

## ECE 730-Txx: Biosensing: Fundamentals and Applications

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### **Course description:**

The **objective** of the course is to impart knowledge needed to evaluate a proposed biosensing technology. In this course, an introduction to the field of biosensors and an in-depth and quantitative view of device design and performance analysis will be given. Biosensors are defined as self-contained integrated devices capable of providing analytical information, using a biological recognition element in conjunction with a secondary transduction element. Students will be introduced to different biosensing techniques, such as electrical biosensors, electrochemical biosensors, and optical biosensors with an emphasis on biomedical and environmental applications. The general principles of sampling and analysis, statistical presentation, and manipulation of data will be also presented. Students will also learn about the continuous and real-time biosensors, such as continuous glucose monitoring (CGM) devices. During first two weeks of the course, students will be briefly introduced to the basic molecular biology, such as DNA, RNA and protein and their role in biosensor. Additional background reading is supplied providing information on basic concepts in chemistry, thermodynamics and cell biology.

### **References:**

There is no formal text, but students will be e-mailed PDF files of important research and review articles. Students may use the below references for extra reading:

- Molecular Biology of the Cell, Bruce Alberts et al., Garland Science, 2002.
- Introductory Bioelectronics: for Engineers and Physical Scientists, R. Pethig and S. Smith, Wiley, 2012, ISBN: 978-1119970873
- Chemical Sensors and Biosensors: Fundamentals and Applications, F. G. Banica, 2012, ISBN: 9780470710661
- Fundamentals of Microfabrication, by Marc Madou.

### **Course Outline (each lecture 3 hours)**

- Introduction to molecular biology (~2 lectures)
  - For this topic, students will be given a brief introduction on the structures of DNA, RNA, and protein as they are target and probes of biosensors. Students will be briefly familiarized with transcription and translation process and the function of different types proteins.
- Biosensor elements (~1 lecture)
  - For this topic, students will be taught about common elements of a biosensor, including bio-receptor (enzyme/antibody/cell/nucleic acid/aptamer), transducer component (semi-conducting material/nanomaterial), and electronic system which includes a signal amplifier, processor, and display.
- Calibration curves, the method of standard addition, and sensitivity (~1 lecture)
  - For this topic, students will learn how to evaluate a biosensor based on its sensitivity and specificity. They will learn about common methods of deriving the calibration curve and determining the limit of detection (LOD) and limit of quantification of a biosensors (LOQ).
- Electrical biosensors, such FET sensors (~ 2 lectures)

- For this topic, students will learn about electrical biosensors and especially they will be taught Bio-field effect transistors (Bio-FET). Bio-FETs couple a transistor device with a bio-sensitive layer that can specifically and with high sensitivity detect biomolecules such as nucleic acids and proteins. Students will learn about Bio-FET system elements: a semiconducting field-effect transistor that acts as a transducer, an insulator layer, and the biological recognition element (e.g. receptors or probe molecules). Students will learn also about the concept of Debye length and its importance in FET transistors.
- **Electrochemical biosensors (~2 lectures)**
  - Electrochemical biosensors are a class of electrical sensors and usually consist of three main electrodes: working electrode, reference electrode, and counter electrode. For this topic, students will be familiarized with the electrochemical biosensor concept while some novel methods, such as incorporating nanostructure to increase their sensitivity, will be presented.
- **Optical biosensors (~2 lectures)**
  - For this topic, the state-of-the-art optical biosensor technologies, including those based on surface plasmon resonance (SPR), optical waveguides, optical resonators, photonic crystals, and optical fibers, are presented. The principles for each type of biosensor are concisely introduced with the particular emphasis on recent achievements.
- **Enzyme-based biosensors, e.g., the blood glucose sensor (~ 2 lectures)**
  - Enzyme-based biosensors uses enzymes as the recognition elements and combines it with a transducer to produce a signal which is proportional to target analyte concentration. Students will learn about this class of biosensor, specifically via introduction of continuous glucose monitoring (CGM) devices as a well-known enzyme-based sensor. In this topic, students will be also introduced to the recent progress in the field of real-time monitoring.
- **Student presentation (will be executed during the final exam period)**
  - Each student should present one paper in the field of nano-biosensors from top tier journals such as (nature nanotechnology, nature biomedical engineering, nature medicine, science, and etc) in class. Preferably, the presentation and the final project should not be on the same topic. The presentation must include in detail introduction, methods, results, and analysis. Presenter must be well-prepared to discuss the paper with other students. Presenter should include their opinion about the future direction of paper and what kind of experiments authors could have done to better articulate their message. The rest of the class should be prepared to challenge these views or offer alternative explanations or insights.

### **Grading**

The course will be assessed by a final report and a presentation given to and marked by the whole class.

- Class participation (5%)
- Assignment (15%)
- Class presentation (30%)
- Final project (50%)

### **Final project**

**Guidance for students:** You should deliver a 25-page final report on your choice of nano-biosensor topic. The report should consist of the following components: 1) ~10 pages on literature review where you discuss in detail the biosensor fundamentals, its application, and the current state of the art; 2) ~2 pages

summarizing the obstacles and problems that field faces; 3) ~8 pages on modeling and simulation; and 4) ~5 pages on mini-proposal. For the first and second part, you should write as an assessment of the current state of the field, together with your own ideas for what would be fruitful areas to pursue. This should be similar to what you did in the presentation, describing what the major goal of the field is, why we haven't been able to reach that goal yet (the obstacles), what people have tried, and where the field is at now. The content should include a critical analysis of the papers in the area (e.g., what they mean to the overall field, and where more work is still needed). For the third part, you are required to deliver a mathematical model/simulation for your choice of biosensor where you would simulate an experiment and derive the sensor characteristics, such as sensitivity and calibration curve. The simulation can be done using COMSOL or any other software that you are familiar with. Since biosensing is a large and diverse field, the final project is an opportunity to investigate an area that is particularly interesting to you. You are highly encouraged to incorporate the perspective from what you have learned from other related courses/your research background. Finally, I would like you to identify the future research needs or projects that should be undertaken. This is kind of a mini-proposal section, where you describe what experiments you think could provide an innovative path for the field, and why these are the key ones to carry out. Don't worry so much about feasibility or specific details of the experiments, but instead try to figure out what the key ones would be. This could be directly linked to your simulation part. You may use your modeling results to propose these new experiments.

In terms of formatting, just make it reasonable font, margins, and spacing. I'm not going to police the length, but having 1.5" margins, double spaced is probably not going to have the information content you would want. The topics can vary widely- neuro interfaces, glucose monitoring, FET sensors, etc. As long as it somehow involves nano and biosensing, it is probably ok. If you have any question about your choice of topic, please let me know. The report should be based on a minimum of ~20 references and have a cogent discussion of the state of the art in the field from these.

I estimate that 20-30 students will be enrolled for this course. For the final project, students are required to solely deliver the report. If the enrollment number increases, students may be asked to form group of two.