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Description of ECE 591:

The interaction of light with matter has found wide spread applications in optoelectronic devices used in communications, optical interconnects and links, optical memory, printing, medicine, and signal processing. The semiconductor laser and light emitting diode serve as prototypical elements enabling these applications.

We study the physical principles underlying the design, fabrication and operation of semiconductor lasers and leds. The interaction of light with matter receives special attention. The course develops the rate equations and uses them to derive the laser output power versus bias current, modulation response and noise figure. We discuss aspects of laser construction including waveguides, mirrors and Fabry-Perot cavities along with relevant transfer matrix theory. We review and apply basic EM theory, optics, quantum mechanics, and solid state electronics. We begin to explore the quantum nature of the electromagnetic fields and their inherent quantum noise as part of the exciting area of coherent and squeezed states of light. The course discusses the Schrodinger equation, quantized electromagnetic field, density operator, Sturm-Liouville equation, density of states and uses them to derive the optical gain, homogeneously broadened spectra, spontaneous and stimulated emission. The course provides selected discussion and applications to CW and pulsed operation, mode locking, and gaseous and solid state lasers.

Prerequisites:

1. ECE 581: Solid state electronics *OR*
2. A semester of graduate level quantum mechanics and a semester of solid state physics at the level of Kittel or Ascroft and Mermin. The student should thoroughly understand the linear algebra presented in the online book. The student should be capable of solving Schrodinger's Equation by separating variables in addition to understanding the connection between the quantum theory and the linear algebra.

Text:

The Physics of Optoelectronics, Draft 1, available as free download from www.ece.rutgers.edu/~maparker go to classes, 591 Lasers, Outline and Book.

Primary Reference:

Quantum electronics, 3rd edition, Yariv, first 12 chapters.

Secondary References:

1. Agrawal and Dutta: Semiconductor Lasers, 2nd Edition, Van Nostrand Reinhold NY, 1993
2. Coldren and Corzine: Diode Lasers and Photonic Integrated Circuits, John Wiley & Sons, Inc., NY, 1995
3. Milonni and Eber: Lasers, John Wiley and Sons, NY, 1988
4. Hunsperger: Integrated Optics, Theory and Technology; Springer-Verlag, NY, 1991
5. Liboff: Introduction to Quantum Mechanics, Addison-Wesley Publishing Co.

Grades: Homework (20%), Midterm (40%), Final (40%)
Max Scale: A: 93-100, B+: 86-93, B:80-86

Time Available: 28 classes (2 days/week)

Course Outline: (x,y)= (x=number of classes, y=cumulative number of classes)

Basic Lasers (8,0)

Introduction to Lasers (2, cumulative=2)

Basic construction: gas, VCSELs, IPLs

Concepts for semiconductors: bands, equilibrium and nonequilibrium statistics

Importance of feedback and noise for oscillation, electronic oscillator

Comments on Semiconductor growth and fabrication

Focus of course

Introduction to Laser dynamics (4,6)

Phenomenological rate equations

PI curves, modulation response and bandwidth

Constituent Relations

Condition on Gain for round trip

Cavity lifetime and mirror/internal losses

Photon density and photon current

Relationship among gain, polarization, susceptibility

Poynting vector and power transport

Maxwell's Equations, complex k and polarization

Noise

AutoCorrelation and variance

Sources of noise, response

Mirror and Cavity Configuration (2,8)

Scattering and transfer matrices

Longitudinal modes, line narrowing

Waveguiding and transverse modes

Effective index approximation (if time permits)

Quantum Theory (13,21)

Brief review of Linear Algebra (3,11)

Brief review vectors and operators: Hilbert Space, Dirac notation, Projection operators, Dual vector space, Orthonormality, Completeness, Dirac Delta function, Operators as matrices, Eigenvalues and Eigenfunctions, diagonalization, unitary and hermitian operators

Exam 1: Covers through Linear Algebra (1,12)

Brief Review of Introductory Quantum Mechanics (2,14)

Relation between linear algebra and QM, observables, commutation relations, Schrodinger's Equation, probability.

Representations

Schrodinger, Heisenberg and Interaction Representations; rate of change of operators and expectation values.

The Harmonic Oscillator (2,16)

Hermite polynomials and Ladder operators

Time Dependent Perturbation Theory (3,19)

Time dependent perturbation theory. Fermi's golden rule.
Introduction to gain (derived from Fermi's Golden Rule)

Density Operator (2,21)

Averages and equations of motion

Quantum Theory of Electromagnetic Fields and Light (Covered as extra topics)

Vector potential and gauges. Fock, coherent and squeezed states. Poisson and sub-poisson distributions. Wigner Distributions. Detecting and producing quantum states of light.

Matter-Light Interaction (7,28)

Liouville Equation and Solution, summary (3,24)

Density matrix for two level atoms, Liouville Equation for the density matrix. Optical Bloch Equations. The steady-state density matrix, polarization and gain, homogeneous broadening. Spontaneous emission and vacuum fields.

Gain and Rate Equations for Semiconductor Lasers, summary (1,25)

Density-Matrix Liouville Equation for semiconductors. Quasi-Fermi Level and pumping, reduced density of states, transition matrix elements. Gain formulas and graphs for bulk semiconductors. Application to photodetectors

Review of some Solid State (1, 26)

Review of Bloch wave functions, effective mass equation.

Density of electronic states in bulk and quantum well semiconductors

Gain and Rate Equations for Quantum Well Lasers (2,28)

Infinite and finite wells, effective mass equation, reduced density of states, transition matrix elements. Gain Formulas and graphs for QW semiconductors. Extension to quantum wires and dots.

Exam 2: Not comprehensive, during finals week.