Biosensors EEL3050

Dr. Swati Rajput
Department of Electrical Engineering, IIT Jodhpur

Considerations for Biosensor Design

Selection of a Biological Receptor

- The specificity and selectivity of a biosensor to the analyte of interest is dependent upon the biological receptor used.
- A suitable receptor with high affinity for the analyte is thus recommended.
- Having knowledge of the advantages and disadvantages of various biological receptors in different biosensor applications is very important in selecting a suitable receptor.

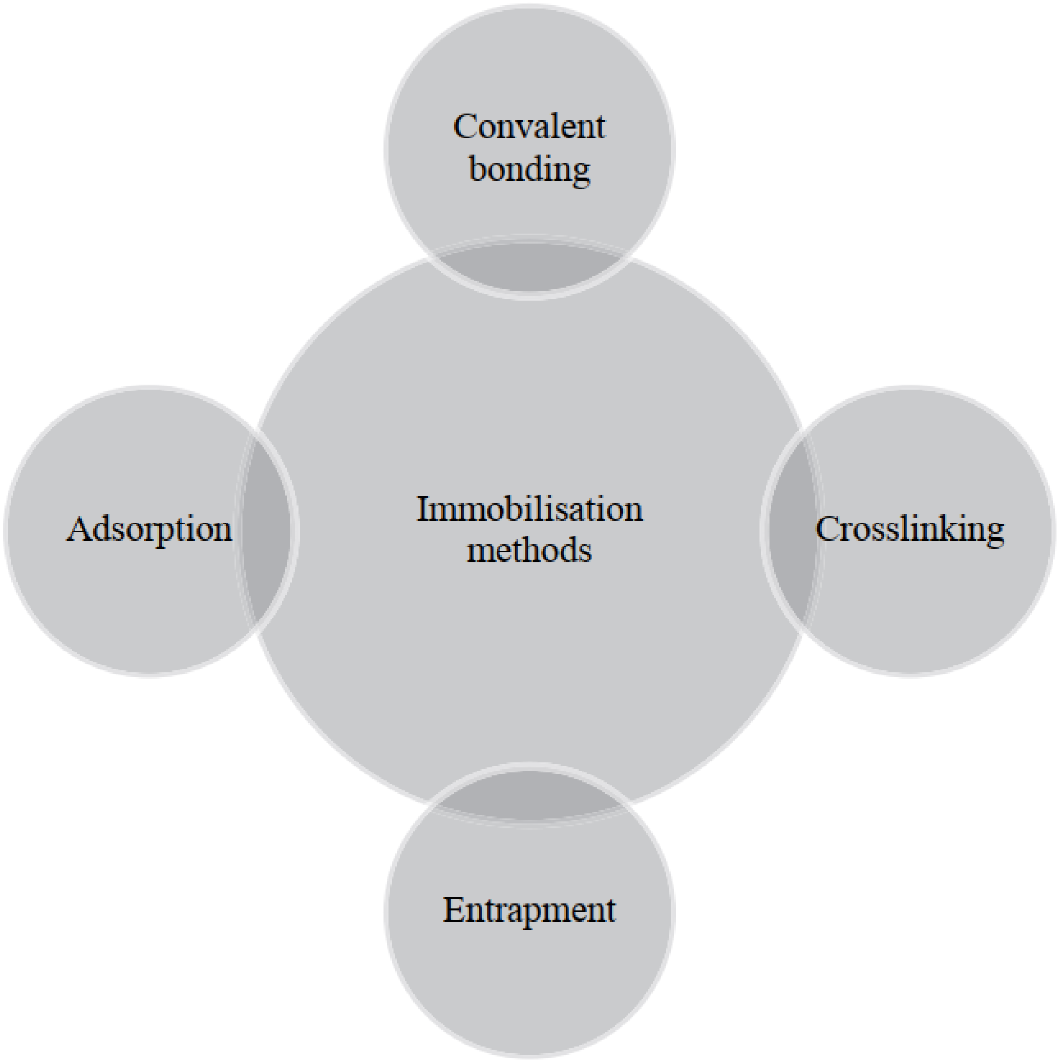
Selection of a suitable immobilization method:

- For any biological molecule to operate reliably as a biological receptor, it requires attachment onto the surface of a transducer. This process is known as immobilization.
- Various methods have been used for this task and include adsorption, entrapment, covalent attachment, micro encapsulation and cross linking.

Selection of a transducer element:

- Transducer element greatly influences the sensitivity of the biosensor device.
- Employing the right transducer will result in a device with increased sensitivity while the sensitivity is more likely to be compromised by the use of an ineffective transducer.

Immobilization Methods



- Process or technique used to attach a biological recognition element (such as enzymes, antibodies, nucleic acids, or cells) onto the surface of a biosensor's transducer in a stable and functional manner.

- Immobilization ensures that the biological element remains fixed and retains its bioactivity during the detection process, enabling the biosensor to interact with the target analyte and produce a measurable signal.

- Choice of immobilization method➔ impact the sensitivity, specificity, and overall performance of the biosensor.
- Biosensors are usually designed with high loading of biomolecules to ensure sufficient biocatalyst activities and, to further sustain the biological activity, an appropriate molecular environment should be provided.
- The local chemical and thermal environment can have profound effects on the stability of the biomolecule.

Immobilization Methods

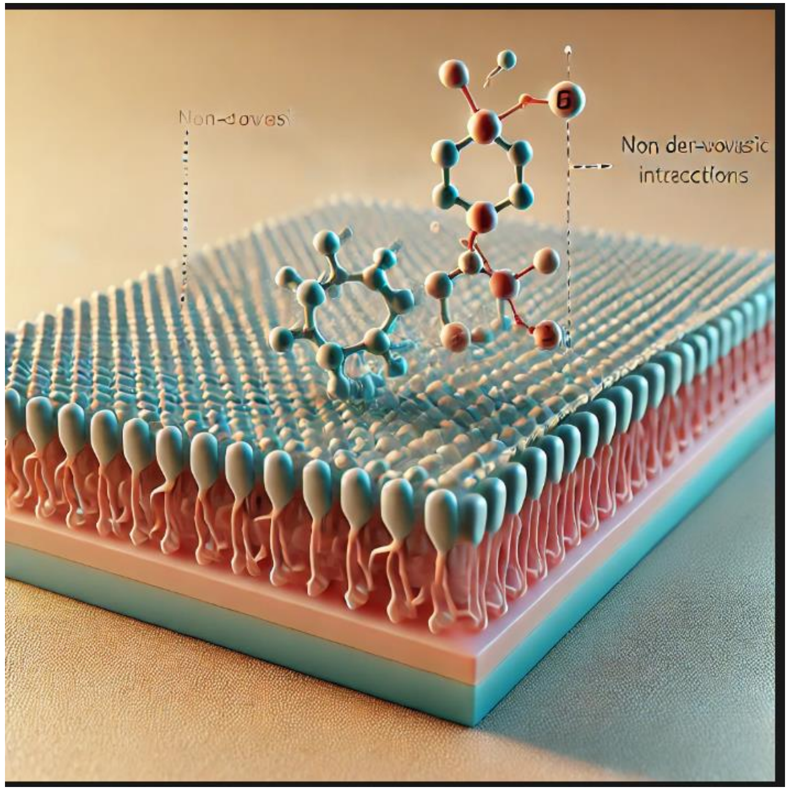
Choice of Immobilization Method depends on:

➔ Physiochemical properties of an analyte
➔ Nature of the Biological Receptor
➔ Type of the transducer used
➔ Operating environment of the biosensor

It is crucial that the biological element should exhibit maximum activity in its immobilized microenvironment

Adsorption:

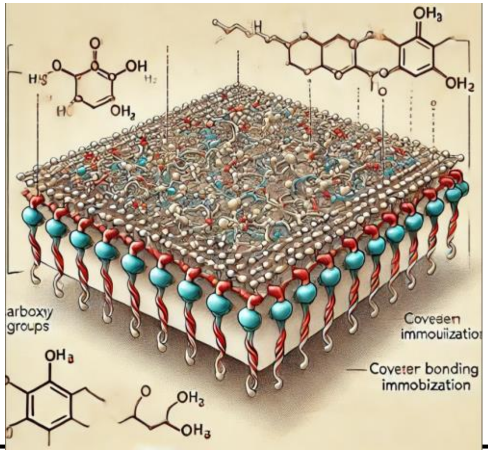
- Biomolecules are adsorbed onto the surface of the transducer through weak forces such as Van der Waals forces, hydrophobic interactions, or electrostatic interactions.
- **Advantages**: Simple, low-cost, and does not require chemical modifications.
- **Disadvantages**: Weak attachment, leading to possible desorption and loss of biomolecule activity over time.
- **Applications**: Commonly used in enzyme biosensors where reversible binding is acceptable.



Immobilization Methods

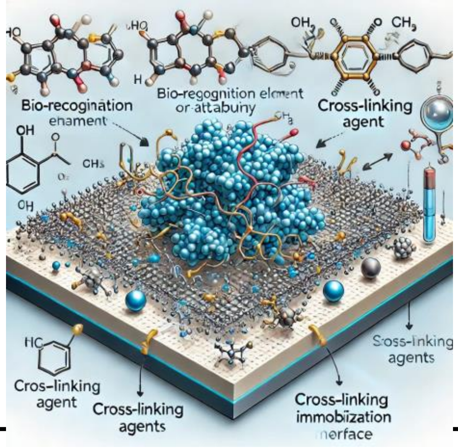
Covalent Bonding:

- **Mechanism**: Biomolecules are chemically bonded to the transducer surface through covalent bonds, often using functional groups like amines, carboxyls, or thiols.
- **Advantages**: Strong attachment, high stability, and reduced risk of biomolecule desorption.
- **Disadvantages**: Potential loss of bioactivity if the binding occurs at the active site or if the reaction conditions are too harsh.
- **Applications**: Widely used in immunosensors and DNA biosensors where stable, long-term use is required



Cross-Linking:

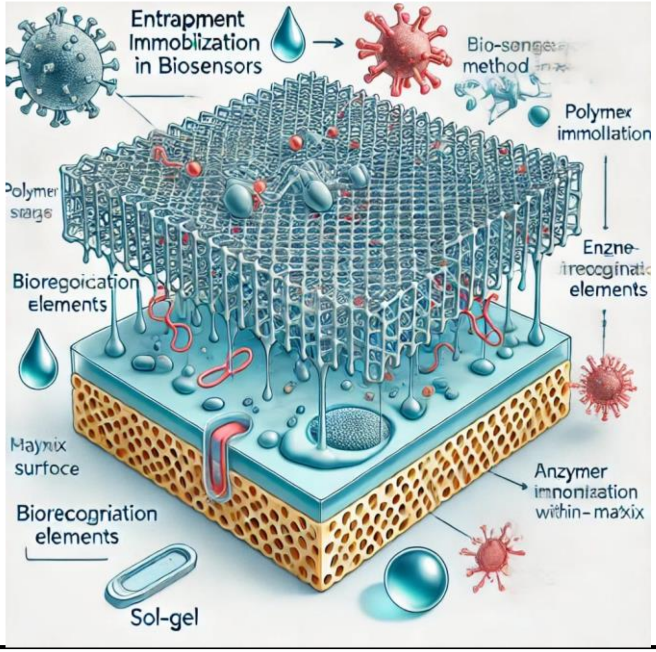
- **Mechanism**: Biomolecules are linked together or to the sensor surface using bifunctional reagents like glutaraldehyde, which forms cross-links between functional groups on the biomolecules.
- **Advantages**: Creates a dense layer of biomolecules, enhancing signal strength.
- **Disadvantages**: Potential for reduced activity due to cross-linking at active sites or changes in the biomolecule's conformation.
- **Applications**: Often used in enzyme sensors where a high density of active sites is beneficial.



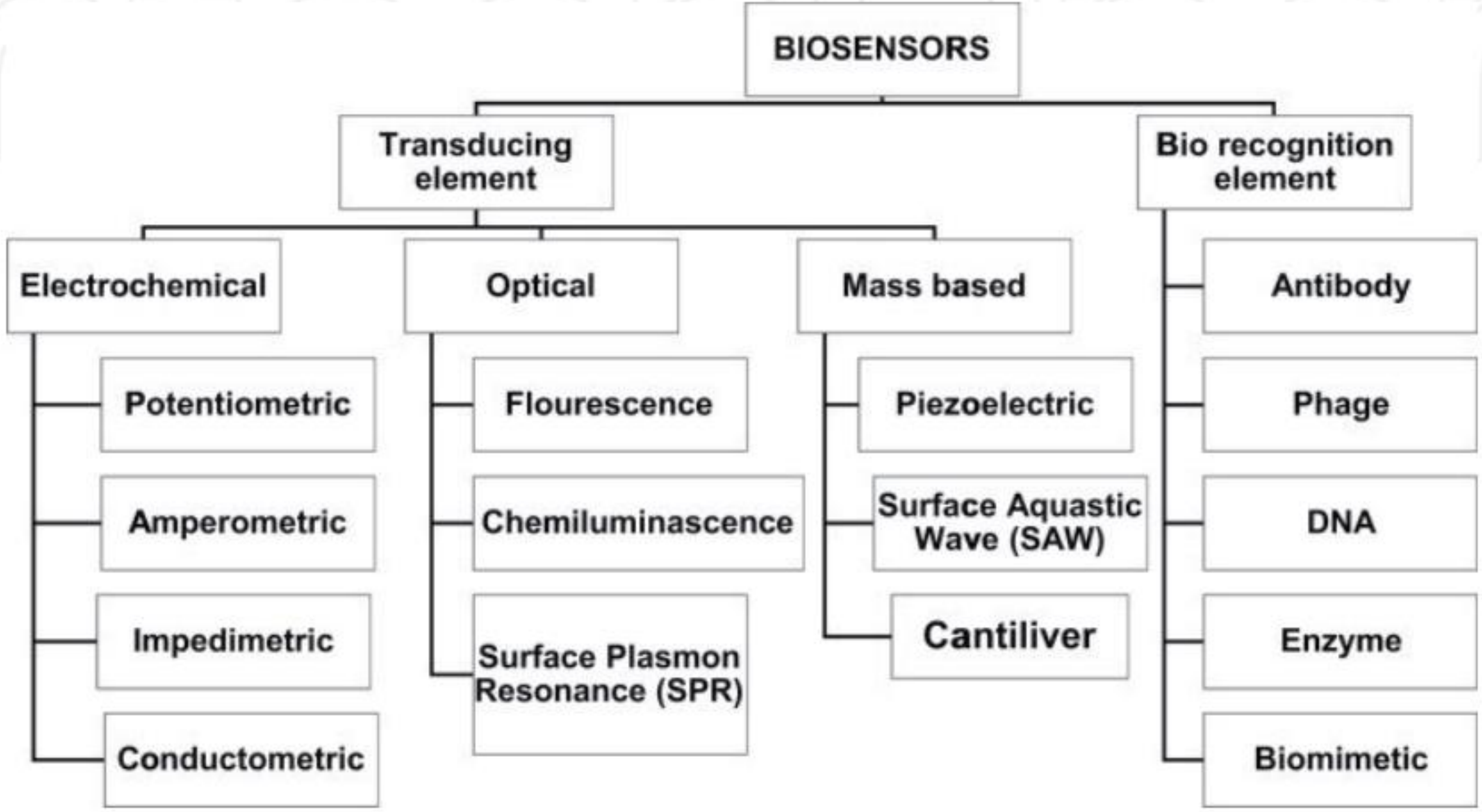
Immobilization Methods

Entrapment:

- **Mechanism**: Biomolecules are physically trapped within a porous matrix or gel (e.g., alginate, polyacrylamide) on the sensor surface.
- **Advantages**: Protects biomolecules from the external environment, allowing for the use of delicate or unstable biomolecules.
- **Disadvantages**: Limited mass transfer of analytes, which can reduce sensitivity.
- **Applications**: Used in biosensors where biomolecules need protection from denaturation, such as in microbial biosensors.



Classification of Biosensors



Classification of Biosensors

Based on Transducing Element

Electrochemical Biosensors:

These biosensors measure the electrical properties of the solution in which the analyte is present. They are further classified into:

- **Potentiometric**: Measures the change in voltage (electric potential) at the electrode surface caused by the interaction between the analyte and the biorecognition element. Commonly used in pH sensors.

- **Amperometric**: Measures the electric current produced by the redox reactions occurring at the electrode surface as a result of the analyte interaction. Widely used in glucose sensors.

- **Impedimetric**: Measures changes in the impedance (resistance to alternating current) of the system. Used in sensors where the interaction with the analyte causes a change in the impedance, such as in cell-based sensors.

- **Conductometric**: Measures the change in the electrical conductivity of the solution due to the interaction with the analyte. Often used in enzyme-based biosensors where the product of the reaction changes the ionic concentration of the solution.

Classification of Biosensors

Based on Transducing Element

Optical Biosensors:

These biosensors rely on the interaction between light and the analyte to generate a measurable signal. They are categorized into:

- **Fluorescence**: Detects the presence of an analyte by measuring the intensity of light emitted by a fluorescent label attached to the biorecognition element. Common in DNA sensors.

- **Chemiluminescence**: Similar to fluorescence but relies on the light emitted by a chemical reaction rather than a fluorescent label. Used in highly sensitive immunoassays.

- **Surface Plasmon Resonance (SPR)**: Measures changes in the refractive index near the sensor surface when the analyte binds to the biorecognition element.

Classification of Biosensors

Based on Transducing Element

Mass based Biosensors:

These sensors measure the mass of the analyte that binds to the biorecognition element. They include:

- **Piezoelectric**: Utilizes piezoelectric crystals that generate an electric signal when subjected to a mechanical stress, such as the binding of an analyte. Used in gas and vapor detection.

- **Surface Acoustic Wave (SAW)**: Detects changes in the properties of surface acoustic waves as they pass over the sensor surface, which changes when the analyte binds. Useful for detecting small molecules.

- **Cantilever**: Involves microcantilevers that bend when an analyte binds to the surface, changing the resonant frequency. Used in DNA and protein detection.

Classification of Biosensors

Based on Biological Receptors

Enzyme based Biosensors:

- Enzyme-based biosensors utilize enzymes as the biorecognition element. Enzymes are biological catalysts that accelerate specific biochemical reactions, making them ideal for detecting particular substrates in a sample.
- **Principle**: The enzyme catalyzes a reaction involving the analyte (substrate), producing a product or consuming the analyte. The transducer converts this biochemical change into a measurable signal, such as an electrical current, change in pH, or optical signal.

Examples

- **Glucose Biosensor**: The most common enzyme-based biosensor. Glucose oxidase is immobilized on an electrode, and the current produced by the oxidation of glucose is measured.
- **Lactate Biosensor**: Uses lactate oxidase to detect lactate levels in blood or sweat, useful in sports medicine.
- **Urea Biosensor**: Urease enzyme converts urea to ammonia and carbon dioxide, and the resulting pH change is measured.

Classification of Biosensors

Based on Biological Receptors

DNA based Biosensors:

- **Definition**: DNA-based biosensors utilize DNA strands as the biorecognition element. These biosensors detect specific DNA sequences by hybridization, where a single-stranded DNA (ssDNA) probe binds to its complementary target DNA strand.
- **Principle**: The hybridization of complementary DNA strands leads to a detectable change that the transducer converts into a signal. This change can be electrical, optical, or based on mass.

Examples:

- **Genetic Testing**: DNA biosensors are used to detect mutations, single nucleotide polymorphisms (SNPs), and specific gene sequences associated with diseases.
- **Pathogen Detection**: Detecting specific bacterial or viral DNA sequences, such as those from E. coli or SARS-CoV-2.
- **Environmental Monitoring**: Detection of genetically modified organisms (GMOs) in food or environmental samples.