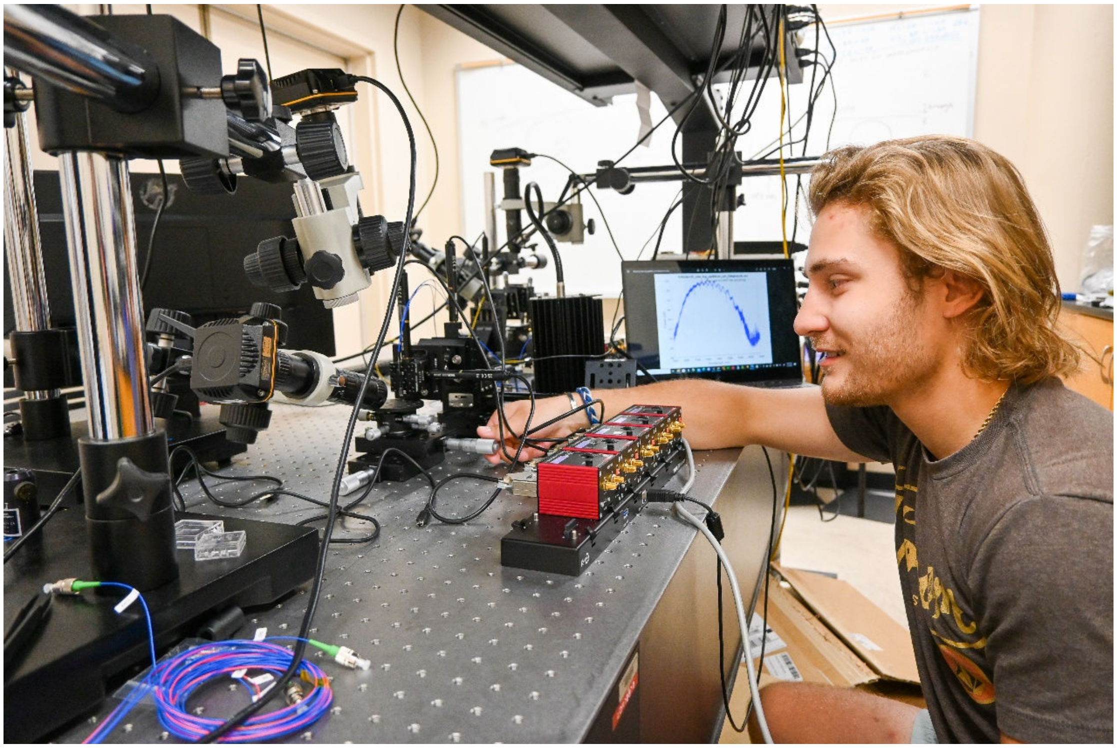
University of Dayton
School of Engineering

Department of Electro-Optics and Photonics



Master of Science (M.S.) in Electro-Optics

Doctor of Philosophy (Ph.D.) in Electro-Optics

Undergraduate Minor in Electro-Optics and Photonics

Undergraduate Minor in Semiconductor Manufacturing

Fall 2023

Milestones

Master’s	
Thesis	***Non-Thesis***
Select an adviser and submit plan of study prior to registering for the tenth credit hour or before the third semester (whichever comes first)	
Submit plan of study including 6 credit hours of EOP 599 (thesis)	Submit plan of study including EOP 598 (non-thesis project)
Remote students may substitute EOP 597 (capstone Project) in place of two EOP labs	
Select two additional committee members in consultation with the adviser	
File application for graduation by the fourth week of the graduation semester	
Obtain adviser's approval of final thesis draft by the middle of the graduating semester	Obtain adviser’s approval for EOP 598 report by the middle of the graduating semester
Submit final thesis draft to committee two weeks before the defense	Submit written report to the committee two weeks before the presentation
Successfully present and defend the thesis to the committee	Successfully present report to the advisory committee
Submit approved thesis to the Graduate Office by the deadline	Submission to Graduate Office is not required

Doctorate
Select dissertation adviser
Submit Plan of Study before the end of the first semester (only the adviser needs to be identified at this stage)
Take the EOP Candidacy Exam (Part 1) after taking all EOP core courses
Select three additional committee members (two from the EOP department and one outside) in consultation with dissertation adviser
Submit dissertation proposal document to committee at least one week prior to the proposal defense date.
Successfully present and defend the dissertation proposal (Part 2 of the Candidacy Exam) within six months of passing the written exam and before registering for the 13th EOP 699 credit hr
Have at least one accepted refereed journal publication as lead author File application for graduation by the fourth week of the graduation semester
Obtain adviser’s approval of final dissertation draft
Submit the final dissertation draft to the committee two weeks before the defense
Present and successfully defend the dissertation to the committee
Submit approved dissertation to the Graduate Office by the deadline

Accelerated Bachelor’s Plus Master's Program

The Department of Electro-Optics and Photonics offers a Bachelor's Plus Master's (BPM) program for qualified undergraduate students from engineering or physics. This program gives undergraduate students the opportunity to graduate with a EOP master’s degree in 5 years.

Non-thesis Route

Senior Fall	Senior Spring	Senior Summer	MS Fall	MS Spring
EOP 500 EOP 501 (BS + MS dual count) EOP 502 (BS + MS dual count) 6 credit hours[1]	EOP 505 EOP 506 EOP 541L 7 credit hours[2]	EOP Technical Elective 3 credit hours	EOP 503 EOP 542L EOP 543L EOP Technical Elective 8 credit hours	EOP 504 EOP Tech. Elective Project Presentation 6 credit hours

Thesis Route

Senior Fall	Senior Spring	Senior Summer	MS Fall	MS Spring	MS Summer
EOP 500 EOP 501 (BS + MS dual count) EOP 502 (BS + MS dual count) 6 credit hours[1]	EOP 505 EOP 506 EOP 541L 7 credit hours[2]	Technical Elective 3 credit Thesis 6 credit hours	EOP 503 EOP 542L EOP 543L 5 credit hours	EOP 504 3 credit hours	3 credit Thesis Thesis Defense 3 credit hours[3]

[1] The 6 credit hours will count towards the technical electives requirements of the BS degree. With the BPM election, the same 6 credits will also count towards the MS degree.

[2] These 7 credit hours will only count towards the MS degree, and do not fulfill any undergraduate requirements. Students pursuing the BPM option will have to plan their undergraduate courses to make room for these courses.

[3] The research work will span over multiple semesters regardless of when you register for the thesis credits.

Undergraduate Minor in Electro-Optics and Photonics

The EOP Minor requires 12 credit hours beyond the courses required by the students' respective program. Taking any four of the following list of courses will qualify for the EOP minor.

- EOP 401 Introduction to Fiber Optics
- EOP 404 Semiconductor Characterization & Metrology
- EOP 501 Fundamentals of Optical Design
- EOP 502 Light and Matter Interaction
- EOP 503 Optical Information Processing
- EOP 504 Guided-Wave Optics
- EOP 505 Introduction to Lasers
- EOP 506 Photonic Devices & Systems

Undergraduate Minor in Semiconductor Manufacturing

The Minor in Semiconductor Manufacturing is managed by the Department of Electro-Optics and Photonics (EOP), Electrical and Computer Engineering (ECE) and Physics. A student must take four courses (12 credit hours) beyond his or her program requirements from the following list:

Required course:

- ECE 205 - Introduction to Semiconductor Engineering

Select any three from the following list:

- EOP 404 - Semiconductor Characterization & Metrology
- EOP 405 - Semiconductor Device Fabrication Lab
- EOP 406 - Advanced Semiconductor Manufacturing
- PHY 321 - Modern Physics
- PHY 420 - Introduction to Solid State

Master's Degree in Electro-Optics

The program of study in electro-optics leading to an M.S. degree must include a minimum of 30 semester hours consisting of:

- Twenty-four (24) semester hours of core courses that include EOP 500 (during your first Fall semester), EOP 501, EOP 502, EOP 503, EOP 504, EOP 505, EOP 506, EOP 510 (every semester) and EOP 541L, and at least two from EOP 542L, EOP 543L and EOP 595 (summer short course).
    - **Thesis option:** six (6) semester hours of thesis credits (EOP 599) and three (3) semester hours of approved technical elective(s).
    - **Non-thesis option:** non-thesis research project (EOP 598) and nine (9) semester hours of approved technical electives.
- A remote MS degree option is available for students with prior approval. Remote students may take EOP 597 (capstone project) in place of the EOP lab classes.

M.S. Thesis

For students pursuing the thesis option and/or receiving a research assistantship, the faculty research supervisor shall serve as the academic adviser. For other students, the EOP department chair or his/her designated faculty member will serve as the adviser.

Students who wish to do a thesis should select a research adviser and demonstrate satisfactory progress towards their selected topic before indicating the thesis option on their plan of study. Any thesis credits taken without the permission of the thesis adviser may not count towards the degree.

All M.S. students supported by a research or teaching assistantship, including off-site research facilitated through the efforts of the EOP department are required to take the thesis option. The research adviser typically will serve as the chair of the thesis committee.

Doctoral Degree in Electro-Optics

To be considered for admission to the Ph.D. program in Electro-Optics, a student must have a M.S. degree in Electro-Optics or equivalent, with a graduate GPA 3.5 or higher out of 4.

The doctoral program of study must include a minimum of 90 semester hours beyond the bachelor's degree (or 60 semester hours beyond the MS degree) consisting of:

- All twenty-one (21) semester hours of the EOP core courses listed under the MS degree, or equivalent.
- Twelve (12) semester hours of approved 600-level electro-optics courses.
- Three (3) semester hours of approved graduate mathematics courses.
- Thirty (30) semester hours of doctoral dissertation in electro-optics (EOP 699).

Please note that the above list adds up to 36 semester hours of courses (6 more than the minimum requirement). Typically, this requirement applies only for students entering the Ph.D. program with a MS in a different field or from a different institution. Students who earned their MS in EOP would have already taken the EOP core courses, or their equivalent, hence requiring only 30 semester hours of courses.

Research & Dissertation

For students receiving a research assistantship, the faculty research supervisor shall serve as the chair of their advisory committee.

At least one journal paper based on the dissertation, with the candidate as lead author, must be accepted in a recognized refereed journal in the area of the candidate's research by the date of the defense.

EOP Candidacy Examination

Students generally take the candidacy examination when all EOP core courses (EOP 501 through 506) listed above have been completed. The exam will include two parts: (1) an examination covering the EOP core courses; and (2) an examination on the dissertation proposal.

Part 1 exam is offered twice a year, at the beginning of the fall and spring semesters. Students with a grade of A- or higher in the core courses will be exempt from taking this exam in those subject areas. If students fail the Part 1 exam in any of the subject areas being examined, they will have one more opportunity to retake the exam in the following semester in the subject area(s) that they failed.

After successful completion of Part 1, Part 2 must be completed within six months, and before registering for their 13th dissertation hour. For full-time students, part 2 must be completed before the end of their second year in the PhD program. For part-time students, part 2 must be completed before the end of their fourth year in the program.

Electro-Optics Graduate Courses and Syllabi

EOP 500: Introduction to Research in Electro-Optics

Instructor: Mikhail Vorontsov, mvorontsov1@udayton.edu
Credit Hrs: 0
Syllabus:

1. Introduction to EOP and the University of Dayton
2. M.S. & Ph.D. program overview, courses, objectives and expectations; Plan of study.
3. Library and online research resources
4. Title IX, community, inclusion
5. Laboratory safety
6. Technical writing
7. Copyright issues, plagiarism and academic honor code
8. Intellectual property, disclosures and rights
9. Research funding
10. How to make effective technical presentations

EOP 501: Fundamentals of Optical Design

Offered every Fall semester

Instructor: Miranda van Iersel, mvaniersel1@udayton.edu
Credit Hrs: 3
Textbook: Field Guide to Geometrical Optics, John E. Greivenkamp, SPIE Press
References:

- Geometrical Optics and Optical Design, Pantazis Mouroulis and John Macdonald, Oxford University Press
- Fundamental Optical Design, Michael J. Kidger, SPIE Press.

Syllabus:

1. Introduction to geometrical optics
2. Reflection & Refraction
3. Object and image planes & cardinal points
4. Paraxial approximation
5. Ray tracing
6. Gaussian optics
7. Thin lenses
8. Optical systems
9. Aberrations
10. Introduction to Zemax, computer based ray tracing

EOP 502: Light and Matter Interaction

Offered every Fall semester

Instructor: Rita Peterson
Textbook: R. Brecha, J.M. O'Hare, 'Optical Radiation and Matter' IOP Publishing Ltd, 2021.
References:

- D. J. Griffith, *Introduction to Eelectrodynamics 4th edition*, Addison-Wesley, Boston, MA, 2012
- G. R. Fowles, *Introduction to Modern Optics 2nd edition*, Dover, Mineola, NY, 1989
- B. E. A. Saleh and M. C. Teich, *Fundamentals of Photonics 2nd edition,* John Wiley & Sons, New York, 2007
- A. Yariv and P. Yeh, *Optical Waves in Crystals*, John Wiley & Sons, New York, 2003

Syllabus:

1. Review of electromagnetic wave: Maxwell's equations, Plane wave solution, Phase and group velocity, Poynting theorem
2. Polarization of light: State of polarization, Jones matrices, Stoke parameters, Poincaré's sphere, polarization devices
3. Radiation and Scattering: Potential theory of electromagnetism, Radiation from dipole, Scattering by a dipole
4. Absorption and line broadening: Extinction by a dipole, Propagation in a dilute medium, Broadening
5. Macroscopic electrodynamics: Macroscopic Maxwell's equations, Dielectric tensor, Electromagnetic wave equation, Reflection and transmission at an interface
6. Crystal optics: Polarizer, Birefringence, Optical activity, Faraday effect
7. Electro-optic effects: EO effects, EO retardation, EO amplitude modulation, EO phase modulation
8. Optical properties of metals: Drude model

EOP 503/ECE 572: Optical Information Processing

Offered every Fall semester

Instructor: Partha Banerjee, pbanerjee1@udayton.edu
Credit Hrs: 3
Text: Introduction to Fourier Optics, 3rd ed., Goodman
References:

1. *Principles of Applied Optics*, Banerjee and Poon
2. *Contemporary Optical Image Processing with MATLAB*, Poon and Banerjee
3. Class notes

Syllabus:

1. 2D signals and systems; 2D Fourier transforms
2. Transfer function and impulse response of propagation
3. Examples of Fresnel and Fraunhofer diffraction; Gaussian beams
4. Transport of intensity and phase
5. Lenses and mirrors for imaging and Fourier transformation
6. Transfer functions of coherent and incoherent imaging systems
7. Analysis and design of complex spatial filters and holograms
8. 3D imaging using holography and transport of intensity
9. Contemporary topics in optical signal and image processing

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EOP 504/ECE 574: Guided Wave Optics

Offered every Spring semester

Instructor: Imad Agha, iagha1@udayton.edu
Credit Hrs: 3
Textbook: C. R. Pollock, *Fundamentals of Optoelectronics*, Richard Irwin Inc., 1995. (out of print but an electronic copy will be given to the class), or C. R. Pollock, and M. Lipson *Integrated Photonics*, Springer; Softcover reprint of hardcover 1st ed. 2004 edition.
Text Notes: Will be handed out in class.
Reference Texts:

- Gerd Keiser, *Optical Fiber Communications*, 4th Ed., McGraw Hill, New York, 2011
- Amnon Yariv and Pochi Yeh, *Photonics*, Sixth Ed., Oxford University Press Inc. 2007
- Dietrich Marcuse, *Theory Of Dielectric Optical Waveguides*, 2nd Ed. Academic Press Inc. 1991

- A. Snyder, and J. Love, *Optical Waveguide Theory*, Springer; 1st Ed. 1983
- A. H. Cherin, *An Introduction To Optical Fibers*, McGraw Hill, New York, 1983

Syllabus:

1. Introduction
2. Review of Maxwell's equations
3. Planar slab waveguide
4. Dispersion in waveguides
5. Graded index waveguides and the WKB method
6. Step index circular waveguides
7. Dispersion in step index and graded index fibers
8. Attenuation in optical fibers
9. Rectangular dielectric waveguide
10. Coupled Mode theory and applications
11. Coupling between optical sources and waveguides

EOP 505: Introduction to Lasers

Offered every Spring semester

Instructor: Miranda van Iersel, mvaniersel1@udayton.edu
Credit Hrs: 3
Textbook: Christopher Davis, *Lasers and Electro-optics: Fundamentals and Engineering*, 2nd Edition, Cambridge (1996).
References:

- Amnon Yariv, *Optical Electronics in Modern Communications, 5th Edition,* Oxford Univ. Press (1997)
- William Silfvast, *Laser Fundamentals, 2nd Edition,* Cambridge University Press, (2004)

Syllabus:

1. Introduction and laser safety
2. Analysis of Optical Systems
3. Optics of Gaussian Beam
4. Optical Resonators
5. Optical Frequency Amplification
6. Optical Resonators Containing Amplifying Media
7. Characteristics of Laser Radiation
8. Control of Laser Oscillators
9. Practical Laser Systems

EOP 506/ECE 573: Photonic Devices & Systems

Offered every Spring semester

Instructor: Andrew Sarangan, sarangan@udayton.edu
Credit Hrs: 3
Textbook: Course notes by Andrew Sarangan
Syllabus:

1. Optical properties of materials
2. Basic semiconductor properties
3. PN junction diodes
4. Light emitting diodes and fiber coupling
5. Semiconductor optical amplifiers and fiber amplifiers
6. Diode Lasers – Fabry-Perot, DFB, VCSELs
7. Photodetectors – junction detectors, photoconductors, avalanche detectors
8. Noise in detection systems
9. Solar photovoltaic devices
10. Image Sensors – CCD & CMOS sensors, IR imagers
11. Electro-Optic Devices – Mach-Zehnder modulators
12. Liquid crystal devices – displays, spatial light modulators
13. Diffraction Grating
14. Electro-Optic Systems – CD pickup units, barcode scanners

EOP 510: Contemporary Topics in Electro-Optics and Photonics (CTOPS)

Offered every Fall and Spring semesters

All MS students must register for EOP 510 every semester.

Instructor: Mikhail Vorontsov, mvorontsov1@udayton.edu
Credit Hrs: 0
Syllabus:

1. Discussion, inquiry and feedback of research progress towards a thesis in electro-optics and photonics
2. review of background research literature
3. discussion of experimental or computation methods and results
4. presentation of research progress reports
5. review of laboratory safety protocols
6. participation in technical conferences and professional workshops and/or Stander Symposium

EOP 532: Optical Thin Film Design

Instructor: Andrew Sarangan, sarangan@udayton.edu
Credit Hrs: 3
Textbook: *Optical Thin Film Design*, Andrew Sarangan, CRC Press
Syllabus:

1. Transfer matrix method
2. Single- and multi-layer antireflection design
3. High reflection designs
4. Equivalent index method
5. Edge filters
6. Line filters
7. Bandpass filters
8. Metal film optics
9. Thin films for oblique incidence
10. Polarization control
11. Optical thin film materials and their properties
12. Phase change materials
13. Production methods

EOP 533/ECE 580: Fundamental Principles of Nanofabrication

Instructor: Andrew Sarangan, sarangan@udayton.edu
Credit Hrs: 3
Textbook: *Nanofabrication: Principles to Laboratory Practice*, Andrew Sarangan, CRC Press.
Syllabus:

1. Cleanrooms for device fabrication
2. Fundamentals of Vacuum
3. Fundamentals of Plasmas for Device Fabrication
4. Physical and Chemical Vapor Deposition
5. Substrate Materials
6. Lithography
7. Wet Chemical Etching
8. Plasma Etching

9. Doping, Surface Modification and Metal Contacts
10. Micro-metrology

EOP 541L: Geometric and Physical Optics Laboratory

Offered every Spring semester

Instructor: Cong Deng, cdeng1@udayton.edu
Credit Hrs: 1
Textbook: The experiments are based on material written by Drs. Cong Deng, Bradley Duncan and Gordon Little, etc
References:

- Born and Wolf, *Principles of Optics,* Cambridge University Press, 1999
- Goodman, *Introduction to Fourier Optics,* Roberts and Company Publishers, 2004
- Hecht, *Optics*, Addison-Wesley, 2001
- Miller, *Geometric and Physical Optics Laboratory Course Documentation and Lab Manual*

Syllabus:

1. Modulation transfer function (MTF) of a pinhole camera
2. Focal length of lenses: Investigate and evaluate several techniques for determining the focal length of a lens with emphasis on experimental measurement uncertainty and error analysis
3. Simple Optical Systems: Investigate the properties of a Gaussian beam expander and an optical relay system
4. The Airy disc and Fraunhofer Diffraction: Study the Airy disc, the diffraction limit of lenses and Fraunhofer diffraction from slit apertures
5. Fresnel diffraction: Study the Fresnel diffraction irradiance pattern from an opaque line stop
6. Polarization: Study several aspects of polarization including: linear polarizers, retarders, birefringent materials, Fresnel reflection, and Brewster's Law
7. Interferometry and temporal coherence: Study the temporal coherence of conventional and laser sources using two-beam interferometers

EOP 542L: Electro-Optic System Laboratory

Instructor:
Credit Hrs: 1
Text:
Syllabus:

1. Optical Fibers: multimode fibers, single mode fibers, cleaving, inspecting, splicing, numerical aperture and light coupling,, V numbers, Erbium doped fiber amplifier
2. Optoelectronic/electronic devices and systems: photocells, photodiodes, LEDs, laser diodes, biasing and sensing circuits, PCB assembly
3. Diffraction gratings: Review of basic principles, measuring the grating periods of grooved gratings, applications in spectroscopy
4. Gratings and Spectrometry: fiber bragg gratings, spectrometry, diffraction gratings, quantum dots.
5. Liquid crystal devices

EOP 543L: Advanced Electro-Optics Laboratory

Offered every Fall semester

Instructor: Swapnajit Chakravarty, schakravarty1@udayton.edu
Credit Hrs: 1
Textbook: The project manuals will be distributed to the students electronically at the beginning of the semester.
Syllabus:

1. Optical spectroscopy
2. Computer generated holography
3. Spectroscopic Ellipsometry
4. Electro-Optic Modulator
5. Photonic Integrated Circuit Measurement

EOP 595: Special Problems

The objective of this course is to provide an opportunity for a student to study a topic of their choosing at the MS level under the guidance of an instructor.
Credit Hrs: 1-6
Prerequisite(s): Permission of instructor.

EOP 595: 1-Week Summer Short Courses

Introduction to LiDAR

Instructors: Paul McManamon, paul@excitingtechnology.com, Edward Watson, ewatson1@udayton.edu
Credit Hrs: 1 (2 CEU)
Course description: Survey of principles of direct detection and coherent detection lidar systems, lidar sources and receivers, effects of illumination path and object scattering, basic lidar range equation, elements of detection theory as applied to direct detection lidar systems.

Digital Holography

Instructor: Partha Banerjee, pbanerjee1@udayton.edu
Credit Hrs: 1 (2 CEU)
Course description: Basic principles of holography, digital holography (DH), holographic interferometry, holographic microscopy and tomography, multi-wavelength DH, phase-shifting holography, compressive holography, dynamic holography, transport of intensity; applications and lab demos.

Design of Optical Thin Films

Instructor: Andrew Sarangan, sarangan@udayton.edu
Credit Hrs: 1 (2 CEU)
Course description: Fundamentals of thin film design; antireflection and optical filter design; numerical methods; metal film optics; fabrication methods; design exercise.

Introduction to Optical Project Design w/ Zemax

Instructor: Cong Deng, cdeng1@uayton.edu
Credit Hrs: 1 (2 CEU)
Course description: Introduction to ZEMAX, fundamental skills for designing practical optical systems, project design with ZEMAX, use of ZEMAX database of sample files, including three real typical design projects. Full access to ZEMAX for 60 days after the course with follow-up discussions.

Quantum Photonics

Instructor: Imad Agha, iagha1@udayton.edu
Credit Hrs: 1 (2 CEU)
Course description: Review of quantum mechanics and density matrix methods, qubits and qubit operations, quantum logic gates and quantum circuits, quantum states of light, quantum theory of measurement, introduction to measurement based linear optics quantum computing, quantum communications and cryptography.

EOP 597: Capstone Project

Instructor: Student's adviser.
Credit Hrs: 2
Syllabus:
Students are expected to design, build and demonstrate an independent project that falls within the scope of Electro-Optics and Photonics. The project must include elements that demonstrate a practical understanding of the course material contained in EOP 541L. Successful completion of this course also meets the requirements of EOP 598.
Prerequisite(s): Permission of chair

EOP 598: Non-thesis Research Project

Instructor: Student's MS research (non-thesis) adviser.
Credit Hrs: 0
Syllabus:
The objective of this course is to ensure that MS students who choose the non-thesis route have the opportunity to demonstrate the skills necessary to write professional documents and make technical presentations on a chosen research topic.

- Research project on a selected topic for non-thesis MS students. Review of relevant research literature.
- Preparation of a written project report and an oral presentation to the student exam committee.

EOP 599: M.S. Thesis

Instructor: Student's M.S. thesis adviser
Credit Hrs: 1-6
Thesis credits can be taken in any increment up to the required 6 credit hours. Please note that thesis research should take place every semester irrespective of when you actually register for thesis credits.

EOP 601: Optical Design

Instructor: Cong Deng, cdeng1@udayton.edu
Credit Hrs: 3
References:

- Robert E. Fischer, Biljana Tadic-Galeb, and Paul R. Yoder, *Optical System Design*, Second Edition, SPIE Press and McGraw-Hill, 2008. ISBN 978-0-07-147248-7
- Michael J. Kidger, *Fundamental Optical Design*, SPIE Press, 2002. ISBN 9-8194-3915-0
- Milton Laikin, *Lens Design, 2nd Ed.*, Marcel-Dekker, Inc., 1995.
- Robert R. Shannon, *The Art and Science of Optical Design*, Cambridge University Press, 1997.
- Warren J. Smith, *Modern Optical Engineering*, 3rd Ed. McGraw-Hill, 2000. ISBN 0-07-135360-2
- Warren J. Smith and Genesee Optics Software, Inc., *Modern Lens Design: A Resource Manual*, McGraw-Hill, 1992

Syllabus:

1. Ray tracing and image evaluation
2. Introduction to ZEMAX
3. Optimization methods and computer lens design
4. Telephoto, wide-angle and normal lenses
5. Optical transfer functions
6. Aspheric surfaces

7. Telescopes and microscopes
8. Optical tolerancing
9. Prism and folded optical systems, rangefinders

Course Requirements

This course mixes lectures on geometrical optics and lens design with computer lab sessions using ZEMAX and Matlab.

EOP 603: Optical Interferometry and Metrology

Instructor: Partha Banerjee, pbanerjee1@udayton.edu

Credit Hrs: 3

Textbook: *Introduction to Optical Metrology*. R. Sirohi, CRC 2016. ISBN 9781482236101

Syllabus:

1. Interference and diffraction; Fourier optics
2. Review of digital signal and image processing
3. Holography: classical, digital; transmission, reflection
4. Interferometers, fringe analysis, Moire patterns
5. Phase shifting, holographic and speckle interferometry
6. Fiber-optic interferometers: gyros and bio-sensors
7. Optical metrology; thickness, velocity, pressure measurements
8. 3D nondestructive testing: optical imaging of surfaces and phase objects
9. Contemporary applications in semiconductor processing, LiDAR and astronomy

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EOP 605/ECE 675: Silicon Photonics

Instructor: Swapnajit Chakravarty, schakravarty1@udayton.edu

Credit Hrs: 3

Reference Material:

- Chrostowski and Hochberg, Silicon Photonics Design: From Devices to Systems
- Kasap, Optoelectronics and Photonics: Principles and Applications

Syllabus:

Photonic Integrated Circuits (PICs) guide, route and manipulate light on a chip to compute, communicate and sense with light, in contrast to electrons in conventional semiconductor electronic integrated circuits (ICs). This course focuses on chip integrated photonic device modeling as building blocks for coherent photonic transceivers and computation circuits and applications

- Review of photonic Integrated Circuits and Applications
- Single Mode vs Multimode Waveguides*
- Optical coupling into single mode waveguides
- Power Splitting Components
- Polarization Manipulation Components
- Photonic Circuit Modeling***
- Silicon Photonics Foundry Fabrication
- Silicon Thermo-Optic Modulator**
- Silicon P-N Junction Modulators
- Understand basics of silicon p-n junctions
- Injection mode vs Depletion mode operation*
- Mach-Zehnder Modulator
- Ring Resonator Modulator
- Design Project
- Software: Ansys/Lumerical *MODE, **FDTD, DEVICE, ***Interconnect

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EOP 606: Advanced Silicon Photonics

Instructor: Swapnajit Chakravarty, schakravarty1@udayton.edu

Credit Hrs: 3

Reference Material:

- Chrostowski and Hochberg, Silicon Photonics Design: From Devices to Systems
- Kasap, Optoelectronics and Photonics: Principles and Applications

Syllabus:

This course focuses on advanced silicon photonic device design, layout and measurements. Hybrid beyond-silicon photonic devices and nanophotonic devices are introduced.

- Layout of Photonic Integrated Circuit Elements for Foundry
- Optical Measurement of Student Designed Foundry Chips
- Mach Zehnder modulator design (Optical and RF)
- Hybrid Silicon Photonics
- Lithium niobate
- III-V materials
- Electro-optic polymers
- chalcogenides and new materials
- Silicon Nanophotonics
- Photonic crystal waveguides and cavities
- Subwavelength devices for integrated photonics
- Optical Phased Array Design on Chip
- Photonic Chemical and Biological Sensors on Chip
- Software: Ansys/Lumerical *MODE, **FDTD, DEVICE, ***Interconnect, Klayout

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EOP 610: Advanced Topics in Electro-Optics and Photonics

Offered every Fall and Spring semesters

All doctoral students must register for EOP 610 every semester

Instructor: Mikhail Vorontsov, mvorontsov1@udayton.edu

Credit Hrs: 0

Syllabus:

1. Discussion, inquiry and feedback of research progress towards a dissertation in electro-optics and photonics
2. review of background research literature
3. discussion of experimental or computation methods and results
4. presentation of research progress reports
5. review of laboratory safety protocols
6. participation in technical conferences and professional workshops
7. preparation, submission and acceptance of a technical article, with student as lead author, in a peer-reviewed journal in Electro-Optics and Photonics.

EOP 621: Statistical Optics

Instructor: Edward Watson, ewatson1@udayton.edu

Credit Hrs: 3

Text: *Statistical Optics* by J. W. Goodman

Additional references:

J. W. Goodman, *Speckle Phenomena in Optics*

E. Wolf, *Introduction to the Theory of Coherence and Polarization of Light*

A. Papoulis, *Probability, Random Variables, and Stochastic Processes*

Syllabus:
1. Random variables
2. Stochastic processes (moments, power spectral density, Wiener-Khinchin Theorem)
3. Modeling of optical waves
4. Thermal light (unpolarized, polarized, and partially polarized)
5. Noise and statistics of detection
6. Temporal coherence of optical fields (degree of coherence, coherence time)
7. Spatial coherence of optical fields (mutual coherence, cross spectral density, van Cittert – Zernike Theorem, imaging as an interferometric process)
8. Speckle (fully and partially developed, speckle in laser radar, extracting information from speckle)
9. Photoelectron statistics (if time allows)

EOP 624: Nonlinear Optics

Instructor: Partha Banerjee, pbanerjee1@udayton.edu
Credit Hrs: 3
Text: Powers and Haus. *Fundamentals of Nonlinear Optics*. Boca Raton, CRC Press
References: *Nonlinear Optics*, Boyd; *Handbook of Nonlinear Optics*, Sutherland; *Nonlinear Optics*, Banerjee
Syllabus:
1. Linear and Nonlinear Materials
    a. Homogeneous isotropic media
    b. Crystals: Isotropic, Uniaxial, Biaxial
2. Nonlinear Optics
    a. Microscopic origin of the nonlinearity – classical picture
    b. Heuristic model of nonlinearity
    c. Nonlinear wave equation: introduction to various processes (SHG, Raman, Brillioun, etc); phase matching and quasi-phase matching
    d. $\chi^{(2)}$ effects and devices: sum frequency generation; second harmonic generation; phase matching and quasi-phase matching; optical parametric generation
    e. $\chi^{(3)}$ effects and measurements: nonlinear index of refraction; nonlinear Schrödinger equation; spatial and temporal solitons; z-scan; numerical techniques; four wave mixing and phase conjugation

EOP 626/ECE 676: Quantum Electronics

Instructor: Andrew Sarangan, sarangan@udayton.edu
Credit Hrs: 3
Textbook: *Quantum Wells, Wires and Dots: Theoretical and Computational Physics*, 3rd Ed. Paul Harrison, 2009, Wiley
Syllabus:
1. Semiconductors and Heterostructures
2. Numerical solutions to Schrodinger's Equation
3. Strained Quantum Wells
4. Quantum Wires and Dots
5. Carrier Scattering - photons and phonons
6. Electron Transport
7. Optical Properties of Quantum Wells
8. Quantum well infra-red photodetectors (QWIP)
9. Superlattice detectors
10. Quantum cascade lasers (QCL)

EOP 657: Principles of Atmospheric Optics and Applications

Instructor: Mikhail Vorontsov, mvorontsov1@udayton.edu
Credit Hrs: 3
Text: class notes
Syllabus:
1. Polarization of beams
2. Laser communication link performance
3. ABCD matrices
4. Numerical techniques for atmospheric optical effects
5. Numerical wave optics propagation basics
6. Turbulence simulations and applications
7. Elementary optical feedback control systems
8. Multi-dithering wavefront control principles
9. Phase and field conjugate adaptive optics
10. Adaptive systems based on stochastic parallel gradient descent techniques
11. Wavefront correctors
12. Wavefront sensing and phase reconstruction
13. Wavefront control and turbulence mitigation in phased fiber arrays
14. Exploitation of turbulence effects.

EOP 658: Principles of Ladar

Instructor: Ed Watson, ewatson1@udayton.edu
Credit Hrs: 3
Text: Lidar Technologies and Systems, Paul McManamon, SPIE Press
References:
- Field Guide for Lidar – Paul McManamon
- National Academy of Sciences, NAS, Report
- Laser Radar: Progress and Opportunities in Active Electro-Optical Sensing (2014)

Syllabus:
1. Introduction to Lidar
2. History of Lidar
3. Lidar Range Equation
4. Types of Lidar
5. Lidar Sources and Modulations
6. Lidar Receivers
7. Lidar beam steering and optics
8. Lidar processing
9. Figures of merit, testing, and calibration
10. Lidar performance metrics
11. Significant Applications of Lidar

EOP 695: Special Problems in Electro-Optics

The objective of this course is to provide an opportunity for a student to study a topic of their choosing at the Ph.D. level under the guidance of an instructor.
Credit Hrs: 1-3
Prerequisite(s): Permission of instructor.

EOP 699: Ph.D. Dissertation

Instructor: Student's Ph.D. dissertation adviser
Syllabus:
Dissertation credits can be taken in any increment up to the required 30 credit hours.

Electro-Optics Undergraduate Courses and Syllabi

EOP 401: Introduction to Fiber Optics

Instructor: Miranda van Iersel, mvaniersel1@udayton.edu
Credit Hrs: 3
Textbook: Introduction to fiber optics, Ajoy Ghatak and K Thyagarajan, Cambridge University Press
Syllabus:

1. Optical fibers
2. Propagation, losses, and dispersion in optical fibers
3. Modes in a fiber
4. Step index and graded index fibers
5. Waveguides
6. Sources and detectors
7. Components in fiber optics: splices. connectors, couplers, amplifiers
8. Fiber optical communication
9. Fiber sensors

EOP 404: Semiconductor Characterization & Metrology

Instructor: Swapnajit Chakravarty, schakravarty1@udayton.edu
Credit Hrs: 3
Textbook: Alain C. Diebold, "Handbook of Silicon Semiconductor Metrology", Marcel Dekker
Syllabus:

1. Silicon MOSFET Manufacturing Process Flow
2. Critical Dimension -Scanning Electron Microscopy (CD-SEM)
3. Bright Field and Dark Field Inspection, Ellipsometry
4. Assist Features, Critical vs Non-Critical Defects, Printed vs Non-Printed Defects
5. Photomask Inspection (Die-Die, Die-Database)
6. Contact Resistance Measurements, I-V, C-V
7. Raman Spectroscopy, IR Spectroscopy, X-Ray Diffraction

EOP 405: Semiconductor Device Fabrication Lab

Instructor: Andrew Sarangan, sarangan@udayton.edu
Credit Hrs: 3
Textbook: Andrew Sarangan, Nanofabrication - Principles to Laboratory Practice, 1st edition, CRC Press, 2017
Syllabus:

1. Silicon wafer handling
2. Hazardous chemical handling and safety training
3. NFET and PFET process flow design
4. Photomask design and fabrication
5. Silicon wafer cleaning, including solvent cleaning (AMI), organic cleaning (SPM), RCA cleaning (APM and HPM)
6. Photomask UV lithography process, including photoresist handling, spin coating, photomask alignment, exposure, and critical dimension inspections
7. Thin film dielectric deposition, including CVD, PECVD, PVD processes
8. Metal film deposition using PVD processes such as DC sputtering and thermal evaporation
9. Etching processes including RIE/ICP plasma etching and wet chemical etching
10. Doping processes, including thermal diffusion and ion implantation
11. Semiconductor device metrology, including SEM, TEM, AFM and Raman inspections
12. Device packaging, including dicing, die-bonding and wire bonding
13. Electrical probe testing of devices

EOP 406: Advanced Semiconductor Manufacturing

This course covers selected advanced topics in Advanced Semiconductors. Topics build on the prior coursework, and lead to a significant design and analysis experience, either as one major design project or several smaller design projects:

1. Design, modeling and simulation of industry-relevant 3D transistors such as FinFETs, Gate-All-Around (GAA) and Nanosheets
2. Immersion, deep-UV and EUV lithography
3. 3D NAND and NOR flash memory technology
4. Thin film transistors (TFT) and display technology
5. Thin film design, including optical thin films, ferroelectrics, varactors
6. MEMS technology
7. Principles of advanced semiconductor metrology
8. Semiconductor packaging technology


References
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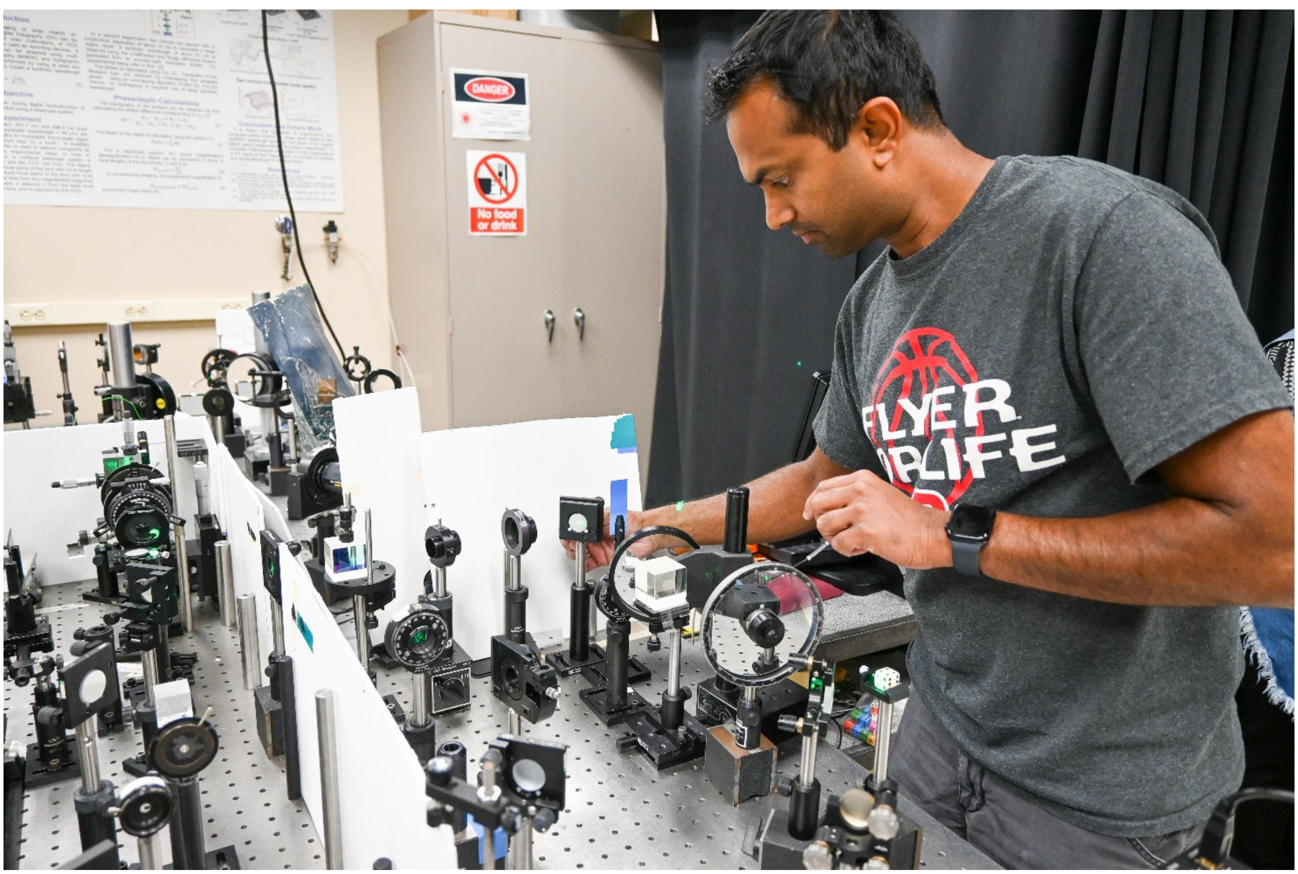
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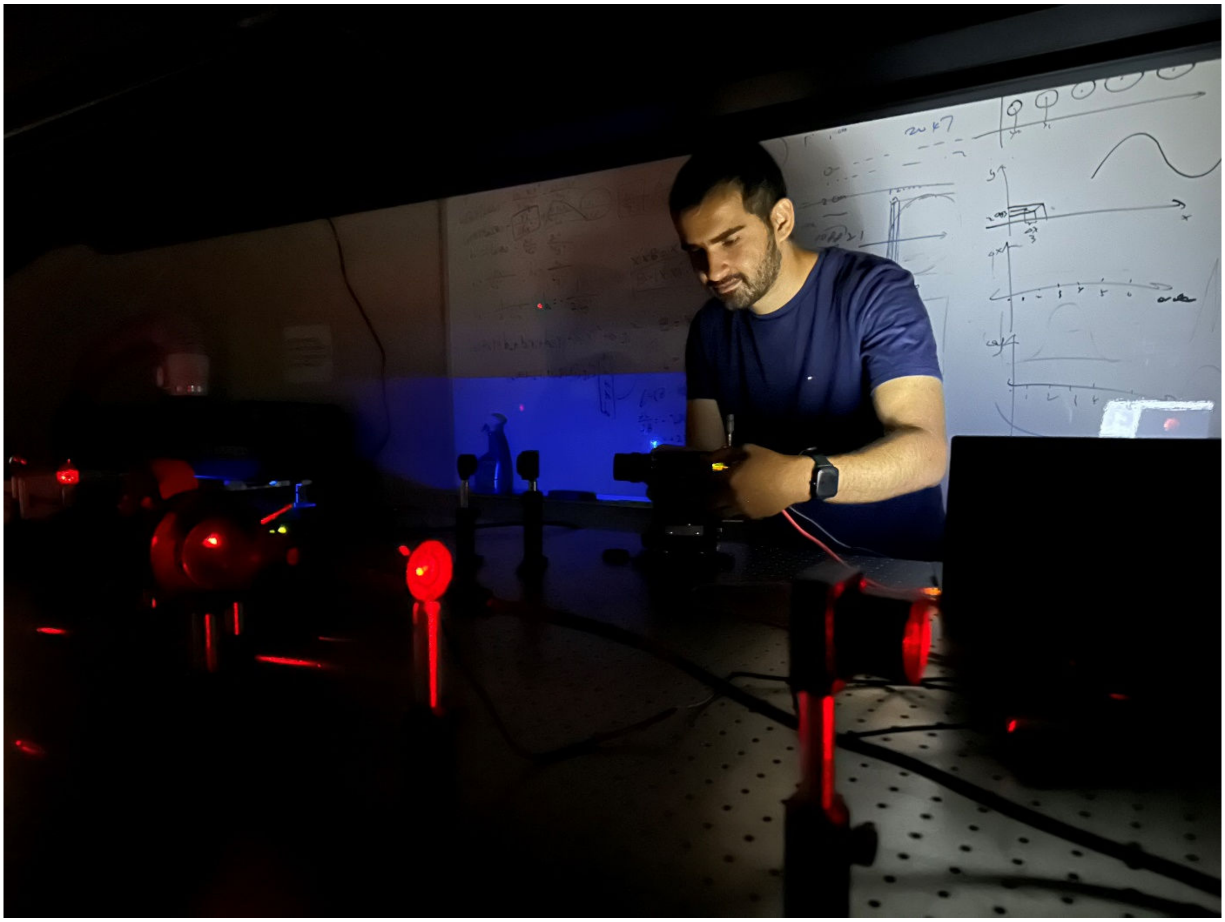
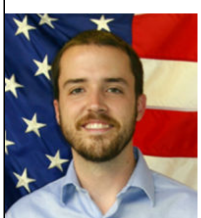


Associated EOP Faculty and Research Staff

Monish Chatterjee, Ph.D., University of Iowa, 1985. Professor of ECE. Nonlinear dynamics and chaos, wave propagation, acousto-optics.

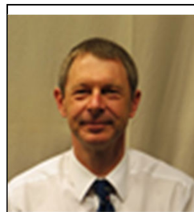
Cong Deng, Ph.D. University of Dayton, 2005. Research Scientist. LIDAR systems, fibers and waveguides, adaptive and active optics, THz and imaging systems.

Shekhar Guha, Ph.D., University of Pittsburgh, 1981. Fellow. OSA. Graduate faculty. Project leader, IR optical materials, AFRL. Nonlinear optics, IR materials, lasers

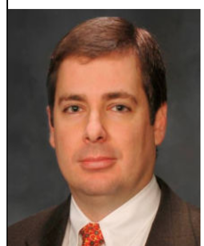


David Rabb, Ph.D., Ohio State University, 2008. Graduate faculty. Senior Electronics Engineer, Ladar Technology Branch (RYMM). LIDAR, synthetic aperture systems, holography.

Thomas Weyrauch, Ph.D., Darmstadt University of Technology, 1997. Senior Research Scientist, EOP. Graduate Faculty. Light propagation through atmosphere: distortion characterization, mitigation; beam control and coherent combining.



Gary Cook, Ph.D., University of Hull, England, 1998. FInstP. AFRL Sensors Directorate. Graduate faculty. Lasers, photorefractives, nonlinear optics.



Dean Evans, Ph.D. University of Georgia, 2000. Fellow, OSA, SPIE, APS. Graduate faculty. Research Leader, Hardened Materials and Processing Research Team, AFRL Materials Directorate. Photorefractives, liquid crystals, hybrids, ferroelectric nanoparticles.

Paul McManamon Ph.D. Ohio State University. 1977, Fellow IEEE, SPIE, OSA, MSS, AFRL, AIAA. Graduate faculty. Laser radar, electro-optical countermeasure systems, optical phased-array beam steering.

Ed Watson, PhD. University of Rochester. 1991, Fellow, OSA, SPIE, AFRL. Research scientist, UDRI. Graduate faculty. Laser radar, optical phased array technology, statistical optics, low light level imaging & pattern recognition, speckle characterization of objects in optical and mm wave domains.

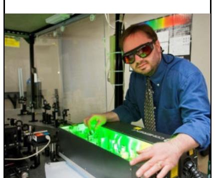
Perry P. Yaney, Ph.D., University of Cincinnati, 1963. *Fellow, APS*. Professor emeritus of Physics and EOP. Laser spectroscopic optical probe techniques including linear and nonlinear Raman scattering.

EOP Faculty

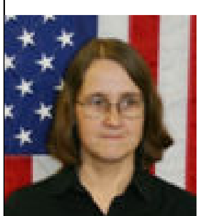
Partha P. Banerjee, Ph.D., University of Iowa, 1983. FInstP, Fellow, OSA, SPIE. Holoknight. Professor, EOP; Director, Holography and Metamaterials Lab. Metamaterials, dynamic and digital holography, nonlinear optics, acousto optics.

Miranda van Iersel, Ph.D., Vrije Universiteit (the Netherlands), 2004. Assistant Professor, EOP. Atmospheric optics, optical communications.

Mikhail Vorontsov, Sc.D., Physics and Mathematics, Moscow State University, 1989. Fellow, OSA, SPIE, ARL. Professor, EOP. Imaging thru turbulence, Laser beam control, non-linear spatio-temporal dynamics.



Jason A. Deibel, Ph.D., University of Michigan, 2004. Chair and Associate Professor of Physics; joint faculty. Ultrafast science, terahertz spectroscopy & imaging, computational electromagnetics, science education research.

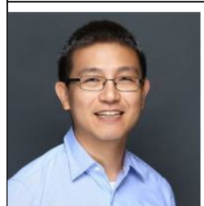


Rita Peterson, Ph.D. University of Central Florida, 2000. Visiting Assistant Professor of Physics; joint faculty. Nonlinear optics and lasers.

Swapnajit Chakravarty, Ph.D., University of Michigan, 2007. Associate Professor, EOP. Photonic integrated circuits, photonic crystals, subwavelength devices, mid-infrared devices.

Andrew M. Sarangan, Ph.D., University of Waterloo (Canada), 1997. Chair and Professor of EOP. Director, Nanofabrication Laboratory. Photodetectors, lithography, thin film optics, phase change materials, semiconductor lasers.

Imad Agha, Ph.D., Cornell University, 2009. Associate Professor of Physics; joint faculty, EOP. Quantum optics, quantum communication, nonlinear optics, nanophotonics.



Keigo Hirakawa, Ph.D., Cornell University, 2005. Professor of ECE; joint faculty, EOP. Color image processing, digital camera processing pipeline, 3D image reconstruction and display.

Guru Subramanyam, Ph.D., University of Cincinnati, 1993. Professor of ECE; joint faculty, EOP. RF and microwaves, nanobiomaterials for sensor applications, micro- and nano-fabrication.

EOP Advisory Board

Chris Brewer	Chief, Photonics Branch, Materials Directorate, AFRL, Wright Patterson AFB
Michael Eismann	Chief Scientist, Sensors Directorate, AFRL, Wright Patterson AFB
Bernard Kress	Google, SPIE President
Akhlesh Lakhtakia	Evan Pugh Professor of Engineering Science and Mechanics, The Pennsylvania State University
Nasser Peyghambarian	Chair of Photonics and Lasers, College of Optical Sciences, University of Arizona
Mike Spicer	Director and General Manager, L-3 Communications
John Taranto	Advanced Imaging Research Engineer, Thorlabs