18ECO133T

Sensors and Transducers

3 Credit Course

UNIT IV

Magnetic sensors: Introduction
Villari effect , Wiedmann effect
Hall effect, Construction, performance characteristics, and its Application
Introduction to smart sensors
Film sensors: Introduction
Thick film sensors
Microelectromechanical systems
Micromachining.
Nano sensors
Applications: Industrial weighing systems:
Link–lever mechanism
Load cells – pneumatic, elastic and their mounting.
different designs of weighing systems.
conveyors type.
weighfeeder type.

Magnetic Sensors

- It serves a strong impact in changing properties of certain materials.
- It produces effects which are mechanical or electrical in nature.
- A magnetic sensor is a sensor that detects the magnitude of magnetism and geomagnetism generated by a magnet or current. There are many different types of magnetic sensors.

Magnetic Sensors-Types

1. Magnetic field sensor
2. Magneto elastic sensors
3. Magnetic elastic sensor
4. Torque/force sensors
5. Magneto resistive sensors
6. Hall effect sensors or magnetogalvanic sensors
7. Distance or proximity sensors
8. Wiegand and pulse wire sensors
9. Superconducting Quantum Interference Devices (SQUIDs)
10. Magnetostriction

Magnetic Field Sensor

- The Magnetic Field Sensor can be used to study the field around permanent magnets, coils, and electrical devices. It features a rotating sensor tip to measure both transverse and longitudinal magnetic fields.
- Developed following 'Δy effect' which is observed as change in Young's modulus with magnetization. The sensors are often termed as Acoustic Delay Line Components (ADLC).
- Note: Young's modulus - the modulus of elasticity in tension or compression (i.e., negative tension), is a mechanical property that measures the tensile or compressive stiffness of a solid material when the force is applied lengthwise. It quantifies the relationship between tensile/compressivestress

Example of Magnetic Field Sensor (Coils)

- Coils are the simplest magnetic sensors that can detect changes of the magnetic flux density

Figure 1. Principle Diagram of Coil

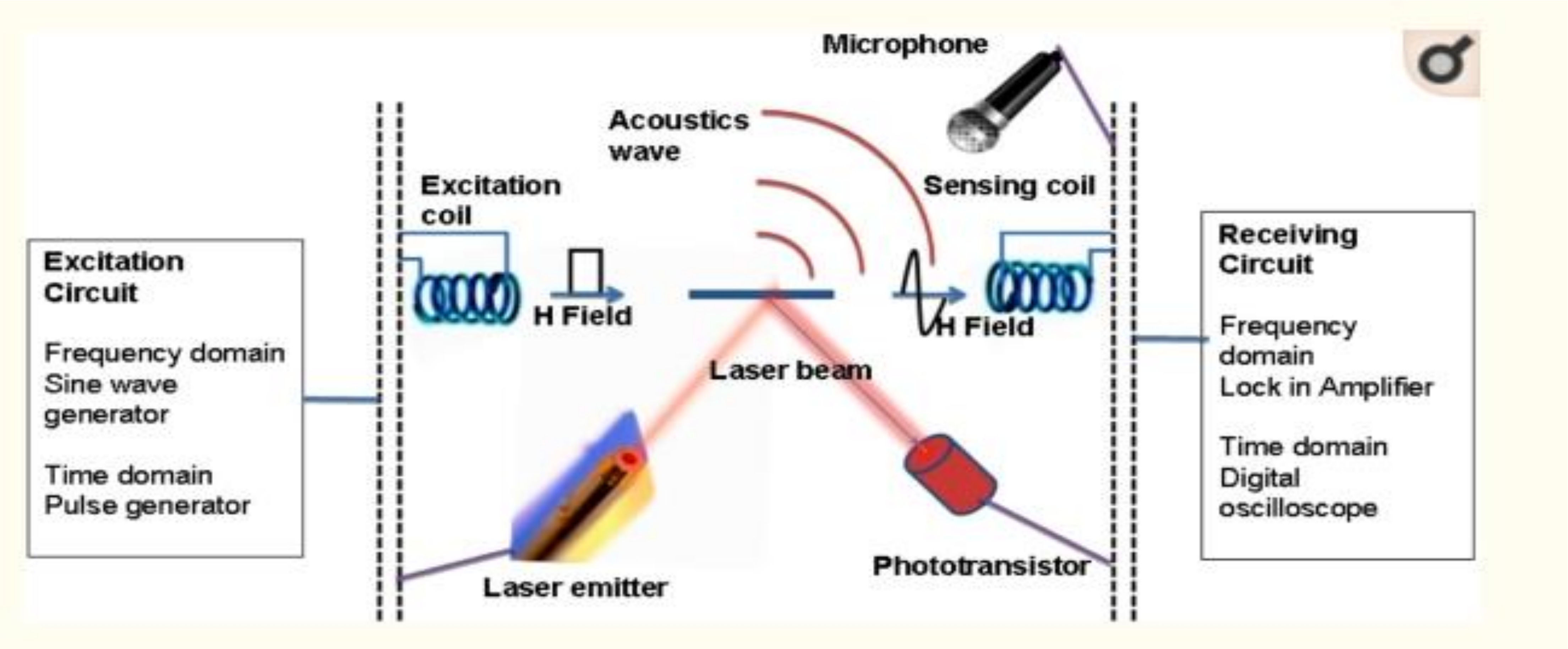
Example of Magnetic Field Sensor (Coils)

- when a magnet is brought close to the coil, the magnetic flux density in the coil increases by ΔB.
- Then, an induced current that generates a magnetic flux in a direction that hinders an increase in magnetic flux density is generated in the coil.
- Conversely, moving the magnet away from the coil reduces the magnetic flux density in the coil, so induced electromotive force and induced current will be generated in the coil to increase the magnetic flux density.

Magneto - Elastic Sensor

- Based on the fact that in a longitudinal field, torsion given in a ferromagnetic rod changes in magnetization – Matteucci effect – (Voltage generating property of a twisted ferro-magnetic wire upon change of magnetization).
- Magnetoelastic sensors are **amorphous ferromagnetic ribbons** that exhibit a magneto-mechanical resonance when excited by a time varying magnetic field. Magnetoelastic sensors have successfully been used for stress, pressure, liquid viscosity and density, fluid flow velocity, elasticity, and temperature monitoring.

Magneto - Elastic Sensor

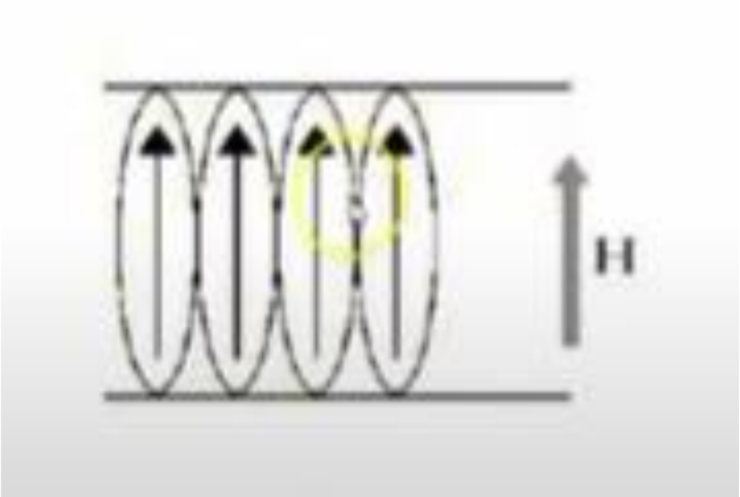


MAGNETIC ELASTIC SENSOR

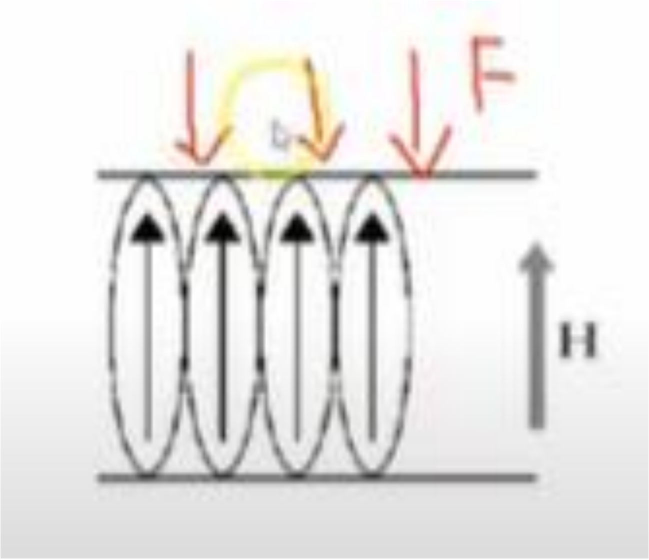
- Produced using villari effect in which a tensile or compressive stress changes magnetization or affects magnetization in some way.
- The **inverse magnetostrictive effect**, **magnetoelastic effect** or **Villari effect** is the change of the magnetization of a material when subjected to a mechanical stress.

Villari effect

- If External magnetic field is applied to ferromagnetic material in vertical direction, the dipoles gets arranged in the same direction

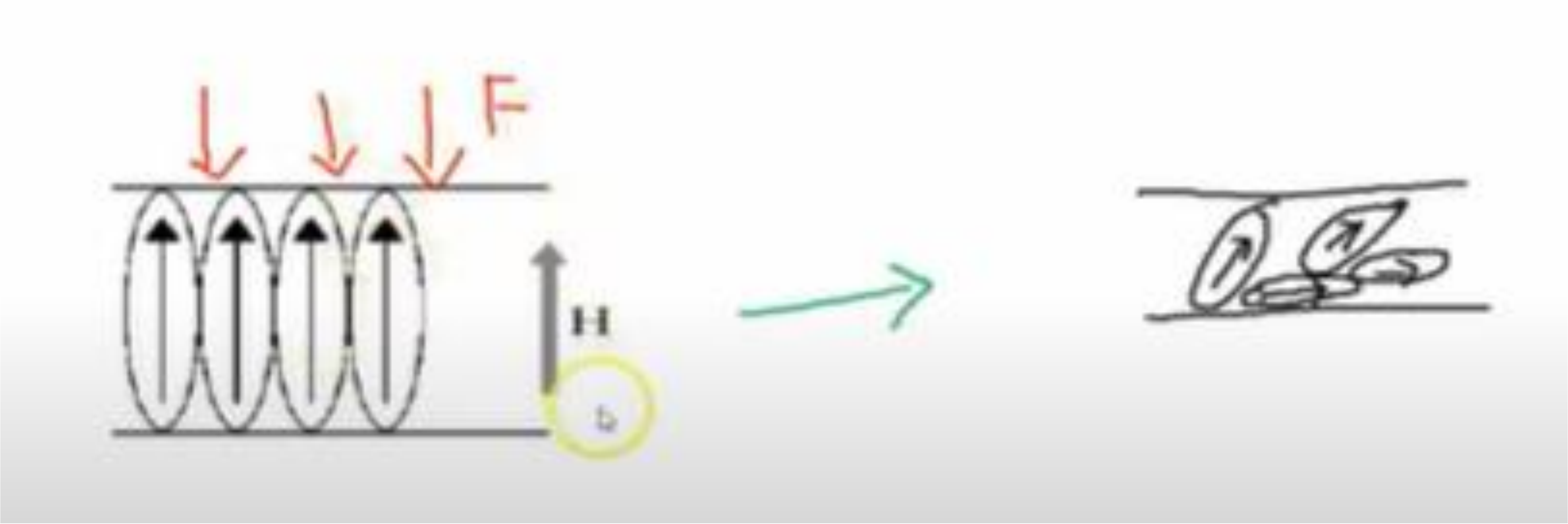


- Apply force to Ferromagnetic material



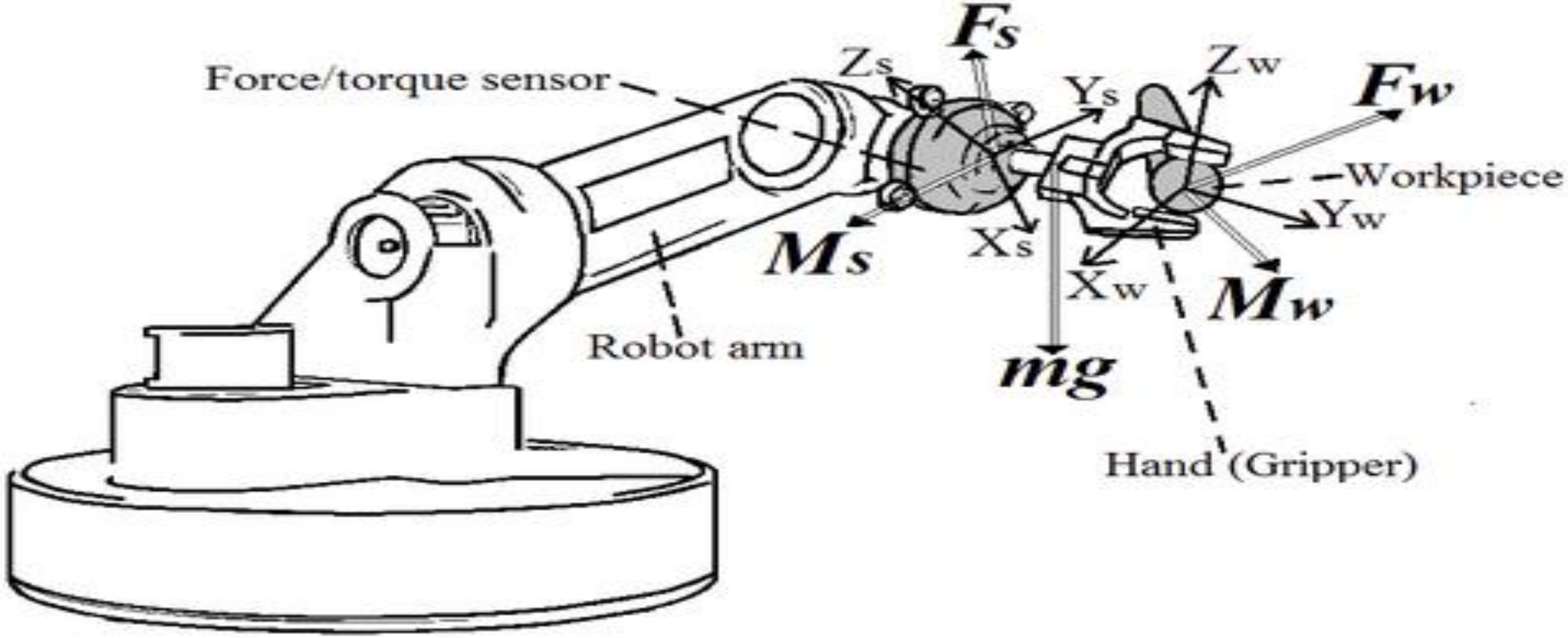
Villari effect

- This changes the direction of dipoles. Even though the external magnetic field tries to align the dipoles, the force changes the structure and direction of dipole (random fashion).



TORQUE/FORCE SENSORS

- A force torque (FT) sensor is an **electronic device that is designed to monitor, detect, record and regulate linear and rotational forces exerted upon it**.

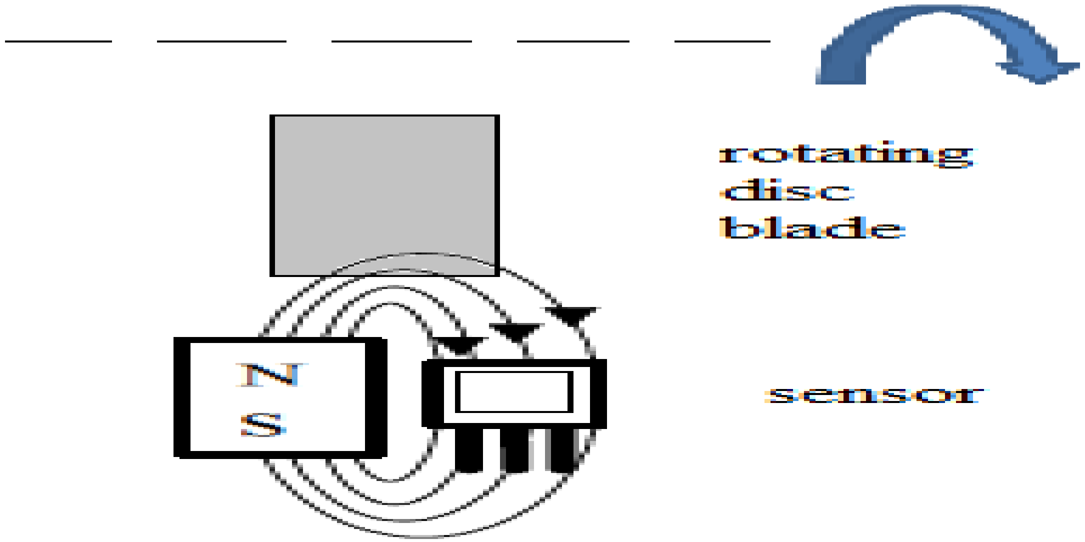


TORQUE/FORCE SENSORS

- Wiedemann effect is used to develop the torque/force sensors. In such sensors, The twisting of a ferromagnetic rod through which an electric current is flowing when the rod is placed in a longitudinal magnetic field

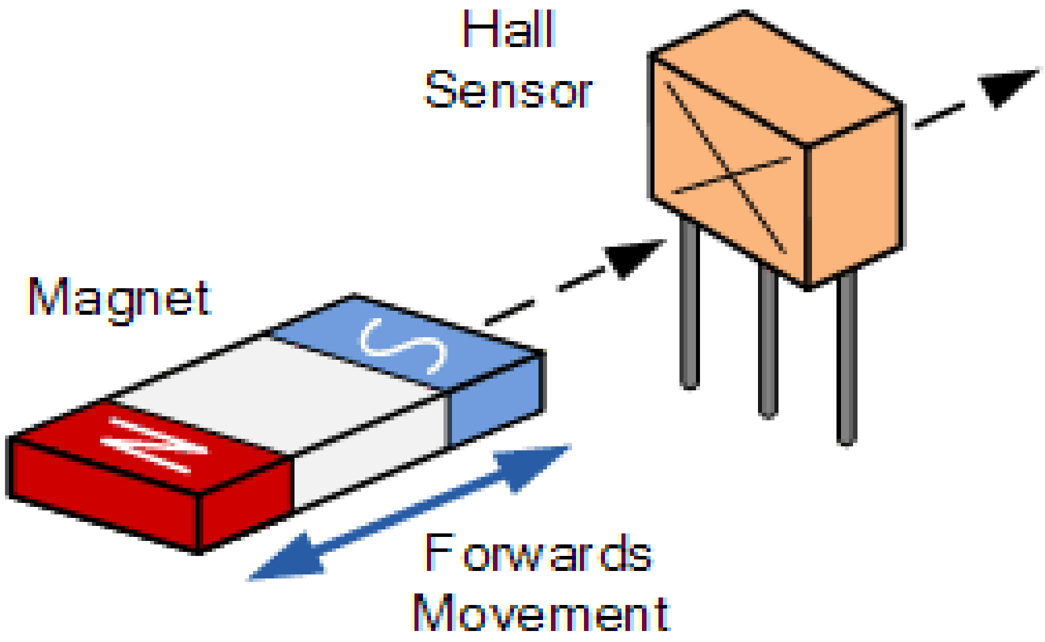
MAGNETORESISTIVE SENSORS

- Becoming increasingly popular, are developed on the basis of 'Thomson effect' which is basically a change in resistance of specified materials with magnetic field impressed.
- A magnetoresistive sensor **uses the fact that the electrical resistance in a ferromagnetic thin film alloy is changed through an external magnetic field**



Hall Effect Sensors (or) Magnetogalvanic Sensors

- Most common and widely used type magnetic sensors.
- These operate on the fact that a crystal carrying a current when subjected to a magnetic field perpendicular to the direction of the current, produces a transverse voltage.

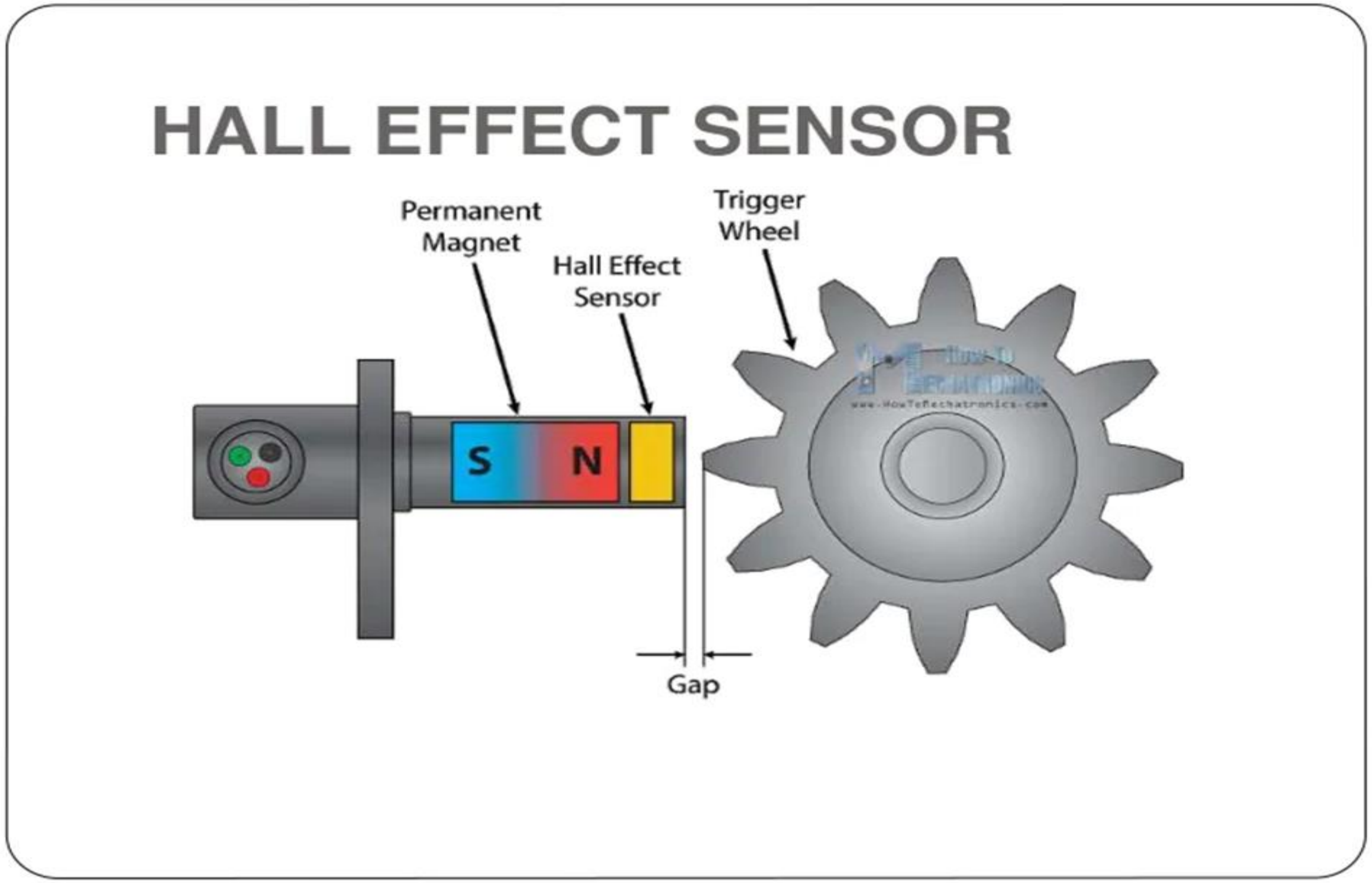


Hall Effect Sensors

- A **Hall effect sensor** (or simply **Hall sensor**) is a type of sensor which detects the presence and magnitude of a magnetic field using the Hall effect. The output voltage of a Hall sensor is directly proportional to the strength of the field
- In a Hall sensor, a current is applied to thin strip of metal. In the presence of a magnetic field perpendicular to the direction of the current, the charge carriers are deflected by the Lorentz force, producing a difference in electric potential (voltage) between the two sides of the strip. This voltage difference (the Hall voltage) is proportional to the strength of the magnetic field.
- Hall sensors are used for proximity sensing, positioning, speed detection, and current sensing applications.

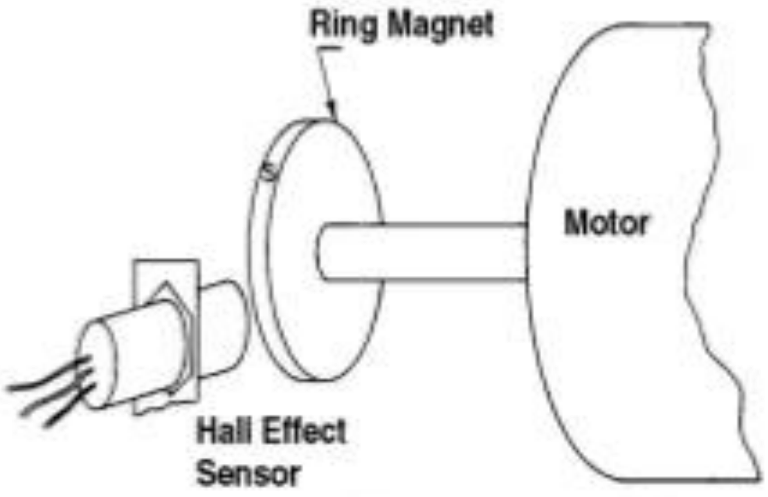
Application of Hall Sensor

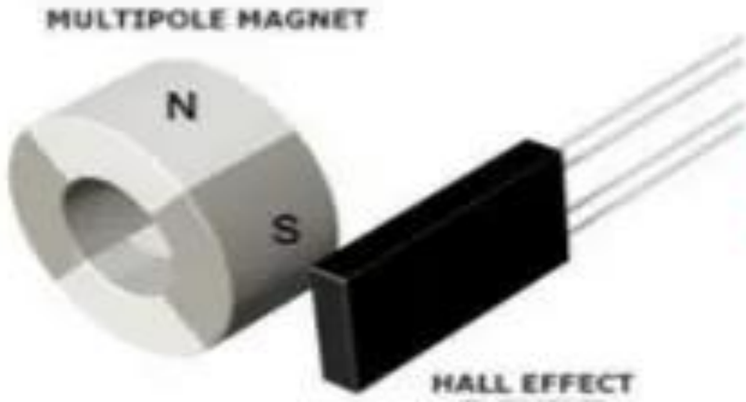
- Voltage produced rotates the gear wheel (in anti lock braking system)



Applications of Hall Field Sensors

Response to South or North Polarity





Motor-Tachometer application where each rotation of the motor shaft is to be detected

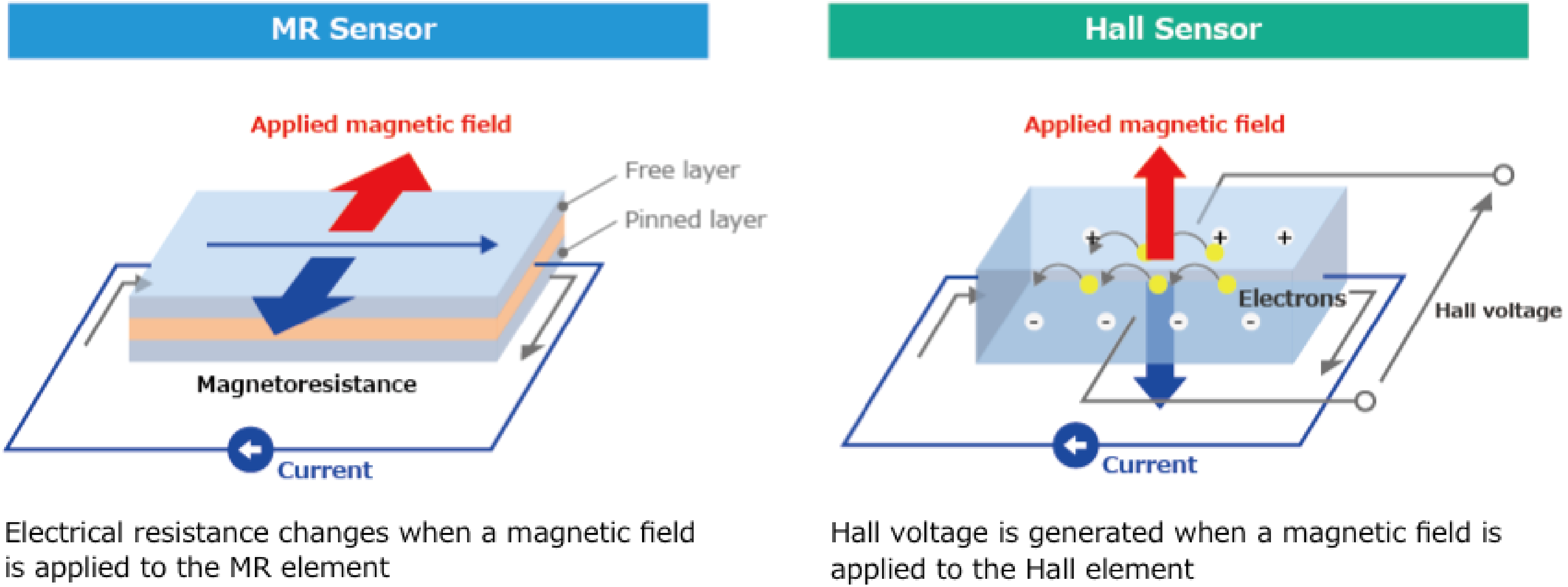
When ring magnet rotates w/ motor, South Pole passes the sensing face of the Hall sensor after each revolution.

Sensor
- Actuated when the South Pole approaches sensor
- Deactuated when South Pole moves away from sensor

Single digital pulse produced for each revolution.

HALL SENSOR VS MAGNETIC SENSOR

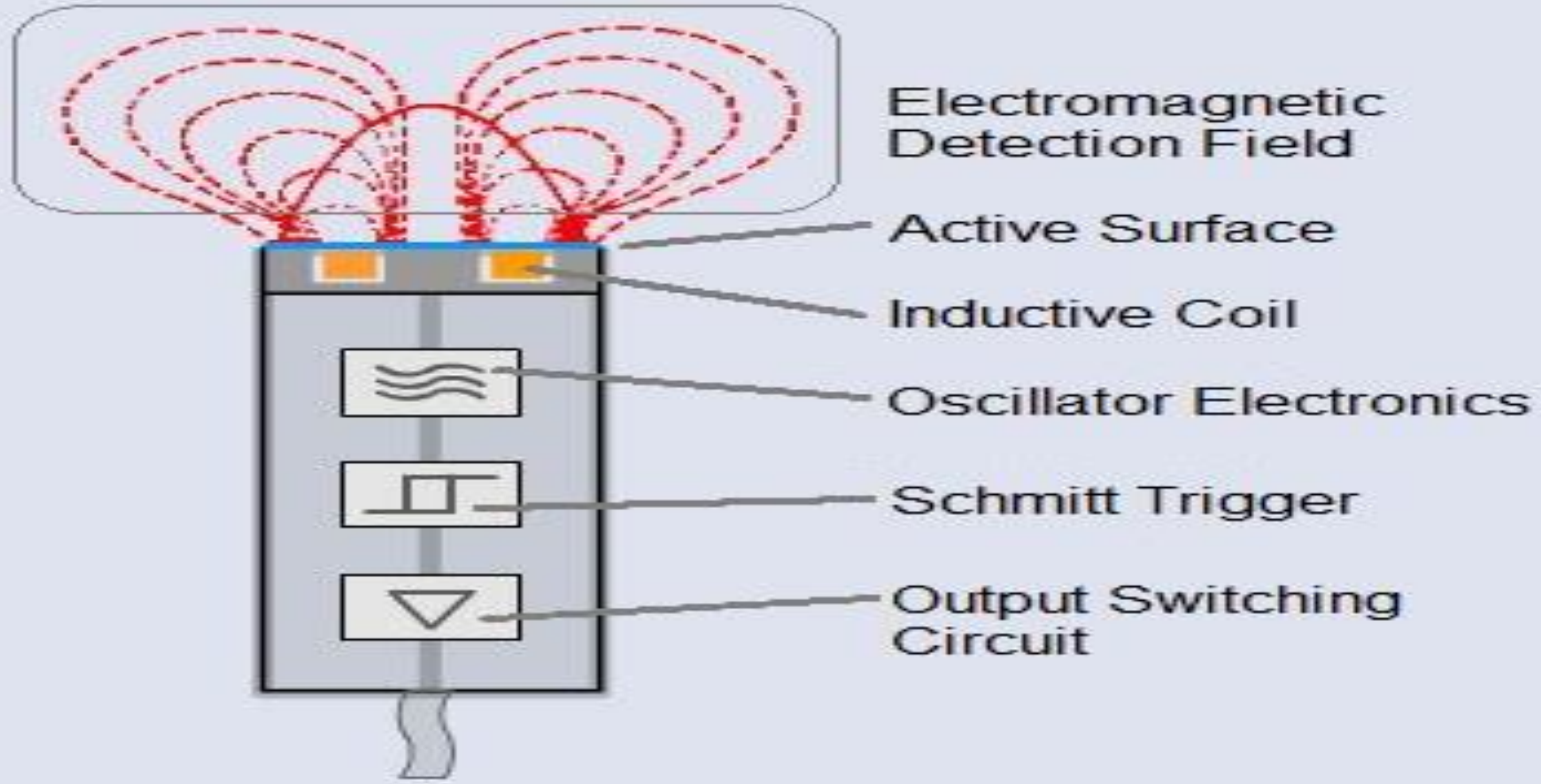
- A **Hall sensor detects the strength of a magnetic field perpendicular to it**, whereas an MR sensor detects the angle of a parall



Distance (or) Proximity Sensors

- Packed in a small package with low power consumption, this IR proximity sensor allows for continuous distance reading with a range of **10cm to 80cm**
- Developed based on ‘skin effect’ in which eddy current forces the current flowing through the interior of a material to move to its surface level.
- Proximity (nearness in space) of the object is detected by a change in capacitance. The sensor can also be used to detect a wide variety of non-metallic and metallic objects and typically operate over a range of **3 to 30 mm**.

Distance (or) Proximity Sensors



Internal Elements of an Inductive Proximity Sensor

Wiegand and Pulse Wire Sensors

- Tiny devices that use variations in an external magnetic field to generate electrical signals and energy

- A specific type of material when subjected to pulse voltages under stress shows switching effect which occurs due to Barkhausen jump.
- This is utilized to produce such sensors. The effect is called ‘Sixtus-Tonks effect’ after the experimenter who demonstrated it.

Wiegand and Pulse Wire Sensors

- Wiegand sensors are built around small sections of Wiegand wire, a specially prepared ferromagnetic alloy that has a unique physical property.
- When exposed to an alternating external magnetic field, a Wiegand wire will initially retaining its magnetic polarity - when the external field reaches a certain threshold, the polarity of the wire segment will abruptly reverse.
- This polarity switch occurs within a few microseconds and can generate a distinct current pulse in a fine copper coil wrapped around the ferromagnetic core.
- This pulse is strong enough to activate logic circuits and can be used to energize low power electronic chips. This self-powering capacity of Wiegand sensors helps make them more reliable – and safer – since they can provide signals for alarm systems without external power sources. There is no need to check or replace backup batteries, sharply reducing maintenance requirements

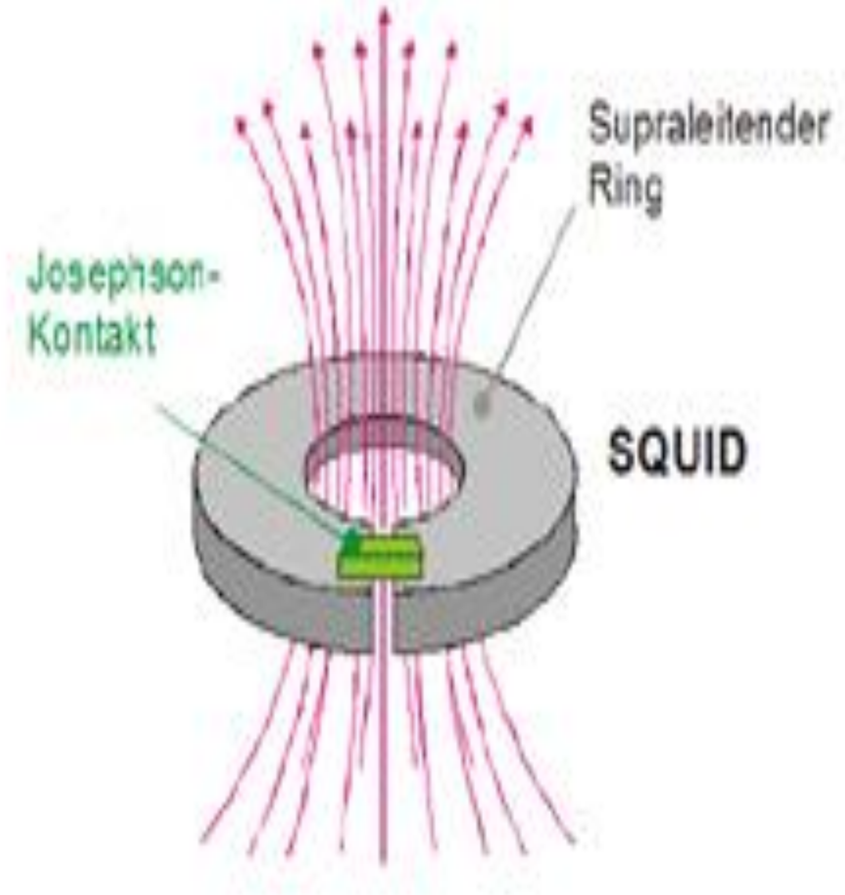
Wiegand and Pulse Wire Sensors

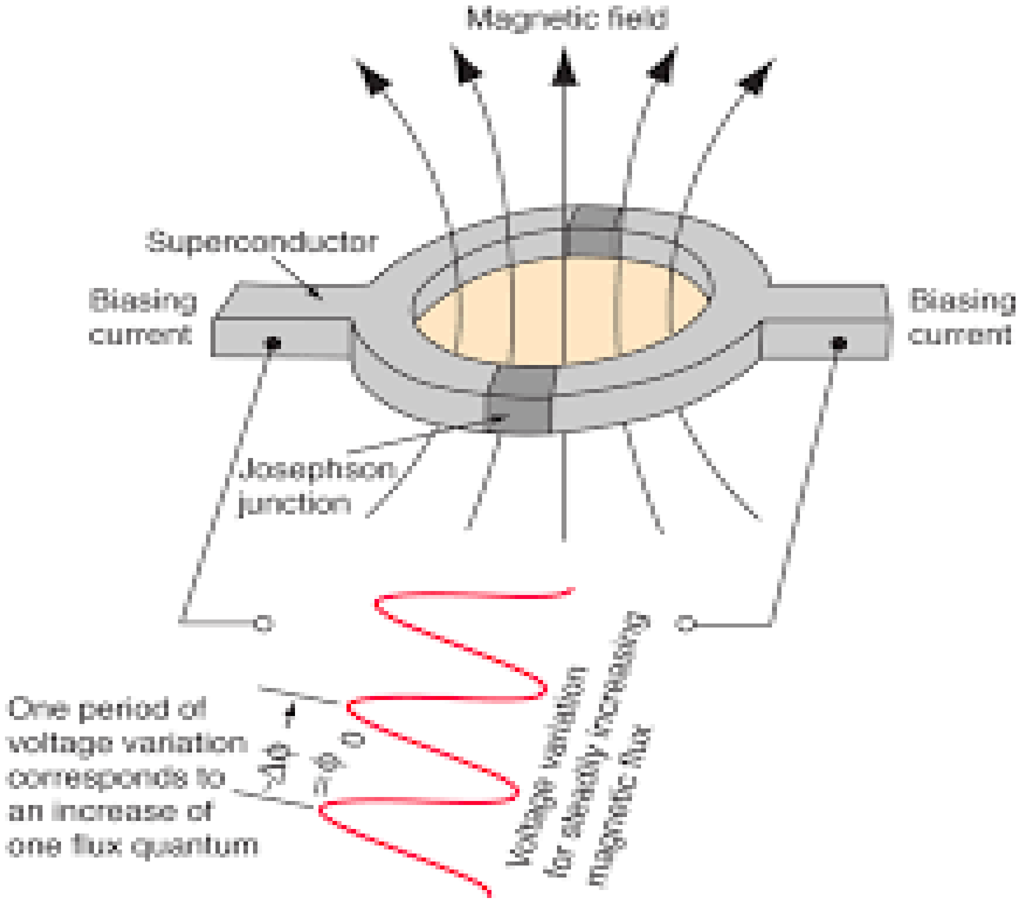
- The **Wiegand effect** is a nonlinear magnetic effect, named after its discoverer John R. Wiegand, produced in specially annealed and hardened wire call ed Wiegand wire
- Wiegand wire is low-carbon Vicalloy, a ferromagnetic alloy of cobalt, iron, and vanadium. Initially, the wire is fully annealed. In this state the alloy is "soft" in the magnetic sense; that is, it is attracted to magnets and so magnetic field lines will divert preferentially into the metal, but the metal retains only a very small residual field when the external field is removed

SUPERCONDUCTING QUANTUM INTERFERENCE DEVICES (SQUIDS)

- A SQUID (Superconducting Quantum Interference Device) is **a very sensitive magnetometer used to measure extremely subtle magnetic fields**, based on superconducting loops containing Josephson junctions.
- SQUIDs are sensitive enough to measure fields as low as 5×10^{-14} T
- Based on the superconducting state specifically, ‘flux quantization and Josephson effect’, SQUODs are used in various applications
- These types of sensors have a resolution of the order of a few femtoTesla(fT).

SQUID


Supraleitender
Ring
Josephson-
Kontakt
SQUID


Magnetic field
Superconductor
Biasing
current
Biasing
current
Josephson
junction
One period of
voltage variation
corresponds to
an increase of
one flux quantum
Voltage variation
for steadily increasing
magnetic flux

Superconductor Magnetometers

- *SQUID sensors*

➢The most sensitive of all instruments for measuring a magnetic field at low frequencies (1 Hz) is the superconducting quantum interference device (SQUID) illustrated in Fig. 6.

➢ It is based on the remarkable interactions of electric currents and magnetic fields observed when certain materials are cooled below a superconducting transition temperature. At this temperature, the materials become superconductors and they lose all resistance to the flow of electricity.

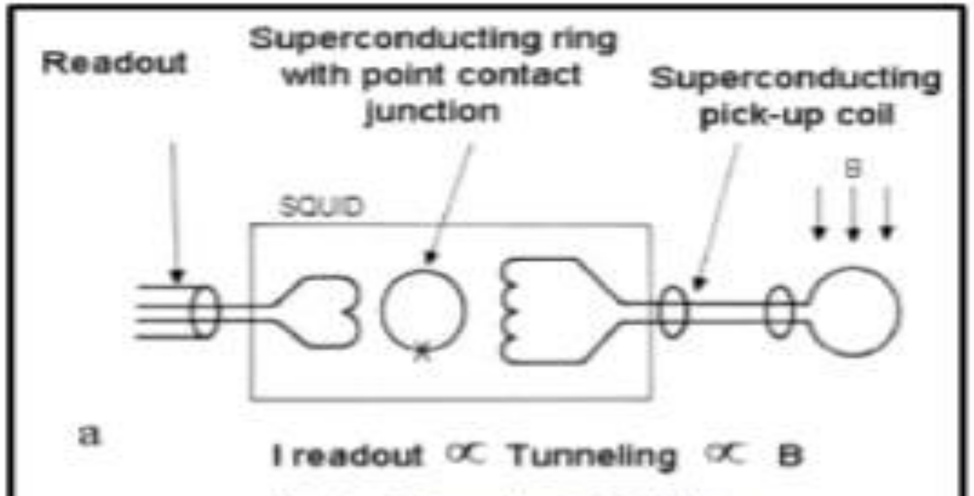


Fig. 6. Schematic of SQUID.

- For a large number of applications extremely small magnetic signals have to be detected and accurately measured.
  - Sensitivities of magnetic sensors:

    Hall probes ~ mT

    Flux gate sensors ~ nT

    SQUIDs ~ *f*T

- SQUIDs allow to detect and characterize the magnetic signals which are so small as to be virtually immeasurable by any other sensors.

- How sensitive? Allows to measure magnetic fields produced by the nerve currents associated with the physiological activity of the human heart (magneto cardiogram – MCG) or the human brain (magnetoencephalogram – MEG); these signals have a typical strength ~ pT.

- Best of the SQUID sensors have energy sensitivity approaching Planck's constant.

- **SQUIDs are the most sensitive detectors of extremely small changes in magnetic flux.**

Fluxes can be created by currents – therefore the most sensitive current sensors as well

SQUIDs - basic facts

- SQUIDs combine the physical phenomena of flux quantization in superconducting loops and Josephson tunneling.
- The Josephson effect refers to the ability of two weakly coupled superconductors to sustain at zero voltage a supercurrent associated with transport of Cooper pairs, whose magnitude depends on the phase difference between the two superconductors.
- The maximum current which a Josephson weak link can support without developing any voltage across it is known as its critical current I_c. When the current passed through a Josephson weak link exceeds I_c, a voltage appears across it
- If a closed loop made of superconductor magnetic field cannot enter the loop ("ideal diamagnetism"). But if there is a weak link flux enters the loop in quanta! Flux quantum

$$\Phi_0 = \frac{h}{2e} \approx 2.07 \times 10^{-15} T \cdot m^2$$

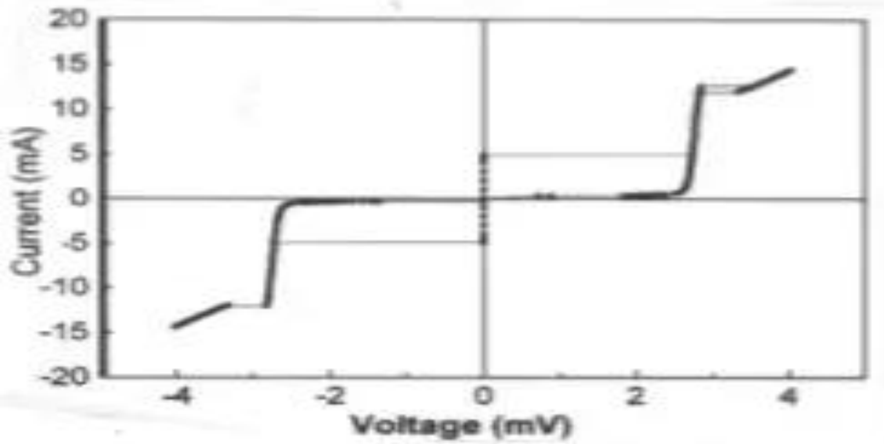


Figure 1. I-V characteristic of a typical Nb–AlOx–Nb Josephson junction at 4.2 K. The junction has a V_m of 60 mV, comparable to the best junctions internationally reported.

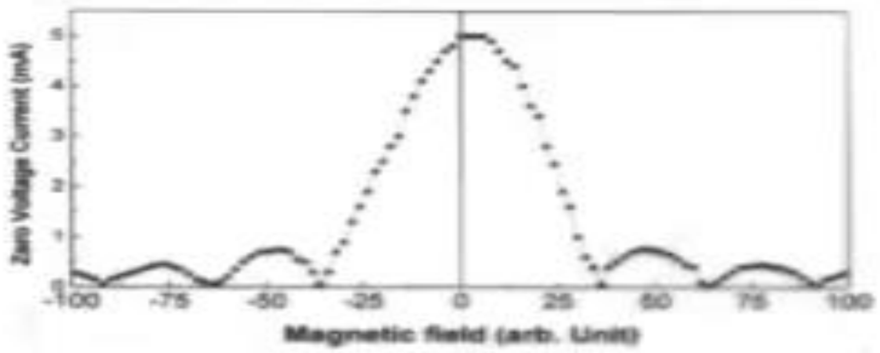


Figure 2. Dependence of critical current I_c of the junction on magnetic field.

Applications of SQUIDS

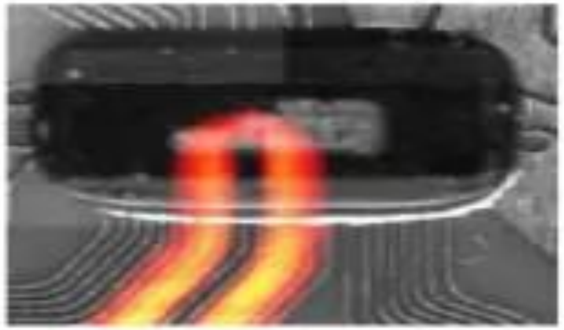
Magnetoencephalograph

Magnetocardiography

Rock magnetometry

Fig. 8. Rockmagnetometer (courtesy 2G Enterprises).

imaging currents
in semiconductor packages



Biosensors

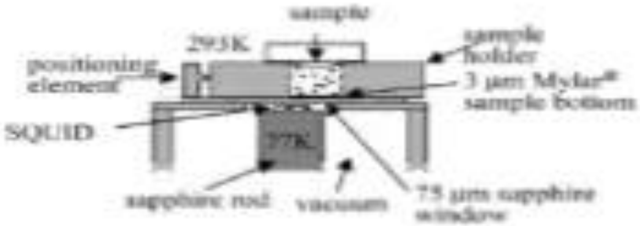


Fig. 9. Top portion of SQUID microscope. The SQUID is mounted on a sapphire rod thermally connected to a liquid nitrogen reservoir (not shown). A 75-μm-thick sapphire window separates the vacuum enclosure from the atmosphere. (From [63], with permission.)

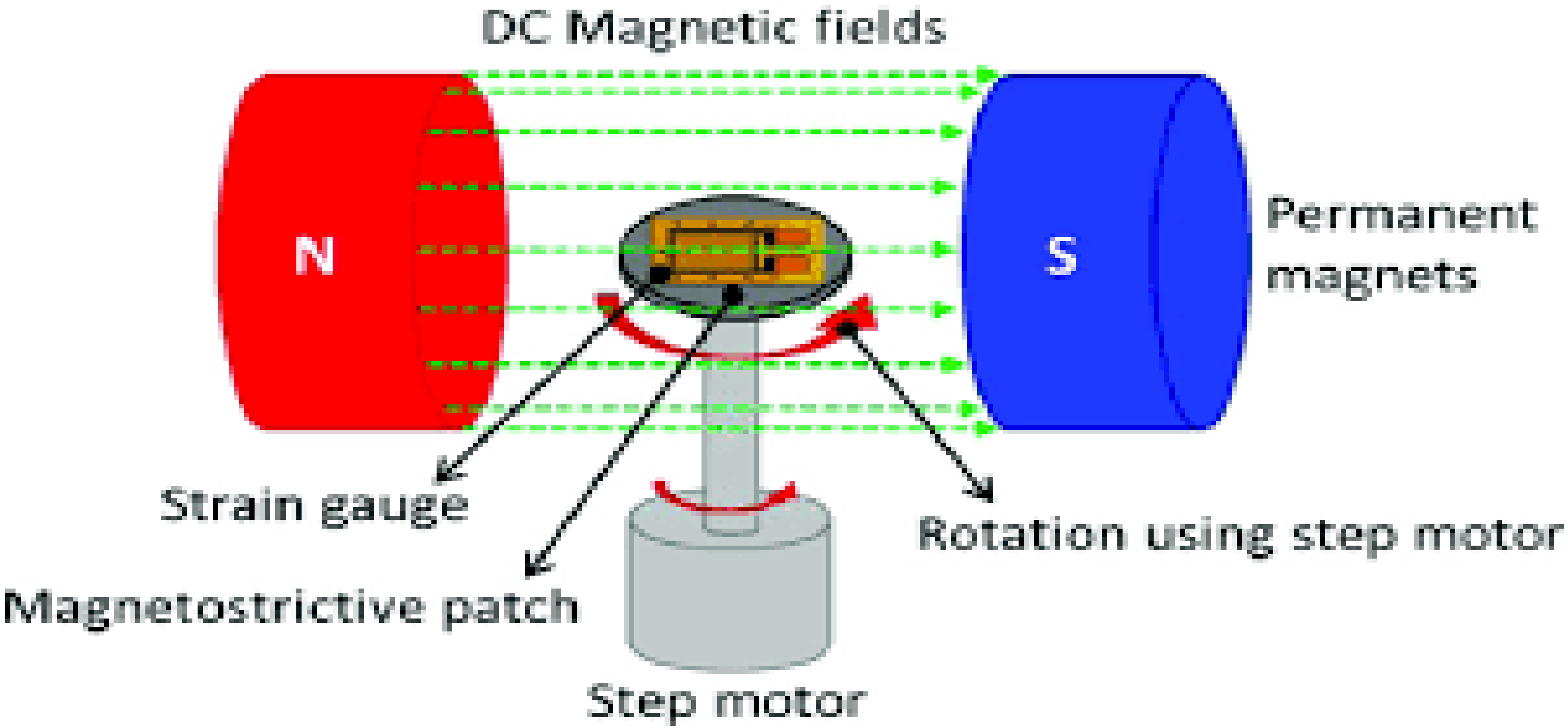
MAGNETOSTRICTION

- Magnetostriction is **a property of ferromagnetic materials that causes them to change their shape when subjected to a magnetic field**.
- Phenomenon known over a century and half, has been used in combination with piezoelectric elements for field measurements.
- This effect is known as ‘Joule effect’ in which magnetization changes the shape of ferromagnetic material body.

MAGNETOSTRICTION

- Magnetostrictive materials are used to **convert electromagnetic energy into mechanical energy and vice versa**. This effect can be used to create sensors that measure a magnetic field or detect a force. The magnetic field or force applied would create a strain in the material, which can be measured.
- Its **magnetic field magnetises the** wire axially. Since the two magnetic fields are superimposed, around the float magnet a torsion wave is generated which runs in both directions along the wire.

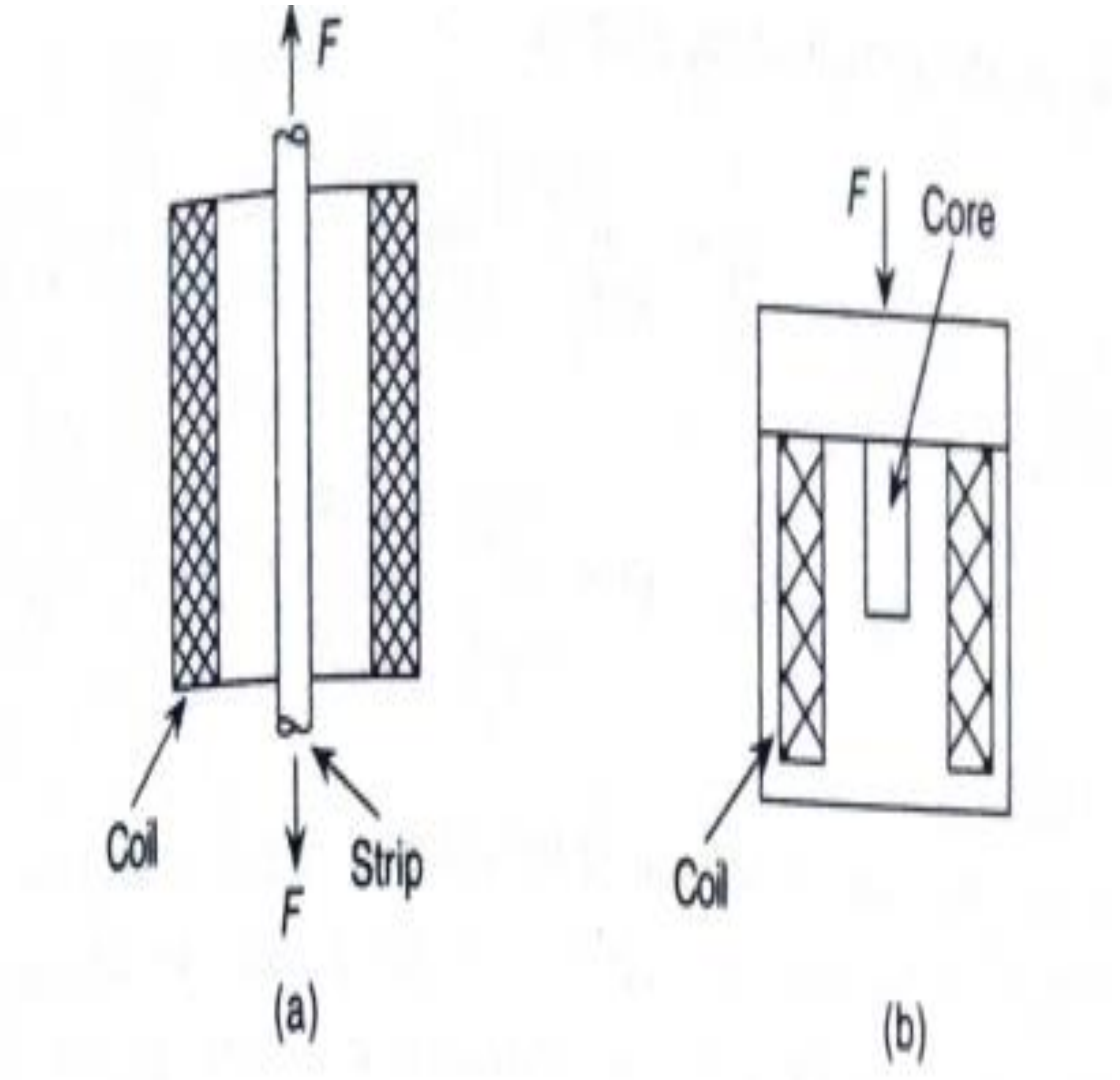
MAGNETOSTRICTION



Villari Effect

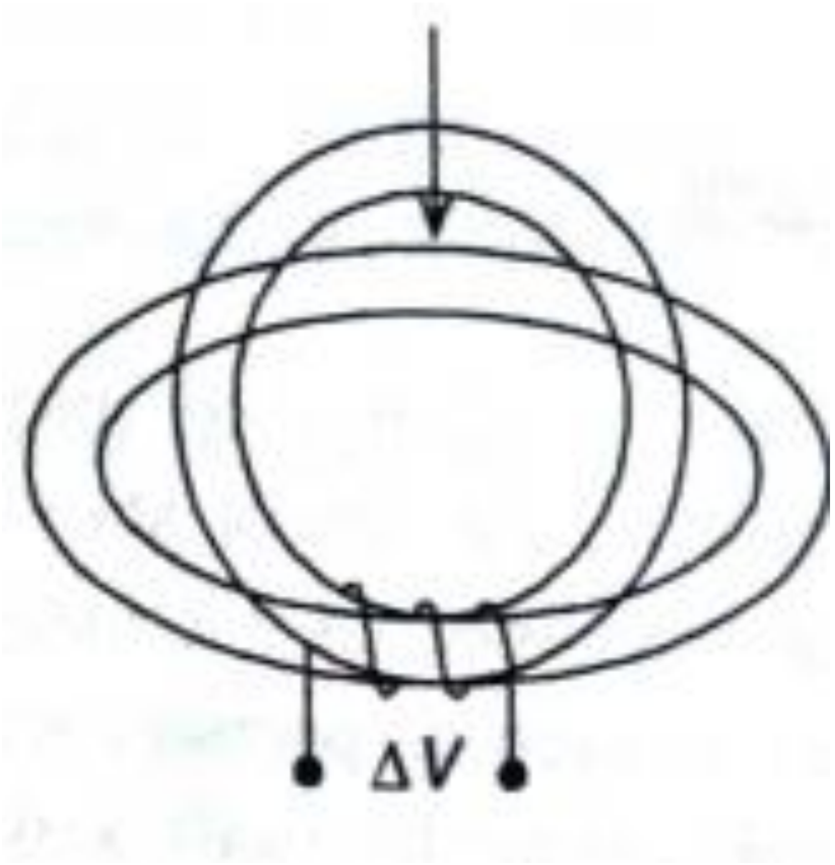
- Based on Villari effect, **three basic types** of magnetoelastic sensors may be designed.

A. The mechanical loading is unidirectional so as to produce compression or tension and this changes the inductance or permeability with the specimen having predefined magnetic flux path, as in choke or coil type design.



Villari Effect

B. Mechanical loading changes the flux in 2 directions or in a plane as in circular rings or laminated cores. Circular ring is deformed into elliptical form and change in inductance of the ring or change in voltage in the secondary winding ΔV gives the value of the load. In case of laminated core load cells, isotropic magnetic materials are used which become anisotropic under stress due to varying deformation in longitudinal and transverse directions relative to load axis and change in voltage can be derived in ring type design.



VILLARI EFFECT

C. Loading changes the flux spatially, that is 3 dimensionally in torque transducers for shafts.

- If the shaft material does not have the requisite magnetic properties such as magnetostriction, an additional magnetic coating on the shaft surface produces the desired mechanical stress on this surface that is to be measured.

Smart Sensors-Introduction

- The Sensors are devices that responds to a physical stimulus heat, light, sound, pressure, magnetism, motion, etc , and convert that into an electrical signal.
- They perform an input function
- The Devices which perform an output function are generally called Actuators and are used to control some external device, for example movement.
- Both sensors and actuators are collectively known as Transducers. Transducers are devices used to convert energy of one kind into energy of another kind.

Common Transducers **Inputs or Outputs, What it measures?**

Quantity being Measured	Input Device (Sensor)	Output Device (Actuator)
Light Level	Light Dependant Resistor (LDR) Photodiode Photo-transistor Solar Cell	Lights & Lamps LED's & Displays Fibre Optics
Temperature	Thermocouple Thermistor Thermostat Resistive temperature detectors (RTD)	Heater Fan
Force/Pressure	Strain Gauge Pressure Switch Load Cells	Lifts & Jacks Electromagnet Vibration
Position	Potentiometer Encoders Reflective/Slotted Opto-switch LVDT	Motor Solenoid Panel Meters
Speed	Tacho-generator Reflective/Slotted Opto-coupler Doppler Effect Sensors	AC and DC Motors Stepper Motor Brake
Sound	Carbon Microphone Piezo-electric Crystal	Bell Buzzer Loudspeaker

SMART SENSOR

A smart sensor is an analog/digital transducer combined with a processing unit and a communication interface. It consists of transduction element, signal conditioning electronic and controller/processor that support some intelligence in a single package.

This integrated sensors which has electronics and the transduction element together on one silicon chip, this system can be called as system-on-chip (SoC).The main aim of integrating the electronics and the sensor is to make an intelligent sensor, which can be called as smart sensor. Smart sensors then have the ability to make some decision.

Smart Sensor Has Its Own Micro Brain

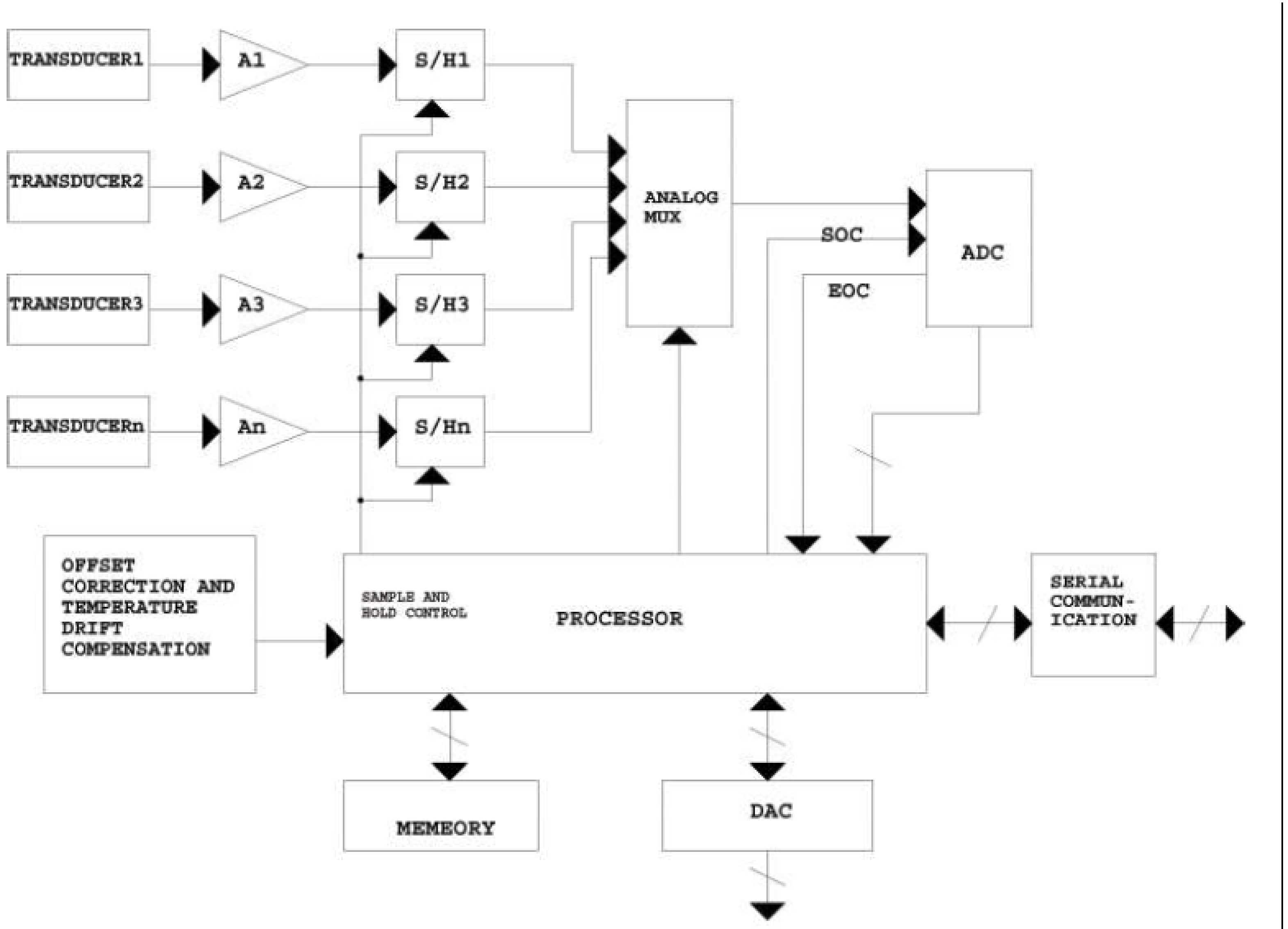
SENSOR + INTEGRATED CIRCUIT = SMART SENSOR

BASIC CONVENTIONAL SENSOR	INTEGRATED CIRCUIT (ARDUINO, MICROPROCESSOR , OR COMMUNICATION SYSTEM)	SENSOR WITH ITS OWN MICRO BRAIN WHICH IS NOW CAPABLE OF WORKING INDEPENDENTLY)

General Architecture of Smart Sensor

The basic architectural components of smart sensor are listed as follows:

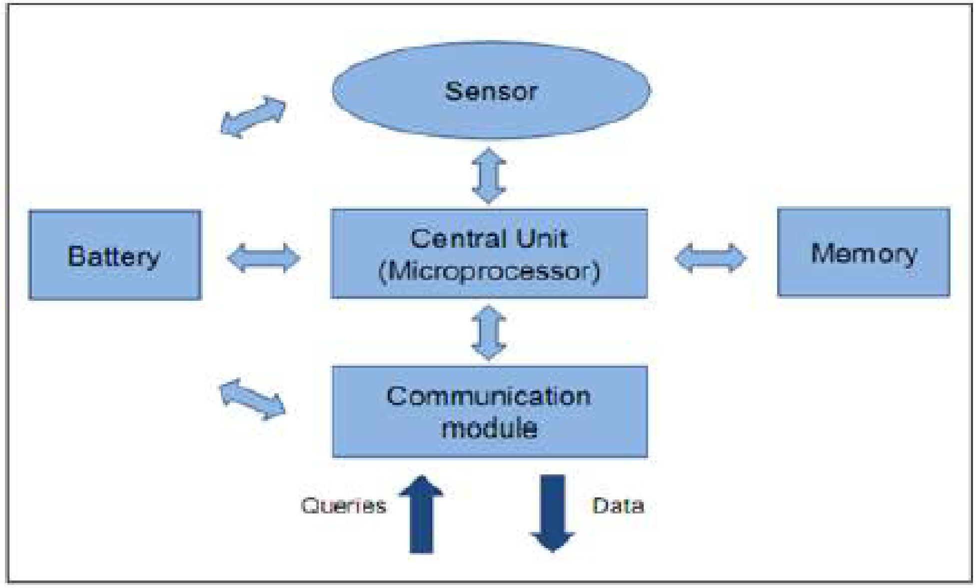
- Sensing element/transduction element,
- Amplifier,
- Sample and hold,
- Analog multiplexer,
- Analog to digital converter (ADC),
- Offset and temperature compensation,
- Digital to analog converter (DAC),
- Memory,
- Serial communication
- Processor



GENERAL ARCHITECTURE OF SMART SENSOR

Five main parts of sensor node are:

- The central unit: It is in the form of microprocessor which manages the tasks.
- Battery: Is the source of energy
- A Transceiver: Interacts with the environment and collects data.
- Memory: Used as storage media for storing data or processing data.
- Communication module: It includes transceivers and forwards queries and data to and from central module. [2]



Information Coding/Processing

- The signals recorded by many sensors are typically low in amplitude, Integration of interface electronics and signal processing circuitry at the sensor site (monolithic or hybrid) serves a number of functions, including signal amplification, impedance transformation, signal filtering and buffering, and multiplexing.
- CMOS amplifiers are perhaps the most suitable since they provide high gain and high input impedance through a relatively simple and compact circuit and are readily compatible with integration of high-density digital circuitry on the same chip.
- In addition to signal amplification, impedance transformation and signal filtering are also required.

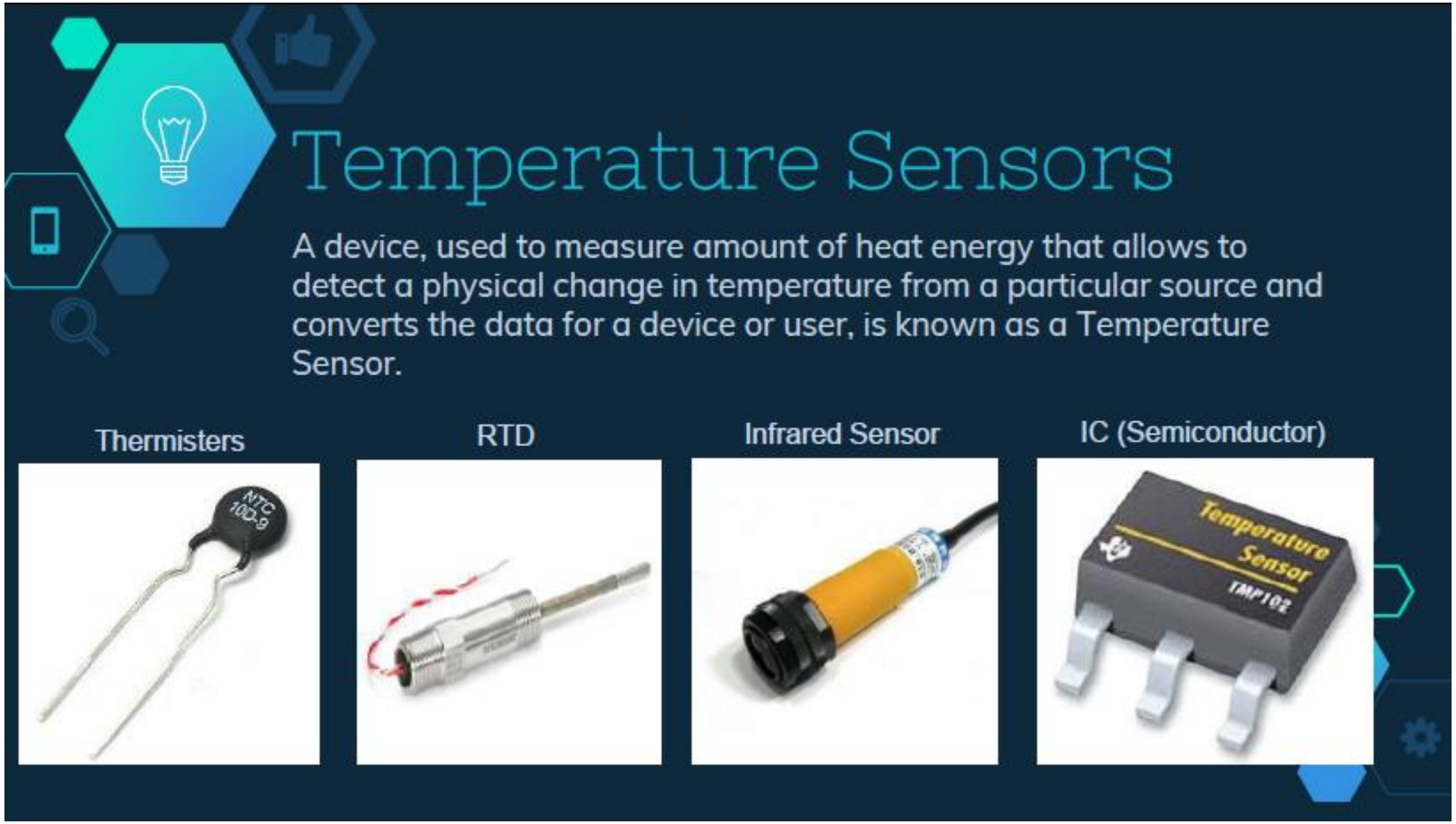
Data Compensation

- The main circuit block required before digital control and manipulation of sensor data can take place is the analog-digital converter.
- Once the sensor data is digitized, a variety of signal processing schemes can be used to correct for a number of errors and shortcomings. These include offset cancellation, auto-calibration, self-testing, fault detection and correction and linearity correction.
- Auto-calibration is a very desirable function for smart sensors. Most sensors should be adjusted for changes in gain and offset.
- Reliability and accuracy.

Top Smart Sensors -

- Temperature Sensors
- Proximity Sensor
- Pressure Sensor
- Gas & Smoke Sensor
- Accelerometer Sensors
- Level Sensors
- Image Sensors
- Motion Detection Sensors
- Optical Sensors
- Gyroscope Sensors

Smart Sensors (Cont..)



Smart Sensors (Cont..)

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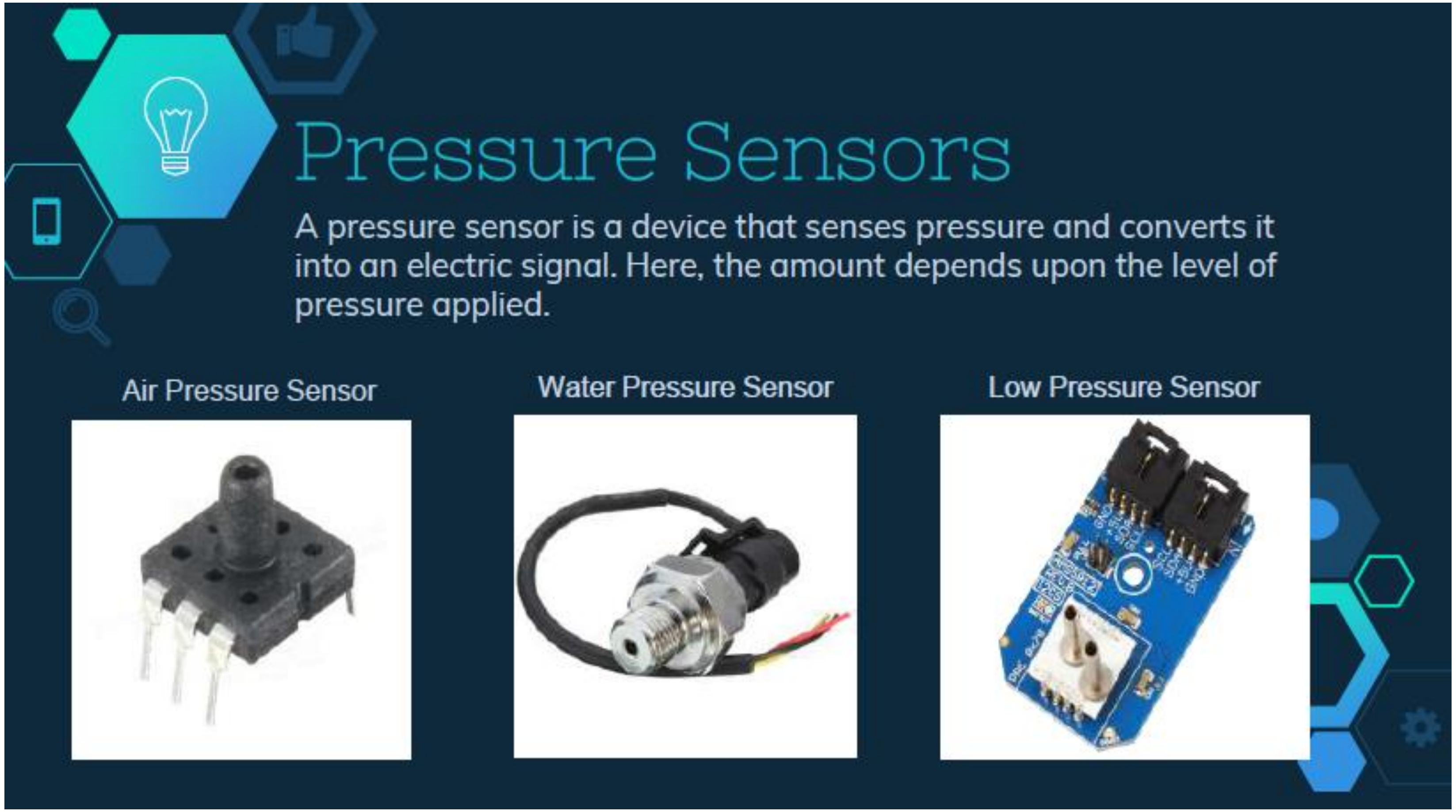

Smart Sensors (Cont..)

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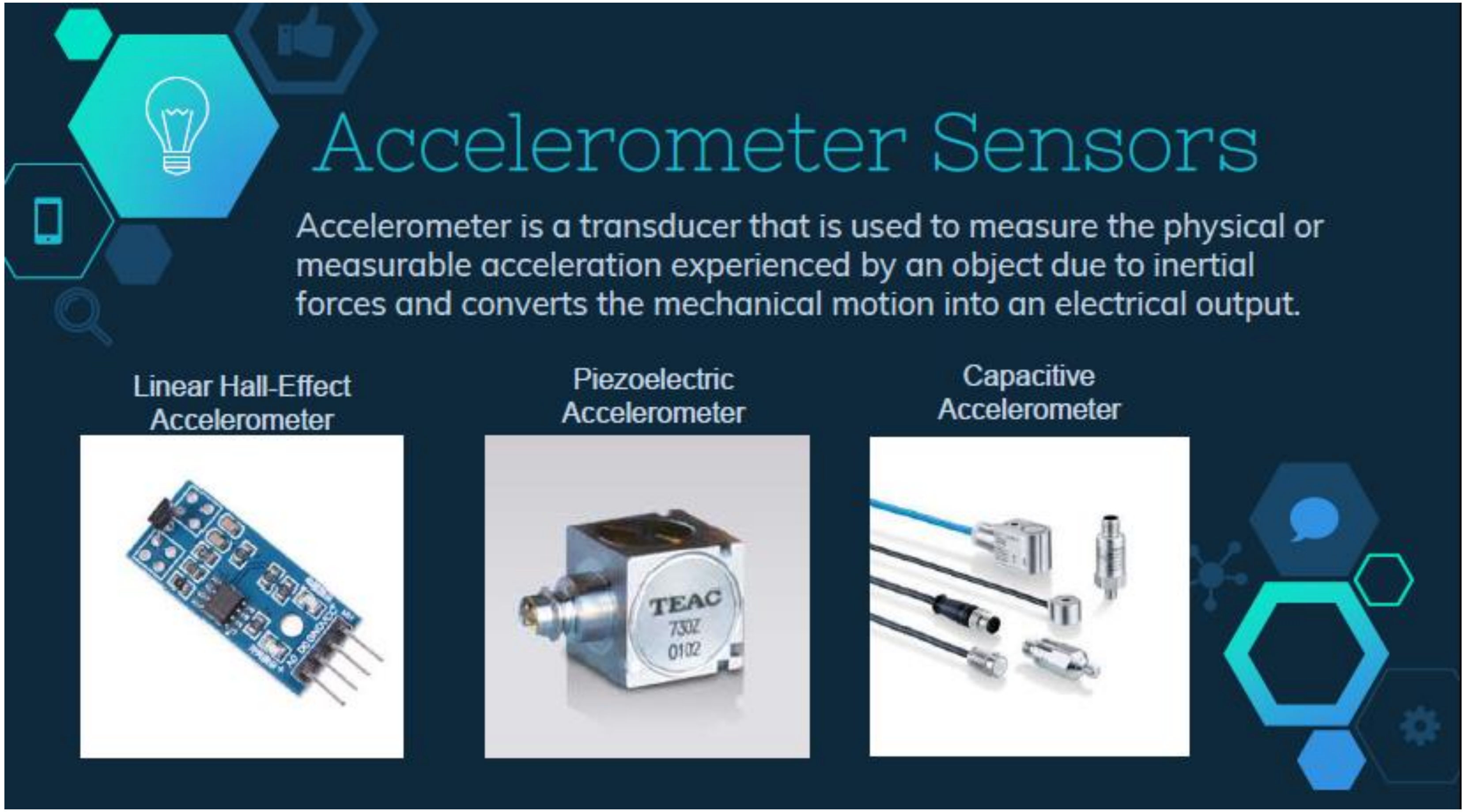
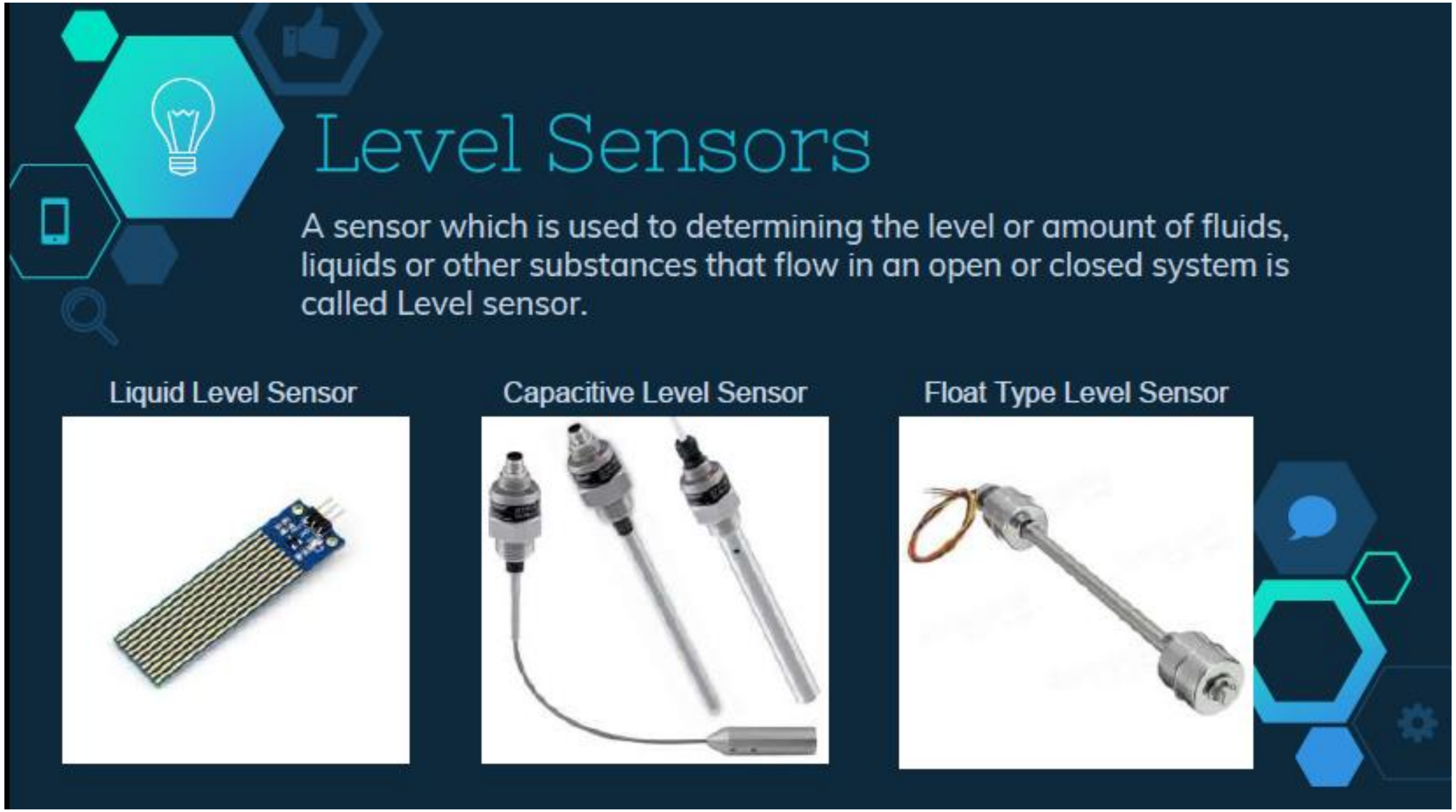


Smart Sensors (Cont..)



Smart Sensors (Cont..)

Smart Sensors (Cont..)

Smart Sensors (Cont..)

Smart Sensors (Cont..)

Advantage -

- The smart sensor takes over the conditioning and control of the sensor signal, reducing the load on the central control system, allowing faster system operation.
- Direct digital control provides high accuracy, not achievable with analog control systems and central processing.
- The cost of smart sensor systems is presently higher than that of conventional systems, but when the cost of maintenance, ease of programming, ease of adding new sensors is taken into account, the long- term cost of smart sensor systems is less.
- Individual controllers can monitor and control more than one process variable.

Disadvantages -

- If upgrading to smart sensors, care has to be taken when mixing old devices with new sensors, since they may not be compatible.
- If a bus wire fails, the total system is down, which is not the case with discrete wiring. However, with discrete wiring, if one sensor connection fails, it may be necessary to shut the system down. The problem of bus wire failure can be alleviated by the use of a redundant backup bus.

MEMS

- A MEMS (micro-electromechanical system) is a miniature machine that has both mechanical and electronic components. The physical dimension of a MEMS can range from several millimeters to less than one micrometer, a dimension many times smaller than the width of a human hair
- The label MEMS is used to describe both a category of micromechatronic devices and the processes used when manufacturing them.
- https://internetofthingsagenda.techtarget.com/definition/micro-electromechanical-systems-MEMS

MEMS

- Some MEMS do not even have mechanical parts, yet they are classified as MEMS because they miniaturize structures used in conventional machinery, such as springs, channels, cavities, holes and membranes.
- Because some MEMS devices convert a measured mechanical signal into an electrical or optical signal, they may also be referred to as transducers.
- In Japan, MEMS are more commonly known as micromachines, and in European countries, MEMS are more commonly referred to as microsystems technology (MST).

MEMS

- MEMS are composed of parts such as microsensors, microprocessors, microactuators, units for data processing and parts that can interact with exterior pieces.
- Unlike conventional mechatronic devices, MEMS are often manufactured with the same batch fabrication techniques used to create integrated circuits (ICs) and many commercial MEMS products are integrated and packaged together with ICs. MEMS fabrication allows micro-sensors, which gather data, and micro-actuators, which convert energy into motion, to integrate on the same substrate.
- Although MEMS have a low per-device production cost, packaging can be a challenge. Each MEMS must be packaged so that electrical or optical circuitry and other device components remain free from air and water contamination, while still being able to interact with the surrounding environment and accommodate motion.

MEMS

- Example:
- The small system on a chip (SOC) that automatically adjusts screen orientation on a smartphone is an example of a MEMS many people interact with each day. As MEMS become smaller, require less power and are less expensive to manufacture, they are expected to play an important part in the wireless internet of things (IoT) and home automation
- Applications:
- Sensor-driven heating and cooling systems for building management systems.
- Micro-mirror arrays for high definition projection systems.
- Smart dust for the detection of environmental changes in molecular manufacturing (nanotechnology) clean rooms.
- Micronozzles to control the flow of ink in inkjet printers.
- Tiny gyroscopes, barometers, accelerometers and microphones to support Mobile apps.
- Disposable pressure sensors for use in healthcare.
- Optical switching devices that allow one optical signal to control another optical signal.

WHAT IS MEMS

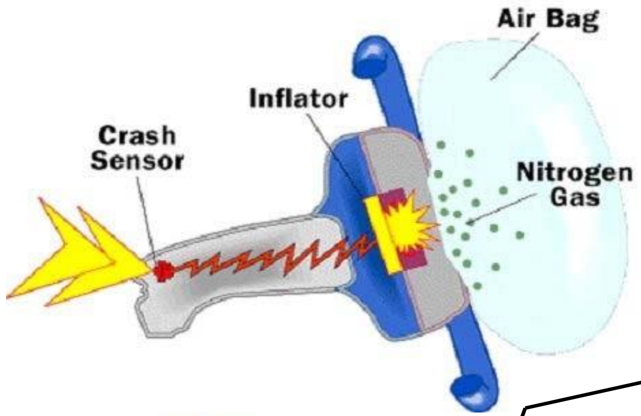
MEMS = MicroElectroMechanical System

Any engineering system that performs *electrical* and *mechanical* functions with *components* in *micrometers* is a MEMS. (1 µm = 1/10 of human hair)

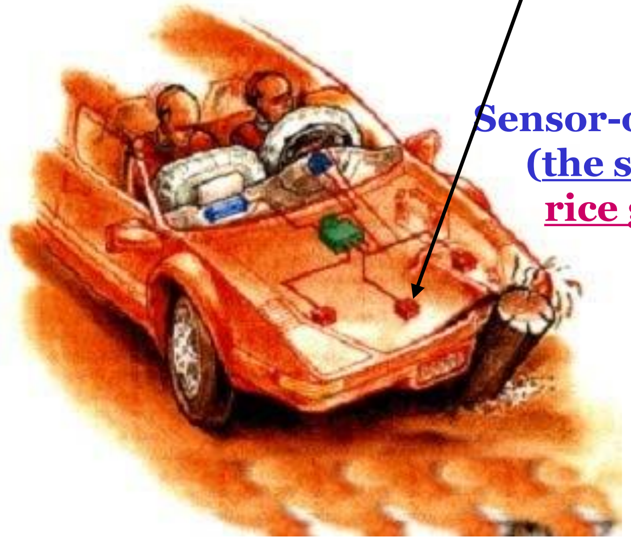
Available MEMS products include:

- **Micro sensors** (acoustic wave, biomedical, chemical, inertia, optical, pressure, radiation, thermal, etc.)
- **Micro actuators** (valves, pumps and microfluidics;electrical and optical relays and switches; grippers, tweezers and tongs;linear and rotary motors, etc.)
- **Read/write heads** in computer storage systems.
- **Inkjet printer heads**.
- **Micro device components** (e.g., palm-top reconnaissance aircrafts, mini robots and toys, micro surgical and mobile telecom equipment, etc.)

Inertia Sensor for Automobile "Air Bag" Deployment System



Micro inertia sensor (accelerometer) in place:

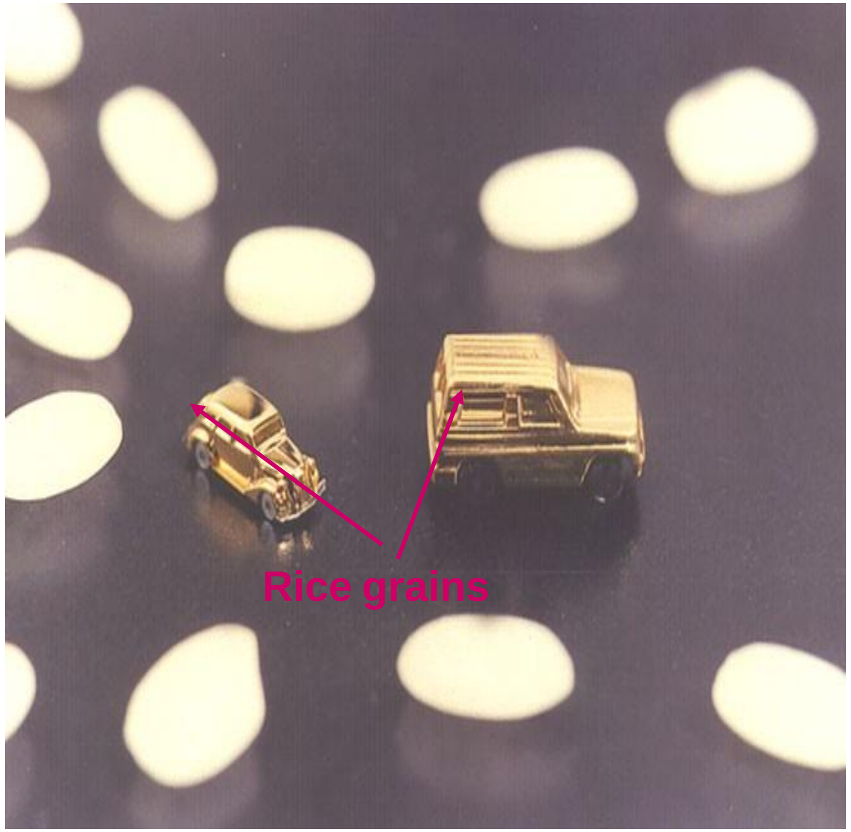


Sensor-on-a-chip: (the size of a rice grain)

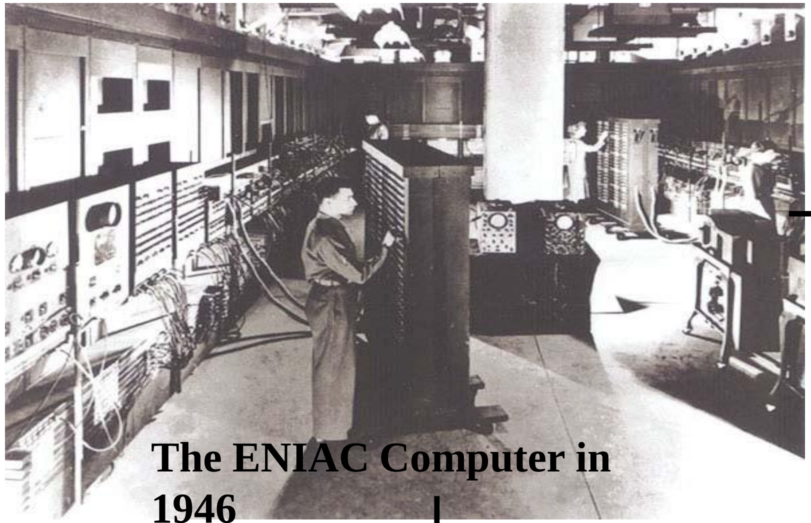
(Courtesy of Analog Devices, Inc)

Micro Cars

(Courtesy of Denso Research Laboratories, Denso Corporation, Aichi, Japan)

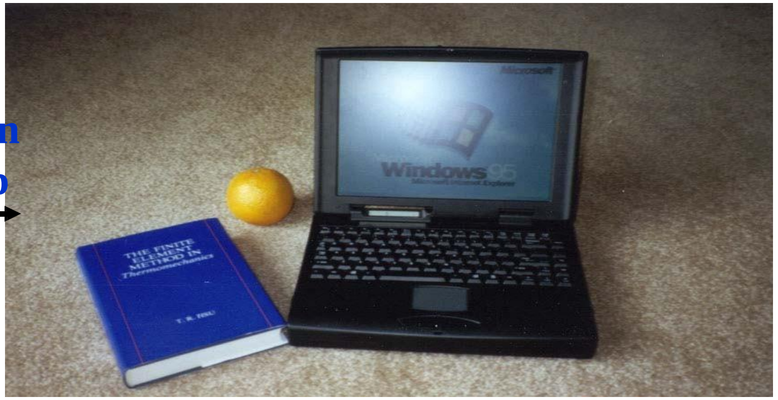


Miniaturization of Digital Computers
- A remarkable case of miniaturization!



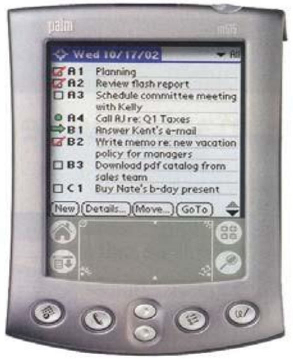
The ENIAC Computer in 1946

Size: 10^6 down
Power: 10^6 up



A "Lap-top" Computer in 1996

Size: 10^8 down
Power: 10^8 up



A "Palm-top" Computer in 2001

This spectacular miniaturization took place in 50 years!!

MINIATURIAZATION – The Principal Driving Force for the 21st Century Industrial Technology

There has been increasing strong market demand for:

"Intelligent,"

"Robust,"

"Multi-functional," and

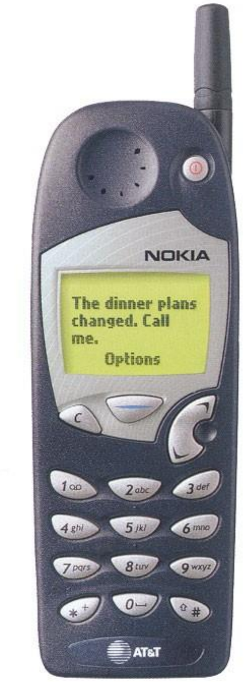
"Low-cost"

industrial products.

Miniaturization is the only viable solution to satisfy such market demand

Market Demand for Intelligent, Robusting, Smaller, Multi-Functional Products - the

Mobil phones 10 Years Ago:



Transceive voice only

Current State-of-the Art:

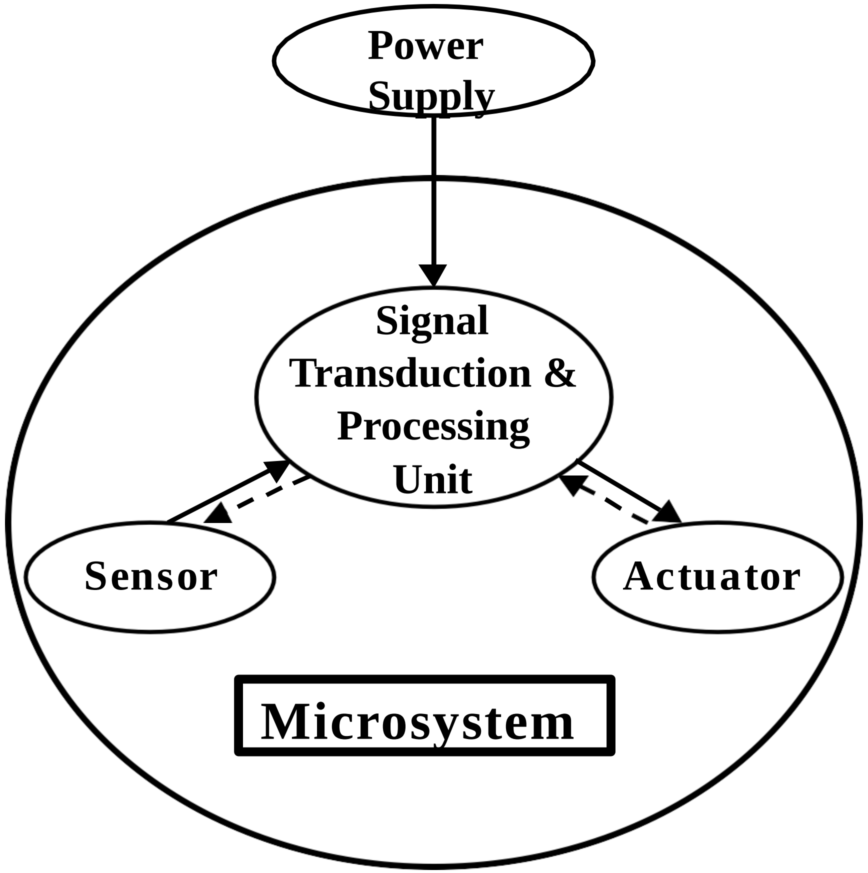
Size reduction

Palm-top Wireless PC

Transceive voice+ multi-media + others (Video-camera, e-mails, calendar, and access to Internet, GPS and a PC with key pad input)

The only solution is to pack many miniature function components into the device

Components of Microsystems



Comparison of Microelectronics and Microsystems

Microelectronics	**Microsystems** (silicon based)
Primarily 2-dimensional structures	Complex 3-dimensional structure
Stationary structures	May involve moving components
Transmit electricity for specific electrical functions	Perform a great variety of specific biological, chemical, electromechanical and optical functions
IC die is protected from contacting media	Delicate components are interfaced with working media
Use single crystal silicon dies, silicon compounds, ceramics and plastic materials	Use single crystal silicon dies and few other materials, e.g. GaAs, quartz, polymers, ceramics and metals
Fewer components to be assembled	Many more components to be assembled
Mature IC design methodologies	Lack of engineering design methodology and standards
Complex patterns with high density of electrical circuitry over substrates	Simpler patterns over substrates with simpler electrical circuitry
Large number of electrical feed-through and leads	Fewer electrical feed-through and leads
Industrial standards available	No industrial standard to follow in design, material selections, fabrication processes and packaging
Mass production	Batch production, or on customer-need basis
Fabrication techniques are proven and well documented	Many microfabrication techniques are used for production, but with no standard procedures
Manufacturing techniques are proven and well documented	Distinct manufacturing techniques
Packaging technology is relatively well established	Packaging technology is at the infant stage
Primarily involves electrical and chemical engineering	Involves all disciplines of science and engineering

Scaling Laws in Miniaturization

In this era of "think small," one would intuitively simply scale down the size of all components to a device to make it small. Unfortunately, the reality does not work out that way.

It is true that nothing is there to stop one from down sizing the device components to make the device small. There are, however, serious physical consequences of scaling down many physical quantities.

<u>TYPES OF SCALING</u>

- Scaling in Geometry
- Scaling in Rigid-Body Dynamics
- Scaling in Electrostatic Forces
- Scaling in Electromagnetic Forces
- Scaling in Electricity
- Scaling in Fluid Mechanics
- Scaling in Heat Transfer

WHY SCALING LAWS?

Miniaturizing machines and physical systems is an ongoing effort in human civilization.

This effort has been intensified in recent years as market demands for:

Intelligent, Robust, Multi-functional and Low cost

consumer products has become more strong than ever.

The only solution to produce these consumer products is to package many components into the product –
making it necessary to miniaturize each individual components.

Miniaturization of physical systems is a lot more than just scaling down device components in sizes.

Some physical systems either cannot be scaled down favorably, or cannot be scaled down at all!

Types of Scaling Laws

Scaling laws become the very first thing that any engineer would do in the design of MEMS and microsystems.

1. Scaling in Geometry:

   Scaling of physical size of objects

2. Scaling of Phenomenological Behavior

Scaling of both size and material characterizations

Scaling in Geometry

- **Volume (V) and surface (S) are two physical parameters that are frequently involved in machine design.**
- **Volume leads to the mass and weight of device components.**
- **Volume relates to both mechanical and thermal inertia. Thermal inertia is a measure on how fast we can heat or cool a solid. It is an important parameter in the design of a thermally actuated device.**
- **Surface is related to pressure and the buoyant forces in fluid mechanics. For instance, surface pumping by using piezoelectric means is a practical way for driving fluids flow in capillary conduits.**
- **When the physical quantity is to be miniaturized, the design engineer must weigh the magnitudes of the possible consequences from the reduction on both the volume and surface of the particular device.**

Scaling in Geometry

If we let ℓ = linear dimension of a solid, we will have:

The volume: $V \propto \ell^3$

The surface: $S \propto \ell^2$

$S/V = \ell^{-1}$

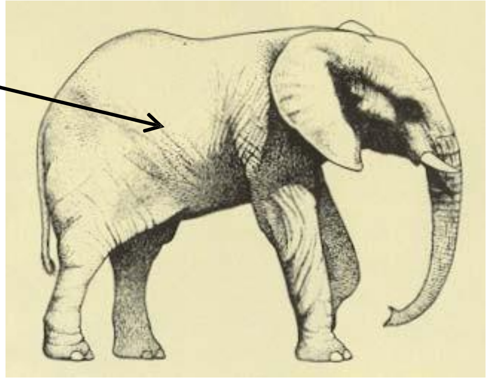
A 10 times reduction in length

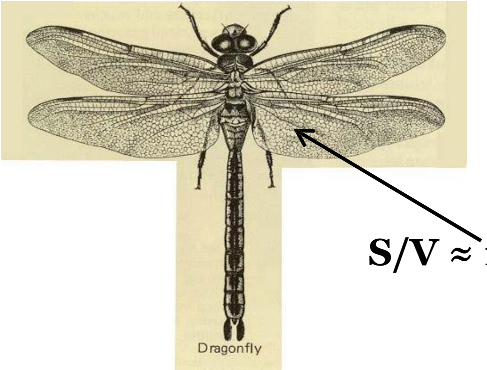
→ $10^3 = 1000$ time reduction in volume. But

→ $10^2 = 100$ time reduction in surface area.

Since volume, **V** relates to **mass** and surface area, **S** relates to **buoyancy force**:

$S/V \approx 10^{-4}$/mm





$S/V \approx 10^{-1}$/mm

So, an elephant can never fly as easily as a dragonfly!!

Scaling Laws in Miniaturization

- Scaling theory is a value guide to what may work and what may not work when we start to design the world of micro.

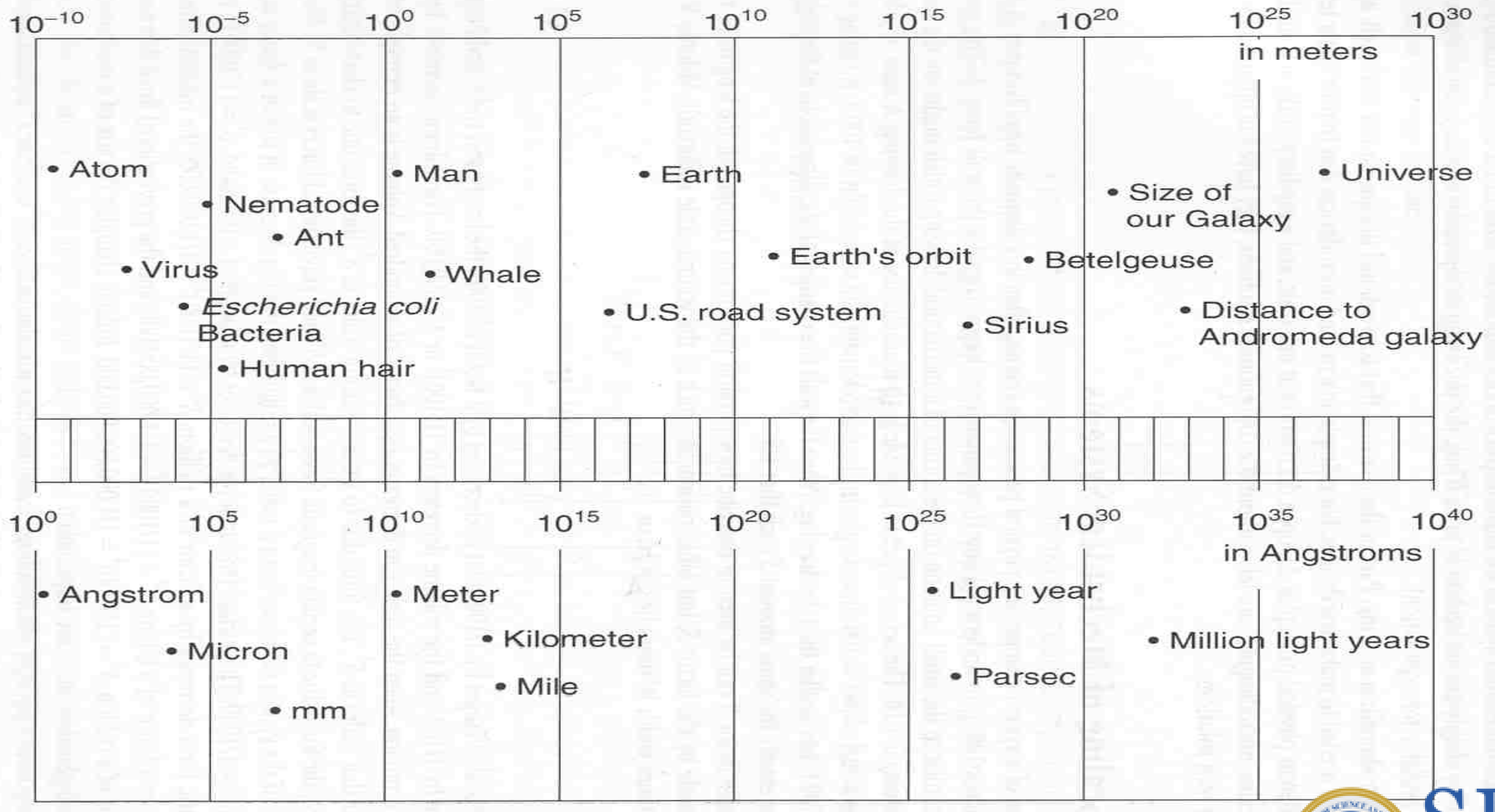
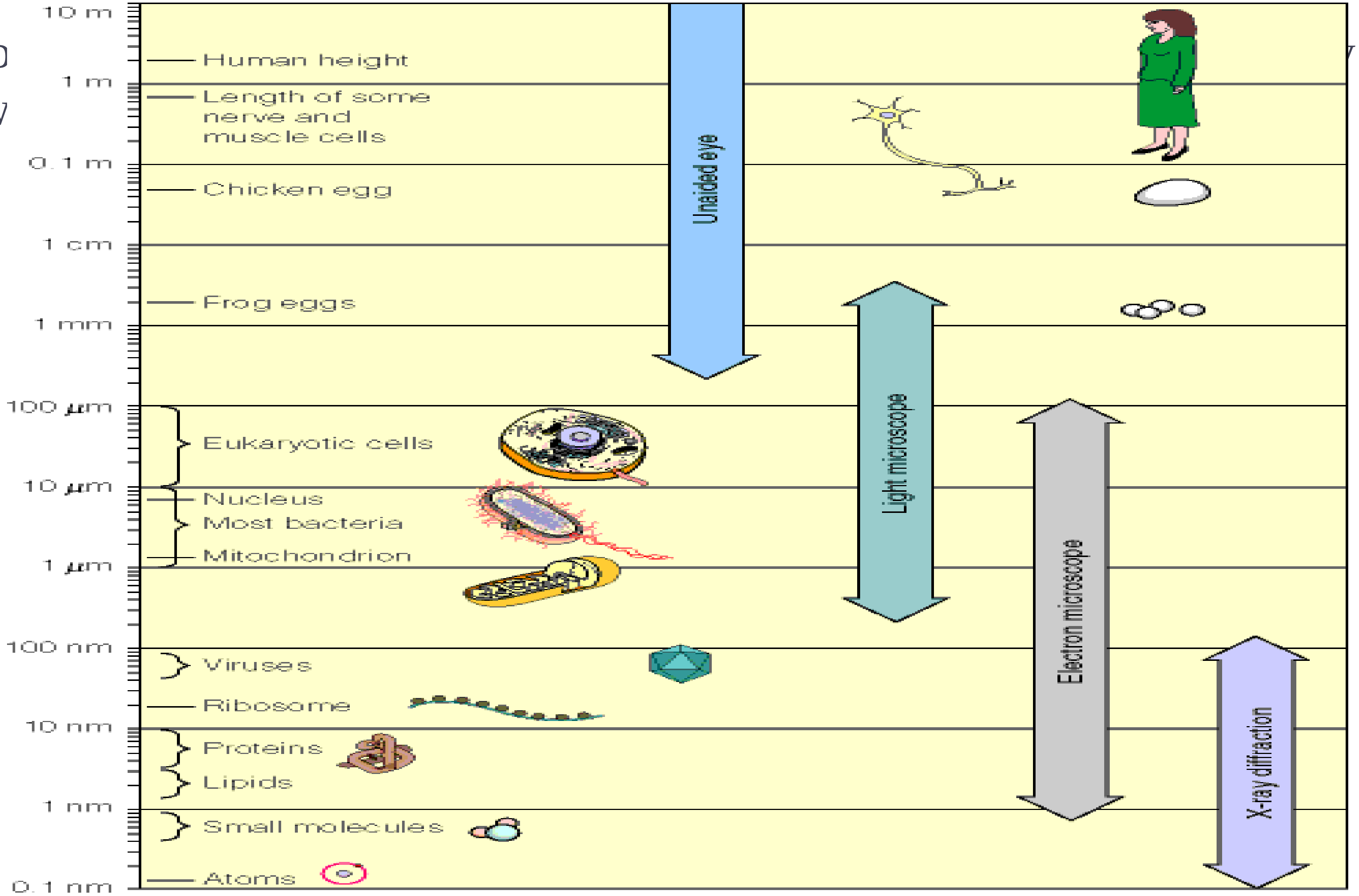


FIGURE 2.1 Log plot of all mechanical systems available for exploration.

Range o… y by
Mathew



SUBSTRATES AND WAFERS

- The frequently used term ***substrate*** in microelectronics means a **flat macroscopic object on which microfabrication processes take place.**

- There are two types of substrate materials used in microsystems: (1) active substrate materials and (2) passive substrate materials

- Active substrate materials are primarily used for sensors and actuators in a microsystem or other MEMS components(Si,Ge,GaAs,Quartz)

SRM INSTITUTE OF SCIENCE & TECHNOLOGY (Deemed to be University u/s 3 of UGC Act, 1956) RAMAPURAM

Silicon – an ideal substrate material for MEMS

- **Silicon (Si) is the most abundant material on earth. It almost always exists in compounds with other elements.**

- **Single crystal silicon is the most widely used substrate material for MEMS and microsystems.**

- **The popularity of silicon for such application is primarily for the following reasons:**

  (1) It is ***mechanically stable*** and it is ***feasible to be integrated*** into electronics on the same substrate.Electronics for signal transduction such as the p or n-type piezoresistive can be readily integrated with the Si substrate-ideal for transistors.

  (2) Silicon is almost an ***ideal structure*** material. It has about the same Young's modulus as steel (2×10^5 MPa), but is as light as aluminum with a density of about 2.3 g/cm^3.

(3) It has a **melting point at 1400^{o}C,** which is about twice higher than that of aluminum. This high melting point makes silicon *dimensionally stable* even at elevated temperature.

(4) Its **thermal expansion coefficient is** *about 8 times smaller* than that of steel, and is more than *10 times smaller than that of aluminum*.

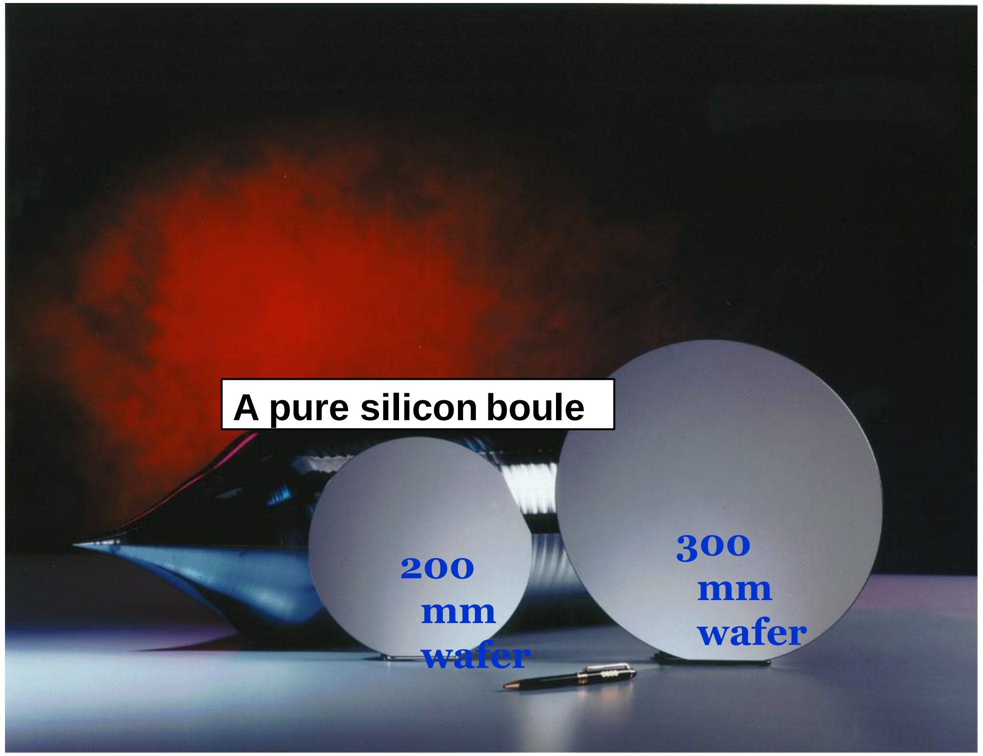
(5) Silicon shows virtually **no mechanical hysteresis.** It is thus an ideal candidate material for sensors and actuators. Silicon wafers are extremely flat for coatings and additional thin film layers for either being integral structural parts, or performing precise electromechanical functions.

(6) There is a **greater flexibility** in design and manufacture with silicon than with other substrate materials. Treatments and fabrication processes for silicon substrates are well established and documented.

Pure silicon wafers

Pure silicon boules of 300 mm diameter and 30 ft long, can weigh up to 400 Kg.

These boules are sliced into thin disks (wafers) using diamond saws.



Standard sizes of wafers are:

100 mm (4”) diameter x 500 μm thick.
150 mm (6”) diameter x 750 μm thick.
200 mm (8”) diameter x 1 mm thick
300 mm (12”) diameter x 750 μm thick (tentative).

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SI WAFER PRODUCTION,
CZ PROCESS,
(S3)

SI WAFER PRODUCTION STEPS

- Crystal Growth and Wafer Slicing Process
- Thickness Sorting
- Lapping & Etching Processes
- Thickness Sorting and Flatness Checking
- Polishing Process
- Final Dimensional and Electrical Properties Qualification

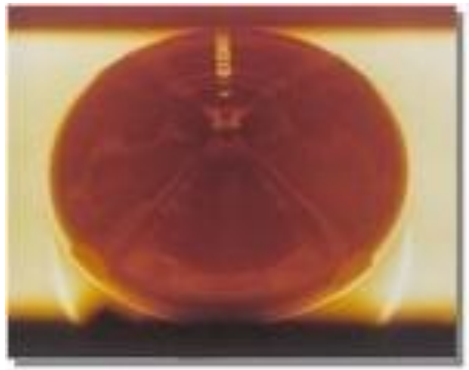
Crystal Growth and Wafer Slicing Process

- **Step 1: Obtaining the Sand**

The sand used to grow the wafers has to be a very clean and good form of silicon.

- **Step 2: Preparing the Molten Silicon Bath**

It is heated to about 1600 degrees C – just above its melting point(1400 degrees C) The *molten sand will become the source of the silicon* that will be the wafer.



Step 3: Making the Ingot

- A silicon seed crystal is now placed into the molten sand bath. This ***crystal will be pulled out slowly*** as it is rotated. The result is a pure silicon cylinder that is called an ingot pure.

- The ***diameter*** of the silicon ingot is determined by the ***temperature*** variables as well as ***the rate at which the ingot is withdrawn***

- Each of the wafers is given either a notch or a flat edge that will be used later in orienting the wafer into the exact position for later procedures

Step 4: Preparing the Wafers

After the ingot is ground into the correct diameter for the wafers, the silicon ingot is ***sliced into very thin wafers.***

This is usually done with a diamond saw.

Thickness Sorting

- Following slicing, silicon wafers are often *sorted on an automated basis into batches* of uniform thickness to increase productivity in the next process step, lapping .
- During thickness sorting, the wafer manufacturer can also *identify defect* trends resulting from the slicing process

Lapping & Etching Processes

- Lapping ***removes the surface silicon which has been cracked*** or otherwise damaged by the slicing process, and assures a flat Surface.
- Wafers are then etched in a chemically active reagent to remove any crystal damage remaining from the previous process step.

Thickness Sorting and Flatness Checking

- Following lapping or etching, silicon wafers are measured for flatness to ***identify and control defect trends*** resulting from the lapping and etching processes
- Wafers are also often ***sorted*** on an automated basis according to thickness in order ***to increase productivity*** in the next process step, polishing.

Polishing Process

Polishing is a chemical/mechanical process that ***smoothes the uneven surface*** left by the lapping and etching processes and makes the wafer flat and smooth enough to support optical photolithography

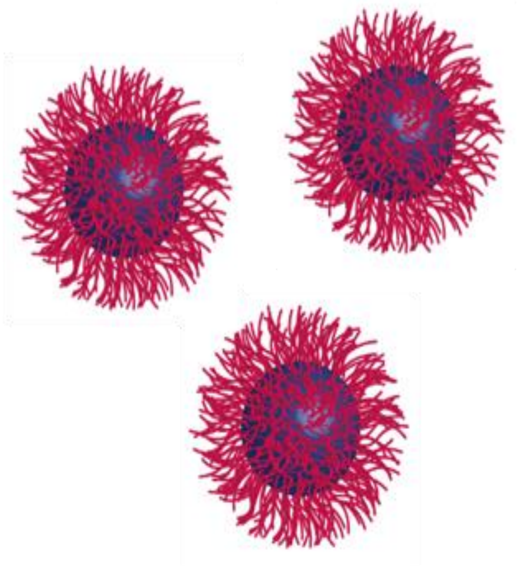
A wafer polishing machine

Wafers in storage trays

NANO SENSOR

Size and Compatibility

Nanoparticles



1 to 100 nm
(10^{-7} m)

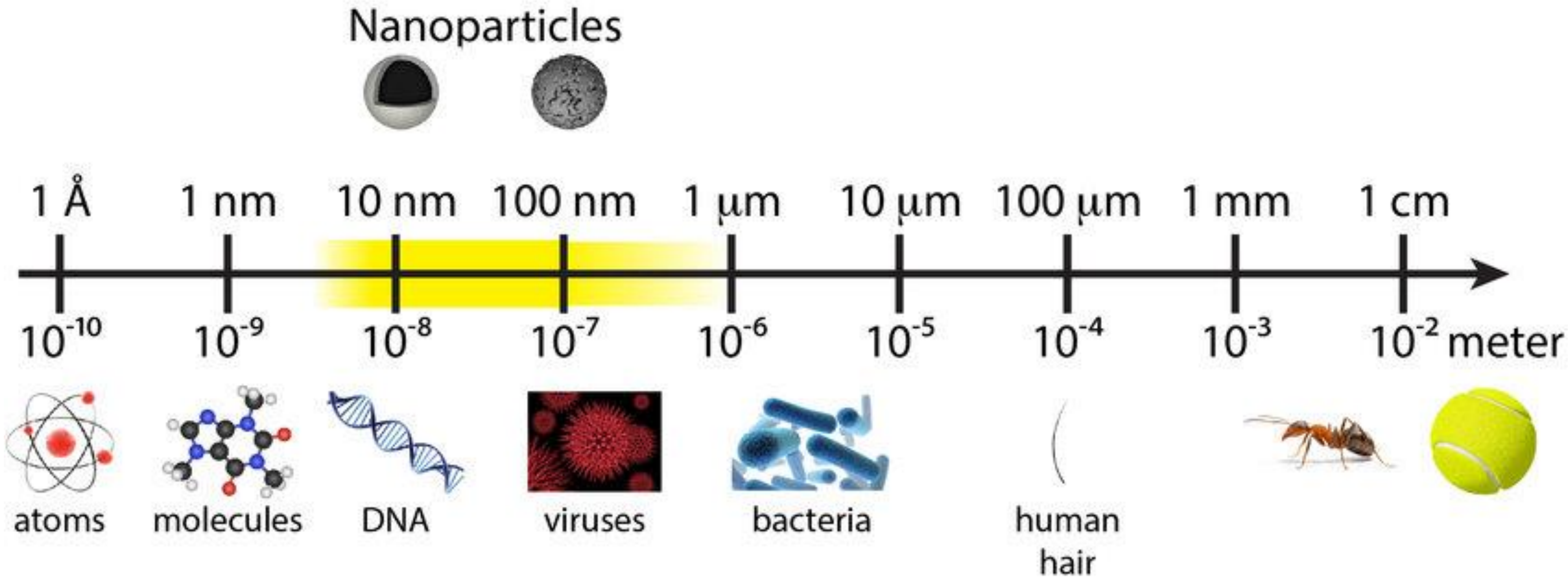
Soccer Ball

~ 0.1 m
(10^{-1})

Earth

~ 10^{7} m

Size and Compatibility



Why Nanosensors?

•Particles that are smaller than the characteristic lengths associated with the specific phenomena often display new chemistry and new physics that lead to new properties that depend on size

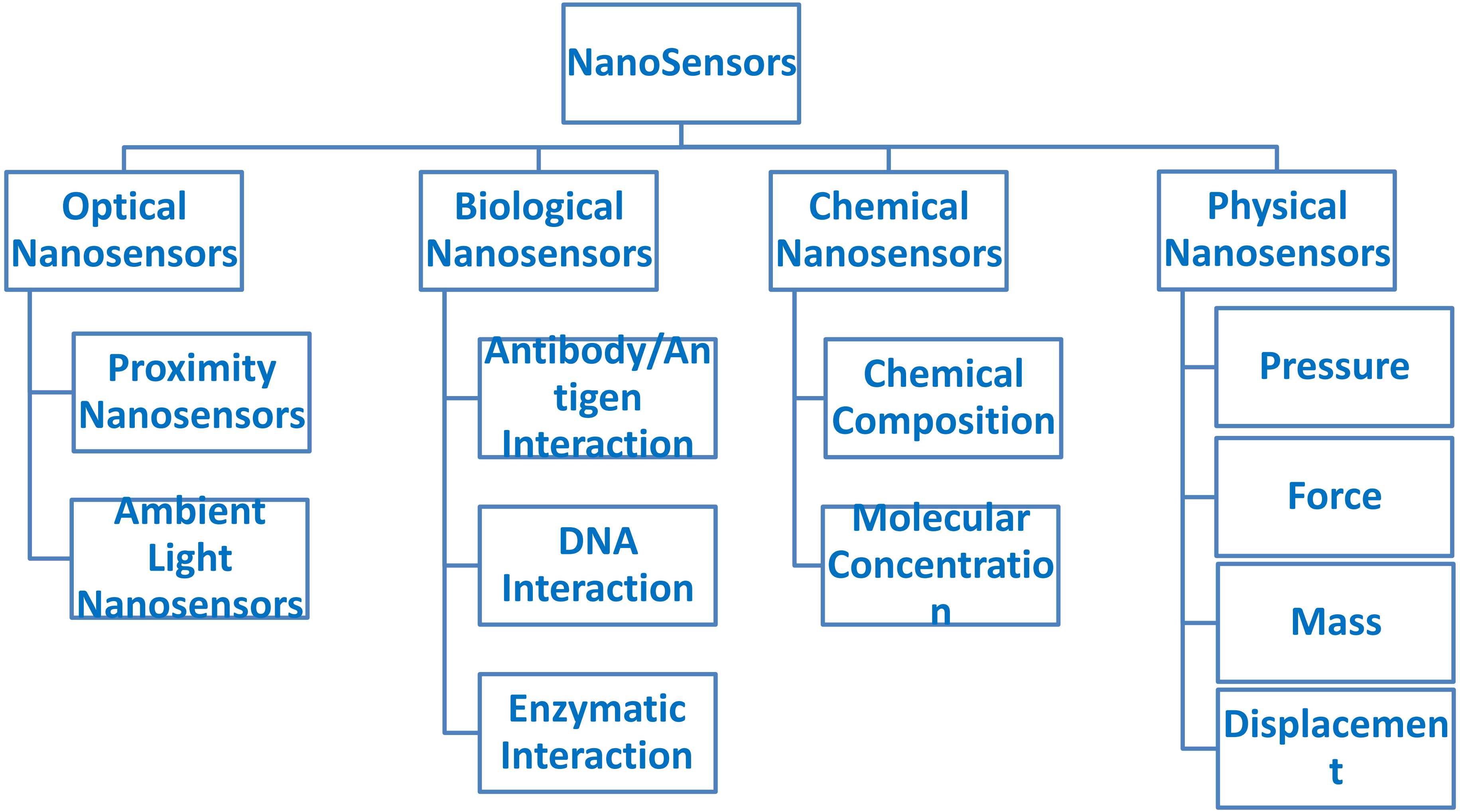
•When the size of the structure is decreased, surface to volume ratio increases considerably and the surface phenomena predominate over the chemistry and physics in the bulk

•The reduction in the size of the sensing part and/or the transducer in a sensor is important in order to better miniaturise the devices

•Science of nano materials deals with new phenomena, and new sensor devices are being built that take advantage of these phenomena

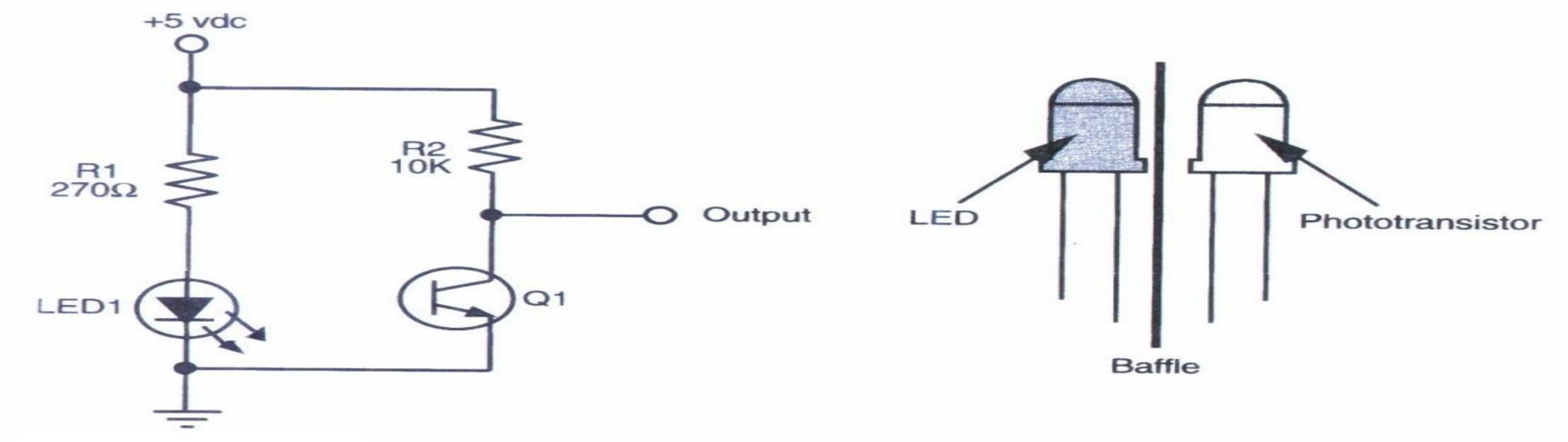
•Sensitivity can increase due to better conduction properties, the limits of detection can be lower, very small quantities of samples can be analysed, direct detection is possible without using labels, and some reagents can be eliminated.

Types of Nanosensors



Optical Sensors- Proximity Sensors

- ✓ Proximity sensors are designed for use in detecting the presence of an object or motion detection in various industrial, mobile, electronic appliances and retail automations.
- ✓ Examples of proximity sensor usage include the detection of an out-of-paper condition in a printer or a mobile phone screen that dims to save battery life when placed near a face.

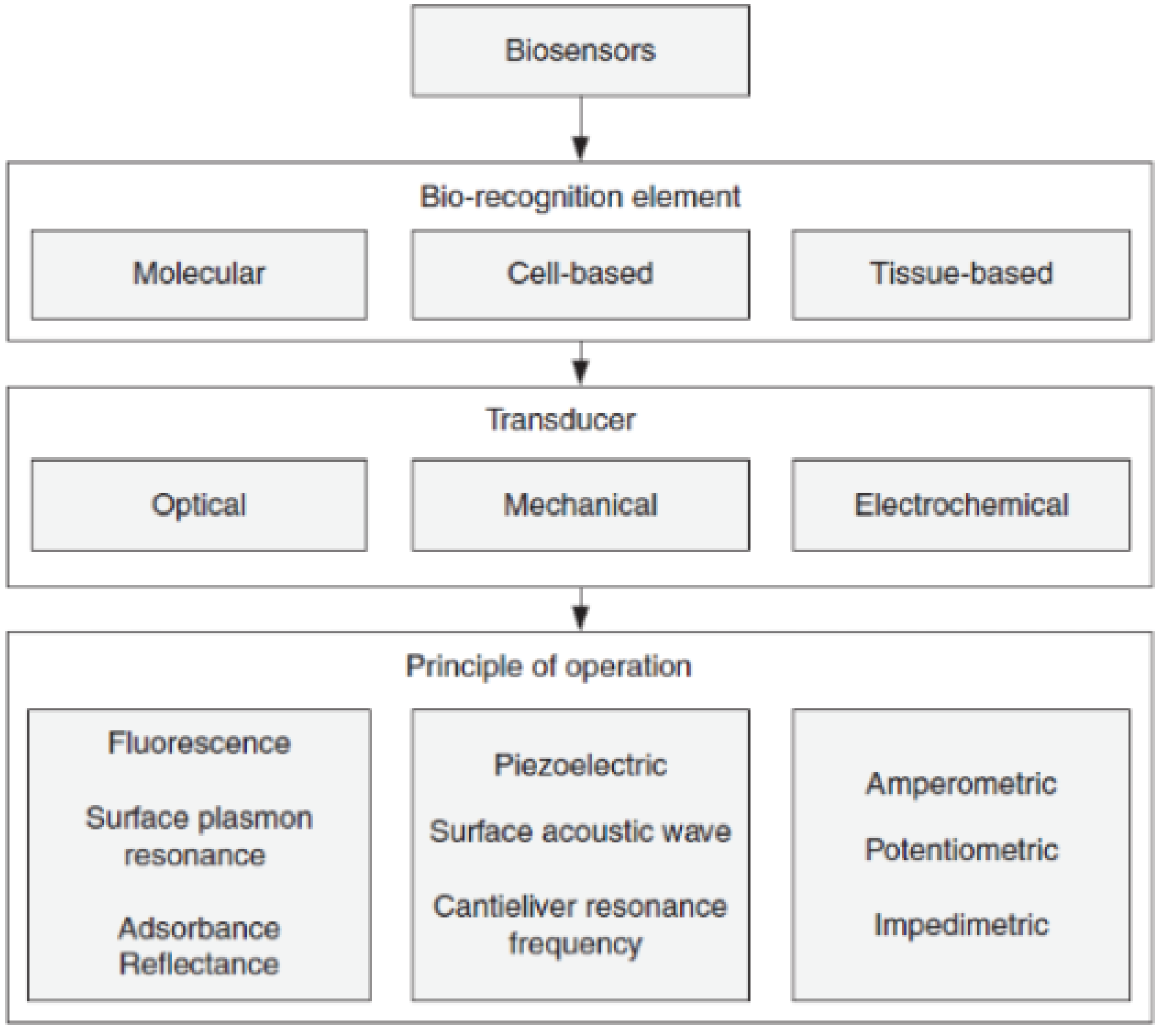


The basic design of the infrared proximity sensor.

Optical Sensors- Ambient Light Sensors

- ✓ Ambient light sensors provide precise light detection for a wide range of ambient brightness and are commonly used in LCD backlight control in mobile phones, LCD TV/panel, and notebook applications.
- ✓ One way to convert the optical signal is by using electro-optical sensors - electronic detectors that convert light, or a change in light, into an electronic signal. Light has many components that can be sensed, such as the wavelength, the intensity, the polarization and the phase. The interaction of light with matter can be quantified by measuring absorbance, reflectance, luminescence and more.

Bio-Nanosensor



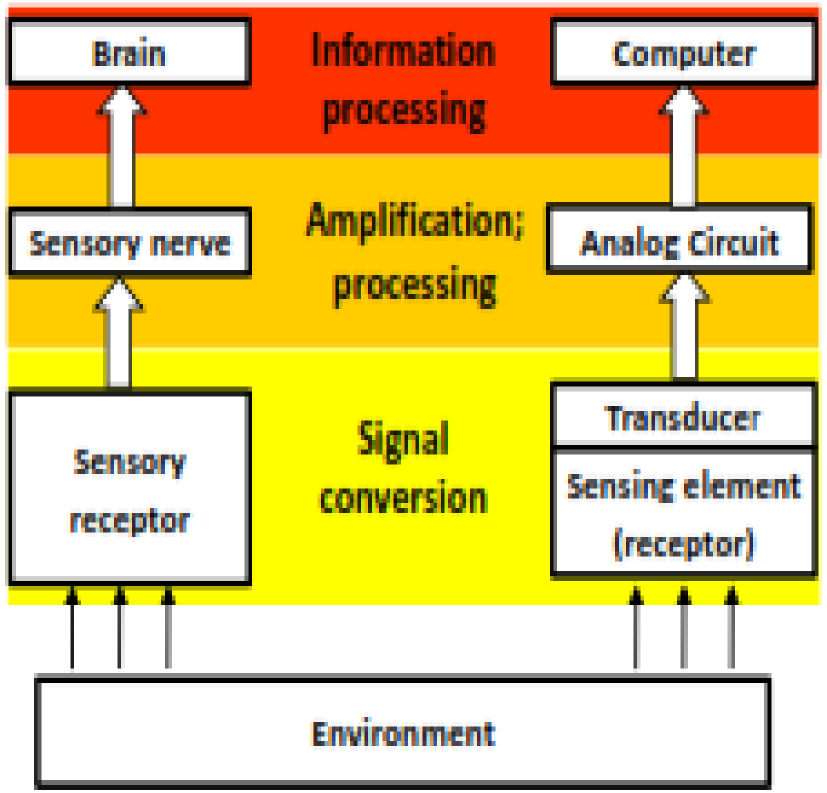


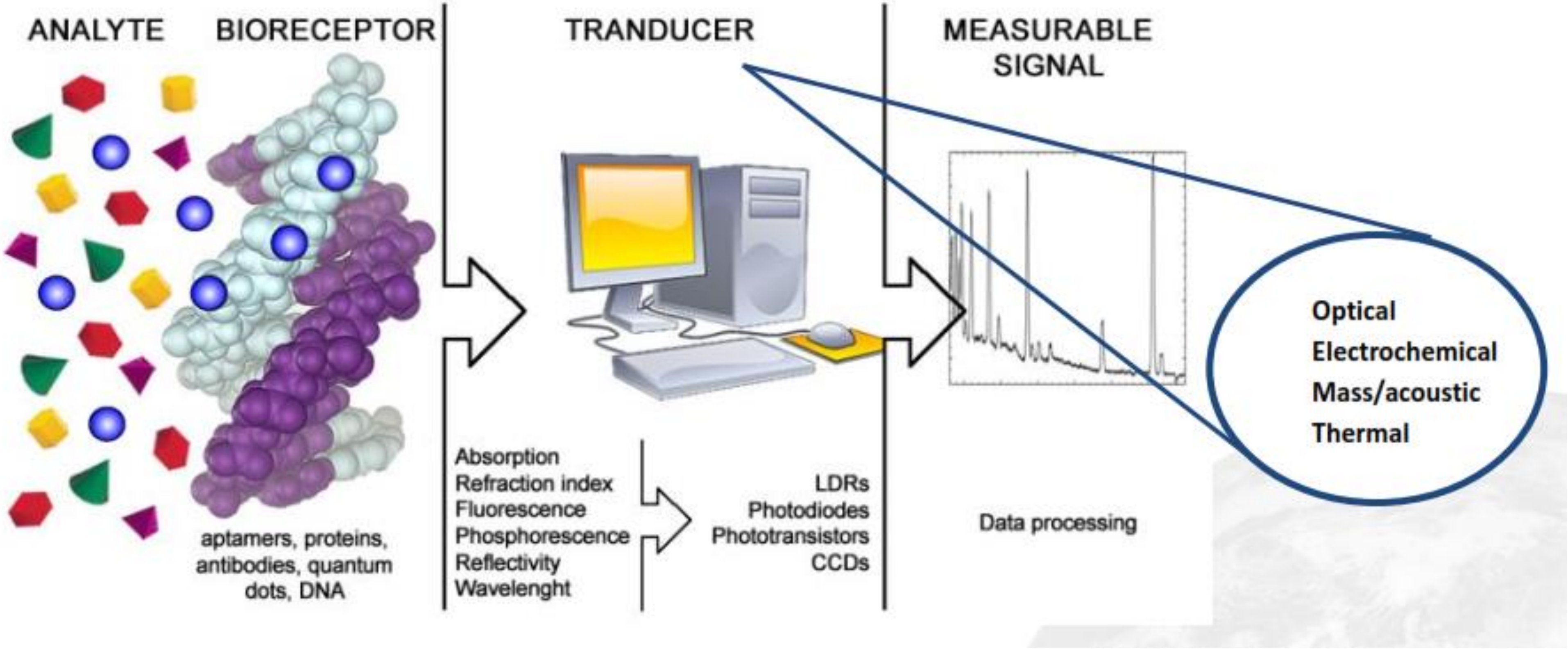
Figure 3-1: Analogy between the human sensing system and artificial sensors.

Biosensors

- Biosensor: analytical device for measurement of a specific analyte
- Biological material + physicochemical transducer(electrochemical, optical, thermometric, piezoelectric, magnetic or micromechanical)

- Nanomaterials and nanosensors increase sensitivity and detection level to pico-, femto-, atto- and even zepto- scales (10^-12-10^-21) – this facilitates helps in early disease detection.

- Bio markers, molecules with a function indicating physiologic or pathologic state, interact with specific receptors fixed onto the surface of a biosensor transducer.



"A biosensor is an analytical device incorporating a biological or biologically derived sensing element either intimately associated with or integrated within a physicochemical transducer. The usual aim is to produce a digital electronic signal which is proportional to the concentration of a specific analyte or group of analytes"

Chemical Nanosensors

- Chemical sensors usually contain two basic components connected in series: a chemical (molecular) recognition (receptor) and a physicochemical transducer. In the majority of chemical sensors, the receptor interacts with the analyte molecules. As a result, the physical properties are altered in such a way that the appending transducer can gain an electrical signal. In some cases, a single physical object acts as a receptor and as a transducer.

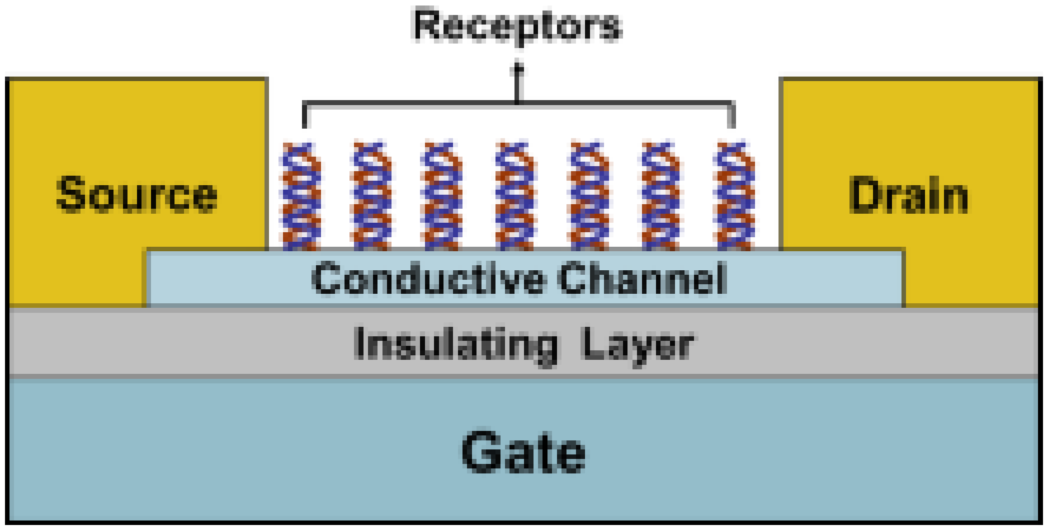
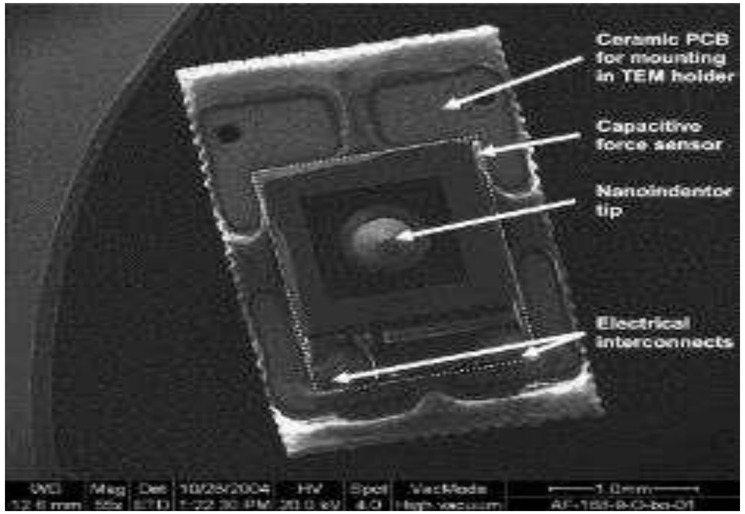


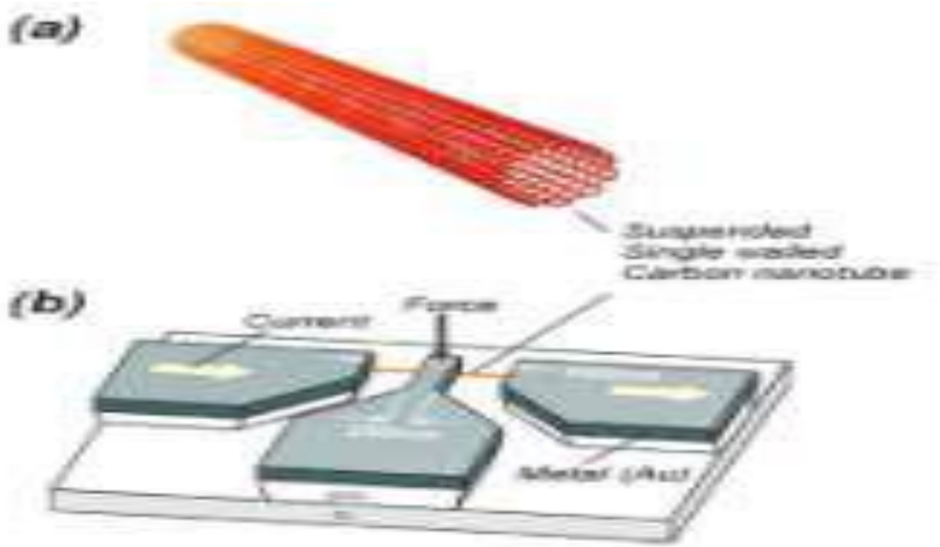
Illustration of chemiresistors with receptors, the binding of bio-molecule with net electrical charges changes the channel conductance.

Physical Nanosensors

- ✓ The physical nanosensor sense the environmental physical change such as
- ✓ Force
- ✓ Acceleration
- ✓ Flow rate
- ✓ Mass
- ✓ Volume
- ✓ Density
- ✓ pressure

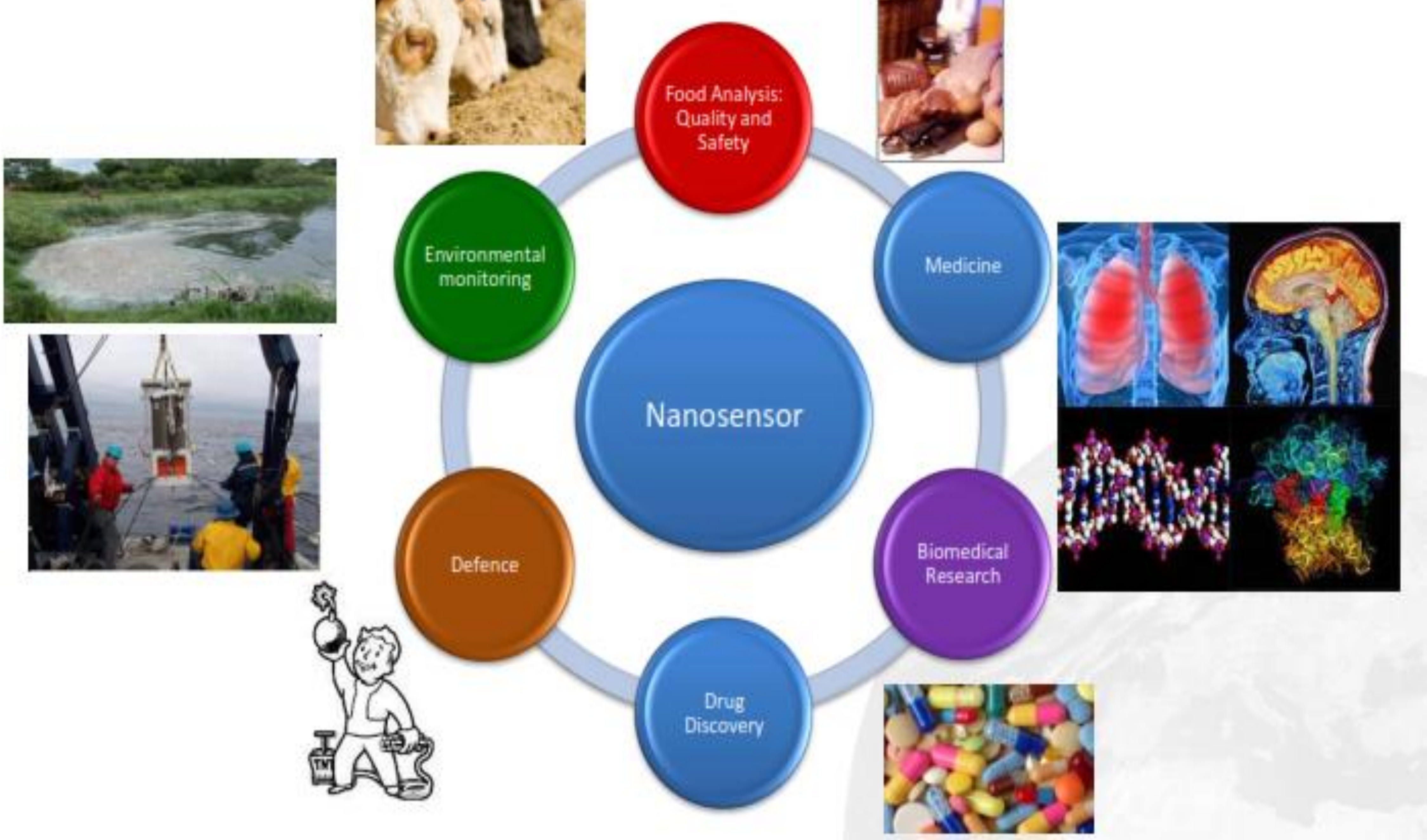


Nanoindentor:The force range is up to 500 μN and 1 mN for the two main designs, with a force resolution of to 0.3 μN.



CNT force sensor

Applications of Nanosensors



Giant (GMR) Magnetoresistance Sensors

Introduction

The giant magnetoresistance (GMR) effect was first described in 1988 by A. Fert (Baibich et al. 1988) and then in 1989 by P. Grunberg (Binasch et al. 1989). In 2007, both were awarded the Nobel Prize in Physics for their contributions (Thompson 2008). Basically, the GMR effect is a significant change in its resistance with an external field at room temperature. It is observed in multilayered structures with ferromagnetic layers separated by a non-magnetic spacer due to the relative orientation of the magnetization vectors.

Initially, GMR structures were used as sensing elements in the read heads of hard drives. In these applications, the magnetoresistance (MR) level shifted, with the influence of the magnetic field generated by the magnetically stored bits, between two limit states: maximum and minimum resistance, as described by

$$MR = \frac{R^{\uparrow\downarrow} - R^{\uparrow\uparrow}}{R^{\uparrow\uparrow}}$$

where:

MR is the so-called magnetoresistance level

$R^{\uparrow\downarrow}$ is the (maximum) resistance in the anti-parallel state

$R^{\uparrow\uparrow}$ is the (minimum) resistance in the parallel state

Structures and Phenomena

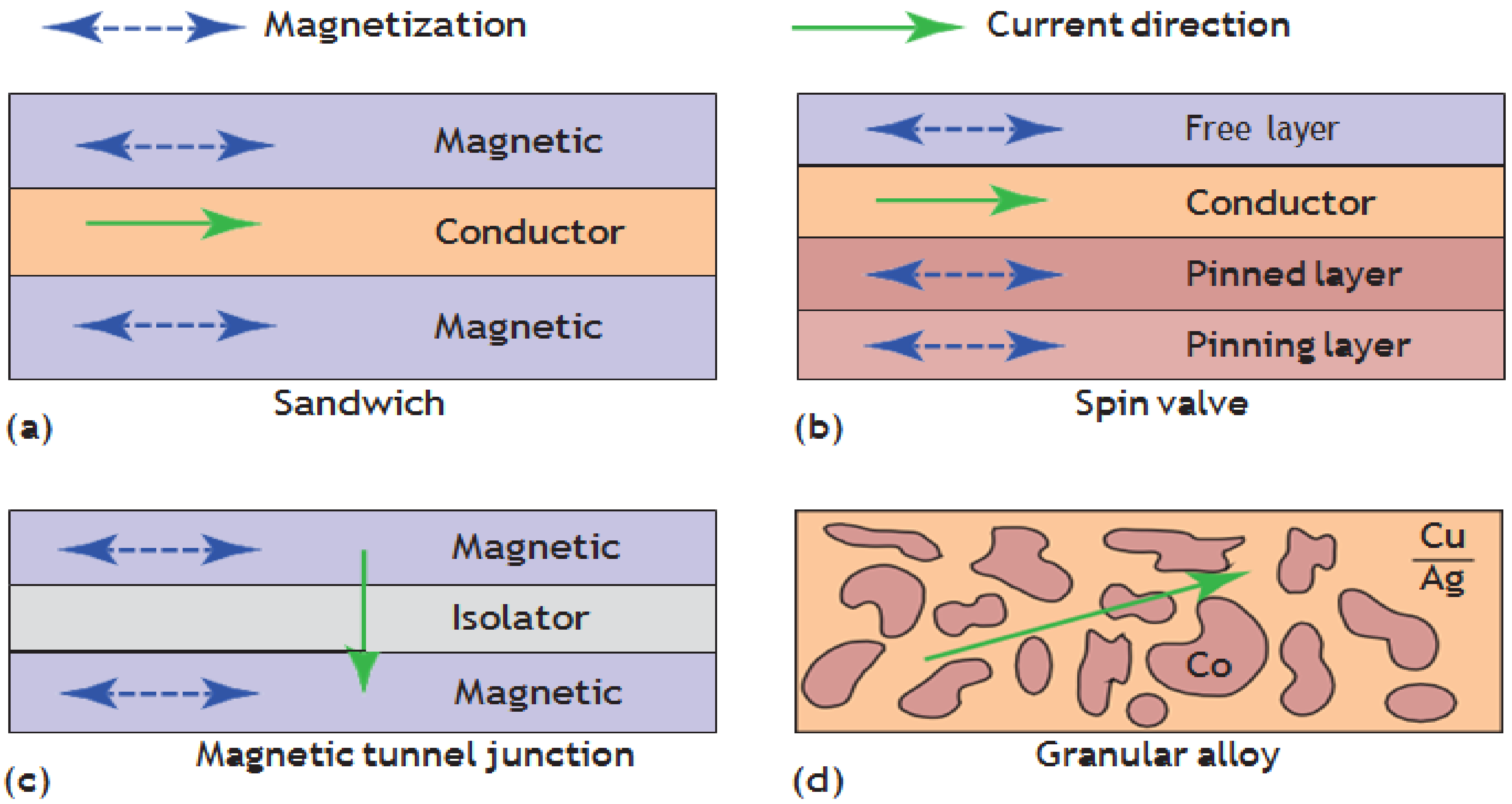
GMR phenomena were initially reported on Fe/Cr thin multilayers (Baibich et al. 1988; Binasch et al. 1989). It was demonstrated that the electric current in a magnetic multilayer consisting of a sequence of thin magnetic layers separated by equally thin non-magnetic metallic layers is strongly influenced by the relative orientation of the magnetizations of the magnetic layers (about 50% at 4.2 K). The cause of this giant variation in the resistance is attributed to the scattering of the electrons at the layers' interfaces. In this way, any structure with metal–magnetic interfaces is a candidate to display GMR. Since then, a huge effort has been made to find structures that enhance this effect (MR levels at room temperature above 200% are achieved in modern GMR structures). We will next describe some of these structures.

Sandwich

A sandwich structure is the general name for multilayered structures. They usually consist of two magnetic layers of an Fe–Co–Ni alloy, such as permalloy, separated by a non-magnetic conductive layer, such as Cu (Ranchal et al. 2002). A general scheme is shown in Figure 2.1a. With magnetic films of about 4–6 nm wide and a conductor layer of about 35 nm, magnetic coupling between layers is slightly small. With these configurations, MR levels of about 4%–9% are achieved, with linear ranges of about 50 Oe. The figures of merit of sandwich devices can be improved by continuously repeating the basic structure, thereby creating a multilayered system. Successful applications of sandwich structures in magnetic field sensing include bio-electronics (Mujika et al. 2009) and angle sensors (Lopez-Martin and Carlosena 2009).

Spin Valves

The origin of spin valves (SVs) comes from the sandwich structure. In SVs, an additional antiferromagnetic (pinning) layer is added to the top or bottom part of the structure, as shown in Figure 2.1b. In this sort of structure, there is no need for an external excitation to get the anti-parallel alignment. Despite this, the pinned direction (easy axis) is usually fixed by raising the temperature above the knee temperature (at which the antiferromagnetic coupling disappears) and then cooling it within a fixing magnetic field. Obviously, devices so obtained have a temperature limitation below the knee temperature. Typical values displayed by SVs are an MR of 4%–20% with saturation fields of 0.8–6 kA/m (Freitas et al. 2007).

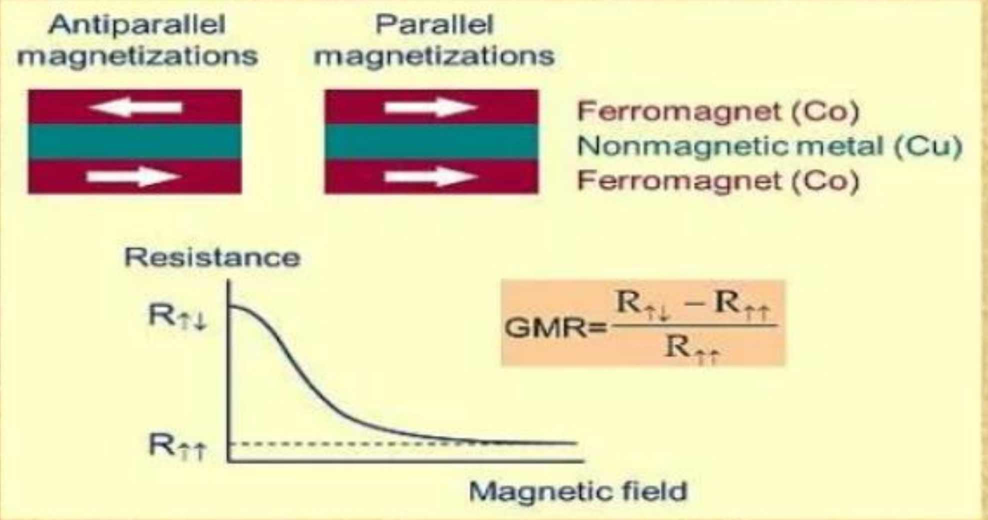


Basic structures displaying GMR phenomena.

GMR

Giant magnetoresistance.

- Giant magnetoresistance (GMR) is a quantum magnetorisitance effect observed in thin film structures composed of alternating ferromagnetic and non magnetic layers.
- It is also a way to control the electrical resistance at the nano scale using magnetic field.



Discovery of GMR.

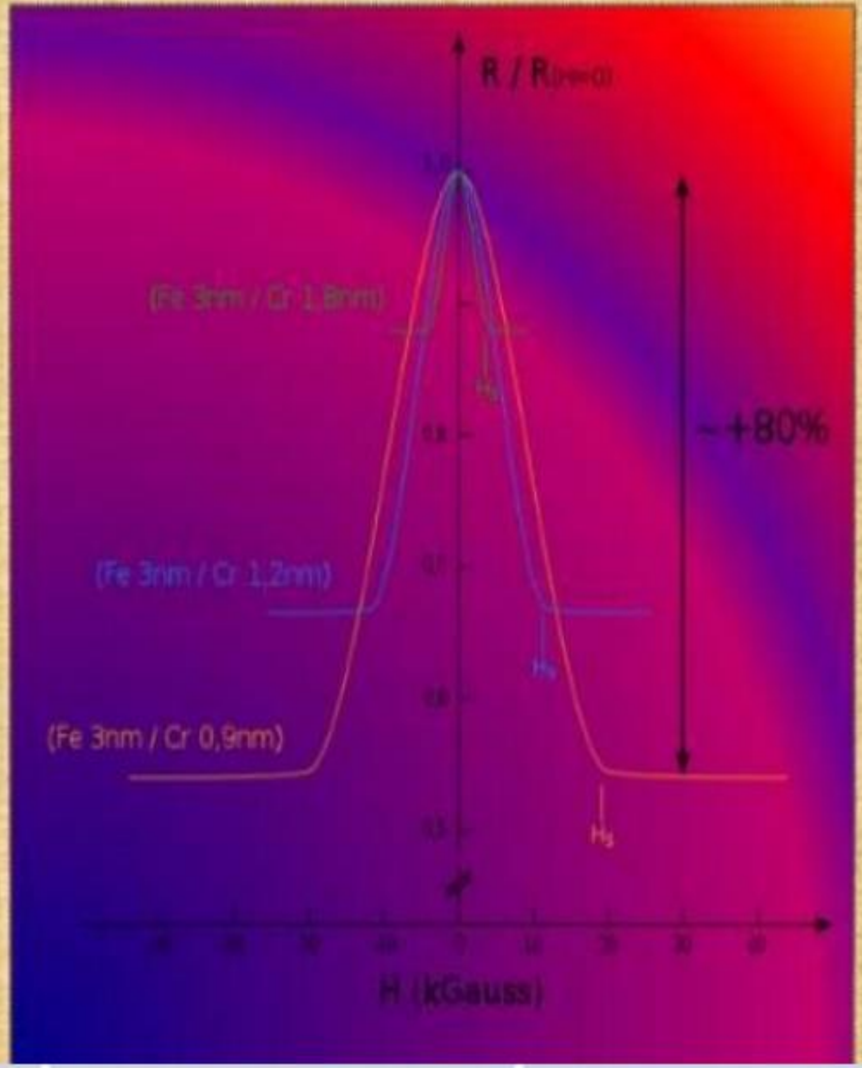
- The **Giant magnetoresistive** (GMR) effect was discovered in the late 1980s by two European scientists working independently.
- Awarded jointly to Peter Grunberg and Albert Fert

Peter Grunberg

Albert Fert

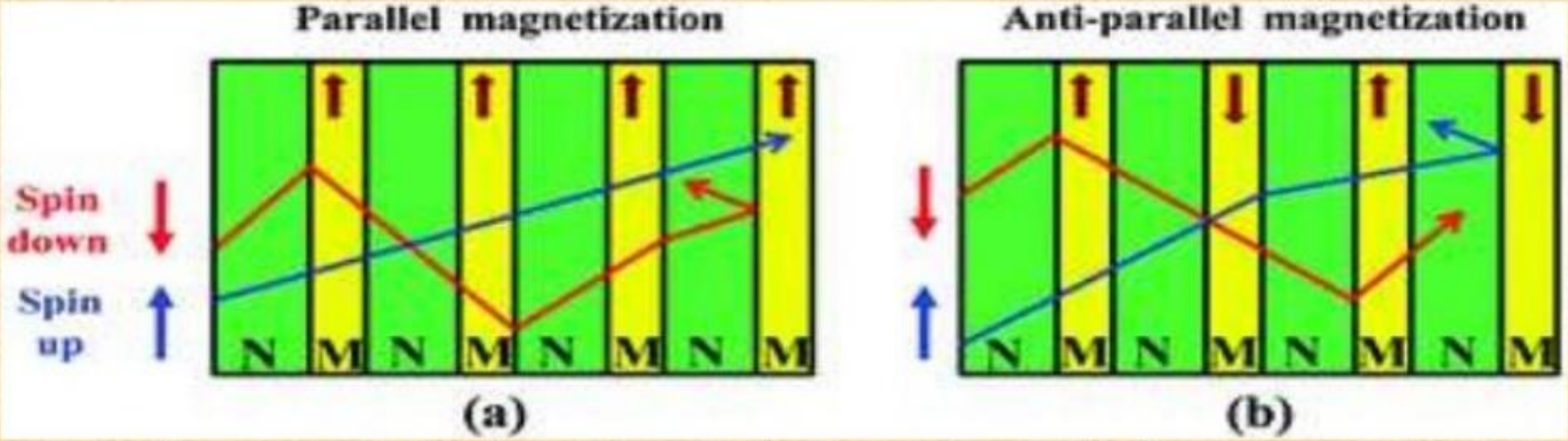
Discovery of GMR.

- Multilayer's of Fe/Cr prepared by molecular beam.
- Fe is **ferromagnetic**
- material can be
- permanently magnetized.
- Cr is **non-magnetic.**
- **Magnetoresistive** effect -50%.



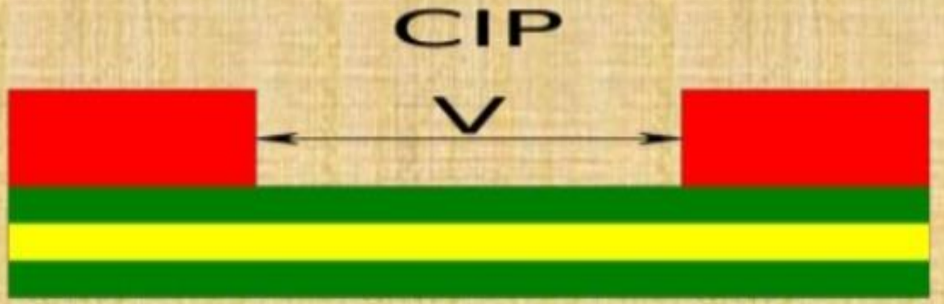
Basic Theory.

- Electron spin & atom magnetic moments.
- On parallel- weak scattering
- On antiparallel-strong scattering
- More scattering= higher electrical reisitance



Why Nanoscale?

- Most scattering occurs at interface of ferromagnetic and nonmagnetic layers.
- Electron mean free path (10-100nm) must be greater than interlayer separation.
- Current-perpendicular-plane (CPP) more effective than current-in-plane (CIP)—also more difficult to achieve.

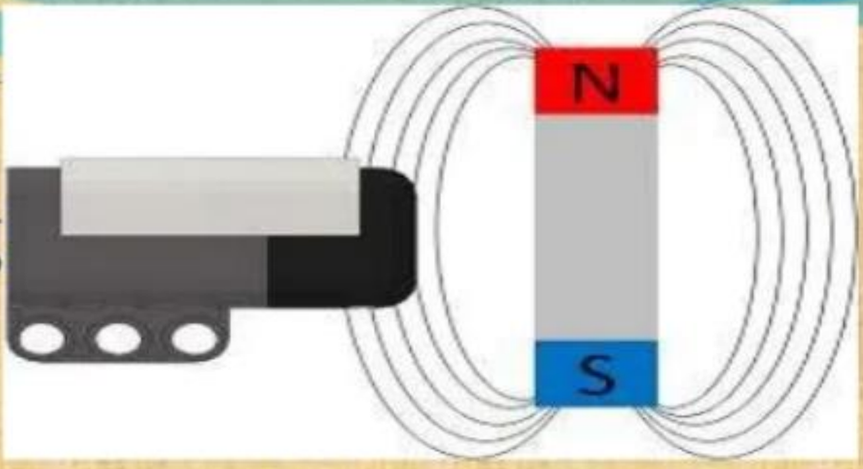


Applications:

- The main **application** of GMR is magnetic field sensors, which are used to read data in **hard disk drives, biosensors, microelectromechanical systems (MEMS),spin value sensor,** and other devices.
- GMR multilayer structures are also used in **magnetoresistiverandom-access** memory (MRAM) as cells that store one bit of information.

Spin-Valve Senser

- Find magnetic field by measuring electrical resistance.



Hard Drive &Mram.

- Information encoded in magnetic domains.
- Reads heads sense magnetic fields: Relay information as electrical signals.

- Before GMR ,hdd made of induction coils and OMR.

MRAM: Magnetic Ram low power consumption,fast speed.

Summary

- Up to 50% change in resistance under external magnetic field.
- Nonmagnetic metal sandwiched between anti-ferromagnetically coupled layers.
- Result of spin-dependent scattering, intrinsically quantum effect.
- Huger impact on magnetic field sensors and hard drives.

Micromaching

Introduction

- Implies parts are made to the size of 1 to 999µm

- By the definition micro engg: as the field where component sizes are a few millimeters

What is Micromachining?

- Micromachining is the basic technology for fabrication of micro-components of size in the range of 1 to 500 micrometers.
- Their need arises from miniaturization of various devices in science and engineering, calling for ultra-precision manufacturing and micro-fabrication.

Important aspects

- Unit removal
- Equipment precision

Why Micro Machining?

- Why Micro Machining? Present day High-tech Industries, Design requirements are stringent.
- Extraordinary Properties of Materials (High Strength, High heat Resistant, High hardness, Corrosion resistant etc) Complex 3D Components (Turbine Blades) Miniature Features (filters for food processing and textile industries having few tens of microns as hole diameter and thousands in number) Nano level surface finish on Complex geometries (thousands of turbulated cooling holes in a turbine blade) Making and finishing of micro fluidic channels (in electrically conducting & non conducting materials, say glass, quartz, &ceramics).

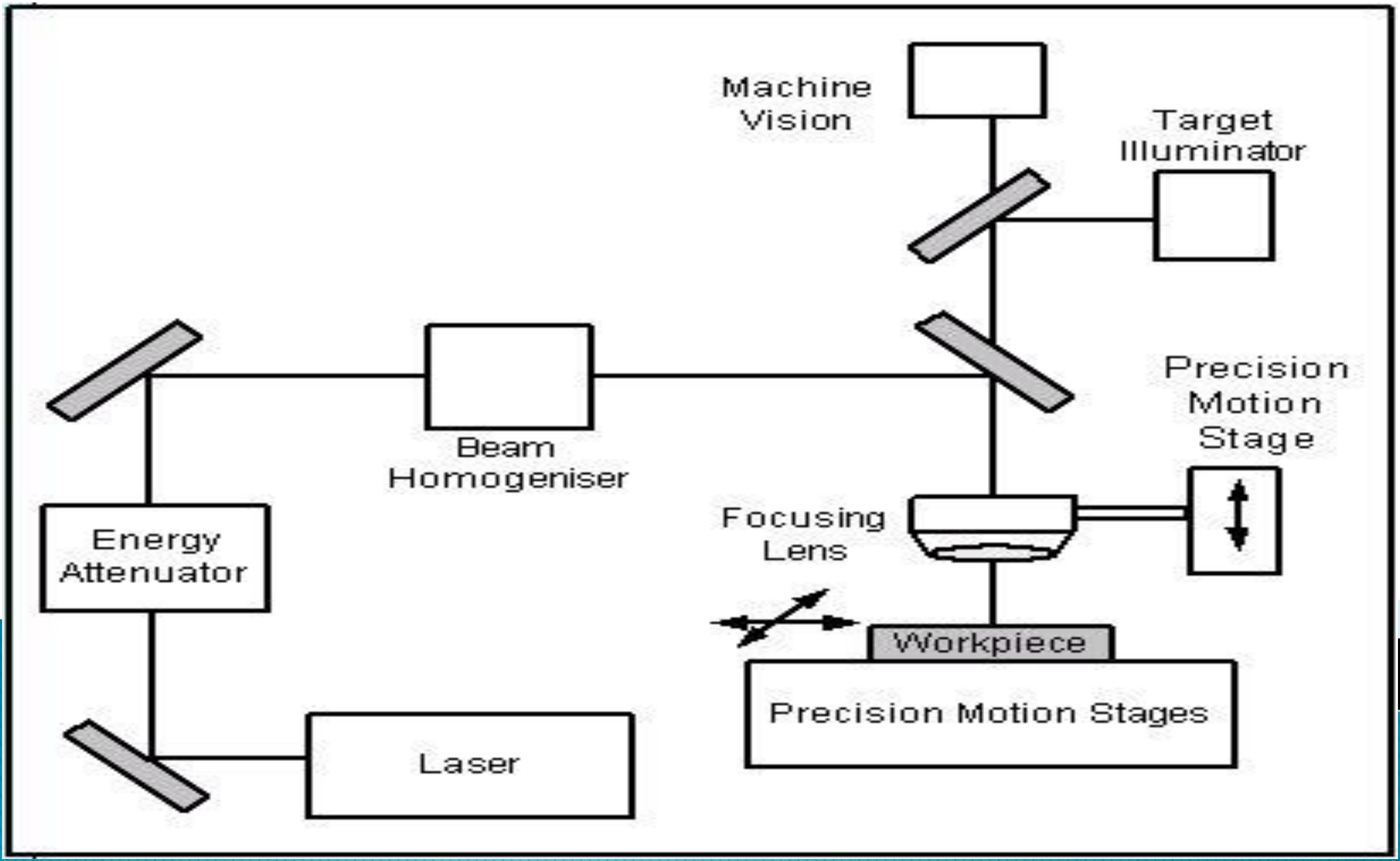
Classification According to Machining phenomena

1. Removal by mechanical force
2. Removal by ablation
3. Removal by dissolution
4. Plastic deformation

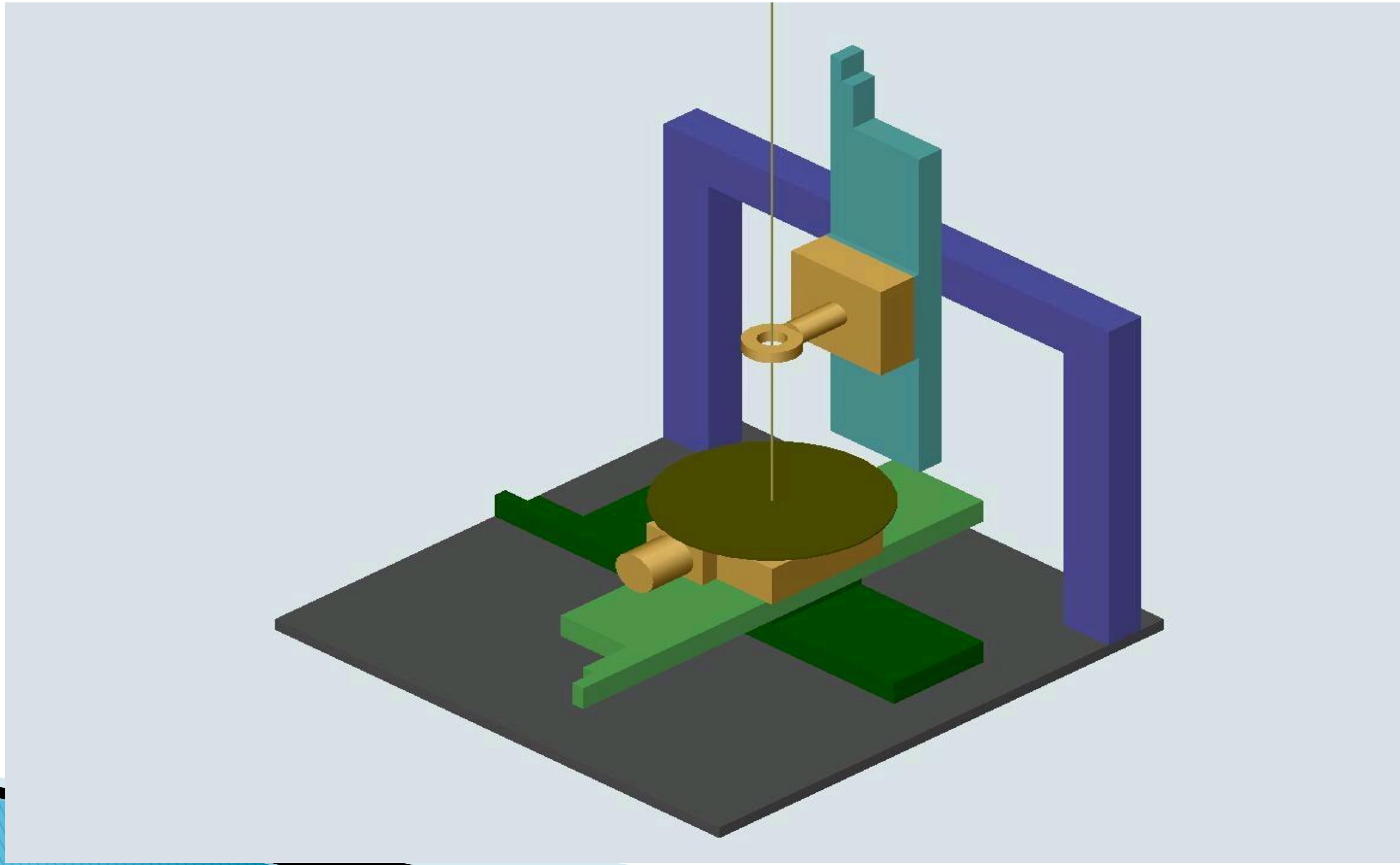
Laser micro machining

- Uses a power source (FS laser, Excimer laser) that emits a beam with very high quantum energy.

Laser Micromachining Process



Conceptual Solid Model of Laser Micromachining Setup



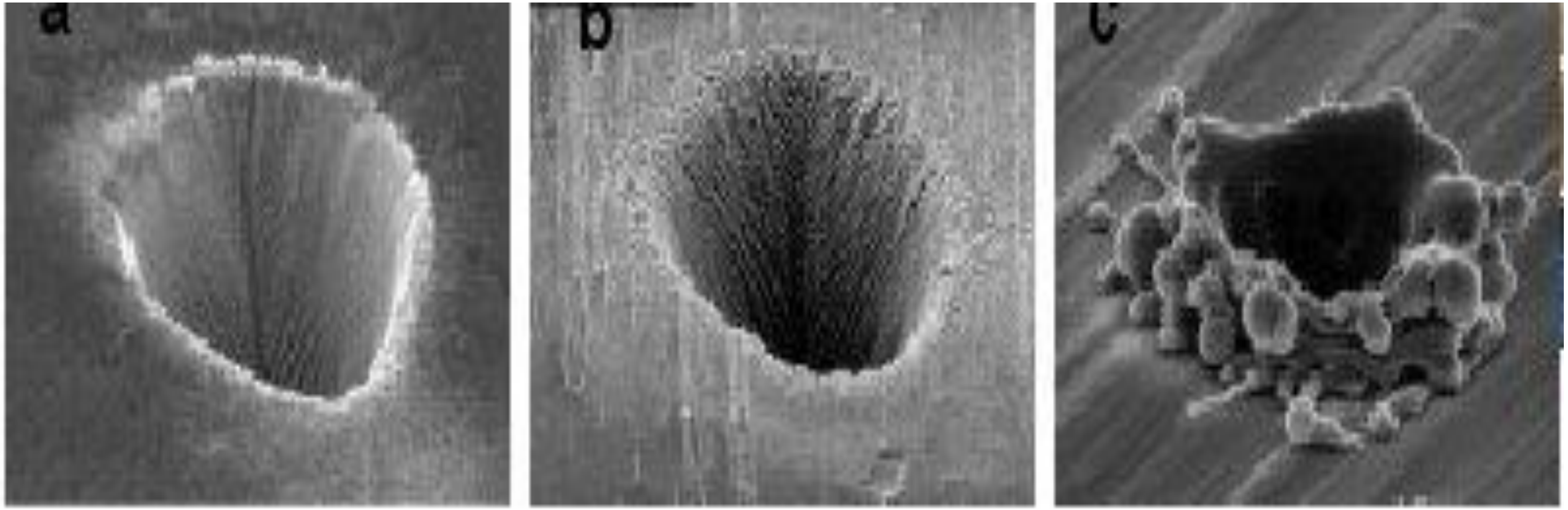
Advantages of Laser Micromachining

- Non-contact machining
- Very high resolution, repeatability and aspect ratios
- Localized heating, minimal redeposition
- No pre/post processing of material
- Wide range of materials: fragile, ultra-thin and highly reflective surfaces
- Process can be fully automated

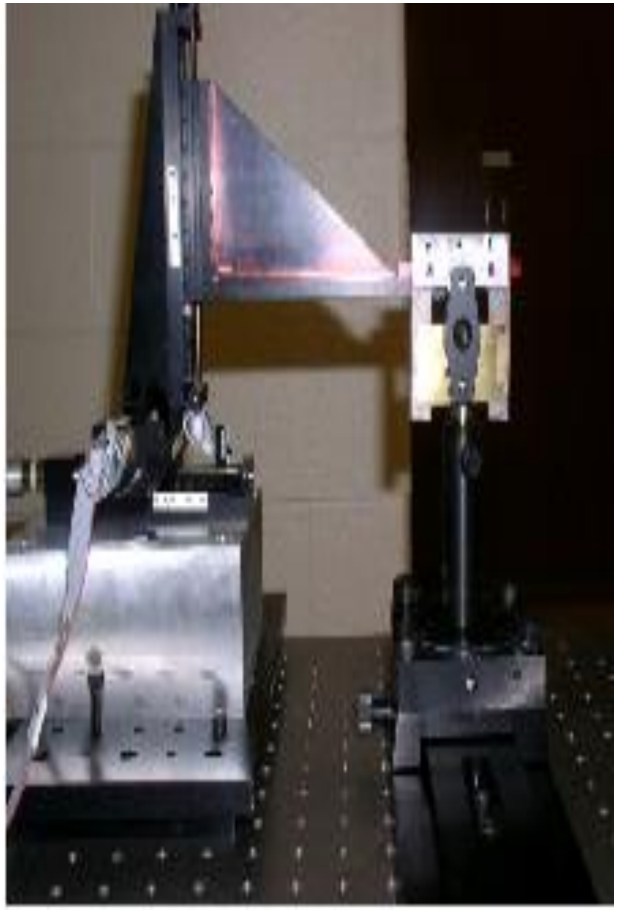
Characteristics of Femtosecond Laser Micromachining

- Very high peak powers in the range $10^{13} W/cm^2$ provide for minimal thermal damage to surroundings
- Very clean cuts with high aspect ratios
- Sub-micron feature resolution
- Minimal redeposition
- Possible to machine transparent materials like glass, sapphire etc

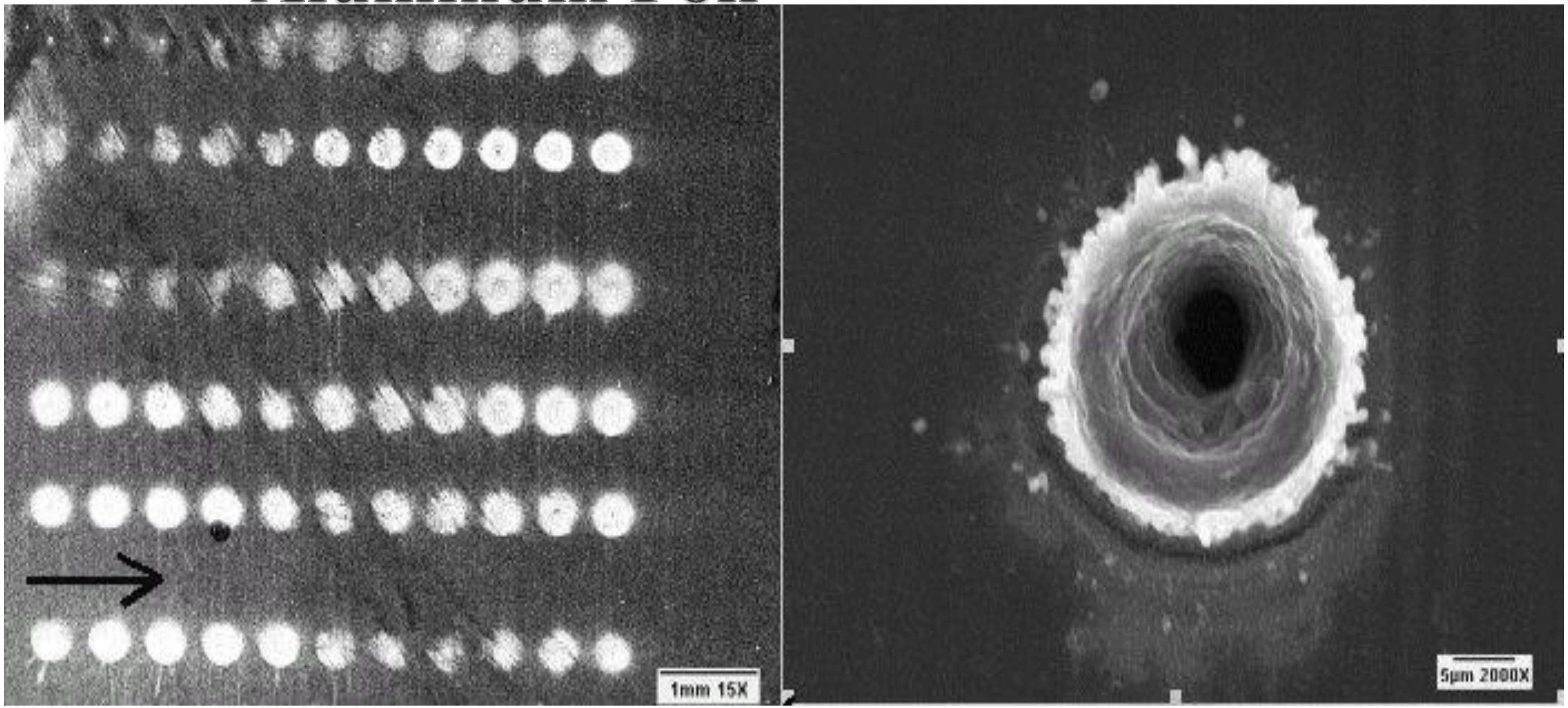
Ultrashort Pulses vs. Long Pulse Micromachining



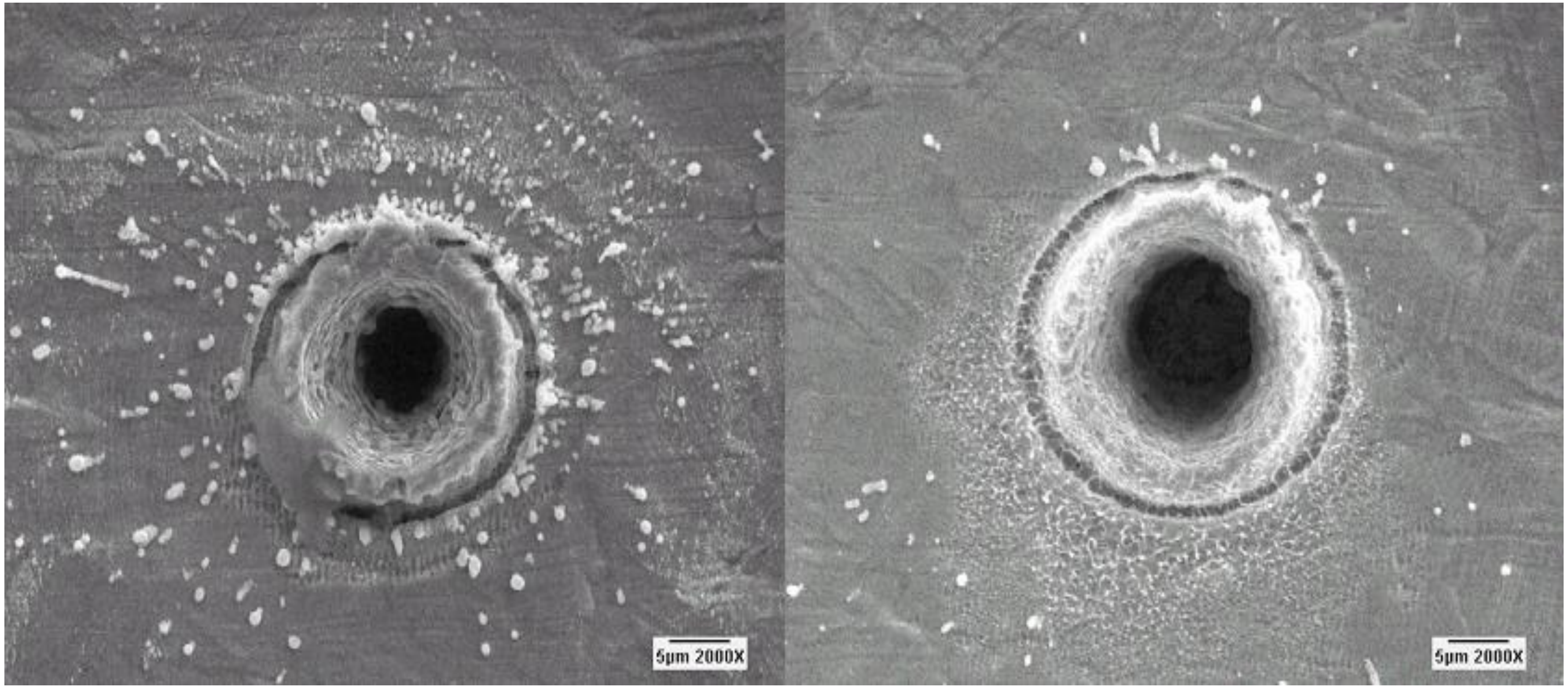
Femtosecond Laser Micromachining



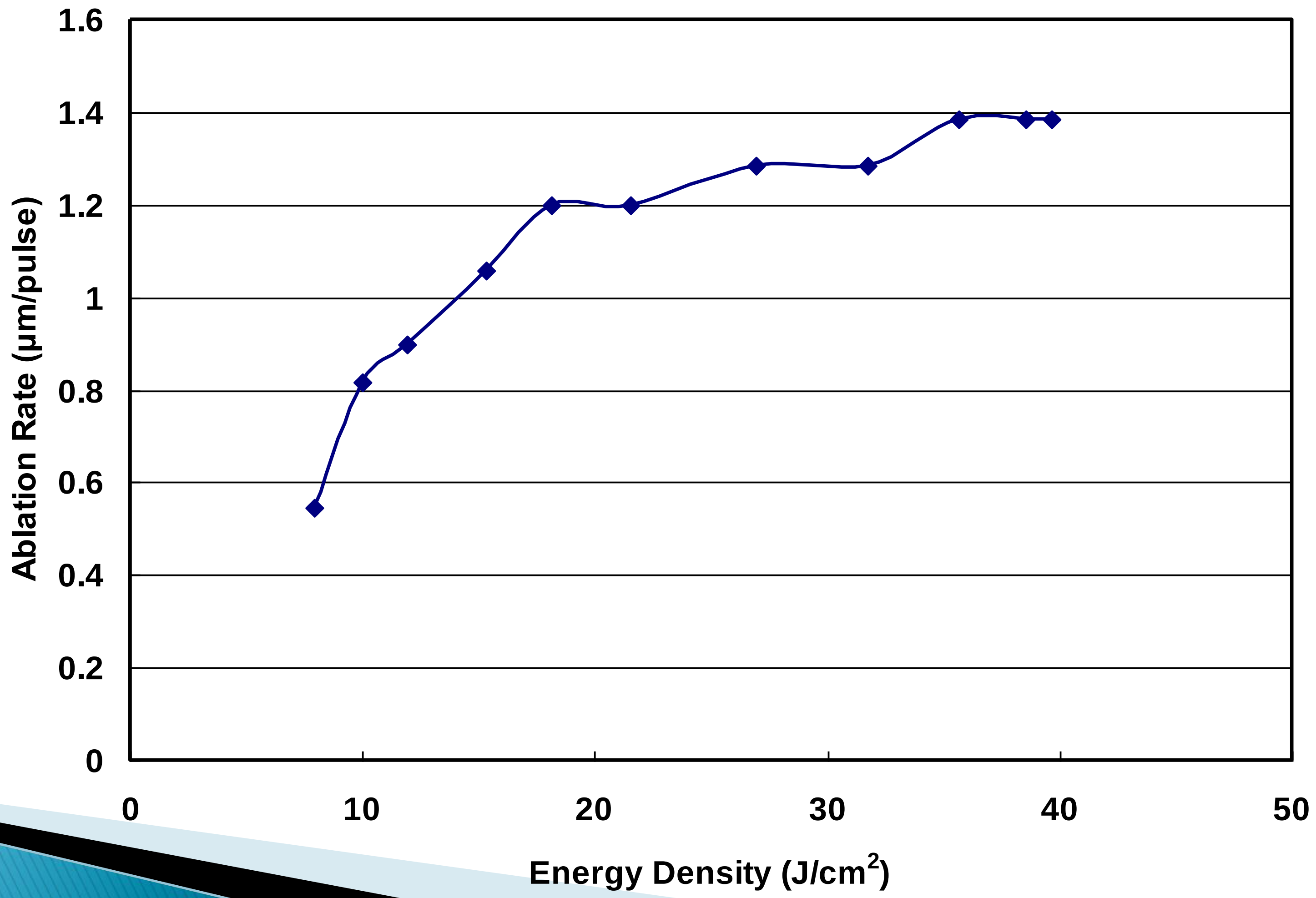
Micromachining in 18μm Thick Aluminum Foil



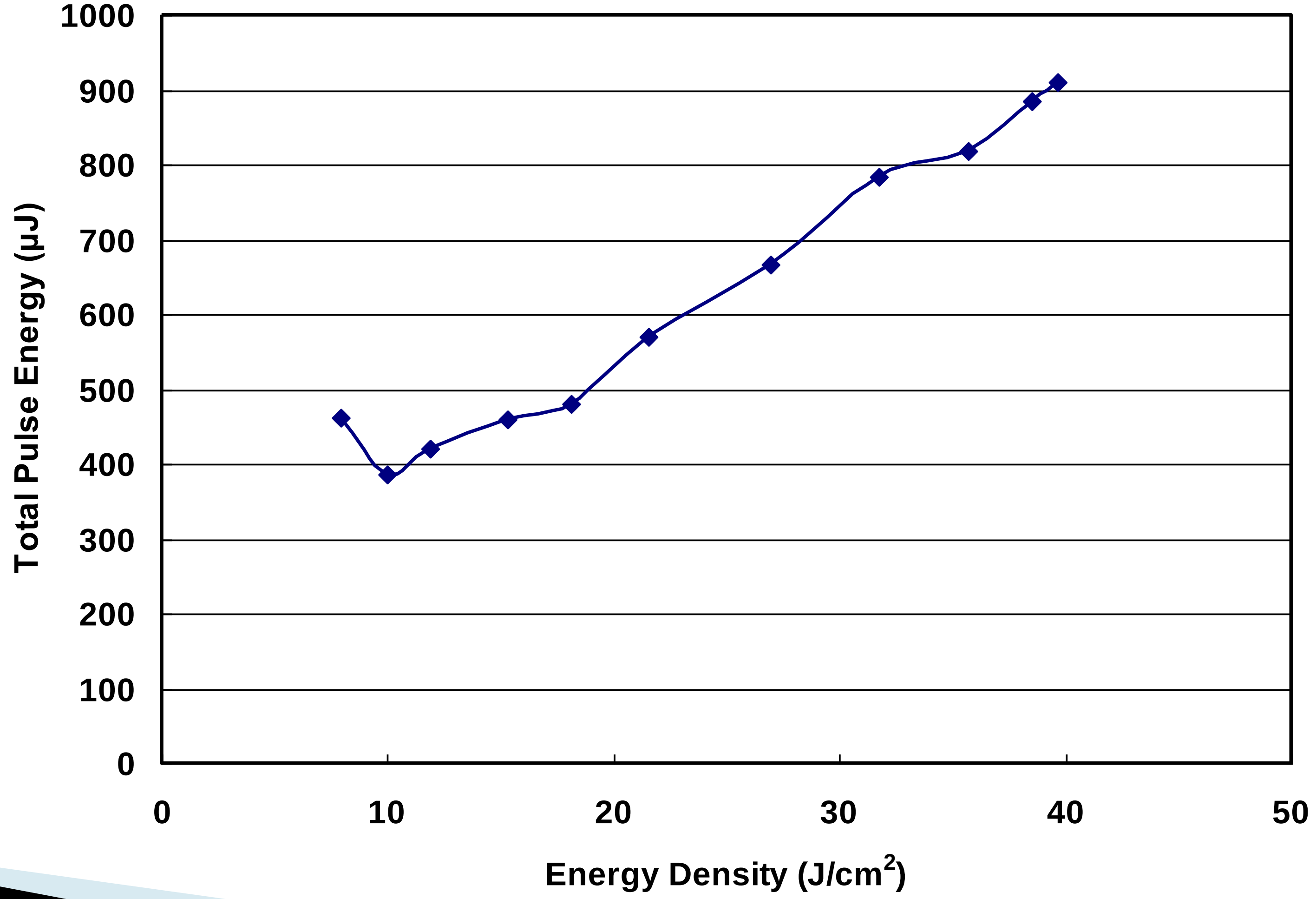
Holes Drilled in 25µm Thick Brass Foil



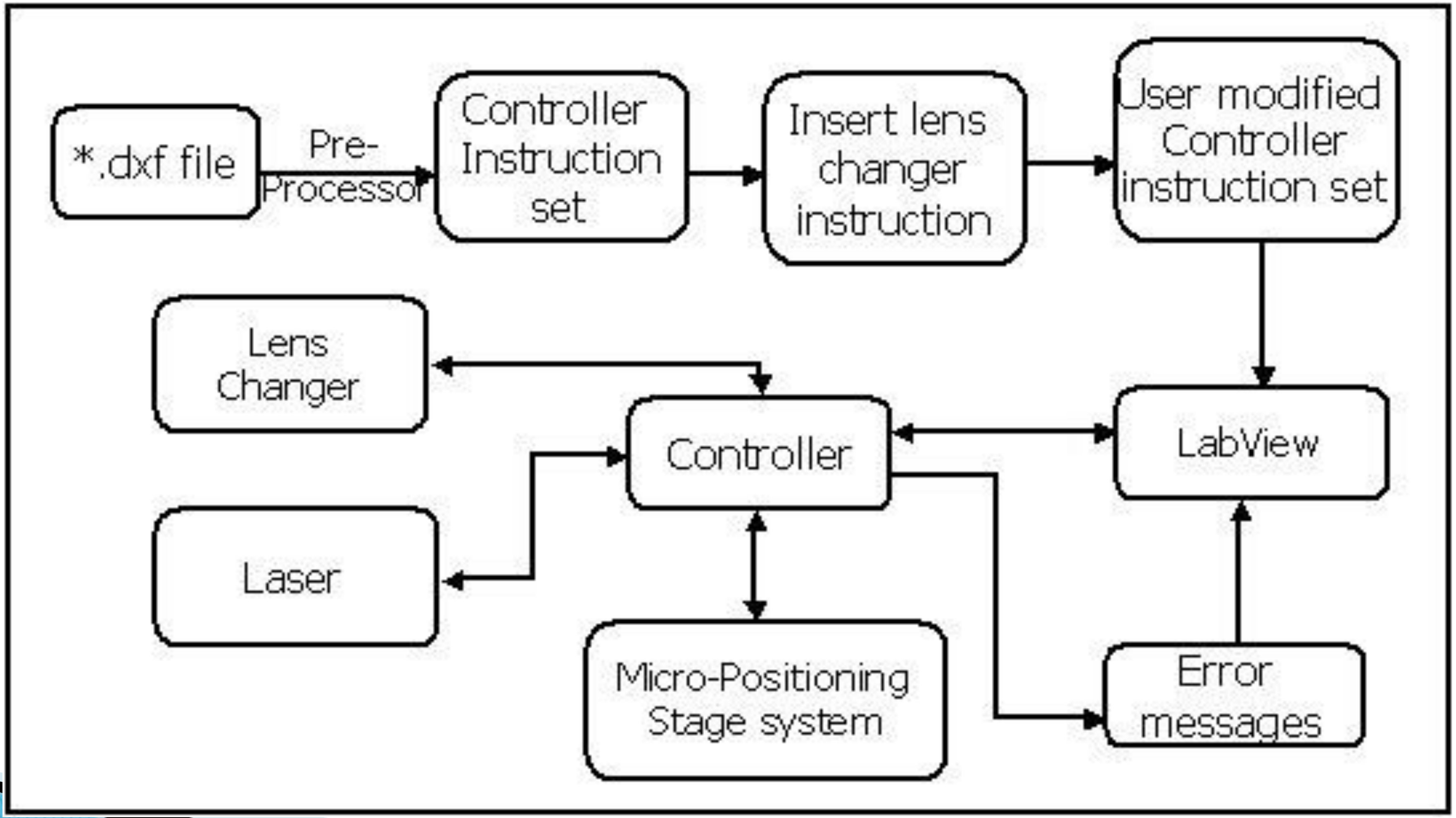
Ablation Rate vs. Energy Density in 18μm Thick Aluminum Foil



Optimization of Pulse Energy Required to Drill Holes



Automation of Laser Micromachining Process



Application of micromachining

- Micro milling
- Micro grinding
- Chemical etching
- Micro punching
- Manufacturing of injection nozzles, Micro surgical tools, VLSI circuits

Magnetic sensors: Introduction, Villari effect ,Wiedmann effect, Hall effect ,Construction, Performance characteristics, Application, Introduction to smart sensors Film sensors: Introduction, Thick film sensors Microelectromechanical systems, Micromachining. Nano sensors, Applications: Industrial weighing systems: Link–lever mechanism. Load cells – pneumatic, elastic and their mounting, different designs of weighing systems. Conveyors type, weigh feeder type.

What's a Magnetic Sensor?

- A magnetic sensor is a sensor that detects the magnitude of magnetism and geomagnetism generated by a magnet or current.
- It serves a strong impact in changing properties of certain materials.
- It produces effects which are mechanical or electrical in nature.
- There are many different types of magnetic sensors.

FILM SENSORS

Basically, such sensors are produced by film deposition of different thicknesses on appropriate substrates. The deposition techniques used are different for the thick and thin film sensors. Sensors produced through these techniques have varying electrical and mechanical properties while a variable is being sensed.

8.2.1 Thick Film Sensors

Thick film deposition is a mature technique and there has not been substantial improvement whilst thin films are being developed almost at the same pace as microelectronics incorporating latest technology. It is to be noted that thick film process had been in use for producing capacitor, resistor, and conductors—and has subsequently been adopted in sensor development. The processing of a sensor can be expressed schematically as

Step 1: Selection and preparation of a substrate.

Step 2: Preparation of the initial coating material in paste or paint form.

Step 3: Pasting or painting the substrate by the coating material or screen printing it.

Step 4: Firing the sample produced in step 3 in an oxidising atmosphere at a programmed temperature format.

The substrates used for developing thick film over them are alumina (96% or 99.5%) and beryllia (99.5%). These are fired at about 625°C. Others used are enamelled steel which is low carbon steel coated with low alkali content glass frit that are fired at around 850°C. Alumina or beryllia have dielectric constants around 9.5 and 7 respectively with dielectric strength around 5600 V/μm. Thermal expansion coefficients are 6.5×10^{-6} and 7.5×10^{-6} respectively with bulk resistivity being almost the same for both, at about 10^{14} Ωcm, thermal conductivities are 0.36 and 2.5 W/(cmK) respectively. Enamelled steel has better strength and machinability being almost double for those of alumina or beryllia which have values around 175 MPa. Though it has better machinability and improved thermal conductivity, enamelled steel is less costly.

For thin film deposition, alumina and beryllia can also be used. Besides, special glass, quartz, fused silica and sapphire are often used which have similar properties and sometimes even better.

It is to be understood that the compatibility between the substrate and the transducing element in film sensors is very important. For example, there should not be difference of thermal expansion coefficients which would induce stress between them and correspondingly result in zero offset, drift, and instability.

Temperature: Thick film sensors such as (i) thermopiles (usually of gold and gold-platinum alloy), (ii) thermistors (usually with oxides of manganese, ruthenium, and cobalt), and (iii) temperature dependent resistances based on gold, platinum, and nickel are used for temperature sensing.

Pressure: Sensing pressure is possible by making thick film diaphragms or capacitive devices made with alumina (Al_2O_3) and $Bi_2Ru_2O_7$, or piezoresistive devices made of same materials.

Concentration of gases: Gases such as methane (CH_4), CO, and C_2H_5OH can be checked for concentration using films of SnO_2 + Pd, SnO_2/ThO_2 + hydrophobic SiO_2. H_2, CO, C_2H_5OH, and isobutane are sensed by SnO_2 + Pd, Pt, Ba^-, Sr^- and $CaTiO_3$ (Nasicon). Oxygen and hydrogen gases also are separately sensed by these types of films

Humidity: It is sensed by (i) resistive films made from RuO_2 (spinel type)/glass and (ii) capacitive films made from glass ceramic/Al_2O_3. On the other hand, dew point is sensed by films made from ($BaTiO_3/RuO_2$)-glass.

Starting from the same basic material, say $SnSO_4$, one can produce SnO_2-based sensors for H_2, CO, and NH_3, as mentioned in the preceding paragraphs. The host material (1% by weight), $PdCl_2$ mixed with SnO_2 as catalyst and $Mg(NO_3)_2$ (also 1% by weight) is mixed presumably for sensitivity range. The combination is fired at about 800°C for one hour. Selectivity is obtained by a second firing process at almost the same temperature by adding different ingredients for different gases. For H_2 detection, for example, it is mixed with Rh (6% by weight) and fired for 1 hour at 800°C. For CO, ThO_2 is added (5% by weight) and for NH_3, ZrO_2 is added (5% by weight) and processed in the same manner as explained.

For control of the porosity of the films which determine the overall sensor sensitivity, organic materials are added in a selective manner. For example, alcohol is added for H_2 and sometimes, inorganic materials work well with appropriate selection. Silica of different varieties is added for CO and NH_3. The materials so produced are now painted on the substrate and dried, then calcined at controlled temperature for varying times.

The other thick film variety is the ceramic-metal or *cemet* which consists of gold/silver/ruthenium/palladium based complex oxides in an insulating medium, mainly glass (lead borosilicate). There are thick film resistors of the cemet which require precise control of heat treatment. The resistivity is controlled by the size, concentration, and distribution of the metallic (conductive) component, that is, their own resistive properties, and the insulating medium. Pure metal powders and resistor pigments differ in so far as changes in their resistive values are concerned and hence, their embedding in per cent weight changes the resistivity of the sensor developed. Figure 8.1 shows the difference for two typical cases.

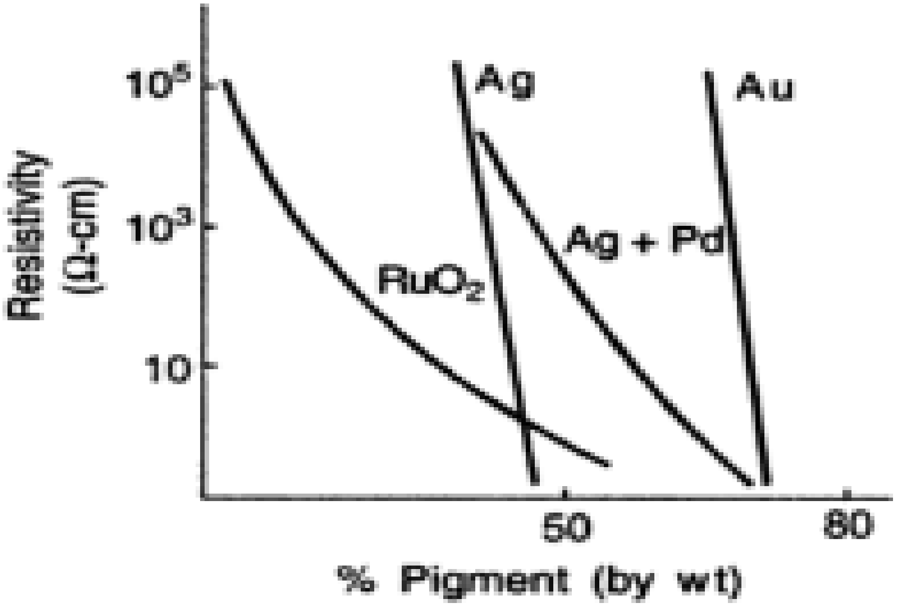


Fig. 8.1 Resistivity variation with change in pigment.

8.2.2 Thin Film Sensors

Thin film sensor processing differs from thick film technology mainly in the film deposition techniques. This technology is similar to that used in silicon micromechanics. A number of techniques are used for thin film deposition, such as:

(a) Thermal evaporation
   (i) resistive heating
   (ii) electron beam heating

(b) Sputter deposition
   (i) DC with magnetron
   (ii) RF with magnetron

(c) Chemical vapour deposition (CVD)

(d) Plasma enhanced chemical vapour deposition (PECVD)

(e) Metallo-organic deposition (MOD)

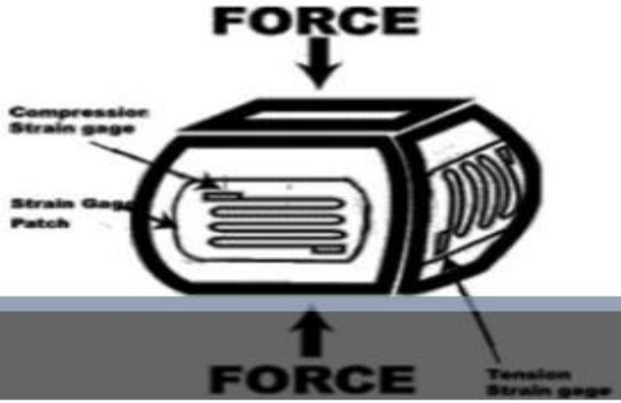
(f) Langmuir–Blodgett technique of monolayer deposition.

Of these, the thermal evaporation and sputter deposition are decades old. However, in the sputter deposition technique, magnetron sputtering is an improved form where a magnetic field perpendicular to the applied electric field is applied. This increases the ionization probability of the electrons as the Lorentz force $\mathbf{E} \times \mathbf{B}$ restricts the primary electrons near the cathode. As a result, sputtering efficiency is also enhanced.

LOAD CELLS

DEFINITION

- Load cell is an electromechanical device.
- A load cell is a force transducer that converts force or weight acting on it into an electrical signal.
- Load cell can be used to measure force, torque and pressure.
- Load cell can measure a wide range of force, from 25grams to 3,000,000lbs.



CLASSIFICATION AND APPLICATION

Mechanical type load cell

- ❑ Hydraulic
- ❑ Pneumatic

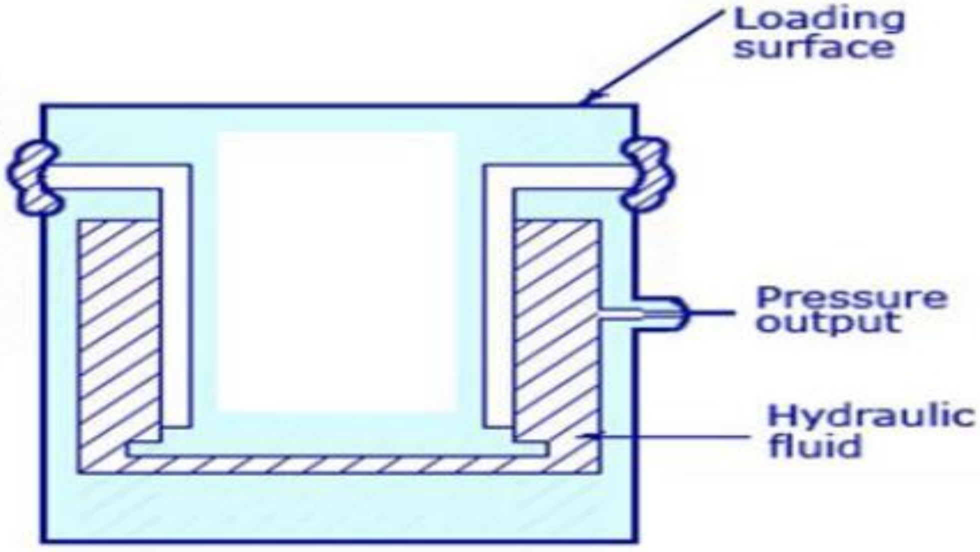
Electrical type load cell

- ❑ Resistance based (strain gauge load cell)
- ❑ Capacitance based
- ❑ Inductance based (LVDT load cell)

Among the many kinds of load cell the most common type is strain gauge load cell.

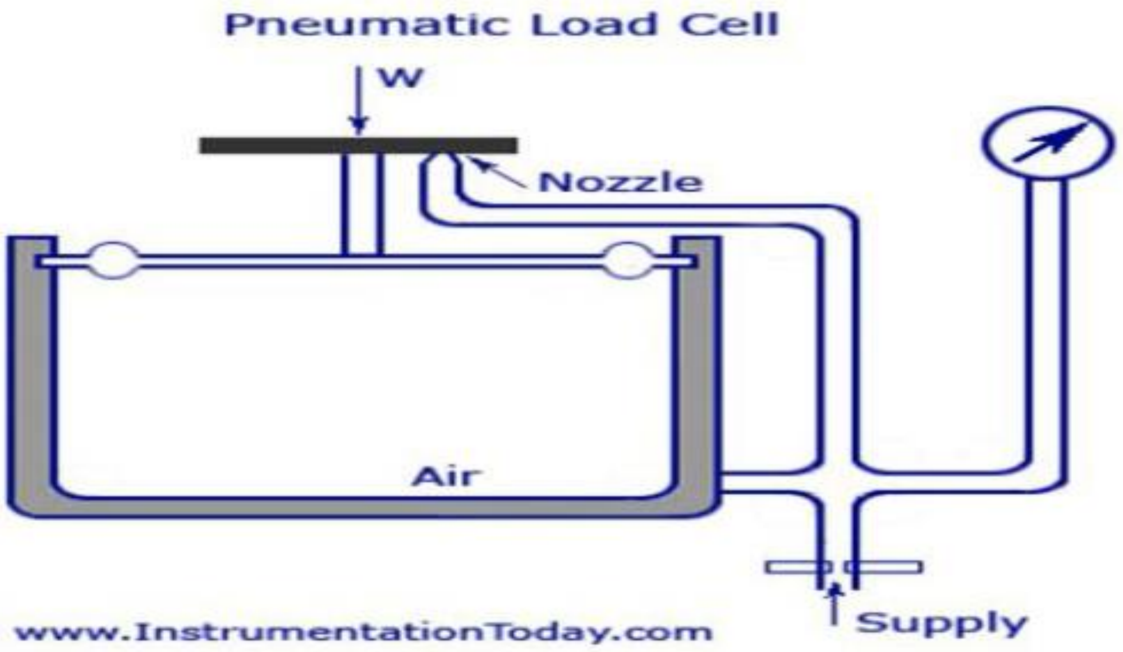
Mechanical Load Cell

<u>Hydraulic load cells</u> are force balance-devices, measuring weight as a change in pressure of the internal filling fluid. It is ideal for use in hazardous areas as there are no any electrical component in it.



Hydraulic Load Cell

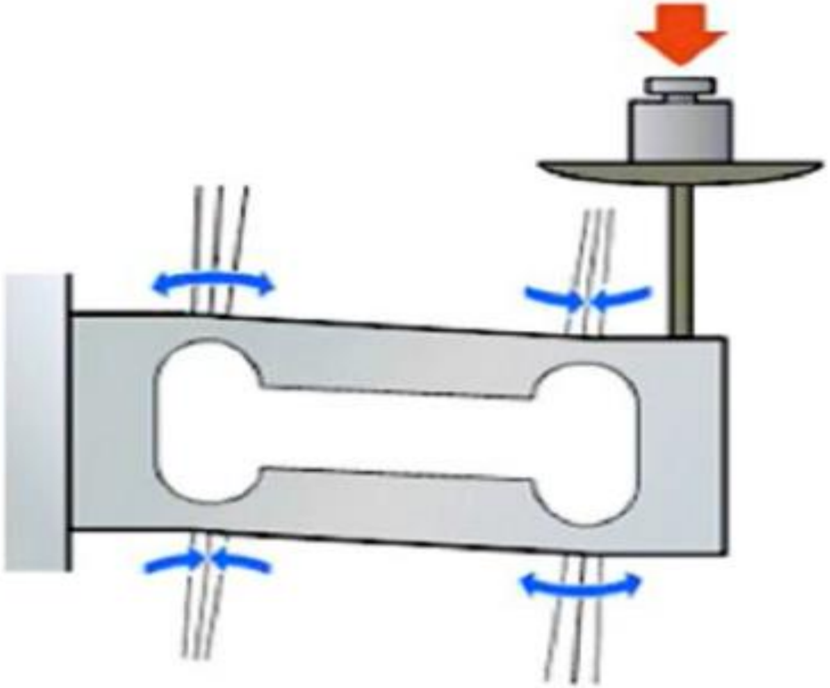
Pneumatic Load Cells also operate on the force-balance principle. These devices use multiple dampener chambers to provide higher accuracy than hydraulic load cell. Pneumatic load cells are often used to measure relatively small weights in industries where cleanliness and safety of prime concern.



Electrical Load Cell

Strain Gauge Load Cell

- ❑ A strain gauge is a device used to measure the strain of an object and convert the load acting on them into electrical signals.
- ❑ Due to application of load, strain changes the electrical resistance of the gauge in proportion to the applied load.
- ❑ Strain gauge shows a very high accuracy of 0.03%.



Theory behind electrical strain gauge load cell

We know that,

$$R=\rho * L/A$$

Where, R= Resistance of the conducting material

ρ =Resistivity

L= Length

A= Cross sectional area

From the above formula we can deduce that resistance of an object is directly proportional to its length.

ie $R \propto L$

First term: under strain, wire changes dimension, and thus the resistance changes.*(dominant for metals)*

Second term: change in resistivity due to the change in crystal lattice of the material under strain.(*dominant in semiconductors*).

Material	**Resistivity**
Conductor	10^{-8} to 10^{-6}
Semi-conductor	1 to 10^{4}
Insulator	10^{6} to 10^{18}

Gauge Factor

For a given amount of strain($\Delta L/L$),the gauge will undergo a corresponding change in resistance ($\Delta R/R$).

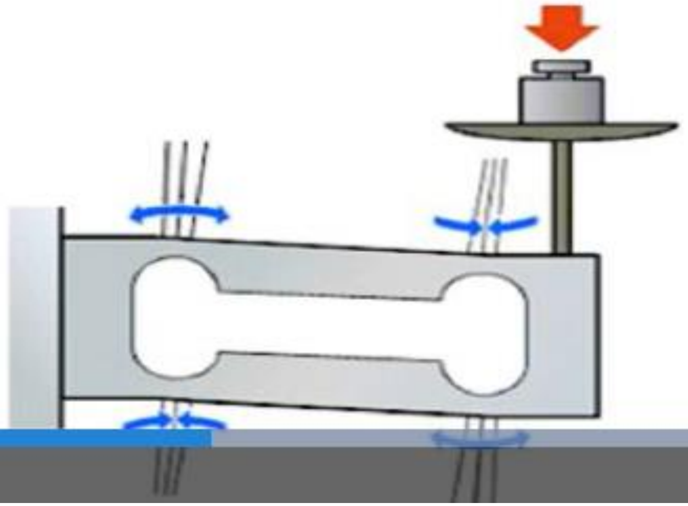
Gauge Factor is defined as the ratio of ($\Delta R/R$) and ($\Delta L/L$). i.e,

$$\boldsymbol{F_g = \frac{(\Delta R/R)}{(\Delta L/L)}}$$

Material	**Gauge Factor**
Conventional foil gauge	1.5 to 3.5
Constantan strain gauge	1.9 to 2.1
Ni-chrome or platinum-iridium	up to 3.5

Strain Gauge Resistance

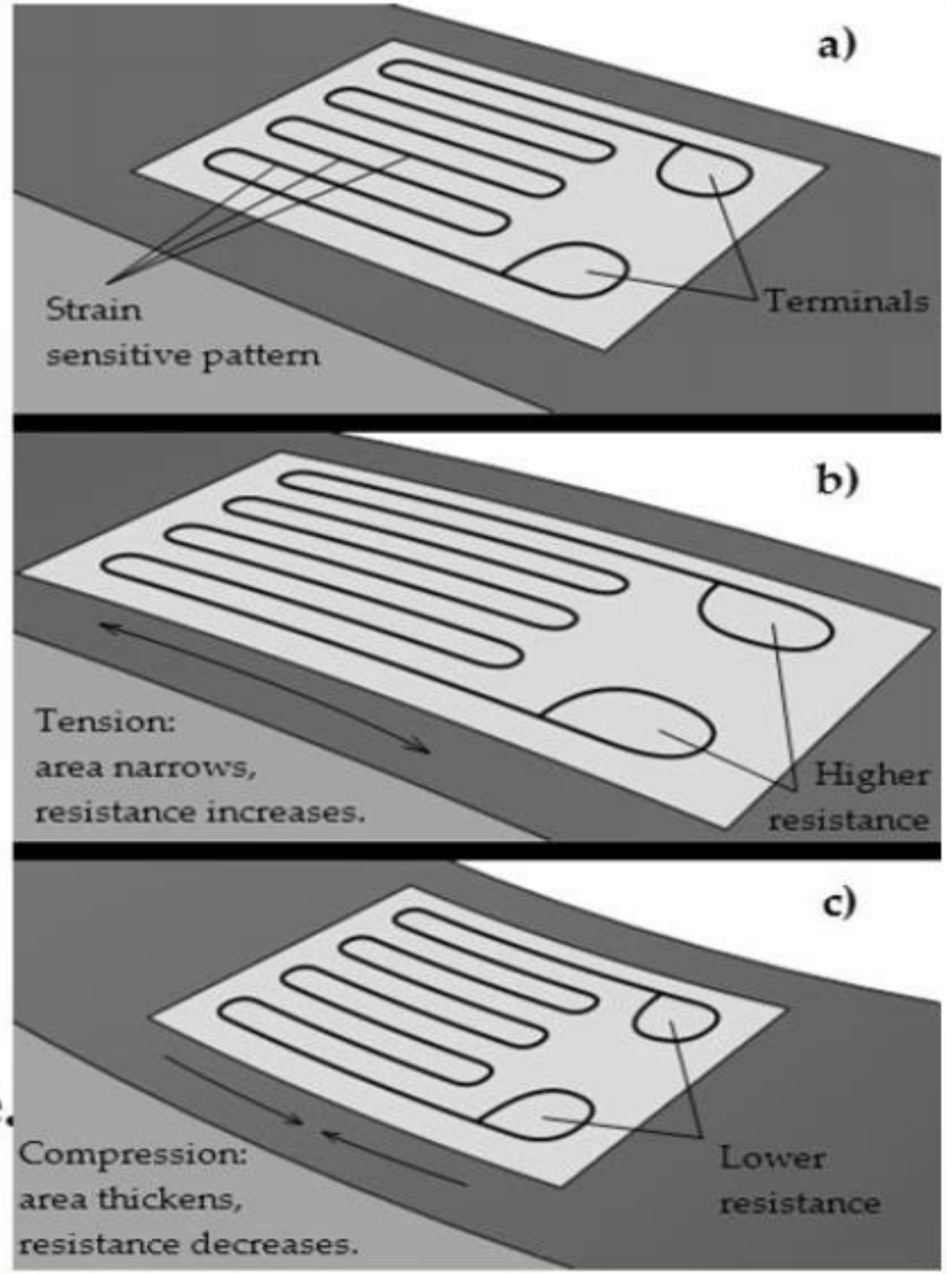
- Strain gauge under tension---Resistance goes up.
- Strain gauge under compression---Resistance goes down.



Strain gauge

How does it work ?

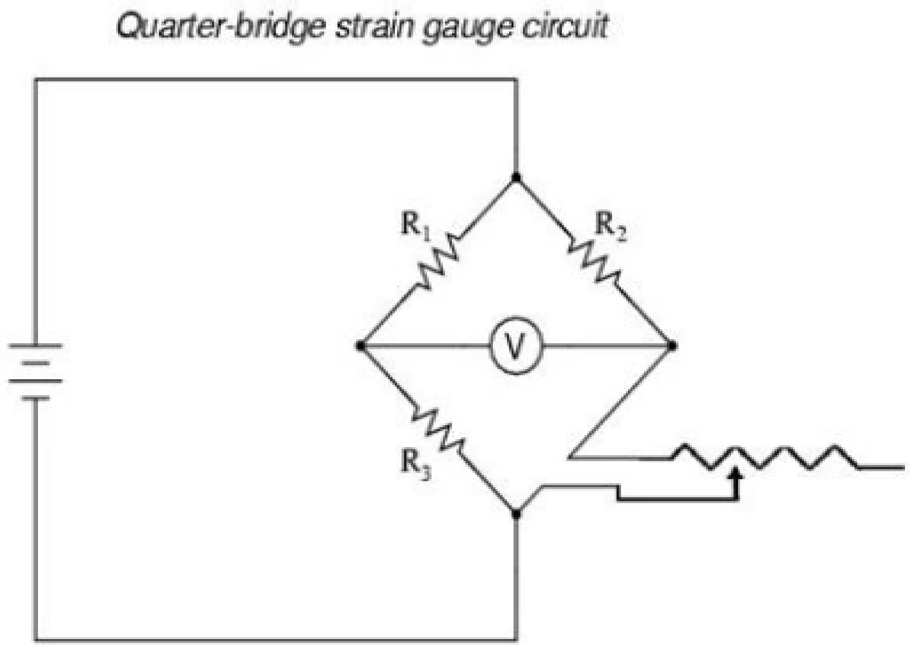
- ❑ Foils/filaments inside the strain gauge are about 1/1000 inch diameter and made up of basic metal conductors.
- ❑ The gauge is attached to the object by a suitable adhesive.
- ❑ As the object is deformed, the foil is deformed causing its electrical resistance to change.
- ❑ The resistance change is commonly measured using a **Wheatstone Bridge.**



Wheatstone Bridge

What is it?

- ❑ A Wheatstone bridge is an electrical circuit.
- ➢ used in a load cell to measure an overall change in resistance.
- ➢ increases sensitivity and reduces the affects of temperature.



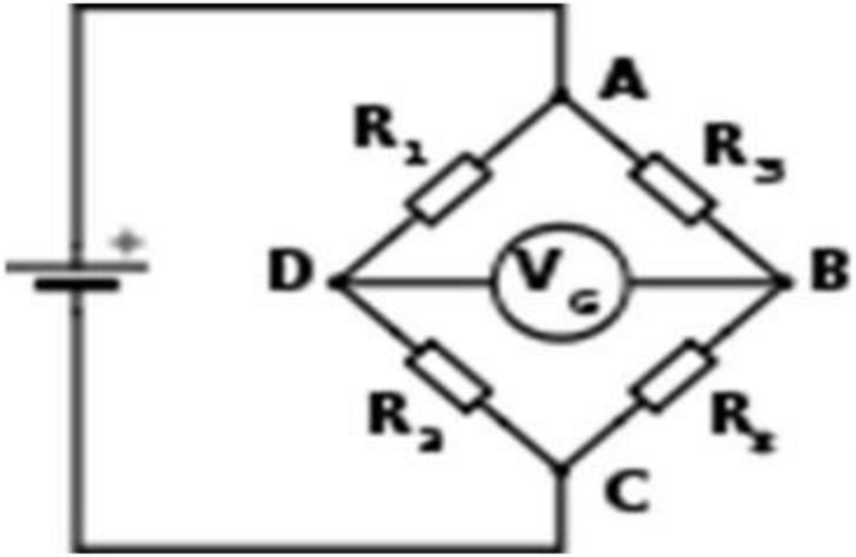
Wheatstone Bridge

How does it work?

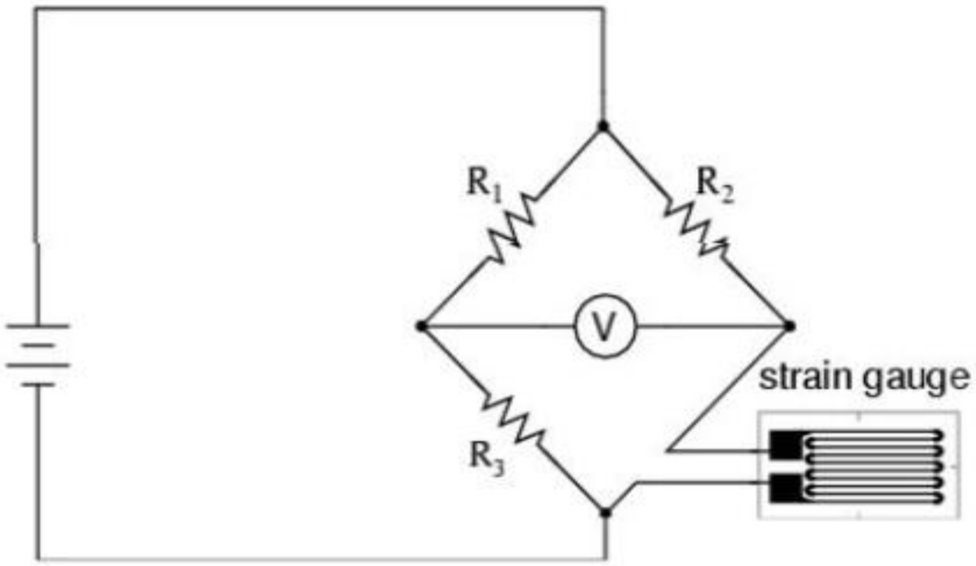
If $\frac{R_2}{R_1} = \frac{R_x}{R_3}$ then circuit is said to be balanced.

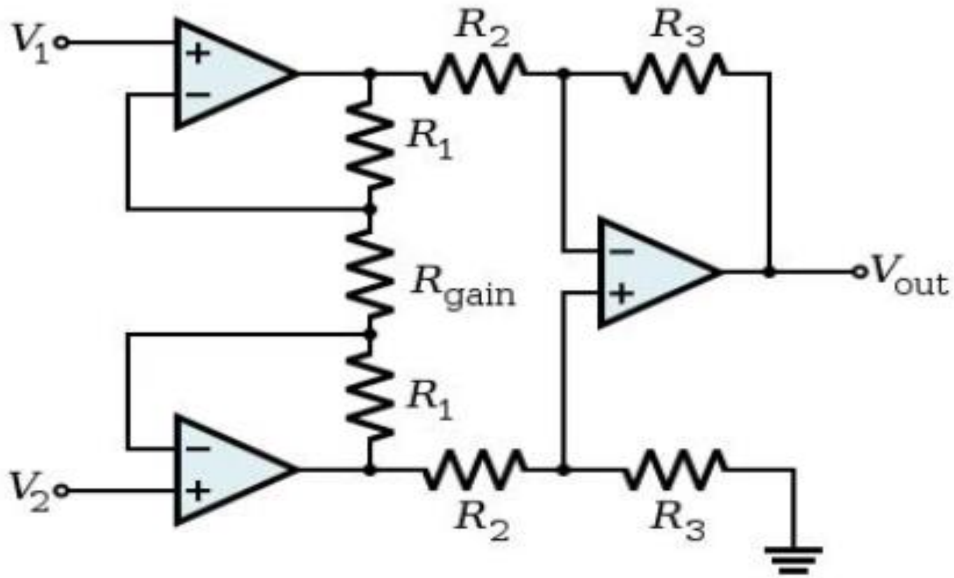
Very small change in R_x disrupt the balance and can be measured precisely.

$$V_G = V\left(\frac{R_x}{R_x+R_3} - \frac{R_2}{R_2+R_1}\right)$$



Load cell Implementation





- Applied force causes small change in resistance in strain gauge that is measured by change in output voltage across the bridge.
- Out put voltage from bridge circuit is typically in the order of a few millivolts and requires amplification by an instrumentation amplifier before it can be used.
- It has very low noise and very high common mode rejection ratio.

Load cell types

S Type

Button

Shear

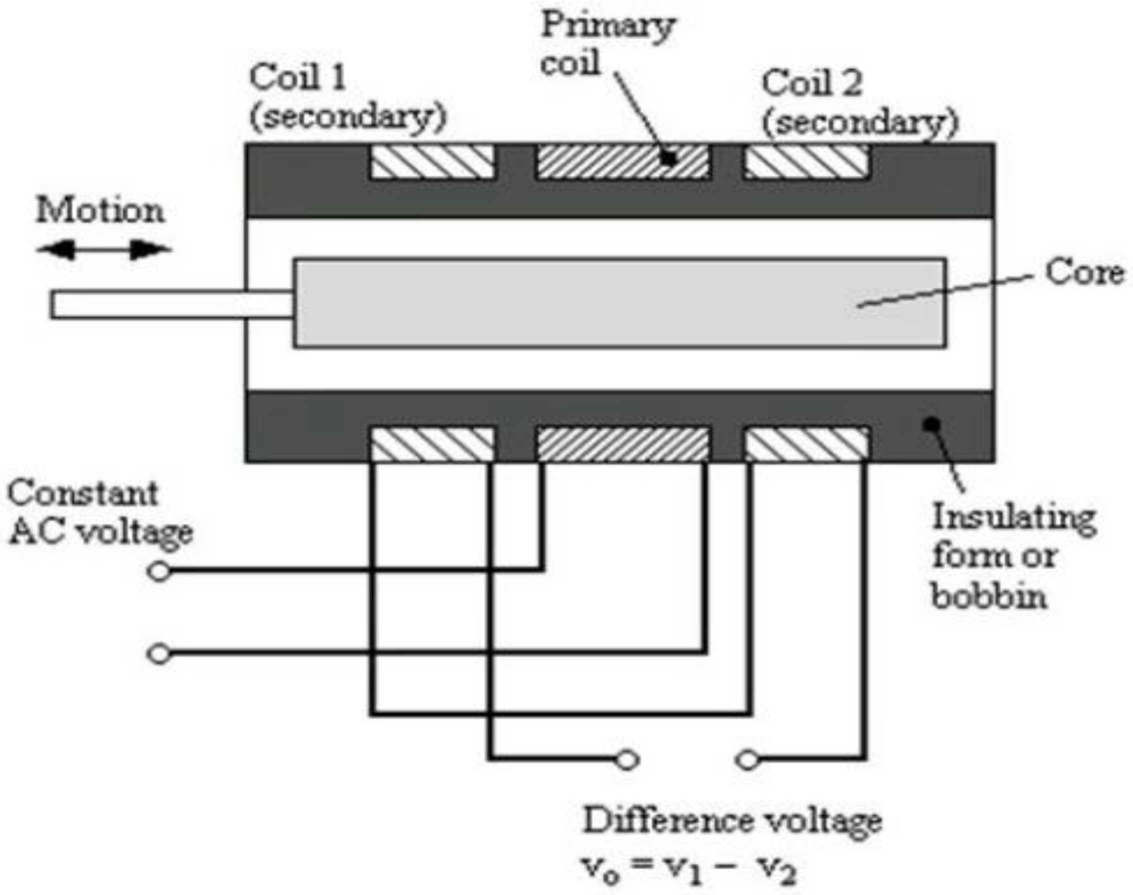
Beam

Continued…….

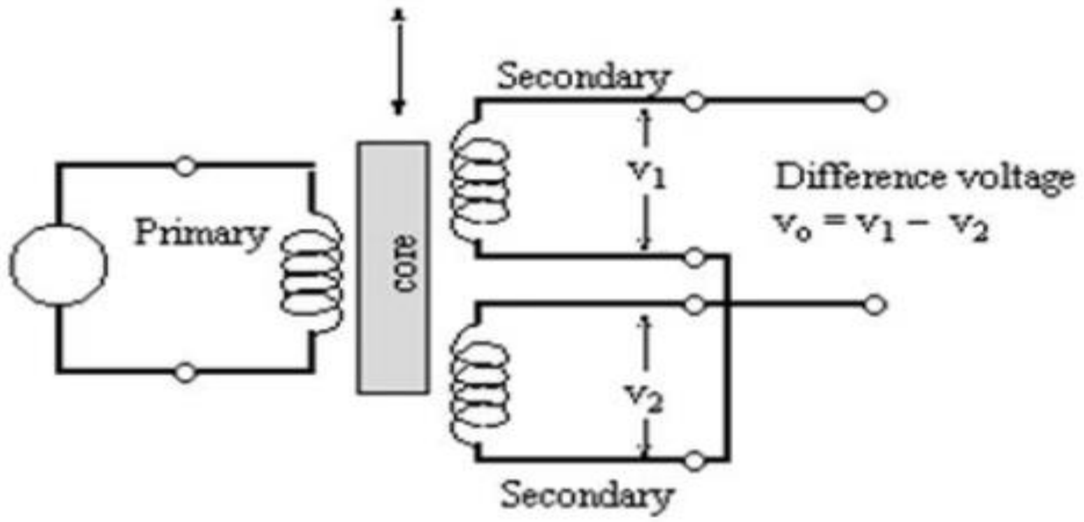
Mechanical and other load cell

Load Cell Type	Weight Range	Accuracy	Apps	Strength	Weakness
Hydraulic	Up to 10,000,000 lbs	0.25%	Tanks, bins, & hoppers	Takes high impacts, insensitive to temp	Expensive complex
Pneumatic	Wide	High	food industry, hazardous areas	Intrinsically safe	Slow response. Require clean, dry air
Helical	0-40k lbs	0.2%	Platform, forklift, wheel load	Handles off-axis loads, overloads	
Fiber Optic		0.1%	Electrical transmission cables	Immune to RFI/EMI	
Piezo-resistive		0.03%		Extremely sensitive, high signal output level	High cost, nonlinear output

LVDT BASED LOAD CELL

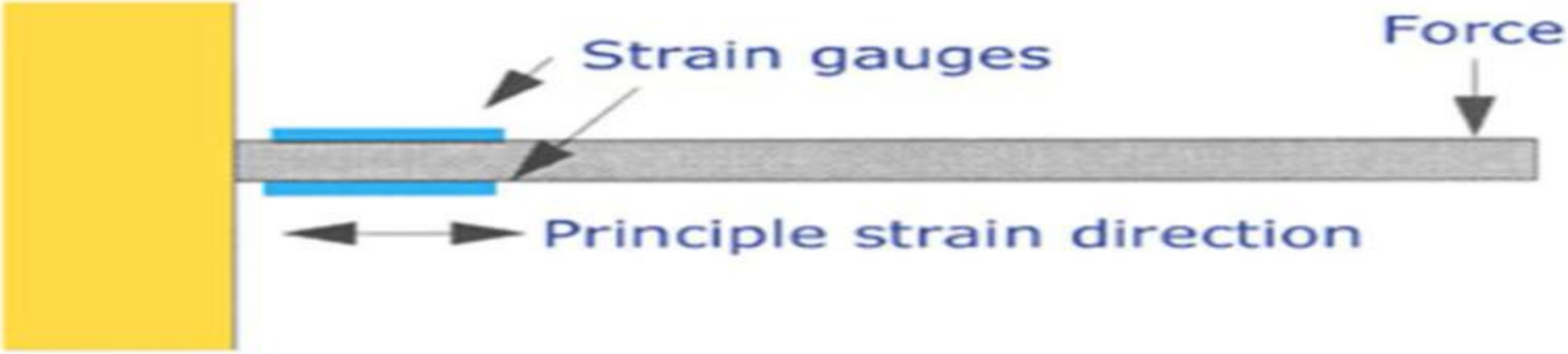


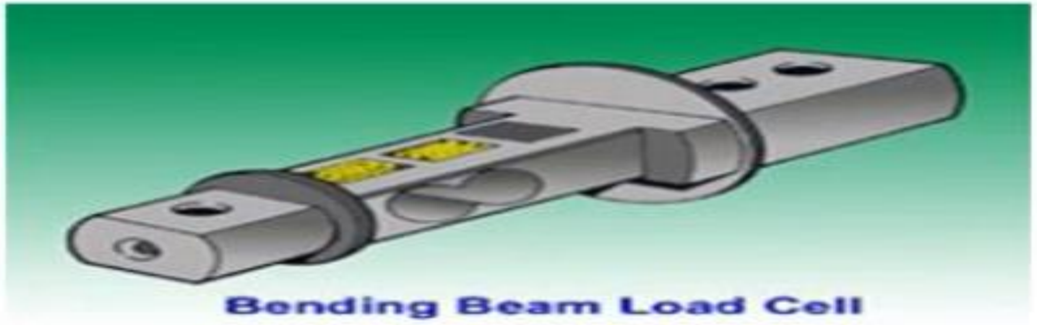
(a)



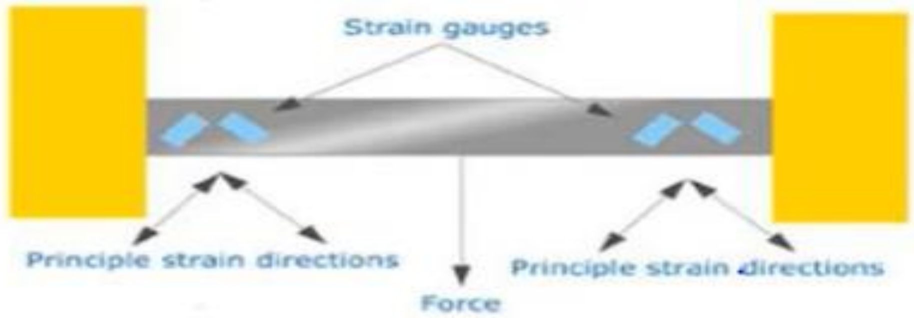
(b)

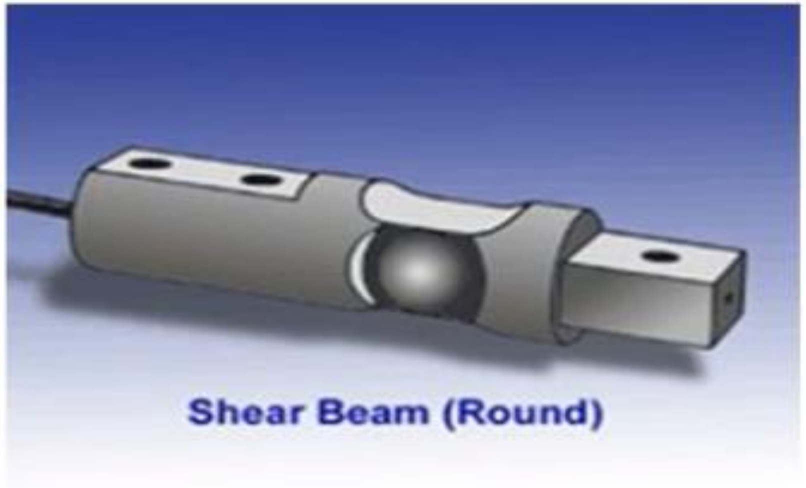
BENDING BEAM LOAD CELL





SHEAR BEAM LOAD CELL





LOAD CELL APPLICATION

IN TEXTILES

1. All types of textile testing (Instron).

2. Measurement of weight (Moisture regain testing).

3. Online measurement of tension during various process (like printing).

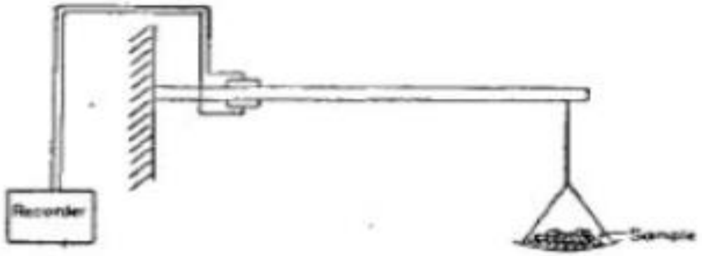
Instron Tensile Tester

- ❑ Used to measure the tensile strength, load-elongation curve for the fabrics as well as yarns.
- ❑ Efficiently detect the strain.

  strain gauges are bounded to the position on the spring material where strain is largest.

Measurement of weight (Moisture regain tester)

- A sample of loose fibre or any textile material which has been subjected to a drying treatment is hung from a cantilever of proper dimensions, to which has been bonded a set of strain gauge.
- As the sample changes in weight because of moisture regain, the stress in the beam increases and following through the changes take place in the gage and with the help of this it is possible to record continuously the rate of moisture regain of the material.



Cost of load cell

SERIESE OF LOAD CELL	SPECIFICATION OF LOAD CELL	CAPACITY	PRICE (in Dollars)
LCFD	Miniature low profile tension/compression	1 kg	750
LCGD	Miniature low profile compression	1000 lb.	460
LC400	Low profile tension/compression	5000 lb.	730
LC100	S-Beam tension/compression	100 lb.	305
LC500	Cantilever beam tension/compression	5000lb.	350
TWA5, TWA6	Self adjusting weight module with LC501 load beam included	10000 lb.	615

CONVEYING SYSTEMS

A **conveyor system** is a common piece of mechanical handling equipment that moves materials from one location to another. Conveyors are especially useful in applications involving the transportation of heavy or bulky materials.

Designing a Conveyor System

- Capacity requirement
- Length of travel
- Material characteristics
- Processing requirements
- Life expectancy
- Costs

MAIN ELEMENTS OF A CONVEYOR

- Conveyor drive
- Conveyor motor
- Auxiliary Equipment
- Control of Conveyors

Conveyor drives

- Conveyor drives may account for from 10 to 30 percent of the total cost of the conveyor system, depending on specific job requirements. They may be of either fixed-speed or adjustable-speed type.
- Fixed-speed drives are used when the initially chosen conveyor speed does not require change during the course of normal operation. Simple sheave or sprocket changes suffice should minor speed alterations be needed. However, for major adjustments motor or speed-reducer changes are required. In any event, the conveyor must be shut down while the speed change is made.
- Adjustable-speed drivesare designed for changing speed either manually or automatically while the conveyor is in operation, to meet variations in processing requirements.

Conveyor Motors

- Conveyor Motors for conveyor drives are generally of 240- and 480-V ratings.
- The squirrel-cage motor is most commonly used with belt conveyors and with drives up to 7.457 kW (10 hp)

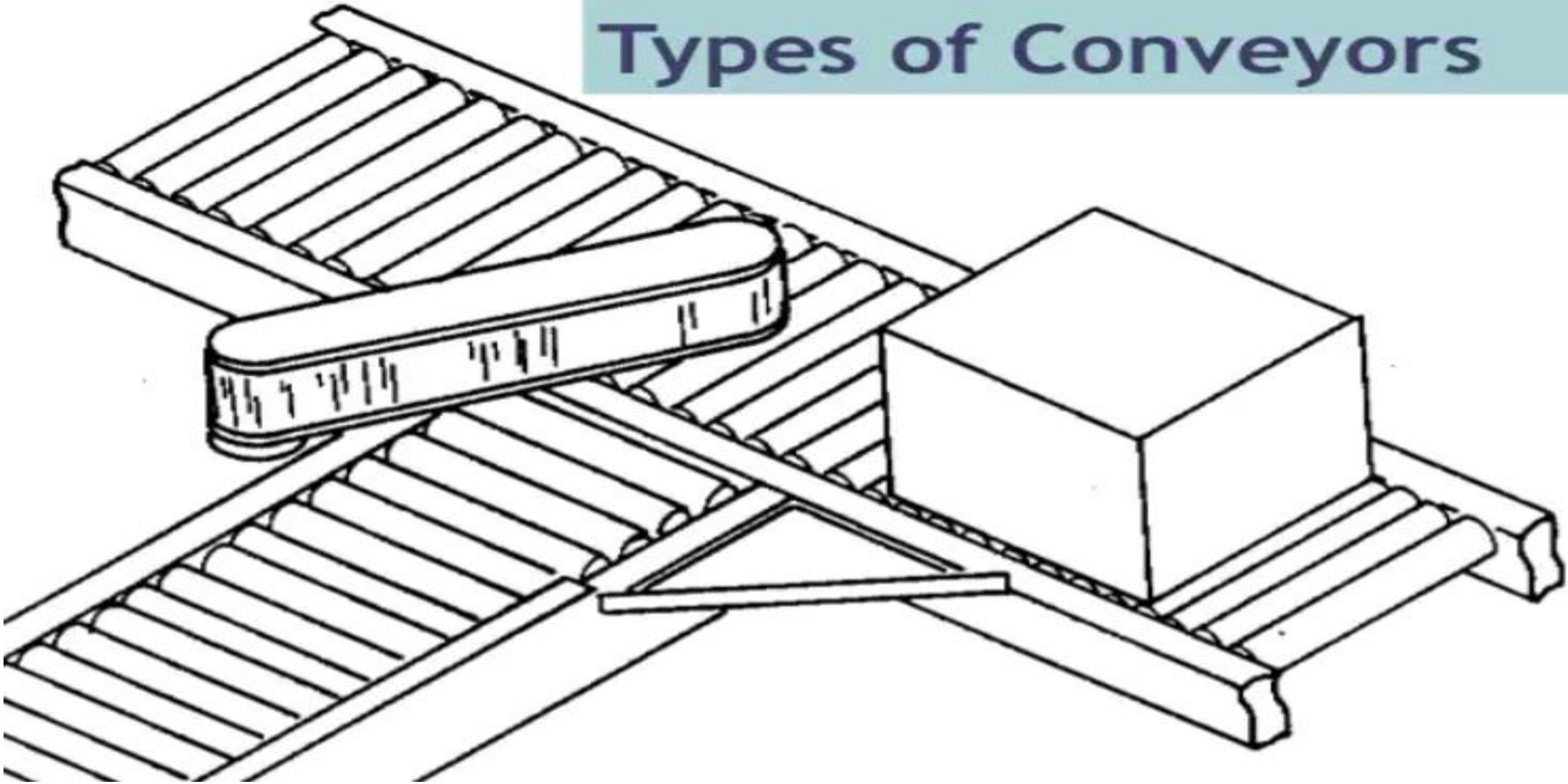
Auxiliary equipment

- They are the addition support equipment. For example
- Elevating conveyors must be equipped with some form of holdback or brake to prevent reversal of travel
- and subsequent jamming when power is unexpectedly cut off

Control of conveyors

- Control has been enhanced considerably
- with the introduction of process-control computers and programmable controllers, which can be used to maintain rated capacities to close
- tolerances. This ability is especially useful if feed to the conveyor
- tends to be erratic. Through variable-speed drives, outputs can be
- adjusted automatically for changes in processing conditions

Types of Conveyors



- Chute conveyor
- Wheel conveyor
- Roller conveyor
  - Gravity roller conveyor
  - Live (powered) roller
- Chain conveyor
- Flight chain
- Apron chain
- Closed belt
- Slat conveyor
- Continuos flow conveyor

- Bucket conveyor
- Vibrating conveyor
- Screw conveyor
- Pneumatic conveyor
- Flat belt conveyor
- Magnetic belt conveyor
- Troughed belt conveyor

Wheel Conveyor

Gravity wheel conveyor

- These can be used as pusher units set horizontally or inclined for gravity flow.
- They are highly standardized and are usually sold in 1.5- or 3-m (5- or 10-ft) sections; special lengths are available at extra charge
- Gravity skate wheel will convey lightweight loads that have firm flat bottoms such as cartons, totes, cases, etc. Skate wheel conveyor “rolls” more easily than roller conveyor allowing for lighter packages and less slope.
- Since wheel units are relatively light, they have relatively low inertia, and loads may be started and stopped quite easily
- Metal plates or projecting hardwood slats are commonly used as stops on conveyor lines.

Roller Conveyor

Roller conveyor

- Gravity rollers are considerably heavier than the wheels on wheel conveyors,
- Non-powered roller conveyors or Gravity Conveyors are the most economical and common method of conveying unit loads. The conveyors are typically mounted on a slight decline angle, therefore using gravity to assist product movement, especially for long distances. They can also be used in applications where the conveyor is level and operators can push the product along to its final destination, allowing for multiple workstations, if needed.
- As with gravity wheel conveyors, roller units are highly standardized and auxiliary equipment is available for supporting the line from ceiling or floor. Many special rollers are available for retarding containers if speed becomes too great for safe handling.


Belt Conveyor

- One of the basic tools in material handling industry,
- Belt conveyors are most commonly used in transportation of bulk materials (grain, salt, coal, ore, sand, etc.).
- Capacity and ability-- It can travel for miles at speeds up to 5.08 m/s (1000 ft/min) and handle up to 4539 metric tons/h (5000 tons/h).

Working principle

Belt conveyor is composed by two pulleys and a closed conveyor belt. The pulley that drives conveyor belt is called drive pulley ; the other one-only used to change conveyor belt movement direction-is called bend pulley. Drive pulley is driven by the motor ,. The drive pulleys are generally installed at the discharge end. Material is fed on the feed-side and landed on the rotating conveyor belt.

TYPES

Flat Belt :

A type of belt conveyor in which the carrying run of the conveyor belt is supported by flat belt or by a flat surface. They are suitable for low speed and low capacity

Magnetic Belt:

A type of conveyor where either a magnetic slider bed or magnetic pulley is used to transport materials.

Troughed Belt:

Troughed belt conveyor is that in which the belt forms a trough on the carrying side while running over the rollers which are either in set of 5 rolls, 3 rolls or 2rolls. They are suitable for bulk quantity materials.


Troughed Belt Conveyor


Magnetic Conveyor
DORNER

- ADVANTAGES OF BELT CONVEYORS

  (a)Noiseless operation. (b) Large length of conveying path (c) Lower power consumption. (d) Long life. (e) Adaptability to different types of goods. (j) Ability to carry almost any bulk material (g) High reliability of operation. (h) Can transport material in any direction.

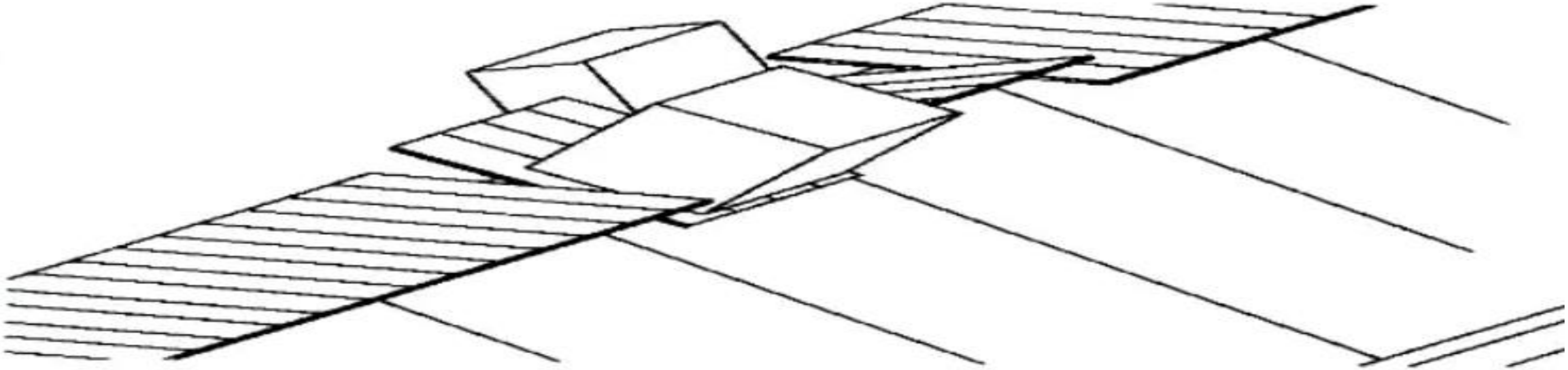
- LIMITATIONS OF BELT CONVEYORS

  (a) Accumulation difficult (b) The loss of light weight bulk material carried away as dust (c) Continuous or periodic monitoring of belt is necessary (d) Heat affects the material of belt.

Slat Conveyor

Slat conveyors

- Uses discretely spaced slats connected to a chain.
- The slats are either of wood or flanged metal.
- Unit being transported retains its position (like a belt conveyor).
- Orientation and placement of the load is controlled.



Working

- Slat Conveyors are conveyors employing one or more endless chains to which non-overlapping, non-interlocking, spaced slats are attached.
- Slat conveyors consist of endless chains, driven by electric motors operating through reduction gears and sprockets, with attached spaced slats to carry objects that would damage a belt because of sharp edges or heavy weights.

Benefits of Slat Conveyors

Flexibility allows for a wide variety of heavy load conveyor applications.

Position and orientation can be controlled and maintained if required.

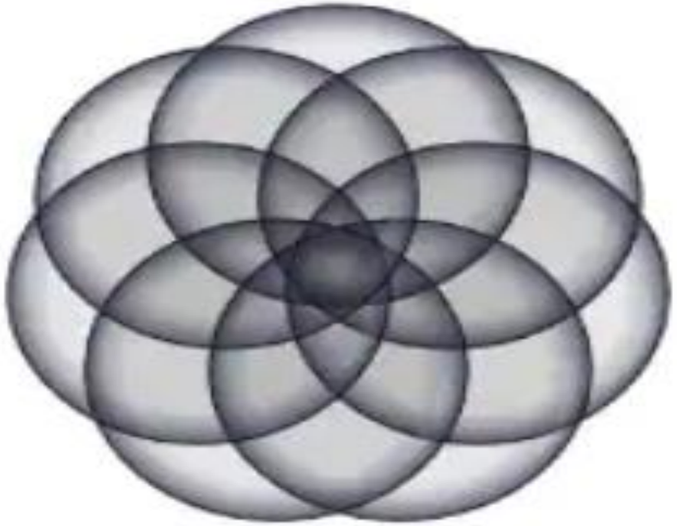
Offers a continuous moving surface to mount product fixturing if desired.

Tilt slat conveyors are used for sortation

Highly reliable, low maintenance.

Can be used for horizontal, inclined and curved routes.

Slats can easily be replaced.



Vibrating Conveyor

Construction & Working

- Most vibrating conveyors are essentially directional-throw units which consist of a spring-supported horizontal pan vibrated by a direct connected eccentric arm, rotating eccentric weights, an electromagnet, or a pneumatic or hydraulic cylinder. The motion imparted to the material particles may vary, but its purpose is to throw the material upward and forward so that it will travel along the conveyor path in a series of short hops.

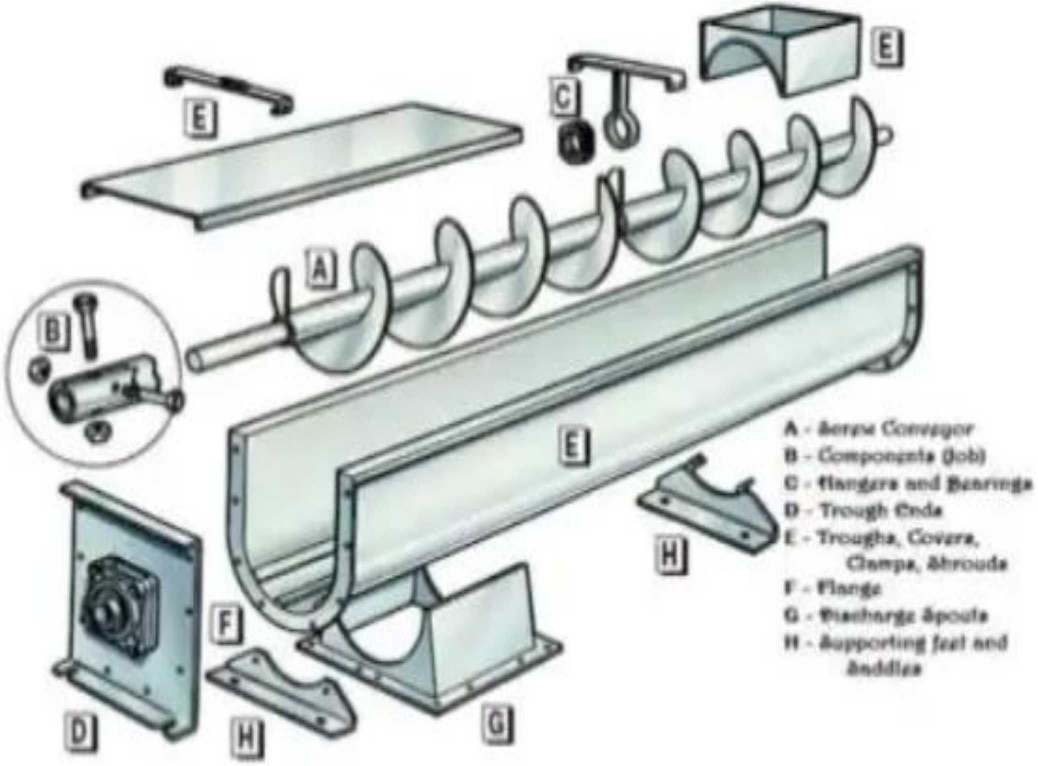
- **Capacity** of directional-throw vibrating conveyors-- is determined by the magnitude of trough displacement, frequency of this displacement, angle of throw, slope of trough, and ability of the material to receive and transmit through its mass the directional throw of the trough.

- The **material** itself is the most important factor. To be conveyed properly it should have a high friction factor on steel as well as a high internal friction factor so that conveying action is transmitted through its entire depth. Thus deep loads tend to move more slowly than thin ones. Material must also be dense enough to minimize the effect of air resistance on its trajectory, and it should not aerate.

- Tests have shown that granular materials handle better than pulverized materials and flat or irregular shapes better than spherical ones.

Screw conveyor

One of the most widely used conveyors
in the processing industry.



WORKING PRINCIPLE

- Consists of a tube or U-shaped stationary trough through which a shaft-mounted helix revolves to push loose material forward in a horizontal or inclined direction

Screw-conveyor abilities

CAPACITY

- generally limited to around 4.72 m3 /min (10,000 ft3 /h).

PROCESSING OPERATIONS

- Screw conveyors operate using a continuous shaftless helicoid screw that moves almost any type of solid material through it.
- They typically operate on an incline and can transport up to 80 feet.
- Can convey up to 1,800 cfh.

Material design

- In addition to a wide variety of designs for components, screw conveyors may be fabricated in materials ranging from cast iron to stainless steel.

Size

- Standard sizes range from 2 in. to 8 in. diameter.

ADVANTAGES

Screw conveyors are capable of handling a great variety of bulk materials from sluggish to free-flowing.

Screw conveyors can have multiple inlet and discharge points. Bulk materials can be conveyed and distributed to various locations as required. Slide gates or valves can be added to control the flow into and out of a screw conveyor.

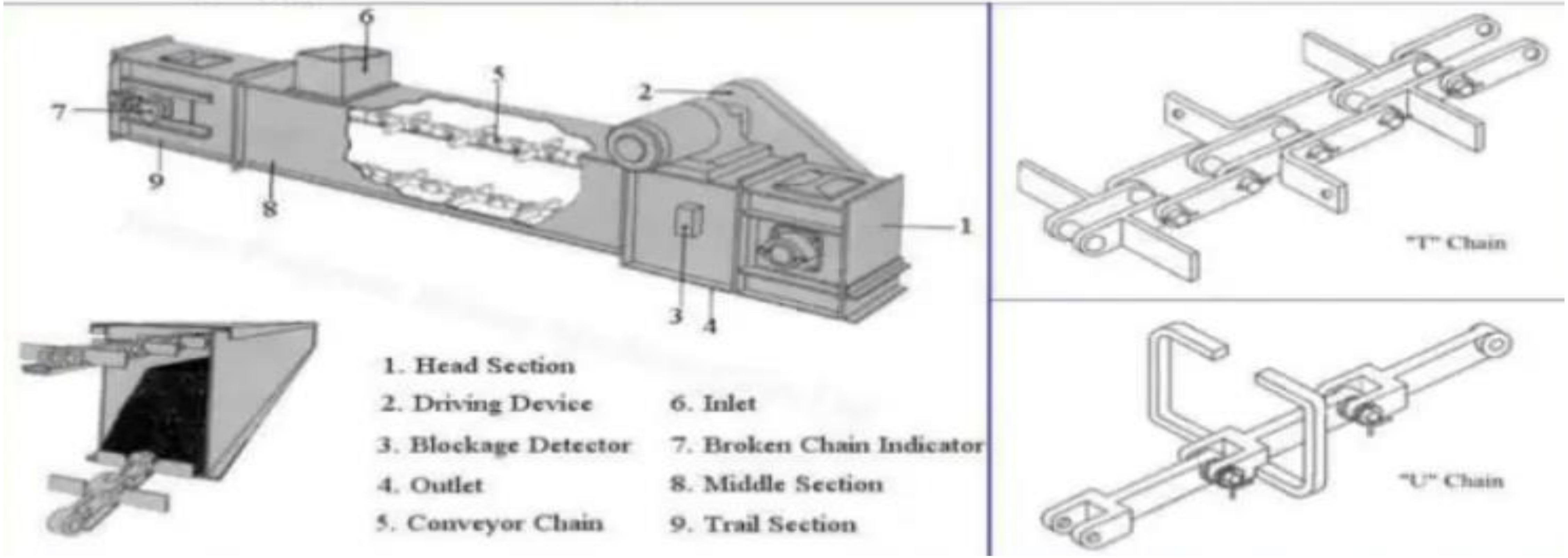
Screw conveyors are totally enclosed to contain the product and prevent spillage. Screw conveyors can be utilized in the horizontal, vertical or any inclined position depending upon the characteristics of the product being conveyed.

Screw conveyors can be used to cool, heat or dry products in transit. Depending on the heat transfer requirements, a screw conveyor can be jacketed, or a hollow-flight design utilized to provide the necessary heat transfer for the application

Screw conveyors can be designed to be vapor-tight or hold an internal pressure. This is very important when conveying toxic or hazardous products such as those in the chemical industry.

FLIGHT CONVEYOR

- An enclosed, rectangular cross - section, made of steel casing is furnished with an endless chain equipped with flights.



Flight chain

- Flight conveyors have scrapers, or flights, mounted at intervals perpendicular to the direction of travel on endless power-driven chains operating within a trough.
- Bulk materials such as sawdust, sand, gravel, coal, and chemicals may be pushed along the trough.

ADVANTAGES	DISADVANTAGES
• Low installation cost. • Suitable for transportation at steep places.	• High power consumption.

Apron conveyor

Design & Operation

Apron conveyors consist of endless chains with attached overlapping and interlocking plates to provide a continuous-carrying surface that forms a leakproof bed suitable for bulk materials without containers.

Their main application is the feeding of material at controlled rates, with lump sizes that are large enough to minimize dribble.

Characterestics of apron chain conveyors

Exclusively used for transportation of heavy loads.

Apron conveyor speeds are typically 50-75 ft/min

They have high load-carrying capacity

The number of branches can be selected depending on the nature of the material being moved

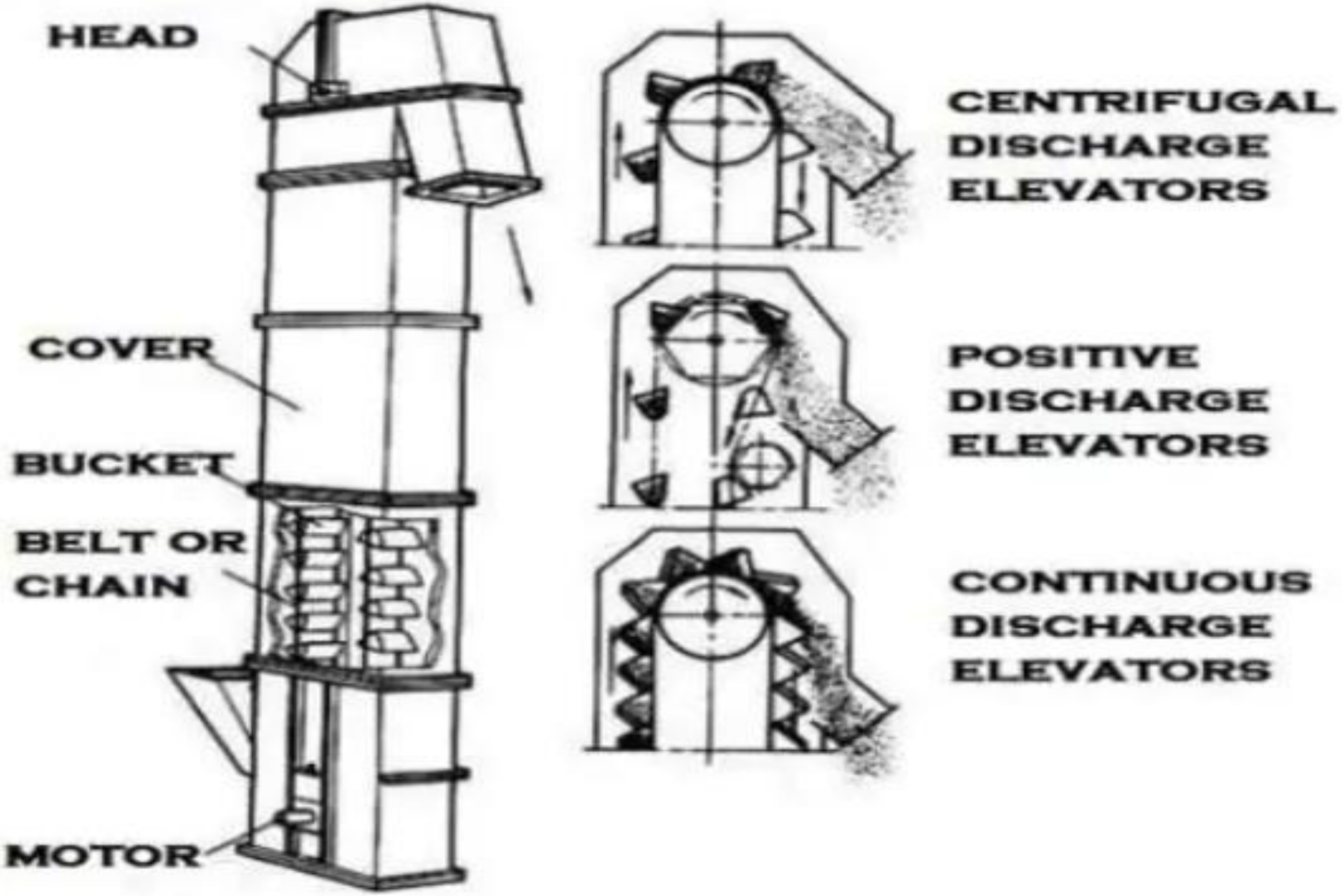
Possibility of managing special requirements of the customers, such as the use of a different chain type, chain with carriers, etc.

BUCKET CONVEYOR

- Bucket elevators are the simplest and most dependable units for making vertical lifts.
- They are available in a wide range of capacities and may operate entirely in the open or be totally enclosed.

WORKING

The product is fed into the moving bucket belt at a controlled rate in a similar manner to feeding a normal belt conveyor. At the end of the conveyor, the buckets are emptied by gravity into the discharge section.



TYPES OF BUCKET ELEVATORS

Centrifugal discharge

- These elevators (Fig. 21-5a) are the most commonMounted on a belt or a chain, the buckets are spaced to prevent interference in loading or discharging. This type of elevator will handle almost any freeflowing fine or small-lump material such as grain, coal, or dry chemicals
- Speeds can be relatively high for fairly dense materials but must be lowered considerably for aerated or low-bulk-density materials [under 641 kg/m3 (40 lb/ft3)] to prevent fanning action.

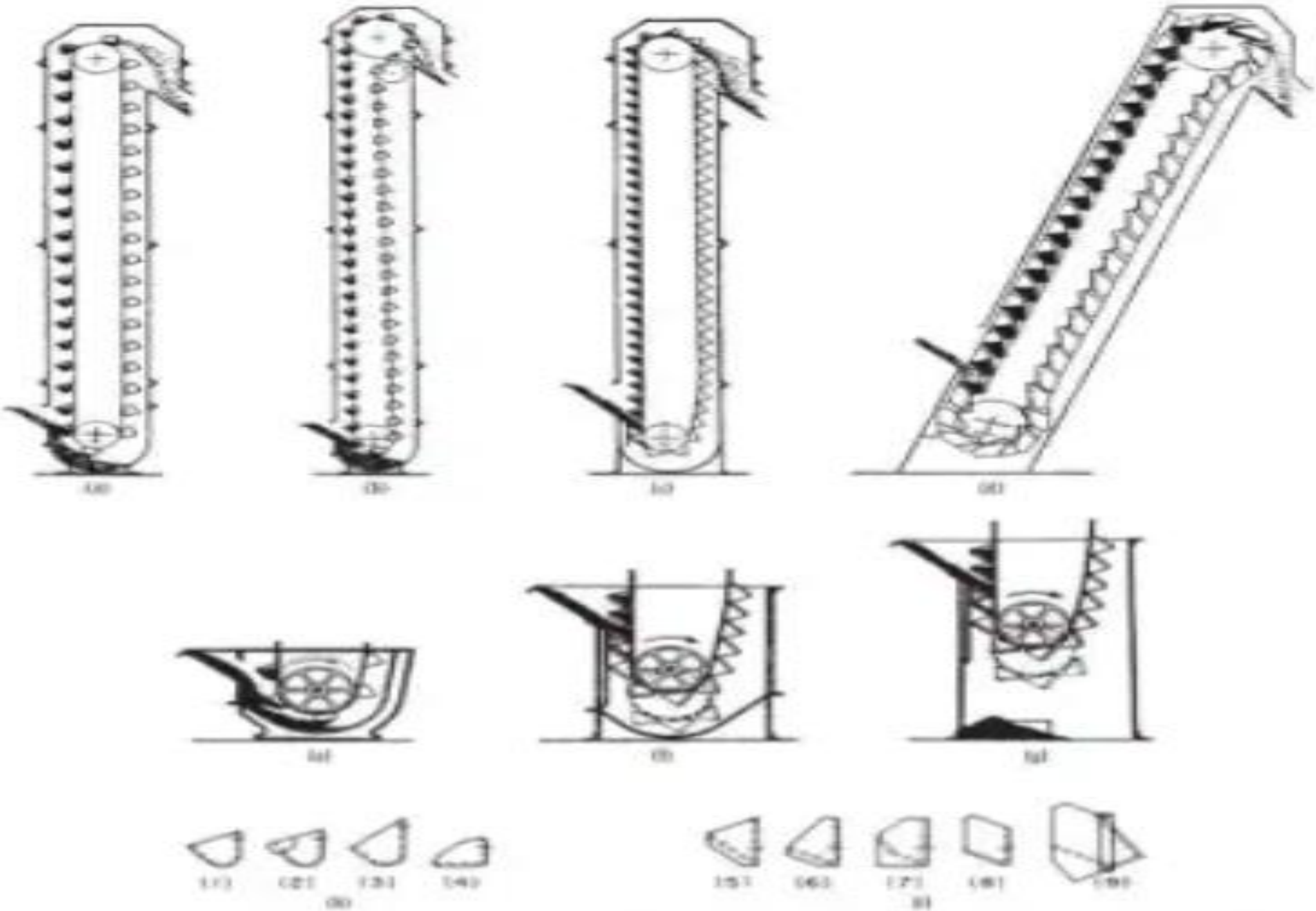


FIG. 21-3 Bucket-elevator types and bucket details. (a) Centrifugal-discharge spaced buckets. (b) Positive-discharge spaced buckets. (c) Continuous bucket. (d) Supercapacity continuous bucket. (e) Spaced buckets receive part of load direct and part by scooping from bottom. (f) Continuous buckets are filled as they pass through loading leg, with feed spout above tail wheel. (g) Continuous buckets in bottomless boot, with cleanout door. (h) Malleable-iron spaced buckets for centrifugal discharge. (i) Steel buckets for continuous-bucket elevators. (Stephens-Adamson Division, Allis-Chalmers Corporation.)

Positive discharge

- Elevators of this type (Fig. 21-5b) are essentially the same as centrifugal-discharge units except that the buckets are mounted on two strands of chain and are snubbed back under the head sprocket to invert them for positive discharge.
- These units are designed especially for materials which are sticky or tend to pack, and the slight impact of the chain seating on the snub sprocket combined with complete bucket inversion is generally sufficient to empty the buckets completely.
- The speed of these units is relatively slow, and buckets must be larger or more closely spaced to reach capacity levels of the centrifugal style.

Continuous bucket

- These elevators (Fig. 21-5c) are generally used for larger-lump materials or for materials too difficult to handle with centrifugal-discharge units.
- Buckets are closely spaced, with the back of the preceding bucket serving as a discharge chute for the bucket which is dumping as it rounds the head pulley.
- Close bucket spacing reduces the speed at which the elevator must run to maintain capacities comparable with the spaced-bucket elevator

ADVANTAGES

- The bucket elevators are used in most of the industries today for a variety of purposes. It has a huge transporting capacity with lower maintenance and better transportation facilities.
- These elevators are durable with low driving power. With the help of elevators, goods and materials can be transported smoothly and easily. Materials can be lifted to a great height with the help of these elevators.
- In addition to reliability, the bucket elevators have a wide range of lifting capabilities.