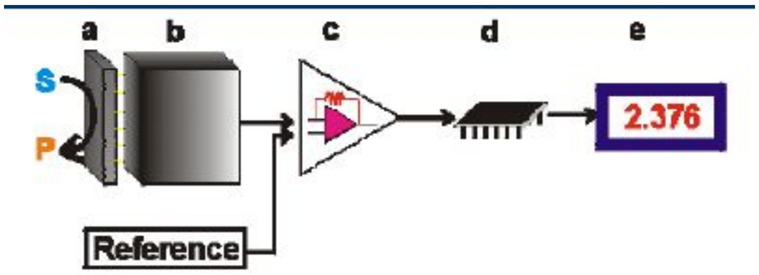
DEPARTMENT OF PHYSICS AND NANOTECHNOLOGY
SRM INSTITUTE OF SCIENCE AND TECHNOLOGY

BIOSENSOR

General principles and applications



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What is a Biosensor?

Biosensors play a part in the field of environmental quality, medicine and industry mainly by identifying material and the degree of concentration present

A biosensor is a self-contained integrated device that is capable of providing specific quantitative or semi-quantitative analytical information using a biological recognition element which is in direct spatial contact with a transduction element (IUPAC, 1996)

What is a Biosensor?

- A biosensor is an analytical device containing an immobilized biological material (enzyme, antibody, nucleic acid, hormone, organelle or whole cell) which can specifically interact with an analyte and produce physical, chemical or electrical signals that can be measured.
- An analyte is a compound (e.g. glucose, urea, drug, pesticide) whose concentration has to be measured.
- Biosensors basically involve the quantitative analysis of various substances by converting their biological actions into measurable signals.
- A great majority of biosensors have immobilized enzymes.
- The performance of the biosensors is mostly dependent on the specificity and sensitivity of the biological reaction, besides the stability of the enzyme.

General Features of Biosensors:

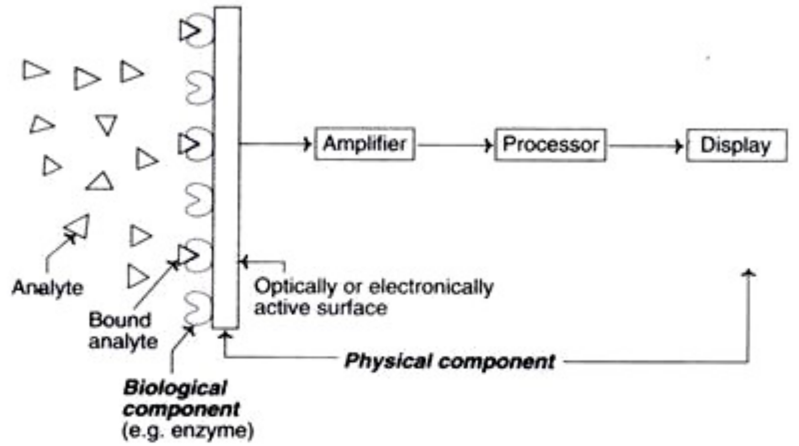


Fig. 21.13 : A diagrammatic representation of a biosensor.

1. Biological component—enzyme, cell etc.
2. Physical component—transducer, amplifier etc.

The biological component recognises and interacts with the analyte to produce a physical change (a signal) that can be detected, by the transducer.

In practice, the biological material is appropriately immobilized on to the transducer and the so prepared biosensors can be repeatedly used several times (may be around 10,000 times) for a long period (many months).

Principle of a Biosensor:

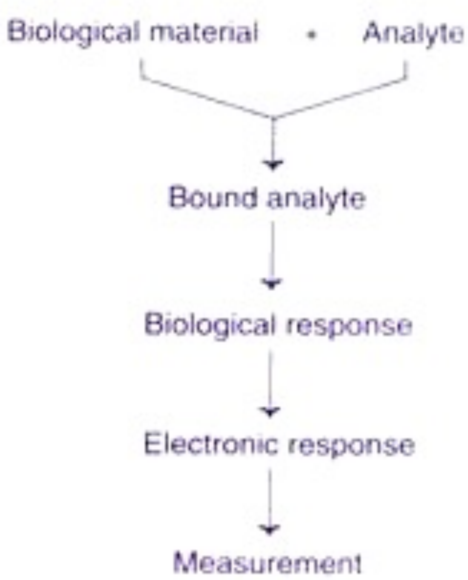
- The desired biological material (usually a specific enzyme) is immobilized by conventional methods (physical or membrane entrapment, non- covalent or covalent binding).

- This immobilized biological material is in intimate contact with the transducer. The analyte binds to the biological material to form a bound analyte which in turn produces the electronic response that can be measured.

Principle of a Biosensor:

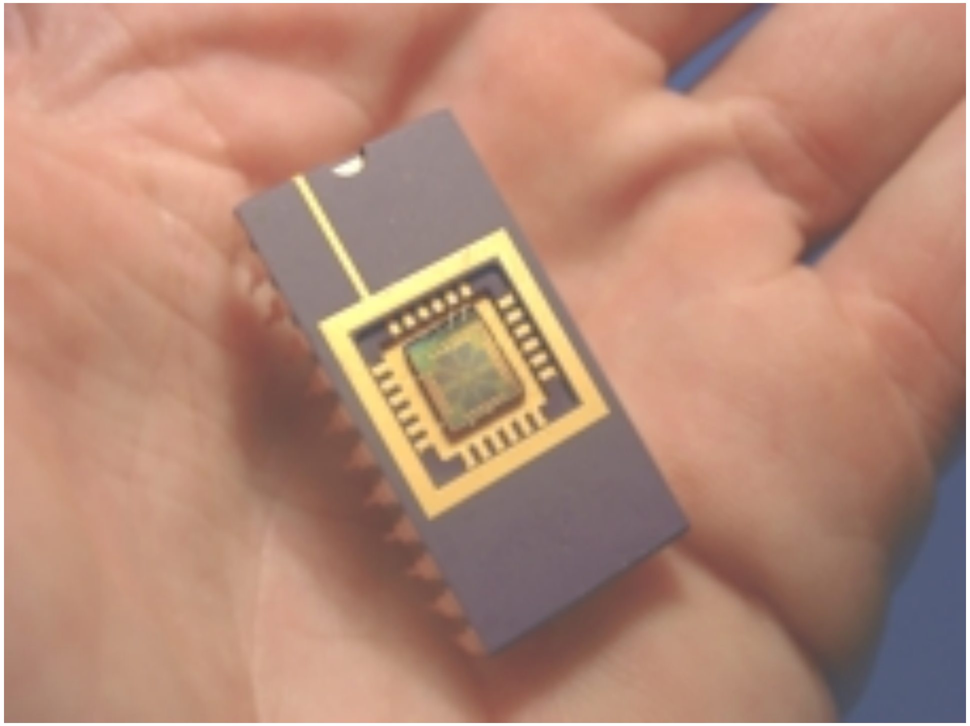
- In some instances, the analyte is converted to a product which may be associated with the release of heat, gas (oxygen), electrons or hydrogen ions.

- The transducer can convert the product linked changes into electrical signals which can be amplified and measured.

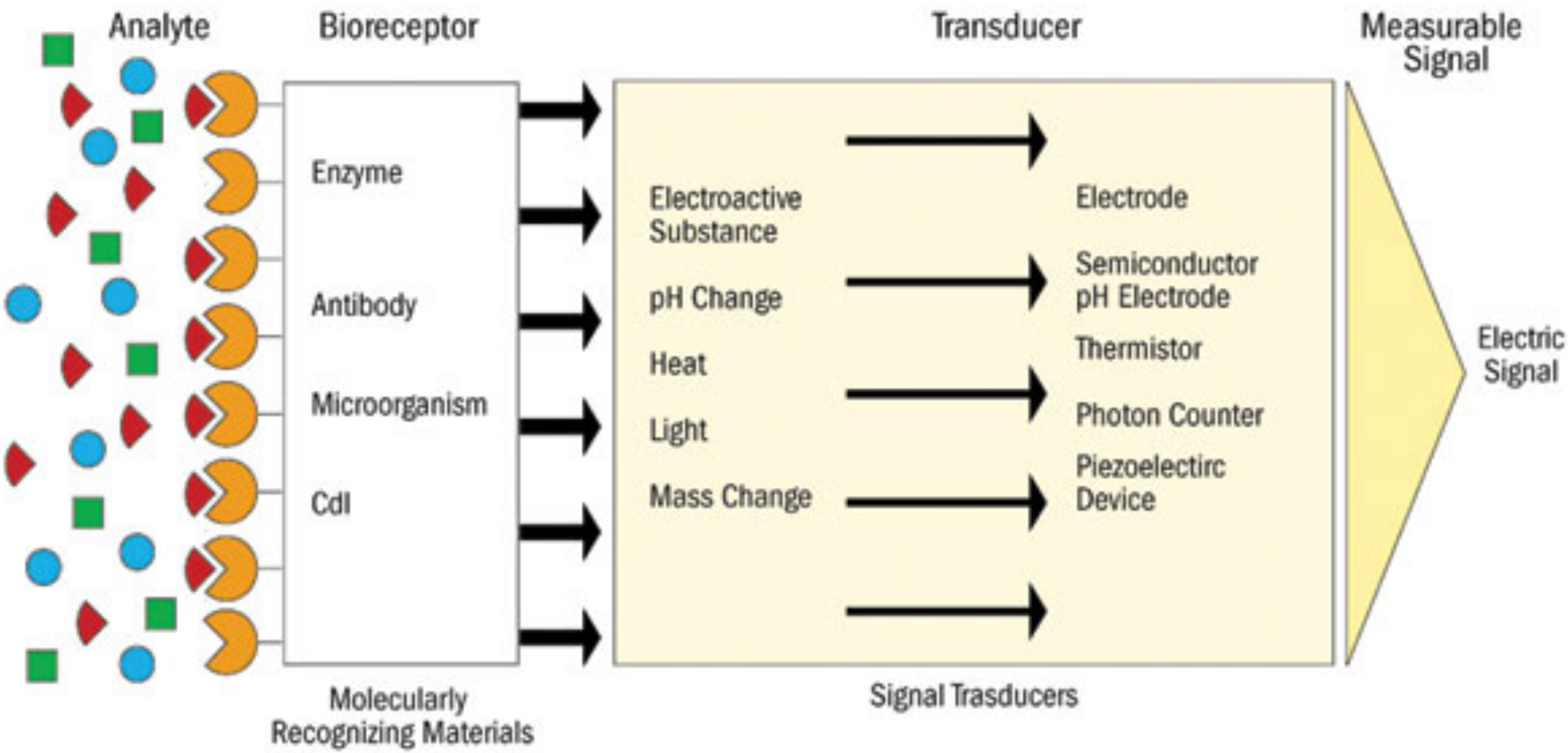


Current Definition

- **A sensor that integrates a biological element with a physiochemical transducer to produce an electronic signal proportional to a single analyte which is then conveyed to a detector.**



Components of a Biosensor



Father of the Biosensor

Professor Leland C Clark Jnr
1918–2005

Basic Characteristics of a Biosensor

- **1. LINEARITY:** Linearity of the sensor should be high forthe detection of high substrate concentration (An ideal sensor would have a perfectly linear response: a unit change in temperature would result in a unit change in voltage output across the entire temperature range of the sensor. In reality, however, no sensor is perfectly linear).
- **2. SENSITIVITY:**Value of the electrode response per substrate concentration (It is defined as the ratio of the changes in the output of an instrument to a change in the value of the quantity being measured. It denotes the smallest change in the measured variable to which the instrument responds).
- **3. SELECTIVITY:** Chemicals Interference must be minimised for obtaining the correct result.
- **4.RESPONSE TIME:** Time necessary for having 95% of the response.

Biosensor

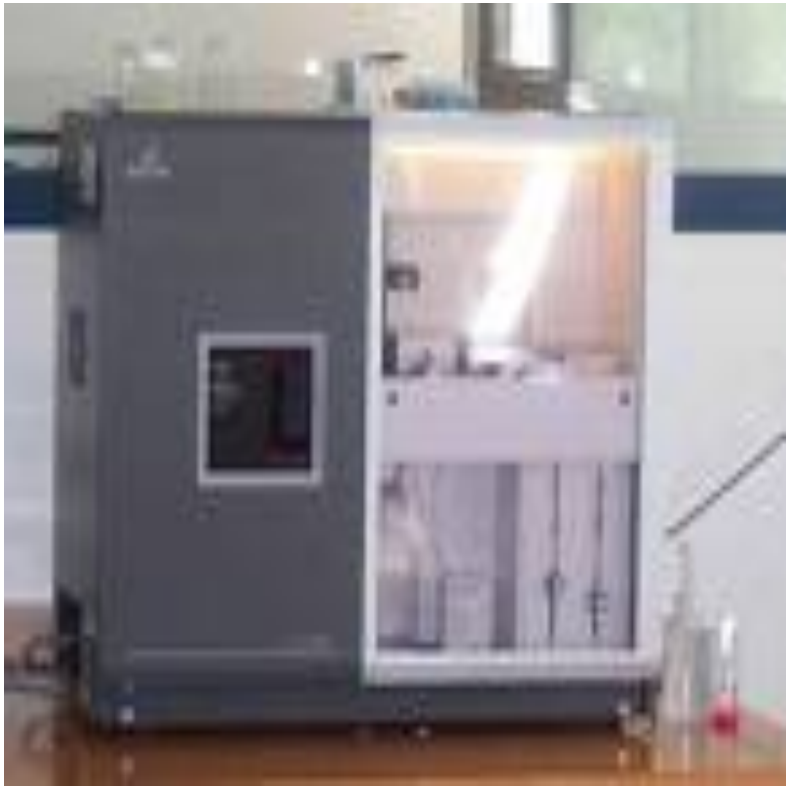
- **1. The Analyte** (What do you want to detect) Molecule - Protein, toxin, peptide, vitamin, sugar, metal ion
- **2. Sample handling** (How to deliver the analyte to the sensitive region?) (Micro) fluidics - Concentration increase/decrease), Filtration/selection
- **3. Detection/Recognition:** (How do you specifically recognize the analyte?)
- **4. Signal:** (How do you know there was a detection)

Example of biosensors

Glucose monitoring device (for diabetes patients)

Monitors the glucose level in the blood.

Research Biosensors



Biacore Biosensor platform

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Typical Sensing Techniques for Biosensors

- ✔ Fluorescence
- ✔ DNA Microarray
- ✔ SPR Surface plasmon resonance
- ✔ Impedance spectroscopy
- ✔ SPM (Scanning probe microscopy, AFM, STM)
- ✔ QCM (Quartz crystal microbalance)
- ✔ SERS (Surface Enhanced Raman Spectroscopy)
- ✔ Electrochemical

Types of Biosensors

1. **Calorimetric Biosensor**
2. **Potentiometric Biosensor**
3. **Amperometric Biosensor**
4. **Optical Biosensor**
5. **Piezo-electric Biosensor**

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Piezo-Electric Biosensors

Piezoelectric biosensors are a group of analytical devices working on a principle of affinity interaction recording.

A piezoelectric platform or piezoelectric crystal is a sensor part working on the principle of oscillations change due to a mass bound on the piezoelectric crystal surface

The change in frequency is proportional to the mass of absorbed material.

Electrochemical Biosensors

- For applied current: Movement of e- in redox reactions detected when a potential is applied between two electrodes.

Potentiometric Biosensor

- For voltage: Change in distribution of charge is detected using ion-selective electrodes, such as pH-meters.

•Optical Biosens

•<u>Colorimetric for color</u>

Measure change in light adsorption

•<u>Photometric for light intensity</u>

Photon output for a luminescent or fluorescent process can be detected with photomultiplier tubes or photodiode systems.

Calorimetric Biosensors

If the enzyme catalyzed reaction is exothermic, two thermistors may be used to measure the difference in resistance between reactant and product and, hence, the analyte concentration.

Electrochemical DNA Biosenso

- Steps involved in electrochemical DNA hybridization biosensors:
- Formation of the DNA recognition layer
- Actual hybridization event
- Transformation of the hybridization event into an electrical signal

Biosensors on the Nanoscale

- **Molecular sheaths around the nanotube are developed that respond to a particular chemical and modulate the nanotube's optical properties.**

- **A layer of olfactory proteins on a nanoelectrode react with low-concentration odorants (SPOT-NOSED Project). Doctors can use to diagnose diseases at earlier stages.**

- **Nanosphere lithography (NSL) derived triangular Ag nanoparticles are used to detect streptavidin down to one picomolar concentrations.**

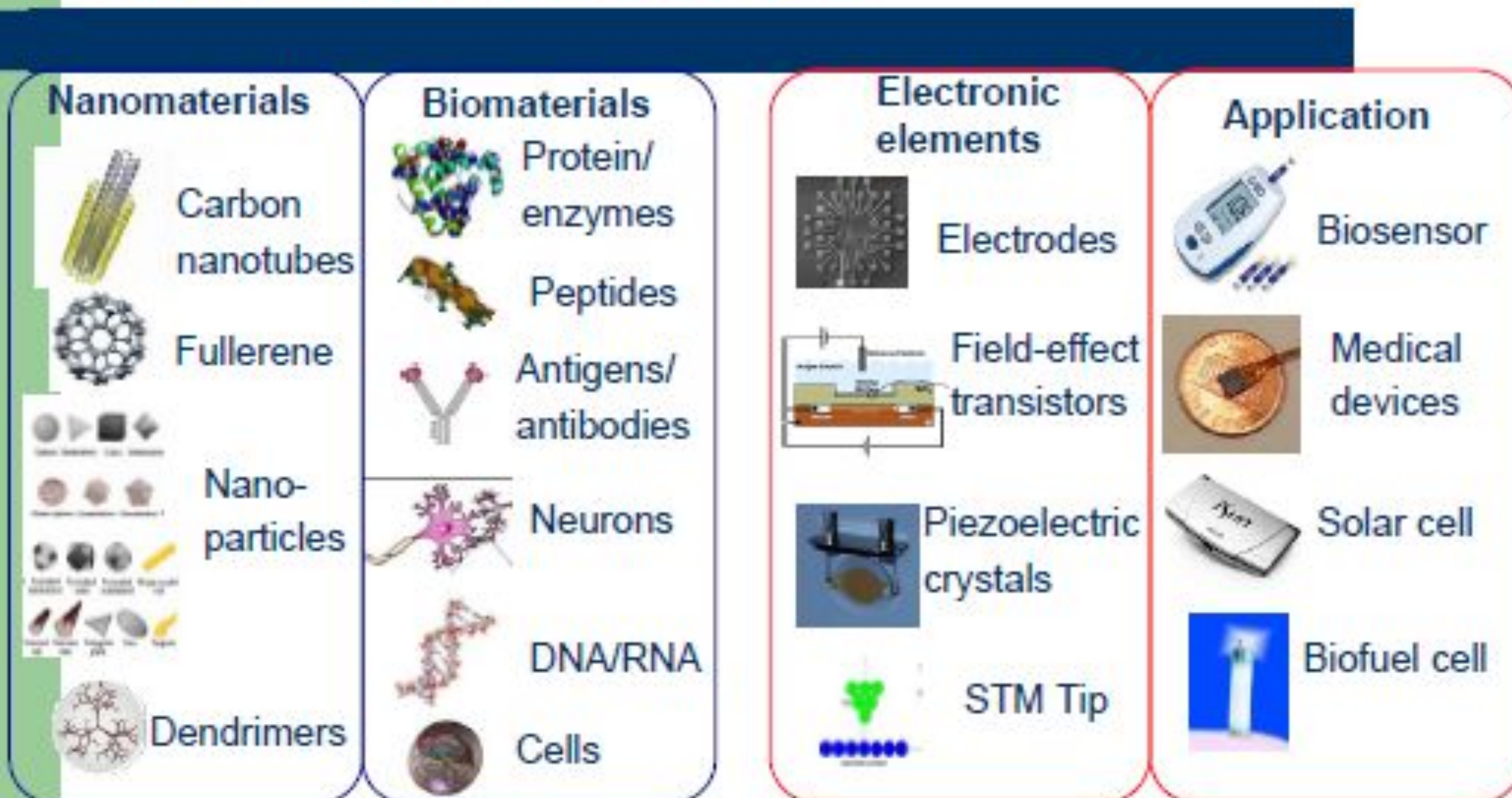
- **The School of Biomedical Engineering has developed an anti-body based piezoelectric nanobiosensor to be used for anthrax,HIV hepatitis detection.**

Application of Biosensor

- Food Analysis
- Study of biomolecules and their interaction
- Drug Development
- Crime detection
- Medical diagnosis (both clinical and laboratory use)
- Environmental field monitoring
- Quality control
- Industrial Process Control
- Detection systems for biological warfare agents
- Manufacturing of pharmaceuticals and replacement organs

Nano-Biotechnology

Current, Potential, Impedance, Electrical power



Biological Sciences – Pharmacy – Chemistry/Biochemistry –Physics – Biomedical Eng. – Electrical Eng. – Mechanical Eng. – Material Eng. – Bioinformatics

Nano fertilizers for balanced crop nutrition:

- At present in agriculture, fertilizer contributes to the tune of 50% of the agricultural productivity of any crop.

- Increasing use of higher doses of fertilizers does not guarantee to improved crop yield but it leads serious issues like degradation of soil and pollution of surface and underground water resources.

- The use efficiency of N, P and K fertilizers remained constant as 30-35%, 18-20%, 35-40 respectively. Which means major portion of fertilizer added fertilizers stays in soils and enter the aquatic system causing eutrophication.

- Absorption of nutrients by the plants from soil can be maximized using Nano fertilizer. To increase food production, TiO2 or titanium that is non-toxic can be used as additives in fertilizers. The additives in fertilizers can increase water retention (Emadian et al. 2017).

- Thus, nanofertilizers technology is very novel approach to address issues such as low fertilizer use efficiency, imbalanced fertilization. Nano fertilizers are advantageous over conventional fertilizers as they increase soil fertility yield and quality parameters of the crop, they are nontoxic and less harmful to environment and humans, they minimize cost and maximize profit.

- Naderi and Abedi (2012) reported nano particles increases nutrients use efficiency and minimizing the costs of environment protection, improvement in the nutritional content of crops and the quality of the taste. Optimum use of iron and increase protein content in the grain of the wheat (Farajzadeh et al. 2009).

- Raliya (2012) reported an enhanced production in pearl millet and cluster bean by foliar application of nanophosphorus fertilizers. He found that 640 mg ha-1 foliar application (40 ppm concentration) of nanophosphorus gives 80 kg ha-1 P equivalent yield. Batsmanova (2013) reported wheat plants grown from seeds which were treated with metal nanoparticles on average increased by 20–25%.

- Prasad et al. (2012) studied effect of nano Zn on peanut seeds treated with different concentrations of zinc oxide nanoparticles. Zinc oxide nanoscale treatment (25 nm mean particle size) at 1000 ppm concentration was used which promoted seed germination, seedling vigor, and plant growth and these zinc oxide nanoparticles also proved to be effective in increasing stem and root growth in peanuts.

- DeRosa et al. (2010) has pointed towards Nano fertilizers impact on economy, energy, and environment due to reduction in nitrogen loss through leaching, emission and long term incorporation by microorganisms. Milani et al. (2012) used Macronutrient fertilizers coated with zinc oxide nanoparticles and reported enhancement of nutrients absorption by plants and the delivery of nutrients to specific sites.

Nano pesticides

- Despite the fact that there are several available alternative methods, pest control is still largely based on the use of pesticides, but there are still concerns about their environmental impact.

- In this regard, pesticide use has been related with mammalian toxicity, environmental contamination, and bioaccumulation.

- ‘‘Nano pesticides’’ is a collective term for designing novel active ingredients with nanoscale dimensions, as well as their formulation and delivery. In order to protect the active ingredients from the environment conditions and to promote persistence, nanotechnology approach ‘nano-encapsulation’ can be used to improve insecticidal value. ‘Controlled release of the active ingredients’ approach is used to improve effectiveness of formulation.

- Liu et al. (2013) [12] used Porous hollow silica nanoparticles (PHSNs) loaded with validamycin (pesticide) as efficient delivery system of water-soluble pesticide for its controlled release. Nano-encapsulation comprises nano-sized particles of the active ingredients being sealed by a thinwalled sac or shell (protective coating).

- Sasson et al. (2007) listed some common benefits of NP-based pesticide formulations include:

- (a) increased solubility of water insoluble active ingredients
- (b) increased stability of formulation
- (c) elimination of toxic organic solvents in comparison with conventionally used pesticides
- (d) capability for slow release of active ingredients
- (e) improved stability to prevent their early degradation
- (f) improved mobility and higher insecticidal activity due to smaller particle size
- (g) larger surface area which is likely to extend their longevity.

- A sensor is a device built to detect a specific biological or chemical compound, usually producing a digital electronic signal upon detection.

- Precision farming utilizes remote sensing devices, computers and global satellite positioning systems to analyze various environmental conditions in order to determine the growth of plants under these conditions and identify problems related to crops and their growing environments.

- Through advancement in nanotechnology, a number of state-of-the-art techniques are available for the improvement of precision farming practices that will allow precise control at nanometer scale.

- The implementation of nanotechnology in the form of small sensors and monitoring devices will create a positive impact on the future use of precision farming methodologies.

- Nanotech-enabled systems help in increasing the use of autonomous sensors that are linked into GPS systems to provide efficient monitoring services focused on crop growth and soil conditions.

- The usage of smart sensors in precision farming will result in increased agricultural productivity by providing farmers with accurate information that will enable them to make accurate decisions related to plant growth and soil suitability.

- Nanobiosensors are used in sensing a broad array of Precision farming, with the aid of smart sensors, could enhance productivity as this technology ensures better management of fertilizers, herbicide, pesticide, insecticide, moisture and soil pH. Which reduces input cost and environment safety Controlled use of biosensors can assist in sustainable agriculture for increasing crop productivity.

- Nanosensors based smart delivery systems could help in the efficient use of natural resources like water, nutrients and agrochemicals by precision farming (Rai et al.2012).

- Quantum dots are efficient luminescence, small emission spectra, have excellent photostability and tenability according to the particle sizes and material composition. By a single excitation light source, QDs can be excited to all colors due to their broad absorption spectra (Warad et al. 2004).

- Quantum dots are used to detect pathogens associated with different plant diseases. Rad et al. (2012) reported witches' broom disease (Phytoplasma aurantifolia). Safarpour et al. (2012) used QDs to detect beet necrotic yellow vein virus Polymyxa betae (Keskin), the only known vector of beet necrotic yellow vein virus.