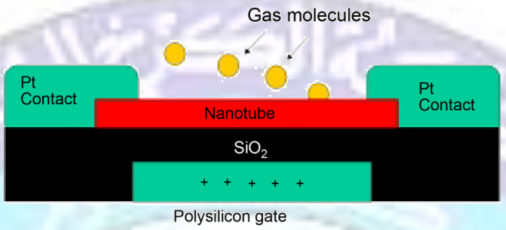
Nanomaterials

2nd year Medical Physics

Lecturer: Dr. Ghaiath A. Fadhil

Lecture 7: Nanosensors



Contents

7.1 Introduction

Sensors are devices that convert information in the form of variations of energy, such as thermal, mechanical, optical, electrical, magnetic, or biochemical into another form of energy.

For example, the information about the kinetic energy in a vehicle could be revealed by the increase of temperature due to the heat released by a disk brake.

Sensors are important to monitor and receive information about the environment surrounding us and to alarm us about specific changes.

A **nanosensor** is a physical, biological, or chemical sensor that is built on the atomic scale in measurements of nanometres (i.e., 10^{-9} m) used to send information about nanoparticles to the macroscopic world. This means a nanosensor can be 3D, 2D or 1D nanomaterial.

Generally, **a nanosensor** is defined as a sensor fulfilling at least one of the three following **requirements**:

- The sensitivity of the sensor is on the nanoscale (e.g., displacements on the nanometre scale, force of the order of nanonewtons, power sensors of the order of nanowatts).
- The interaction of the sensor with the object is on the nanometre scale.
- The size of the sensor is on the nanometre scale.

Nanosensors have noticed great advancements in the development of nanosensors for many different applications within medical, national security, aerospace and integrated circuits fields.

7.2 The benefits of nanoscale to sensors

Engineered nanoscale materials have **benefited** the field of sensors in many aspects, namely:

1- Nanomaterials demonstrate many unique and desirable physical properties for new sensors such as increased reactivity, optical absorption, catalytic efficiency, electrical conductivity, wear resistance, strength, and magnetic properties in comparison to bulk matter of the same composition.
2- Smaller size and lighter weight.
3- Larger reactive surface area.
4- Improved sensitivity.
5- Improved response times.

For example, a single-walled carbon nanotube has a surface area of 1600 m^2/g, which means that just 4 g of nanotubes have approximately the same surface area of a football field!

The larger surface area provides a great advantage to nanosensors that is represented in the increase in signal intensity allowing the detection of trace amounts (low amounts).

7.3 Types of nanosensors

Nanosensors can be classified according to their main field of performance into the following:

7.3.1 Chemical sensors

Generally, chemical sensors are used to detect very small amounts of chemical vapours.

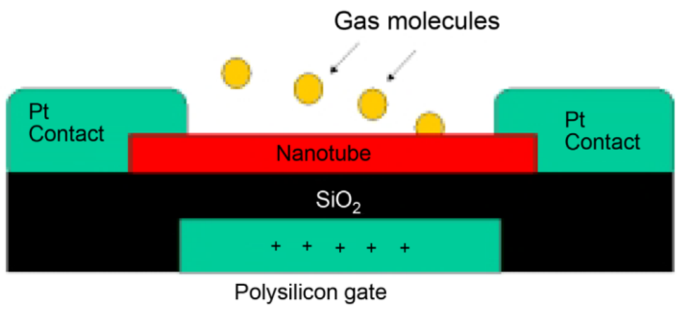
A chemical sensor uses capacitive readout cantilevers and electronics to analyse a transmitted signal. This sensor is sensitive enough to detect a single chemical or biological molecule.

Different types of detection elements can be used as chemical sensors, such as:

- Carbon nanotubes.
- Zinc oxide nanowires.
- Palladium nanoparticles.

These detection elements change their electrical characteristics, such as resistance or capacitance once they absorb a gas molecule.

Due to the small size of the detection elements, only a few gas molecules are sufficient to change the electrical properties of the sensing elements allowing for high sensitivity and selectivity.

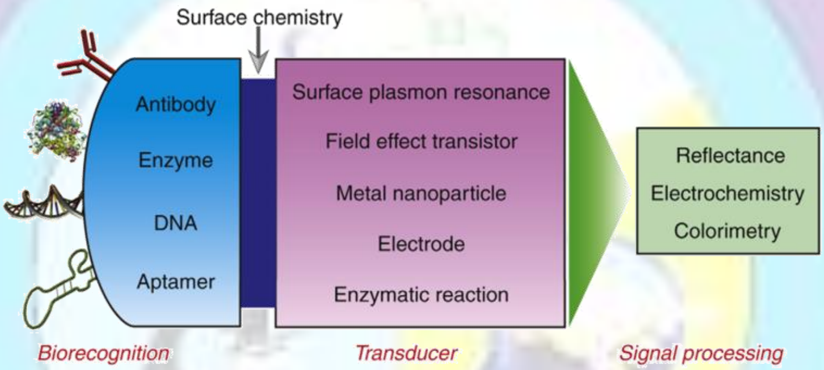


An image of a nanotube-based chemical sensor

7.3.2 Biosensors

The main components of a biosensor consist of:

1- A biological element (bioreceptor)
2- A physiochemical transducer
3- A detector (signal processing)



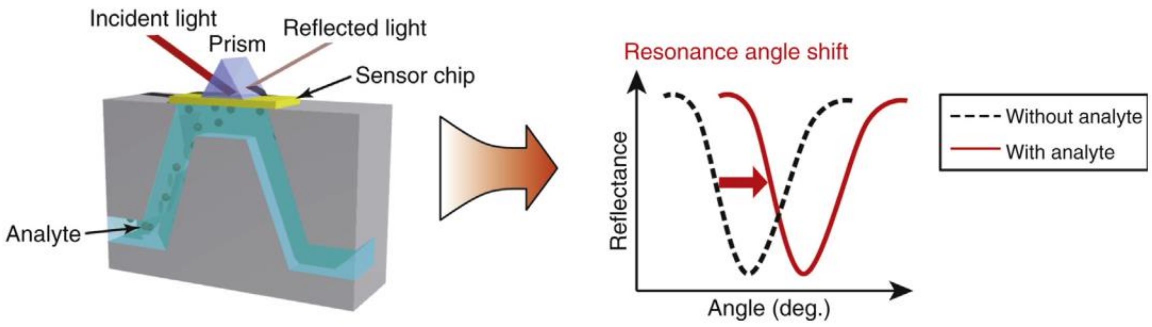
The field of biosensors is one of the largest funded areas of research in nanosensors.

This is due to all the potential applications that this technology could lead to, such as:

- Early cancer detection
- Detection of various types of diseases
- Detection of specific types of DNA.

The data is then converted to measurable units and transferred to a display or data storage device.

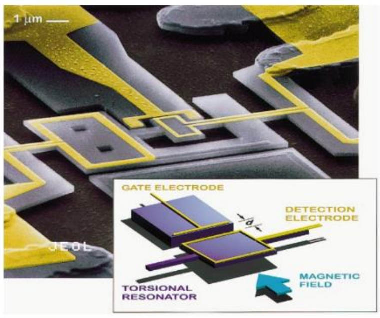
The nanobiosensor can work on several principles of detection, physical, electrochemical, optical, or calorimetric.



7.3.3 Nanoelectrometer

A nanoscale electrometer is a nanometre-scale mechanical electrometer, which is used to couple charge to the mechanical element.

An example of an electrometer sensor is shown in the figure on right.



7.3.4 Multianalyte sensor arrays

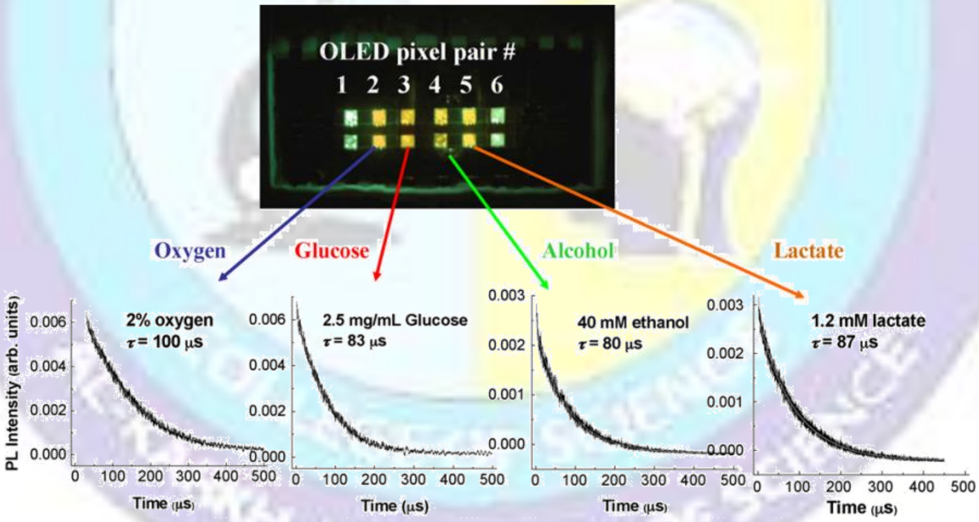
Most traditional chemical sensors are designed to detect a single chemical species.

Nanosensor arrays improve on this not only by detecting the target chemical, but also distinguishing between multiple chemical species in a sample stream.

This technology has allowed for vast improvements of real-time chemical monitoring and disease identification.

Because nanosensors are so small, an array of sensors—potentially hundreds or thousands—could all be used within a single device, known as ‘sensor chips’.

These are essentially a mix of nanowires and nanotubes with different coatings or functional groups.



A sensor array

When a nanosensor array is exposed to a sample, the device can generate a unique fingerprint based on the responses of the individual nanosensors as shown in the figure below.

7.4 Applications of nanosensors

7.4.1 Medicine

Nanosensors are particularly interesting to the medical field because they enable early detection of various diseases. Examples of the diagnostic processes are:

- Early breath detection where the human breath is analysed to detect different types of gases that have been shown to announce the presence of certain types of diseases.
- Nanosensors also have the ability to detect early stages of cancer, which would increase the chance of patient survival.
- The use of nanosensors to detect mitosis and cell atrophy has the potential effect for cell immortality.
- Nanosensors allow for the continuous detection of glucose, ultimately increasing the living capabilities of patients with diabetes.

7.4.2 Security

Nanosensors has the ability to detect harmful chemical and biological constituents in the atmosphere.

In addition, the ability to detect trace amounts of explosives such as trinitrotoluene (TNT) by the use of nanosensors is a prime example of how the nanosensors can be used for preventative security measures.

7.4.3 Environment

Nanosensors has the ability to sense for chemicals and biological agents that pollutes air and water.

7.4.4 Industrial

Nanosensors also have useful applications in the industrial field. One of the most prominent applications is the ability to detect various industrial gas leaks.