# Advanced Electronic Materials Processing

EMA 4614/6616
***Class Periods:*** MWF, 1:55-2:45 PM (Period 7)
***Location:*** Online, via Canvas and Zoom
***Academic Term:*** Fall 2020

***Instructor:***
Ryan F. Need (they/them)
150 Rhines Hall
rneed@ufl.edu
352-294-1690

***Teaching Assistants***
There are none for this course.

***Course Description***
This is a 3 credit undergraduate/graduate class (4614/6616). The course provides an overview of how semiconductors and related materials are processed into devices that enable modern information technology like computers and wireless communication. We begin by reviewing basic properties of electronic materials, then cover several key processing techniques – crystal growth, lithography, etching, deposition, implantation, annealing and oxidation – that are needed to pattern materials into devices. Common electronic and photonic devices, such as bipolar transistors, metal-semiconductor field effect transistors, metal-oxide semiconductor field effect transistors, diode lasers and light-emitting diodes, will be described. Finally, we will address limitations in current materials and device technologies, and the frontier research areas attempting to solve those problems, such as 2D electronic materials and correlated electron materials.

***Course Pre-Requisites / Co-Requisites***
None, but some knowledge of the electronic properties of materials is assumed.

***Course Objectives***
To provide the student with an up-to-date picture of how modern semiconductor chips are fabricated; comparison of Si versus compound semiconductors; processing modules such as diffusion, ion implantation, wet and dry etching and metal deposition; materials selection requirements; yield and reliability requirements; basics of component devices such as MOSFETs, bipolar transistors, LEDs and laser diodes; introduction to emerging electronic technologies and materials.

***Materials and Supply Fees***
None

***Required Textbooks and Software***
- Nanohub.org account – will be used for device simulations in the latter half of the semester

***Recommended Course Materials***
- Main text:
  - *Fabrication Engineering at the Micro- and Nanoscale*, S. A. Campbell, fourth edition, Oxford University Press, 2012, ISBN-10: 0199861226.
  - Note: This text can rented digitally for the semester for $60 through RedShelf.
- Supplementary texts:
  - *Principles of Electronic Materials and Devices*, S. O. Kasap, third edition, McGraw-Hill, 2006, ISBN-10: 0072957913.
  - *Semiconductor Device Physics and Design*, U. K. Mishra and J. Singh, first edition, Springer, 2008, ISBN: 9781402064807

***Professional Component (ABET)***
3 credits Engineering Topics.

***Relation to Program Outcomes (ABET)***

| Outcome | Coverage* |
|---|---|
| 1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics | Medium |
| 2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors | |
| 3. an ability to communicate effectively with a range of audiences | |
| 4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts | |
| 5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives | |
| 6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions | |
| 7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies. | |

*Coverage is given as high, medium, or low. An empty box indicates that this outcome is not covered or assessed in the course.

***Course Schedule*** *(subject to change)*

| Module | Lecture | Broad Topic | Subtopics |
|---|---|---|---|
| | 1 | Course Introduction | Historical perspective, course overview, syllabus |
| 1 | 2 | Metals | Electronic material classes, key metals, Drude model |
| | 3 | Semiconductors I | Key semiconductors, intrinsic vs. extrinsic semis |
| | 4 | Semiconductors II | Band theory, direct vs. indirect gaps, effective mass |
| | 5 | Dielectrics | Key dielectrics, polarization, capacitance |
| 2 | 6 | Bulk Crystal Growth | Czocharlaski, float zone, Bridgman |
| | 7 | Thin Film Growth I | PVD overview, thermal evaporation, MBE |
| | 8 | Thin Film Growth II | Sputtering, e-beam deposition, PLD |
| | 9 | Thin Film Growth III | CVD overview, MOCVD, CBE |
| 3 | 10 | Lithography I | Photolithography, proximity and contact methods |
| | 11 | Lithography II | Projection, immersion, e-beam, and X-ray lithography |
| | 12 | Lithography III | Masks and photoresists |
| 4 | 13 | Etching I | Wet etching, chemical mechanical polishing |
| | 14 | Etching II | Plasma etching, high-density plasma etching |

| | | | |
|---|---|---|---|
| | 15 | Etching III | Ion milling, reactive ion etching |
| 5 | 16 | Implantation I | Ion implantation, ion sources, Coulomb scattering |
| | 17 | Implantation II | Channeling, shallow junctions, implantation damage |
| 6 | 18 | Diffusion | Fick's law, dopant diffusion |
| | 19 | Thermal Oxidation | Deal-Grove model, oxidation regimes, SiO2 vs. GeO2 |
| | 20 | Rapid Thermal Processing | Radiative heat transfer, RTP uses |
| | 21 | Exam 1: Synthesis and Processing | |
| 7 | 22 | Characterization I | Diffraction: X-rays, neutrons |
| | 23 | Characterization II | Microscopy: SEM, AFM, STM (link to 1D well) |
| | 24 | Characterization III | Transport: conductivity, dielectric strength |
| 8 | 25 | Diodes I | Contact formation, Ohmic vs. Schottkey |
| | 26 | Diodes II | Pn junction transport, LEDs, PV |
| | 27 | Diodes III | Lasers and other applications |
| 9 | 28 | Logic Devices I | MOSFET |
| | 29 | Logic Devices II | High-k gate dielectrics |
| | 30 | Logic Devices III | MESFETs, HBTs |
| | 31 | Logic Devices IV | HEMTs, FinFETs, TunnelFets |
| 10 | 32 | Memory Devices I | DRAM, SRAM |
| | 33 | Memory Devices II | Flash, ReRAM, MRAM |
| 11 | 34 | 2D electronics I | vdW prototypes, exfoliation processing |
| | 35 | 2D electronics II | Valleytronics, processing problems |
| 12 | 36 | Oxide electronics I | TMOs, correlated electron physics |
| | 37 | Oxide electronics II | Spintronics, processing problems |
| | 38 | Course Review I | Topics up to Exam I |
| | 39 | Course Review II | Topics after Exam I |

***Class Format, Lectures & Office Hours***

All lectures for this class will be pre-recorded and posted online to Canvas *approximately* two days before the corresponding MWF class time. For example, the first class of this term is Monday, 8/31. The first lecture will be posted roughly Saturday, 8/29, which is also when the course's Canvas will become open. The next class is Wednesday, 9/1, and the corresponding lecture will be available on Monday, 8/31.

During the "live" class times, MWF 1:55-2:45, I will hold Zoom sessions that serve as a combination of office hours, group discussion, and group practice problems. Basically, I'll end each recorded lecture either with a suggested, ungraded practice problem (or two) designed to reinforce the lecture content. If you would like to work/discuss the problem in a group, please join us for the following live class session. I am also willing to create one additional regularly occurring office hour for any students who have a standing conflict with the class time. If needed, the time will be determined by polling all the students for whom this applies.

***Recording Notification***

Our class sessions may be audio visually recorded for students in the class to refer back and for enrolled students who are unable to attend live. Students who participate with their camera engaged or utilize a profile image are agreeing to have their video or image recorded. If you are unwilling to consent to have your profile or video image recorded, be sure to keep your camera off and do not use a profile image. Likewise, students who un-mute during class and participate orally are agreeing to have their voices recorded. If you are not willing to consent to have your voice recorded during class, you will need to keep your mute button activated and communicate exclusively using the "chat" feature, which allows students to type questions and comments live. The chat will not be recorded or shared. As in all courses, unauthorized recording and unauthorized sharing of recorded materials is prohibited.

***Attendance Policy***

Attendance to the live Zoom sessions is not required but it is ***strongly*** encouraged, and experience has shown it adds significantly to the student's understanding of the course materials. If you attend the lectures, be prompt in

your arrival as a courtesy to me and the other students. Any persistent and disruptive behavior in Zoom sessions will result in the student being removed from the virtual classroom and, depending on the nature of the behavior, reported to the department, college, or university for misconduct.

***Make-Up Policy***
Generally, at least one-week advance notice is required for assignment or exam extension request. In accordance with university attendance policy, acceptable reasons for failure to participate in class include illness, serious family emergencies, special curricular requirements, military obligation, severe weather conditions, religious holidays, and participation in official university activities such as music performances, athletic competition or debate. For more detail on excused absences, refer to the undergraduate catalog (https://catalog.ufl.edu/ugrad/current/regulations/info/attendance.aspx).
Absences from class for court-imposed legal obligations (e.g., jury duty or subpoena) must be excused. Other reasons also may be approved. Please note that assignment deadlines for other courses will not be considered. Students who do not follow the approved procedure and timeliness for an assignment or exam will receive a score of zero. Assignments or exams missed for excused reasons must be re-scheduled in consultation with the lecturer.

***Class Expectations***
*Contacting the Professor:* Students should use Canvas to contact me. While you may email me at my UF email account, the university strongly encourages we communicate via Canvas to avoid the potential of violations of student confidentiality protected by FERPA. I strongly encourage students to attend virtual office hours (or schedule a meeting) to discuss any questions or concerns regarding the course.

*Messaging/Email Hours:* You may contact me via Canvas or email at any time that is convenient to you. I will respond within roughly one business day. If you do not receive a reply from me after 48 hours, please resend your message. Responses are not guaranteed after 5 PM on weekdays, on weekends, or on academic holidays. Please plan accordingly to have your questions answered in advance of assignment and exam deadlines.

*Interpersonal Conduct:* Mutual respect for your classmates, the TA, the professor, and yourself is expected in all communication; all class members are expected to treat each other at all times with respect, courtesy, tolerance, fairness, and justice.

*Effort*: The university recommends that students typically spend 9 to 12 hours per week for a 3 credit class. This can of course vary, but is a good initial guideline as the term begins.

*Recommendations for the Virtual Classroom:* Set boundaries you need to so you can focus in class: use headphones; tell roommates you're "in class"; and quiet audio and visual distractions from other electronics, books, and pets (as feasible). Maybe get ready as if you're going to class in person (This one works for me!). In general, ***set some boundaries and take ownership of your learning experience***.

*Recommendations for This Classroom:* For lectures, assignments, quizzes, and exams, please ask questions or let me know when content or a question is not making sense so that we can review it or I can change my approach.

***Evaluation of Grades: Option 1 (standard for 4614)***

| **Assignment** | **Points** | **Percentage of Final Grade** | **Frequency** | **Due** |
|---|---|---|---|---|
| Feedback (12) | 1 ea | 5% | One per module | **Three days** after the last lecture of the module posts |
| HW/Discussion (10) | 5 ea | 15% | One per module (except modules 11 &12) | |
| Quizzes (10) | 10 ea | 35% | | **Two days** after the last lecture of the module posts |
| Midterm Exam | - | 20% | Once | 10/21 |
| Final Exam | - | 25% | Once | 12/16 (3-5pm) |
| | | 100% | | |

***Evaluation of Grades: Option 2 (required for 6616, optional for 4614)***

| Assignment | Points | Percentage of Final Grade | Frequency | Due |
|---|---|---|---|---|
| Feedback (12) | 1 ea | 5% | One per module | **Three days** after the last lecture of the module posts |
| HW/Discussion (10) | 5 ea | 15% | One per module (except modules 11 &12) | |
| Quizzes (10) | 10 ea | *25%* | | **Two days** after the last lecture of the module posts |
| Midterm Exam | - | 20% | Once | 10/21 |
| *Term Paper* | - | *10%* | *Once* | *12/4* |
| Final Exam | - | 25% | Once | 12/16 (3-5pm) |
| | | 100% | | |

***** For students enrolled in 4614 who wish to complete a Term Paper and use the second grading option, ***you must notify me in writing before the midterm exam***. Once chosen, you will not be able to revert to the first grading option.

*Exams:* There will be two exams in this course, a midterm and final. Exams will be given through Canvas on the dates listed in the tables above. Once students begin the exam, they will have a finite time window with which to complete the exam. Exams *must* be completed individually with no collaboration.

*Quizzes:* The first ten modules will have quizzes associated with them. Quizzes are due by 11:59PM two days after the last lecture of the module is posted in Canvas, which is the same day as the last Zoom session of the module. That way students can ask any final questions about the module's content before taking the quiz. Quizzes are open note but *must* be completed individually with no collaboration.

*Homework & Discussion Prompts:* The first ten modules module will be accompanied by *either* a small problem set homework or a discussion post assignment. These assignments will be accessed and submitted through Canvas. Email and physical copies are not acceptable for submission methods. Homework and discussion posts are due by 11:59PM three days after the last lecture of the module posts – one day after the module's quiz is due.

*Feedback:* Each module I would like you to give me some feedback. Just two questions: What was the clearest or most useful part of the module? What was the muddiest or least useful part of the module? This will help me adjust my teaching approach both in the remainder of the semester and in future years. Feedback is graded for completion and due by 11:59PM three days after the last lecture of the module posts – the same day the homework or discussion post is due.

*Term Paper*: This assignment is designed to bring together course content and build writing skills. Specific topics will be assigned individually following the midterm taking into consideration each student's interest, but the general outline is to pick either a hypothetical device and describe why its advantageous and how it might be made, or to pick one realized/manufactured device and give a history of it's development and impact on the semiconductor industry.

**All unexcused missed assignments will be accepted within the first 24 hrs after the deadline for maximum 50% credit. After 24 hrs the assignment will receive a zero.**

***Grading Policy***

| 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 |

**Grades in this course are absolute and are not curved.**

**For EMA 4614 students:**
A "C" will not be a qualifying grade for critical tracking courses. In order to graduate, students must have an overall GPA and an upper-division GPA of 2.0 or better (C or better). Note: a C- average is equivalent to a GPA of 1.67, and therefore, it does not satisfy this graduation requirement. For more information on grades and grading policies, please visit: https://catalog.ufl.edu/ugrad/current/regulations/info/grades.aspx

**For EMA 6616 students:**
In order to graduate, graduate students must have an overall GPA and an upper division GPA of 3.0 or better (B or better). Note: a B- average is equivalent to a GPA of 2.67, and therefore, it does not satisfy this graduation requirement. For more information on grades and grading policies, please visit:
http://gradschool.ufl.edu/catalog/current-catalog/catalog-general-regulations.html#grades

More information on UF grading policy may be found at:
https://catalog.ufl.edu/ugrad/current/regulations/info/grades.aspx

***Students Requiring Accommodations***
Students with disabilities requesting accommodations should first register with the Disability Resource Center (352-392-8565, https://www.dso.ufl.edu/drc) by providing appropriate documentation. Once registered, students will receive an accommodation letter which must be presented to the instructor when requesting accommodation. Students with disabilities should follow this procedure as early as possible in the semester.

***Course Evaluation***
Students are expected to provide feedback on the quality of instruction in this course by completing online evaluations at https://evaluations.ufl.edu/evals. Evaluations are typically open during the last two or three weeks of the semester, but students will be given specific times when they are open. Summary results of these assessments are available to students at https://evaluations.ufl.edu/results/.

***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://www.dso.ufl.edu/sccr/process/student-conduct-honor-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 broad diversity within our community and is committed to individual and group empowerment, inclusion, and the elimination of discrimination. It is expected that every person in this class will treat one another with dignity and respect regardless of gender, sexuality, disability, age, socioeconomic status, ethnicity, race, and culture.

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
• Robin Bielling, Director of Human Resources, 352-392-0903, rbielling@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***
*Technology Resources*
The entirety of our course will take place virtually, requiring the use of a working computer and access to audio-visual resources (webcam, microphone, speakers). If you are struggling to use Zoom or Canvas, please review these UF Quick Start guides. This link also connects to UF resources regarding internet connectivity.

The UF Computing Help Desk can assist you with any of your technical issues. You can access the Help Desk 24/7 at https://helpdesk.ufl.edu/, 352-392- HELP (4357), or helpdesk.@ufl.edu. If you use email, write from your gatorlink@ufl.edu email address, or include your UFID and/or GatorLink username (NOT your password!) in the body of the email. Provide complete information regarding the course and content to which you are referring.

*Financial and COVID Related Services*
In case of emergency financial need, UF's Aid-a-Gator program provides students with emergency funding: https://www.sfa.ufl.edu/aidagator/. The program is intended to "help our students need to cover costs related to unanticipated travel, additional technology requirements, or other needs related to an emergency situation."

If you have a family member whose financial situation was affected by the COVID-19 crisis, especially loss of work hours or job, you may submit a revision petition for consideration of having their income reevaluated. UF is encouraging these students to complete the 2019-20 Financial Aid Revision Petition and the 2020-2021 Revision Petition.

*Health and Wellness*
If you or someone you know is struggling with any crisis including but not limited to gender, sexual, racial, or domestic violence, there are many community and University of Florida resources available. Some of these include:

- *RESPECT – UF Division of Student Affairs* (respect.ufsa.ufl.edu)
- *Student Health Care Center* (352-392-1161, shcc.ufl.edu)
- *Multicultural & Diversity Affairs* (352-392-1217, multicultural.ufl.edu)
- *UF Health Shands Emergency Room / Trauma Center* (352-733-0111)
- *Gainesville Police Department* (non-emergency #: 352-955-1818, gainesvillepd.org)

While faculty and staff in our department are also resources for you, please keep in mind some of us (including me) are Title IX mandatory reporters.

**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.

**Hitchcock Field & Fork Pantry:** https://pantry.fieldandfork.ufl.edu, assisting members of our campus community who experience food insecurity.

**Counseling and Wellness Center:** http://www.counseling.ufl.edu/cwc, 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 Resource Center**, Reitz Union, 392-1601. Career assistance and counseling. https://www.crc.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://www.dso.ufl.edu/documents/UF_Complaints_policy.pdf.

**On-Line Students Complaints***:* http://www.distance.ufl.edu/student-complaint-process.