Updated Nov 1st 2020

Solid-state Electronics and Photonics Area Qualifying Examination
Effective Autumn 2021

The following applies to qualifying examination for ECE department graduate students intending to pursue a Ph.D. with a major area specialization in **Solid-State Electronics and Photonics (SSEP) area** only, **effective Autumn 2021**.

The guidelines given here are supplemental to department-wide policies (available in the ECE Graduate Handbook, https://ece.osu.edu/current-students/phd-qualifying-exam).

1. General Department Guidelines (excerpt from ECE Graduate Handbook)

- The purpose of the Qualifying Exam is to test the fundamental knowledge acquired by the student over prior coursework and assess the ability to apply this fundamental knowledge to approach research questions/problems.
- Two QE attempts are allowed. The 2nd attempt must be scheduled during the one-month window in the semester following the semester of the failed attempt. The QE committee remains the same for the second attempt. If the advisor changes between the first and second attempts, the two other committee members remain the same. If a student fails after two attempts, the student is no longer in the PhD program and can earn a master's degree after completing master's requirements. If the student does not take the QE during the semester he/she is required to take it, this will be considered a failed attempt.
- Format: The exam will be 90 minutes long. The student will be asked to give a short presentation (10 minutes) on a research problem chosen by the advisor and the student. The presentation will be "uninterrupted" to assess its clarity, coherence and depth without external input. The presentation will be followed by 20 minutes of questioning by each member, followed by a second round of final questions. These questions will be on fundamentals testing the student's ability to integrate the material learned in the courses they took and the ability to apply their knowledge to solve research problems. These questions may not be associated with the presentation.
- Each QE committee member will submit a grade of 0 (fail), 1 (marginal) or 2 (pass) to the Graduate Studies committee. A score of 4/6 is required to pass. When all results have been submitted, the Graduate Studies committee notifies the student and the QE committee about the outcome of the exam.

2. SSEP-Specific Guidelines

The two main modifications from department guidelines are in (a) syllabus, and (b) format for the examination.

2 (a) Syllabus

- Students will be tested on the following topics:
    - Mandatory Topic M1: Quantum mechanics and semiconductor physics
    - Mandatory Topic M2: Basic semiconductor devices (electronic + photonic)
    - Advanced Topic A1: Advanced electronic devices or A2: Advanced photonic devices
- Students must prepare for questions related to both M1 and M2, and can select either A1 **or** A2 in consultation with their primary research advisor. Therefore, students will either prepare for an exam that is either M1/M2/A1 or M1/M2/A2.
- Details of topics and learning resources are provided in **Appendix 1**. Students are encouraged to review class notes, homework assignments, quizzes, tests from the relevant courses, and can contact faculty for further assistance or suggestions.
- All topics in the qualifying exam syllabus will be covered in ECE classes that are offered annually: ECE 3030, ECE 5530, ECE 6531, and ECE 6535. However, it is **not mandatory** to take these courses.
- If the student's research area requires advanced training in topics that are different from A1/A2, the student and advisor should contact SSEP Area Chair to discuss other advanced topics to replace A1/A2.

2 (b) Examination Format

- The format of the exam will be as follows:
  - 10 minutes for presentation on any research topic of the student's interest, including brief introduction to student's academic preparation/coursework
  - 5 minutes for clarifications/questions related to presentation
  - 75 minutes for questions
- Prior to the examination, SSEP area faculty will decide among themselves which topics they will test. They will then prepare two questions each, so that there are total of 4 questions as follows. The maximum time allowed for the student to complete the questions is given below. If the student completes before this time, then the next question can be asked.

- **Maximum duration/points allotted for questions:**
  - M1 Quantum mechanics (10 minutes/1 point) and semiconductor physics (15 minutes/1 point)
  - M2 Basic semiconductor devices: 10 minutes/1 point
  - O1 or O2 (Advanced electronic/photonic devices): 15 minutes/1 point
  - Minor area: 25 minutes

The minor area examiner will have 25 minutes for questions. No guidelines are provided by SSEP for minor area examiners.

Updated Nov 1st 2020

Appendix 1: Syllabus Topics and Resources

M1: Quantum Mechanics and Semiconductor Physics

Suggested Course: ECE 5530 (offered Autumn Semester of each year)

Syllabus

1. Fundamentals of Quantum Mechanics

Eigenfunctions, eigenvalues, orthogonality, stationary and non-stationary states, linear superpositions of two states
Free electron gas, bound states, square well
1D scattering, 1D tunneling, probability currents in tunneling/scattering
Free electron gas, Fermi energy/velocity/wavevector, Fermi circle/sphere

2. Crystal structure, reciprocal lattice, and phonons

Crystal lattice, basis, unit cell, primitive cell, directions, Miller indices, planes
Lattice dynamics and phonons – monoatomic chain
X-ray diffraction, reciprocal space, Brillouin zone

3. Electrons in periodic potentials

Bloch theorem, nearly free electron model
Kronig Penney model
Energy band theory – energy bands in a 2D lattice
Energy band theory – electron dynamics, effective mass, holes, Bloch oscillations
Density of states in 1, 2, and 3 dimensions

4. Carrier statistics and doping

Maxwell Boltzmann and Fermi Dirac statistics, Fermi energy, chemical potential
Temperature dependence, Fermi level, effective density of states, effect of anisotropic bands
Intrinsic and extrinsic semiconductors
Dopants and electronic defects, Bohr radius, deep donors and acceptors, electrostatics

5. Non-equilibrium phenomena

Excess carriers in semiconductors, non-radiative recombination, SRH model
Radiative recombination, photoluminescence, quantization effects, Auger recombination
Boltzmann transport equation, scattering, drift, diffusion
Drift diffusion equation, continuity equation, Einstein relation

Suggested Learning Resources

C. Kittel, Introduction to Solid State Physics 7th edition, Wiley
N. W. Ashcroft and N. D. Mermin, Solid State Physics, Thomson
C. Wolfe, N. Holonyak, G.E. Stillman, Physical Properties of Semiconductors, Prentice-Hall
Lecture notes from ECE 5530 will provided for download from https://nano.osu.edu

M2: Basic Semiconductor Devices

Suggested Course: ECE 3030 (offered every semester)

Syllabus

Structure, analysis, and operation of: PN junctions, Schottky junctions, MOSFETs, BJTs, LEDs, solar cells. Clear understanding of basic energy band diagrams, carrier dynamics, minority carrier profiles in device structures.
A broad understanding of various devices, their operation principles, and applications should be tested.

Suggested Learning Resources:

Any undergraduate semiconductor device textbook

Updated Nov 1st 2020

A1: Advanced Electronic Devices

Suggested Course: ECE 6531 (offered Spring Semester of each year)

Syllabus

Abrupt and graded heterojunctions, metal semiconductor junctions – electrostatics Thermionic emission transport, polarization in III-Nitrides
PN Junctions – electrostatics and current, generation/recombination currents, avalanche and Zener breakdown, solar cells, photodiodes, LEDs
Heterojunction bipolar transistors – DC operation Early effect, Kirk effect, frequency performance and delays in HBTs, base transit time, collector transit, space charge delays
MOS capacitor – electrostatics and energy bands Capacitance voltage characteristics
Field Effect Transistors – long channel MOSFET Subthreshold effects, short channel effects, scaled MOSFET models, ballistic MOSFETs, MESFET, JFET, HFET – energy band diagram, operation of devices, analysis and design of high frequency FETs, high voltage FETs – design and operation

Suggested Learning Resources

U.K. Mishra and J. Singh, Semiconductor Device Physics and Design, Springer
Available as PDF and for paper copy purchase on SpringerLink for OSU students
http://link.springer.com/book/10.1007%2F978-1-4020-6481-4
B. V. Zeghbroeck, Physics of Semiconductor Devices
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

A2: Advanced Optoelectronic Devices

Suggested Course: ECE 6535 (offered Spring Semester of each year)

Syllabus

Compound Semiconductor Materials: Optoelectronic materials, and Epitaxial growth techniques
Recombination Processes and Heterostructures: Absorption, spontaneous emission and stimulated emission, Franz-Keldysh and Stark effect, Kramer-Kronig Relation, Radiative, non-radiative recombination, Measurement of absorption and luminescence spectra, and Schottky barriers, heterojunctions
Semiconductor Light Emitters (LEDs and Lasers): Structure and types of LEDs and their characteristics, LEDs for solid state lighting, UV LEDs, Guided waves and optical modes, Optical gain, Confinement factor, laser structures, Edge-emitting and VCSELs, Design of laser cavity, Threshold current, LI and IV characteristics, and Frequency response, relaxation oscillations and modulation bandwidth
Photodetectors: Optical detection processes, Photoconductive and Photovoltaic detectors, Avalanche photodiodes, Noise in detectors, Figures of merit for detectors, and Different types of detection schemes
Solar cells: Photogeneration and carrier collection probability; quantum efficiency and spectral response; solar cell figures of merit; energy conversion efficiency limits; carrier loss mechanisms; bulk, surface and interface carrier recombination; single, multijunction and concentrator solar cells; terrestrial and space photovoltaics; crystalline and thin film solar cells.

Suggested Learning Resources

Semiconductor Optoelectronic Devices by Pallab Bhattacharya (Second Edition)