Draft: Aug 24th 2021

SYLLABUS: ECE 5530 Fundamentals of Semiconductors for Microelectronic and Photonics

Semester: Au 2021

Course Instructor:

Prof. Sanjay Krishna
377 Caldwell Lab
614 292 3715
krishna.53@osu.edu

Lecture Times:

MWF, 10:20-11:15AM, Dreese Lab 264
https://osu.zoom.us/j/8906116294?pwd=T2lFb1RXQ2tqbWtmVU1vblVnQjRCQT09
Meeting ID: 890 611 6294
Password: 3MaJyr

Office Hours:

Wed, 11:30AM-12:30PM (Zoom or in person, Caldwell 377) or any time by appointment
https://osu.zoom.us/j/8906116294?pwd=T2lFb1RXQ2tqbWtmVU1vblVnQjRCQT09
Meeting ID: 890 611 6294
Password: 3MaJyr

Teaching and Grading Assistants:

Modeling Project Assistance: Sri Harsha Kodati, 374 Caldwell Lab
kodati.2@buckeyemail.osu.edu
Grader: Amber Arquitola, 370 Caldwell Lab,
arquitola.1@buckeyemail.osu.edu
Office Hours: Dr. Piotr Martyniuk, 372 Caldwell Lab,
martyniuk.3@osu.edu

Course Description:

Crystal structure, semiconductor energy band structure, electron transport and carrier recombination, heterostructures, and optical and dielectric properties. Prereq: 3030 (432), or Grad standing in Engineering, Biological Sciences, or Math and Physical Sciences. Not open to students with credit for 730. Units: 3 credit hours.

Learning Goals:

1. Become knowledgeable of various technologically important semiconductor materials beyond silicon
2. Learn advanced semiconductor physics
3. Learn electronic and optical properties of semiconductors and heterostructures
4. Learn about quantum effects and engineered properties of semiconductors
5. Learn how advanced properties are used in state of the art microelectronics and optoelectronics

Course Delivery:

Mode of delivery: This course is hybrid (in person/online and will be delivered synchronously). The lectures will take place on Mondays, Wednesdays, and Fridays from 10:20-11:15AM in Dreese Lab 264 and the lectures will be recorded over zoom. It is highly recommended that you attend the lectures for this course during the scheduled class time. The university is closely monitoring the COVID situation and if we need to provide a better mode of delivery that is better suited to the safety and convenience of the student, we will arrange to do that.

Pace of online activities: This course is divided into modules and lecture slides will be posted on Carmen prior to the lectures. Lecture videos will be posted on Carmen after the class lecture. Students are expected to keep pace with weekly deadlines but may schedule their efforts freely within that time frame.

Credit hours and work expectations: This is a 3-credit-hour course. According to Ohio State policy (go.osu.edu/credit hours), students should expect around 3 hours per week of time spent on direct instruction (instructor content and Carmen activities, for example) in addition to 6 hours of homework (reading and assignment preparation, for example) to receive a grade of (C) average.

Attendance and participation requirements: Because this is an hybrid course delivered synchronously, your attendance is recommended for the lectures and you are expected to participate in online activities during class.
The following is a summary of students' expected participation:

- Participating in online lectures for attendance: HIGHLY RECOMMENDED
  - You are expected to login to the course on Carmen every week, however most weeks you will probably login many times.
  - **If you have a situation that might cause you to miss an entire week of class, discuss it with me as soon as possible.**
- Office hours: OPTIONAL
  - All office hours are optional, however engaging with the instructor and teaching assistant will help with you to be successful in this course and with your overall learning experience.
- Participating in discussion forums: OPTIONAL

- This class features a substantial amount of class discussion, including discussion board posts. As part of your participation, each week you can expect to post at least twice on discussion boards related to the week's topics.

Course Technology:

CarmenCanvas will be used as the learning management system (LMS). All information related to the course including syllabus, learning modules, announcements, quizzes, discussions, grades, etc., will be on CarmenCanvas.

Technology skills needed for this course
• Basic computer and web-browsing skills
• Navigating Carmen (go.osu.edu/canvasstudent)
• CarmenZoom virtual meetings (go.osu.edu/zoom-meetings)
• Recording slide presentations with audio narration (go.osu.edu/video-assignment-guide)
• Recording, editing, and uploading videos (go.osu.edu/video-assignment-guide)

Required equipment
• Computer: current Mac (MacOs) or PC (Windows 10) with high-speed internet connection
• Webcam: built-in or external webcam, fully installed and tested
• Microphone: built-in laptop/ tablet mic or external microphone
• Other: a mobile device (smartphone or tablet) to use for BuckeyePass authentication

Required software

Homework problems and the theoretical modeling problem will require you to use mathematical tools such as Mathematica or Matlab, and plotting software. Both Mathematica and Matlab are available free of cost to OSU students. Make sure you have access to them by the end of the first week of class.

Microsoft Office 365: All Ohio State students are now eligible for free Microsoft Office 365. Full instructions for downloading and installation can be found at go.osu.edu/office365help.

Carmen access
You will need to use BuckeyePass (buckeyepass.osu.edu) multi-factor authentication to access your courses in Carmen. To ensure that you are able to connect to Carmen at all times, it is recommended that you take the following steps:
• Register multiple devices in case something happens to your primary device. Visit the BuckeyePass - Adding a Device help article for step-by-step instructions (go.osu.edu/add-device).

• Request passcodes to keep as a backup authentication option. When you see the Duo login screen on your computer, click Enter a Passcode and then click the Text me new codes button that appears. This will text you ten passcodes good for 365 days that can each be used once.
• Download the Duo Mobile application (go.osu.edu/install-duo) to all of your registered devices for the ability to generate one-time codes in the event that you lose cell, data, or Wi-Fi service

Technology support
For help with your password, university email, Carmen, or any other technology issues, questions, or requests, contact the Ohio State IT Service Desk. Standard support hours are available at ocio.osu.edu/help/hours, and support for urgent issues is available 24/7.
• Self-Service and Chat support: ocio.osu.edu/help Phone: 614-688-4357(HELP)
• Email: servicedesk@osu.edu TDD: 614-688-8743 If none of these options will meet the needs of your situation, you can contact the IT Service Desk at 614-688-4357(HELP) and IT support staff will work out a solution with you.

ABET-EAC Criterion 3 Outcomes

Course Contribution		College Outcome
***	a	An ability to apply knowledge of mathematics, science, and engineering.
	b	An ability to design and conduct experiments, as well as to analyze and interpret data.
	c	An ability to design a system, component, or process to meet desired needs.
	d	An ability to function on multi-disciplinary teams.
**	e	An ability to identify, formulate, and solve engineering problems.
	f	An understanding of professional and ethical responsibility.
	g	An ability to communicate effectively.
	h	The broad education necessary to understand the impact of engineering solutions in a global and societal context.
*	i	A recognition of the need for, and an ability to engage in life-long learning.
*	j	A knowledge of contemporary issues.
**	k	An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Text: Lecture Notes/Slides posted online

References (supplemental reading):

- J. H. Davies, The Physics of Low-Dimensional Semiconductors, Cambridge
- B. V. Zeghbroeck, Physics of Semiconductor Devices – Excellent online resource http://ecee.colorado.edu/~bart/book/book/contents.htm
- S. Sze and M.K. Lee, Semiconductor devices: Physics and Technology, available online http://proquest.safaribooksonline.com/9780470537947 - This book is encyclopedic and has information on a broad range of

semiconductor device concepts. It also has a great set of references that you can use for further learning.

- C. Kittel, Introduction to Solid State Physics 7th edition, Wiley – classic text on on solid-state physics
- N. W. Ashcroft and N. D. Mermin, Solid State Physics, Thomson – classic text on solid-state physics
- U.K. Mishra and J. Singh, Semiconductor Device Physics and Design, Springer Available as PDF and for paper copy purchase (recommended) on SpringerLink for OSU students http://link.springer.com/book/10.1007%2F978-1-4020-6481-4
- Quantum Physics of Semiconductor Materials and Devices, D. Jena (in print soon)
- Solid State Electronic Devices, Ben G. Streetman and Sanjay Kumar Banerjee, 7th Edition, ISBN-13: 978-0133356038; ISBN-10: 0133356035
- Fundamentals of Semiconductor Devices, B.L. Anderson and R.L. Anderson, ISBN-13: 978-0073529561 ISBN-10: 0073529567
- Semiconductor Physics and Devices, Donald Neaman, 4th Edition, ISBN13: 9780073529585 ISBN10: 0073529583

Grading and Important Dates:

Homework	20% (Every two weeks)
Project	10% (Teams Due Fri, Sept 3rd 2021, Report Due Dec 3rd 2021)
Midterm 1	20% (Wed, Sept 29th 2021)
Midterm 2	20% (Mon, Oct 25th 2021)
Final Exam	30% (10AM-11:45 AM, Tuesday, Dec 14th 2021)

<u>You are allowed to drop one homework with the least score.</u>

Policy on Late Homeworks: Homework is due at the beginning of class on the date shown. No late work will be accepted without prior arrangement. Late work (with arrangements) will be docked 10% per day.

Working together: Students are encouraged to work together on homework but each student should hand in his or her individual solution.

Exams: Exams are closed book. You will be allowed a single cheat sheet, 8.5" by 11", with handwritten notes only, on one side only. Scientific/graphic calculators are allowed. No internet-enabled devices are permitted. No cooperation on the examination is allowed. I am required to report any academic misconduct to the Committee on Academic Misconduct (COAM).

Missed exams: Any missed exam will result in a zero grade unless arrangements are made in advance. Suitable circumstances include illness, death in the immediate family, and situations of comparable gravity. In such cases, *if and only if arrangements are*

made in advance, a make-up exam can be arranged. Midterms dates are announced will in advance, so plan your job interviews and such around them.

Reaching me: You may reach me during office hours, or make an appointment by email if you cannot make my office hours.

Disabilities Statement

Any student who feels s/he may need an accommodation based on the impact of a disability should contact the instructor privately to discuss specific needs. Please contact the OSU Office for Disability Services for assistance in verifying the need for accommodations and developing accommodation strategies.

Academic Misconduct Statement

Any student found to have engaged in academic misconduct, as set forth in the Code of Student Conduct Section 3335-23-04, Prohibited Conduct, will be subject to disciplinary action by the university. Academic misconduct is any activity that tends to compromise the academic integrity of the university, or subvert the educational process.

Student Conduct

Students are expected to abide by the provisions in the Code of Student Conduct. The University's Code of Student Conduct and Sexual Harassment Policy are available on the OSU Web page

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ECE 5530: Class and Homework Schedule (Au 2021)

DATE	Lec #	Topics To be Covered	Homework Schedule
Module 0: Course Overview and Key Concepts			
Wed, Aug 25th 2021	1	From Atoms to Systems: The Empirical Skepticist Approach	Theoretical Project Assigned
Fri, Aug 27th 2021	2	Metals and Classical Electron	HW1 Assigned
Module 1: Semiconductor Physics Concepts			
Mon Aug 30th 2021	3	Quantum Mechanics: Operators, Charge Current Density	
Wed Sept 1st 2021	4	Crystal Structure (Bravais Lattices, Unit Cell, Directions/Planes)	
Fri Sept 3rd 2021	5	Crystal Structure (Diamond, ZincBlende, Wurtzite, HCP/FCC)	
Mon Sept 6th 2021		Labor Day No Class	
Wed Sept 8th 2021	6	Phonons (1D Monoatomic/Diatomic Chain, Group Velocity)	
Fri Sept 10th 2021	7	k-space(Reciprocal lattice, lattice planes)	HW2 Assigned/HW1 Due
Mon Sept 13th 2021	8	k-space (Brillouin zone, x-ray diffraction)	
Module 2: Semiconductor Band-Structure (E-k Diagram)			
Wed Sept 15th 2021	9	Free electron model	
Fri Sept 17th 2021	10	Nearly free electron model and Bloch Theorem	
Mon Sept 20th 2021	11	Kronnig Penny Model	
Wed Sept 22nd 2021	12	Degenerate Perturbation Theory	
Fri Sept 24th 2021	13	Tight Binding Model/Pseudopotential Model	HW3 Assigned/HW2 Due
Mon Sept 27th 2021	14	k.p model	
Wed Sept 29th 2021		**Mid Term I**	
Module 3: Carrier Statistics and Dynamics			
Fri Oct 1st 2021	15	Maxw ell Boltzmann/Fermi Dirac Distribution	
Mon Oct 4th 2021	16	Bose-Einstein Distribution	
Wed Oct 6th 2021	17	Maxw ell Boltzmann/Fermi Dirac Distribution	
Fri Oct 8th 2021	18	Degenerate and Non-degenerate semiconductors	HW4 Assigned/HW3 Due
Mon Oct 1th 2021	19	Semiconductors in equilibrium	
Wed Oct 13th 2021	21	Excess Carriers: Generation and Recombination	
Fri Oct 15th 2021		Fall Break No Class	
Mon Oct 18th 2021	22	Excess Carriers: Band to band, Trap assisted recombination	
Wed Oct 20th 2021	23	Emission Probabilities and Auger Recombination	
Fri Oct 22nd 2021	24	Low level and High Level Injection	HW5 Assigned/HW4 Due
Mon Oct 25th 2021	25	**Mid Term II**	
Module 4: Junctions and Band-diagrams			
Wed Oct 27th 2021	26	PN Junction: Qualitative Descriptiopn	
Fri Oct 29th 2021	27	PN Junction: Mathematical derivation	
Mon Nov 1st 2021	28	Metal-semiconductor junction	
Wed Nov 3rd 2021	29	Schottky and Ohmic Contacts	
Fri Nov 5th 2021	30	Metal-oxide-semiconductor junction	HW6 Assigned/HW5 Due
Mon Nov 8th 2021	31	Capacitance and CV Measurements	
Wed Nov 10th 2021	32	Heterojunctions	
Fri Nov 12th 2021	33	High Electron Mobility Transistors	
Mon Nov 15th 2021	34	Field Effect Transistors	
Module 5: Carrier Transport			
Wed Nov 17th 2021	35	Boltzmann Transport Equation	
Fri Nov 19th 2021	36	Limitations of BTE	HW6 Due
Mon Nov 22nd 2021	37	Field, diffusion and scattering	
Mon Nov 29th 2021	38	Ambipolar transport equation	
Wed Dec 1st 2021		Thanksgiving/Columbus Day No Class	
Fri Dec 3rd 2021	39	Low injection and high injection transport	Project Report Due
Mon Dec 6th 2021	40	Tunneling and Avalanche	
Wed Dec 8th 2021	41	Course Review	
Tue Dec 14th 2021		Final Examination (10AM-11:45AM)	