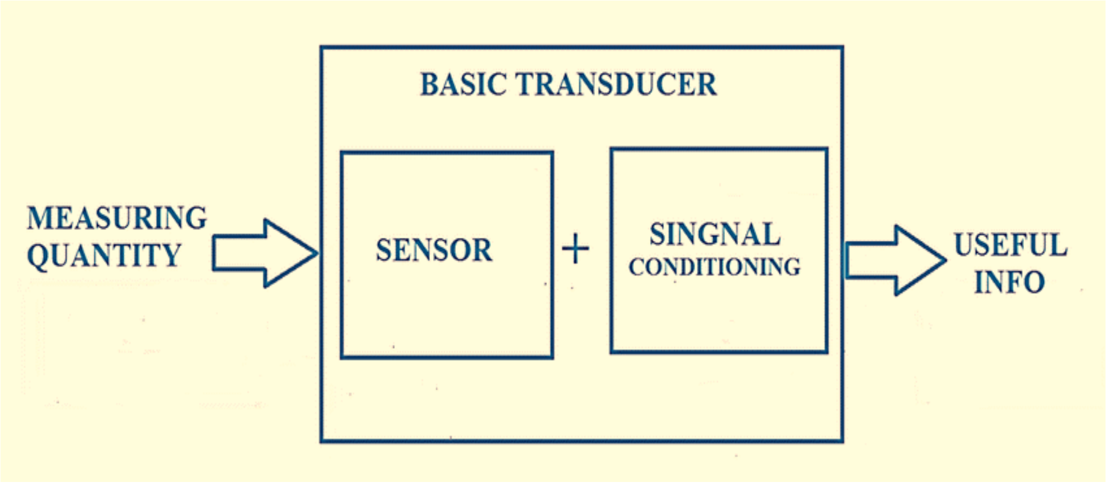
Sensors

UNIT-IV **09 Hrs**	**Smart sensors and devices**
RFID and IONT materials: Synthesis, properties and applications in logistic information, intelligent packaging systems (Graphene oxide, carbon nanotubes (CNTs) and polyaniline). **Sensors**: Introduction, types of sensors (Piezoelectric and electrochemical), nanomaterials for sensing applications (Strain sensors, gas sensor, biomolecules and volatile organic compounds).	

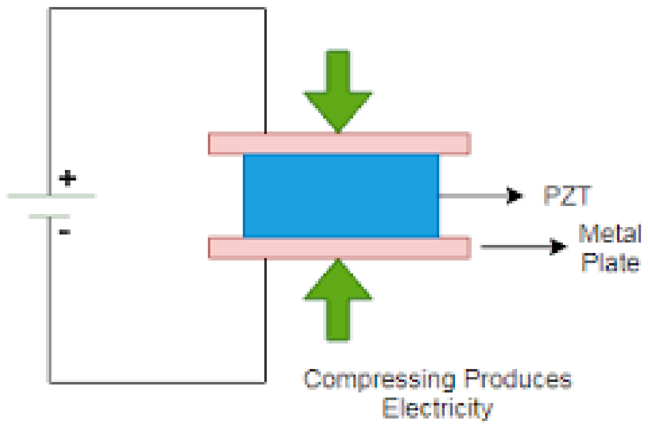
Sensor: It is device that measures change in a physical (heat, light, sound, pressure etc) and/or chemical (pH, smell, taste, concentration, humidity etc) parameters of interest in an environment and transforms it into an electronic signal.

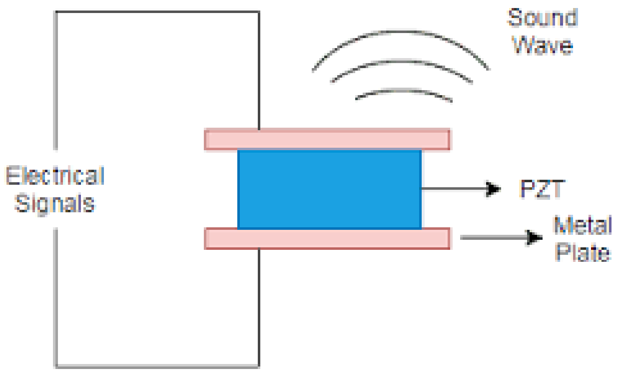
Transducer: A transducer is a device that transforms a signal from one energy form to another energy form.



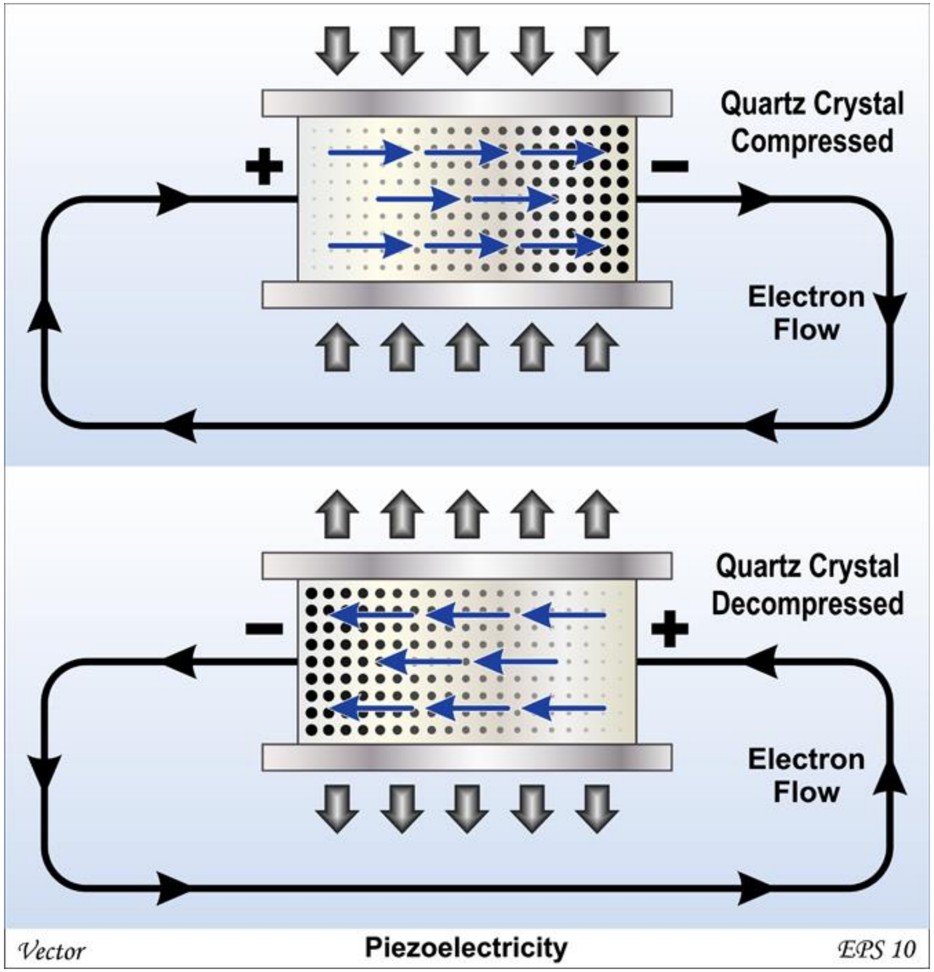
Piezoelectric (PE) Sensors

- “Piezo” is word derived from Greek, it means for “press” or “squeeze”.
- A device, which converts physical parameters like acceleration, strain, pressure, vibration, temperature, or force into an electrical charge which can then be measured.
- Fabrication by using the perovskite ceramic material (lead zirconate titanate (PZT)) and also other lead-free ceramic piezoelectric sensors using bismuth sodium titanate (BST), barium titanate ($BaTiO_3$), boride and silicide ceramics (TiB_2, $TaSi_2$, WSi_2)





Mechanism



Quartz Crystal
Compressed
Electron
Flow
Quartz Crystal
Decompressed
Electron
Flow
Vector
Piezoelectricity
EPS 10

Characteristics of PE sensors:

- High strength
- High stability
- High voltage output
- highly flexible
- Wide frequency range
- Impact resistance
- High mechanical strength
- Elastic compliance etc

Strain Sensor: Upon applying the external force on an object, the strain (permanent/temporary) is induced in the object due to its structural (internal) deformation, this results in change in internal resistance of the object, which can be measured by using the device called strain sensor. Various nanomaterials like graphene, CNT, PVDF, and their hybrids are used in these sensors.

- **Pulse measurement** – PE sensors are very sensitive to record pulse measurements and effective in monitoring the patients' health.

- **Stethoscopes** – Due to high sensitivity and robustness PE sensors, they are often used within stethoscopes.

- **Anesthesia Effectiveness -** PE sensors are capable of accurately measuring the muscles stimulations, and hence can be helpful in understanding the effectiveness of anesthesia.

- **Sleep Studies -** PE sensors can be attached to various parts of the patient body and can be used to measure the smallest movements of patients during the sleep also.

Respiration Monitoring
40 s exposed
Sensor
Chest
Deep breathing
Normal breathing
ΔR/R0
Time (Sec)
Pulse Monitoring
wrist pulse
ΔR/R0 (%)
Time (s)
Drug Delivery
stretch
drug release
Healthcare and Biomedical Engineering
Soft Prosthetic Hand
Soft Robotics
Artificial Skin
Soft Robotic Grippers
Wearable Strain Sensors
Sensitivity
Durability
Scalability
Linearity
Stretchability
Gaming and Virtual Reality
Soft Virtual Reality Glove
Wireless Smart Glove
Press
Basic Motion
Reload
Interactive Gaming
Sport Performance Monitoring
Finger Bending
Wrist Bending
Knee Bending
Elbow Bending
Whole Body Monitoring
Sensor
End Cap
CS3 Fiber
Joint Motion Detection
Smart Wearable Strain Sensor

Electrochemical (EC) Sensors: a device that converts chemical composition data of the analyte into an analytically usable signal.

Components: (a) electrodes system, (b) transducer (c) amplifier and (d) recorder.

(a) electrode system consist

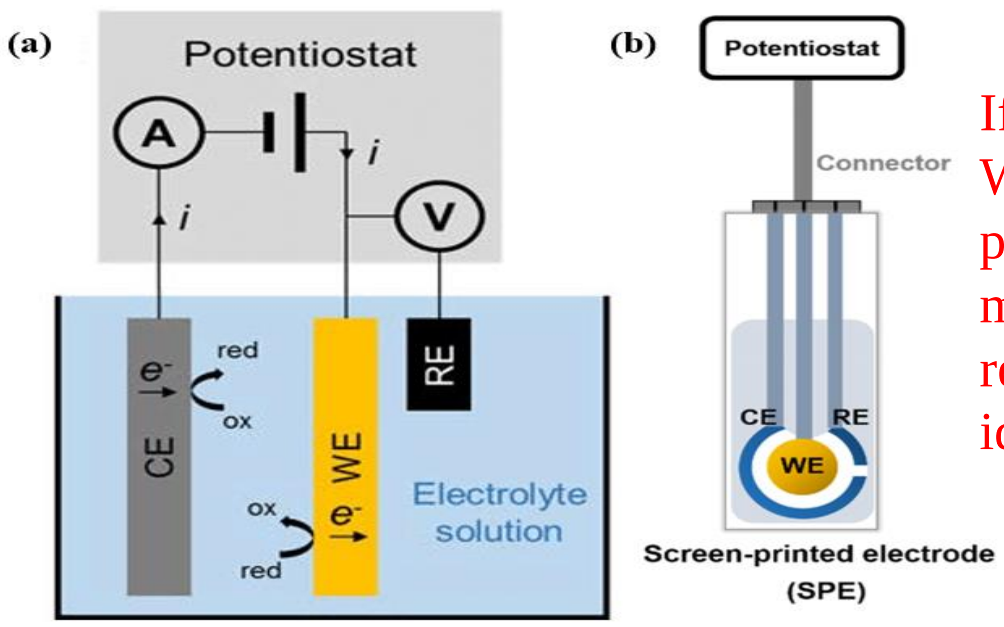
- Working electrode (Working electrode (WE) is very sensitive to any change in analyte solution, provides the surface for the analyte to undergo reaction. Example- Carbon, glassy carbon electrode (GCE))

- Counter/auxiliary electrode (The CE helps in completing the circuit by allowing the reaction, which is opposite to WE reaction, to happen. If an oxidation reaction happens at WE, reduction reaction will take place at CE, and vice versa. Example- Gold, platinum and carbon electrodes)

- Reference electrode (The RE is independent of the analyte and other ions concentration. Example- Standard Hydrogen Electrode (SHE), calomel electrode, silver-silver chloride)

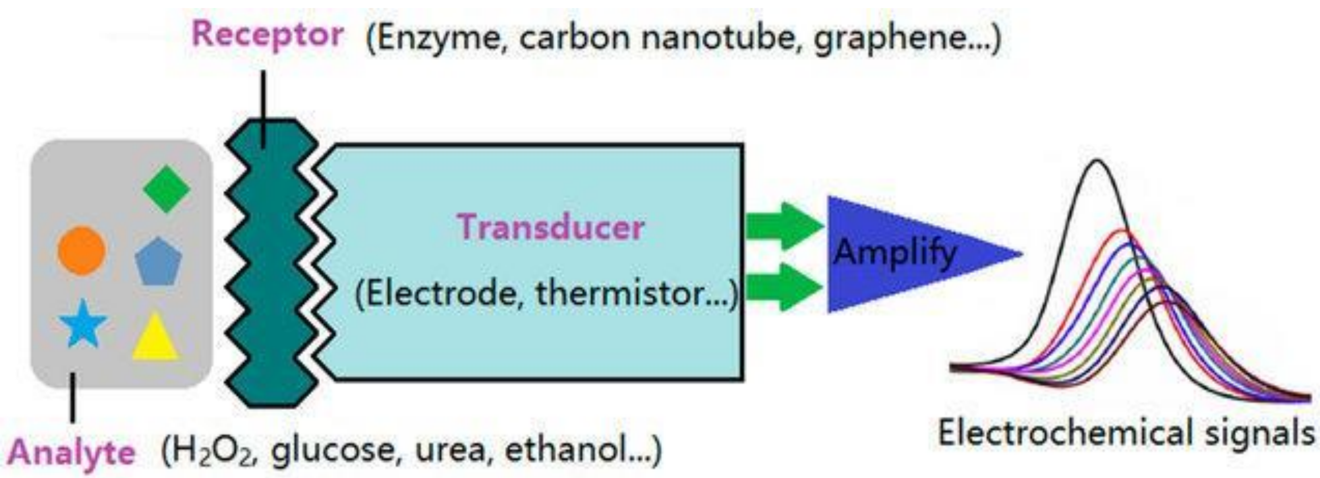
Working principle: The basic principle of EC sensor is that it measures the current produced by chemical reactions in the electrochemical system.

- Potentiostat - controls the voltage between two electrodes (WE and RE).
- when the potential is applied between WE and RE.
- RE potential is constant while measuring the potential of WE.
- By measuring the current of redox reaction, the analyte can be identified.



If an oxidation reaction happens at WE, reduction reaction will take place at CE, and vice versa.. By measuring the current of redox reaction, the analyte can be identified.

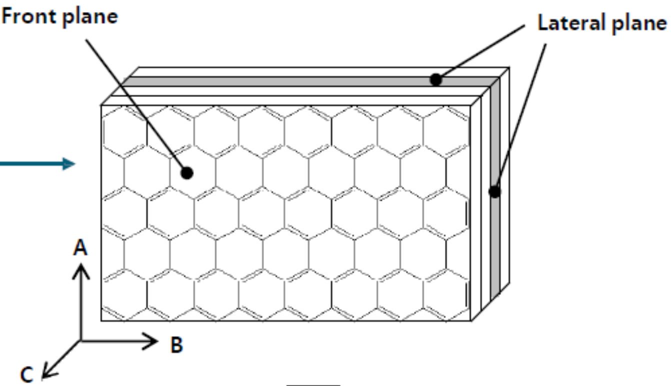
- The EC sensor used to for various analytes such as hydrogen peroxide, glucose, urea, alcohol etc,
- which are adsorbed on receptors (nanomaterials, Graphene, CNTs metal oxides).
- They undergo redox reaction upon applying voltage
- The resultant current (electrons released) is measured by transducer, which is characteristic property of a biomolecule under study.
- Then the current is quantified by using amplifier and recorder as shown below.

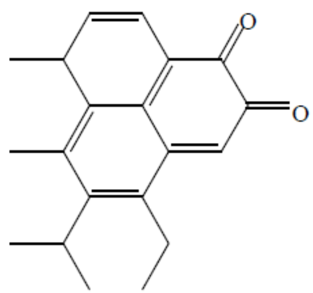


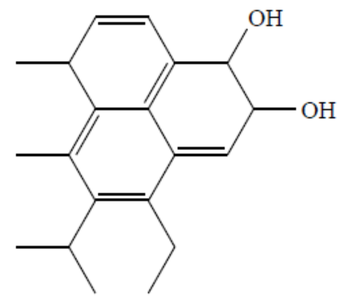
Electrochemical (EC) Sensors: electrodes

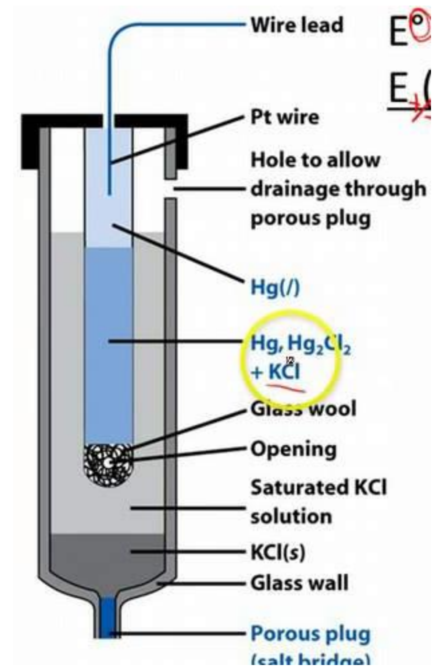
Conventional carbon based probes:

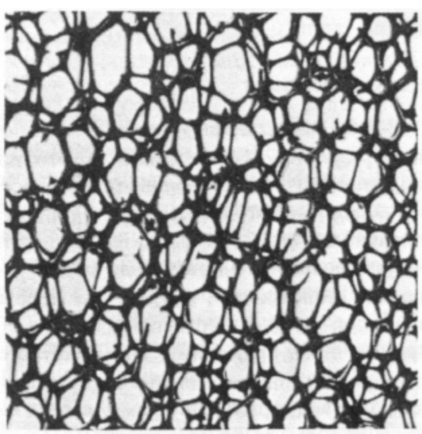
- graphite
- carbon paste
- pyrolitic graphite
- glassy carbon





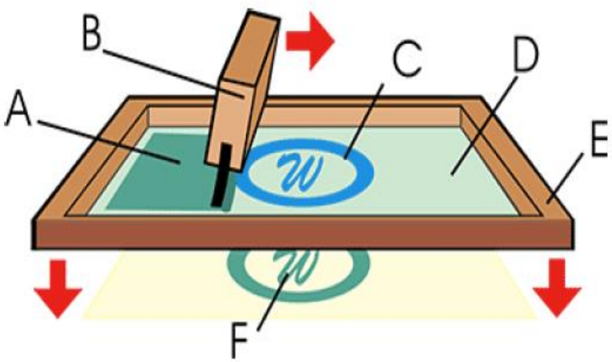


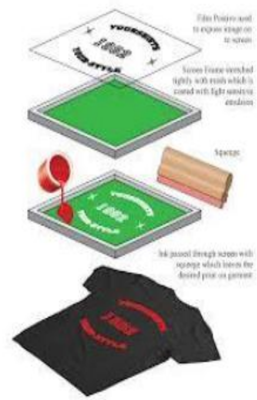




Polished graphite- glassy carbon

Electrochemical (EC) Sensors: Screen printed electrodes



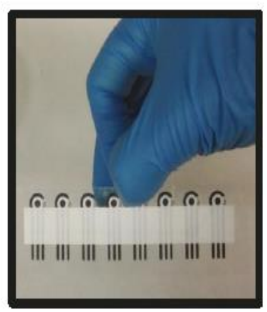


A. ink; B. squeege;

C. printing mask;

D. printing mesh;

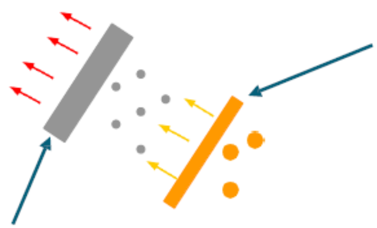
E. frame; F. printed ink



Advantages:
- Dimension
- Disposable
- Low-Cost

Electrochemical (EC) Sensors: mechanism

The biological element translates the info of the biochemical domain (e.g. concentration) into a chemical or physical signal with a certain selectivity



Biological binding system

- selectivity
- sensitivity

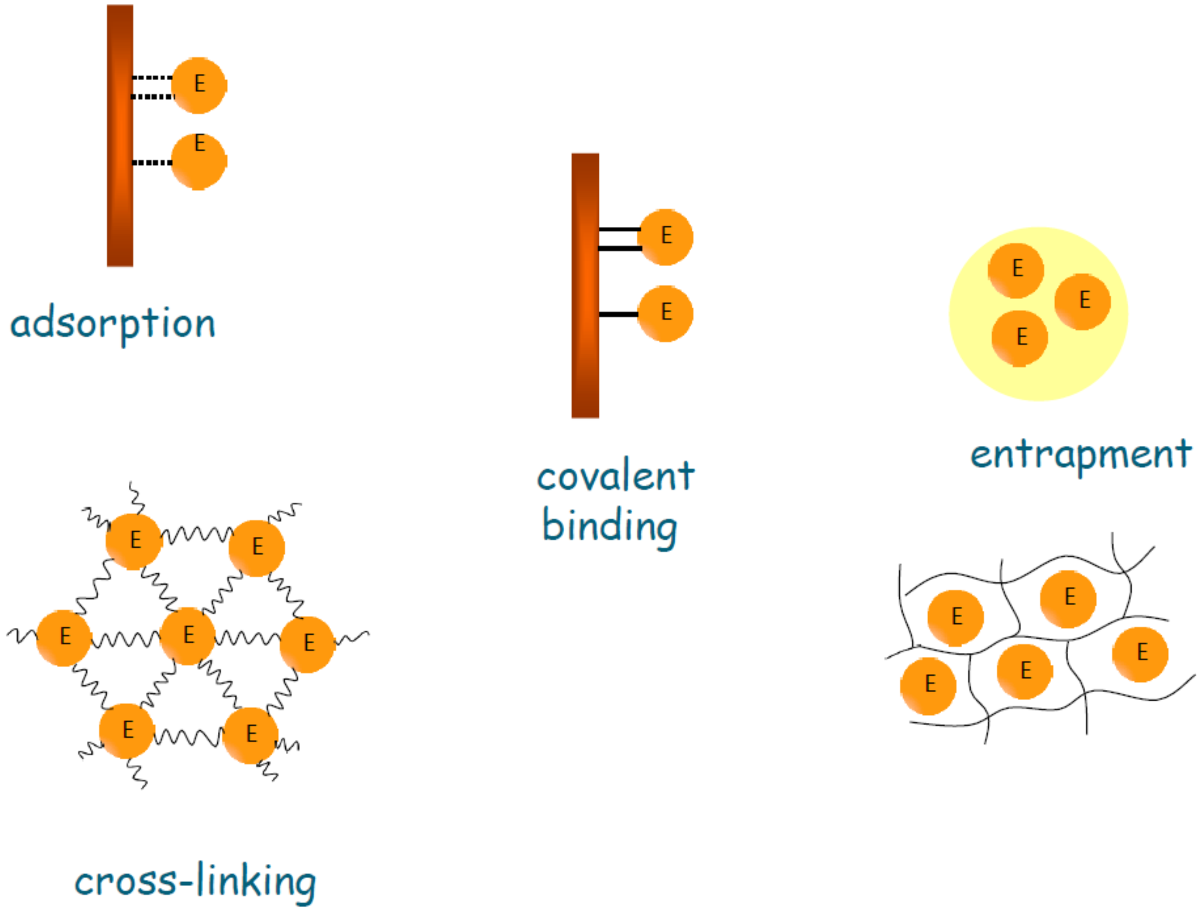
Transducing element

Tranducers

- electrochemical
- optical
- piezoelectric
- thermal

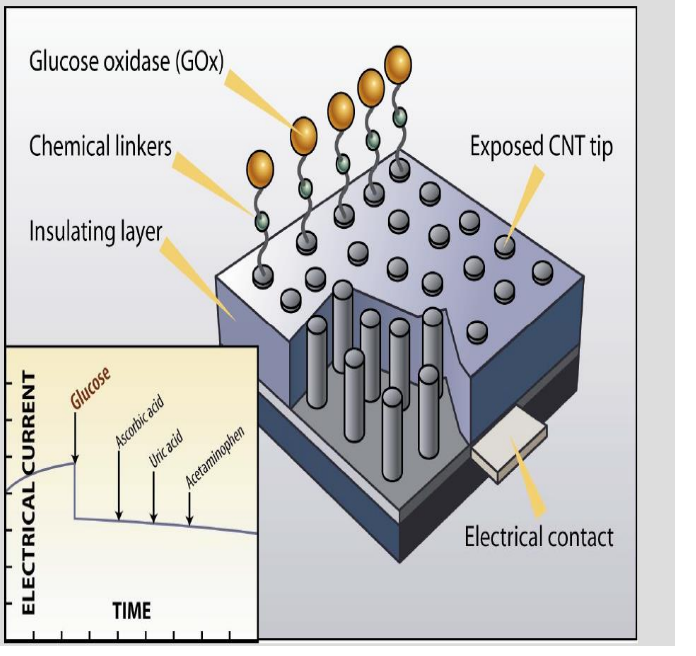
- potentiometric
- amperometric
- voltammetric
- conduttimetric, impedimetric

Mechanism of binding analyte



Glucose sensor

In EC sensor, glucose and oxygen react in the presence of nanomaterials or glucose oxidase (GOx) functionalized WE, and thus oxygen is consumed and hydrogen peroxide is produced. Further, the glucose concentration can be detected indirectly by electron transfer of oxygen at CE



WE:

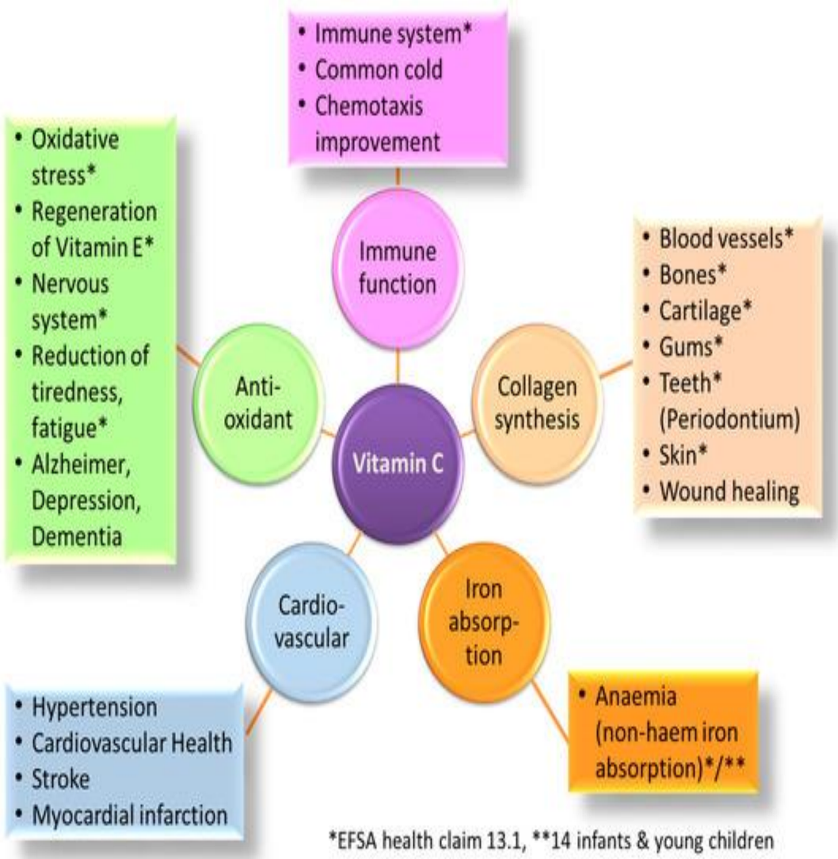
Glucose + O_2 + H_2O → Gluconic acid + H_2O_2

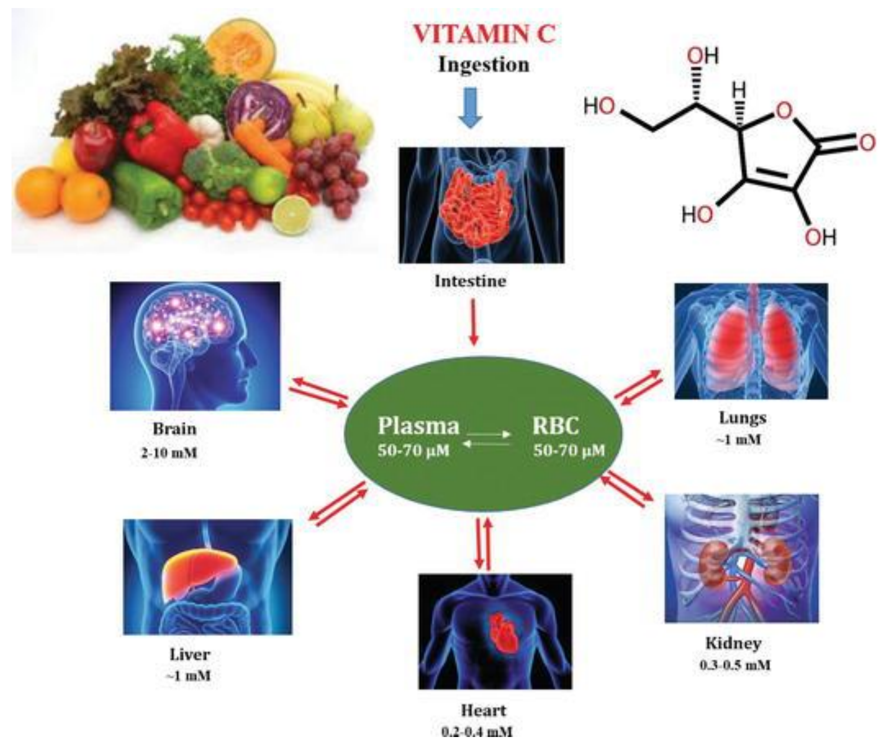
H_2O_2 -----------→ $2H^+ + O_2 + 2e$

CE:

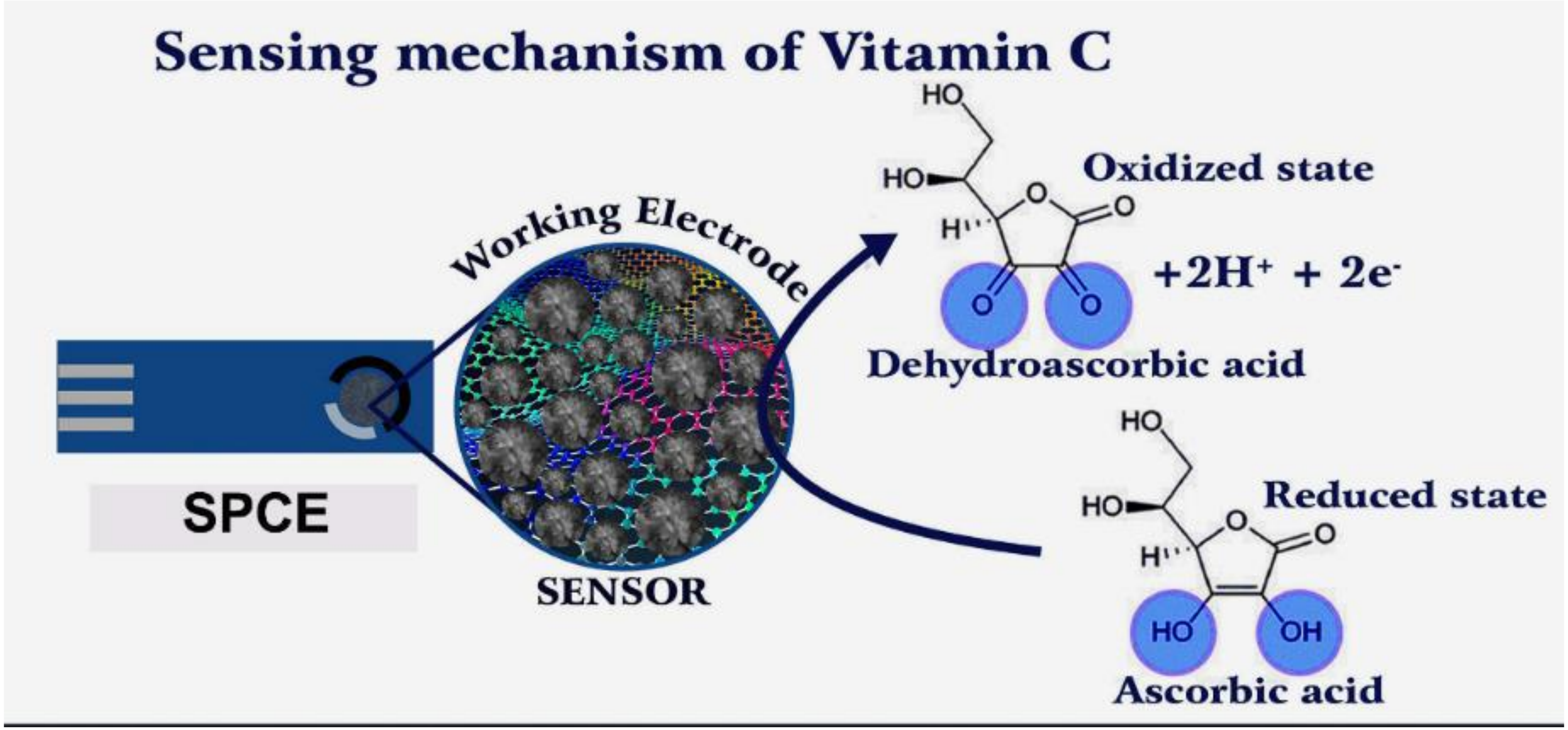
$O_2 + 4H^+ + 4e$ → $2H_2O$ (please correct it in notes its given as hydrogen peroxide)

Electrochemical sensor :Ascorbic acid sensor



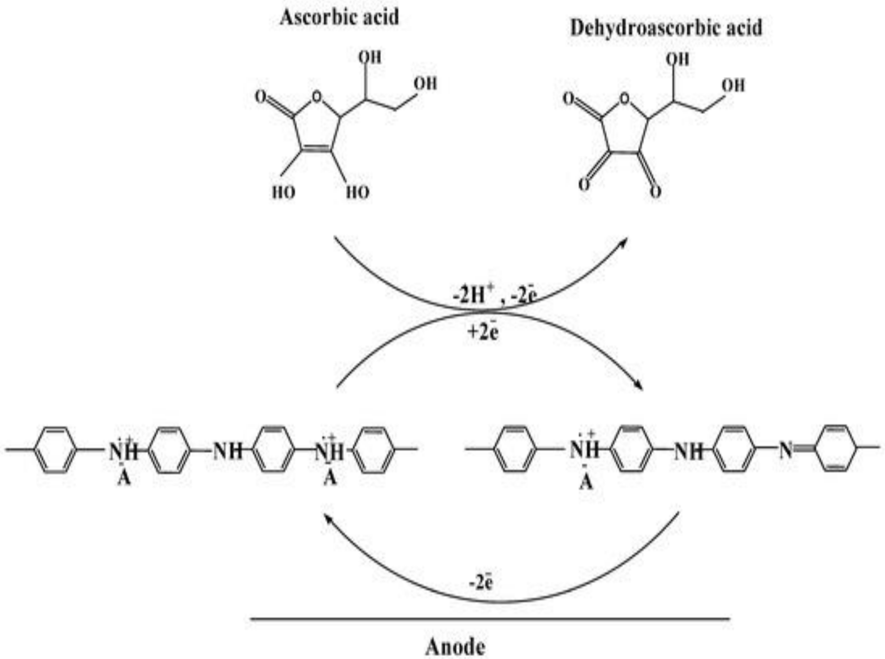


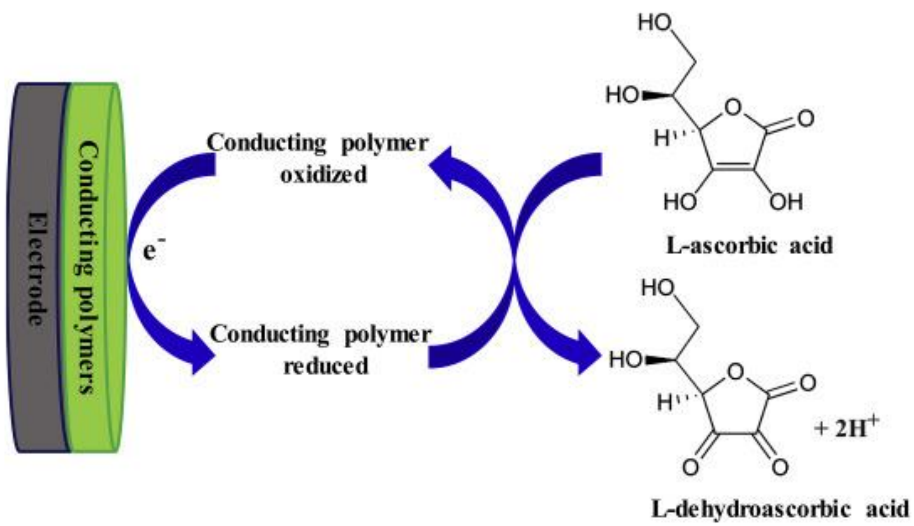
Electrochemical sensor :Ascorbic acid sensor



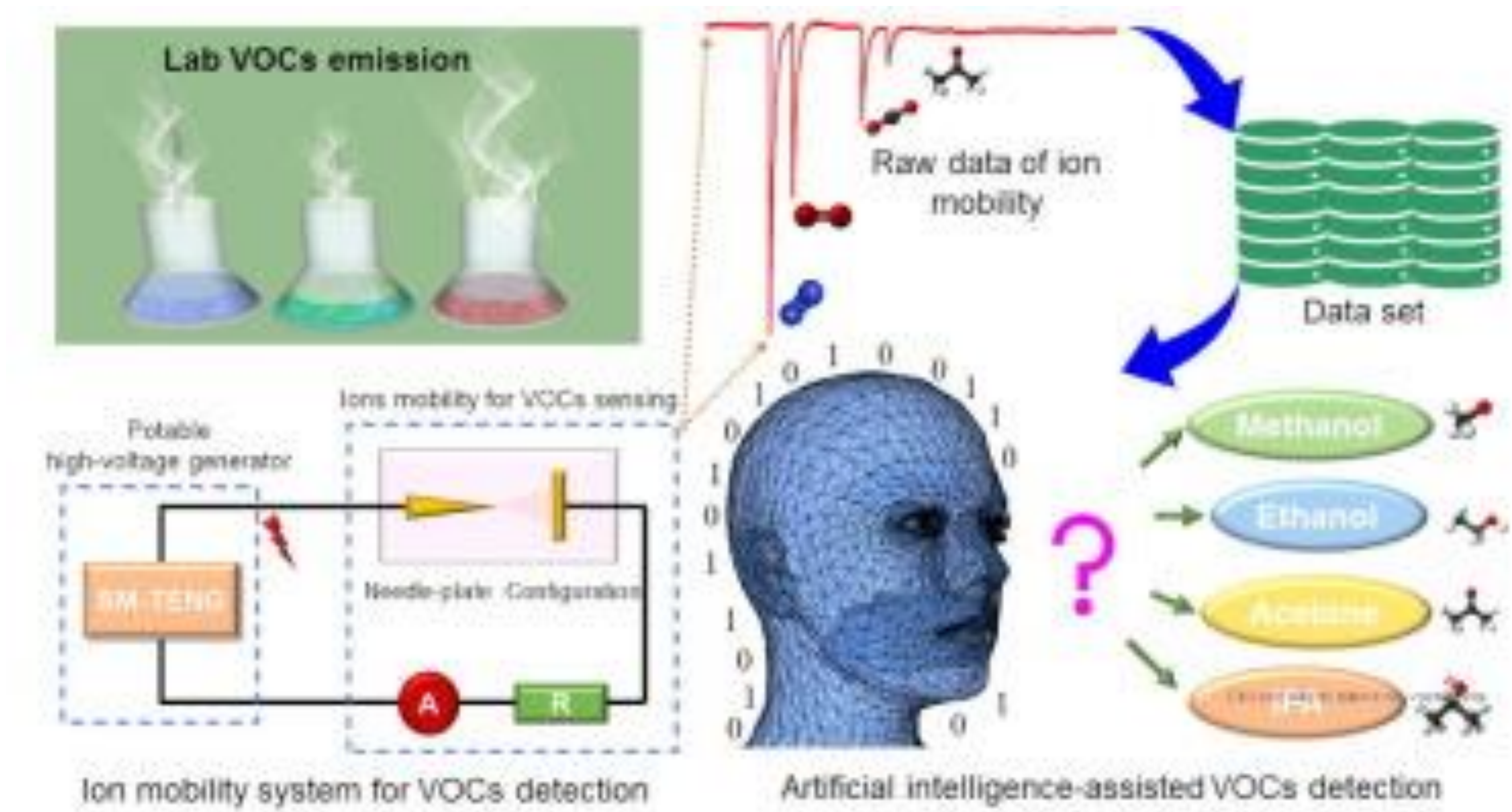
Screen Printed Carbon Electrode
Example- CE(silver), WE (CNT), RE(CNT)

Ascorbic acid sensor using poly aniline

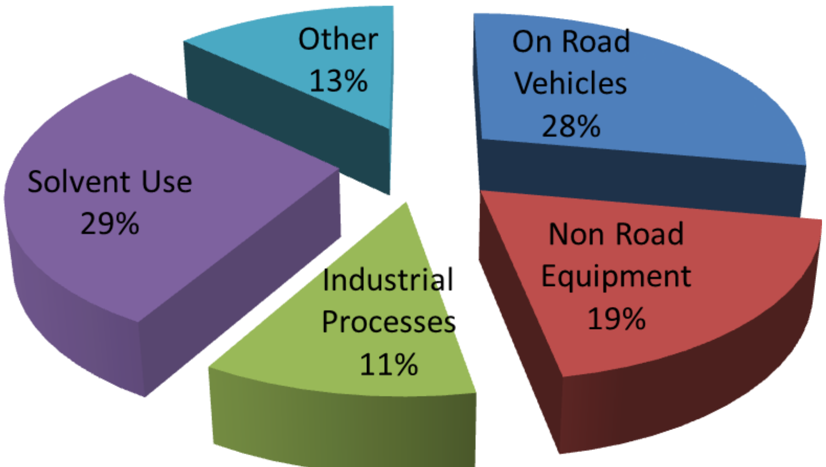


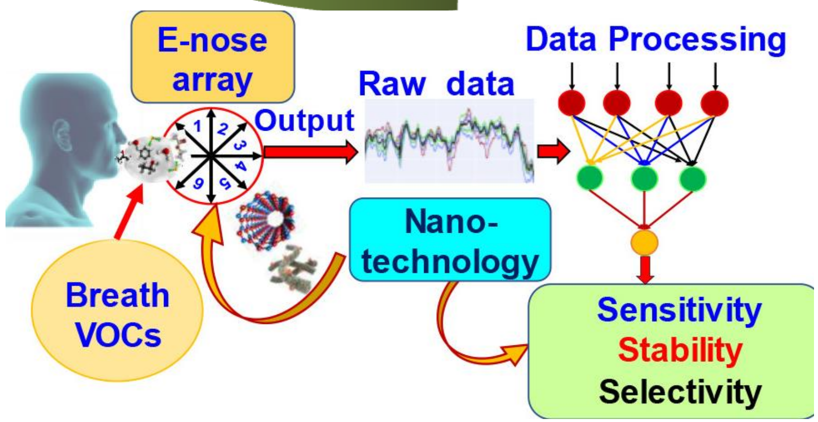


Volatile organic matter detection



Volatile organic matter detection





Furniture	Pesticides
Cosmetics	Adhesives
Laminates	Paint solvents
Detergents	Tobacco smoke
Fabric softeners	Traffic emissions
Air fresheners	Stored Fuels
Plastics	Lubricants
Carpets	Auto Parts
Dyes	Molds

Volatile organic matter detection: Applications

VOC monitoring applications

Environmental monitoring

Typical target compounds:

- BTEX (benzene, toluene, ethylbenzene, xylene)
- Trichloroethylene

Concentration range: ppb to several ppm

Interferents: CO, NO_x, O_3, H_2, other VOC, RH

Indoor Air Quality

Typical target compounds:

- TVOC (total VOC concentration), also CO_2
- Toxic VOC, e.g. benzene, formaldehyde

Concentration range: sub-ppb to several ppm

Interferents: other VOC, RH, CO, NO_x

Fire detection

Typical target compounds:

- Acetic acid, complex VOC cocktail
- also: CO_2, CO, NO_x, H_2

Concentration range: ppb to several 10 ppm

Interferents: other VOC, RH, CO, NO_x, H_2

Odor monitoring

Typical target compounds:

- organosulfur compounds, H_2S
- isovaleric acid, ketones, amines etc.

Concentration range: sub-ppt to ppm

Interferents: other VOC, RH, CO, NO_x, H_2

Industrial applications

Typical applications and target compounds:

- Workplace safety: BTEX
- Emission monitoring: various toxic pollutants

Concentration range: ppb to several 100 ppm

Interferents: CO, NO_x, O_3, H_2, other VOC, RH

Health (disease analysis)

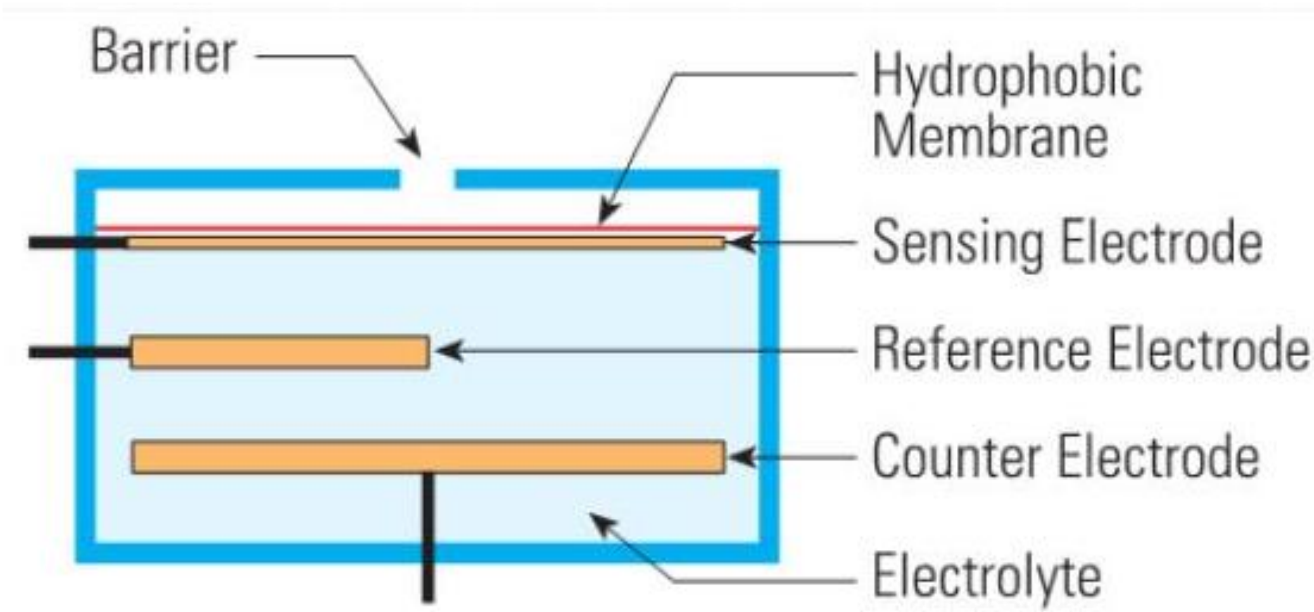
Typical applications and target compounds:

- Diabetes (breath analysis): acetone, isoprene etc.
- Cancer screening: complex VOC cocktail

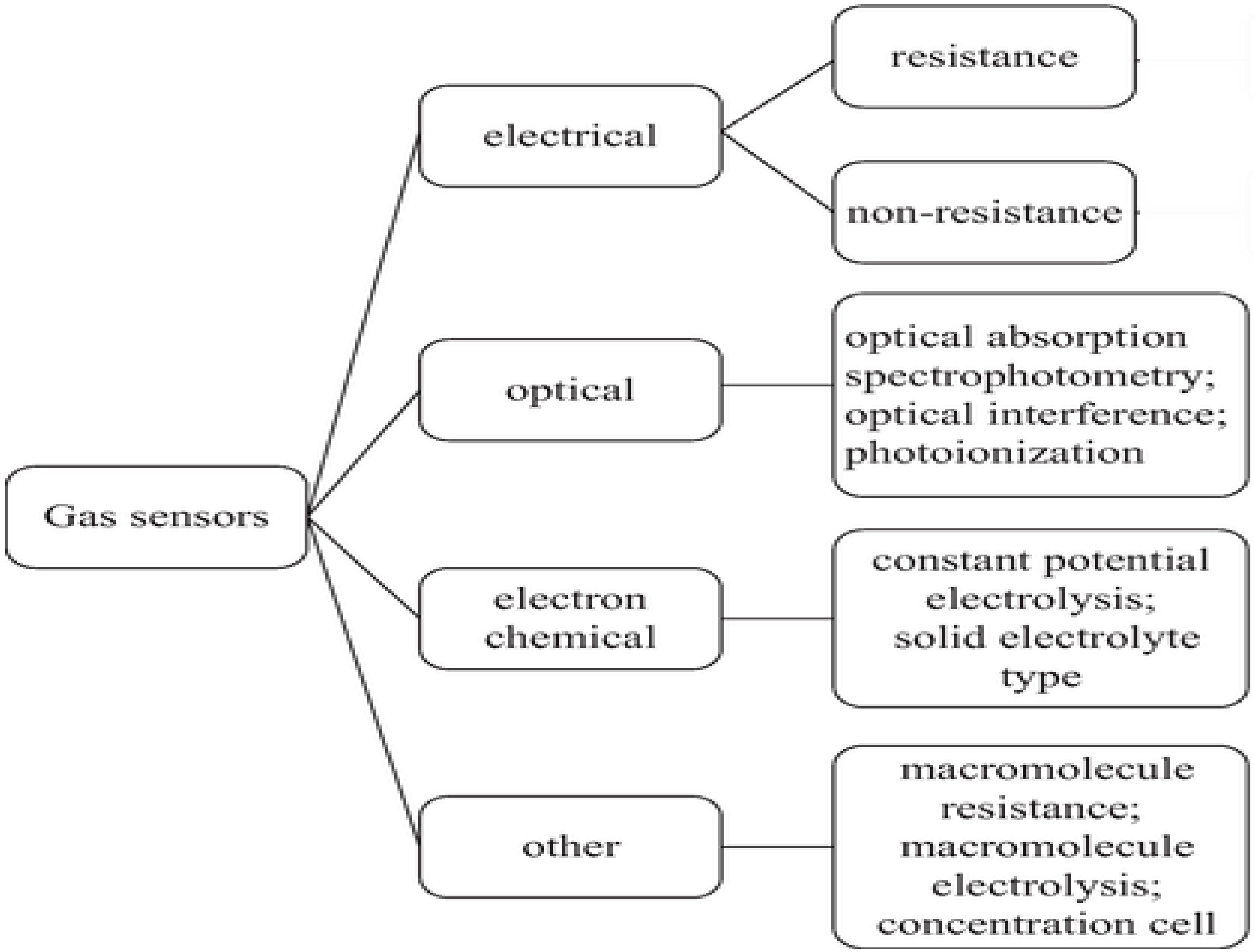
Concentration range: sub-ppb to several ppm

Interferents: CO, NO, H_2, other VOC

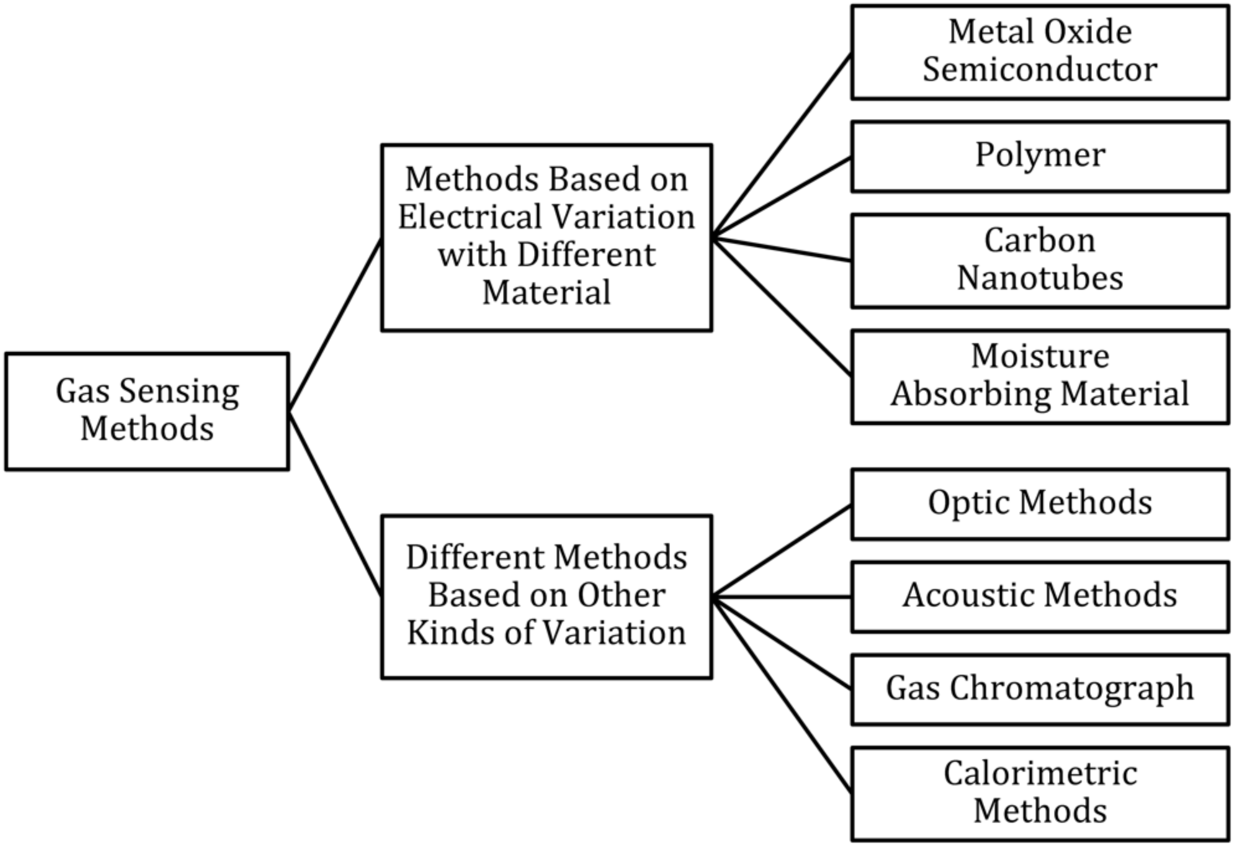
Electrochemical Gas sensors



Electrochemical Gas sensors: Types



Electrochemical Gas sensors: Materials



Chemical reactions involved in gas sensing

[CO]: $CO + H_2O \rightarrow CO_2 + 2H^+ + 2e^-$

[$\mathbf{H_2S}$]: $H_2S + 4H_2O \rightarrow H_2SO_4 + 8H^+ + 8e^-$

[**NO**]: $NO + 2H_2O \rightarrow HNO_3 + 3H^+ + 3e^-$

[$\mathbf{H_2}$]: $H_2 \rightarrow 2H^+ + 2e^-$

[**HCN**]: $2HCN + Au \rightarrow HAu(CN)_2 + H^+ + e^-$

[$\mathbf{O_2}$]: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

[$\mathbf{NO_2}$]: $NO_2 + 2H^+ + 2e^- \rightarrow NO + H_2O$

[$\mathbf{Cl_2}$]: $Cl_2 + 2H^+ + 2e^- \rightarrow 2HCl$

[$\mathbf{O_3}$]: $O_3 + 2H^+ + 2e^- \rightarrow O_2 + H_2O$

Electrochemical Gas sensors: Applications

- Process control industries
- Environmental monitoring
- Boiler control
- Fire detection
- Alcohol breath tests
- Detection of harmful gases in mines
- Home safety
- Grading of agro-products like coffee and spices

THANK YOU

Glucose sensor