COURSE: NE 476 / ECE 634 (Winter 2025)

COURSE TITLE: **Organic Electronics**

INSTRUCTOR: Prof. Hany Aziz h2aziz@uwaterloo.ca

TA: TBD

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 photo-physics (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
- NE476 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 anti-bondig 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, 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 NE476:

NE476:

- 10% Quiz
  The quiz will be ~20 minutes long and will be held during regular lecture time on **Monday, Feb 3, 2025.**
- 25% Midterm Exam
  The exam will be ~60 minutes long and will be held during regular lecture time on **Monday, Feb 24, 2025.**
- 20% Design Assignment
  Students will be given the assignment to design a specific organic electronic device that will meet certain performance and/or fabrication method requirements. See page 4 for more details.
- 45% Final Exam.
  The Final Exam will be held during UW regular final exam period.
  IMPORTANT NOTE:
  To pass this course NE476 students must obtain a total of at least 40/80 in the quiz, midterm and final exam combined. Otherwise, that total will be the mark they will get in this course.

ECE634:

- 10% Quiz
  The quiz will be ~20 minutes long and will be held during regular lecture time on **Monday, Feb 3, 2025.**
- 25% Midterm Exam
  The exam will be ~60 minutes long and will be held during regular lecture time on **Monday, Feb 24, 2025.**
- 25% 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 critique. See page 5 for more details.
- 40% Final Written Exam.
  The Final Exam will be held during UW regular final exam period.
  IMPORTANT NOTE:
  In addition to satisfying ECE minimum grade requirements for passing graduate courses, ECE634 students must also obtain a total of at least 45/75 in the quiz, midterm and final exam combined in order to pass 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* 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 *>>> Quiz*
6	05.Electronic Conduction in Organic Solids
7	06. OLED Physics and Technology *>>> Midterm*
8	06. OLED Physics and Technology
9	07.Organic Light Harvesting devices
10	07.Organic Light Harvesting devices
11	08. Organic Electronic Materials & OTFTs
12	08. Organic Electronic Materials & OTFTs *>>> NE 476 Design Assignment due* *>>> ECE 634 Oral Presentations & Written Critiques*

NE 476 DESIGN ASSIGNMENT:

General Scope:

Students will design a specific organic electronic device that will meet certain performance and/or fabrication requirements. The design will be conducted by a **team of two students** (typically)**. The instructor may provide some ideas for students to choose from. Students however are encouraged to come up with their own ideas of the device they wish to design. In all cases students must seek the TA's approval of their idea to make sure it is suitable and has not been taken by other students (first come first serve basis), and must confirm their final design idea with the TA **by Friday, Mar 14, 2025.** The design will be presented in a 8-13 page write-up (as a pdf file) to be submitted by uploading to the designated Dropbox on Learn by **Friday, April 4, 2025.**

Design Elements:

Your design will involve selecting:

a. the general device structure including the different components (e.g. the layers to be included in the device that you deem necessary for the proper functioning of the device and their sequence, 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. any other elements that 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, layer sequence and layer thickness selection:

i. the mobility of holes and/or electrons in the material (for all layers with a charge transporting role)

ii. the HOMO and LUMO energy levels of the material (for achieving the desired charge transfer across inter-layer interfaces)

iii. the bandgap of the material (for layers with light emission or absorption functionalities)

iv. the quantum yield and exciton relaxation efficiency of the material (for layers with light emission functionalities)

v. the optical density of the material (for layers with light absorption functionalities)

vi. the exciton diffusion length (for layers where the diffusion of excitons can play an important role on its functionality)

vii. etc.

The Write-up:

The design will be presented in a 8-13 page (single-spaced) write-up, to be submitted by uploading it to the designated Dropbox folder on Learn. **Turnitin® software will be used in assessing the originality of the writing.** The write-up should include the following info in separate sections using the subtitles provided in italics and numbered with the same numbers 1-7):

1. *Executive Summary (0.5-1 page) :* This section will consist of two paragraphs. The first paragraph will outline the main objectives of the design and the set of performance and/or fabrication requirements that the device needs to satisfy. This paragraph will serve as a "problem definition". The second paragraph will briefly summarize your design and its various aspects, including a description of the general device structure (see bullet a above) and the specific materials used in it (see bullet b above). This second paragraph will serve to articulate your proposed solution to the problem outlined in the first paragraph,

2. *General Device Structure (2-3 pages):* This section will provide a detailed description of the structure (bullet a above) of your device and its operation mechanism. Include 1 or 2 schematic diagrams (showing device structure cross sectional views and/or energy band diagrams as appropriate).

3. *Choice of Materials (3-5 pages):* This section will provide an account of the material(s) proposed for each layer of the device proposed in the previous section. Give a brief justification/explanation for your choice of each material based on the relevant properties (bullets i-viii above) of each material, backing your claims with references from scientific papers. For each organic or organometallic semiconductor material selected in your design, i) show the molecular structure in a schematic diagram that also includes the full chemical name of the material plus any acronyms used for this material in your document, and ii) a brief explanation of how the molecular structure enables or supports the properties you desire from this material (this info can be found in research or review papers; make sure to cite all papers properly!).

4. *Layers Thicknesses (1-2 pages):* This section will provide an explanation for the thickness ranges proposed for each layer of your device. In general, layers of semiconductor materials should be as thin as possible (to minimize ohmic losses across layers as well as material utilization and cost since these materials can be expensive) but thick enough to ensure the layers are continuous and pinhole free, and more importantly, to meet certain design requirements (such as achieving sufficient light absorption, limiting (or promoting) exciton diffusion effects, counter-balancing differences between electron and hole mobilities in order to achieve more balanced conduction, etc. as may be relevant).
5. *Other Design Considerations (1-2 pages)*: This section will provide an account of any other considerations or choices you made in your design that you felt were relevant.
6. *Conclusion (0.5-1 page): In this section provide a conclusive summary of your design (which can be similar to the second paragraph of the Executive Summary)*
7. *Learning Reflection (0.5-1 page). In this section each team member will outline at least 3 aspects (new knowledge, perspectives, ideas, etc.) that conducting this design assignment has helped them learn or expand their knowledge in. These aspects will be outlined in bullet format and each student (i.e. team member) will put their initials next to their own bullets.*

** Note: Students who choose to work individually on the assignment or cannot find a partner will receive 2 extra points to their assignment mark 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 written critique** on the papers

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 (i.e. March 7, 2025).**

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 >5.0
   c. Must have received >10 citations (papers published in the last two years are exempted from this requirement)
   d. Must be at least 5 journal pages long (excluding references)

4) PDF copies of the confirmed papers (i.e. after they have already been approved by the instructor earlier) should be emailed to the instructor **no later than the end of week 8 of the term**. The following file name format must be used for the PDFs: **YourLastName_FirstAuthorLastName_YearPublished.pdf**

5) Marking Scheme:
   a. Oral Presentation: 14% of total course grade
   b. Participation in the Q&A sessions of the other ECE634 students presentations: 2% of total course grade
   c. Written Critique: 9% of total course grade

6) 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), they 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 7 of the term.
   b. A copy of presentation slides should be uploaded to the designated Dropbox on Learn **by 8:00 am on the day of your presentation.** The following file name format must be used for your slides file: **YourLastName.pdf.** The slides will be uploaded on LEARN and made available to all students in the class.
   c. In general, your review, and hence your presentation, should include the following elements:
      i. Background: This part should give some introduction to the general topic that the selected papers represent. This part can be for all papers combined, or divided to serve as a separate background for each paper, as may be appropriate
      ii. Results & Discussion: A brief outline of the important results or findings in each paper
      iii. Conclusions: A summary of the main conclusions of each paper
   d. Marking: The following general and approximate marking scheme will be used:
      Background (3/14); Results & Discussion (4/14); Summary of Conclusions (1/14); General Presentation (2/14); Answers to questions (4/14).
      Note: The variety in the nature of the different topics may require customizing the marking scheme to make it more relevant to the individual topics. Therefore, the actual marking scheme may differ from this one.

7) Written Critique:
   a. The critique will be 3 single-spaced pages max (+ a title page, that shows your name, the main topic covered by the papers, and the full bibliographic information of the papers) written in font size 12, and will include two parts; 1) a ~¼ - ½ page overview for each paper, each in a separate section, that summarizes the main findings and conclusions of the paper, and 2) a personal critique section that presents your own views of the strengths and/or weaknesses of the papers, with appropriate justifications, and areas where results or conclusions of the papers may agree or disagree with each other.
   b. The critique **is due by Friday, April 4th, 2025.** The document should be submitted by uploading it to the designated Dropbox folder on Learn. **Turnitin® software will be used in assessing the originality of the writing.**
   c. Marking: The following general and approximate marking scheme will be used: Part 1 (4.5/9); Part 2 (4.5/9)
      Note: The variety in the nature of the different topics may require customizing the marking scheme to make it more relevant to the individual topics. Therefore, the actual marking scheme may differ from this one.

Important information:

Fair Contingencies for Emergency Remote Teaching: The course outline presents the instructor's intentions for course assessments, their weights, and due dates in Winter 2023. **As best as possible, we will keep to the specified assessments, weights and dates**. To provide contingency for unforeseen circumstances, the instructor reserves the right to modify course topics and/or assessments and/or weight and/or deadlines with **due and fair notice to students**. In the event of such challenges, **the instructor will work with the Department/Faculty to find reasonable and fair solutions that respect rights and workloads of students, staff, and faculty**.

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 the Office of Academic Integrity for more information.]

Grievance: A student who believes that a decision affecting some aspect of their university life has been unfair or unreasonable may have grounds for initiating a grievance. Read Policy 70, Student Petitions and Grievances, Section 4. 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 to avoid committing an academic offence, and to take responsibility for their actions. [Check the Office of Academic Integrity for more information.] 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. For typical penalties, check Guidelines for the Assessment of Penalties.

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 they have a ground for an appeal should refer to Policy 72, Student Appeals.

Note for students with disabilities: AccessAbility Services, located in Needles Hall, Room 1401, 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 AccessAbility Services at the beginning of each academic term.

Turnitin.com: Text matching software (Turnitin®) may be used to screen submissions, assignments and other deliverables in this course. Turnitin® is used to verify that all materials and sources in assignments are documented. Students' submissions are stored on a U.S. server, therefore students must be given an alternative (e.g., scaffolded assignment or annotated bibliography), if they are concerned about their privacy and/or security. Students will be given due notice, in the first week of the term and/or at the time assignment details are provided, about arrangements and alternatives for the use of Turnitin in this course.