**GAZİANTEP ÜNİVERSİTESİ**
**FEN BİLİMLERİ ENSTİTÜSÜ**
**DİSİPLİNLERARASI OPTİK MÜHENDİSLİĞİ ENSTİTÜ ANABİLİM DALI**

# OPTİK MÜHENDİSLİĞİ TEZSİZ YÜKSEK LİSANS PROGRAMI (İNGİLİZCE)

## Programın Dersleri ve İçerikleri

**OPE501 Semiconductor Physics & Lasers-I (3-0)6**
Introduction to Semiconductor Optoelectronic; Introduction to quantum mechanics: Energy, momentum, Uncertainty Principle, Schrödinger wave equation, potential well; Atoms and Solids: Pauli exclusion principle; Metal, Insulator, Semiconductor; Conduction band, valance band, energy gap; Electrons and holes; Various semiconductors: IV, III-V, II-VI; Direct and indirect band; Intrinsic, extrinsic (P and N doping): electron-hole concentration, Fermi level; Carrier Transport; P-N Junction: equilibrium potential, space charge, current-voltage; Metal-Semiconductor Schottky contact, ohmic contact; Heterojunction; Light absorption and light emission, spontaneous vs. stimulated process.

**OPE502 Semiconductor Physics & Lasers-II (3-0)6**
Photoconductor, Photodiodes, Photovoltaic solar cells; Light emitting diodes; Waveguides: Snell's law, TIR; Semiconductor Lasers: Inversion of population, gain, amplification, lasing condition, Fabry-Perot Lasers, threshold gain, spectrum, L-I characteristics; Multimode and single mode Lasers; Quantum well lasers; Other types of Photonic components: optical amplifiers, Modulator

**OPE503 Optical Design (3-0)6**
Design optical systems for a particular application based on specifications. Develop insight to determine the necessary image quality for an application as well as the limitations of designs. Develop the knowledge to evaluate lens designs via various figures of merit, i.e., MTF, Strehl ratio. Provide an understanding of classical lens designs, characteristics/limitations, and investigation of certain patents.

**OPE504 Lasers and Photonics (3-0)6**
Principles of lasers; properties and manipulation of laser light; physical effects and operating principles of photonic components and devices including light modulators and optical fibers; elements of photonic telecommunications.

**OPE505 Radiometry, Sources and Detectors (3-0)6**
Radiometry, Sources and Detectors. Radiometric concepts, symbols, units and nomenclature. Radiative transport in free space and through optical systems. Effect of material properties on radiative transport. Blackbodies and other radiation sources. Fundamentals of radiation detectors, including principles of operation, noise and figures of merit. Illustrative imaging and nonimaging radiometric systems.

**OPE506 Optical Instrumentation-I (3-0)6**
Eye: Human eye, Animal eye. Introduction to microscopy: Objectives, Reflective objectives, Tube lens, Illumination, Stereo microscopes, Eyepieces. Advanced microscopy: Phase contrast microscope, Differential interference contrast microscope, Polarization microscope. Fluorescence imaging systems: Fluorescence microscope, Multiphoton microscope, Total internal reflection fluorescence (TIFF) microscopy, Fluorescence lifetime imaging microscopy (FLIM), Fluorescence imaging systems. Telescopes: Refracting telescopes, reflecting telescopes, Tilted-component telescopes, large telescopes.

**OPE507 Optical Instrumentation-II (3-0)6**
Photographic systems: Film and image sensor, Photographic lenses, Zoom lenses, Digital camera, Phone camera, Image stabilization, Special aspects of photographic lenses. Displays: Projection displays, DMD projection display, LCD projection display, LCoS projection display, Pico projector, Flat panel displays, Digital cinema, 3D displays. Spectral imaging systems: Optical configurations, Design considerations.

**OPE508 Optical Instrumentation-III (3-0)6**
Optical Coherence Tomography (OCT): Low coherence interferometry, Optical coherence tomography, Ultra-high resolution OCT, Multimodal OCT. Confocal system: Basic components and requirements, Confocal scanning systems, Optical design of the objective lenses, Fiber-optic confocal imaging systems. Endoscopy: Basic optics for endoscopes, Relay lenses, Objective lenses, Illuminations, Wireless endoscopes. Infrared systems: Infrared materials, Infrared detectors, Infrared imaging systems, Optical design for infrared systems, Athermalization, Narcissus. Lithographic systems: Physical optics aspects, Performance of lithographic lenses, Evolution of lithographic lens systems, Optical design for lithographic systems.

**OPE509 Photovoltaic Solar Energy Systems (3-0)6**
This course is intended to provide an introduction to the theory and operation of different types of photovoltaic devices, the characteristics of solar illumination, and the advantages and characteristics of concentrating and light management optics. The physical limits on photovoltaic cell performance and practical device operation will be analyzed. The main device emphasis will focus on different types of silicon photovoltaic cells including crystalline, amorphous, multi-crystalline, and thin film solar cells. An overview of other types of photovoltaic cells including multi-junction III-V, CdTe, CuInSe2, and organics will also be given. A discussion of radiometric and spectral properties of solar illumination will be presented and the impact of these factors on solar cell design will be explored. Techniques for increasing the performance of solar cells by light trapping, photon recycling, and anti-reflection coatings will be covered. The design and operation of imaging and non-imaging concentrators will also be discussed. Basic experiments related to PV cell measurements and the optical properties of concentrators are also planned for the course.

**OPE510 Optical Specifications and Fabrication (3-0)6**
Properties of Optical Systems: Optical Properties of a Single Spherical Surface, Aperture and Field Stops, First Order Properties of an Optical System, Measurement of First Order Properties of Optical Systems, Diffraction and Aberrations, Optical Quality Metrics, Aspheric Surfaces. Fabrication of Optical Surfaces: Optical Materials, Grinding and Polishing Flats, Windows and Prisms, Grinding and Polishing Spherical Surfaces, Grinding and Polishing Aspheric Surfaces, Diamond Turning and Fast Tool Servo, Magnetorheological Finishing.

**OPE511 Optical Specifications and Testing (3-0)6**
Non-interferometric Testing: Autocollimator Tests, Surface Radius of Curvature, Wavefronts. Basic Interferometry and Optical Testing: Review of Two Beam Interference, Newton’s Rings, Fizeau Interferometer, Twyman-Green Interferometer, Mach-Zehnder Interferometer, Lateral Shearing Interferometers, Interferograms, Phase-Shifting Interferometry, Testing Aspheric Surfaces. Optical Specification: ISO 1101 Standard, ISO 10110 Standard.

**OPE512 Modern Astronomical Optics-I (3-0)6**
Introduction to course, Fundamentals of astronomical imaging systems: diffraction limit, photon noise. Fundamentals of space-based imaging systems: System engineering, Project management. Fundamentals of Telescope design: First-order design: plate scale, field of view, pixel size, diffraction limit. Telescope types: refractive, reflective. Wide field of view designs and aberration correction. Space and ground: cryogenic telescopes, design choices, challenges. Measuring large optics. Fabrication challenges and solutions (large optics fabrication, integrating optics and telescope structure). Fundamentals of spectroscopy: science goals, prisms, gratings, spectral resolution, detector sampling, wavelength coverage. Types of spectrographs: slit, multi-object, Integral Field Units (IFUs).

**OPE513 Modern Astronomical Optics-II (3-0)6**
Interferometry: First-order design; angular resolution, wavelength. Applications to stellar diameter measurement, exozodiacal dust detection, exoplanet detection, image synthesis. Beam combination in interferometers. Phase correction in interferometers: delay lines and adaptive optics. Interferometry on a single aperture: aperture masking, speckle interferometry. Adaptive Optics: Introduction to adaptive optics systems, Atmospheric turbulence and its effect on image quality, Wavefront sensing for adaptive optics, Wavefront correction, Laser guide stars, Wide field of view correction: ground-layer, multi-conjugate and multi-objects adaptive optics, System design, control strategies. High contrast imaging science: exoplanets and disks, Coronagraphs, High contrast imaging systems

**OPE514 Introductory Optomechanical Engineering (3-0)6**
Review of optics from a mechanical perspective: Review of first order optics – emphasizing coupling of imaging relationships to mechanical motion, Use of fold mirrors and prisms, Metrics for performance of optical systems, Tolerancing of optical systems, Specification of optical components, Introduction to mechanical modeling with SolidWorks, Mechanical drawings, Fabrication issues and limitations. Introductory engineering mechanics: statics, deflections, thermal effects, Introduction to finite element modeling, Vibration isolation, Materials – Engineering properties. Topics in optomechanical engineering: Kinematic systems, Precision adjustments and motion control Mounting of windows and prisms, mounting of lenses, Mounting and interface for mirrors, Optomechanical system design.

**OPE515 Optomechanical Design and Analysis (3-0)6**
Fundamentals of optomechanical design: Fundamentals of optomechanical engineering – fill in the gaps, Systems Engineering as applied to optomechanics, Layout for optical systems, Technique of design for fabrication. Design of mounts for common optics: Lens barrels, Fold mirror, Window. Precision mechanics design and analysis: Coarse and fine adjustments, Motion control, Use of flexures. Software tools for optomechanical design and analysis: Modeling of 3-D objects using Solid Works, developing mechanical drawings from SolidWorks models, Finite Element modeling within SolidWorks, Using Matlab to post-process finite element results. Independent Design Project. Each student will pursue an independent project, which must include the following: Define requirements, Preliminary design and analysis, Detailed design, Fabrication and test plan.

**OPE516 Biomedical Optic Instruments-I (3-0)6**
Design principles of basic biomedical instruments: hoton transport in tissue, Biophotonics phenomenon: fluorescence, Raman scatter, nonlinear optical processes, and photon damage, Devices for biomedical spectroscopy and imaging: coherent and incoherent light sources, single point and imaging detectors, light manipulating devices such as modulators and position scanners. Basic biomedical optical instruments: Spectroscopy instruments (UV-VIS and fluorescence spectrometers, Foruier transform spectrometer), Microscopes (wide field, dark field, DIC, phase contract and TIRF microscopes), Fluorescence microscopes (wide field, confocal microscope). Flow cytometer.

**OPE517 Biomedical Optic Instruments-II (3-0)6**
Specialized biomedical optic techniques: Optical coherence tomography, Fluorescence lifetime imaging, multi-photon imaging, Optical diffusion tomography, Photoacoustic tomography, Optical biosensing. Advanced techniques: Fluorescence energy transfer, fluorescence recovery after photobleaching, Coherent anti-Stokes Raman scatter imaging and Stimulated Raman scatter imaging, Optical tweezers, Single molecule imaging, Super resolution microscopy, Gene sequencing.

**OPE518 Optical Systems Engineering (3-0)6**
Systems Engineering fundamentals: Establishing requirements, Systematic design, applied to requirements, Risk management, Quality control, reliability. Optical system design: First order architecture studies, Creative design, Trade studies (performance, cost, schedule, risk), Detailed design and analysis, Tolerancing, Manufacturing issues, Integration and testing. Quantifying system performance for optical systems: Image quality metrics, Sensitivity, SNR, Spectral resolving power, ROC curves, Temporal bandwidth. Procurement of optical components and systems: Specification of optics, Specification of coatings, Practical selection of detectors and focal planes, Sources and illumination, electronic interfacing. Possible optical systems used as design projects and case studies: Machine vision, Custom metrology system, Infrared detection, Free space communication, Spectrograph, Adaptive optics.

**OPE519 Integrated Optics for Information Technology (3-0)6**
Introduction to Integrated Optics, Optic Communication and other applications. Elements of Integrated optics: Slab, channel waveguides, Y-junction, Directional coupler, Fabry-Perot etalon, Ring resonators, Waveguide grating, Wavelength filters and switches. Micro/Nanofabrication in Integrated optics: Epitaxial growth, Lithography, Etching, Metallization, Passivation and packaging. Active semiconductor components: Diode Lasers, Detectors. Semiconductor lasers: heterojunction, quantum wells. Various types of diode lasers, DFB, DBR, VCSEL, tunable lasers. Optical amplifiers: EDFA, Semiconductor. Modulators: Electroabsorption, electrooptic, Mach-Zehnder. Integration challenges.

**OPE520 Optical Communication Systems-I (3-0)6**
Introduction to Optical Communications and Networks. Optical Fibers: Geometrical-Optics Description, Wave Propagation, Chromatic Dispersion, Polarization Mode Dispersion, Dispersion-Induced Limitations, Fiber Losses, Nonlinear Optical Effects. Optical Transmitters, Modulators: Light-Emitting Diodes, Semiconductor Lasers, Control of Longitudinal Modes, Laser Characteristics, Transmitter Design, Mach Zehnder and Electroabsorption Modulators. Optical Receivers: Common Photodetectors, Receiver Design, Receiver Noise, Receiver Sensitivity, Sensitivity Degradation, Receiver Performance. Optical Amplifiers: Semiconductor Optical Amplifiers, Raman Amplifiers, Erbium-Doped Fiber Amplifiers, System Applications.

**OPE521 Optical Communication Systems-II (3-0)6**
Lightwave Transmission Systems: Intensity Modulation - Direct Detection Systems, Homodyne and heterodyne detection, Modulation formats: ASK, FSK, PSK, QAM, Demodulation schemes, Polarization multiplexing, Coherent OFDM systems, Bi-error rates and receiver sensitivity, Sensitivity degradation, System performance. Multichannel Systems: WDM Lightwave Systems and Components, WDM System Performance Issues, Orthogonal Frequency Division Multiplexing (OFDM). Optical Transmission Enabling Technologies: Dispersion Management, Modulation Formats, Nonlinearity Management, Wavelength Conversion, Optical 3R, Forward Error Correction, Optical Networks: Access and Metro Networks, Long-Haul Networks, Design Guidelines.

**OPE522 Electrical and Optical Properties of Materials (3-0)6**
Band structure and its relation to electrical and optical properties of materials, metals, insulators, thin films, semiconductors, gain and cavities, lasers, non-linear and electro-optic properties. Emphasis is also placed on polarization processes and wave propagation.

**OPE523 Visual Optics-I (3-0)6**
What is vision? Anatomy of the eye. Dissection. Average and range of sizes, shapes and indices of ocular components. Overview of optical modeling. Definition of visual acuity. Schematic eye models. Gullstrand-LeGrand and Helmholtz models. First-order properties. Locations of cardinal points. Definitions of near point, far point, myopia and hyperopia. Aspheric eye models. Stiles-Crawford, photopic response, diffraction. Location of eye axes. Spherical, Chromatic, Astigmatism (axial and oblique). Techniques for measuring aberrations. Nominal values. Derivation of these quantities from raytrace data. Retinal curvature. Visual performance - Theoretical resolution. Vernier acuity, grating acuity, Snellen acuity. Vision charts. Specification of visual acuity. Contrast sensitivity. Fourier theory - PSF, MTF, modulation threshold. Campbell and Green experiments. Van Nes and Bouman experiments. Changes in contrast sensitivity. Square-wave response. Double-pass measurement of PSF. Deconvolution. Asymmetric passes. Aberroscope. Shack-Hartmann test, Raytracing, Talbot-Moire. Zernike Polynomials and wavefront representation.

**OPE524 Visual Optics-II (3-0)6**
Spherical ametropia, cylindrical error, Scheiner disk, vector addition of crossed cylinders. Correction with sphero-cylindrical spectacle lenses. Correction with spherical, aspheric and toric contact lenses. prism ballast. Optometers, Autorefractors: image analysis, retinoscopic scanning and Scheiner disk types. Fogging. Lensmeters, Accommodation, age changes, near addition. Progressive lenses. Spherical and astigmatic considerations. Intraocular lenses. Power calculations. Multifocal contact and intraocular lenses. Aphakia and pseudophakia. Defocus Transfer Function. Other corrections: RK/AK, PRK, ALK/LASIK, orthokeratology, interscleral ring. Pupillometry. Measurement of the anterior cornea. Placido disks, stereo-photogrammetry and scanning slit devices. Height, slope and curvature representations of the cornea. Derivation of relationships. Keratometric index of refraction.

**OPE525 Visual Optics-III (3-0)6**
Calculation of radii of curvature, astigmatic axis and conic constant from Zernike expansion coefficients. Keratoconus detection. Miscellaneous Ocular Measurements. Measurement of corneal thickness - scanning slit, pachymetry. Measurement of the angle in glaucoma. Gonioscopy. Scheimpflug imaging. Phakometry, Purkinje images. Visual Fields. Spatial and temporal summation. Perimetry: Tangent Screen, Goldman projection, Static and Kinetic. Scotomas. Measurement and imaging the retina. Direct and indirect ophthalmoscopy, fundus camera. Confocal scanning laser ophthalmoscope. Optical coherence tomography. Applications: glaucoma screening, nerve fiber layer measurement. Radiometry and Photometry. MPE. Color matching. Additive and subtractive color mixing. Color vision - Trichromatic vs. opponent-process theories. Spectral response of cone pigments. Color blindness.

**OPE526 Introduction to Lasers (3-0)6**
The fundamental physical processes and introduction of engineering relevant to lasers, and explore a variety of specific laser systems. Topics to be covered include, optical laser gain and oscillation, resonators, numerical methods for beam propagation, and Q switching, and laser applications.

**OPE527 Optical Physics (3-0)6**
Review of linear algebra and classical mechanics, atomic models, Lorentz model, EM propagation, optical properties of dielectrics and metals, magneto- and electro-optics, concepts of nonlinear optics.

**OPE528 Introduction to Optical Spectroscopy (3-0)6**
Basic light-matter interactions: absorption, emission, elastic scatter, Raman scatter, and second harmonic generation. Optical measurements: noise statistics, photon detectors and cameras. Steady state absorption spectroscopy: dispersive absorption spectrometer and Fourier transform spectrometer. Steady state emission spectroscopy: fluorometer. Time-resolved photon detection: time-correlated single photon counting (TCSPC), streak camera, and gated image intensifier. Fluorescence lifetime spectroscopy: time-domain and frequency domain. Ultrafast-pulse measurement methods: autocorrelation and frequency-resolved optical gating (FROG). Time-of-flight measurement methods: Optical Frequency-Domain Reflectometry (OFDR), and Optical Coherence Tomography (OCT).

**OPE529 Optical Thin Films (3-0)6**
The optical properties of single films, design and multilayer optical coatings, calculation and visualization aids, accurate computation methods, introduction to manufacturing methods, non-ideal behavior of thin films.

**OPE530 Illumination Engineering (3-0)6**
Fields: Illumination, Nonimaging, and Concentrators; Sources: Incandescent, Fluorescent, LED, HID, Modeling, and Experimental Measurement; Modeling: Ray Tracing, Radiometry and Photometry, Color, Polarization, and Scattering; Theory: Radiometry, Photometry, Étendue, Skew Invariant, and Concentration; Design Methods: Edge Ray, Flow Line, Tailored Edge Ray, Non-Edge Ray, and Imaging; Optics: Reflectors, Lightpipes, Couplers, Films, and Hybrids; Applications: Displays, Automotive, Solar, Sources, and Lighting; Special Topics: Software Modeling, Optimization, Tolerancing, and Rendering.

**OPE531 Photonic Communications Engineering (3-0)6**
Optical fiber light guiding, wave propagation characteristics, materials properties, and fabrication. Optical transmitters, receivers and amplifiers. Communications systems, fiber optics networks, and Internet infrastructure.

**OPE532 Software Tools for Photonics (3-0)6**
MATLAB: General modeling and simulation strategies. OPNET: Modeling a broad scope of network technologies and protocols to automate network design. VPISYSTEM: Introduction to fiber-optic communications, Modeling of optical components including optical Transmitters, optical receivers, and optical amplifiers, Modeling of fiber propagation, polarization effects, chromatic dispersion, and Kerr nonlinearities, Modeling of optical modulators and modulation formats, WDM systems and optical networking modeling, Photonic measurements.

**OPE533 Diffraction and Interferometry-I (3-0)6**
Introduction to Theory of Interferometry and Diffraction. Maxwell's Equations. Wave Equation: Transverse waves, Plane waves, Complex representation, Spherical waves, Linear superposition, Polarization. Basic Interference: Two plane waves, Two spherical waves, Plane wave ans spherical wave, Plane wave and cylindrical wave, Methods of beam division. Concepts of Coherence: Coherence time, Coherence length, Theory of partial coherence, Fringe visibility reduction, Fringe localization, Correlation interferometry. Classical Two-Beam Interferometers: Plane parallel plate, Fizeau, Michelson, Twyman-Green, Mach-Zehnder, Lateral shear, Radial shear. Multiple Beam Interference: Airy's formula, Absorbing coatings, Fabry Perot (plane and spherical), FECO. Multilayer Films: Theory, AR film, High reflectance film. Direct Phase Measurement: Methods of phase shifting, Algorithms.

**OPE534 Diffraction and Interferometry-II (3-0)6**
Preliminary Description of Diffraction. Mathematical Description of Diffraction: Helmholtz equation, Green's theorem, Integral theorem of Helmholtz and Kirchhoff, Kirchhoff formulation of diffraction by a plane screen, Kirchhoff boundary conditions, Fresnel-Kirchhoff diffraction formula and Huygens-Fresnel principle, Rayleigh-Sommerfeld formulation of diffraction by a plane screen, Plane wave spectrum approach, Babinet's principle. Fresnel and Fraunhofer Diffraction: Fresnel approximation, Fraunhofer diffraction, Fresnel Diffraction: Fresnel zones, Circular aperture, Zone plate, rectangular aperture, large aperture - long slit and stright edge, Talbot images. Fraunhofer Diffraction: Single slit, rectangular aperture, Circular aperture, Double slit, Multiple slits, Binary diffraction gratings, Sinusoidal amplitude and phase gratings. Optical Transfer Function: Coherent imaging, Incoherent imaging. Gaussian Beams: Basic theory, Propagation through optical systems.
Holography: Physical description, Mathematical proof of reconstruction process, Minimum reference beam angle to separate orders, Recording and playback geometry, Light sources and recording materials, Volume holograms, Applications. Speckle: Physical origin, Applications.

**OPE535 Solid-State Optics (3-0)6**
Basic concepts in crystals and in optical response; optical properties of metals, insulators and semiconductors; quantum wells; glass and polymers; optical nonlinearities; solid-state devices and laser diodes.

**OPE536 Photonics-I (3-0)6**
Maxwell Equations. Wave Equations. Dielectric Media. Constitutive Relations. Anisotropic Media. Electromagnetic Waves, Absorption and Dispersion. Resonant Medium. Pulse Propagation. Optics of Anisotropic Media. Optical Activity and Magneto-Optics. Beam Splitter. Waveplates. Optical Isolator. Dispersion. Grating and Wavelength Separation. Wavelength Switches. Fabry Perot Filters and Bragg Mirrors. Mirror and Dielectric Waveguides. 2D Waveguides & Optical Coupling in Waveguides. Mode Dispersion. Phase & Group Velocity and Waveguide Loss. Waveguide Materials & Fabrication. Arrayed Waveguide Gratings. Compact Photonics: Microring Resonators & Photonic Bandgap Devices.

**OPE537 Photonics-II (3-0)6**
Electro-optic Waveguide Modulators. Fiber: Rays and Waves, Field Distribution, Modes, Polarization and V number. Attenuation and Dispersion. Fiber-based Devices: Gratings, Splitters, Sensors, Filters, and Compensators. Practical Aspects of Fiber: Manufacturing, Coupling, Splicing, Connectorizing, Testing, & Telcordia Standards. Nonlinear Effects in Optical Fiber and Their Effects on Optical Networks. EDFA, SOA and Raman Amplifiers. Fiber Optical Components and Fiber communication Systems. Optical Interconnects, OEO vs. OOO, Wavelength Switches and Time Domain Switches. LEDs. pn Junctions. Laser Diodes. More Laser Diodes, VCSEL and their Applications. Photodetectors and Photoconductors. Photodiodes and Avalanche Photodiodes.

**OPE538 Optical Physics-I (3-0)6**
Introduction to quantum mechanics, wave/particle duality, uncertainty principle. Quantum mechanics of free and bound particles, wave packets. Schrodinger equation, wave functions, eigenvalue equations. Postulates of quantum mechanics. Measurements in quantum mechanics, expectation values. Quantum harmonic oscillator. Hydrogen atom, quantum mechanics of the real hydrogen atom. Dirac notation, matrix formulation of quantum mechanics. Spin angular momentum, Pauli exclusion principle.

**OPE539 Optical Physics-II (3-0)6**
Hamiltonian for light/matter interaction, time-dependent probability amplitudes. Electric diple approximation, Rotating wave approximation. Two-level atom approximation, Rabi oscillations. Collisional decay and spontaneous emission, rate equations. Blackbody radiation, Einstein A and B coefficients. Steady-state absorption coeffecient, saturation. Inhomogeneous line broadening, absorption lineshapes. Quantization of the electromagnetic field, vacuum field fluctuations. Photon statistics.

**OPE540 Lasers (3-0)6**
Optical resonators, resonator stability. Population inversion. Threshold gain and steady-state laser operation. Laser output characteristics and output control. Pulsed lasers, Q-switching, mode locking. Argon-ion Lasers and Optical Tweezers. Fundamentals of Mode-locked Lasers. Semiconductor Diode Lasers.

**OPE541 Optical Testing and Testing Instrumentation-I (3-0)6**
Measurement of Paraxial Properties of Optical Systems: Thin Lenses, Thick Lenses. Qualification of Optical Material: Internal Defects, Measurement of Refractive Index, Strain, Mechanical and Thermal Properties. Aberrations: Sign Conventions, Aberration Free Image, Spherical Wavefront, Defocus, and Lateral Shift, Angular, Transverse, and Longitudinal Aberration, Seidel Aberrations, Relationship between Zernike Polynomials and Third-Order Aberrations, Peak-Valley and RMS Wavefront Aberration, Strehl Ratio, Chromatic Aberrations, Aberrations Introduced by Plane Parallel Plates, Aberrations of Simple Thin Lenses, Conics and General Aspheres. Basic Interferometry and Optical Testing: Two Beam Interference, Pioneer Fizeau Interferometer, Twyman-Green Interferometer, Fizeau Interferometer – Laser Source, Mach-Zehnder Interferometer, Typical Interferograms, Interferograms and Moiré Patterns, Classical techniques for inputting data into computer.

**OPE542 Optical Testing and Testing Instrumentation-II (3-0)6**
Direct Phase Measurement Interferometry: Zero-Crossing Technique, Phase-Lock Interferometry, Up-Down Counters, Phase-Stepping and Phase-Shifting Interferometry, Phase-Shifting Nondestructive Testing, Multiple Wavelength and White Light Phase-Shifting Interferometry, Vertical Scanning (Coherence Probe) Techniques. Measurement of Surface Quality: View transmitted or reflected light, Mechanical Probe – Stylus Profilometry, AFM– Atomic Force Microscope or SPM – Scanning Probe Microscope, Lyot Test (Zernike Phase Contrast), FECO – Fringes of Equal Chromatic Order, Nomarski Interferometer - Differential Interference Contrast (DIC), Interference Microscope.

**OPE543 Optical Testing and Testing Instrumentation-III (3-0)6**
Testing Flat Surface Optical Components: Mirrors, Windows, Prisms, Corner Cubes, Diffraction Gratings, Index inhomogeneity. Testing of Curved Surfaces and/or Lenses: Radius of Curvature, Surface Figure. Special Interferometric Tests for Aspherical Surfaces: Aspheric Surfaces, Null Test, Non-Null Test. Absolute Measurements: Flat Surfaces, Spherical Surfaces, Surface Roughness. System Evaluation: Resolution Tests, Veiling Glare, Spread Function Measurement, Encircled Energy Measurement, Optical Transfer Function Measurement.

**OPE544 Lens Design (3-0)6**
Imaging. Review of first-order optics. Aberration theory. Higher order aberrations. Control of spherical aberration. Ray tracing. Chromatic aberrations. Control of coma, astigmatism, field curvature and distortion. The Brownie camera. Image evaluation. Periscope lens. The Petzval portrait lens. Diffractive lenses. Lens optimization. Cooke triplet. Double Gauss. Pupil effects. Tolerancing. A periscope lens design. Lens manufacturing.

**OPE545 Introduction to Aberrations (3-0)6**
Preliminaries: Geometry and Coordinate systems, Optical path, optical path difference, Axially symmetric systems and other types, Geometrical wavefront propagation and aberration theory goals. Images and their relationship to the geometrical wavefront, Review of pupils and field and aperture vectors. Wave and ray aberrations: Wave aberration function scalar and vector representation, Classification of wavefront aberrations, Fourth order and sixth order aberrations, Aberration coefficients, Wavefans, meridional and sagittal, Chromatic aberrations, Transverse ray aberrations, Relation to wave aberrations, Ray fans, Spot diagrams and grid choice, Caustics, Change of reference sphere, Interferometric representation, Point Spread function, Aberrated spread function, Rayleigh-Strehl ratio, Aberration balancing, Focus, tilt, spherical aberration, coma, astigmatism. Aberration Coefficients: Seidel sums, Petzval field curvature, Spherical aberration, Field dependent aberration, Stop shift, Special surfaces, Structural aberration coefficients.

**OPE546 Holography and Diffractive Optics (3-0)6**
Basic concepts. Introduction–terminology. Basic Holographic Recording Process. Analysis of Holographic Recordings–spatial frequency analysis. Fourier Analysis of gratings. Image analysis of holograms. Hologram Recording Requirements. Coupled wave analysis. Holographic materials –recent developments. Computer generated holograms. Digital Holography. Optical Data Storage. Other Applications.Introduction to photonic bandgap materials and devices.

**OPE547 Digital Image Analysis (3-0)6**
Image file formats, edge detection, edge map processing, segmentation, region processing, morphological filtering, texture analysis, stereoscopy, optical flow.

**OPE548 Digital Image Processing-I (3-0)6**
2-D Signals and Systems: Discrete-space signals, Sampling and quantization, Linear shift-invariant systems, Fourier transform. 2-D z-Transform: Definition, Difference equation, Stability. Discrete Fourier Transform: Derivation of DFT, Discrete cosine transform, Fast Fourier transform. Computer Programming: Common image file formats, Dynamic memory allocation, Pointers vs. array indexing. 2-D FIR Filter Design: Window method, Frequency sampling method, Frequency transformation method. Spectral Estimation: Fourier techniques, Maximum likelihood method, Autoregressive modeling, Maximum entropy method.

**OPE549 Digital Image Processing-II (3-0)6**
Image Perception: Luminance, hue, and saturation, Color representation, Visual phenomena, Image processing hardware. Image Enhancement: Histogram modification, Linear filtering, Nonlinear filtering, Adaptive filtering, Pseudocolor. Image Restoration: Degradation models, Wiener filtering, Inverse filtering, Blind deconvolution. Image Compression: Scalar quantization, Vector quantization, Spatial coding, Transform coding.

**OPE550 Introduction to Image Science (3-0)6**
Overview of modern imaging and image formation. Objects as vectors in a vector space, image formation as a continuous to continuous or continuous to discrete mapping from an object vector space to an image vector space. Eigenfunctions, linear systems, Fourier transforms. Indirect imaging, inverse problems, iterative algorithms. Geometrical optics description of imaging, radiometry. Physical optics description of imaging. Coherent and incoherent imaging, diffraction limit. Optical and electron microscopy. Digital imaging, sampling, image detectors, displays. Advanced optical microscopy, optical coherence tomography, near-field imaging. Imaging in astronomy and remote sensing. Radar, Lidar. Sonar, ultrasound imaging. Shadow casting, coded apertures. X-ray imaging, computed tomography. Nuclear imaigng, SPECT, PET. Magnetic resonance imaging. Classification and estimation tasks. Image quality, performance evaluation. Image processing.

**OPE551 Foundations of Quantum Optics-I (3-0)6**
Classical linear optics. Maxwell's equations, Lorentz atom, dipole approximation, dipole force. Lorentz atom with damping. Classical theory of absorption. Complex polarizability and index of refraction. Two-level atom and classical electric field. Rabi solutions. Comparison to Lorentz atom. Multi-level atoms, selection rules for electric dipole transitions, Raman coupling in 3-levels ystems.
Density-matrix formalism. Application to two-level atom. Relaxation. Spontaneous emission and collisions. Population rate equestions. Einstein A and B coefficients. Optical Bloch equations. Photon echoes, free-induction decay, selfinduced transparency. Maxwell-Bloch equations. Solitons.

**OPE552 Foundations of Quantum Optics-II (3-0)6**
Introduction to semiclassical laser theory. Fundamental laser equation. Stability analysis, laser threshold, frequency pulling. Small signal and saturated gain. Laser linewidth. Field quantization in the Coulomb gauge. Field observables, vacuum fluctuations. Number states, coherent states, squeezed states, wave packets. The quantum beam splitter. Atom-field interaction in the dipole approximation. Two-level atom. The Jaynes-Cummings model. Dressed states. Weisskopf-Wigner theory of spontaneous emission. Quantum theory of photodetection. Classical and quantum theories of optical coherence. Correlation functions. Hanbury Brown and Twiss interferometry. Photon antibunching. Two-photon interferometry.

**OPE553 Physical Optics (3-0)6**
Paraxial ray optics, Diffraction and propagation, Interferometers and resonators, Optical interactions: non-relativistic classical electrodynamics, Classical theory of dispersion, Periodic structures, Magneto- and Electro-optics, Introduction to Nonlinear Optics.

**OPE554 Beam Propogation Method (3-0)6**
Maxwell ‘s equations in a dielectric medium. Free-space propagation. Numerical beam propagation in 1D and in 2D. Numerical beam propagation in 2D, for radially symmetric problems. Modeling other optical systems. Beam propagation in dielectric structures. Split-step Beam Propagation Method. Propagation in 1D and 2D waveguides. Finite difference approaches to BPM. Finite difference approaches to BPM: material interfaces. Spatially varying structures. Further generalizations: Time dimension, and pulsed beam propagation, numerical analogies analogies between space and time, Inclusion of loss and gain, nonlinear propagation, self-focusing, nonlinear absorption.

**OPE555 Atom Optics (3-0)6**
Introduction to the experiments and theoretical concepts of atom optics and matter-wave optics. In atom and matter-wave optics, the wave-like properties of matter are utilized for the manipulation and control of matter (often by laser light), and are centrally important for an understanding of physics at the atomic level and for modern quantum optics applications. This course will introduce some new concepts, but will primarily cover foundational and groundbreaking atom optics ideas and experimental results.

**OPE556 Optical Detectors and Detector Systems (3-0)6**
Detection techniques, detectors types and noise processes. Radiometry and Natural sources. Introduction to noise, Detector Figures of merit and Photodiodes. Photoconductive detectors and Thermal detectors. Quips and Strained super lattice. Two Dimensional Arrays. FPA Data Processing. Target Phenomenology: Reflection and Emission of Materials. Bi-directional Reflectivity Distribution Function (BRDF), Radiation Sources: Natural and manmade. Signal-Noise Calculations and NETD. System Figures of Merit: NETD and NEFD. Probability of Detection and False Alarm Analysis. Linear Mixing problem and Imaging Spectrometer.

**OPE557 Thin Film Optics (3-0)6**
Growth of thin films: Sputtering, Evaporation (with emphasis on Molecular Beam Epitaxy), Nucleation and Growth Phenomena. Structure of thin films: Physical Structure and Chemical (Compositional) Structure. Optical Coatings: reflection, antireflection, beam splitters, dichroic filters, bandpass filters, etc. Optical Data Storage: magneto-optical media, phase-change media, etc. Active Optical Thin Films: diode lasers.

**OPE558 Polarization in Optical Design (3-0)6**
Principals of the calculation of polarization effects in optical systems; Geometrical optics; Polarization ray tracing. Polarization aberration function. Examples of polarization aberrations. Polarization Models. Realistic Polarization Elements.

**OPE559 Introduction to Display Science and Technology (3-0)6**
Human visual system: Eye anatomy and eye optics, Visual performance of the eye and Models of visual performance and photometry. Color vision and colorimetry: Color vision basics, Color matching experiments and color matching functions, Color systems and spaces, Colorimetry. 2D display technology and operation: Display system interfaces and performance parameters, CRT displays, Flat panel displays: AMLCD, LCOS, Plasma, OLED, and Projection systems. New display technologies: high dynamic range display, enriched color display. Display metrology: display performance measurement and calibration, General principles of display evaluation, Evaluation of 2D displays, Color management and calibration. Binocular vision and 3D display technology: Binocular vision and perception basics, 3D display principles and techniques, head-mounted displays, spatially immersive displays, Auto-stereoscopic displays, Volumetric displays, Holographic displays. Human factors associated with 3D displays and 3D display evaluations.

**OPE560 Aberrated Imaging and Propagation (3-0)6**
Fundamentals of Image Formation: Diffraction theory of image formation with emphasis on aberrations, Compare diffraction and geometrical PSFs and OTFs, Strehl, Hopkins, and Struve ratios, Asymptotic behavior of PSF. Imaging by systems with circular pupils: Aberration-free PSF and beam focusing, Strehl ratio and aberration balancing and tolerance, Zernike circle polynomial expansion of aberration function, Aberrated PSF and its symmetry properties, Encircled and ensquared power, Aberrated OTF and Hopkins ratio, Line of sight and centroid of PSF of an aberrated system, Line-spread function and Struve ratio, Polychromatic PSFs and OTFs. Imaging by systems with annular pupils: Discuss similar topics as for systems with circular pupils, including Zernike annular polynomials. Imaging by systems with Gaussian pupils: Effect of Gaussian apodization on PSF and OTF, Zernike-Gauss polynomials and aberration balancing, Propagation of Gaussian beams. Random Aberrations: Random image motion, Fabrication errors, Propagation through atmospheric turbulence.

**OPE561 Advanced Geometrical Optics (3-0)6**
Light Rays. Velocity of Light. Electromagnetic character of light. Sources of light and their spectra. Absorption, transmision ans scattering of light. Reflections and Refractions of Light. Double Refraction. Polarization of Light. Plane ans Spherical Mirrors. Plane and Spherical Surfaces. Prisms. Thin and Thick Lenses. Effects of Stops. Ray Tracing and Lens Aberrations.

**OPE562 Wave Optics (3-0)6**
Light waves. Superpositions of waves. Interference of two beams of light. Interference involving multiple reflection. Fraunhofer diffraction by a single opening. Double slit. Difraction grating. Fresnel diffraction. Interference of polarized light. Optical Interferometry.

**OPE 599 M.Sc. Research and Thesis**
**OPE 701-750 Graduate Seminar**
**OPE 801-899 Special Studies**