EE 457/EE 557

Quantum Structure Devices: Optical and Optoelectronic Properties of Nanostructures.

Instructor: Dr. Vladimir Mitin

312C Bonner Hall, Department of Electrical Engineering

Email: vmitin@buffalo.edu, Phone: (716) 645-1036

Office Hours: Tuesday and Thursday 14:00-15:00 and 17:00-18:00, also by appointment

Teaching Assistant: TBD

Course Meeting Days, Times, and Locations, TBD

Course Description:

The major goals and objectives are to provide students with knowledge and understanding of nanoelectronics as an important interdisciplinary subject. Through the examples, exercises, virtual labs, hands-on labs, and lectures the course covers in details Optics, Electro–Optics, Nonlinear Optics, and Plasmonics of Quantum Structures, and Optical and Optoelectronic Devices Based on Quantum Structures. A short review of Materials for Nanoelectronics and Optoelectronics and of Electrons in Quantum Structures is given as well. The course is developed on the level of the senior undergraduate and entrance graduate course in Solid State Electronics. Students will also learn how to do optical characterization of nanomaterials and nanodevices.

Prerequisites: EE 324 for EE 457 and graduate standing for EE 557.

Corequisite: None

Course Requirements

Requirement	**Quantity**	**Material Covered**	**Date**
Exams	2	(1) Chapters 4-6 (2) Chapters 7, 8	(1) Week 6 (2) Week 15
Quizzes	5	Variable; related to material covered within lecture, see schedule	Announced one week in advance
Homework assignments	5	Variable; related to material covered within lecture, see schedule	Due one week after the assignment
Laboratory reports	8	List of labs is below	Week 12-14
Term Ppaper	1	Topic selected by student in consultation with instructor	Week 12
Oral presentation of the Term Paper	1	Topic selected by student in consultation with instructor	Week 12

Course Learning Outcomes

The following table lists learning outcomes for this course. Upon completing this course, students will be able to clearly identify difference between nano-functional and micro-functional devices, to use analytical and numerical methods and applets to solve identified problems of nano-devices, to operate advanced characterization instrumentation, to analyze and interpret obtained experimental results, and to do literature search, prepare a written report and deliver a presentation.

	Course Learning Outcome	Program Outcomes*	Assessment Methods
1	Ability to clearly identify difference between nano-functional and micro-functional devices	1	Home works, quizzes, and exams
2	Ability to use analytical and numerical methods and applets to solve identified problems of nano-devices	3	home works, quizzes, and exams
3	Ability to operate advanced characterization instrumentation	2	Lab reports
4	Ability to analyse and interpret obtained experimental results	2	Lab reports
5	Ability to do literature search, prepare a written report and deliver a presentation	6	Term paper submission and presentation of results

* The Student Outcomes from the Engineering Accreditation Commission of ABET have been adopted, see http://www.abet.org/

Program Outcome Support
0: not covered, 1: introduced, 2: practiced, 3: mastered

Program Outcome	1	2	3	4	5	6	7
Support Level	2	3	2	0	0	2	0

Textbook and/or Other Required Materials
Course pack available at the bookstore: V. V. Mitin, V. A. Kochelap, M. Dutta and M. A. Stroscio "Introduction to Optical and Optoelectronic Properties of Nanostructures".
The course pack (to be published by Cambridge University Press at the end of 2018 or in 2019) is an updated version of the earlier printed text that students may use as an additional reference:
V. V. Mitin, V. A. Kochelap, and M. A. Stroscio "Quantum Heterostructures: Microelectronics and Optoelectronics", Cambridge University Press, 1999, 634 p, ISBN 0-521-63177-7.

LAB MANUAL: The students are required to purchase the "EE457/557 Quantum Structure Devices: Optical and Optoelectronic Properties of Nanostructures Lab Manual" from the bookstore. The handouts for all the experiments are contained in the Lab manual.

Topics covered:

LECTURES

After the short review of Part 1 of the course pack:
Some Trends in Optoelectronics, Materials for Optoelectronic Applications, and Materials for Optoelectronic Applications**, focus of the course will be on Part 2:**
Chapter 4 Light-Semiconductor Materials Interaction
1 Introduction

2 Electromagnetic waves and photons
2.1 Electromagnetic fields, modes, and photons in free space
2.2 Photons in nonuniform dielectric media
2.3 Optical resonators
2.4 Photon statistics
3 Light interaction with matter: photo-transitions
3.1 Photon absorption and emission
3.2 Calculation of photo-transition probabilities
4 Optical properties of bulk semiconductors
4.1 Interband emission and absorption in bulk semiconductors
4.2 Spectral density of spontaneous emission
4.3 Photo-transitions in semiconductors with consideration for real band structure.
4.4 Excitonic effects
4.5 Optical properties of group-III-nitrides
4.6 Refractive index
Chapter 5 Optics of Quantum Structures
1 Introduction
2 Optical properties of quantum structures
2.1 Electrodynamics of heterostructures
2.2 Light absorption by confined electrons
2.3 Effects of complex valence band of compounds
2.4 Other factors affecting the interband optical spectra
2.5 Polarization effects
3 Intraband transitions in quantum structures
3.1 Intraband absorption and conservation laws
3.2 Intersubband photo-transitions
3.3 Photo-transitions to extended states
4 Optical properties of two-dimensional (few monolayer) crystals
4.1 Optics of graphene and bigraphene
4.2 Optics of transition metal dichalcogenides
5 Optics of quantum dots
Chapter 6 Electro–Optics and Nonlinear Optics
1 Introduction
2 Electro–optics in semiconductors
2.1 Electro–optical effect in conventional materials
2.2 Electro–optical effect in quantum wells
2.3 Electro–optical effect in superlattices
3 Terahertz coherent oscillations of electrons in an electric field
4 Nonlinear optics in heterostructures
4.1 Linear and nonlinear optics
4.2 Optical nonlinearities in quantum wells
4.3 Virtual, field–induced mechanism of nonlinear optical effects
4.4 Nonlinear optical effects due to generation of excitons and electron–hole plasma
4.5 Nonlinear effects induced by nonthermalized electron–hole plasma
5 Plasmonics and its peculiarities in nanostructures
5.1 Dielectric permittivity of a free electron gas

5.2 Plasmons in metals
5.3 Surface plasmon-polariton at dielectric-metal interface.
5.4 Plasmons in low-dimensional systems
5.5 Localized surface plasmons. Field-enhancement effects.

Chapter 7 Light Emitting Devices Based on Interband Phototransitions in Quantum Structure

1 Introduction
2 Light amplification in semiconductors
   2.1 Criteria for light amplification
   2.2 Estimates of light gain
   2.3 Methods of pumping
   2.4 Motivations for using heterostructures for light amplification
   2.5 Light amplification in quantum wells, quantum wires and quantum dots.
3 Light–emitting diodes and lasers
   3.1 Light–emitting diodes
   3.2 Amplification, feedback, and laser oscillations
   3.3 Laser output power and emission spectra
   3.4 Modulation of the laser output
   3.5 Quantum well lasers
   3.6 Surface–emitting lasers
4 Blue and ultraviolet light-emitting diodes
   4.1 Nitride based light-emitting diodes
   4.2 Methods of enhancement of hole injection currents in group-III-nitride heterostructures.
   4.3 Short-wavelength laser diodes
5 Quantum wire and quantum dot emitters and lasers
   5.1 Quantum wire lasers
   5.2 Quantum dot emitters

8 Devices Based on Intraband Phototransitions in Quantum Structures and Silicon Optoelectronics

1 Introduction
2 Unipolar intersubband quantum–cascade lasers
3 Terathertz cascade lasers
4 Photodetectors on intraband photo–transitions
   4.1 Photoconductive detector
   4.2 Intraband photo–transitions and electron transport in multiple quantum well structures
5 Silicon photonics
6 Perspectives of optoelectronic devices based on two-dimensional crystals
7 Adaptive photodetectors

LABS

Nanoscience and Nanotechnology Laboratory, 312B Bonner Hall

The goal of the labs is to explore the experimental basis of Optical and Optoelectronic Properties of Nanostructures and Nanodevices.

LAB MANUAL: The students are required to purchase the **"EE457/557 Optical and Optoelectronic Properties of Nanostructures Lab Manual"** from the bookstore. The handouts for all the experiments are contained in the Lab manual.

GRADING: 30 % of the Final EE 423/523 Grade is determined from your lab reports.

LAB REPORTS: Reports are due at the next regular session after each completed experiment. You will work with lab partners in taking data, but you must prepare the report by yourself.

PREPARATION FOR THE LABORATORY: Each student MUST read the appropriate lab before coming to lab each week and make an effort to understand the relevant material. Bring your Manual to each lab session.

LAB LOCATION: Labs 2-9 will be performed in 312B Bonner Hall. We will update you on the place for the first lab.

EACH LAB TAKES APPROXIMATELY 1.5 HOURS

The lab schedule will be arranged to accommodate each student if preferable time will be not the time of class schedule.

EXPERIMENTS:

Eight lab experiments will be carried out by all students. Students will work in groups of two. Students with disabilities or special requirements (e.g. military service) should inform the TA as early as possible.

Experiment 1: Propagation of Errors

Experiment 2: Diffraction of Light from a Two Dimensional Lattice

Experiment 3: Electron Diffraction from Graphite

Experiment 4: Optical Absorption by CdSe Nanocrystals

Experiment 5: Photoluminescence from InP Quantum Dots

Experiment 6: Ultrafast Fiber Laser Part 1: Pumping the Laser and Yb Amplifier Fluorescence

Experiment 7: Ultrafast Fiber Laser Part 2: Continuous Wave Operation

Experiment 8: Ultrafast Fiber Laser Part 3: Pulsed Operation

Grading Policy

Grades will be based on points accumulated from the course requirements. There are 100 total points possible, distributed as follows:

Course Requirement	**Points**	**Percent of Final Grade**
Exams (3)	30	30% (15% each)
Quizzes (5)	10	10% (2% each)
Homework assignments (5)	10	10% (2% each)
Laboratory reports (8)	30	30% (10% each)
Term Paper submission (1)	15	15%
Oral presentation of Term Paper (1)	5	5%

Total Points	Percentage	Final Grade
85-100	85-100	A
80-84	80-84	A-
75-79	75-79	B+
70-74	70-74	B
65-69	65-69	B-
60-65	60-65	C+
55-59	55-59	C
50-54	50-54	C-
45-49	45-49	D+
40-44	40-44	D
<39	<39	F

In certain cases, students may be eligible to receive a temporary incomplete ('I') grade. A grade of incomplete ('I') indicates that additional course work is required to fulfill the requirements of a given course. Students may only be given an 'I' grade if they have a passing average in coursework that has been completed and have well-defined parameters to complete the course requirements that could result in a grade better than the default grade. An 'I' grade may not be assigned to a student who did not attend the course. Detailed information is available from the Undergraduate Course Catalog, https://catalog.buffalo.edu/policies/explanation.html.

Expectations of Students

- Students are expected to act in a professional manner. A student's grade may be reduced due to unprofessional or disruptive behavior. Examples include coming to class late, texting (or otherwise using your cell phone) during class, your cell phone ringing during class and/or exams, etc.
- Homework is assigned and collected one week after the assignment.
- Homework assignments will be graded and returned to students.
- Late homework assignments receive a grade of zero.
- Lab reports should be submitted one week after each lab is done.
- Students are allowed to share ideas regarding homework problems and labs, but each student must independently write and submit their own solution and lab report.
- Makeup exams will be given in the following circumstances only:
  1. You contact the instructor prior to the exam
  2. You have a valid and documented reason to miss the exam
     - Serious illness or family emergency are acceptable excuses
     - Sleeping in, lack of preparation, ennui, grogginess, etc. are not acceptable excuses

Course Schedule

Meeting	Date	Day	Topic	Reading
1	Week 1-5	T,R	Chapters 4-6	Chapters 4-6
2	Week 6	T,R	Recitation and 1st Exam	Chapters 4-6
3	Week 7-11	T,R	Chapters 7-8	Chapters 7-8
4	Week 12	T,R	Term Paper presentation	
5	Week 12-14	T,R	Recitation 2 and Labs 1-8	Lab Manual
6	Week 15		Second Exam	Chapters 7-8

Accessibility Services and Special Needs
If you have any disability which requires reasonable accommodations to enable you to participate in this course, please contact the Office of Accessibility Resources, 60 Capen Hall, 645-2608, and also the instructor of this course. The office will provide you with information and review appropriate arrangements for reasonable accommodations. Additional information is available at http://www.buffalo.edu/studentlife/who-we-are/departments/accessibility.html.

Academic Integrity
Academic integrity is a fundamental university value. Through the honest completion of academic work, students sustain the integrity of the university while facilitating the university's imperative for the transmission of knowledge and culture based upon the generation of new and innovative ideas. The UB undergraduate academic integrity policy is available at https://catalog.buffalo.edu/policies/integrity.html.

Diversity:
The UB School of Engineering and Applied Sciences considers the diversity of its students, faculty, and staff to be a strength, critical to our success. We are committed to providing a safe space and a culture of mutual respect and inclusiveness for all. We believe a community of faculty, students, and staff who bring diverse life experiences and perspectives leads to a superior working environment, and we welcome differences in race, ethnicity, gender, age, religion, language, intellectual and physical ability, sexual orientation, gender identity, socioeconomic status, and veteran status.