**EECS 538 Course Syllabus**

**Course #**: EECS 538
**Course Title**: Optical Waves in Crystals
**Term**: Fall 2015
**Course Website**: umich.instructure.com
*Note that we have switched to the new canvas website*

**Instructor:** Prof. Hafiz K. M. Sheriff, Jr.
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**Course Prerequisites:**
Anyone of EECS 434 (Principles of Photonics), EECS 334 (Principles of Optics), EECS 330 (Electromagnetics II) or graduate standing

**Principal Textbook:**
Yariv, Amnon and Yeh, Pochi, *Optical Waves in Crystals: Propagation and Control of Laser Radiation*, A Wiley Interscience Publication, John Wiley & Sons, USA, 1984, ISBN 0-471-43081-1

**Supplementary Textbook:**
A. Siegman, *Lasers*, University Science Books, USA, 1986, ISBN 0-935702-11-3

**Lectures:**
M & W 9:00 AM – 10:30 AM in EECS 3427

**Office Hours:**
M 4:00 PM – 5:00 PM, Tu 10:00 AM – 11:00 AM, and F 3:00 PM – 4:00 PM

You may also request an appointment via email. I strongly admonish you to fit within the given office hours. I do not guarantee you securing an appointment with me outside of the office hours. All appointments must be schedule for the week days (Mondays through Fridays) and during normal working hours.

**Overview of Course Objectives:**
This course is intended to provide the student with a complete coverage of the propagation of optical waves in anisotropic crystals and a complete study of electro- and acousto-optic phenomena and the devices that may result from these phenomena. By the end of this course, the student will be able to analyze the propagation of optical waves through any sort of media (anisotropic or isotropic) and explain the electro- and acousto-optic effects in crystals. The concept of the polarization of light is covered in every detail. This course also aims at extensively discussing the coupled-more theory and Bragg diffraction. Finally, this course intends to give the student a very brief but essential introduction to non-linear optical phenomena especially that of second harmonic generation.

**Grading Scheme:**
Homework ---------- 20 %
Mid-term Exam ---------- 20 %
Final Exam ---------- 30 %
Project:
- Report ---------- 20 %
- Presentation ------- 10 %

**Exam Dates, Times and Rooms:**

Mid-term Exam ---------- November 3 from 7:00 PM to 9:00 PM (EECS 3427)
Final Exam ---------- December 21 from 4:00 PM to 6:00 PM (EECS 1002)

**Class Policies:**

- **Honor Code:** The College of engineering Honor Code applies to all homework, exams and project work. I assume that you are familiar with this code. Please ask me if you are not. There may be no more cooperation on homework other than what I have allowed (see policy on homework below). Any violation of the Honor Code will be reported to the Honor Council.

- **Grading:** There will be at least seven (7) homework sets. Each set will be worth 20 points. Your final homework score will be the average on all your homework scores. The final score for your project will be derived from your group report and presentation. Although you are to work in groups on your projects, your total project score will be based upon your individual contribution (each student most indicate his/her name against the section of the project report he/she was in charge of in the report). Also, you will be expected to structure your presentation in such a way that everyone in the group will have the chance to participate. Your final course grade will be a straight one as opposed to a curved grade.

- **Homework:** All homework are due one week after they are assigned and before lectures. Homework will typically be assigned on Wednesdays and will be due the following Wednesdays (in class and before lectures begin). If you have to submit your homework late, you must seek my permission to do so via and email. Send me an email at least before 10 hours before the due time when seeking an extension in the due date. Typically, an extension will be granted if I deem your request genuine. However, this is not a promise. I strongly encourage you to submit your homework on time. In the case when extension is sought, the student will be given no more than 24 hours of extension. No points will be deducted in this case. Otherwise, no late homework will be accepted. If a student has to submit a ***permitted late homework*** and I am not in my office, he/she may slide it under my door. The amount of collaboration allowed on homework is limited to discussions of the subtleties of the homework. Absolutely, no more collaboration is allowed. Copying of previous homework solutions is strictly prohibited and consider a violation of the honor code.

- **Class Attendance:** Attendance is strictly required. Although no extra point is given for attendance, unauthorized absences from class will be regarded as the lack of regards for class. However, students having genuine reasons to miss class may obtain my permission to do so by sending me and email at least one day before the class (except in the case of emergency). In the case of emergency, please do not wait for my permission to attend to the emergency. Attend to the emergency first! Tell me about it later.

- **Religious Holidays:** Revert to the University of Michigan policy on this.

- **Missing Exams:** If a student misses the mid-term or final exam upon my permission, the responsibility is solely upon me to schedule his/her exam within time for his/her grade to be reported within the 72-hour reporting period. Any absence from the mid-term or final exam other than the mentioned scenario will be resolved according to the Department of Electrical Engineering policy on the issue.

- **Exams:** All exams will be open book. However, there might be restrictions on the materials you may be allowed to use and these restrictions will be announced on the class day preceding the exam. If no such announcement is made, you are allowed to bring your class notes, posted lecture notes, and the main textbook (*Optical Waves in Crystals: Propagation and Control of Laser Radiation*), a standard scientific calculator (no more sophisticated than the TI series) and nothing else. The mid-term schedule is tentative and could be changed as the needs might be and with the consent of the class. The final exam schedule is fixed by the University of Michigan. All exams are two hours in length. No extra time shall be given since the exams' rooms might be booked for other activities immediately after the exam of our class.

- **Project:** There will be at least three intermediate project meetings with each project group during the semester. These meetings will not be held during class time. During the second week of lecture, the project groups will be formed and the meeting dates for each group will be decided. The purpose of these meetings will be to make sure that each group is making significant progress on the project. These meetings are not intended to grade you during the execution of your projects. Feel free to state the difficulties you encounter while working on your project during these meetings. These meetings are not substitutes for the final project presentation.

**Notes:** *(1) The Thanksgiving recess will not affect our lectures. See the detailed course outline below.*
*(2) There will be one bonus lecture on December 16 from 7:00 PM to 9:00 PM in EECS 1002.*
*(3) Refer to the website: http://ro.umich.edu/calendar/fa15.php and take note of the drop dates.*
*(4) Students with disabilities are encouraged to meet with me for special accommodations.*
*(5) All of the above rules are subject to change when needs be. You will be duly informed in such instance.*

**Course Outline:**

09/07 – Day 0 (Monday)
- Labor Day: No lecture

09/09 – Day 1 (Wednesday)
- Course overview and syllabus
- Review of Electromagnetics: Maxwell's equations; constitutive relations; material polarizations; boundary conditions; Poynting theorem
- Time Harmonic Fields: plane electromagnetic waves; Helmholtz equation
- Polarization of Light

09/14 – Day 2 (Monday)
- Polarization of Light: coordinate systems (rotated and laboratory frames); polarization ellipse; special cases (linear and circular); complex number representation of polarization states
- Jones Vector
- Formation of Project Groups

09/16 – Day 3 (Wednesday)
- Jones Vectors: Jones units vector; normalization; orthogonality
- Stokes Parameters: Stokes vector; Stokes parameters for partially polarized light; degree of polarization;
- Homework #1: Due Sept. 23

09/21 – Day 4 (Monday)

- Review of Stokes Parameters and Complex Fields
- Relation between Stokes Parameters and the Polarization Ellipse
- Poincare Sphere
- Jones Calculus: Jones matrix
- Retarders (wave/phase plates): special wave plates (half-wave and quarter-wave plates)

09/23 – Day 5 (Wednesday)

- Retarders
- Polarizers
- Some General Properties of Jones Matrices: unitarity; reciprocity; Hermitian conjugates
- Some Applications of Polarizers: intensity transmission; Malus Law, intensity transmission of birefringent media placed between polarizers; transmission of arbitrarily polarized light through a polarizer at 45˚
- Homework #2: Due Sept. 30

09/28 – Day 6 (Monday)

- Measurement of Stokes Parameters
- Mueller Matrices
- Wave Propagation in Anisotropic Media: tensor susceptibility; permittivity tensor; general relation between **E, D, H, B,** and **S** vectors

09/30 – Day 7 (Wednesday)

- Review of Wave Propagation in Anisotropic Media
- Physical Interpretation of $|\mathbf{M}| = 0$ (special case)
- Normal Refractive Indices and k-Surfaces
- Fresnel Equation for $n^2$
- Eigenmodes of Light Waves in Anisotropic Media

10/05 – Day 8 (Monday)

- Classification of Different Anisotropic Materials: three principal refractive indices; biaxial crystals; uniaxial crystals (positive and negative uniaxial crystals); isotropic crystals
- Phase, Group, and Energy Velocities of Optical Waves in Anisotropic Crystals
- Index Ellipsoid

10/07 – Day 9 (Wednesday)

- Index Ellipsoid (continues): getting normal surfaces from index ellipsoids
- Finding the Eigenmodes of Optical Waves in Anisotropic Crystals by the Method of the Intersection Ellipse (a proof)
- Double Refraction
- Homework #3: Due Oct. 14

10/12 – Day 10 (Monday)

- Double Refraction (continues): the Glenn Prism
- Polarization Maintaining Fibers: beat length
- Circular Birefringence and Faraday's Effect: optical activity; gyration vector; Faraday Effect

10/14 – Day 11 (Wednesday)

- Faraday Effect (continues): Verdet Constant

- Some Applications of Faraday Effect: optical isolators
- Induced Circular Birefringence
- Coupled-Mode Theory for Wave Propagation in An Anisotropic Medium: brief derivation

10/19 – No Lecture (Monday)
- Fall Break

10/21 – Day 12 (Wednesday)
- Coupled-Mode Theory for Wave Propagation in An Anisotropic Medium (continues): a solution
- Fiber-optic Current Sensor (an application)
- Talk about Mid-term Exam
- Homework #4: Due Oct. 28

10/26 – Day 13 (Monday)
- Waves in Periodic Structures: Bragg reflections
- Coupled-mode theory (for periodic structures): derivation of equation; solution
- Some Applications: optical filter; diffraction gratings; holograms; distributed feedback lasers; fiber-Bragg gratings

10/28 – Day 14 (Wednesday)
- Generalization to Arbitrary Periodic Structures: Helmholtz equation; orthogonality of eigenmodes; Fourier expansion
- Special Cases: co- and counter-directional coupling
- Discussion of Specific Conditions of the Mid-Term Exam

11/02 – Day 15 (Monday)
- Periodic Structures and Fourier Expansion
- Review of Mid-Term Exam: question and answers

11/03 – Not a Lecture Day (Tuesday)
- Mid-term exam: 7:00 PM to 9:00 PM

11/04 – Day 16 (Wednesday)
- Coupled-mode Theory (continues): coupling coefficient
- Electro-optic Effect
- Impermeability Tensor
- An Overview of Tensors: rank; transformations
- Linear Electro-optic Effect
- Homework #5: Due Nov. 11

11/09 – Day 17 (Monday)
- Mid-term Exam Result: discussion or result; review of solution to mid-term
- An Example of Linear Electro-optic Effect in KDP ($KH_2PO_4$) crystal

11/11 – Day 18 (Wednesday)
- KDP Crystal and the Electro-optic Effect
- $LiNbO_3$ Crystal and the Electro-optic Effect
- Electro-optic Modulation: half-wave voltage; amplitude modulation

- Homework #6: Due Nov. 18

11/16 – Day 19 (Monday)
- Electro-optic Modulation: phase modulation; phase modulation in $LiNbO_3$ Crystal; transverse electro-optic modulation (Example: $LiTaO_3$ crystal
- General Approach to Diagonalizing the Impermeability Tensor in the Presence of an Applied Electric Field

11/18 – Day 20 (Wednesday)
- General Approach to Diagonalizing the Impermeability Tensor in the Presence of an Applied Electric Field: an example
- High Frequency Considerations and the Modulation of Power
- Modulation of Power Required for a Given Phase Shift
- Geometries of Some Practical Modulators: waveguide electro-optic modulators; Mach-Zehnder interference modulator; Fabry-Perot electro-optic modulator

11/23– Day 21 (Monday)
- Fabry-Perot Electro-optic Modulator (continue): free spectral range; finesse
- Quadratic Electro-optic Effect: second order Taylor expansion; Kerr Effect
- An Example of Kerr Effect in An Isotropic Medium
- Some Applications of Kerr Effect: Q-switching; modulations

11/25 – Day 22 (Wednesday)
- *Note that Thanksgiving recess begins at 5:00 PM and our class meets at 9:00 AM. So we will meet on 11/25 at our class time!*
- Liquid Crystal Displays: a career example
- Acousto-optic Effect
- Applications: modulators; optical switches; beam scanners; deflectors; tunable filters; mode-locking lasers
- Strain and the Strain Tensor: longitudinal waves; an example of acousto-optic effect in germanium crystal
- Diffraction of Light by Periodic Index Modulation: Bragg condition

11/30 – Day 23 (Monday)
- *Note that classes resume [after Thanksgiving recess] at 8:00 AM on November 30 and our class meets at 9:00 AM. So we will meet on 11/30 at our class time!*
- The Strain Tensor (recap)
- Coupled-mode Theory with Periodic Index Perturbation
- Small-Angle Bragg Diffraction: wave vector mismatch; diffraction efficiency

11/02 – Day 24 (Wednesday)
- Small-Angle Bragg Diffraction (continue)
- Large-Angle Bragg Diffraction
- Coupled-mode Equations for Large-Angle Bragg Diffraction
- Homework #7: Due Dec. 9

12/07 – Day 25 (Monday)
- Examples: coupled-mode equations for large-angle Bragg diffraction

12/09 – Day 26 (Wednesday)

- Raman-Nath Diffraction
- Criterion for Raman-Nath (multiple) Scattering
- Raman-Nath Diffraction (recap): examples
- Applications of Acousto-optic Effect: modulators; beam deflectors and scanners

12/14 – Day 27 (Monday)

- Special Topic: An Introduction to Non-linear Optics
- Effects Due to Second Order Nonlinear Polarization
- Second Harmonic Generation: phase matching
- Calculating the Phase-Matching Angle: A Fundamental Nonlinear Optics Problem
- Official Lectures End

12/16 – Bonus Lecture (Wednesday)

- Second Order Harmonic Generation: non-critical phase-matching; self-focusing; the Hercules Laser (at the University of Michigan)
- Special Topic: A Brief Introduction to Metamaterials
- Discussion of the Final Exam

12/21 – Not a Lecture Day (Monday)

- Final Exam: 4:00 PM to 6:00 PM