**"Semiconductors Beyond Si"**
EMA 4615: Compound Semiconductor Materials/
EMA 6412: Synthesis and Characterization of Electronic Materials
***Class Periods:*** MWF, Period 3, 9:35-10:25 am
***Location:*** NEB 201
***Academic Term:*** Spring 2024

***Instructor:***
Jennifer Hite
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352.272.2714
Office Hours: TBD, 152 Rhines Hall

***Teaching Assistant/Peer Mentor/Supervised Teaching Student:***
There are none for this course

***Course Description***
This is a 3-credit co-listed undergraduate/graduate class (4615/6412). The course builds on a basic understanding of electronic properties of materials (EMA 3413) and nanofabrication processing techniques (EMA 4614) and provides an overview of electronic materials that have emerged over the last few decades. These "beyond silicon" electronic materials enabled more flexible, energy-efficient, and better light-emitting electronics and led to the development of many familiar technologies including flat screens, wearable devices, and infrared detectors.

***Course Pre-Requisites / Co-Requisites***
Suggested: EMA 4614/6616, and either EMA 3413 or EEE 3396C

***Course Objectives***
The objective of this course is to understand epitaxial semiconductor growth, electronic and optoelectronic device structure and operation, and uses of semiconductor materials and devices in materials systems beyond silicon. The structure of the class is based around those three areas. It will start with a recap of crystal structures and then form an understanding of epitaxial growth mechanisms and techniques. The formation (and effects) of defects as well as characterization techniques will be included. The next focus will be on why we grow these materials – first focusing on electronic band structures and the physics of electronic devices (transistors), then moving to optoelectonic devices (LEDs, lasers). The first two sections will mainly involve the III-V compound semiconductors (GaAs). The last section expands to materials beyond the classic III-Vs or Si and moves to wide bandgap materials (SiC, GaN) for power electronics, organic semiconductors, and then oxides for piezoelectric and ferroelectric applications.

***Materials and Supply Fees***
None.

***Required Textbooks and Software***
None.

***Recommended Materials***
- Helpful texts:
- **For Background/Foundation:** *Principles of Electronic Materials and Devices*, S. O. Kasap, third edition, McGraw-Hill, 2006, ISBN-10: 0072957913.
- **MOCVD**: *Organometallic Vapor Phase Epitaxy*, G. B. Stringfellow, second edition, Associated Press, 1998, ISBN-10: 0126738424
- **Solid State Physics and Device Physics:**
    - *Introduction to Solid State Physics*, C. Kittel, eighth edition, Wiley, 2004, ISBN-10: 047141526X

- *Semiconductor Device Physics and Design*, U. K. Mishra and J. Singh, first edition, Springer, 2008, ISBN: 9781402064807

- Nanohub.org account – will be used for device simulations occasionally

***Course Schedule (Tentative)***

| Section | Module | Lecture | Content |
|---|---|---|---|
| S1: Epitaxial Growth + Dimensionality | M1: Intro/Compound Semiconductors | 1 | Intro/Syllabus/Why compound? |
| | | 2 | Crystal structures & materials |
| | | 3 | Beyond Binary, Structure review |
| | M2: Epitaxy | 4 | Epi Basics |
| | | 5 | Epi Thermodynamics and Kinetics |
| | | 6 | Controlling Epi, doping |
| | | 7 | Epi Review/MOCVD |
| | | 8 | MOCVD |
| | | 9 | MBE |
| | | 10 | PLD, ALD |
| | | 11 | Growth Review/Practice |
| | | 12 | Epi Characterization |
| | | 13 | Defects |
| | | 14 | Defect Practice |
| | M3: Dimensionality | 15 | Introduction, 2D |
| | | 16 | 1D, 0D |
| | | 17 | Review |
| | | 18 | **EXAM** |
| S2: Electric and Optoelectronic Device Physics | M4: Physics of Electronic Devices | 19 | Electronic Structure |
| | | 20 | Eg Engineering/Fermi |
| | | 21 | Contacts/Practice |
| | | 22 | Heterojunctions (ideal vs non-ideal) |
| | | 23 | BJTs and HBTs |
| | | 24 | FETs |
| | | 25 | Buffer/E-Device Review |
| | M5: Optoelectronic Devices | 26 | Photonics |
| | | 27-29 | LEDs, Lasers, Multijunctions |
| | | 30 | Review |
| | | 31 | **EXAM** |
| S3: Non-Classic Compound Semiconductors | M6: Power Electronics | 32 | Intro/Basics |
| | | 33 | SiC--> GaN |
| | | 34 | Beyond GaN |
| | | 35 | Diamond |
| | M7: Organic & Oxide Semiconductors | 36-37 | Organic Semiconductors |
| | | 38-39 | Oxide Semiconductors - Piezoelectrics, Ferroelectrics |
| | | 40 | Buffer/Review |
| | | 41 | **EXAM** |
| | M7B: Next Generation Chips | 42 | Quantum |
| | | 43 | Photonic IC/Heterogeneous Incorporation |

***Attendance Policy, Class Expectations, and Make-Up Policy***

Sections of this course are offered online via UF EDGE. Lectures will be recorded, and the lecture videos are available on the UF e-Learning (Canvas) website for all students (not just those who registered for the EDGE section) to review at any time. However, class attendance is strongly encouraged for all non-EDGE students to enhance classroom learning and interaction. Students are encouraged to actively participate in various in-class interactive activities. Questions from students are also encouraged.

Proper behavior in class is required. Eating, texting, chatting, or other activities that are not part of the class are not allowed. Students who do not comply with these requirements or who behave disorderly or disrespectfully may be asked to leave the classroom. Cell phones and other electronic devices must be completely silence or turned off.

Excused absences must be consistent with university policies in the Graduate Catalog (https://catalog.ufl.edu/graduate/regulations) and require appropriate documentation. Additional information can be found here: https://gradcatalog.ufl.edu/graduate/regulations/. Other than in emergency situations, you must *notify the instructor of your scheduled absence for exams and discuss make-up options* ***at least one week prior*** to your absence; failure to do so may not allow you to make up for the missed exam.

***Evaluation of Grades***

| Assignment | Percentage of Final Grade |
|---|---|
| Homework | 10% |
| Exam 1 | 25% |
| Exam 2 | 25% |
| Exam 3 | 20% |
| Final Project | 20% |
| | 100% |

*Homework:* Homework will be given for each of the modules, and is mainly graded for completion. The homework is to reinforce concepts and help prepare for exams. Homework will be posted around the beginning of the module, and will be due two days after the completion of the module, unless otherwise noted. All unexcused missed assignments will be accepted between 0-24 hours after the deadline for a maximum 50% credit.
*Final Project*: You will record a 5-minute mini-lecture video with slides to teach your peers more about one of the subtopics from the course schedule, or a closely related topic to be approved by the instructor. Your first-drafts will be uploaded to Canvas mid-semester, and you will receive peer and my feedback. You will then have the option to incorporate that feedback, refine your video, and turn it in at the end of the semester for a final round of peer and professor grading, or keep your initial grade and skip the final submission. More details will be on Canvas.

***Grading Policy***

The following is given as an example only.

| Percent | Grade | Grade Points |
|---|---|---|
| 93.4 - 100 | A | 4.00 |
| 90.0 - 93.3 | A- | 3.67 |
| 86.7 - 89.9 | B+ | 3.33 |
| 83.4 - 86.6 | B | 3.00 |
| 80.0 - 83.3 | B- | 2.67 |
| 76.7 - 79.9 | C+ | 2.33 |
| 73.4 - 76.6 | C | 2.00 |
| 70.0 - 73.3 | C- | 1.67 |
| 66.7 - 69.9 | D+ | 1.33 |
| 63.4 - 66.6 | D | 1.00 |

| | | |
|---|---|---|
| 60.0 - 63.3 | D- | 0.67 |
| 0 - 59.9 | E | 0.00 |

More information on UF grading policy may be found at:
UF Graduate Catalog
Grades and Grading Policies

***Students Requiring Accommodations***
Students with disabilities who experience learning barriers and would like to request academic accommodations should connect with the disability Resource Center by visiting https://disability.ufl.edu/students/get-started/. It is important for students to share their accommodation letter with their instructor and discuss their access needs, as early as possible in the semester.

***Course Evaluation***
Students are expected to provide professional and respectful feedback on the quality of instruction in this course by completing course evaluations online via GatorEvals. Guidance on how to give feedback in a professional and respectful manner is available at https://gatorevals.aa.ufl.edu/students/. Students will be notified when the evaluation period opens, and can complete evaluations through the email they receive from GatorEvals, in their Canvas course menu under GatorEvals, or via https://ufl.bluera.com/ufl/. Summaries of course evaluation results are available to students at https://gatorevals.aa.ufl.edu/public-results/.

**In-Class Recording**
Students are allowed to record video or audio of class lectures. However, the purposes for which these recordings may be used are strictly controlled. The only allowable purposes are (1) for personal educational use, (2) in connection with a complaint to the university, or (3) as evidence in, or in preparation for, a criminal or civil proceeding. All other purposes are prohibited. Specifically, students may not publish recorded lectures without the written consent of the instructor.

A "class lecture" is an educational presentation intended to inform or teach enrolled students about a particular subject, including any instructor-led discussions that form part of the presentation, and delivered by any instructor hired or appointed by the University, or by a guest instructor, as part of a University of Florida course. A class lecture does not include lab sessions, student presentations, clinical presentations such as patient history, academic exercises involving solely student participation, assessments (quizzes, tests, exams), field trips, private conversations between students in the class or between a student and the faculty or lecturer during a class session.

Publication without permission of the instructor is prohibited. To "publish" means to share, transmit, circulate, distribute, or provide access to a recording, regardless of format or medium, to another person (or persons), including but not limited to another student within the same class section. Additionally, a recording, or transcript of a recording, is considered published if it is posted on or uploaded to, in whole or in part, any media platform, including but not limited to social media, book, magazine, newspaper, leaflet, or third party note/tutoring services. A student who publishes a recording without written consent may be subject to a civil cause of action instituted by a person injured by the publication and/or discipline under UF Regulation 4.040 Student Honor Code and Student Conduct Code.

***University Honesty Policy***
UF students are bound by The Honor Pledge which states, "We, the members of the University of Florida community, pledge to hold ourselves and our peers to the highest standards of honor and integrity by abiding by the Honor Code. On all work submitted for credit by students at the University of Florida, the following pledge is either required or implied: "On my honor, I have neither given nor received unauthorized aid in doing this assignment." The Honor Code (https://sccr.dso.ufl.edu/process/student-conduct-code/) specifies a number of behaviors that are in violation of this code and the possible sanctions. Furthermore, you are obligated to report any condition that facilitates

academic misconduct to appropriate personnel. If you have any questions or concerns, please consult with the instructor or TAs in this class.

***Commitment to a Safe and Inclusive Learning Environment***
The Herbert Wertheim College of Engineering values varied perspectives and lived experiences within our community and is committed to supporting the University's core values, including the elimination of discrimination. It is expected that every person in this class will treat one another with dignity and respect regardless of race, creed, color, religion, age, disability, sex, sexual orientation, gender identity and expression, marital status, national origin, political opinions or affiliations, genetic information, and veteran status.

If you feel like your performance in class is being impacted by discrimination or harassment of any kind, please contact your instructor or any of the following:
• Your academic advisor or Graduate Program Coordinator
• HWCOE Human Resources, 352-392-0904, student-support-hr@eng.ufl.edu
• Curtis Taylor, Associate Dean of Student Affairs, 352-392-2177, taylor@eng.ufl.edu
• Toshikazu Nishida, Associate Dean of Academic Affairs, 352-392-0943, nishida@eng.ufl.edu

***Software Use***
All faculty, staff, and students of the University are required and expected to obey the laws and legal agreements governing software use. Failure to do so can lead to monetary damages and/or criminal penalties for the individual violator. Because such violations are also against University policies and rules, disciplinary action will be taken as appropriate. We, the members of the University of Florida community, pledge to uphold ourselves and our peers to the highest standards of honesty and integrity.

***Student Privacy***
There are federal laws protecting your privacy with regards to grades earned in courses and on individual assignments. For more information, please see: https://registrar.ufl.edu/ferpa.html

***Campus Resources:***
*Health and Wellness*

**U Matter, We Care:**
Your well-being is important to the University of Florida. The U Matter, We Care initiative is committed to creating a culture of care on our campus by encouraging members of our community to look out for one another and to reach out for help if a member of our community is in need. If you or a friend is in distress, please contact umatter@ufl.edu so that the U Matter, We Care Team can reach out to the student in distress. A nighttime and weekend crisis counselor is available by phone at 352-392-1575. The U Matter, We Care Team can help connect students to the many other helping resources available including, but not limited to, Victim Advocates, Housing staff, and the Counseling and Wellness Center. Please remember that asking for help is a sign of strength. In case of emergency, call 9-1-1.

**Counseling and Wellness Center:** https://counseling.ufl.edu, and 392-1575; and the University Police Department: 392-1111 or 9-1-1 for emergencies.

**Sexual Discrimination, Harassment, Assault, or Violence**
If you or a friend has been subjected to sexual discrimination, sexual harassment, sexual assault, or violence contact the **Office of Title IX Compliance**, located at Yon Hall Room 427, 1908 Stadium Road, (352) 273-1094, title-ix@ufl.edu

**Sexual Assault Recovery Services (SARS)**
Student Health Care Center, 392-1161.

**University Police Department** at 392-1111 (or 9-1-1 for emergencies), or http://www.police.ufl.edu/.

*Academic Resources*

**E-learning technical suppor***t*, 352-392-4357 (select option 2) or e-mail to Learning-support@ufl.edu. https://lss.at.ufl.edu/help.shtml.

**Career Connections Center**, Reitz Union, 392-1601. Career assistance and counseling; https://career.ufl.edu.

**Library Support**, http://cms.uflib.ufl.edu/ask. Various ways to receive assistance with respect to using the libraries or finding resources.

**Teaching Center**, Broward Hall, 392-2010 or 392-6420. General study skills and tutoring. https://teachingcenter.ufl.edu/.

**Writing Studio, 302 Tigert Hall***,* 846-1138. Help brainstorming, formatting, and writing papers. https://writing.ufl.edu/writing-studio/.

**Student Complaints Campus***:* https://sccr.dso.ufl.edu/policies/student-honor-code-student-conduct-code/;https://care.dso.ufl.edu.

**On-Line Students Complaints***: https://distance.ufl.edu/getting-help/; https://distance.ufl.edu/state-authorization-status/#student-complaint.*