit difference is there. Here the aspect ratio may be different, which is used in case of VLSI is not used in case of micromachining.
- Photolithography and etching technique employed in case of VLSI fabrication.
- In 1982 the famous paper which is published in Processing IEEE, which is the silicon as an excellent material.
- Silicon was known to be excellent material for integrated circuits in VLSI. But later on they found, it is also excellent mechanical material. Because, silicon's mechanical properties are also excellent.
- So, it can be used for sensor which will sense the mechanical behaviour of any anybody or any system.

- So that is why the silicone is entered into the MEMS area in a big way.
- And after that there is a mushrooming growth of the MEMS industries has taken place because it has very good market potential.
- So, lots of companies, small size big size companies are coming up to initiate the MEMS research and to market or to produce MEMS device commercially.

MEMS MARKET

- The characteristics of the MEMS markets are fragmented.
  1. Because of different amount of application in different areas.
  2. Even then the cumulative annual growth rate of the MEMS market is nearly 25 percent.
- Today large volume applications of MEMS device or in the area of
  1. Ink jet head
  2. In case of pressure and acceleration sensors for automobile application and
  3. Pressure sensors for medical application.
- These three area, big market at present one is the
  1. Ink jet head
  2. Pressure sensors and
  3. Acceleration sensors.
- Application areas are automotive application and medical application. Now new killer applications expected. Those at present, this market is not very big but within 1or 2years, it will be the killer application.
- One is RMMs for wireless communication you know at present lot of wireless devices are coming up. Because one example is your mobile handset. Then opto MEMS for telecommunication application. It may restart but not within the next 24 months people are predicting.
- Other is a killer applications is bio MEMS.
- A strong growth since 1997 for DNA chip and proteomic chip but very fragmented in terms of applications and technologies.
- Major growth areas of MEMS, they use a specific process to make devices for key customers that is the applications specific.

MEMS MARKET GROWTH:

SALES OF MEMS DEVICES:

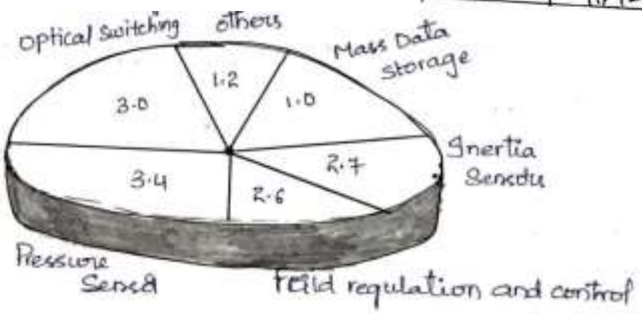
MEMS WORLS MARKET:

(Millions of US Dollars).

Year	Automotive	Medical	IT & Industries	Military & Aerospace	Total
1996	355	165	492	62	1074
2000	646	291	733	111	1781
2004	1172	716	1514	202	3604

(in Millions of Euro's)

Devices and Applications	1996	2003
Ink jet printers, Mass-flow sensor, biolab chips : Micro fluidics.	400 - 500	3000 - 4450
Pressure Sensors : automotive, Medical, and Industrial	390 - 760	1100 - 2150
Accelerometers and Gyroscopes : ~~photonics and~~ automotive & aerospace	350 - 540	700 - 1400
Optical switches and displays : photonics and communications.	25 - 40	440 - 950
other devices such as micro-relays, Sensors & disk heads	510 - 1050	1230 - 2470
Total in Million (€)	1675 - 2890	6,470 - 11,420



APPLICATIONS OF MEMS

- The micro mechanical device embedded with electronics/electrical system fabricated through a mix of integrated circuit manufacturing and micro-machining process where material is shaped by etching away micro layers is called Micro Electro Mechanical System (MEMS).
- The intelligent electronic system part is integrated in the same way of IC device fabrication. The most popular material used for MEMS is Silicon for it's semiconductor, physical and commercial properties.
- Micro-Electro-Mechanical Systems consists of mechanical elements, sensors, actuators, and electrical and electronics devices on a common silicon substrate.
- The sensors in MEMS gather information from the environment through measuring mechanical, thermal, biological, chemical, optical, and magnetic phenomena.
- The electronics then process the information derived from the sensors and through some decision making capability direct the actuators to respond by moving, positioning, regulating, pumping, and filtering, thereby controlling the environment for some desired outcome or purpose.
- The advantages of semiconductor IC manufacturing such as low cost mass production, reliability are also integral to MEMS devices.
- The size of MEMS sub-components is in the range of 1 to 100 micrometers and the size of MEMS device itself measure in the range of 20 micrometers to a millimeter.

Some of the advantages of MEMS devices are,

1. Very small size, mass, volume
2. Very low power consumption
3. Low cost
4. Easy to integrate into systems or modify
5. Small thermal constant
6. Can be highly resistant to vibration, shock and radiation
7. Batch fabricated in large arrays

8. Improved thermal expansion tolerance

9. Parallelism

Typical Applications:

There are plenty of applications for MEMS. As a breakthrough technology, MEMS is building synergy between previously unrelated fields such as biology and microelectronics, many new MEMS and Nanotechnology applications will emerge, expanding beyond that which is currently identified or known.

MEMS technology finds applications in the below general domains

Automotive domain:

1. Airbag Systems
2. Vehicle Security Systems
3. Inertial Brake Lights
4. Headlight Levelling
5. Rollover Detection
6. Automatic Door Locks
7. Active Suspension

Consumer domain:

1. Appliances
2. Sports Training Devices
3. Computer Peripherals
4. Car and Personal Navigation Devices
5. Active Subwoofers

Industrial domain:

1. Earthquake Detection and Gas Shutoff
2. Machine Health
3. Shock and Tilt Sensing

Military:

1. Tanks
2. Planes
3. Equipment for Soldiers

Biotechnology:

1. Polymerase Chain Reaction (PCR) microsystems for DNA amplification and identification
2. Micro machined Scanning Tunnelling Microscopes (STMs)
3. Biochips for detection of hazardous chemical and biological agents
4. Microsystems for high-throughput drug screening and selection
5. Bio-MEMS in medical and health related technologies from Lab-On-Chip to biosensor & chemo sensor.

The commercial applications include:

1. Inkjet printers, which use piezo-electrics or thermal bubble ejection to deposit ink on paper.
2. Accelerometers in modern cars for a large number of purposes including airbag deployment in collisions.
3. Accelerometers in consumer electronics devices such as game controllers, personal media players / cell phones and a number of Digital Cameras.
4. In PCs to park the hard disk head when free-fall is detected, to prevent damage and data loss.
5. MEMS gyroscopes used in modern cars and other applications to detect yaw; e.g. to deploy a roll over bar or trigger dynamic stability control.
6. Silicon pressure sensors e.g. car tire pressure sensors, and disposable blood pressure sensors.
7. Displays e.g. the DMD chip in a projector based on DLP technology has on its surface several hundred thousand micro mirrors.
8. Optical switching technology, which is, used for switching technology and alignment for data communications.
9. Interferometric modulator display (IMOD) applications in consumer electronics (primarily displays for mobile devices).
10. Improved performance from inductors and capacitors due the advent of the RF-MEMS technology

MEMS devices:

Few examples of real MEMS products are,

1. Adaptive Optics for Ophthalmic Applications
2. Optical Cross Connects
3. Air Bag Accelerometers
4. Pressure Sensors
5. Mirror Arrays for Televisions and Displays
6. High Performance Steerable Micro mirrors
7. RF MEMS Devices
8. Disposable Medical Devices
9. High Force, High Displacement Electrostatic Actuators
10. MEMS Devices for Secure Communications

MEMS devices used in Space exploration field include:

1. Accelerometers and gyroscopes for inertial navigation
2. Pressure sensors
3. RF switches and tunable filters for communication
4. Tunable mirror arrays for adaptive optics
5. Micro-power sources and turbines
6. Propulsion and attitude control
7. Bio-reactors and Bio-sensors, Micro fluidics
8. Thermal control
9. Atomic clocks

MEMS MATERIALS

- Broad spectrums of materials are used in fabrication of MEMS structures and devices.
- Major material families are:
  1. Metal and metal alloys
  2. Polymers
  3. Semiconductors
  4. Ceramic materials

METAL AND METAL ALLOYS:

- Thick metal films for those devices which are used for structural materials for final sensors and sometimes it is also used as a mould which has inserted into the polymer on ceramic micro moulding.
- Micro electroplating or photoforming are used to build thick metal film structure for different components of the microsystems or MEMS devices.
- Electroplating is another technique which is used for making thick metal films. Thick means several microns may be 20 micron, 30 micron, 40 micron in that range.
- We can have the metals of thicker film for example gold, nickel, copper, chromium those are deposited by electroplating techniques and various applications are their for the electroplating of gold, nickel and copper.
- The alloy cobalt, nickel, manganese is used for permanent magnetic materials for magnetic actuation.
- So titanium and nickel are used for shape memory application.
- An electroplating of nickel and iron Permalloy on silicon for magnetic MEMS is also getting importance now a day.
- So these are the various kinds of metals and their alloys which are used for microsensors devices.

POLYMERS:

- Polymers are extensively used now days as both structural and functional materials for micro devices and MEMS.
- Polymer can be used as a structural as well as it can be used as a functional material also.
- Now the main properties used for polymers are elasticity, optical properties of polymer, biocompatibility of the polymer. These are the main advantages of the polymer because of that it can be used as the structural materials for MEMS.
- Now polymer strain gauges and capacitors serve as a sensing element of piezoresistive and capacitive microsensors.
- Electrostatic polymer microactuators can be formed from polymide.
- Polymide is a one class of polymer it has got electrostatic properties and it is used for making microactuators.

- Polymide based ferrite magnetic composites for magnetic microactuator is another application.
- Polymer as electronic material and that electronic material like, semiconductor silicon, germanium.
- Similarly polymer can be used as a electronic material because now a day polymer transistor has come up and has win successfully fabricated using polymer and people are thinking a polymer can be used for active device fabrication also.

Polymer Names	fabrication process	Property Utilised
Polymide	Coating	Elasticity
Parylene C	Coating	Wafer barrier
PMMA	LIGA	elasticity, optical
Polyester	Casting	Elastility
Polycarbonate	Hot embossing	Elasticity, Optical.
Polymer Names	**Functional Property**	**Applications.**
PVDF	Piezoresistivity	Sensor, actuator
Polypyrrole	Conductivity	Sensor, Conductor
Flurosilicone Silicone	Electrostrictivity	Actuator.
Polyurethane		

CERAMIC MATERIALS:

- So ceramics are inorganic materials that consist of metallic and non-metallic elements chemically bonded together.
- That is the definition of ceramics and the materials used or ceramic materials used in MEMS are aluminium oxide, silicon dioxide, silicon nitrite, sodium chloride, calcium fluoride and $YBa_2Cu_3O_6$..

- So this is a new ceramic material we have started using in case of MEMS devices ceramic pressure microsensor for high temperature environment in which area ceramic materials are promising, particularly two areas; one is high temperature, another is harsh environment.
- Other promising functional ceramics are zinc oxide and PZT. Lead Zirconate and Titanate that is PZT and Zinc Oxide.
- These two materials are extensively used now a day as the functional material for MEMS.
- Fabrications of ceramic MEMS, techniques used are screen printing, tape lamination, micro moulding, Sol Gel and MSL. MSL stands for Microstereolithography, so microstereolithography technique is used to get 3D structure in polymer, in ceramics and in sometimes in case of the composing materials also.

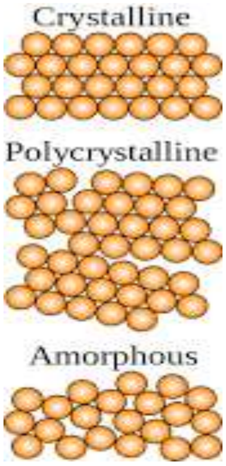
COMPOSITE MATERIALS:

- Of these 4 groups, if you combine materials from different group to obtain the desired material characteristic, then it is known as a composite material and lot of research is going on composite material to achieve various specific properties.
- If you combine the metal with ceramic, you can combine polymer ceramic and metal. Sometimes, semiconductor materials are also used to have some composite thing which has got unique properties or unique application.
- So these materials are used as passive materials in microsensors and MEMS. Smart materials when used as an active material in MEMS.

SEMICONDUCTOR MATERIALS:

- Semiconductor, mostly we use silicon. So there silicon is the single crystal silicon.
- So crystal, there are 3 kinds of material crystalline, polycrystalline and amorphous.
- There is a difference between the crystal and polycrystalline and, amorphous material and amorphous and polycrystalline.
- **Crystalline** is known because it will have long range regular order and a periodic arrangement of atoms in a crystal and that periodic arrangement of atom, these are known as the lattice and all the atoms in a crystal are located in the lattice points and the distance between the lattice points is known as the lattice constant.
- **Polycrystalline**, then it is not long range, in a short range, locally the regularity is maintained, the structure is maintained, but over the long range it is not maintained.

- On the other hand, **the amorphous**, there is no regularity between the crystal lattice structures. It is a highly irregular and the crystal are or atoms inside the crystal are oriented or all placed in different direction. So in the half hazard direction, so it is known as amorphous material.



MEMS MATERIAL PROPERTIES

- Different kinds of properties of the materials are use for making sensors and actuators

SILICON AS AN EXCELLENT MECHANICAL MATERIAL:

- So silicon is a mechanical material and which is having single crystal and it has got diamond crystal structure.
- Its **density** we have seen is equal to aluminium, nearly equal to aluminium but 1ne third of the steel. So in their respect the silicon is lighter than steel.
- In a second point its **hardness**. Hardness is half of steel and greater than iron tungsten and aluminium. So called a hardness is concerned the silicon hardness is greater than the iron tungsten and aluminium.
- **Thermal expansion coefficient** is a half of steel. There is a good thing that in thermal expansion and coefficient is not very hard.
- **Yield strength** is 2 times greater than steel.
- **Young's modulus** is almost equal to steel.
- **Thermal conductivity** that is 1.5 times of steel.
- **Deform** elasticity and remember not plasticity.

WHY SILICON FOR MEMS/MICRO SENSOR/MICROMECHAHNICS:

- Silicon got excellent mechanical performance and it enables effectively to replace a majority of all other sensing technologies.
- The existing infrastructure of the mainstream IC industry is available.
- So that, we will use in case of MEMS fabrication or micro sensors fabrication.
- Performance will be very good and price will be low. So the ratio of price to performance is extremely low in case of silicon because of the available of the infrastructure which is very important.
- Silicon mechanical strength is comparable to even higher than steel but at a lower density and better thermal conductivity.
- Silicon density it's lower than iron and its thermal conductivity also very high compared to1.5 times of that.
- So because of that it cannot generate, lot of heat distribution is more and that is advantageous compared to other materials, so that is desired thing. So these are the favourable points in case of silicon.
- Silicon, mechanical and thermal both hysteresis are extremely low.

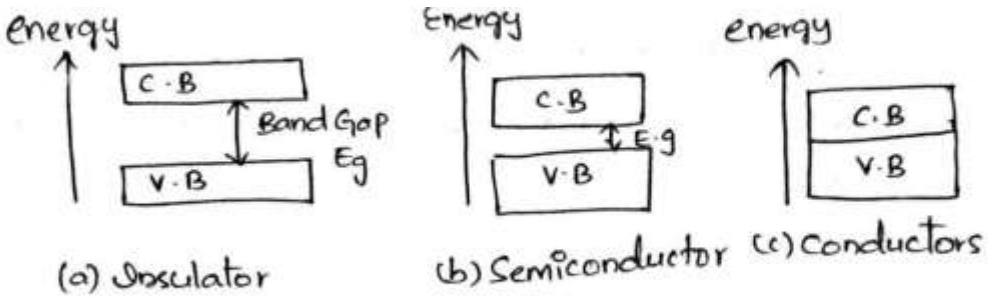
ELECTRONIC PROPERTIES OF MATERIALS:

Electronic properties of materials are:

1. Energy band gap
2. Intrinsic semi conductor
3. Extrinsic semiconductor
4. Mobility
5. Resistivity
6. Piezo resistivity
7. Piezo electricity
8. Thermo electricity
9. Pyro electricity

Energy band gap:

- Silicon has 4 valence electrons that took part on bonding to adjacent atoms.



Intrinsic semi conductor:

- Intrinsic semiconductor does not have any impurity and conductivity is provided by thermal excited electrons.
- Because there is no impurities doped in intrinsic, impurity electrons will not take part in a current conduction only intrinsic electrons and volts which are available they will take part in current conduction. So obviously its conductivity will not be very high.

Extrinsic semi conductor:

- Extrinsic semiconductor, here you have to dope some extrinsic impurity materials and because of doping of the material, if you dope impurity atoms which have got a higher level of the silicon.
- That means for example, higher group if you dope with a phosphorus atoms or arsenic atoms which is having 5 which is having five electrons in the outermost orbit.
- So here, if it replaces silicon there so then 1 extra electron is available for conduction. Here you see in addition to the thermally generated electron you are having much more carrier.
- These are the free carriers from the impurity atoms. Now impurity atom, if you dope to a large extent, so there are 2 kinds of carriers wants are thermally generated carriers in addition to the extra carriers available from the impurity atoms.
- So both the carriers will take part in current conduction mechanism. So as a result to be conductivity will be higher in case of extensive semiconductor in time.

MOBILITY (μ):

- So mobility is defined as the drift velocity of the carriers per unit potential gradient.
- So it is denoted by the term μ and its unit is centimetre square per volt second.

RESISTIVITY:

- Resistivity in a semiconductor bar is a given by rho

$$R = p.\ L/A$$

Where L is the length of the semiconductor material and

A is the cross sectional area.

So rho is the resistivity

PIEZORESISTIVITY:

- That is another electronic property of the semiconductor material which is very important and which is used for making micro sensors, either it is a many kinds of micro sensors, MEMS micro sensors like the pressure sensors, gyros or accelerometer. These are based on the piezoresistive property of silicon materials.
- **It is a property of a material where the bulk resistivity is changed by mechanical stresses applied to the material. If you apply mechanical stressor force on a bulk material, then its property particularly resistivity will change. That is the Piezo resistivity**.
- There are three reasons for changing:
  1. **Change of carrier**: Mobility will take place if you apply pressure on a particular semiconductor body.
  2. **Change of number of charge carriers as a function of volume of material**: So if we apply stress on a body its volume may change and because of change of volume, the number of the charge carriers may change and because of that, also resistivity may change.
  3. **Volume change which affect the energy gap** between valency band and conduction band. That is another property, important electronic property, if you apply pressure or stress on a particular semiconductor material its band gap that means the energy gap between the conduction and valency band may change.
- Although all materials have piezoresistance effect to some extent, single crystal silicon has a high Piezo resistivity along with excellent mechanical property.
- Piezoresistance property is available in most of the materials. But in some cases it is very small in some cases is very large.

- Fortunately, silicon material will have very large piezoresistance effect and along with the good mechanical property. So it is a good conduct for micro sensors.

* fractional change in resistance due to applied mechanical stress to the material:

$$\frac{\Delta R}{R} = (1+2\nu)\frac{\Delta L}{L} + \Delta\rho/\rho$$

↳ deformation length changes

PIEZO ELECTRICITY:

- So piezoelectricity is understood as a linear electromechanical interaction between mechanical and the electrical state in crystal without a center of symmetry.
- Those crystals which do not have the center of symmetry will show the piezoelectric property.

$$\frac{\Delta\rho}{\rho} = \pi\sigma$$ (π is a Piezoresistive Coefficient)

In general $\frac{\Delta\rho}{\rho} = \pi_i\sigma_i + \pi_t\sigma_t$

π_i & π_t ⇒ longitudinal and transversal Piezoresistive co-efficients

σ_i → longitudinal stress llel to direction of current flow

σ_t → transversal stress ⊥lar to direction of current flow.

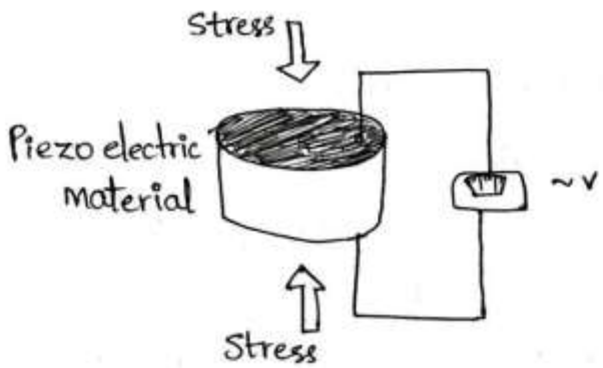
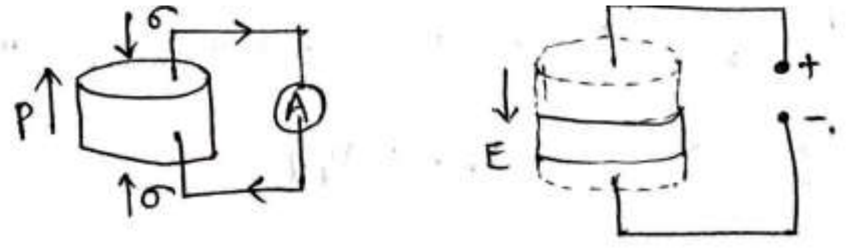


fig: Piezoelectric Effect

- Piezo electric is of two types:
  1. Direct Piezo electric
  2. Indirect or Converse Piezo electric

Direct Piezo electric:

- The direct piezoelectric effect is used for microsensor and the converse piezoelectric effect is used for actuators, microactuators.
- So direct piezoelectric effect basically, if we apply certain external force or pressure on the surface of the crystal, so some charge will accumulate at the surface.
- As a result of which you will get some voltage if you connect the 2 surface with wire, you will get some voltage.
- So that means there is an electromechanical, if you apply the mechanical pressure you are getting some electric field that can be used as a microsensor.
- On the other hand if you apply certain electric field at the surface of the crystal then the crystal inside the crystal there is a movement or strain will be developed.
- That means mechanical energy or mechanical force will generate so that property can be used for designing a micro actuator.
- That means piezoelectric material can be used either microsensor, then it is a direct piezoelectric effect or it can be used as an actuator when you are taking help of converse piezoelectric effect.



(a) Direct PE (b) Converse PE

Converse Piezo electric:

- The material is deformed when electrical voltage V is applied.
- This effect can be used for sensing and actuation.
- The effect produces DC charge but not Dc current.

Thermo electricity:

- If you change the temperature the resistance will change that property is known as thermo resistivity.

$$R = \rho L / A \quad (\rho = \text{resistivity})$$

L= length of bar, A = area

$$R = \frac{\rho L}{Wt} \quad (t = \text{thickness of bar}, W = \text{width})$$

$$1/\rho = \sigma = q\,(\mu_n n + \mu_p p)$$

Pyro electricity:

- Pyroelectricity effect is basically development of electric polarization due to temperature change.
- Temperature change that means if you change the temperature of that particular body or crystal or material the electric polarization dipole realignment will be done inside the crystal.
- As a result of which you will have certain charge at the surface which is a Pyroelectric effect.

$$P_\sigma = \delta P / \delta T \quad (c/cm^2 k)$$

P= Polarization , T= temparature

- So materials in the Pyroelectricity with materials which show the pyroelectric effect are zinc oxide and PZT and lead titanate