ELECTRICAL AND COMPUTER ENGINEERING ECE 5206

ECE 5206: Basic Semiconductor Devices (CRN 97672)

1. Instructor: Dr. Mantu K. Hudait, Associate Professor, ECE Department
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2. Office Hour: Tuesday 1:30-3:00pm

3. Course Description:

Optoelectronics and integrated optics has become an important part of our lives. Wherever light is used to transmit information, tiny semiconductor devices are needed to transfer electrical current into optical signals and vice versa. Examples include light-emitting diodes in radios and other appliances (automobiles and computer, TV, etc), photodetectors in elevator doors and digital cameras, and laser diode. Generally, the research program in optics and photonics deals with the design, fabrication, and characterization of materials, devices and systems for the generation, transmission, amplification, detection, and processing of light signals. These are enabling and pervasive technologies applied in fields like communications, sensing, bio-medical instrumentation, consumer electronics, and defense. Understanding the underlying physics and technology of the modern optoelectronics and integrated photonics are important for the above applications. The course objective is advanced treatment of the operating principles of semiconductor optoelectronic devices with direct comparison to experimental data reported in the literature. This course will provide a graduate level understanding of the principles of light generation and detection, operation, and design of the state-of-the art of optoelectronic and photonic devices.

4. Learning Objectives

Upon successful completion of this course, students should be able to (1) explain the basic physical models underlying the operation of semiconductor based optoelectronic devices and (2) evaluate the impact on device performance of changes in material composition and/or structure.

The lecture session provides learning opportunities that should enable students to do the following upon completion of this course:

A. Develop a basic understanding on the following key concepts in quantum and statistical mechanics relevant to physical, electrical and optoelectronic properties of materials and their applications to optoelectronic devices and photonic integrated circuits that emit, modulate, switch, and detect photons.

i. Quantum mechanics:

Crystal structure of solids; propagating electron wave in a periodic lattice; elemental and compound semiconductor materials, alloy semiconductors, reciprocal lattice.

ii. Electronic structure of semiconductor heterostructures:

Energy bands, density of states in 3D, 2D, and 1D; non-degenerate and degenerate semiconductors; heavy doping effect; carrier scattering phenomena, density of carries in intrinsic and extrinsic semiconductors, band tail states.

iii. Optical processes in semiconductor heterostructures:

Maxwell equations and boundary equations; recombination, absorption in semiconductors, matrix elements and oscillator strength for band-to-band transitions, absorption and emission spectra, auger recombination.

iv. Heterojunction and quantum wells:

Theory of the heterostructure band alignment; transport properties; drift-diffusion equation; generation-recombination; abrupt structures and thermionic emission.

v. Propagation of light:

Light propagation in isotropic and anisotropic media; optical waveguide theory; dielectric optical waveguides; the effective index method, gains guidance and index guidance in semiconductor laser; losses and gains in waveguide.

vi: Generation of light:

*S*emiconductor lasers; Fabry-Perot and distributed-feedback lasers and vertical-cavity surface-emitting lasers (VCSEL).

vii: Solar cells:

Carrier recombination and lifetime; carrier transport of p-n junction under illumination; solar cell parameters and device design; III-V heterojunctions single and multijunction solar cells; tailor-made bandgaps for matching solar spectrum.

B. Become proficient with the fundamental and applied optoelectronic device physics and its applications.

C. Learn to analyze optoelectronic device characteristics in detail and brainstorm ways towards improving them or adapting them to new applications.

5. Text Book: Different book chapters and journal articles will be used as the major source of information and it will be posted in Scholar.

- Shun Lien Chuang; *Physics of Photonic Devices (2nd Edition;* John Wiley & Sons (2009)
  ISBN-10: 0470293195; ISBN: 978-0470293195 (paperback)

Useful books and links:

- Larry A. Coldren and Scott W. Corzine; *Diode Lasers and Photonic Integrated Circuits*
  John Wiley & Sons (1995); ISBN: 0-471-11875-3 (hardcover)
- Umesh Mishra and Jasprit Singh, *Semiconductor Device Physics and Design*, Springer, 2008 (e-book available through www.lib.vt.edu)
- http://ecee.colorado.edu/~bart/book/
- http://cleanroom.byu.edu/EW_orientation.phtml
- http://www.ioffe.rssi.ru/SVA/NSM/Semicond/index.html
- Manasreh, *Semiconductor Heterojunctions and Nanostructures*, McGraw Hill

Laser:

- Eli Kapon edited, *Semiconductor Laser-I &II: Academic Press (1999); ISBN 0123976308 (v.1) and 0123976316 (v.2)*

Solar cells:

- Nelson, *The Physics of Solar Cells*, Imperial College Press
- Luque and Hegedus (Editor), *Handbook of Photovoltaic Science and Engineering*, Wiley

6. Pre-requisite: ECE 5200 or ECE 4214 or Equivalent

7. Detailed Syllabus

I. Introduction to course

II. Quantum mechanics 5%
   a. Crystal structures
   b. Particle in a box
   c. Bandgap

III.	Electronic structure of semiconductor heterostructures a. Density-of-states: 3D, 2D, 1D b. Effective mass c. Heavy doping effect	5%
IV.	Optical process in semiconductors a. Maxwell equations and boundary equations; b. Recombination, absorption in semiconductors, matrix elements and oscillator strength for band-to-band transitions, radiation in semiconductors, relation between absorption and emission spectra, Auger recombination	15%
V.	Heterojunction band alignment and quantum wells a. Theory of band alignment b. Measurement and interpretation of band alignment c. Drift-diffusion d. Transport properties e. Heterojunction diode current	10%
VI.	*Propagation of light* a. Light propagation in isotropic media Hetero p-n junctions b. Light propagation in anisotropic media c. Optical web guide theory and coupled-mode theory	15%
VII.	*Semiconductor lasers* a. quantum well lasers b. vertical cavity surface emitting lasers	15%
VIII.	*Photodetectors and integrated photonics* a. Quantum efficiency; gain and bandwidth; b. Integrated laser-modulator; multi-section phase; gain; c. Distributed Bragg reflector devices	15%
IX.	*Solar cells* a. Carrier recombination and lifetime b. Carrier transport under illumination c. Heterojunction III-V single and multijunction cells d. Design of a multijunction solar cell e. QW and QD based cells	20%

8. Grading Policy

Homework	25%
Midterm	30%
Final Exam	40%
Class participation	5%
	100%

<u>Home Work:</u>

Homework problems will be typically be assigned throughout the semester and will be due at the end of class one week following its assignment. Late homework will be accepted only in extraordinary circumstances AND by specific arrangement with the instructor. It is your responsibility to present your work in a clear and logical fashion. No assignments will be accepted beyond one day late, except in the case of unforeseen, officially documented absences. *Each* problem solution should be neatly worked out. You may consult with other students and with your instructor while you are working on assigned problems but your goal in consulting should be limited to exploring options and approaches rather than avoiding work. Experience tells us if you do not work on the homework yourself, you will pay for it later during exams. The ability to solve problems develops through disciplined effort and the exams will require you to be able to solve problems. To obtain full credit for a homework assignment you must submit it to your instructor in class on the due date. Experience tells us if you do not work on the homework yourself, you will pay for it later during exams.

Computer problems: Some of the homework may involve computer problems. It is expected students are familiar with one or more basic programming languages to solve numerical problems (C, Basic, FORTRAN, MATLAB, Mathematica etc.) Students may need to familiarize themselves with device simulators like SenTaurus, BandProf, NextNano etc.

In-Class Activities:

Students have the ultimate responsibility for their learning and must decide for themselves on how to maximize progress and efficiency. Class attendance, participation in classroom discussions, reading the text in advance of class lectures, homework effort and the use of office hours may all be collectively viewed by the instructor as indications of student's interest and effort in learning the course material in addition to exams.

Exams:

There will be **one mid-term exam and a final exam**. One sheet of course notes may be used during the exam and other materials including textbook is not allowed.

Academic Integrity:

The Virginia Tech Honor Code establishes the standard for **ACADEMIC INTEGRITY** in this course, and will be strictly enforced. *Discussion* of class material with your classmates or the instructor is encouraged; however, ALL submitted work, must represent your own efforts, and you must pledge to this effect on all work. For more details on the relevant honor codes, consult the websites listed below:

- Graduate Honor System, http://filebox.vt.edu/studentinfo/gradhonor/

Announcements:

I will use Scholar to post lecture notes, homework assignments, homework solutions, and other information pertaining to the course materials. You should check your email and the Scholar on a regular basis.

Attendance:

Attendance all lecture classes is expected and critical to your successfully completing the requirements of this course. Though it is not a policy, come to the class and have fun! Since it is an advanced level class, it will greatly help you while you are present in class. In the event that you miss a lecture, it is your responsibility to obtain the missed notes from one of your classmates or from Scholar. If you have a conflict with a scheduled exam or with the submission of any in-class assignments, you must make arrangements with your instructor well in advance so that alternate times can be scheduled.