Biosensors and bioelectronics I

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TUM

Tuesdays, 10:30 – 12:00
WSI seminar room: S101
**Biosensors and bioelectronics I: Course objectives**

*Winter semester*

**Introduction to biosensors**
Definition, models, structure and principles of operation, applications and market

**Physical Chemistry of Surfaces**
Solid/Solid junctions
Electrochemical systems
Solid/Liquid junctions

**Electrochemical transducers**
Review of electrochemistry
Potentiometric sensors
Amperometric sensors
  - Electron transfer at the electrode/liquid interface
Chemical sensitive Field Effect Transistors

**Optical transducers**
Surface plasmon resonance
Internal reflection spectroscopy

**Acoustic transducers**
Quartz crystal microbalance
Surface acoustic wave
Biosensors and bioelectronics II: Course objectives

**Summer semester**

- Bioelectric potentials and currents
- Electron transfer in proteins
- Membrane electrochemistry
- Ion channels
- Action potentials
- Synapse and neuromuscular junctions
Introduction to biochemical sensors

**Definition of Sensor**

“... device, that responds to a physical (or chemical) stimulus (heat, light, sound, pressure, motion, magnetism...) and transmits a resulting impulse (as for measurement or operating a control).”

Webster’s Collegiate Dictionary

**Biochemical Sensor**

“... a device incorporating a biochemical sensing element either intimately connected to or integrated within a transducer”
Introduction to biochemical sensors

Human versus bioelectronic noses
Introduction to biochemical sensors

Human versus bioelectronic noses

Comparison with calibration data:
- Analytical chemistry data
- Human odor panels
- Biological function tests
- Process parameter tests
- ...

Specific molecules
- Combustible gases
- Air quality
- Odor characterization
- Food identification
- Toxic / healthy
- Ok / not ok
- ...

Results
# Introduction to biochemical sensors

## System complexity

<table>
<thead>
<tr>
<th>Molecular hierarchy in the complexity of structures and functions, which may be used in the design of bioelectronic noses. The respective parts of the biological nose are given in italics</th>
</tr>
</thead>
<tbody>
<tr>
<td>- inorganic structures and organic molecules</td>
</tr>
<tr>
<td>- biomimetic recognition sites</td>
</tr>
<tr>
<td>- biological recognition sites</td>
</tr>
<tr>
<td>- odorant binding proteins</td>
</tr>
<tr>
<td>- olfactory receptors</td>
</tr>
<tr>
<td>- recognition sites embedded in biological membranes</td>
</tr>
<tr>
<td>- olfactory receptors in cilia</td>
</tr>
<tr>
<td>- recognition sites in membranes with subsequent signal amplification</td>
</tr>
<tr>
<td>- whole cells</td>
</tr>
<tr>
<td>- olfactory cells</td>
</tr>
<tr>
<td>- cell arrays</td>
</tr>
<tr>
<td>- neural tissue</td>
</tr>
<tr>
<td>- olfactory mucosa</td>
</tr>
<tr>
<td>- neural tissue with subsequent signal processing step</td>
</tr>
<tr>
<td>- olfactory mucosa and olfactory bulb</td>
</tr>
<tr>
<td>- brain</td>
</tr>
<tr>
<td>- olfactory mucosa, olfactory bulb, and olfactory cortex</td>
</tr>
<tr>
<td>- animals</td>
</tr>
<tr>
<td>- humans</td>
</tr>
<tr>
<td>- odor sensation of distinguished test persons</td>
</tr>
</tbody>
</table>
Introduction to biochemical sensors

Biochemical receptors

<table>
<thead>
<tr>
<th>Organisms</th>
<th>Enzymes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tissues</td>
<td>Antibodies</td>
</tr>
<tr>
<td>Cells</td>
<td>Nucleic acids</td>
</tr>
<tr>
<td>Organelles</td>
<td>Organic molecules</td>
</tr>
<tr>
<td>Membranes</td>
<td>Chemoreceptors</td>
</tr>
</tbody>
</table>

selectivity
stability

Biochemical transducers

chemical information

- Molecules
- Proteins
- Ions
- Nucleic acids

transducer principles

- Electrochemical (amperometric, potentiometric)
- Field Effect Transistors
- Mechanical-Piezoelectric
- Acoustic
- Optical
- Calorimetric
- “Molecular” Electronic

output signal

- Electrical
- Optical
- Optical

sensitivity
response time
miniaturization

Biosensors & Bioelectronics I (2011/2012)
Electrochemical transducers

Potentiometric transducers

measured signal: potential difference between a biochemical sensitive electrode and a reference electrode.
Sensitivity: $10^{-1} - 10^{-5}$ M

NH$_3$ $\rightarrow$ Urea, amino acids, creatinine
CO$_2$ $\rightarrow$ Urea, amino acids, enzymes
pH $\rightarrow$ Penicillin, DNA, RNA, glucose, pH-enzymes
I$^-$ $\rightarrow$ Glucose, cholesterol, amino acids

Amperometric transducers

measured signal: current flowing between the working electrode and the reference electrode, which is related to the concentration of the electroactive analyte in the solution.
Sensitivity: $10^{-8} - 10^{-9}$ M

Enzyme electrodes $\rightarrow$ kinetics of protein/enzyme interactions

Field Effect Transistor transducers

measured signal: changes in the conductivity of a surface modified FET sensitive to changes in solution pH.
Semiconductor technology
Electrochemical transducers

Optical transducers

**measured signal**: changes in the optical properties of the sensing material, resulting from molecular adsorption or surface reactions.

Mechanical / Piezoelectric Transducers

Based on membranes/cantilevers which are deformed by stress or mass changes produced by surface adsorption of analytes.

1 picogram/Hz

Acoustic / Piezoelectric transducer

Piezoelectric substrates + acoustic wave
Human Health Care Market

Global market: $250 billions

- Surgical instruments supplies: 100 bln
- Healthcare IT: 97 bln
- Diagnostic imaging and monitoring: 29 bln
- Other equipment & Services: 29 bln

(Frost & Sullivan, 2001)
Clinical uses ⇒ In vitro analysis

New concepts:
- remote health care (ecare)
- home point-of-care
- physician office point-of-care

Human genetic diseases

In-vitro-Diagnostics Market:
- $21B in 2000
- $30B in 2007
Current market situation for biosensors

• Market size:
  • ~ 8 billion USD (2009) +9% p.a
  • ~14 billion USD (2016)

• Medical devices market:
  • 250 billion USD (2012)

• Market share:
  • USA and Europe ~ 69%
  • Asia (Japan) and Pacific ~ 18%
End user application
Other fields of application

Biodefense
- Biochemical weapons, explosives detectors
- military equipment

Food processing
- rapid food quality tests
- bacteria, diseases, decay
- processing quality tests
General bibliography


*Physical Chemistry of Surfaces*, A. Adamson, A. Gast, J. Wiley & Sons, New York, 1997


Some websites for chemical sensor information (these are just a few of many):
- Internet Chemistry Resources (general); http://falcon.sbuniv.edu/~ggray/interrec.htm
- Berkeley Sensors and Actuators Center; http://bsac.eecs.Berkeley.edu
- Sensors Portal; http://www.sensorportal.com ! sensors ! chemical
- Univ. of Maine, LASST; http://www.ume.maine.edu/LASST/
- Gordon Research Conf.s., Chemical Sensors & Interfacial Design; http://www.grc.uri.edu ! Chemical Sensors & Interfacial Design
- Chemical Sensors Research Group; http://www.ch.pw.edu.pl/~dybko/csrg
- ETH Zurich, Physical Elect. Lab; http://www.iqe.ethz.ch/pel/
- PNNL Sensors & Electronics; http://www.technet.pnl.gov/sensors/
- Sensors Review, MCB Univ. Press; http://www.mcb.co.uk/sr.htm
- IEEE Sensors Journal, IEEE
- Sensors & Actuators, Elsevior
- Analytical Chemistry, ACS
- Journal of Applied Physics, AIP
- IEEE Trans. on Ultrasonics, Ferroelectrics, and Frequency Control (UFFC), IEEE
- IEEE Trans. on Microwaves Theory and Techniques (MTT), IEEE
- Journal of the Electrochemical Society, ECS
- Accounts of Chemical Research, ACS
- Biosensors & Bioelectronics, Elsevier
- Langmuir (chemical interfaces information)
- Electronics Letters
- On-Line Chem Sensors (contents and abstracts)
- Sensors Magazine (trade journal); http://www.sensorsmag.com