(10.524) Nanostructures and Biosensors

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Outline

Introduction of Biosensor
Nano-Biosensor
Examples of Nano-Biosensor
Electrochemical Biosensor
Lab Session

Biosensors- commercial products

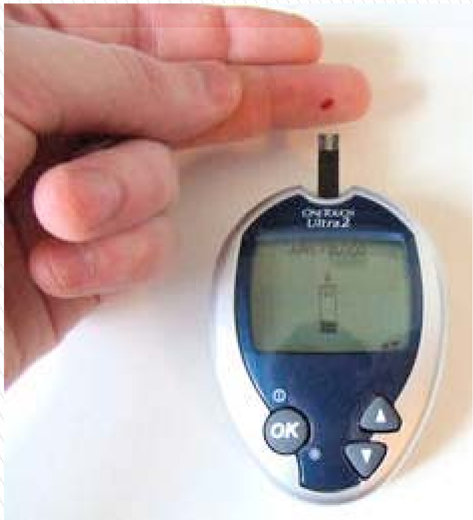
Biosensor

"…a self-contained integrated device which is capable of providing specific quantitative or semi-quantitative analytical information using a biological recognition element which is in direct spatial contact with a transducer element." - IUPAC

or

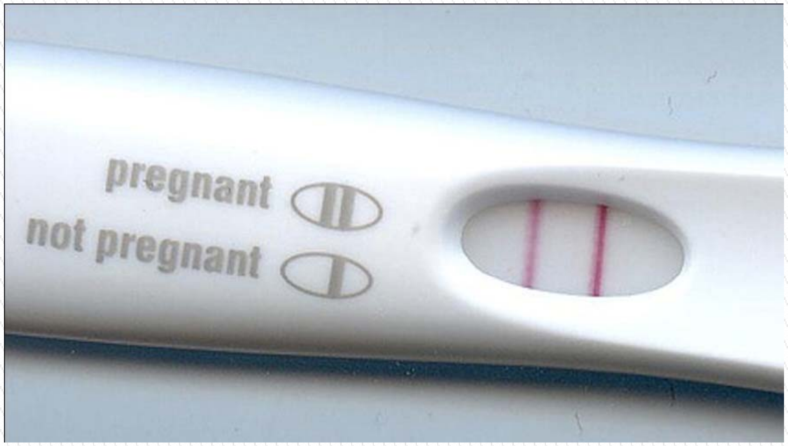
Any analytical device which converts a biological response into a electrical signal.

Diabetes - Glucose Sensor - Blood



Breath alcohol tester

Pregnancy test - Urine



Application of Biosensor

Study of biomolecules and how they interact with one another

- Drug Development
- In- home medical diagnosis
- Environmental field monitoring
- Scientific crime detection
- Quality control in small food factory
- Food Analysis

- Glucose-based on glucose oxidase
- Cholesterol - based on cholesterol oxidase
- Antigen-antibody sensors - toxic substances, pathogenic bacteria
- Small molecules and ions in living things: H^+, K^+, Na^+, NO, CO_2, H_2O_2
- DNA hybridization, sequencing, mutants and damage

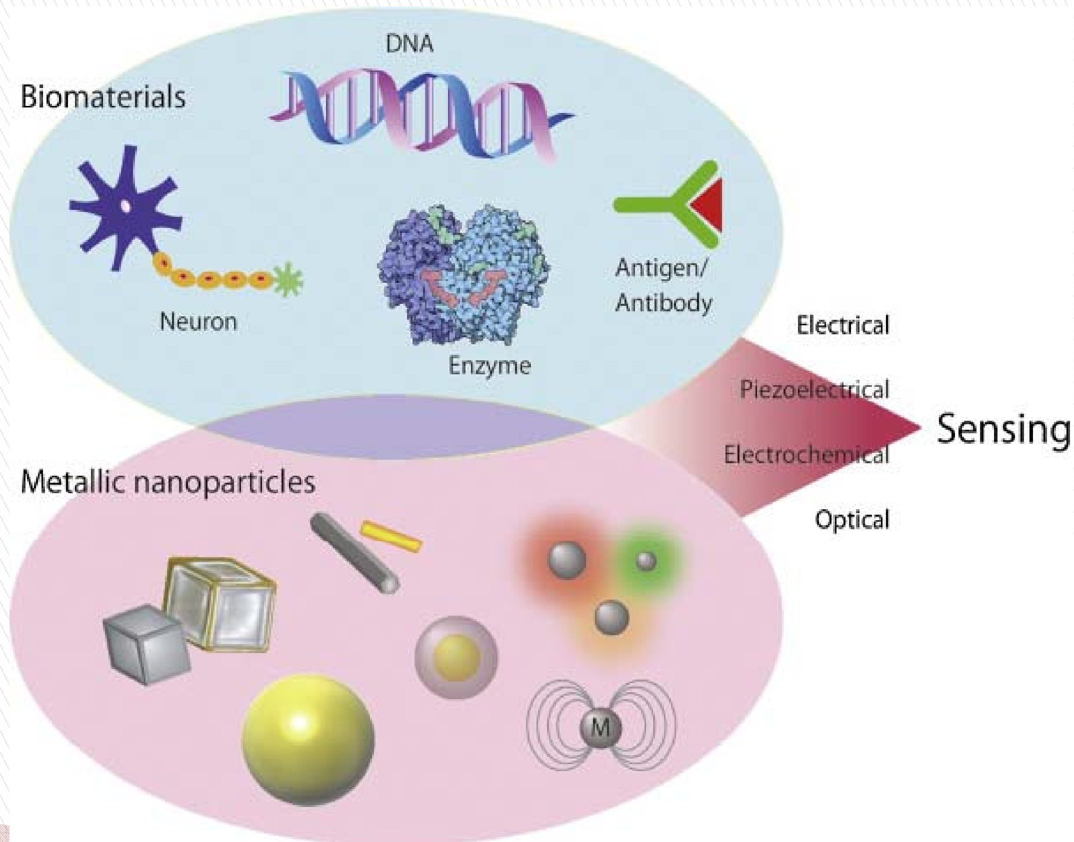
Nanosensors

If I want to measure something small, I need something small…

Introduction to Nanobiosensing

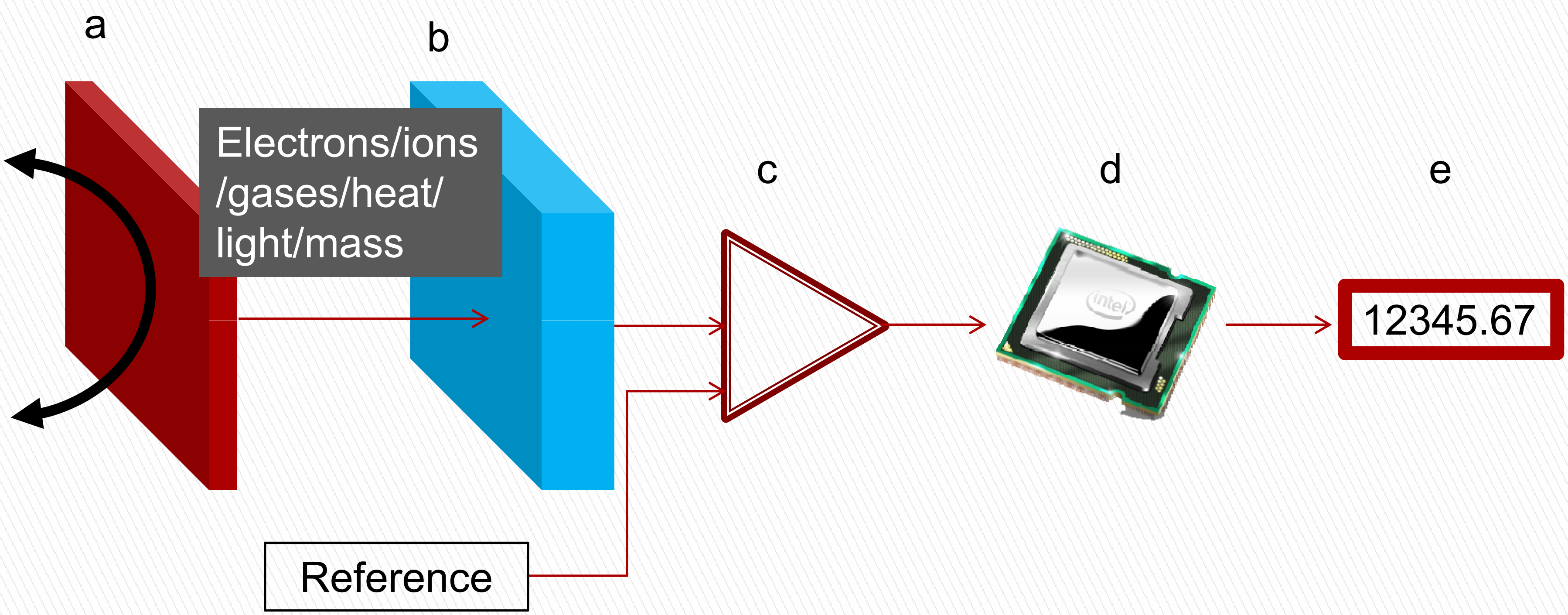
http://www.youtube.com/watch?v=qaFdm6Qj7A4&list=PLC13263D45846876C&index=11

cheaper, faster, and easier-to-use analytical tools



Synthesis and bioanalytical applications of specific-shaped metallic nanostructures: A review

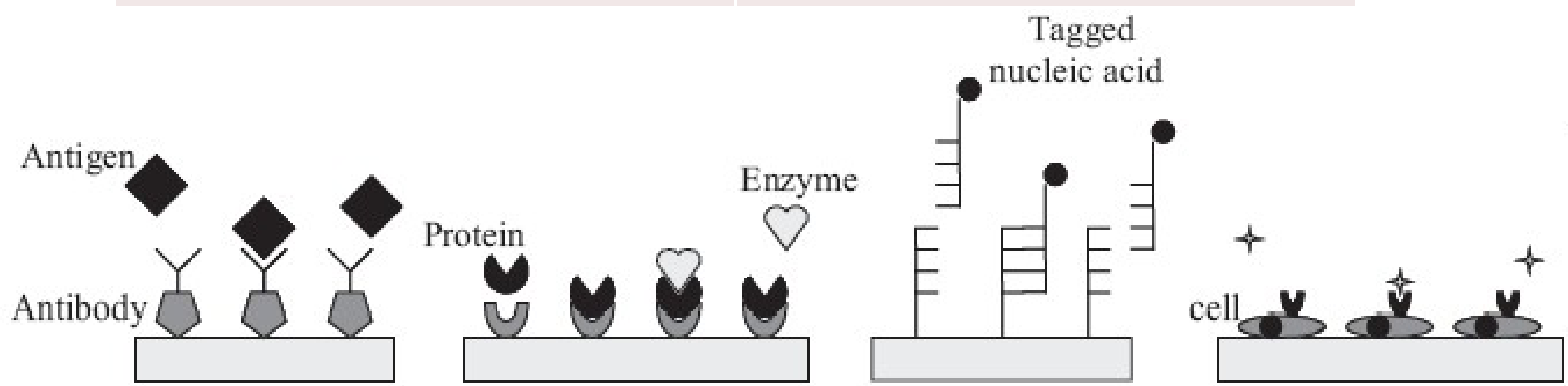
Biosensor Components

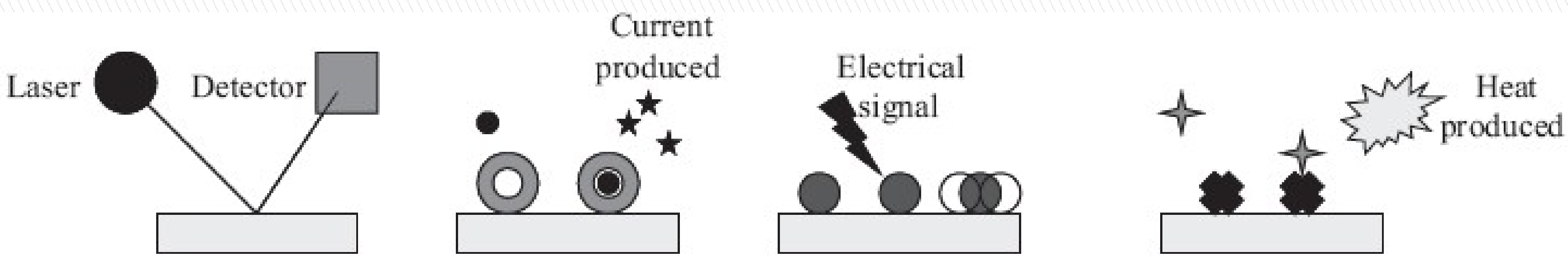


Schematic diagram showing the main components of a biosensor. The bio-reaction (a) converts the substrate to product. This reaction is determined by the ***transducer*** (b) which converts it to an electrical signal. The output from the transducer is amplified (c), processed (d) and displayed (e).

Types of Nanobiosensor

Biological signaling mechanism	Method of Transduction
Antibody/antigen	Optical-detection
Enzymes	Electrochemical
Nucleic acids	Mass-sensitive
Cells and viruses	Thermal detection





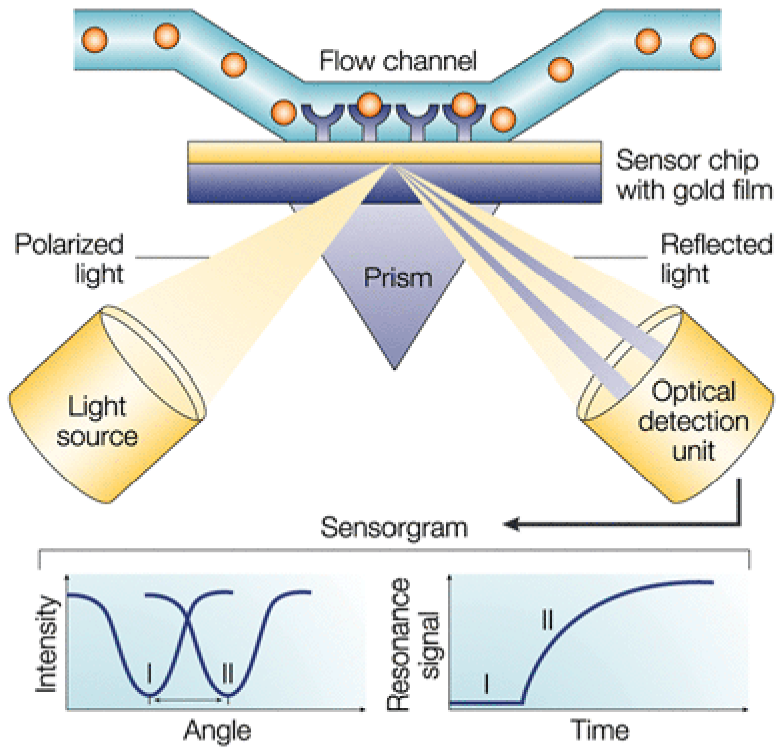
Optical Biosensors

Video (2 min) http://www.youtube.com/watch?v=yEnycUe3mpY

Surface plasmon resonance (SPR) (3 min)

http://www.youtube.com/watch?v=sM-VI3alvAI

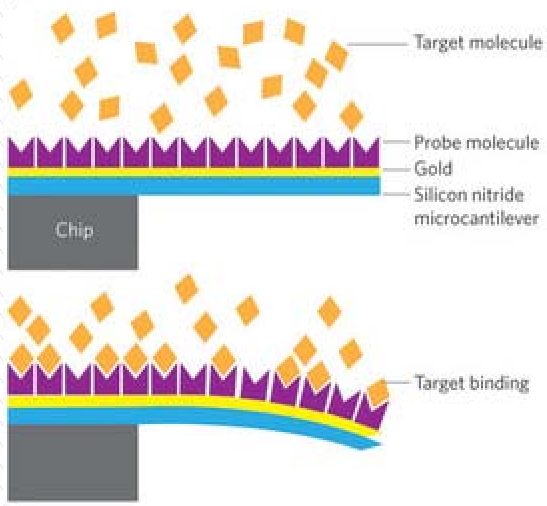
Optical biosensor - A sensor that uses light to detect the effect of a chemical on a biological system.



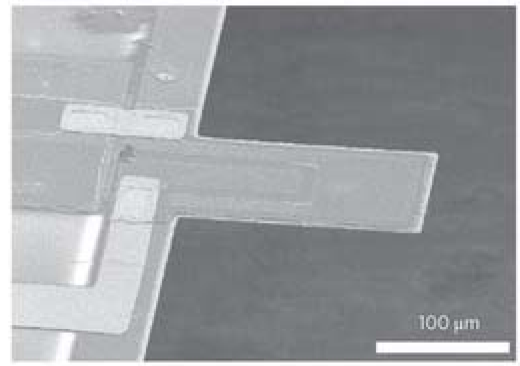
Nature Reviews Drug Discovery **1**, 515-528 (July 2002) | doi:10.1038/nrd838

Mass-sensitive Biosensor

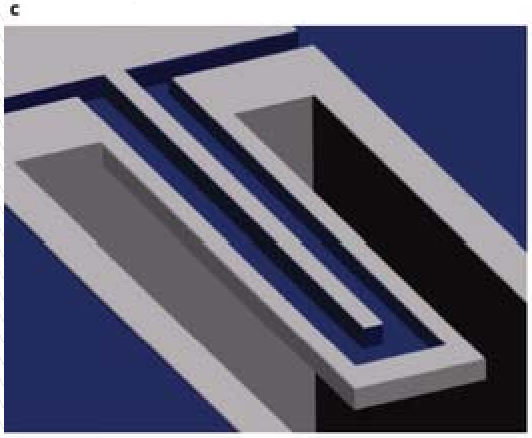
a



b

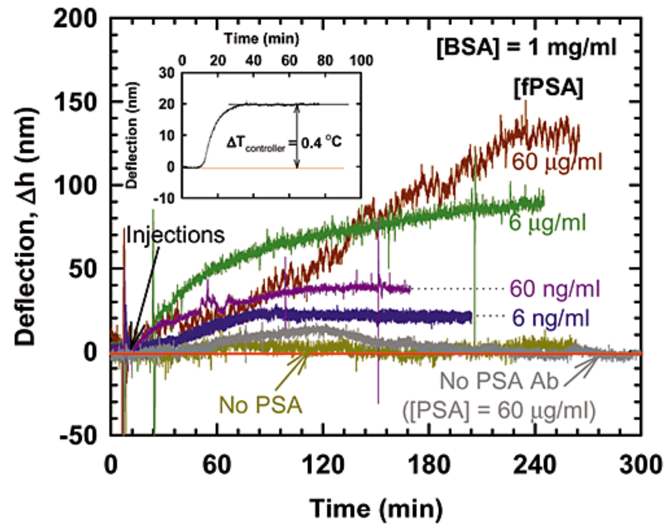


c



molecular detection using a cantilever's bending deflection motion

A



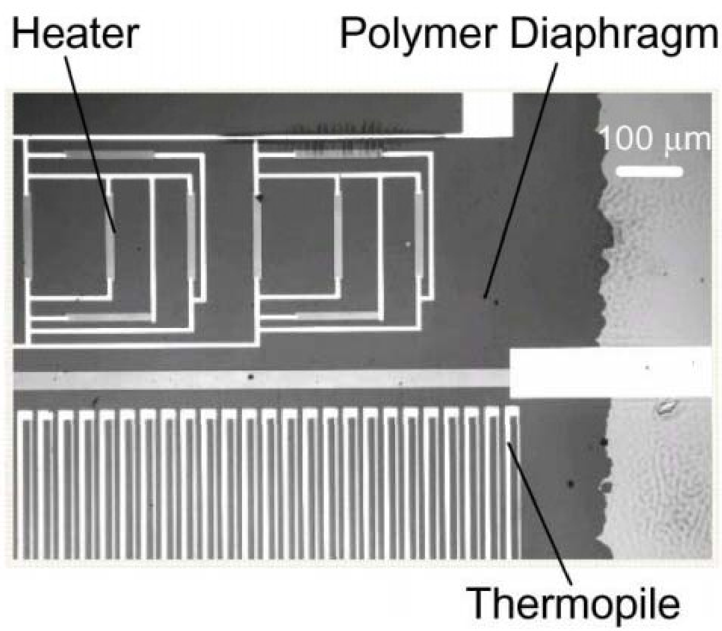
Nature Biotechnology **19**, 856 - 860 (2001) doi:10.1038/nbt0901-856

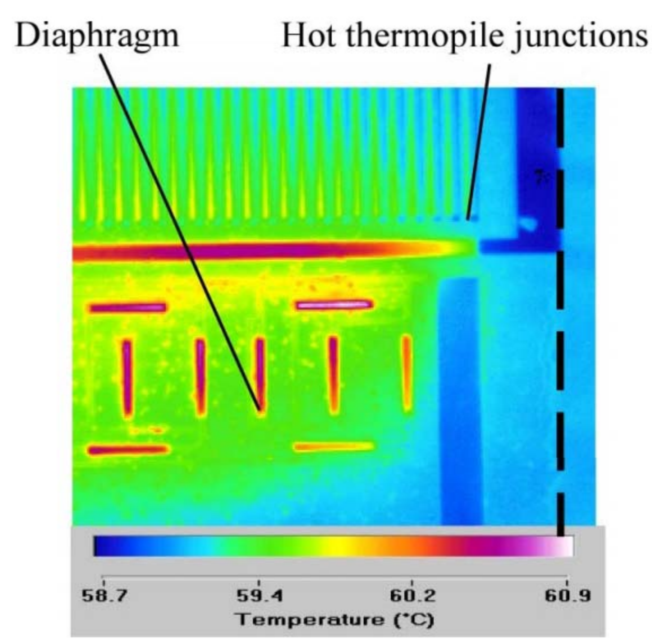
Nature Nanotechnology 6, 203–215 (2011) doi:10.1038/nnano.2011.44

Thermal Biosensors

Thermal biosensors measure thermal energy released or absorbed in biochemical reactions.

Example? Fever → Thermometer

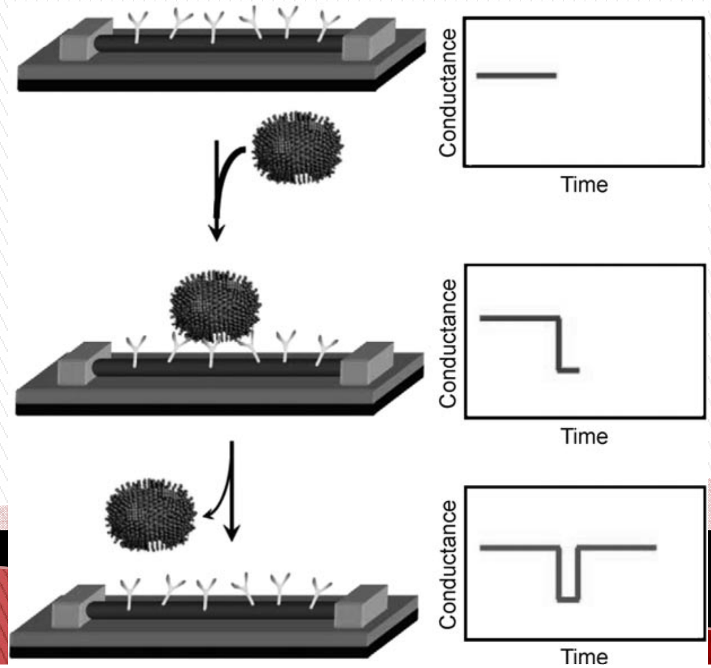




A MEMS Thermal Biosensor for Metabolic Monitoring Applications JOURNAL OF MICROELECTROMECHANICAL SYSTEMS, VOL. 17, NO. 2, APRIL 2008

Examples of Nanostructured Biosensors

Nanoparticle
Nanowire
Nanotube
Graphene

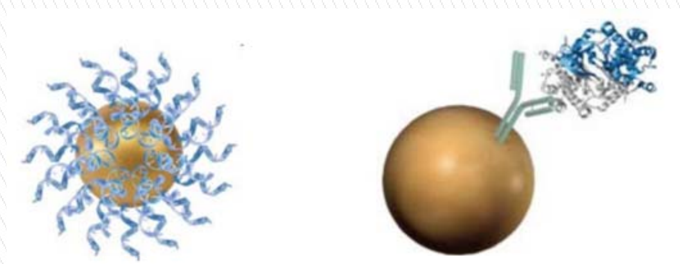


Mechanism of nanowire based biosensors

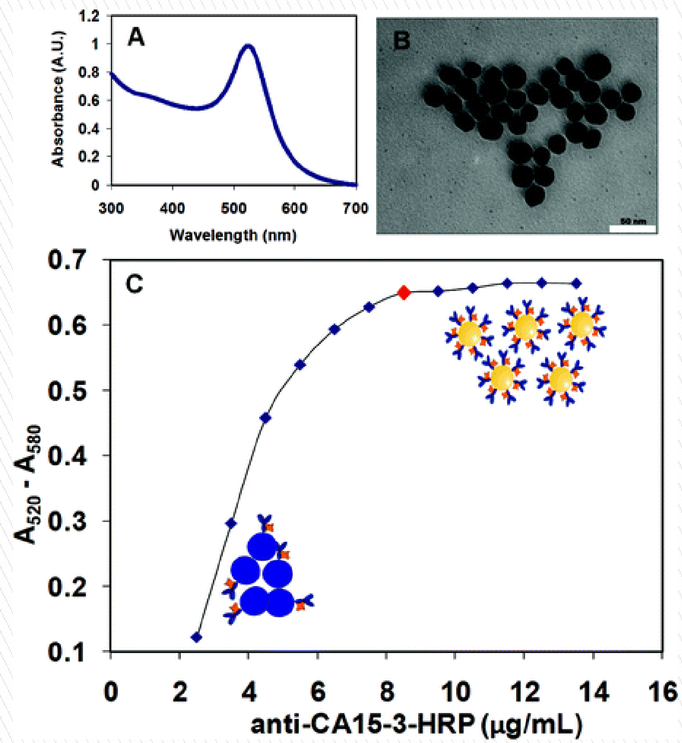
Nanoparticle-Based Biosensor

Nanoparticles are used as new optical and electronic materials due to their interesting electrical, optical, magnetic and catalytic special properties

- Biocompatibility
- Rapid and simple chemical synthesis
- Excellent electroactivity
- Efficient coating by biomolecules



Enhanced Gold Nanoparticle for a Breast Cancer Biomarker

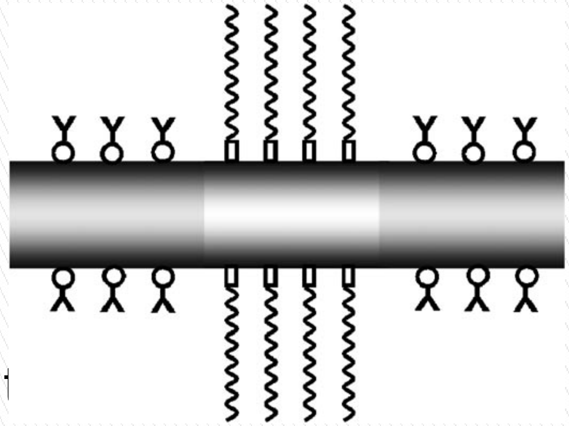


(A) UV−vis spectrum and (B) transmission electron micrographs of AuNPs; (C) gold aggregation test performed to evaluate the charging of AuNPs with anti-CA15-3−HRP antibody.

Anal. Chem., **2010**, *82* (3), pp 1151–1156

Nanowire-based Biosensor

Video of “nanowire biosensor”: (optional)
http://www.youtube.com/watch?v=CcIWEkf_FWs



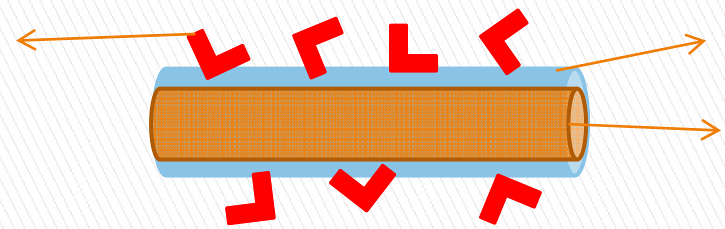
Advantages

- 1-D structure: high aspect ratio →highly sensit
- Different materials: metal, semiconductor, polymers, metal oxides→ selectivity

  For example: Au - alkyl thiols
  Ni - histidine
  Pt – isocyanides

- Different types: Single-segment Nanowire / Multi-segment Nanowires
- Easily assembled to hybrid system or device→ FET

Nanowire Functionalization



- Chemical treatment / Surface modification

Covalent functionalization is a chemical process in which a strong bond is formed between the 1-D nanostructured material and the biological molecule or its linkers.
e.g. Au-Ni nanowire

Au→alkanethiols with terminal hexa(ethylene glycol) groups (EG6)

Ni→ palmitic

Exposed to a fluorescently tagged protein

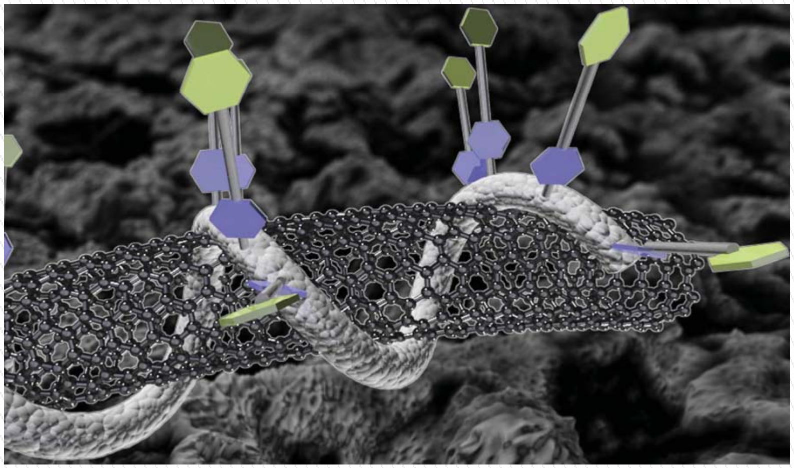
Ni (hydrophobic) wires →bright fluorescence

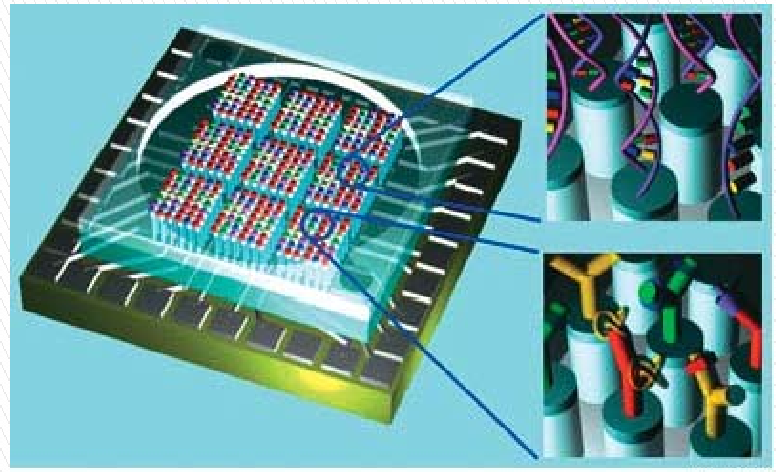
Au (EG6) → None

Proteins selectively adsorbed to one portion of these multi-component nanostructures

- Enzyme-functionalized nanowires
- DNA coated

Carbon Nanotube-Based Biosensor





Disadvantages of CNT

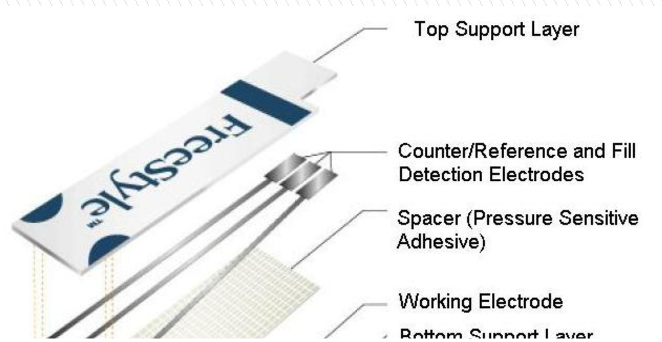
Molecular level structure will be easily changed when modified the surface by chemical which may weak the original properties.

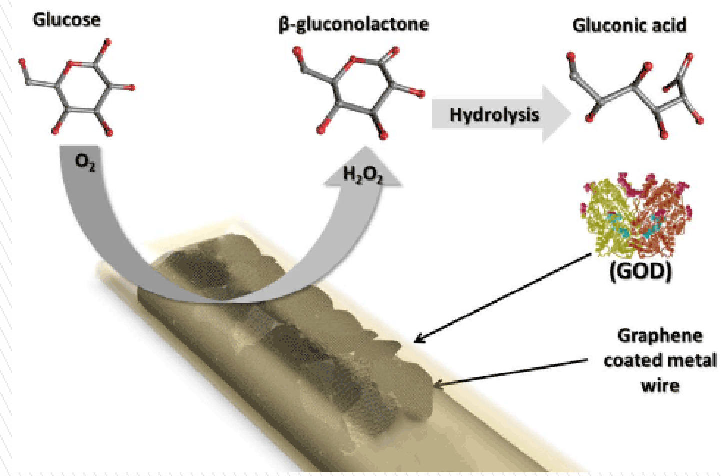
Insolubility in water

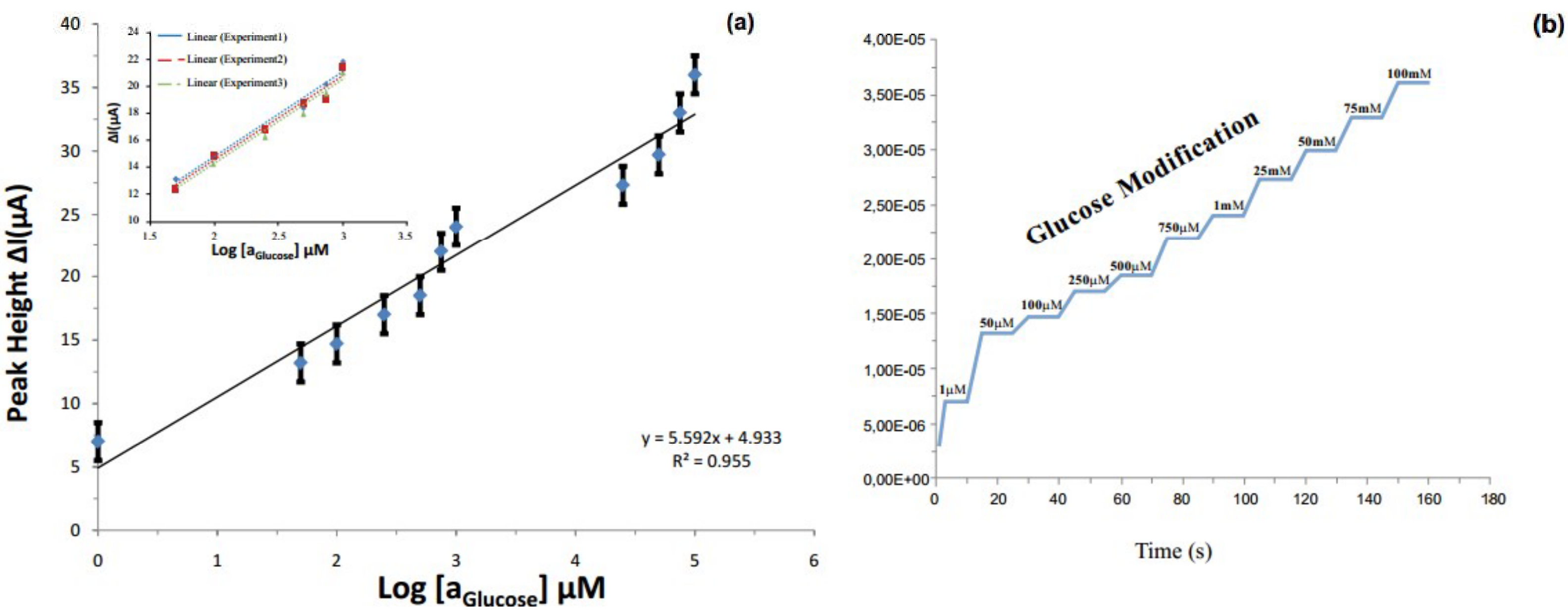
http://www.kurzweilai.net/new-biosensor-melds-c ... notubes-dna

http://www.sensorsmag.com/sensors/chemical-gas/nanotechnology-enabled-sensors-possibilities-realities-and-a-1074

Graphene Biosensor







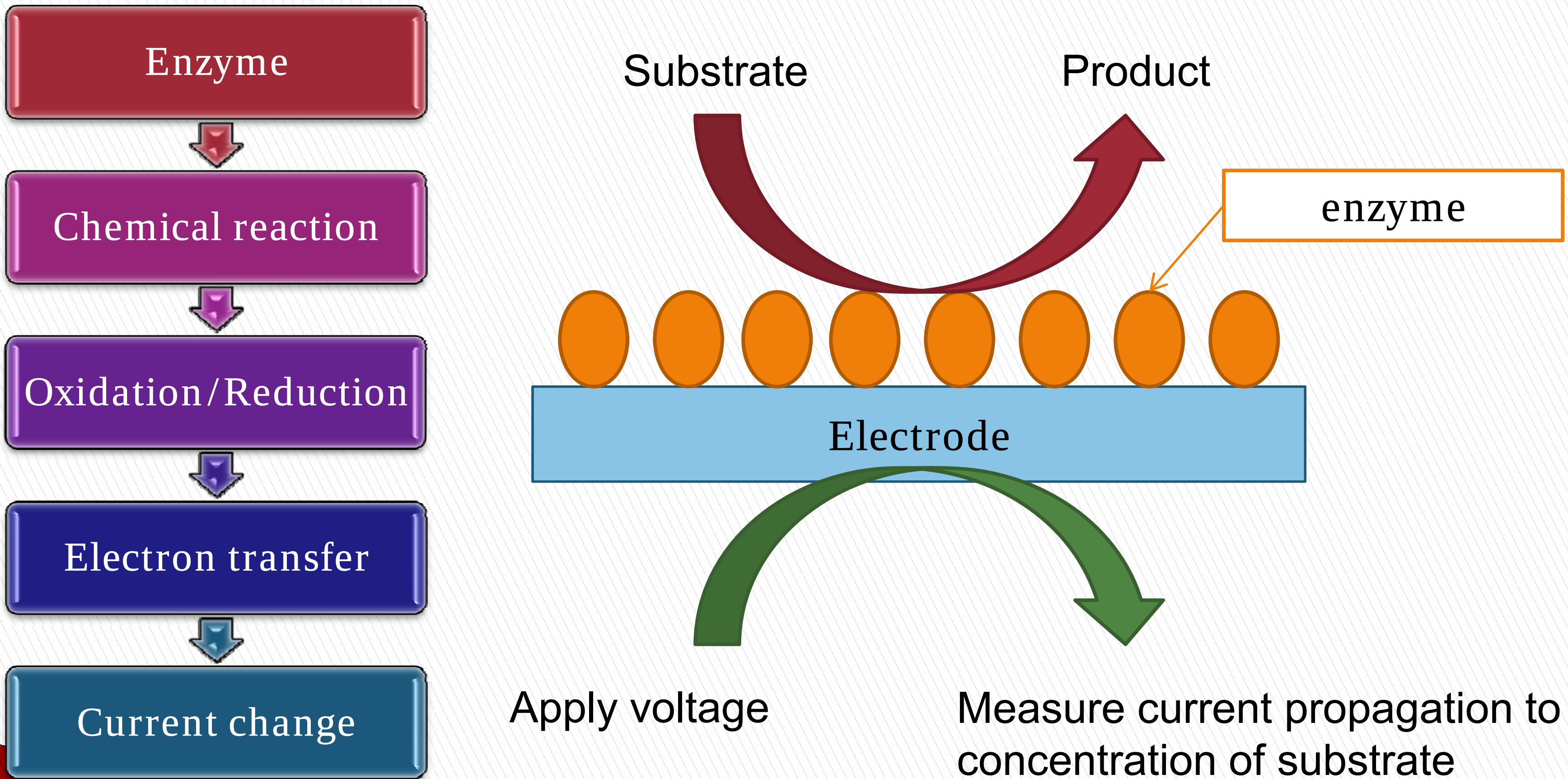
(a) Typical amperometric response at the GOD immobilized graphene decorated electrode versus glucose concentration, (b)The amperometric response versus time as the glucose concentration is modified surrounding the graphene decorated electrode.

ul Hasani et al. J Biosens Bioelectron 2012, 3:1
http://dx.doi.org/10.4172/2155-6210.1000114

Electrochemical Nano-Biosensors

Electrochemical Biosensor

Electrochemical biosensors combine the sensitivity of electroanalytical methods with the inherent bioselectivity of the biological component.



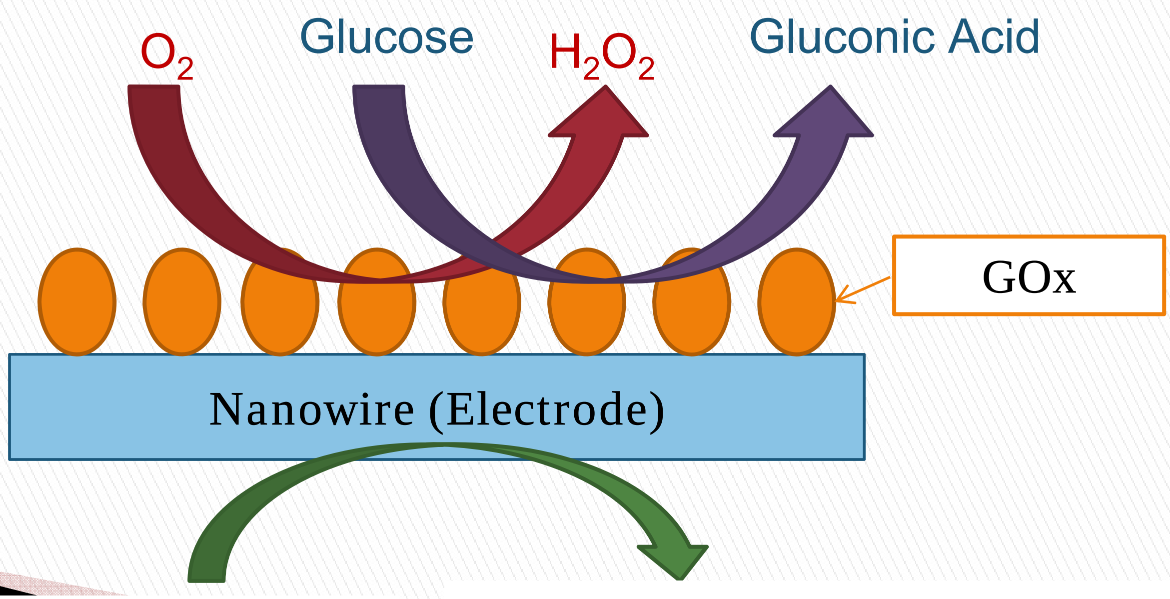
Glucose Sensor

Biggest biosensor success story!

Glucose oxidase (enzyme)

$$\text{Glucose} \xrightarrow{\text{GOx}} \text{Gluconic Acid} + e^-$$

$$O_2 + H_2O + e^- \longrightarrow H_2O_2$$

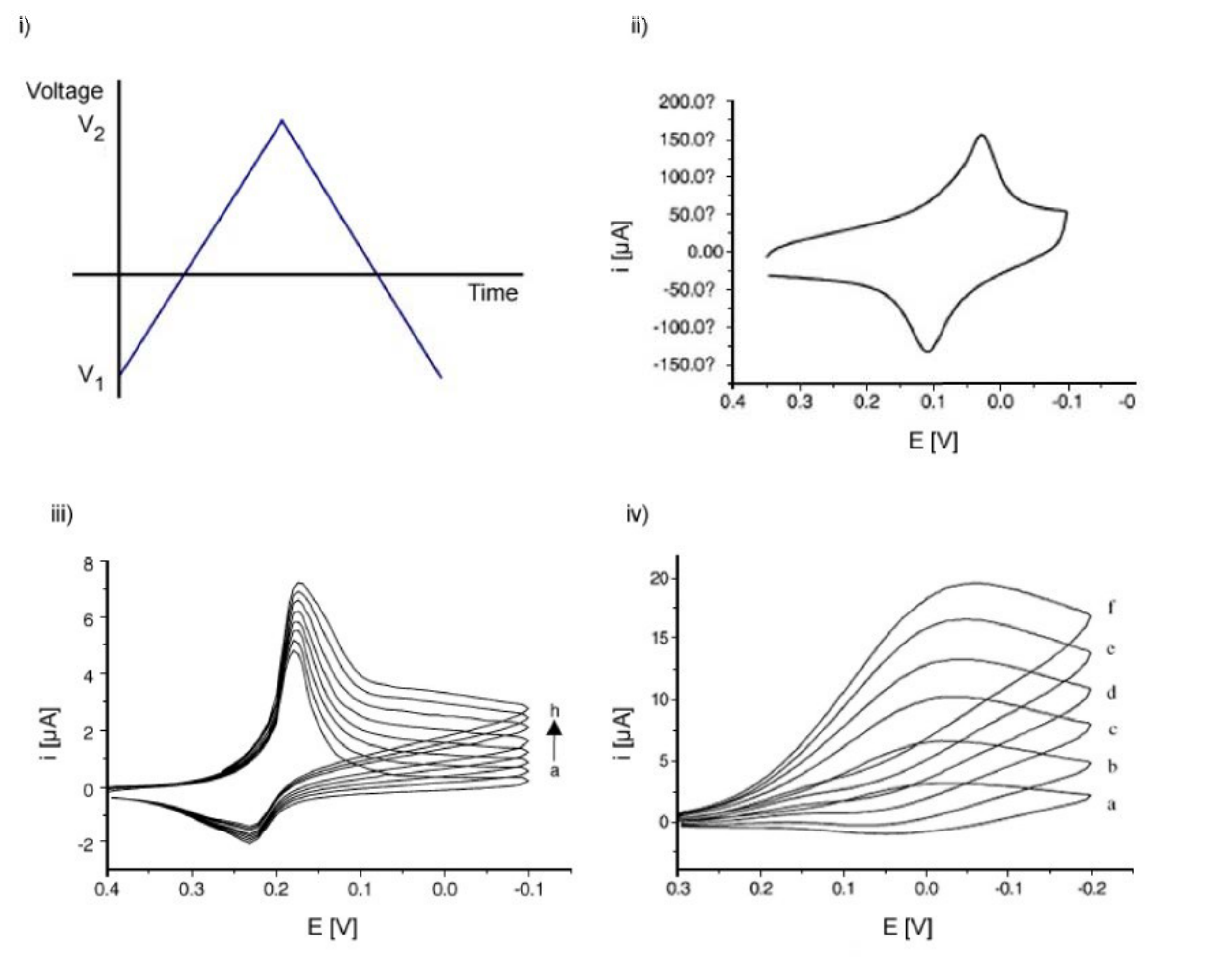


Apply voltage

Measure current propagation to concentration of substrate

Electrochemical Biosensor

How to read those electrochemical signals?



Lab Session

Pt Nanowire Functionalized Glassy Carbon Electrode towards Sensing of H_2O_2

Basic Characteristics of a Biosensor

1. Linearity: Maximum linear value of the sensor calibration curve. Linearity of the sensor must be high for the detection of high substrate concentration.

2. Sensitivity: The value of the electrode response per substrate concentration.

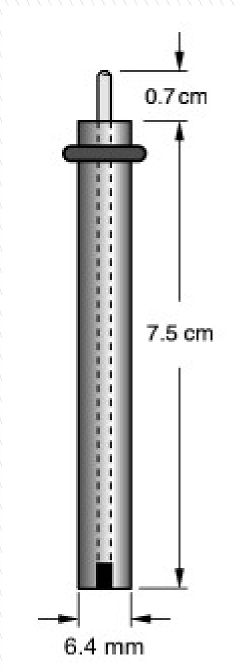
3. Selectivity: Interference of chemicals must be minimized for obtaining the correct result.

4. Response time: The necessary time for having 95% of the response.

Motivation

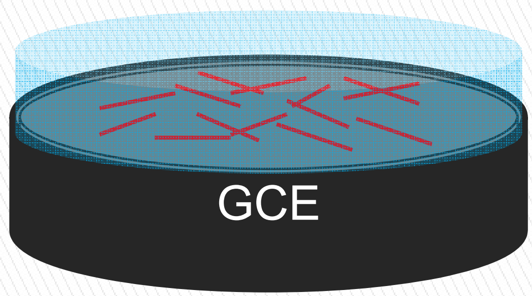
- Develop a biosensor with increased sensitivity and selectivity
- Fast, accurate, reproducible, and low cost
- Use of nanowires have the potential to increase sesitivity and selectivity of sensors
  - Catalysts for reaction property

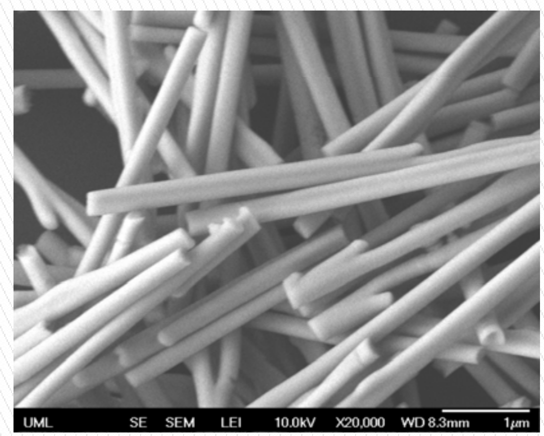
Electrode Preparation



Glassy Carbon Electrode (GCE) - is a non-graphitizing carbon which combines glassy and ceramic properties with those of graphite

Pt Nanowire- was fabricated through electrodeposition method



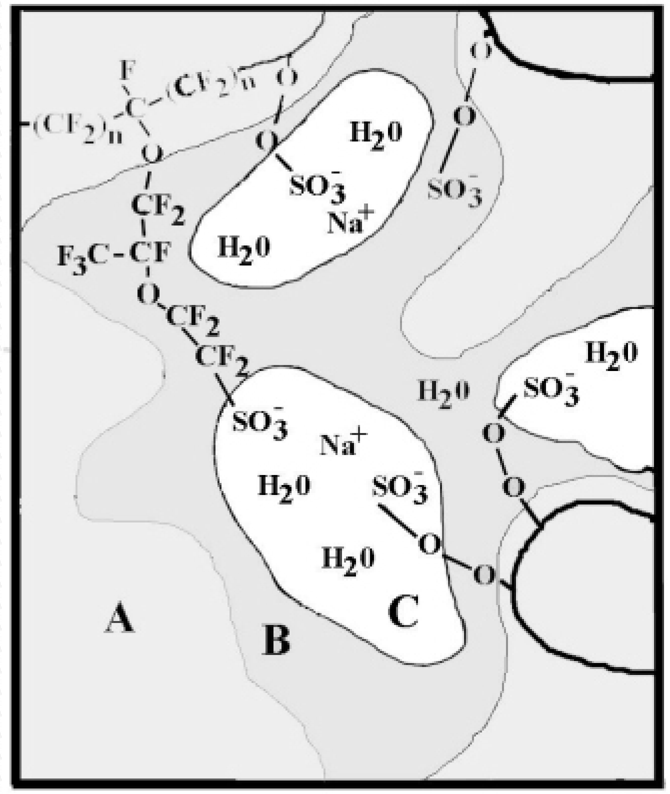


Nafion

Nafion films have been used extensively for the construction of amperometric biosensors

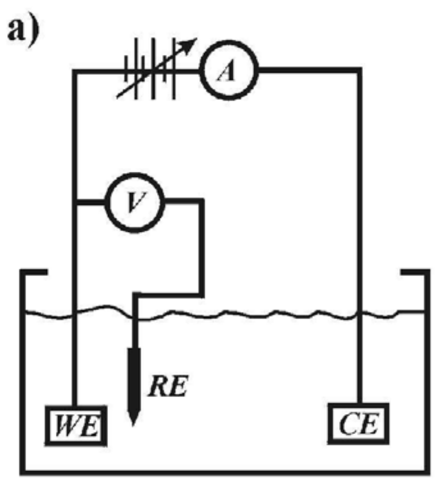
Cation exchange membrane - Pores allow movement of cations but the membranes do not conduct anions or electrons

•Resistant to chemical attack
•High temperatures
•Super acid catalyst



http://www.intellectualism.org/questions/QOTD/dec03/Nafion3.jpg

Experiment Setup

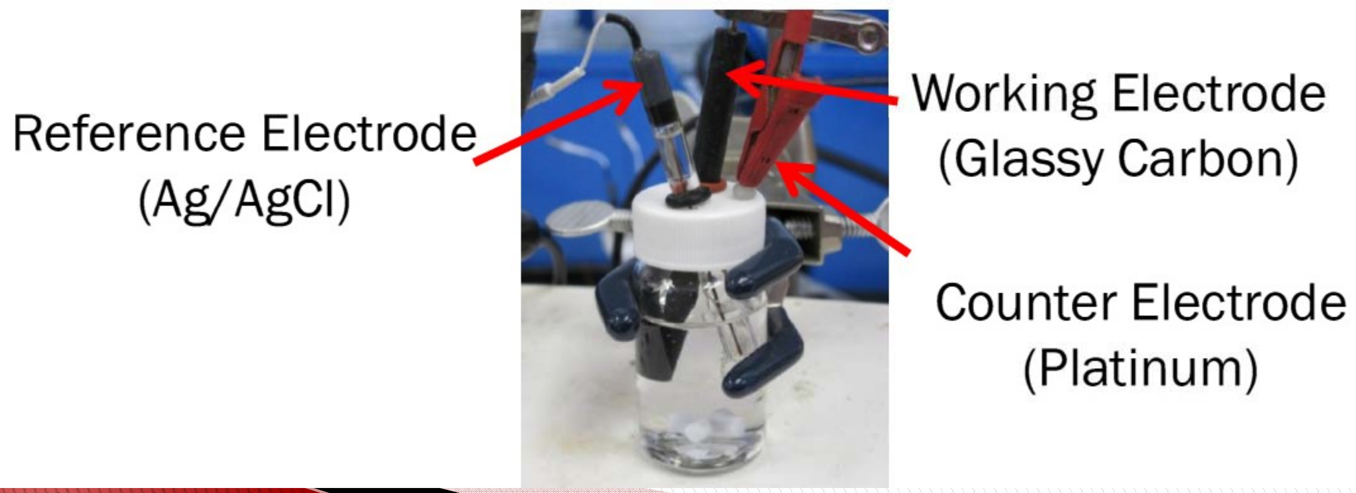


Standard Three-electrode setup

Working electrode (WE) – GCE/Pt NW/Nafion

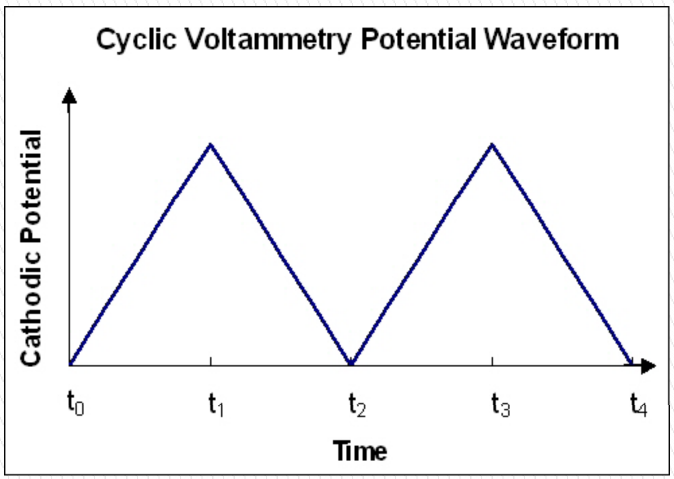
Reference electrode (RE) – Ag/AgCl

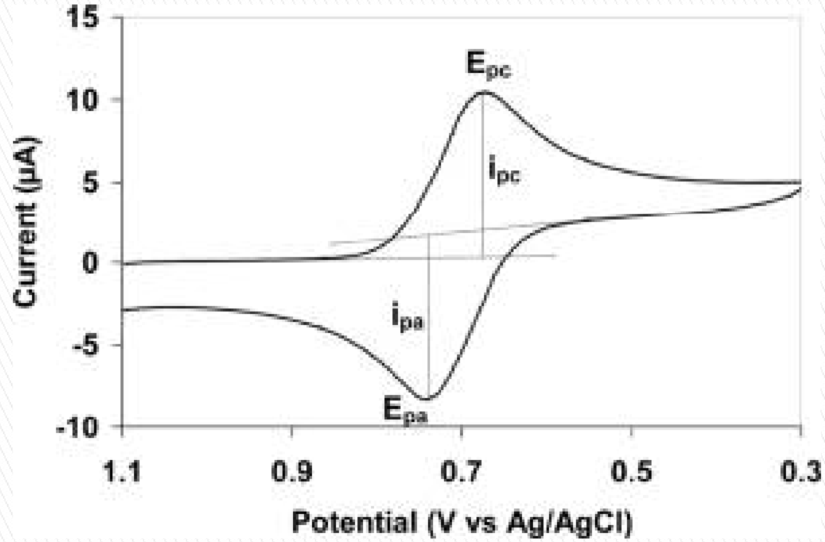
Counter electrode (CE) – Pt wire



Experimental Method: Cyclic Voltammetry

Cyclic voltammetry (CV) is generally used to study the electrochemical properties of an analyte in solution.





The working electrode potential is ramped linearly versus time

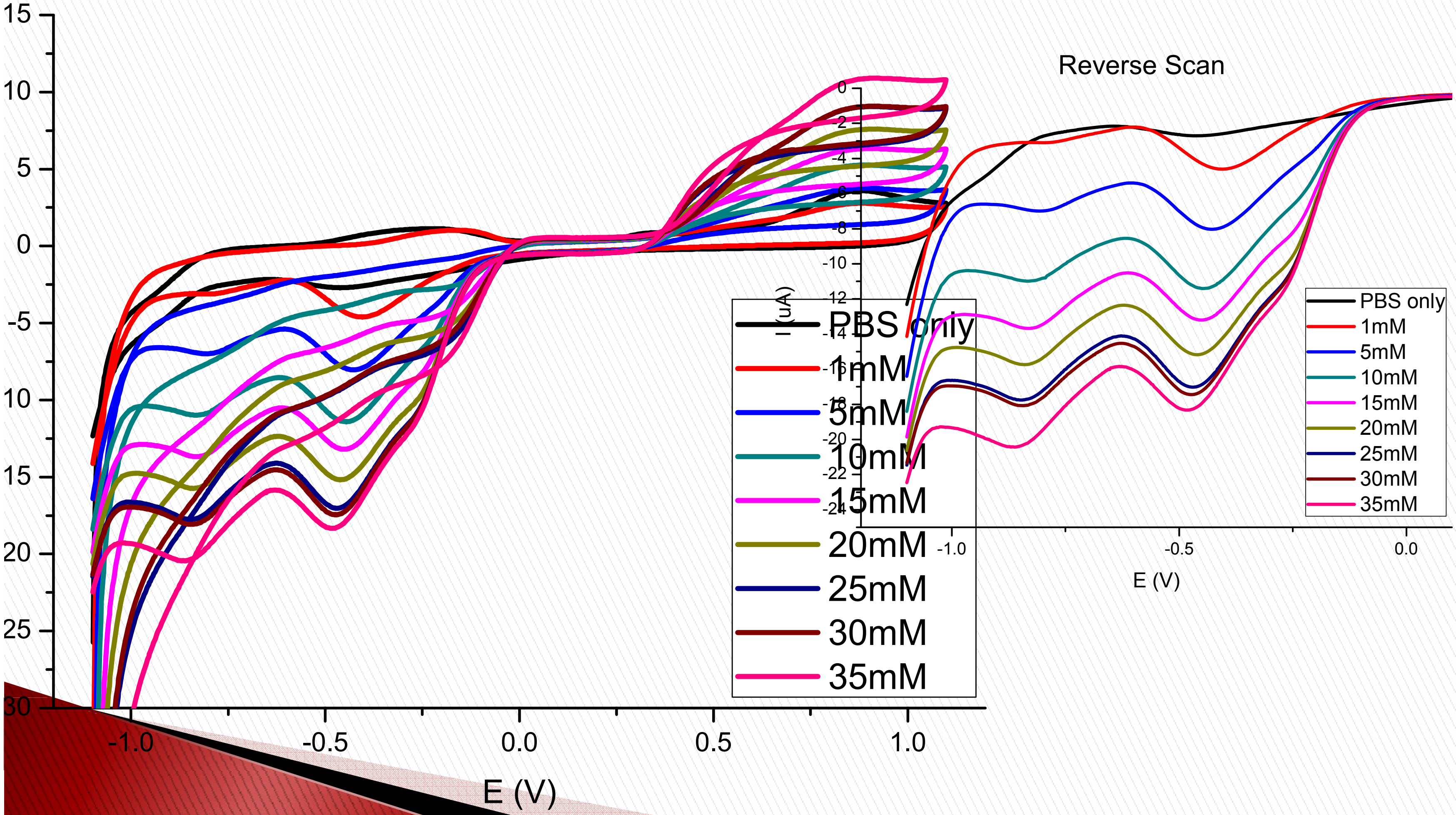
Experiment Plan

Sensing material: Hydrogen Peroxide (H_2O_2)

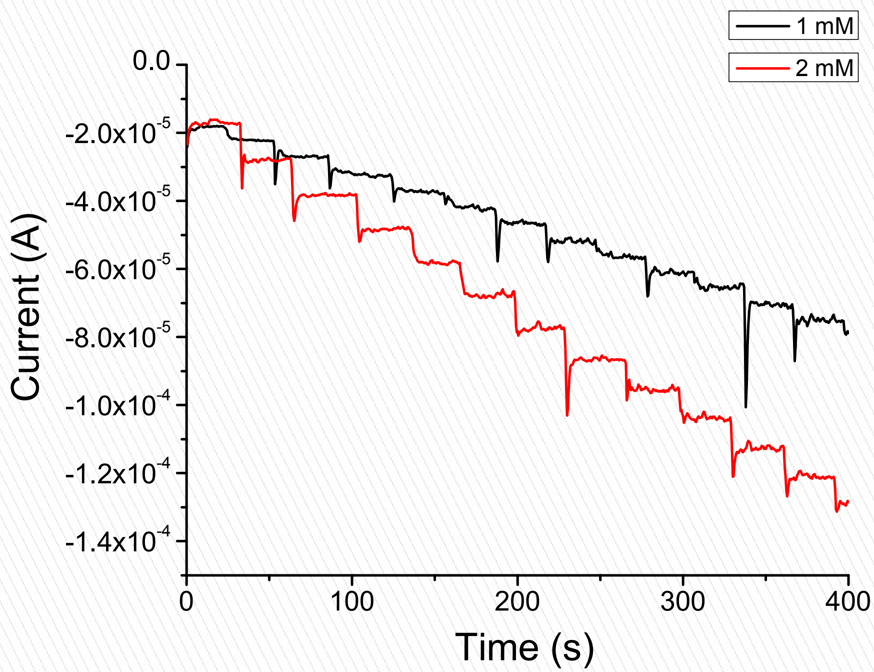
1. Control experiment
   CV of bare GCE and Pt nanowire functionalized GCE
2. CV curve of GCE/Pt NW in different concentration of H_2O_2

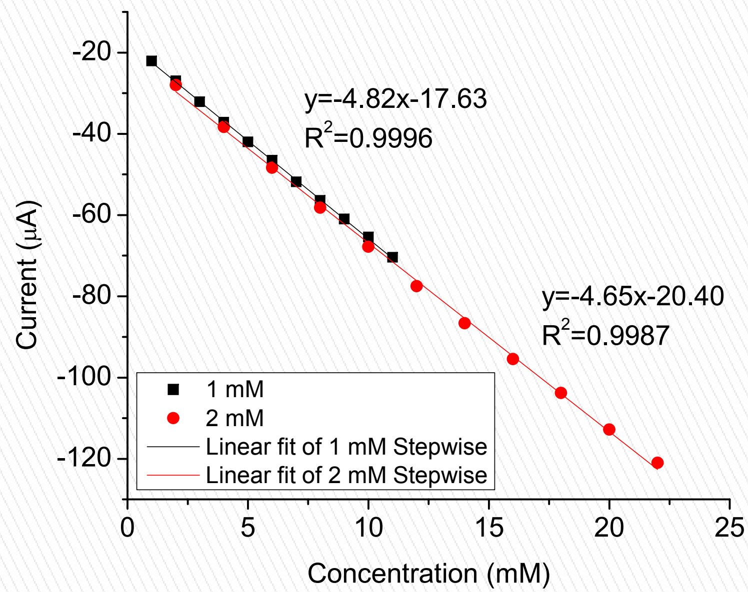
   2 mM, 5 mM, 10 mM, 20 mM, 50 mM
3. Dynamic test of GCE/Pt NW
4. Selectivity test (optional)
   Compare with other chemical compound such as glucose, AA and UA
5. Data analysis

Plot Examples
CV of different concentration H_2O_2



Plot Examples
Dynamic Testing and Data Analysis





Assignment –
Due on Feb 20th (Hard Copy is required)

1. Plot CV of bare GCE and Pt nanowire modified GCE in PBS solution without H_2O_2.

2. Plot CV of different concentration H_2O_2 by using GCE/Pt NW biosensor.

3. Plot Current vs. Concentration (I vs. c) based on the dynamic testing result.

4. Calculate the sensitivity, linear range of the GCE-Pt NW biosensor.

5. Find at least two reference papers related with hydrogen peroxide sensing by nanostructures and compare the limit of detection (LOD), linear range with experimental data, and try to explain why they performed different values.