E3 220 August 3:0

Foundations of Nanoelectronic Devices

Instructor

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Teaching Assistant

No Teaching Assistant
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Department: Electrical Communication Engineering (ECE)

Course Time: Tue, Thu, 10:00 AM - 11:30 AM

Lecture venue: ECE 1.07

Detailed Course Page: http://www.ece.iisc.ernet.in/~kausikm/teaching.html

Announcements

None.

Brief description of the course

The course is primarily designed for M. Tech. or Ph.D. students who are beginning their career in the broad field of electronic and opto-electronic devices. The course provides a solid mathematical background to quantum mechanics, and also how to apply quantum mechanical principles to describe electrons in solid state materials. The concepts learnt are applied to various classical and modern day electronic devices.

Prerequisites

None.

Syllabus

Module 1: Introduction

Module 2-4: Mathematical foundations of quantum mechanics - Hilbert space, observables, operators and operator algebra, commutators, bra and ket notation, representation theory, change of basis.

Module 5-8: Postulates of quantum mechanics, uncertainty principle, coordinate and momentum representation, quantum dynamics using unitary operator, Schrodinger and Heisenberg pictures, stationary states, time evolution.

Module 9-11: Free particle, wave packet, Hydrogen atom, Excitons.

Module 12-14: Electrons in solids - Drude and Sommerfield model, k-space quantization from periodic boundary condition, density of states, Fermi energy, derivation of Fermi-Dirac distribution, chemical potential and its relation with Fermi level.

Module 15-21: Crystal lattice, Reciprocal lattice space, Brillouin zone, Electron levels in periodic potential with BVK boundary condition, Bloch theorem and its proof, Bandstructure, Crystal momentum, band velocity, density of states, effective mass, bandstructure examples in common semiconductors (Si, Ge, III-V) and implications to device physics.

Module 22-24: Semiclassical theory of electron dynamics in periodic lattice, Bloch electrons and wave packets, Comments on the model including validity, conductivity of perfect crystal, conservation of energy, current carrying capability by empty, filled and partially filled bands, introduction to the concept of holes.

Module 25-30: Principles of operation of MOSFET, concept of top of the barrier, Short channel effects, Quantum effects in MOSFET - Coupled Poisson-Schrodinger equations and iterative solutions, quantization in MOSFET channel, quantum capacitance, Tunneling, One dimensional barrier transmission problem, Gate oxide tunneling, Direct source to drain tunneling, Band-to-band tunneling.

Module 31-34: Lattice vibrations, one dimensional chain of atoms, effect of introduction of a basis, acoustic and optical branches, quantum theory of linear harmonic oscillators, creation and annihilation operators, quantization of energies, phonons, phonon bandstructure and density of states, effects in devices due to electron-phonon scattering.

Module 35-37: Quantization of angular momentum, Ladder operators, possible eigenvalues of total angular momentum and its components, electron spin, Pauli spin matrices, spin-orbit coupling.

Course outcomes

The students would learn the following from this course:

(1) Mathematical foundation of quantum mechanics, including bra and ket algebra.

(2) Fundamental postulates of quantum mechanics,

(3) Uncertainty principle, quantum dynamics, and aspects of time evolution.

(4) Application of quantum mechanical principles in formulation of free particle, Hydrogen atom, and Excitons.

(5) Description of electrons in solids, and understanding Fermi energy and its difference with chemical potential.

(6) Crystal lattice and reciprocal space, Bloch's theorem, electronic structure and its related concepts.

(7) Basic concepts of carrier transport in semiconductors.

(8) MOSFET device concepts and details of its operations, different quantum mechanical effects including quantization, quantum capacitance, Intra- and Inter-band tunneling.

(9) Coupled Poisson-Schrodinger equations and numerical solution.

(10) Quantum theory of linear harmonic oscillator, Concepts of lattice vibration and phonons, implication into devices.

(11) Quantum theory of angular momentum, Electron spin.

Grading policy

10% for assignments,

30% for mid-term examination,

25% for project, and

35% for final examination.

Assignments

Typically assignments are grouped int two or three parts and distributed over the entire semester.

Besides, there is a project work where the students need to develop a device simulator using numerical

solution coupled Poisson-Schrodinger equations.

Resources

The main resource for the course is the class notes. Apart from that, the following are useful for references in various parts of the syllabus:

Books:

D. J. Griffiths, Introduction of Quantum Mechanics, Prentice Hall.
A. Ghatak and S. Lokanathan, Quantum Mechanics, Trinity Press.
V. K. Thankappan, Quantum Mechanics, New Age.
Solid State Physics, N. W. Ashcroft and N. D. Mermin.
S. M. Sze, Physics of Semiconductor devices, Wiley-Interscience.
Y. Taur and T. H. Ning, Fundamentals of modern VLSI devices, Cambridge University Press.

Papers:

Various recent as well as classic papers.