Module - 7

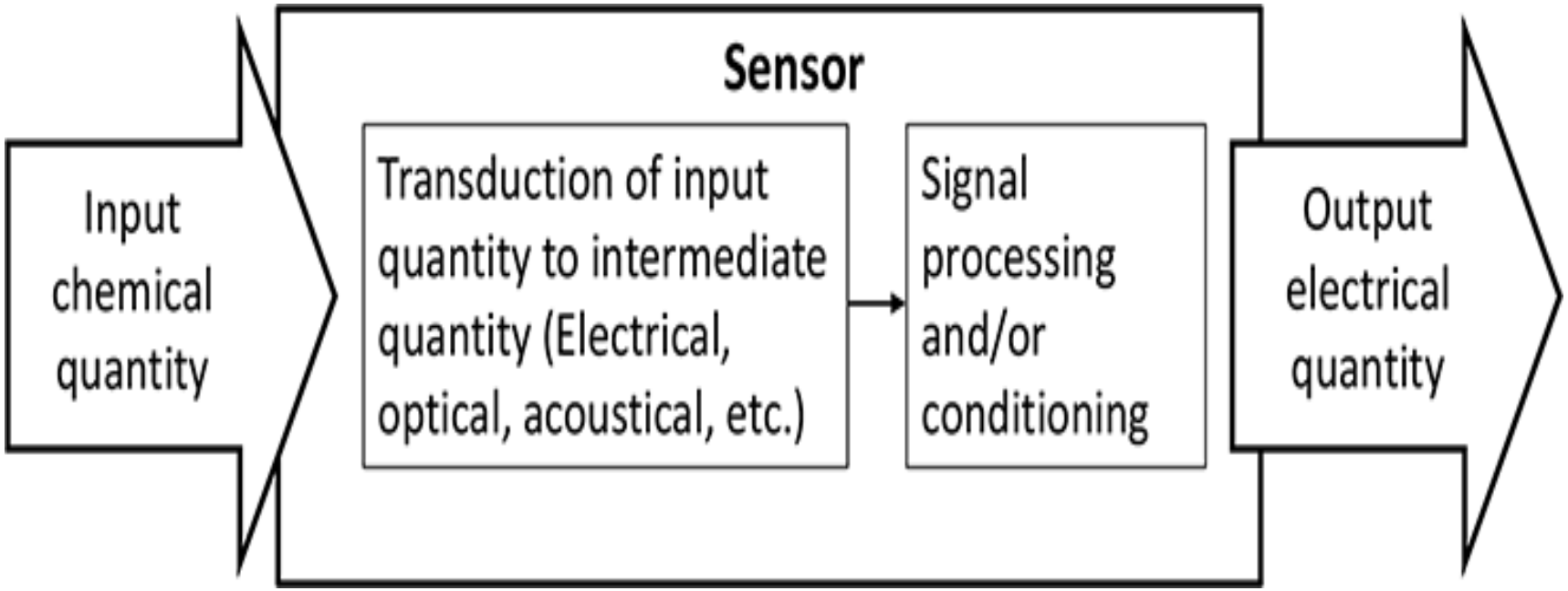
Chemical sensors for environmental monitoring -

Gas sensors

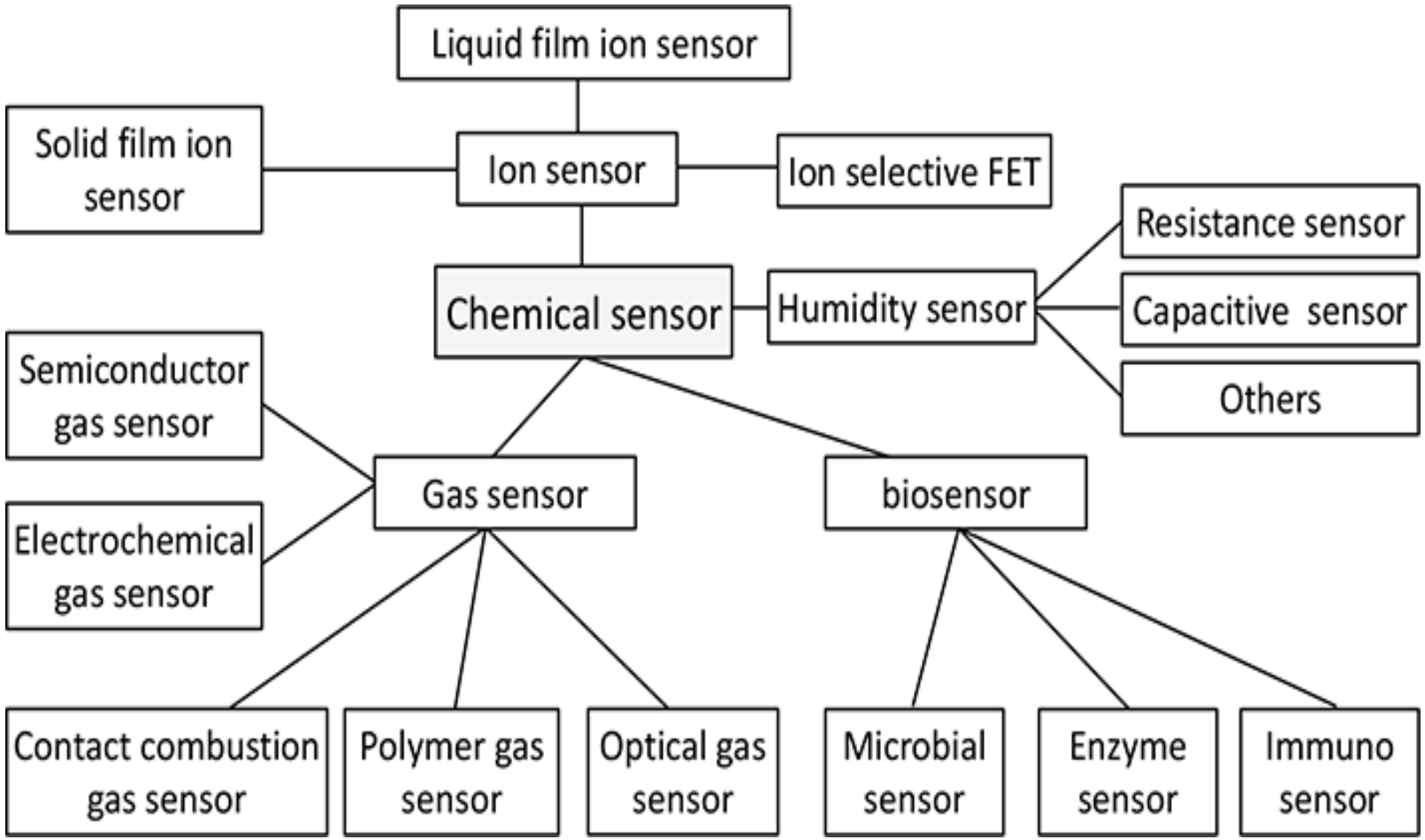
Introduction

- **Chemical sensors** are measurement devices that convert a **chemical** or physical property of a specific analyte into a measurable signal, whose magnitude is normally proportional to the concentration of the analyte.
- A **chemical sensor** typically contains **two main components**: a receptor and a transducer. The receptor transforms **chemical** information about a sample into a form of energy. The transducer then transforms the energy into some form of analytical signal.
- The chemical sensor is an analyser that responds to a particular analyte in a **selective and reversible way and transforms input chemical quantity**, ranging from the concentration of a specific sample component to a total composition analysis, **into an analytically electrical signal.**

How it works?


Sensor
Input chemical quantity
Transduction of input quantity to intermediate quantity (Electrical, optical, acoustical, etc.)
Signal processing and/or conditioning
Output electrical quantity

Classification of Chemical Sensors



Gas sensors

- Gas sensor is a subclass of chemical sensors.
- Gas sensor measures the concentration of gas in its vicinity.
- Gas sensor interacts with a gas to measure its concentration.
- Each gas has a unique breakdown voltage i.e. the electric field at which it is ionized. Sensor identifies gases by measuring these voltages.
- The concentration of the gas can be determined by measuring the current discharge in the device.
- Types of gas sensors:
  - Electrochemical gas sensor
  - Contact combustion gas sensor
  - Optical gas sensor
  - Polymer gas sensor
  - Semiconductor gas sensor

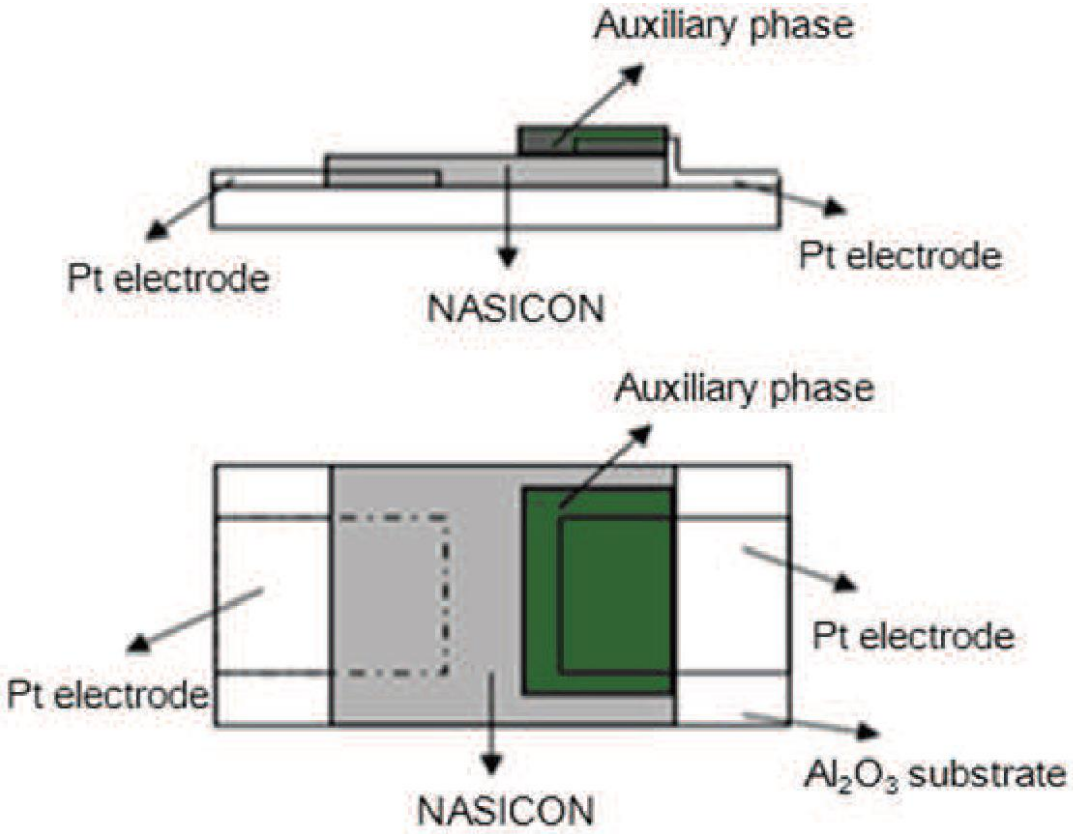
IR absorption type CO_2 gas sensor

- CO_2 absorbs infrared light therefore CO_2 sensor consists of a tube containing an infrared source at one end and an infrared detector at the other end.
- The infrared detector detects the infrared light which is not absorbed by CO_2 between source and detector.
- Infrared radiation which is not being absorbed by CO_2 produces heat so the temperature will increase.
- The infrared detector measures the temperature.
- A voltage is produced due to the temperature increase in the infrared sensor.
- We can read amplified voltage into the data logger.

Solid electrolyte-type CO_2 sensors

- Low-cost, high-sensitivity, high-selectivity and simple-element structure.
- **NASICON** is the active element. Formula $Na_{1+x}Zr_2Si_xP_{3-x}O_{12}$ $(1.8 < x < 2.4)$
- A commercial NASICON with a nominal-composition is **$Na_3Zr_2Si_2PO_{12}$**
- Binary carbonate systems such as Na_2CO_3-$BaCO_3$, Na_2CO_3-$CaCO_3$, Li_2CO_3-$BaCO_3$, and Li_2CO_3-$CaCO_3$ are also used as active elements (as auxiliary constituents).
- The NASICON layer was screen-printed with a paste on the alumina substrate. The Pt electrodes were also screen-printed on the designated regions before and after the deposition of the NASICON layer.
- The assembly was sintered at 900°C, 1000°C, and 1100°C for 4 hours in air, respectively. After this, a series of auxiliary phases (Na_2CO_3-$CaCO_3$) was screen-printed on the Pt sensing electrode.
- The EMF response to CO_2 content as a function of the CO_2 concentration is calculated. Greater the CO_2 concentration greater the EMF recorded.

Solid electrolyte-type CO_2 sensors



Hydrogen gas sensor

- Mostly palladium is used to detect hydrogen because palladium selectively absorbs hydrogen gas and forms the chemical palladium hydride.
- Types of hydrogen gas sensor:
- Electrochemical
- Thin film sensor
- Thick film sensor
- Chemochromic hydrogen sensors
- Diode based Schottky sensor
- Optical fiber hydrogen sensors
- Nanoparticle-based hydrogen microsensors

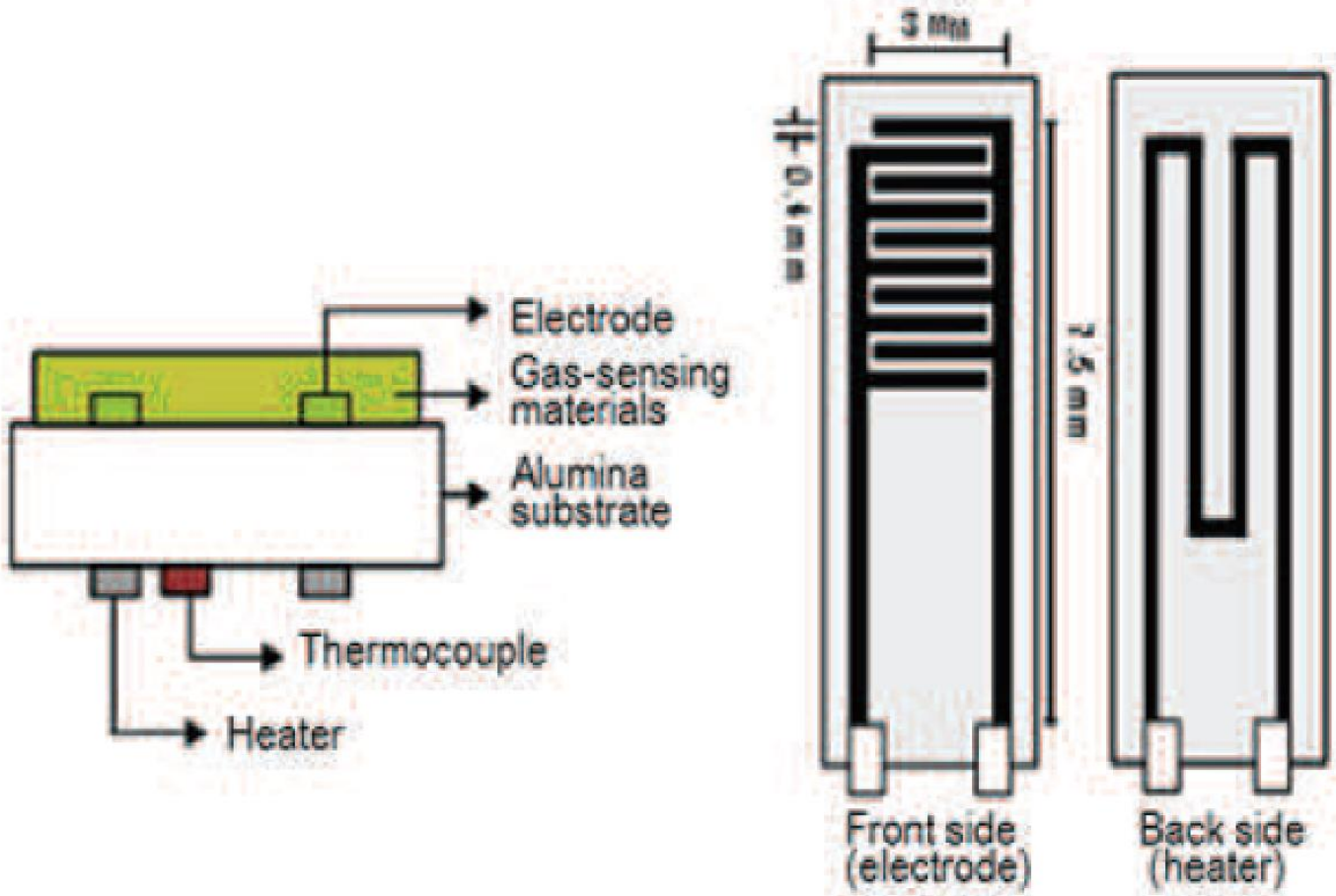
NO_x gas sensor – Metal oxide type

- WO_3 is known as the most promising NOx gas-sensing material
- Other materials: ZnO, SnO_2, In_2O_3, TiO_2, etc.
- These sensing materials are oxygen-deficient nonstoichiometric compounds
- The conductivity of these n-type semiconductors, such as WO_3 and In_2O_3, is estimated based on the electron created by the surplus metal.
- When sensing materials are exposed to oxidizing gases at temperature ranging from 200ºC to 300ºC, the concentration of electrons is decreased due to the reaction between the electron and the gas.
- Consequently, the conductivity decreases and the resistance increases.
- As NOx is also an oxidizing gas, the concentration of electrons is decreased due to the reaction between the electrons in the sensing materials and NOx gas, as shown in the following equations:

$$NO + 2e^- \longrightarrow \frac{1}{2}N_2 + O^{2-}$$

$$NO_2 + 2e^- \longrightarrow NO + O^{2-}$$

NO_x gas sensor



Carbon monoxide gas sensor

- CO is a colourless, tasteless and odourless gas produced by incomplete combustion of carbon-containing materials. It is often referred to as the "silent killer" because it is virtually undetectable by humans.
- **Types of CO sensors:**
  - Semiconductor sensor
  - Electrochemical sensor
  - Biomimetic type
  - Opto-chemical type (Widely used)

Opto-chemical type CO sensor

- The detector consists of a pad of a coloured chemical which changes colour upon reaction with carbon monoxide. They only provide a qualitative warning of the gas however. The main advantage of these detectors is that they are the lowest cost, but the downside is that they also offer the lowest level of protection.
- One reaction used for carbon monoxide detection is potassium disulphitopalladate (II) catalytic oxidation.

$$CO + K_2Pd(SO_3)_2 \longrightarrow Pd + CO_2 + SO_2 + K_2SO_3$$

- As reaction progresses, atomic palladium release causes the color to change from yellow to brown to black.

Biomimetic and electrochemical type CO sensor

- A biomimetic sensor works in a fashion similar to haemoglobin which darkens in the presence of CO proportional to the amount of carbon monoxide in the surrounding environment.
- It uses cyclodextrins, a chromophore, and a number of metal salts. This can either be seen directly or connected to an infrared source of photons such as an IR LED and then monitored using a photodiode.
- The electrochemical detector uses the principle of a fuel cell to generate an electrical current when the gas to be detected undergoes a chemical reaction.
- The generated current is precisely related to the amount of carbon monoxide in the immediate environment close to the sensor.
- Essentially, the electrochemical cell consists of a container, two electrodes, connection wires and an electrolyte, typically sulfuric acid. Carbon monoxide is oxidized at one electrode to carbon dioxide while oxygen is consumed at the other electrode.
- Advantages of electrochemical cell over other technologies: highly accurate and linear output to carbon monoxide concentration, requires minimal power as it is operated at room temperature, and has a long lifetime.