**COURSE:** NE 479 / ECE 634 (Winter 2020)

**COURSE TITLE:** **Organic Electronics**

**INSTRUCTOR:** Prof. Hany Aziz
Office: [redacted]. Office hours: by appointment (via email)
email: h2aziz@uwaterloo.ca

**TA:** (TBD)

**LECTURES:** [redacted]

**DESCRIPTION:**

The course gives an overview of organic electronic and optoelectronic devices. It begins with a review of electronic structure of single organic molecules as a guide to the electronic behaviour of organic aggregates. Various relevant material phenomena are reviewed; including topics from photophysics (absorption and emission of light, excited states, radiative and non-radiative transitions), intermolecular charge transport mechanisms (hopping, disorder), charge injection and transport models, and energy transfer processes. Their applications in light emitting devices, solar cells, thin film transistors, photodetector and imaging photoreceptors, etc. are discussed. Aspects related to device fabrication and patterning may also be addressed.

**COURSE/TEACHING OBJECTIVES:**

This course will help students with no or limited prior background in the field to:

- Acquire a general background in the field of organic electronics and optoelectronics, basic theory, applications, challenges, recent developments, etc.
- Know and understand relevant fundamental scientific theory (qualitatively), and its relationship to organic semiconductor material and device design concepts.
- Become familiar with relevant terminology, and be able to read and understand scientific literature in the field
- NE479 only: Become familiar with basic device design parameters and implement a simple design of a certain organic electronic device.
- ECE634 only: Become able to survey and analyze research papers on certain relevant topics in the field

**SYLLABUS:**

01. Introduction to OLEDs:
    OLED Operation Mechanism, injection, transport and emission of light. Organic heterojunction. General comparison of inorganic versus organic devices
02. Electronic Structure of Organic Molecules
    Atomic and Molecular Orbitals, LCAO, Bonding and antibondig orbitals, Orbital hybridization, HOMO and LUMO levels, Conjugated Molecules
03. Photophysics of Organic Molecules
    Excited states: (Absorption and emission, Singlet and triplet states), Rates of electronic transitions, Transition moment, Frank Condon Principle, Radiative and non-radiative transitions, Excited state kinetics
04. Exciton Processes in Organic Solids
    The Solid State: (Bonding, states of matter, amorphous & crystalline states), Excitons, Forester and Dexter energy transfer, Exciton quenching processes
05. Electronic Conduction in Organic Solids
    Conductivity: (carrier concentration versus mobility), Carrier generation, Hopping transport, Mobility measurements, Traps.
06. Aspects of OLED Physics and Technology
    Charge injection from metal contacts, Charge transport and device characteristics, Exciton formation and luminescence, OLED Efficiency, Stability and aging, RGB patterning approaches.
07. Organic Light Harvesting Devices
    Photoreceptor Devices, Photodetector Devices, Photovoltaic Devices: General background, device operation mechanism and characteristics, important phenomena, current challenges, recent developments
08. Organic Electronic Materials & Organic TFTs
    Small molecule and polymer materials for OEs. Hole and electron transport. Molecular design rules for mobility and chemical stability. OTFT operation mechanism and characteristics, important phenomena, recent developments
09. Selected Topics in Organic Electronics (if time permits)
    Quantum-dot OLEDs. Conducting polymers. Printing-based fabrication. etc.

**TEXTBOOK:**

No textbook required. Lecture notes and handouts will be provided.

**GENERAL REFERNCES**

- "Electronic Processes of Organic Crystals and Polymers" , Pope & Swenberg, Oxford University press, 2nd edition (1999).
- "Essentials of Molecular Photochemistry" , Gilbert & Baggott, CRC Press, 1991.
- "Organic Semiconductors" H. Meier, Verlag Chemie GmbH, 1974
- "Physics of Organic Semiconductors" Wolfgang Brütting, John Wiley & Sons Canada; 1 edition (2005)
- "Organic Electronics: Materials, Manufacturing, and Applications" , Hagen Klauk, John Wiley & Sons; 1st edition (2006)
- "Electrical transport in solids : with particular reference to organic semiconductors", Kao, Pergamon Press; 1st edition (1981).

**MARKING SCHEME**

Different marking schemes will be used for ECE634 and NE479:

**NE479:**

- 5% Quiz
  The quiz will be ~15 minutes long and will be held during regular lecture time on **Monday, Feb 3, 2020.**
- 25% Midterm Exam
  The exam will be ~75 minutes long and will be held during regular lecture time on **Friday, Feb 28, 2020.**
- 20% Design Assignment
  Students will be given the assignment to design a specific organic electronic device that will meet certain performance, fabrication and/or cost requirements. See page 4 for more details.
- 50% Final Written Exam.
  The Final Exam will be 150 minutes long and will be held during UW regular final exam period, at a time and a place to be determined by the university.

**IMPORTANT NOTE:** You must obtain a total of at least 50% in both the midterm and final exams (i.e. a total of at least 37.5/75) in order to pass this course. Otherwise, that total will be the mark you will get in this course.

**ECE634:**

- 5% Quiz
  The quiz will be ~15 minutes long and will be held during regular lecture time on **Monday, Feb 3, 2020.**
- 25% Midterm Exam
  The exam will be ~75 minutes long and will be held during regular lecture time on **Friday, Feb 28, 2020.**
- 30% Literature Review Project
  Students will conduct a literature review on a certain relevant topic of a *fundamental scientific* nature. The outcome of the review will be delivered as an oral presentation and a written report. See page 5 for more details.
- 40% Final Written Exam.
  The Final Exam will be 150 minutes long and will be held during UW regular final exam period, at a time and a place to be determined by the university.

**IMPORTANT NOTE:** To pass this course, you must obtain a total of at least 42/65 in the midterm and final exams combined. Otherwise, that total will be the mark you will get in this course.

**COURSE WEBSITE:**

A course homepage is available on LEARN. It will contain copies of lecture slides and notes. The slides and notes will be uploaded weekly prior to each lecture. The site also contains a copy of this course outline. It will also be uploaded with any important updates, etc.

**TENTATIVE SCHEDULE:**

A tentative schedule is shown below. The instructor reserves the right to change the outline and/or the schedule as needed.

| **Week No.** | **Main Subject/Topics Covered during Lecture** |
|---|---|
| 1 | *>>>Course introduction*<br>01.Introduction to OLEDs |
| 2 | 02.Electronic Structure of Organic Molecules |
| 3 | 03.Photophysics of Organic Molecules |
| 4 | 03.Photophysics of Organic Molecules |
| 5 | 04.Excitonic Processes in Organic Solids<br>*>>> Quiz* |
| 6 | 05.Electronic Conduction in Organic Solids |
| 7 | 06. OLED Physics and Technology<br>*>>> Midterm* |
| 8 | 06. OLED Physics and Technology |
| 9 | 07.Organic Light Harvesting devices |
| 10 | 07.Organic Light Harvesting devices<br>*>>> No class on March 20 due to NE FYDP symposium* |
| 11 | 08. Organic Electronic Materials & OTFTs<br>*>>> NE 479 Design Assignment due* |
| 12 | 08. Organic Electronic Materials & OTFTs<br>*>>> ECE 634 Oral Presentations and Reports due* |

**NE 479 DESIGN ASSIGNMENT:**

*General Scope:*

Students will design a specific organic electronic device that will meet certain performance, fabrication and/or cost requirements. The design will be conducted by a **work group of two students** (typically)**. Some design ideas will be suggested by the instructor for students to choose from. Alternatively, students can come up with their own ideas of the device they wish to design, but must seek the TA's approval of their idea to make sure it is suitable and is not already taken by other students (first come first serve basis). All students must confirm their final design idea with the TA **by Friday, March 6.** The design will be presented in a 4-6 page write-up, to be submitted by email to the TA (as a pdf file), due on **Friday, March 27, 2020.**

*Design Elements:*

Your design will involve selecting:

a. the general device structure including the different components (e.g. layers to be included in the device that you deem necessary for the proper functioning of the device, outlining the role(s) of each layer and/or component

b. the specific material for each layer of the device including the substrate, electrodes, semiconductor layers, etc.

c. the thicknesses of each layer

d. the general fabrication process to be used for making each layer (e.g. vacuum deposition, spin-coating, ink-jet printing, sputtering, etc.), justifying your choice in each case

e. any other elements you consider to be important for making your device satisfy the desired requirements

In making the above design choices for the various layers of the devices, the fundamental material properties that are relevant for the function of the specific layer or layers should be considered. The following are examples of some of the fundamental properties that should be considered in making choices about the material, thickness and/or fabrication process selection:

1. the mobility of holes and/or electrons in the material (for all layers with a charge transporting role)
2. the HOMO and LUMO energy levels of the material (for achieving the desired charge transfer across inter-layer interfaces)
3. the bandgap of the material (for layers with light emission or absorption functionalities)
4. the quantum yield and exciton relaxation efficiency of the material (for layers with light emission functionalities)
5. the optical density of the material (for layers with light absorption functionalities)
6. the exciton diffusion length (for layers where the diffusion of excitons can play an important role on its functionality)
7. material – fabrication process compatibility (e.g. using vacuum deposition for fabricating layers made of low solubility materials, or, alternatively, choosing higher solubility materials if using solution-coating fab is desired).
8. etc.

*The Write-up:*

The design will be presented in a 4-6 page (single-spaced) write-up, to be submitted by email to the TA (as a pdf file). The write-up should include:

1. a description of the structure (bullet a above) and operation mechanism of your device. Include 1 or 2 schematic diagrams (showing device structure cross sectional views and/or energy band diagrams as appropriate)
2. a complete yet concise justification of the decision elements and choices related to bullets a-e above, making the case for how your design will allow for the desired performance, fabrication and/or cost requirements to be realized.

** Students who choose to work individually on the assignment or cannot find a partner will receive 2 extra points to their assignment mark (out of 20) as a bonus. The final mark of the assignment, including any bonus points, will not exceed 20.

**ECE634 LITERATURE REVIEW:**

1) Each student will conduct an in-depth, individually conducted review of at least 3 scientific papers on one topic relevant to organic electronics. The students will give an oral presentation and write a report on the topic

2) The topic and papers are to be selected by the student, but must be approved by the course instructor. The final choice of topic and papers must be confirmed to the instructor by email and approved by the instructor **by the end of week 8 of the term.**

3) In general, in order to be acceptable, each selected paper must meet the following conditions:
   a. Must be a peer-reviewed research article on a topic in the field of organic electronic materials and devices
   b. Must be published within the last 7 years in an ISI-indexed journal with an impact factor > 2.0
   c. Must have received >10 citations (papers published in the last two years are exempted from this requirement)
   d. Must be at least 6 journal pages long

4) PDF copies of the confirmed papers should be emailed to the instructor **no later than the end of week 9 of the term**. The following file name format must be used for the PDFs:
**[YourLastName in square brackets]_FirstAuthorLastName_YearPublished_JournalName_Volume_Pages.pdf**

5) In general, your review, and hence both your presentation and report, should each include the following elements:
   a. Introduction: This should contain enough information to allow audience to follow and appreciate the topic that is being covered in the papers and presented by you.
   b. Results & Discussion: A brief outline of the main results reported in each paper
   c. Novelty Aspects: A highlight of the new findings or conclusions of each paper
   d. Personal Critique: Your own view of the strengths and/or weaknesses of the paper, with appropriate justifications, and areas where results or conclusions of the papers may agree or disagree with each

6) Marking Scheme:
   a. Oral Presentation: 5% of total course grade
   b. Written Report: 25% of total course grade

7) Oral Presentation:
   a. The presentation will typically be 25-30 minutes long including time for Q&A. **The presentations will be scheduled (tentatively) for weeks 11 & 12 of the term.** The presentations are normally scheduled during regular class hours, however, depending on the number of students taking the course (and hence the number of presentations), some presentations may have to be scheduled outside of regular class hours. The exact dates and times (as well as presentation length) will depend on the final number of students enrolled in the course and therefore will be confirmed later by Week 6 of the term
   b. A copy of presentation slides should be emailed to the instructor **no later than 9:00 am on the day of your presentation.** The following file name format must be used for your slides file: **[YourLastName in square brackets]Pages.pdf.** The presentation slides will be uploaded on LEARN and available to all students in the class to access.
   c. Marking: The mark will be based on demonstration of sufficient understanding of the topic and papers as may become evident from the delivered material as well as responses to questions in the Q&A period that follows the presentations.

8) Written Report:
   a. A written report presenting the main findings of the literature search on the topic **is due by Friday, April 3rd, 2020.** Email an electronic copy (.pdf) to the instructor, and place a hard copy of the report in the instructor's mail slot (ECE reception area in EIT),
   b. The report should include: (i) title page, (ii) abstract, (iii) main body, and (iv) references sections.
   c. The "abstract" should be no longer than 1 page (single spaced), and should concisely capture the main points of the report.
   d. The "main body" should typically be 10-15 single-spaced pages (excluding any figures and/or tables), font size 12, and will include sections using the same titles/subtitles as outlined in bullet 5 above.
   e. Marking: Introduction (20%), Results & Discussion (40%), Novelty Aspects (15%), Personal Critique (15%), general presentation (10%). Note that the variety in the nature of the different topics will require customizing the marking scheme to make it more relevant to the individual topics. Therefore the actual marking scheme may differ from this one.

**OTHER IMPORTANT INFORMATION AND RELEVANT LINKS:**

**Academic Integrity:** In order to maintain a culture of academic integrity, members of the University of Waterloo community are expected to promote honesty, trust, fairness, respect and responsibility. [Check www.uwaterloo.ca/academicintegrity/ for more information.]

**Grievance:** A student who believes that a decision affecting some aspect of his/her university life has been unfair or unreasonable may have grounds for initiating a grievance. Read Policy 70, Student Petitions and Grievances, Section 4, www.adm.uwaterloo.ca/infosec/Policies/policy70.htm. When in doubt please be certain to contact the department's administrative assistant who will provide further assistance.

**Discipline:** A student is expected to know what constitutes academic integrity [check www.uwaterloo.ca/academicintegrity/] to avoid committing an academic offence, and to take responsibility for his/her actions. A student who is unsure whether an action constitutes an offence, or who needs help in learning how to avoid offences (e.g., plagiarism, cheating) or about "rules" for group work/collaboration should seek guidance from the course instructor, academic advisor, or the undergraduate Associate Dean. For information on categories of offences and types of penalties, students should refer to Policy 71, Student Discipline, www.adm.uwaterloo.ca/infosec/Policies/policy71.htm. For typical penalties check Guidelines for the Assessment of Penalties, www.adm.uwaterloo.ca/infosec/guidelines/penaltyguidelines.htm.

**Appeals:** A decision made or penalty imposed under Policy 70 (Student Petitions and Grievances) (other than a petition) or Policy 71 (Student Discipline) may be appealed if there is a ground. A student who believes he/she has a ground for an appeal should refer to Policy 72 (Student Appeals) www.adm.uwaterloo.ca/infosec/Policies/policy72.htm.

**Note for Students with Disabilities:** The Office for persons with Disabilities (OPD), located in Needles Hall, Room 1132, collaborates with all academic departments to arrange appropriate accommodations for students with disabilities without compromising the academic integrity of the curriculum. If you require academic accommodations to lessen the impact of your disability, please register with the OPD at the beginning of each academic term.