PHYS/OPTI 561 | Physics of Semiconductors | SPRING 2026

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Office Hours: see D2L (Brightspace)
Homework Assignments and Announcements: Available on D2L (Brightspace)

Description:

This course addresses basic properties of crystalline solids. The chief focus is on those properties which are relevant for the understanding of current topics in nonlinear semiconductor optics. However, the importance of these concepts, which include various kinds of elementary excitations, such as excitons and plasmons, is not restricted to semiconductor optics. Certain traditional aspects of solid-state physics, like the theory of superconductivity, are not part of this course. A central topic of the course will be the linear and nonlinear optical response of semiconductors. The course also includes an introduction to charge carrier transport and p-n junctions, and a brief discussion of the concept of geometric phase, the Berry phase and the (first) Chern number.

This course will mainly deal with theoretical physics and will include the application of advanced quantum mechanical concepts (quantum field theory of solids, also called second quantization, and commutator algebra) to the physics of semiconductors. However, very advanced concepts such as the nonequilibrium Green's function formalism are not part of this course.

Learning Outcomes:

- The students will be able to classify crystals in terms of their crystal structure (i.e. their Bravais lattice and basis).
- The students will be able to formulate the Schrodinger equation for a solid with a lattice-periodic potential.
- The students will be able to interpret the electronic bandstructure of a crystal,
- The students will be able to formulate and solve the tight-binding model for a one-dimensional crystal.
- The students will be able to derive the expression for the inverse effective mass tensor using non-degenerate k-dot-p perturbation theory.

- The students will be able to derive the Luttinger Hamiltonian using degenerate k-dot-p perturbation theory and obtain realistic valence band structures for III-V semiconductors.
- The students will become familiar with Fermionic operator algebra in quantum field theory (second quantization).
- The students will be able to derive the Fermi distribution function for electrons in thermal equilibrium.
- The students will be able to derive the canonical form of the many-particle Hamiltonian for particles interacting via the Coulomb potential.
- The students will be able to apply the Hartree-Fock factorization to four-operator expectation values.
- The students will become familiar with ground state properties such as the ground state energy and pair-correlation functions of an interacting electrons gas.
- The students will become familiar with linear and nonlinear optical response of classical oscillators and atoms.
- The students will be able to derive the equations of motion for the interband polarization and carrier distribution functions in a two-band semiconductor (semiconductor Bloch equations).
- The students will be able to distinguish optical transitions in semiconductors with and without excitonic effects.
- The students will understand the concept of geometric phase, the Berry phase, and the Chern number as an example of a topological invariant.
- The students will be able to identify quantum confinement effects on optical transition frequencies.
- Using the Luttinger Hamiltonian for a quantum confined system, the students will be able to derive the valence band structure of III-V semiconductors within k-dot-p perturbation theory.

Literature:

- CLASS NOTES (available at no cost on D2L).
- H. Haug and S. W. Koch, Quantum Theory of the Optical and Electronic Properties of Semiconductors, 3rd, 4th or 5th edition (World Scientific, Singapore). [Strongly recommended. A substantial portion of the course contents is based on this text.]
- R. Binder (ed.), Optical Properties of Graphene (World Scientific, Singapore, 2017) [Not required. Contains an introductory tutorial in which the formalism developed in PHYS/OPTI 561 is applied to graphene.]
- N. Peyghambarian, S. W. Koch, and A. Mysyrowicz, Introduction to Semiconductor Optics (Prentice Hall, New Jersey, 1993). [Not required. This book is a very good introduction to semiconductor optics. As for the contents, it is similar to the Haug/Koch

book but but contains more of an overview of physical effects rather than formal proofs and derivations.]

- H. Haken, Quantum Field Theory of Solids : An Introduction. (North-Holland, Amsterdam, 1976) [Not required. Very good introduction to quantum field theory.]
- A. Fetter and J. Walecka, Quantum Theory of Many-Particle Systems (McGraw Hill, New York, 1971) [Not required. Formal and rigorous introduction to and application of quantum field theory.]
- N.W. Ashcroft and N.D. Mermin, Solid State Physics (Rinehart and Winston, New York, 1976) [Not required. Comprehensive presentation of many "classical" aspects of the physical properties of solids.]
- C. Kittel, Introduction to Solid State Physics (Wiley and Sons, New York, 1986) [Not required. Similar to Ashcroft/Mermin.]
- P.Y. Yu and M. Cardona, Fundamentals of Semiconductors (Springer, Berlin, 1996) [Not Required. Comprehensive text on semiconductors.]
- J. K. Asboth, L. Oroszlany and A. Palyi, A Short course on Topological Insulators (Springer, Heidelberg, 2016)
- D. Vanderbilt, Berry Phases in Electronic Structure Theory (Cambridge University Press, 2018)
- R. Shankar, Topological Insulators - A Review (https://arxiv.org/abs/1804.06471)
- W.W. Chow, S.W. Koch and M. Sargent III, Semiconductor-Laser Physics, 1st or 2nd edition (Springer, Berlin) [Not required. This book contains more details about the Luttinger Hamiltonian for bulk semiconductors and semiconductor quantum wells than the Haug/Koch book.]
- C. Klingshirn, Semiconductor Optics (Springer, Berlin, 1995) [Not Required. Comprehensive text on semiconductor optics, mainly from an experimental point of view.]
- S. L. Chuang, Physics of Optoelectronic Devices (Wiley, New York, 1995). [Not required. Comprehensive text on application-oriented semiconductor theory.]
- W. Schäfer and M. Wegener, Semiconductor Optics and Transport Phenomena (Springer, Berlin, 2002). [Not required. A very good and comprehensive text on semiconductor optics.]
- Ch. Hamaguchi, Basic Semiconductor Physics (Springer, New York, 2001). [Not required.]

Homework: Weekly homework assignments with a few problems, posted on D2L. Some of the problems will be designed to complete intermediate steps of derivations presented in class. Credit from short low-stakes in-class quizzes will be grouped with homework points.

Exams: Closed book one-hour in-class midterm exam. Closed-book two-hour in-class FINAL EXAM.

Grades: The grades will be based 30% on homework, 30% on the midterm, and 40% on the final exam.

Required extra curricular activities: None.

Special materials required: Simple pocket calculator, plus a computer (laptop or tablet) or smartphone for in-class quizzes and exams taken on D2L/Brightspace.

CONTENTS

1. Basic concepts in solid state physics (crystal structure, electronic bandstructure, tight-binding approach, $\vec{k} \cdot \vec{p}$ theory and Luttinger Hamiltonian).
2. Introduction to many-particle theory (second quantization, commutator algebra, equations of motion in the Heisenberg picture).
3. Ideal quantum gases (Fermi distribution functions).
4. Charge carrier transport (electrons and holes, drift and diffusion currents, p-n junctions)
5. The interacting electron gas (jellium model, Hartree-Fock factorization).
6. Review of basic concepts of linear optical response (classical oscillator and two-level systems).
7. Linear and nonlinear optical response of semiconductors (linear optical band edge spectra including excitonic effects, absorption and gain, Pauli blocking, semiconductor Bloch equations).
8. Introduction to topological effects (Berry phase and Chern numbers).
9. Semiconductor quantum wells (envelope function approach, $\vec{k} \cdot \vec{p}$ theory and Luttinger Hamiltonian for quantum wells).
10. Timer permitting: Screening and plasmons.
11. Time permitting: phenomenological treatment of scattering and relaxation, electron-electron scattering, phonons.

Academic Integrity

According to the **Arizona Code of Academic Integrity,**
https://deanofstudents.arizona.edu/policies/code-academic-integrity ,

integrity is expected of every student in all academic work. The guiding principle of academic integrity is that a student's submitted work must be the student's own." Unless otherwise noted by the instructor, work for all assignments in this course must be conducted independently by each student. Co-authored work of any kind is unacceptable. Misappropriation of exams before or after they are given will be considered academics misconduct.

Misconduct of any kind will be prosecuted and may result in any or all of the following:

- Reduction of grade
- Failing grade
- Referral to the Dean of Students for consideration of additional penalty, i.e., notation on a student's transcript re: academic integrity violation, etc.

Students with Learning Disabilities
If a student is registered with the **Disability Resource Center**, he/she must submit appropriate documentation to the instructor if he/she is requesting reasonable accommodations.

The information contained in this syllabus may be subject to change with reasonable advance notice, as deemed appropriate by the instructor.

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