ECE/BioE 416 - Biosensors

Lecture 1

Introduction

Welcome to Biosensors… Online Edition!

- Don’t worry… we will get through this together!
- I’ll lecture “live” from my office at home during the regular class meeting time
- I will record the lectures and put them on Compass (mp4 format)
- I will “arrive” ~15 mins early and “stay” late to chat, answer questions… so we can get acquainted
- All the Powerpoint slides and reading assignments are already available in advance on Compass
  - Don’t download them all right now… I usually make some updates on the weekend before
- Why did I choose to do it this way?

Zoom etiquette for class

- Please have your video on and your audio muted
- I'll keep an eye on the class and on the chat
- Questions very welcome during lecture
- I won't get too fancy with Zoom, but I might try out the polling feature
- I'll also pause to ask questions and try some discussions… un-mute yourself to answer
- Eating, brushing your teeth and other stuff we don't all want to see… stop your video for that!

Administrative Details

- My background
- Course handout
  - Contact information
  - Compass 2G site
  - Grading
  - Homework assignments
  - Course schedule
  - Reading assignments
  - Weekly quiz
  - Term Paper

Teaching Assistant

- Weijing Wang (weijing4@illinois.edu)
- On weeks HW is due office hours are
  - Wednesdays:
    - 6-7PM
    - By Zoom (link to be shared)
    - Also by appointment

Prerequisites

- Course is geared toward engineering students with senior standing or beginning graduate students
  - Should be familiar with some basic physics concepts
    - Spring/mass/damper oscillators
    - Refractive index
    - Total internal reflection
    - Polarization
  - Should be familiar with a little chemistry
    - Chemical reaction equilibrium kinetics
  - We will review a little biology

Educational Objectives

- To teach the fundamental concepts behind the operation of the most important classes of biosensors
- To teach how biosensors are characterized, compared to each other, and designed to suit particular applications
- To teach how biochemical functionality is coupled to a biosensor transducer
- To describe the major applications of biosensor technology in diagnostic tests, life science research, and environmental testing
- To expose students to several of the most important emerging biosensor technologies
- To develop literature research skills, to encourage creative thinking, and to develop proposal-writing skills

Desired Outcomes

- Preparation for a job in the commercial development of sensors and instruments
- Preparation for graduate school research in the field of biosensors
- Preparation for graduate school or a job requiring the utilization of biosensors

Places to Get a Job in Biosensors

- Any research university or teaching hospital
- Big companies
  - GE Healthcare
  - Perkin-Elmer
  - Becton-Dickinson
  - Molecular Devices
  - Waters
  - 3M
  - Agilent
  - Abbott Diagnostics
  - IDEXX Laboratories
  - Hologic
  - Baxter
  - LIFE Technologies
  - Novartis
  - GSK
  - Amgen
  - Bio-Rad
  - Medtronic
- More Big Companies
  - Roche
  - Thermo-Fisher
  - Illumina
  - Merck Millipore
  - Quidel
- Any government national lab
- Dept of Homeland Security
- Big defense contractor
- Small-Medium Companies
  - Luminex
  - Quanterix
  - Nexcelom
  - NanoString
  - Evident Technologies
  - Fluidigm
  - Meso-Scale Discovery
  - Pacific Biosciences
  - MANY MANY OTHERS

Markets with a lot of growth

- Genomics-related
- Wearables
- Point of care
  - Home diagnostics, food safety, environment
- Personalized medical treatment

"The overall biosensors market is expected to group from $21.2B in 2019 to $31.5 by 2024"

Markets & Markets research report, October 2019

For more information

Both available under Lecture 1 reading materials

<u>Biosensor Market Report</u>
Frost & Sullivan
(from 2010 but still informative)

<u>Review paper</u>
S.K, Metkar and K. Girigoswami
“Diagnostic biosensors in medicine”
Biocatalysis and Agricultural Biotechnology
Vol. 17, p. 271-283, 2019

Homework Plan

- 5 assignments, every 2 weeks
  - Last HW is due April 9
- Due dates are on a Friday
- Solutions posted online afterwards
- In ECE/BioE416, the challenges will be in the HW, rather than in exams…

Exams

- Weekly online quiz on Compass
  - Available Friday 12 Noon through Sunday 10PM
  - Covers the material in lecture and reading during the week
  - Should be easy if you are paying attention
  - Might “force” you to read something I want you to pay attention to
  - In honor of COVID… Low stress is the intention…
    - Up to two attempts, keep the higher score

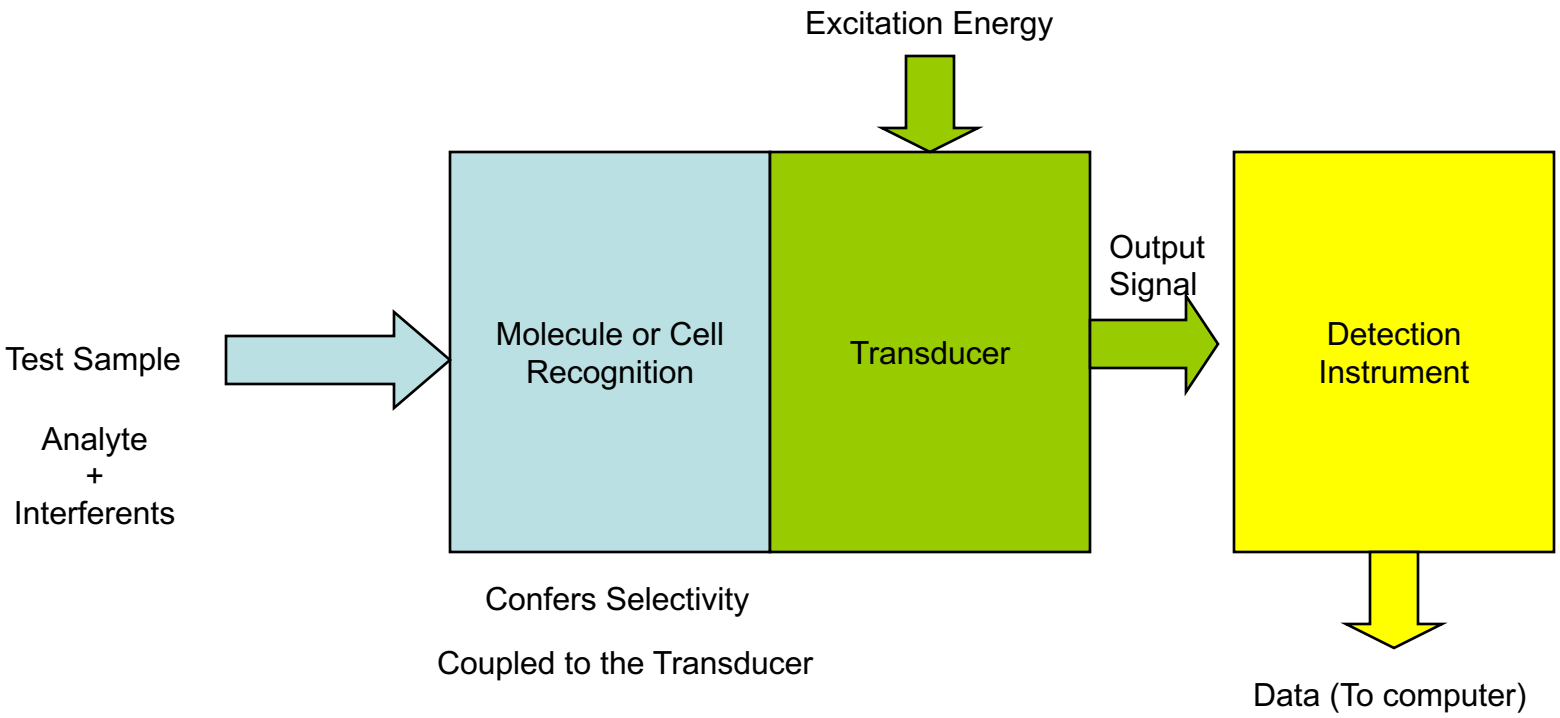
- No midterm or final exam
  - Term paper instead

Term paper

- To discuss more about it on Friday
- Each person will prepare a ~6-page NSF-style research proposal for a biosensor idea of your choosing
  - New section of term paper due every two weeks (on weeks with no HW assignment)
  - Feedback from me on each part
  - Final version due last day of class (May 5!)
  - Final exam period: Share a short ~5 min summary of your idea

Summary of the class

- Introduction
  - What is a biosensor and what are they used for?

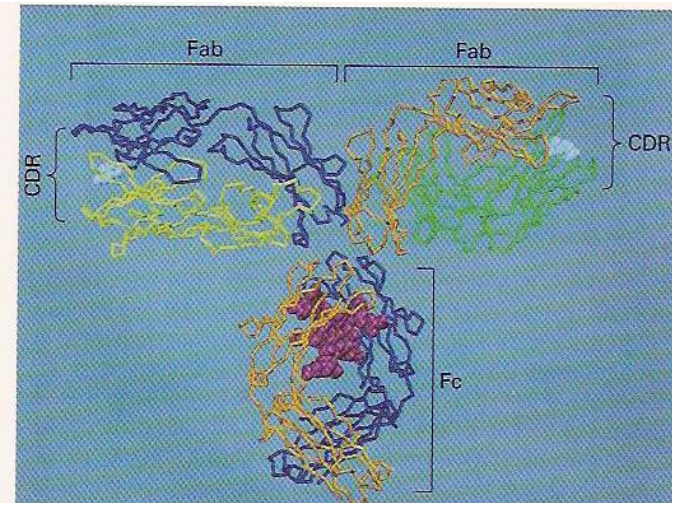


Summary of the class

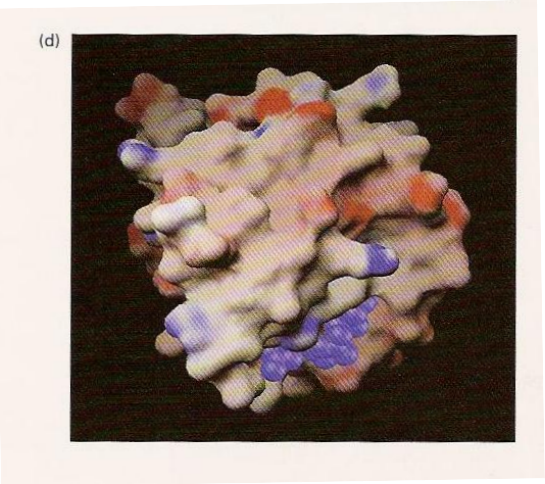
- Bioselective Layers
  - How do you get a biosensor to recognize a particular molecule, and how do you interface a transducer with a test sample
  - Common types of assays

Summary of the class

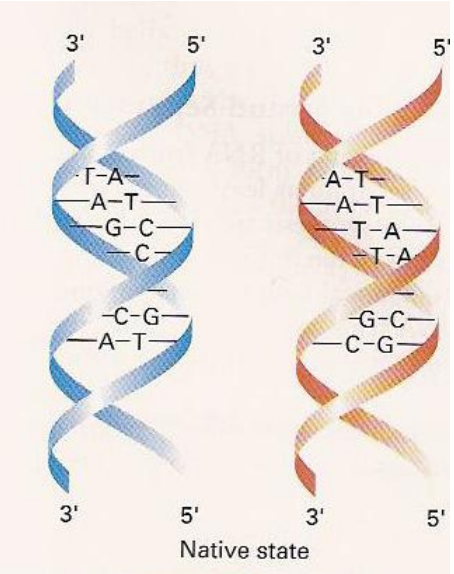
- Biomolecular Structure & Function
  - A review of what proteins and DNA molecules are composed of and important properties for their use in a biosensor system



Antibody



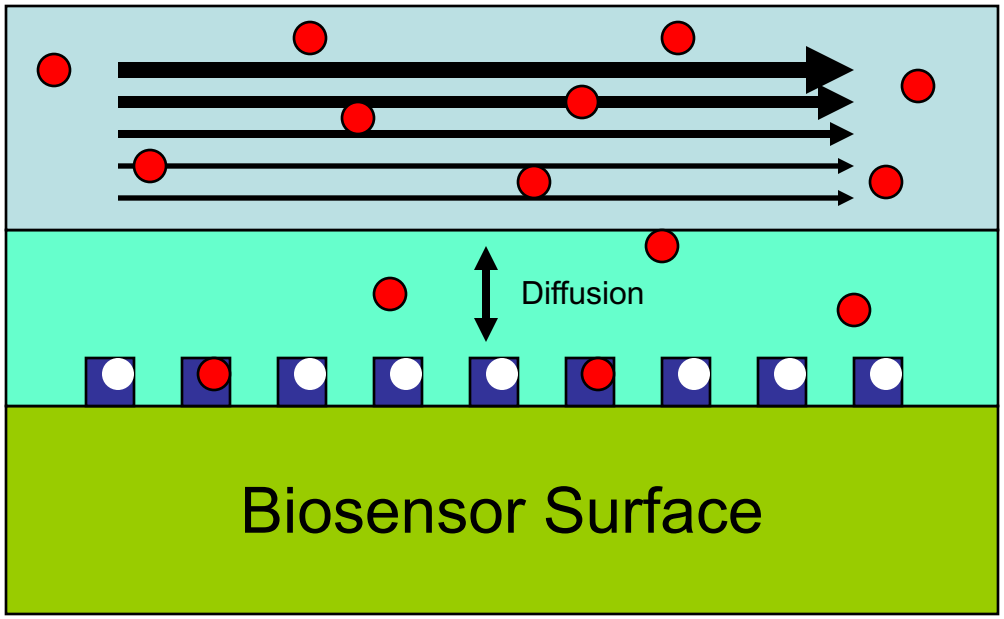
Globular Protein



DNA

Summary of the class

- Mass Transport
  - How you get the sample to the biosensor surface really matters!

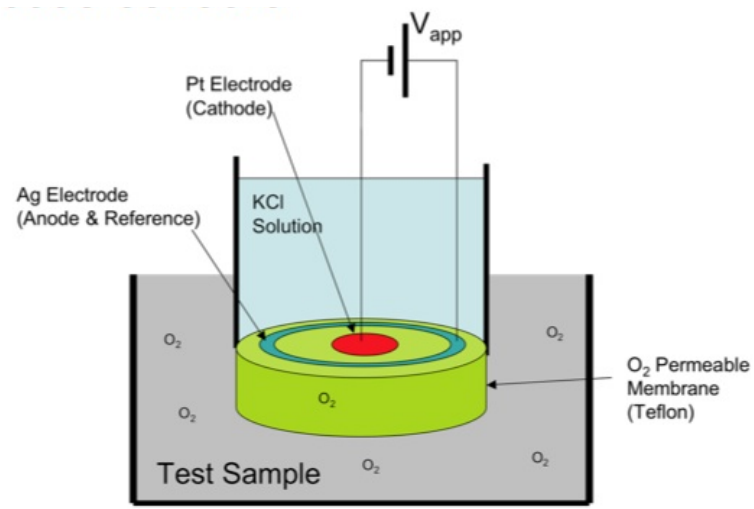


"Bulk" Liquid

Stagnant Layer

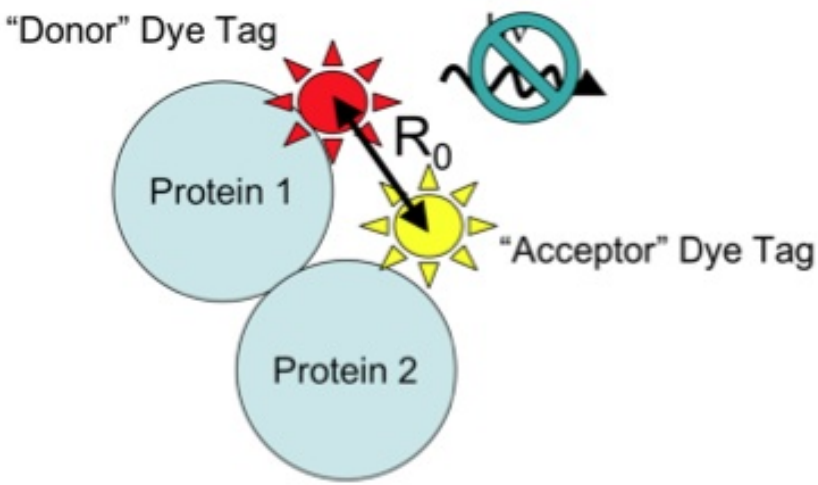
Summary of the class

- Electrochemical sensors
  - Background behind two of the most commercially successful biosensors of all time: O_2 sensors and blood glucose sensors



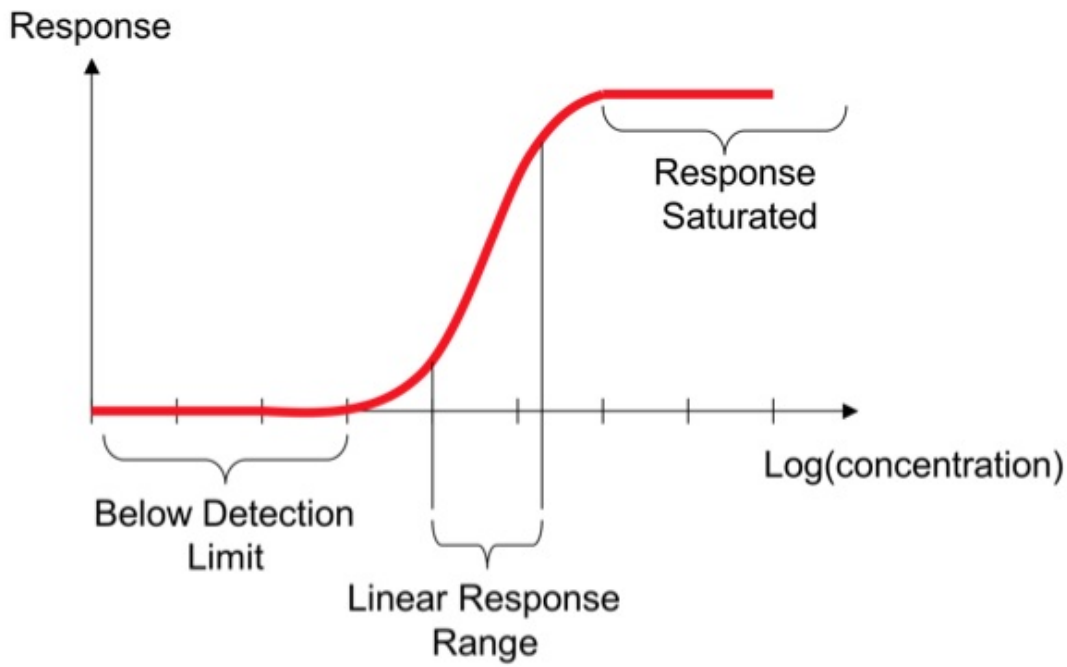
Summary of the class

- Fluorescence-based Assays
  - Fluorescent dyes attached to biomolecules
  - Fluorescent Resonant Energy Transfer (FRET)



Summary of the class

- Biosensor Figures of Merit
  - How we mathematically define sensitivity, resolution, dynamic range, and selectivity
  - Noise sources



Summary of the class

- Major classes of biosensors
  - Discuss physics of operation and examples of
    - Clark glucose sensor
    - Acoustic biosensors
    - Optical biosensors
    - Impedance-based biosensors
    - Fluorescence
    - Raman spectroscopy
    - Quantum dots
  - Label or label-free?

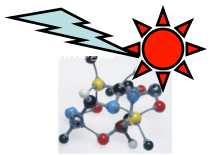
Modes of Label-Free Detection

- A transducer tells you whether the molecule or cell is present, and in what quantity

What physical characteristic does a molecule have?

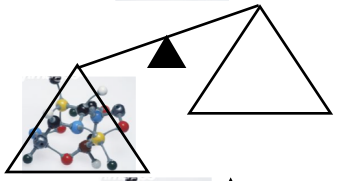
How would you detect it?

Fluorescent Tag



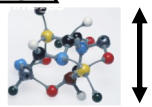
Photodiode or Camera

Mass



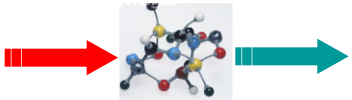
Acoustic Resonators

Height



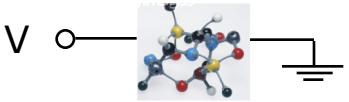
Atomic Force Microscope

Electric Susceptibility



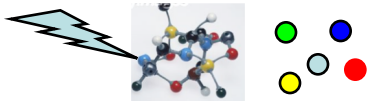
Light

Resistivity, Capacitance



Resistors & Transistors

Molecular Composition



Mass Spec & Raman

Summary of the class

- Surface functionalization - in more detail
  - Methods that apply to nearly all the biosensor transducers
    - Avidin-biotin
    - Bifunctional linkers
    - Hydrogels
    - Polymers

Summary of the class

- Recent biosensor technologies and applications
  - DNA Engineering (Prof. Xing Wang)
  - Optical force nanoscopy (Prof. Yang Zhao)
  - Campus COVID SHIELD Testing
  - Luminex fluorescent bead labels
  - Photonic crystal biosensors
  - Digital biomolecule detection
  - Fluorescence amplification
  - Smartphone biosensors
  - Laser biosensors
  - Next generation DNA sequencing technology
  - Surface enhanced Raman spectroscopy (SERS)

Impact of Biosensors on Society

- Diagnostic testing for disease
- Diagnostic testing for genes
- Personalized medicine
- Point-of-care sensors
- Life science research
- Drug research
- Environmental detection