

OPTICS GRADUATE HANDBOOK 2016-2017
 Graduate Study and Research In Optics

The Institute of Optics
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Official Bulletin of Graduate Studies:

<http://www.rochester.edu/GradBulletin/>

This Optics Graduate Handbook are the rules for Optics that add to the rules in the above Graduate Studies Bulletin

THE INSTITUTE OF OPTICS COMMITTEE ASSIGNMENTS 2016-2017

GRADUATE COMMITTEE

N. Vamivakas, Chair
J. Kruschwitz
J. Rolland
C. Stroud
J. Fienup

GRADUATE ADMISSIONS

J. Fienup, Chair
C. Guo
J. Bromage
W. Renninger

UNDERGRADUATE COMMITTEE

G. Agrawal, Chair
A. Berger
J. Zavislan
J. Bentley

Additional Assignments

W. Knox	Master's Co-Op Advisor
J. Cardenas	Colloquium Chair
A. Berger	Biomedical Engineering Advisor
G. Wicks	Part-Time M.S. Advisor
T. Brown	HSEAS Administrative Committee
J. Zavislan	HSEAS Computing Committee
J. Fienup	HSEAS Graduate Committee
J. Fienup	University Council On Graduate Studies
T. Brown	Committee on Educational Policy
R. Boyd	Library Representative
J. Zavislan	Undergraduate OSA Advisor
J. Zavislan	Committee of Optics Networking
X-C. Zhang	Industrial Associates and Alumni Relations Coordinator

DIRECTOR OF THE INSTITUTE

Scott Carney

Gina Kern -- Administrative Assistant to the Director

ADMINISTRATIVE STAFF

– Graduate Program Coordinator

Lori Russell – Administrator of the Institute

Adrienne Snopkowski – Financial Analyst

Daniel Smith – Undergraduate Program Manager

Maria Schnitzler – Sponsored Programs Administrator / International Visitors Coordinator

TECHNICAL STAFF

Michael Koch - Molecular Beam Epitaxy

Brian McIntyre -- Scanning Electron Microscopy Facility

Per Sven Adamson -- Undergraduate Teaching Laboratories

USEFUL WEB RESOURCES

Graduate Studies Office <http://www.rochester.edu/gradstudies/>

Registering for courses takes a few steps:

http://www.rochester.edu/college/gradstudies/grad_reg.html#reg

The menu on the right includes useful online Forms

The intuitive choice is: Registering for Courses, but then you have to Click on “register on-line” which takes you to Undergraduate Registration because there is only one portal to online registration.

So:

In “Quick Links” on the right, click on Online Registration

Click on I agree, enter your ID and password and now you can begin registering.

Registrar: <http://www.rochester.edu/registrar/>

CDCS takes you to all course schedules.

Selecting the term and department are the easiest views of an given semester.

Libraries: Carlson Library (in the Computer Science Building):

<http://www.library.rochester.edu/carlson/home>

and the Physics /Optics /Astronomy Library (or POA in the Bausch & Lomb Bldg.):

<http://www.library.rochester.edu/poalibrary/home>

Bursar: <http://www.rochester.edu/adminfinance/bursar/>

Housing: <http://www.rochester.edu/reslife/graduate/index.html>

Health: <http://www.rochester.edu/uhs/>

International Services Office: <http://www.iso.rochester.edu/>

Graduate Ombudsperson: <http://www.rochester.edu/college/gradstudies/current/ombuds.html>

GRADUATE ACADEMIC CALENDAR

FALL SEMESTER 2017

August 30, 2017 (Wednesday)	Classes begin at the College.
September 4, 2017 (Monday)	Labor Day (no classes).
October 9, 2017 (Monday - Tuesday)	Fall term break (10/09 - 10/10).
November 22, 2017 (Wednesday - Sunday)	Thanksgiving recess (11/22 - 11/26) begins at noon.
December 13, 2017 (Wednesday)	Last day of classes.
December 17, 2017 (Sunday)	Final examinations (12/17 - 12/22).
December 22, 2017 (Friday)	Winter recess begins at end of examinations.

SPRING SEMESTER 2018

January 17, 2018 (Wednesday)	Classes begin at the College.
March 10, 2018 (Saturday)	Spring recess (3/10 - 3/18).
May 1, 2018 (Tuesday)	Last day of classes.

May 6, 2018
(Sunday)

Final examinations (5/6 - 5/13).

May 18, 2018
(Friday)

Commencement Weekend (5/18 – 5/20)

**For a more detailed calendar, please visit:

<http://www.rochester.edu/college/gradstudies/events/index.html>

Thesis Advisors:

The faculty members listed below are approved thesis advisors for degrees in Optics. Students doing thesis research for professors with primary faculty appointments in The Institute receive stipends that are set by the faculty of The Institute. The stipends of students doing thesis research for professors with primary appointments in other departments or units may be set by others. In particular, students working for faculty with primary appointments in the Laboratory for Laser Energetics (LLE) might receive LLE-set stipends that may be slightly lower than Optics stipends.

Professor	Department of Primary Appointment
Govind Agrawal	The Institute of Optics
Miguel Alonso	The Institute of Optics
Julie Bentley	The Institute of Optics
Andrew Berger	The Institute of Optics
Nicholas Bigelow	Physics
Robert Boyd	The Institute of Optics
Tom Brown	The Institute of Optics
Jaime Cardenas	The Institute of Optics
Joseph Eberly	Physics
Jon Ellis	Mechanical Engineering
James Fienup	The Institute of Optics
Tom Foster	Radiology
Chunlei Guo	The Institute of Optics
Wayne Knox	The Institute of Optics
Todd Krauss	Chemistry
Qiang Lin	Electrical Engineering
John Marciante	The Institute of Optics
Duncan Moore	The Institute of Optics
Jannick Rolland	The Institute of Optics
Carlos Stroud	The Institute of Optics
Nick Vamivakas	The Institute of Optics
Gary Wicks	The Institute of Optics
David Williams	The Institute of Optics
Emil Wolf	Physics
Geunyoung Yoon	Dept of Ophthalmology M&D
Jim Zavislan	The Institute of Optics
Xi-Cheng Zhang	The Institute of Optics

For more information about the research of the different faculty members, visit www.optics.rochester.edu/people/faculty/index.html.

REQUIREMENTS FOR THE M.S. DEGREE IN OPTICS

Overview

The Master of Science Degree Program is designed to provide a student who has a strong undergraduate preparation in physics, electrical engineering or optics with the knowledge and skills to contribute to state-of-the-art optics research and development. A number of options are available within the general degree requirements to satisfy the needs of students with a variety of goals in mind.

- Students wishing to acquire basic training in optics to enter an industrial or governmental laboratory position can obtain that training in as little as nine months. This is attractive for engineers working in industry who desire the benefits derived from advanced study in optics. Employers are often willing to grant a leave of absence for this relatively short period of time.
- It is also possible to obtain the M.S. degree through part-time study, an option of particular interest to those working in the Rochester area.
- Students who would like to combine formal education with practical industrial experience may find the M.S. Co-op program of interest.
- Students who are about to complete a B.S. in Optics at the University of Rochester might wish to begin advanced study early by entering the BS/MS Program.

Students who wish advanced and specialized training in some particular area of optics can elect the Plan A thesis option or the Plan B (non-thesis) option with a Certified Specialty.

- The Plan A option generally requires 18 - 24 months to complete, but it allows the student to develop a high level of expertise in a specialized field.
- The Plan B option with a Certified Specialty allows for coursework to be more concentrated in a particular area than the standard, more general Plan B option.

All of these options provide a solid preparation for the student who wishes to continue advanced study to obtain a doctorate in optics, electrical engineering, or physics.

General Requirements

A minimum of 30 semester hours of credit is required for the M.S. degree in Optics. A minimum grade point average (GPA) of 3.0 is required in classroom courses taken at the University of Rochester and counted toward the MS degree. The GPA calculation will not ordinarily include reading courses and research credits. If the GPA requirement is initially not met, a course can be re-taken (with the old grade being replaced by the new grade in the GPA computation) or a new course can be taken. Normally, no more than ten hours of course work taken at another university can be accepted as transfer credit. All transfer credits must be approved by the Optics Graduate Committee and by the Associate Dean for Graduate Studies in The College.

Plan A: Thesis Route

There is a required set of courses for the Plan A route:

- Optics 443 - Foundations of Modern Optics;
- Optics 463 - Wave Optics and Imaging;
- Optics 423 – Detection of Optical Radiation;
- Optics 456 - Optics Laboratory
See the note under Plan B about substituting Optics 441 for 443 and 461 for 463.
Plan A Masters degree also requires:
- Any one additional 400- or 500-level Optics course;
- Thesis research (6 - 12 semester hours) and written M.S. Thesis;
- Successful Final Defense of the M.S. Thesis.

This plan contains a fair amount of flexibility, as the thesis research may be counted for a minimum of six and a maximum of twelve credits. A recommended program of study is to take six courses and seven hours of thesis research, which sums to the required 30 semester hours. Each student should work closely with his/her thesis advisor to decide how best to decide among the possibilities.

The thesis route is available to all M.S. students, but some comments should be made about special cases. Students in the Institute's BS Program may be able to begin research in their senior year for the Bachelor's Senior Thesis and build on that research at the graduate level. With early planning, they may be able to take graduate courses in the senior year as well. It is possible for a part-time student to carry out the research in an industrial setting. However, the work must be public and publishable in the open literature and an Optics professor must supervise the research in a direct fashion in order to use that research for an MS thesis. To successfully arrange such a project, the student must get approval of detailed plans for the project both by the prospective faculty thesis advisor and by the company management. These same general remarks apply to students in the M.S. Co-op Program who wish to carry out thesis research during the industrial portion of the program.

Thesis

The thesis must show evidence of independent work based in part upon original material. It must demonstrate that the candidate possesses the ability to plan study over a prolonged period and to present the results of such a study in an orderly fashion. The thesis should also display the student's thorough acquaintance with the literature of a limited field.

The Examination Appointment Form must be filled out and filed. The thesis must be registered with the Associate Dean for Graduate Studies and copies given to the members of the Examining Committee at least two weeks prior to the Oral Examination (Final Defense of the thesis). Always consult the Graduate Academic Calendar to be sure of deadlines. If the thesis is accepted by the student's Examining Committee, two permanent copies must be presented to the Office of the Associate Dean for Graduate Studies and one copy given to the Institute of Optics Graduate Program Coordinator.

Final Oral Examination

Each candidate for a Plan A M.S. degree in Optics must pass a final oral examination and thesis defense before a committee of at least three members of the faculty appointed by the Associate Dean for Graduate Studies. One member will be from a department other than that in which the student has done the major portion of the work. No candidate may appear for the final examination until permission is received from the faculty advisor. The examination will not be held until at least two weeks have elapsed after registration of the completed thesis. A student who fails the final oral examination may require re-examination not less than four months later. No student will be allowed to take the examination a third time without a recommendation from the department and the approval of the Optics Graduate Committee.

Plan B: Non-thesis Route

There are two versions of Plan B. The standard version provides a general coverage of the important areas in optics. The version with a Certified Specialty allows for more concentrated study in a particular area.

Standard Plan B

There is a required set of courses for the Standard version of Plan B:

- Optics 443 - Foundations of Modern Optics;
- Optics 463 - Wave Optics and Imaging;
- Optics 423 – Detection of Optical Radiation;
- Optics 456 - Optics Laboratory

Upon approval by a student's advisor, an MS student may substitute OPT 425 for OPT 423, OPT 441 for OPT 443, and/or OPT 461 for OPT 463, which could be advisable if the student has a definite plan to apply for a PhD program to begin immediately after the MS. (OPT 423, 443 and 463 better prepare a student for an immediate job.) For any course that has OPT 425 or OPT 441 or OPT 461 as a prerequisite, then OPT 423 or OPT 443 or OPT 463, respectively, serve to satisfy that prerequisite.

In addition to these core requirements, the following are required for this plan:

- One additional course in Physical Optics;
 - examples: Optics 446, 447, 450, 452, 462, 468, 492 (THz), 535, 561, 564, 592
- One additional course in Geometrical Optics;
 - examples: Optics 432, 433, 442, 444, 449 (Design/tolerance/fabricate/coat, Spring 2017)
- One additional course in Quantum Optics;
 - examples: Optics 412, 421, 428, 453, 464, 465, 467
- One additional course to reach a total of 30 semester hours;
- A research essay written under supervision of a faculty member on a selected topic. The final version of this essay should have signed approval of the faculty member supervising the essay, and signed approval by a second reader. Students should always consult the Graduate Academic Calendar to be sure of deadlines.

The complete list of additional courses that can be used to satisfy the requirements above varies as new courses are introduced and old courses modified or discontinued. Students should consult with their faculty advisors about which courses can be used for these categories during their period of study. The elective course (fourth item above) is normally a 400-level Optics course. A course in another department such as Physics, Electrical & Computer Engineering, or Mathematics may be substituted, however, with the permission of the faculty advisor.

There are exceptions to the above rules for the Plan B MS Program. First, part-time students are not required to take Optics 456 - Optics Laboratory. They must, however, take another course in its place. The second exception involves students in the BS/MS Program. These students frequently take 400-level Optics courses during the senior year, a fact that can have an impact on the requirements for the Plan B Program. Students admitted to the BS/MS Program should work closely with their faculty advisors to develop an appropriate academic program.

Plan B with Certified Specialty

This version of Plan B concentrates study in a particular area. Like the general version of Plan B, at least 30 hours of coursework and the completion of research essay are required. The certified specialty areas are summarized in the Table. The courses outlined in the table are guidelines, not rigid requirements. Students interested in the Plan B option with Certified Specialty should meet with their advisor.

Optics MS Specialty Areas

Specialty Area	Physical Optics	Courses in Specialty Area Required, (Electives)	Supervisors
Optical Communications	462	423, 428, (421, 468, 521, 528, ECE 435)	Agrawal, Brown, Cardenas, Knox
Electro-optics/ Nonlinear Optics	462	421, 467, (427, 468, 492 [THz], ECE-435)	Agrawal, Boyd, Cardenas, Guo, Marciante, Zhang
Optical Materials	462	421, 423, (433, 453 ECE 435, ME 451, ME 452, CHE 486, 468)	Cardenas, Wicks
Laser Engineering	463	423, 465, 468 (428, 467)	Guo, Maricante, Eberly, Stroud
Biomedical Optics	462	Two of 476, 448 and BME 455, (425, 452)	Berger, Cardenas, Foster, Knox, Rolland, Williams, Zavislan
Image Science	463	561 and/or 564, ECE 447 and/or OPT 413 (448, 452)	Fienup, Rolland
Optical Design, Fabrication and Testing	463 or 462	442, 433, (425, 432, 444, 445, 544)	Bentley, Ellis, Moore, Rolland, Zavislan,
Nano- and Integrated Photonics	462	423 or 425, 421, 453, (407, 429, 468, 464/ECE436, ECE 435)	Cardenas, Lin, Krauss, Vamivakas, Wicks
Business Administration	463 or 462	423, 481 (Entrepreneurship); any two of ACC 401, FIN 402, STR 401, OMG 402, and MKT 402; and any one of OPT 428, 442 or 476	Moore, Zavislan

All must take:

- OPT 443 or 441 (Fundamentals of Modern Optical Systems or Geometrical Optics);
- OPT 463, 461, or 462 (Wave Optics and Imaging, Fourier Optics, or Electromagnetic Waves)
- A quantum optics course such as OPT 465 (Lasers); and
- OPT 456 Lab -- except for Business Administration Specialty.

The Master's Essay (Plan B)

The MS essay consists of a brief but comprehensive overview, including an appropriate bibliography, of the state of the art of a given area in optical science and/or technology. This essay must be supervised by a member of the Optics faculty, which can include professors with a joint or adjunct appointment in Optics. Its main body should have a length of 10 to 15 pages (1.5 spacing), including figures and bibliography. The cover page should include the title, name of the student, submission date, as well as signatures of the faculty supervisor and a second faculty member who have read and approved the essay. The student is expected to spend approximately 40 hours in the preparation of this document.

The student is responsible for securing two faculty readers of the MS Essay, the Essay Advisor and another professor who has agreed to be the second reader. The Essay Advisor is responsible for the detailed quality of the essay. The second reader is to provide a pass/fail sanity check. If the Essay Advisor is a joint or adjunct member of the Optics faculty, the second reader must be a full-time Optics faculty member. The end of the semester and academic year makes extra demands on everyone's time. Students must follow the timeline below to graduate on time (dates in parentheses are for MS Plan B students finishing in the Fall semester):

End of Fall (Spring) Semester:

- Master's Program of Study Form has been submitted to GSO.
- Consider topic for MS Essay.

February 15 (October 1):

- The student must submit a title, abstract, and list of references for the desired topic to the Essay Advisor and to the Graduate Coordinator, identifying the Essay Advisor.

March 15 (November 1):

- The student must submit a finished first draft to the Essay Advisor who will suggest necessary changes. Concurrently submit a copy to the Graduate Coordinator. The student must identify the second reader.
- Begin corrections as soon as possible. After a first round of changes, send the second draft to the second reader as well as the Essay Advisor for further comments.

April 14 (December 1):

- The final version of the essay, endorsed by the Essay Advisor and the second faculty reader, must be submitted to the Graduate Coordinator.
 - This final submission should include the "Examination Report Form" signed by the readers. Return this with the final essay to the Graduate Coordinator.

Final notification that the essay is approved must be submitted to Graduate Studies Office by **April 18 (January 8) for May 2016 (March) degree conferral.**

The student is strongly encouraged to begin work on this essay before the start of the second (final) semester.

M.S. Cooperative Program

The curriculum and requirements for this program are the same as those for our regular program. The program consists of three blocks: 1) a four-month, full-time (16 credits) Fall semester at the University of Rochester; 2) a twelve-month "work block" in industry or at a government lab, and 3) a second four-month semester, a full-time (16 credits) Spring semester, at the University of Rochester to complete the Masters program.

In order for the student to participate in the work block, he or she must satisfactorily complete the Fall semester academic block. Failure to do so will result in termination from the program. Students will, of course, have to fulfill the normal conditions of employment at the various corporations (these conditions may include, for example, passing a health examination, signing nondisclosure agreements, etc.). During the work block, the student will be paid wages comparable to those of other employees with similar educational backgrounds and experience.

Interviews for the work block are held on campus during the Fall semester, usually in October or November. Students are admitted to the M.S. Co-Op at the discretion of the Graduate Admissions Committee and only after the student has been placed with a company.

During the time the student is employed in industry, he or she will be registered for the Co-op program (OPT 894, which carries zero credits) and will have all of the normal rights and privileges of a matriculated student, even though he or she is not in residence during that period. For both the Spring semester of the first year and the Fall semester of the second year, the student will need to pay the OPT 894 course fee (currently \$1,035) as well as the mandatory health fee and health insurance (although this might be able to be waived) and the GSA \$10 fee. During the summer after the first year, the Spring registration carries through, so the student would remain full-time but not need to register for anything.

Filing of M.S. Program of Study Form

Each student must submit a proposed masters degree program for approval by the department and by the Associate Dean for Graduate Studies. The student should list the courses he or she has taken, and intends to take, to fulfill the requirements for the M.S. degree. These are submitted on an official form after consultation with the student's advisor. It is the student's responsibility to see that this form is filed by the end of the first semester. Alterations in the program can be made almost any time. This form must be approved and on file before a student may begin work on the MS Thesis or Essay. Forms are available on line: <https://www.rochester.edu/asei/docs.php>. The purpose of this form is to allow the Registrar to monitor each student's compliance with the plan of courses which satisfy the M.S. requirements. If plans are changed or modified, the Registrar must also be duly notified.

REQUIREMENTS FOR THE PH.D. IN OPTICS

I. Overview

The Official Bulletin of Graduate Studies describes the general requirements for a Ph.D. as:

"The degree of Doctor of Philosophy is awarded primarily for completion of scholarly work, research, or outstanding creative work satisfactorily described in a dissertation. It is assumed that recipients of this degree are well versed in the subject matter and research techniques of a specific discipline and have demonstrated breadth of interest and originality of outlook that indicate promise of success in future research and teaching."

It is expected that a student completing this program in Optics will be ready to assume a role as an independent researcher in a university, industrial, or government laboratory. Most of the time in the program is devoted to learning specialized research skills and carrying out thesis research. However, it is also important that the student master the subject matter and develop a breadth of interest in the whole field of optics. To this end, a set of required core courses, a number of elective courses and a Preliminary Examination are included in the program.

The outline below illustrates a student's progress in the Ph.D. program. Details are given in subsequent sections.

First Year

Full time coursework and study
Choose Thesis Advisor (by April 15th)
Summer Research
Preliminary Examination

Second Year

Advanced specialized coursework
Teaching Assistantship
Research
File Program of Study Form

Third Year

Thesis Proposal
Oral Qualifying Examination
Elective Courses
Research

Fourth Year and Beyond

Research
Elective Courses
Thesis submission
Oral Thesis Defense

II. Entering Orientation

The students meet with the Director and the Graduate Committee Chair during an orientation meeting. They work with a Faculty Advisor assigned to them to plan course schedules for the first year. Students who have taken graduate courses prior to their enrollment in the Ph.D. program may take courses other than the ones on the standard program. The planning Advisor is replaced by the thesis Advisor at the end of the first year.

III. First Year of Graduate Study

First-year financial support is usually in the form of a fellowship allowing the student to devote full time to course work. The full load is 16 hours of credit per semester. The purpose of this year's work is to provide a broad background in optical physics and engineering. The following is recommended to provide a broad survey of optics.

<u>Fall</u>	<u>Spring</u>
OPT 411 Mathematical Methods for Optics	OPT 442 Instrumental Optics
OPT 425 Radiation & Detectors	OPT 462 Electromagnetic Waves
OPT 441 Geometrical Optics	OPT 412 Quantum Mechanics for Optics
OPT 461 Fourier Optics	Elective

With the exception of the elective, these courses are core courses and are normally required for a Ph.D. They can be waived by petition to the Graduate Committee in those cases where they seem inappropriate for a student with an unusual background or interests.

Students should consult the schedule of courses to determine what courses are available. The elective could be a course which covers some of the material included in the preliminary examination. Students that are interested in engaging in research early on can substitute this course by research credits under the supervision of a faculty member.

A final, very important part of the first year program is getting acquainted with the faculty, advanced students, and research in The Institute. Students should make a point of meeting and getting acquainted with every faculty member. They are welcome to stop in and see what is going on in the laboratories. They are strongly encouraged to attend as many "What's Up in Optics" presentations as possible, as well as the Optics Colloquium Series.

Normally, the first summer is spent working with a faculty member on a research project. Students should talk with faculty members whose research areas are of interest and select a thesis advisor. The arrangements should be made by April 15th.

The Department requires that, before the end of the summer, students prepare the Program of Study form, have it signed by their advisor and returned to the Graduate Coordinator.

IV. Credit and GPA Requirements

Ninety hours of credit are required for the Ph.D. Approximately sixty hours should be course work, including reading and special topics courses. Elective courses may include those offered in other departments, having some relevance, with the permission of the faculty advisor. The remaining thirty hours are usually research credits. Reasonable variations in this distribution are subject to approval by the thesis supervisor, the Director, and the Dean for Graduate Studies.

At least 8 hours of the sixty hours of course work required for the Ph.D. must be in advanced courses, which include any 500-level course and any 400-level course that has another 400-level course as a prerequisite. These may be in Optics or in other subjects that have relevance to optics. The Optics courses that satisfy this requirement are identified by an asterisk next to their title in the "Graduate Course Description" section of this handbook. Reading courses (Optics 591), research credit (Optics 595), and the seven required courses do not fulfill this requirement.

If a student has a M.S. degree prior to enrollment in the Ph.D. Program, she/he can transfer up to thirty credit hours of the M.S. degree toward the sixty hours of course work required for the Ph.D. once it is approved by the Dean for Graduate Studies.

A minimum grade point average (GPA) of 3.0 in courses taken at the University of Rochester counted toward the Ph.D. degree is required for graduation. Additionally, students taking the Ph.D. preliminary exam are expected to have a GPA of 3.0 or higher for the graduate courses taken at the University of Rochester. Students whose GPA is lower than 3.0 who wish to take the preliminary exam must write a petition to the Graduate Committee Chair.

V. Ph.D. Preliminary Examination

The examination consists of three segments and is given one or two weeks before classes start in the Fall semester. It is normally taken before the start of the third semester of graduate study. Each of the three-hour segments of the examination is taken on a separate day. Further details are given later in the Guide to the Ph.D. Preliminary Examination.

Faculty grade their respective exam questions. Thereafter, the scores are presented to a faculty review board. Passing the preliminary exam is dependent not only on proficiency shown on the test, but also on the student's entire body of work including past course work, past and current research activity within The Institute, and recommendation from his/her advisor and other faculty. Students are placed in three categories: "pass", "conditional pass", or "fail", and receive notification of their status via letter from the graduate committee chair. Students who fail are allowed to take the test a second time the following year. "Conditional pass" means that the student's performance in one or more parts of the exam require some mandatory remedial action, specified in the notification letter. Such remedial action could consist on taking a related course, writing an essay on the topic, or taking an oral exam on the topic(s), as determined by the faculty grader of the question. If the remedial action (unless it is taking or TAing a Spring course) is not completed by the first day of class in the January following the preliminary exam, the student must retake the preliminary exam the next summer

VI. Second Year of Graduate Study

During this year, the student takes courses in advanced subjects and concentrates in some area of specialty in preparation for Ph.D. research. Note that to be considered a full-time graduate student, the College requires a minimum of 12 credit hours per semester, or 9 hours for a Teaching Assistant (TA) or Research Assistant.

During the second year, students usually fulfill their TA requirement, which is two semesters of service. This service is required whether or not the student has received financial support from the University. It is the intent of the Optics faculty that this teaching should be more than merely grading papers for a course and should include some sessions in the classroom.

During this year, the student should become familiar with some of the research and should discuss possible thesis research topics with his/her thesis advisor. This discussion leads to the preparation of a research proposal, which is discussed later in this section.

VII. Thesis Proposal and Oral Qualifying Examination

According to University regulations, the oral examination is the official Ph.D. Qualifying Examination. However, the written Preliminary Examination must be passed to become eligible to take the oral examination. The Qualifying Examination should be taken no later than 21 months after the student successfully passes the Preliminary Examination.

The procedure is as follows:

1. The student finds a prospective thesis advisor and selects a topic for Ph.D. research.

2. The student prepares a written document which describes the proposed research. This Thesis Proposal shall be no longer than 12 pages in length, not counting additional page(s) for references. It includes a brief literature survey and should convince the reader that the candidate is aware of the problems he or she is attempting to solve and has some inkling of how to solve them (the section "A Guide to the Preparation of Ph.D. Thesis Proposals" provides more details.). The thesis proposal should be circulated (in electronic form) to all the Optics faculty members at least two weeks before the examination and a copy given to the Graduate Coordinator.
3. The student prepares a 25-30 minute presentation for the oral examination. The committee members can ask questions during and following this presentation. The question session can take up to one and a half hours.

The thesis advisor and committee members sign the Examination Report Form (checking PhD Qualifier) and indicate whether the candidate failed or passed. A copy is kept on file by the Graduate Coordinator and the original is submitted to the Graduate Studies Office.

VIII. Filing of Ph.D. Program of Study Form

The student should list the courses he or she has taken or intends to take to fulfill the requirements for the Ph.D. These are submitted on an official form after consultation with the thesis advisor. It is the student's responsibility to see that this form is filed by the end of the first year of graduate study. Alterations in the program can be made at a later time. Forms are available on line: <https://www.rochester.edu/asei/docs.php>. The purpose of this form is to allow the Registrar to monitor each student's compliance with the plan of courses which satisfy the Ph.D. requirements. If plans are changed or modified, the Registrar must also be duly notified.

IX. Annual Progress Reports

Starting in the Spring semester of the second year of graduate studies at The Institute of Optics, each Ph.D. student must write a brief report describing the activities carried out during the last twelve months (including research, publications, conference attendance and presentations, courses taken, TA and other service, academic visits, etc.). The report should also include a list of objectives for the following twelve months, as well as for the rest of the Ph.D. studies. The student must use the form entitled "Ph.D. Student Annual Progress Report" included later in this handbook. This form must be completed, and sent by email to the Academic Advisor, all Thesis Advisory Committee members (in the case of students who have passed their qualifier exam), the Graduate Coordinator and the Graduate Committee Chair, by May 30. The completion of this requirement is mandatory; students will be allowed to register the following Fall semester only if they have submitted their Annual Progress Report.

X. Thesis Advisory Committee

The regulations of the School of Engineering and Applied Science require that a Thesis Advisory Committee be appointed for each student, and that it meet periodically to review the student's research. This committee is formed at the time of the oral qualifying examination.

The program of research undertaken by the student will be reviewed by the committee, which will meet with the candidate not less than once each academic year. The committee will report to the Associate Dean that it has met and reviewed the progress of the candidate. A copy of this report will be placed in the student's file. It is the student's responsibility to see that the Advisory Committee meets. The purpose of this committee is to provide guidance and advice and to see that the program is leading toward a thesis.

In Optics, typically members the Oral Qualifying Exam Committee, the PhD Thesis Advisory Committee, and the Final Oral (thesis defense) Examining Committee are the same people, but they

need not be. Following the rules of the college, the minimum membership of these committees are three faculty: two with primary appointments in Optics (which for this purpose includes Jon Ellis) and one with a primary appointment outside of Optics (which may include those with secondary appointments in Optics, such as N. Bigelow, J. Eberly, T. Foster, T. Krauss, Q. Lin, G. Yoon and E. Wolf). Note that, if the advisor does not have a primary appointment in Optics, then he/she becomes a third "inside reader" and cannot count as the outside member. The dean of graduate studies may be petitioned to approve as a committee member someone other than a full-time faculty member (e.g., a senior research associate or an adjunct faculty member) to serve on the committee as an outside member.

XI. Requirements for Formal Review of Progress of Optics PhD Student

1. A thesis advisory committee must be in place before the end of the third year of study.
2. Any student who has not passed his or her oral qualifying exam by the middle of year four must meet with each member of the thesis advisory committee each semester and file a report of that meeting with the Graduate Coordinator.
3. Every student must take and pass the oral qualifying exam (thesis proposal) before the end of the fifth year of study.
4. Any student who has not completed degree requirements before the end of year six must prepare, in consultation with his or her advisor, a schedule, including intermediate goals, for completing the degree. This schedule will be reviewed with each member of the thesis advisory committee either individually or collectively each semester until the degree is completed.
5. Any student undertaking thesis research supervised by a professor without primary appointment in Optics must have a thesis advisory committee in place by the end of the second academic year, or by the end of the semester after joining such a research group if that occurs after the end of the second academic year.

Any student in violation of these rules will not be allowed to register for the next semester. Failure to maintain registration will lead to dematriculation.

XII. Preparation of the Ph.D. Thesis and the Final Oral Examination

The cost of typing, illustrating, reproducing, and binding a thesis is borne by the student. Details on the format of the thesis, etc., are given in a document called "The Preparation of Doctoral Theses", available on-line at <http://www.rochester.edu/Theses/>.

Once the student is ready to defend, he/she should speak with the Graduate Coordinator about the necessary steps required to register for the thesis defense. The University's [Official Bulletin of Graduate Studies](#) gives details on the selection of the Final Oral Examination Committee, the scheduling of the examination, and so on. Each student is required to provide one bound copy of the finished thesis to the Graduate Coordinator for the departmental archives. The Final Oral Examination consists of two parts: 1) a one-hour public presentation (50 minutes of talk plus 10 minutes for questions by the audience), and b) a closed-door oral examination by the Committee.

XIII. Duration of Program

Time for completion of the Ph.D. degree varies in the range of 4 to 7 years. Students entering a Ph.D. program with a Bachelor's degree are expected to complete the Ph.D. degree within six years. Those entering a Ph.D. program with a Master's degree are expected to complete the Ph.D. degree within five years. Students who have not graduated by the end of their sixth year in the program must

meet with the Optics Graduate Committee and the Director of The Institute of Optics to discuss their progress.

XIV. Other Topics

This document is a supplement to the [Official Bulletin for Graduate Studies](#). Details of university-wide regulations are found in the Bulletin and are not always included here. Make sure you are aware of all the regulations mentioned in the Official Bulletin for Graduate Studies.

A. Foreign Language Requirement

There is no foreign language requirement for the Ph.D. in Optics.

B. Compatibility of the M.S. and Ph.D. Degree Requirements

The Masters Degree in Optics is a valued degree in its own right, and is not a consolation prize for students who do not meet the standards for the Ph.D. The Masters degree is not automatically granted to anyone satisfying the Ph.D. requirements. It is possible, however, to satisfy the M.S. requirements while working for the Ph.D. by satisfying the appropriate course requirements, filing an approved M.S. program form, and completing the Master's Essay. Ph.D. students must have satisfied their two-semester TA requirement in order to be eligible to earn the M.S. degree.

This option allows the student to receive both degrees without delaying the Ph.D. (thirty graduate hours from an approved M.S. degree can be counted towards the ninety hours required for the Ph.D. degree in Optics). It is also possible for the Ph.D. student to do a Masters Thesis. This is not generally recommended because writing two theses seriously delays the completion of the Ph.D.

Ph.D. students who wish to receive an M.S. degree can petition that the OPT 456 requirement be waived if they have performed extensive, diverse experimental work equivalent to OPT 456. The faculty or staff teaching OPT 456 must sign the petition and certify that the student's experimental experience is adequate.

TIME LIMITATIONS ON INCOMPLETES

If a student needs to take an Incomplete for a course(s) due to unforeseen circumstances, the student must first contact the Graduate Coordinator. In order to receive an Incomplete, a student along with the professor (s) must write up a "Memo of Intent" (MOI) which states the timeline for completing the work. This memo needs to be signed by both the student and the professor (s) and filed with the Department and the Office of Graduate Studies.

The following is departmental policy on incompletes for Optics graduate students. An Incomplete (I) grade in an Optics course must be made up within four weeks after the start of the following semester. At the end of this time, the Registrar's Office will be instructed to change the I to an E, unless another grade has been assigned. This means that students should:

a) (preferably) complete, within four weeks after the start of the new semester, all work required to change the I to a passing grade;

OR

b) complete enough work to justify a request for a time extension. Extensions will be granted solely at the discretion of the instructor, and are not automatic. Please note that positive action on both the

student's part and the instructor's is required to prevent the I from becoming an E. It would be wise for students to check that required paperwork has been carried out.

PETITIONS FOR EXCEPTIONS FROM THE RULES

No set of rules can be expected to handle properly every situation. Any student who feels that his or her educational needs would be better served if an exception were made to the regulations given in this handbook should first discuss the matter with a faculty advisor, and with the Chairman of the Graduate Committee, and if need be, asking a formal waiver of the relevant requirement.

The petition should be in the form of a letter addressed to the Chair of the Graduate Committee stating the desired exception and providing whatever supporting information might be useful. In the case of requests for waiver of a particular course requirement, a supporting letter from the instructor in the course is helpful.

A GUIDE TO THE PH.D. PRELIMINARY EXAMINATION

This is a 9-hour written examination made up of 3 segments, one of which is given on each of 3 successive mornings in late August or early September. It is designed to be taken by students who have completed the normal first year Ph.D. course work in optics. There are two main purposes which the examination serves. First, the preparation for the examination enables the student to gain an overview of some five years' study in physics, optical engineering, and mathematics. Students have an opportunity to review past courses, to sift out the important topics, and to distill the essential subject matter. Secondly, the examination provides the Optics faculty with a quantitative basis for deciding whether the student has the foundation of knowledge necessary to begin course work and thesis research in a specialized area. Although the performance on this examination is not the only criterion that is considered in making this judgment, it is weighted heavily.

Content of the examination

In order to prepare for the preliminary exam, the students should:

- a) Review some of the exams from recent years. Copies of these exams are distributed early in the summer by the Graduate Coordinator to the students who are taking the exam. These previous exams should be reviewed judiciously for several reasons. First, the emphasis on some of the subjects might have shifted. Another reason is that the examination questions are submitted by individual faculty. Questions which bear the hallmark of some faculty member may depend on whether he or she is in charge of writing the corresponding part of the exam that year or not.
- b) Review the topics listed in the guide which follows. While the faculty who prepared this guide did their best to list the likely topics for the preliminary examination, the term "guide" is used because it is not guaranteed that these and only these topics will appear on the examination.
- c) Confer with faculty. Often there will be a point that was not clear in a course. During review, as these points become apparent, students should avail themselves of the opportunity to discuss such problems with the faculty.

Day 1

Quantum and Atomic Physics - 45 minutes

Simple quantum mechanical systems, such as a harmonic oscillator, a spin, or a two-level atom interacting with an external electric or magnetic field. Application of either time-dependent or time-independent perturbation theory or solving the time-dependent Schrodinger equation, or Heisenberg equation for the dynamics of the system. Coherent states of harmonic oscillators, electric dipole selection rules for optical transitions in atoms and molecules, as well as the vector model of addition of angular momenta.

References:

Cohen-Tannoudji, Diu, and Laloe, *Quantum Mechanics*

R. Shankar, *Principles of Quantum Mechanics*, 2nd ed., Plenum Press (1994).

E. Merzbacher, *Quantum Mechanics*

OPT 412 material

Electromagnetism - 45 minutes

First-year graduate level material on electromagnetism, including important results from Maxwell's equations, potentials and gauge transformations, Green's function method for solving inhomogeneous wave equations, plane waves and thin films, dipole radiation, radiation spectrum, polarization and crystal optics, arrays, scattering, and propagation into the right space.

References:

OPT 462 material

J.A. Kong, *Electromagnetic Wave Theory*
C.A. Balanis, *Advanced Engineering Electromagnetics*
J.D. Jackson, *Classical Electrodynamics*
Born & Wolf, *Principles of Optics*

Fourier Optics - 45 minutes

Diffraction in free space, the linear system formulation for imaging systems, Fourier transform theory, optical information processing, and holography.

References:

OPT 461 material

J. W. Goodman, *Introduction to Fourier Optics*

Mathematical Methods - 45 minutes

Vector Calculus, Taylor and Laurent series. Fourier, Laplace & Hilbert transforms. Contour integrals, residues, singularities. Ordinary differential equations. Sturm-Liouville operator, Green's functions. Partial differential equations. Separation of variables.

References:

OPT 411 material

G.B. Arfken and H.J. Weber, *Mathematical Methods for Physicists*,

H.W. Wyld, *Mathematical Methods for Physics*,

Susan Lea, *Mathematics for Physicists*,

Dennerly & Krzywicki, *Mathematics for Physicists*,

G.J. Gbur, *Mathematical Methods for Optical Physics and Engineering*.

Day 2

Lasers - 45 minutes (except 30 minutes for 2017 only)

This subject will cover the theory of lasers and the operating characteristics of different types of lasers. Students should know the basic concepts such as spontaneous and stimulated emission, optical gain, pumping schemes, and laser threshold. The main topics include stable and unstable resonators, longitudinal and transverse modes, ABCD law for Gaussian beams, rate equations, gain spectrum, Q-switching, and mode locking.

References:

OPT 465 material

Svelto, *Principles of Lasers*,

Milonni and Eberly, *Lasers*.

Instrumental Optics - 45 minutes

Testing and measurement principles based on interference and diffraction, including: Newton interferometer, Fizeau, Twyman-Green/Michelson interferometers, common path interferometers, shearing interferometers, diffraction grating spectrometer, Fabry-Perot interferometer, low-coherence interferometer. Wavefront sensors (Shack-Hartmann).

Interpreting optical tests, including: Wavefront aberrations and interferometry; interpreting interferograms; system measurement metrics. Phase shifting algorithms and error analysis.

Coherence phenomena and the influence on instrumentation, including: Interference as a field correlation; effect of polarization on interference; changes in correlation on propagation (the Van-Cittert Zernike theorem), and in condenser systems.

Coherence based instruments, including: The Michelson Stellar Interferometer; the Fourier Transform spectrometer; optical coherence tomography; low coherence metrology.

Illumination, coherence and its influence on imaging, including two-point resolution, and the modulation transfer function. Illumination direction cosine (Goodman) diagrams.

References:

Optics 442 material

Malacara, *Optical Shop Testing*

Born and Wolf, *Principles of Optics* (Coherence Chapter)

Radiation and Detectors - 45 minutes

Radiometry; Photometry; Colorimetry; Blackbody radiation; Statistics of photons and noise; Figures of merit of detectors; Specific detector types: photomultiplier, photoconductive detector, photovoltaic detector, avalanche photodiode, bolometer, pyroelectric detector, thermopile, CCD.

References:

OPT 425 material

R.W. Boyd, *Radiometry and the Detection of Optical Radiation*

E.L. Dereniak and D.G. Crowe, *Optical Radiation Detectors*

R. H. Kingston, *Optical Sources, Detectors, and Systems*.

Geometrical Optics - 45 minutes

Foundations of Geometrical Optics. Fermat's principle. Implications of symmetry in axial systems (rotation invariants). Imaging properties expanded in Taylor series-definitions of first- and third-order properties. First order analysis and design of optical systems. First-order transfer and refraction. Thin lens equations. Cardinal Points. Stops and Pupils (marginal and chief rays). Primary chromatic aberrations. Afocal, visual, transverse, and longitudinal magnifications. Lagrange invariant. First-order layout in simple systems--achromatic doublets, telescopes, microscopes, telephoto, reverse-telephoto, etc. Third order analysis and design of optical systems. Primary third-order monochromatic aberrations. Wave aberration function and transverse ray errors. Stop shift equations. Thin lens equations.

References:

OPT 442 material

W.J. Smith, *Modern Optical Engineering*

Day 3

The third day consists of questions on courses that the majority of students taking the preliminary exam have not yet taken. The benefits of this set of questions include the following. These questions test the ability of the students to study and acquire knowledge by themselves, a skill that they will need in order to do independent research. It also gives them some familiarity with areas that they might not otherwise study, broadening their knowledge. Studying these areas also affords the students to learn a little about special topics in optics that are active areas of research at the Institute.

Vision – 30 minutes

Roorda, A. "Human Visual System - Image Formation" in: Vol. 1 of The Encyclopedia of Imaging Science and Technology, Editor Joseph P. Hornak, (John Wiley & Sons, New York) pp 539-557 (ISBN #0-471-33276-3) (2002).

Williams, D.R. (2011). Imaging single cells in the living retina. *Vision Research*, 51(13):1379-1396. doi: 10.1016.

J. M. Wolfe, K. R. Kluender, D. M. Levi, L. M. Bartoshuk, R. S. Herz, et al. (2012) *Sensation and Perception*. 3rd Edition Sunderland, MA: Sinauer Associates, Inc.

Chapter 2: The First Steps in Vision: From Light to Neural Signals

Chapter 3: Spatial Vision: From Spots to Stripes

Chapter 5: The Perception of Color

Optical Materials and Spectroscopy – 30 minutes

Saleh & Teich, *Fundamentals of Photonics* 2nd edition. Sections 5.5 and 5.6, Chapter 7, 16, 19 and 20
Yariv and Yeh, *Photonics* 6th edition, Chapter 5

Waveguides and Nonlinear Optics – 30 minutes

R.W. Boyd, *Nonlinear Optics, Third Edition*, Sections 1.1 through 1.5, Sections 2.1 through 2.3,; Section 4.1, Section 7.1 and 7.5

G.P. Agrawal, *Lightwave Technology: Components and Devices*, Wiley (2004); Chapters 1 and 2.

System Design – 90 minutes

As optical scientists and engineers we strive to develop systems that are capable of detecting and reporting the experimental quantities of interest. This question asks the student to consider how the goals of an entire system get converted to the specifications of the individual sub-systems or components. The process of partitioning the system into subsystems and attributing performance characteristic to each part often involves estimation, approximation and “rules of thumb.” After proposing first-order system designs, testing plans for the sub-systems and the overall system must be developed to ensure the system does work as needed and problems can be identified and appropriately attributed.

In this question you will be presented with some form of either an optical system, electro-optical system or opto-mechanical system. As you approach the question, you should consider the first-order design of the entire system and not merely focus on a single part or functional attribute of the system. Your goal would be to partition the system into sub-systems and/or develop specifications for either the sub-systems or components such that the entire system should in principle work. You will be asked to outline testing strategies that could be applied to the overall system and the individual sub-systems.

The question presented will draw from topics covered in the core PhD curriculum, Optics 441, 442, 461, 462, 425 and 465. The question will present either a question on the design of an optical system to meet a specified purpose, the tolerancing of an optical system or the application of an optical principle (e.g. the Lagrange invariant) to solve an optical system problem.

The question will be graded primarily on the *consistency*, *completeness* and *appropriateness* of the first-order design and the *adequacy* of the testing plan.

References: Principally, the curriculum of OPT 425, 441, 442, 461, 462 and OPT 465.

Additional insight on this topic can be gleaned from:

Philip C. D. Hobbs, *Building Electro-optical Systems: Making it all work*, Wiley, 2009, ISBN 978-0-470-40229-0. This reference is very comprehensive and provides in depth examples. It is especially good at covering topics of signal to noise and photon budgets.

Optical Engineering Handbook, OSA/SPIE publishers 2003, Chapter 25.

W. Smith, *Modern Optical Engineering*, McGraw-Hill, 2000, Chapter 15.

W. Welford, *Useful Optics*, Univ. Chicago Press, 1991, Chapter 16.



Ph.D. Student Annual Progress Report

Student's Name: _____ Date: _____

Advisor's Name: _____ Year of enrollment in PhD program: _____

Thesis Committee members (if applicable):

All course requirements have been met; Program of Study form is attached (or was in a previous year) [yes/no]: _____

Thesis proposal completed or expected month:

Thesis defense expected year/month:

In the past 12 months I have accomplished these things:

-Research, publications, conference attendance and presentations, courses taken, TA, etc.

My goals for the upcoming 12 months:

-Objectives you have for the coming 12 months, as well as for the rest of your PhD studies.

Comments and signature from advisor:

Please complete this form, **obtain your advisor's comments and signature**, and give a hard-copy to the Graduate Coordinator (Kari Brick) by **May 31**.

Note: If you are advised by a faculty outside Optics, we need your internal advisor's signature as well

A GUIDE TO THE PREPARATION OF PH.D. THESIS PROPOSALS

In order to help students conduct research that will lead to successful completion and defense of the doctoral dissertation, The Institute of Optics faculty has established a requirement that all students prepare and defend a thesis proposal in the early phases of their research. It is felt that the experience gained through the completion of this requirement will be beneficial to all students, for it will make them conduct thorough review of their field of specialization, clearly delineate the problem to be investigated, and establish goals and objectives that are appropriate in scope for a doctoral research project.

The thesis proposal and any subsequent revisions are to be submitted to The Institute faculty as a whole; all are invited to make whatever comments or suggestions they feel appropriate. In order to allow time for the faculty to make these comments, the proposal must be circulated to the entire faculty at least two weeks before the examination. The proposal must have the general approval of the student's prospective thesis advisor prior to submission to the faculty. However, the thesis advisor is not expected to vouch for all statements made in the proposal, nor to assume the student's burden of responsibility for the proposal.

It is expected that students will submit thesis proposals no later than 21 months after they demonstrate, by passing the written Preliminary Examination, their general competence at the level required for doctoral research. It is very much in the student's best interests to write the proposal as soon as possible. This will organize the research efforts so as to complete the dissertation with the least wasted time and effort.

At the time of circulation to the faculty, a copy of the proposal should be given to the Administrator for Graduate Studies who will place it in the files. The Administrator will also provide a copy of the "Examination Appointment Form for the Master's Final, Doctor of Philosophy Qualifying". This form nominates the faculty members to serve on the examination and sets a date for it. This form must be submitted to the Associate Dean for Graduate Studies at least two weeks before the date of the examination.

Oral Qualifying Examination

According to University regulations, the oral qualifying examination is the official Ph.D. Qualifying Examination, and the written examination must be passed for the student to become eligible to take the oral examination.

The oral qualifying Examination is subject to the following University rules. It must be taken at least seven months before the final examination. A vote to pass the candidate must be approved by at least three-fourths of the designated members of the committee. The votes of all committee members will be recorded. The office of the Associate Dean must be notified at least two weeks before a qualifying examination is to be held, and passage or failure must be reported to the Dean within one month after the examination. A second qualifying examination may be taken only upon the recommendation of the College Graduate Committee and the approval of the Associate Dean.

In the oral qualifying examination, the student is expected to present a defense of the thesis proposal and to demonstrate competence in areas that are generally related to the proposed research. The Examining Committee, after hearing the defense, will either pass the student, allowing formal commencement of research, or fail the student, with an appropriate recommendation for future action. An exception is that when only minor deficiencies in the proposal or defense are brought out in the exam, the Examining Committee may postpone its decision to a later date, to give the student an opportunity to eliminate the deficiencies.

The procedure is as follows:

1. The student finds a prospective thesis advisor and selects a topic for Ph.D. research.

2. The student prepares a written document which describes the proposed research. The Thesis Proposal serves three purposes. It organizes the student's efforts along a path which the Faculty agree may reasonably lead to a doctoral thesis. It acquaints the Faculty as a whole with the research effort so that they may offer assistance and counsel as is appropriate. It forms the focus for the Oral Qualifying Examination.

In order to properly serve these purposes, it is essential that the proposal state as clearly and succinctly as possible the nature and scope of the project proposed. It is also essential that the proposal be prepared in a timely fashion so that it can assist and guide the research. It should not be a draft of the first half of the thesis describing completed work.

FORM OF THESIS PROPOSALS

Thesis proposals should be typeset (double-spaced) and made into a pdf file. Copies of recent successful thesis proposals are available from the Graduate Coordinator. The thesis proposal should contain the following parts:

1. Title/Abstract Page

The first page of the thesis proposal, the cover page, should give the tentative title of the thesis, the student's name, the prospective faculty advisor's name, and the date of the proposal. This should be followed by a 200-word abstract. The abstract should summarize the proposed research, rather than give a description of what is contained in the proposal.

2. Introduction

The introduction should give a general description of the field within which the proposed research falls. It should make use of extensive literature references, both to permit the discussion to be concise and to demonstrate that the student is familiar with the literature in the chosen field.

3. Proposed Research

This section is the heart of the thesis proposal, and should present, in detail, the objectives of the proposed research. The discussion should describe the particular contributions that are anticipated, and how they relate to previous work in the field. Alternative courses of action should be considered, and the chosen one justified. Anticipated problems should be described.

4. Total Length

The total length of the proposal, including text, figures, appendices, etc., should not exceed 12 pages, not counting the cover page and additional page(s) for references.

Dissertation Timeline:

***Inform Graduate Coordinator when you start the process to prepare for your defense**

Leading up to the defense...

- Nominate a faculty member to serve as chair for your defense
 - Must be a non-member of the student's program, department, and committee
 - Must be at assistant professor rank or higher
- Get Thesis Manual and other documents from Graduate Coordinator

AT LEAST 6 weeks before defense

- Provide Committee Chair and committee members with a bound copy of your dissertation
 - It is OK to send your committee an electronic copy of your thesis if you have gained their permission to do so. ASK THEIR PREFERENCE!
- Pick a date
 - Inform Graduate Coordinator
 - Fridays are the best day, if possible, as it is easiest to find vacant rooms on Fridays.
- Book a room
 - Graduate Coordinator will help you

AT LEAST 4.5 weeks before defense

- Log onto <https://phdprocess.ur.rochester.edu/> and click the link in the top left corner to create a new student record.
 - You will need to fill out all required information (denoted with *) before you save the file (just because you "save" the file does not mean you "submit" the file... you can save it multiple times and come back and work on it).
 - If there is an address book icon next to the space to be filled, please click on it and use the tool to search the information. (i.e.: where it asks for the Graduate Coordinator, do not put my name. Rather, use the address book icon to search "Brick" and click on my name to enter it.)
- Attach a PDF file of your thesis to your online registration record
 - This should be the same version of your Thesis that you give to your committee members for review

Upon submitting final corrections

- The Institute requires that you donate 1 bound copy of your thesis to add to our collection in the copy room
 - Please print this 1-sided and in color (if possible). Do not bind or staple the document, simply hold it together with a clip. Give your thesis to Kari Brick, along with \$15 (or instructions on how to bill you) which will be used for binding the document

Explanation of Timeline:

6 weeks before you defend you should give your committee copies of your thesis to read. Technically, these are supposed to be bound copies, but most professors don't mind receiving it electronically. Please check with your committee members about how they prefer to receive the thesis.

The committee is given 2 weeks to read the thesis. During these two weeks, you are creating your online registration, and the Graduate Coordinator is gathering external documents, etc. During this time, you should also send me a PDF file of the thesis that you gave to your committee (or you can also just upload this straight to your online registration. Whatever is best for you).

4 weeks before you defend (2 weeks after you give your committee the thesis), the Graduate Coordinator will approve your online registration. Once the Graduate Coordinator approves your registration, it will be automatically sent to your committee members for approval. At this point, your

committee members will have to electronically approve that *they have read your thesis and it is defensible*. (<—This is why they needed 2 weeks to read your thesis)

Once all the committee members have approved your registration, it will be sent to the Director of the Institute. Once he approves, it will be sent to GSO.

Your electronic registration is due to GSO no later than 3 weeks before you defend. So essentially, your committee and the Director have 1 week to approve the document, the caveat being that the Director cannot approve until your entire committee has approved.

GRADUATE COURSE DESCRIPTIONS

Unless otherwise noted, all courses carry 4 hours of credit. **An asterisk (*)** after the course name indicates that this course satisfies the advanced course requirement.

OPT 407 – SCANNING ELECTRON MICROSCOPY PRACTICUM

Overview of techniques for using the SEM (Scanning Electron Microscope) and Scanning Probe (AFM, STM) and analyzing data. Students perform independent lab projects by semester's end.

OPT 411 – MATHEMATICAL METHODS FOR OPTICS

Study of mathematical techniques such as vector calculus, series expansions, contour integration, integral transforms (Fourier, Laplace and Hilbert), asymptotic estimates, and second order differential equations.

Prerequisites: ME 201, 202 or equivalent, and permission of the instructor.

OPT 412 – QUANTUM MECHANICS FOR OPTICS

This course covers the topics in modern quantum theory which are relevant to atomic physics, radiation theory and quantum optics. The theory is developed in terms of Hilbert space operators. The quantum mechanics of simple systems, including the harmonic oscillator, spin, and the one-electron atoms, are reviewed. Also, methods of calculation useful in modern quantum optics are discussed. These include manipulation of coherent states, the Bloch sphere representation, and conventional perturbation theory.

Prerequisite: One course in undergraduate wave mechanics or permission of instructor.

References: Cohen-Tannoudji, Diu and Laloe, Merzbacher, Schiff, Dirac.

OPT 413 – INTRODUCTION TO RANDOM PROCESSES

Random signals and noise in linear systems. Selected topics in probability theory, random variables, random vectors, random sequences (random walk, Martingales, ARMA model, Markov chains), random processes (Poisson process, Gaussian process, Wiener process, Markov process), stationary and cyclostationary processes, random process inputs to linear systems, ergodicity, filtering, linear estimation, bandlimited and bandpass processes.

OPT 414 – DETECTION AND ESTIMATION*

Loss and utility; Bayesian inference; risk functions, randomized decisions, admissible decisions; empirical Bayes for unknown prior; Neyman-Pearson hypothesis testing, receiver operating characteristic; sufficient and minimal sufficient statistics and Rao-Blackwellization; unbiased estimation; minimum variance unbiased estimation and Cramer-Rao inequality, maximum likelihood estimation; nonparametric estimation of cdfs.

Prerequisite: ECE440 or equivalent, or permission of instructor.

OPT 421 – OPTICAL PROPERTIES OF SEMICONDUCTORS

The course concerns the aspects of the solid state physics of materials, which influence their optical properties. Semiconductors are emphasized, but metals and insulators are treated also. The physics of optical absorption, emission, reflection, modulation, and scattering of light is covered. Optical properties of electrons, phonons, plasmons, and polaritons are detailed. The optical properties of reduced dimensionality structures such as quantum wells are contrasted with those of bulk semiconductors.

Prerequisites: undergraduate Quantum Mechanics

OPT 422 – COLOR TECHNOLOGY

Color Technology is more than just pigments, dyes, paints, and textiles. Everywhere in modern technology (smart phones, tablets, displays, lighting, cinema, printers, etc.) is the need for a basic understanding of how we measure, identify, communicate, specify, and render color from one device to another. This course addresses color order systems, color spaces, color measurement, color difference, additive and subtractive color, and rendering of color images. The student will learn about color matching, lighting conditions, metamerism, and color constancy. At the semester's end, each student will have compiled a Color Toolbox with useful functions to derive different necessary color values within MatLab.

OPT 423 – DETECTION OF OPTICAL RADIATION

The course covers modeling of optical radiation, human perception of light, emission of thermal radiation, statistics of light and detectors, basic parameters of photodetectors, and different types of detectors.

References: Robert W. Boyd, Radiometry and the Detection of Optical Radiation, Wiley, 1983, ISBN 0-471-86188-X; William L. Wolfe, Introduction to Radiometry, SPIE, 1998, ISBN 0-8194-2758-6; Bahaa E. A. Saleh and Malvin C. Teich, Fundamentals of Photonics, Wiley, 2007, ISBN 978-0471358329

OPT 424 – FUNDAMENTALS OF LASERS (for external students)

Fundamentals and applications of lasers and laser systems, including optical amplification, cavity design, beam propagation and modulation. Emphasis is placed on developing the basic principles needed to design new systems, as well as an understanding of the operation of those currently in use.

Prerequisites: Permission of instructor. Not available for Optics and Physics graduate students.

OPT 425 – RADIATION AND DETECTORS

The course covers the following topics: emission of thermal radiation, modeling of optical propagation (radiometry), quantifying the human perception of brightness (photometry) and of color (colorimetry), fundamentals of noise in detection systems, parameters for specifying the performance of optical detectors, and a survey of several specific types of detectors.

References: Boyd, Radiometry and the Detection of Optical Radiation; Kingston, Detection of Optical and Infrared Radiation.

OPT 427 – OPTICAL LIQUID CRYSTALS

This course will introduce the materials, terminology, effects, and devices used in the field of liquid crystal optics. Basic structures in nematic and cholesteric liquid crystals will be discussed and related to optical phenomena like transmittance, absorption, scattering, birefringence and selective reflection (the effect seen in scarab beetles and utilized to protect the OMEGA laser at LLE from blowing itself up). Two keys for device applications are LC chemical composition and molecular alignment, and these will be covered in order to understand the manufacture and operation of passive devices like wave plates and selective reflection polarizers. The basic electro-optics for active devices like EO switches and LC displays will also be covered. Other applications to be explored include mood rings, polarizing pigments for document security, smart windows, and car paint.

OPT 428 – OPTICAL COMMUNICATION SYSTEMS

The course is designed to give the student a basic understanding of modern optical communication systems while making him/her aware of the recent technological advances. The following topics will be covered: analog and digital signals, multiplexing techniques, modulation formats, dispersive and nonlinear effects in optical fibers, light-emitting diodes and semiconductor lasers, receiver design, noise and signal-to-noise ratio, bit error rate, optical amplifiers, dispersion management, multichannel systems, soliton systems, coherent lightwave systems.

Course Textbook: G. P. Agrawal, Fiber-Optic Communication Systems, 3rd ed. (Wiley, New York, 2002); Reference books: Ramaswami and Sivarajan, Optical Networks, (Moragn, 2002); G. Keiser, Optical Fiber Communications, (McGraw-Hill, 2000).

OPT 429 – CHEMICAL BONDS; MOLECULES AND MATERIALS

An introduction to the electronic structure of extended materials systems from both a chemical bonding and a condensed matter physics perspective. The course will discuss materials of all length scales from individual molecules to macroscopic three-dimensional crystals, but will focus on zero, one, and two dimensional inorganic materials at the nanometer scale. Specific topics include semiconductor nanocrystals, quantum wires, carbon nanotubes, and conjugated polymers.

OPT 432 – OPTO-MECHANICAL DESIGN

The mechanical design and analysis of optical components and systems will be studied. Topics will include kinematic mounting of optical elements, the analysis of adhesive bonds, and the influence of environmental effects such as gravity, temperature, and vibration on the performance of optical systems. Additional topic include analysis of adaptive optics, the design of lightweight mirrors, thermo-optics and stress-optics (stress birefringence) effects. Emphasis will be placed on integrated analysis which includes the data transfer between optical design codes and mechanical FEA codes. A term project is required.

OPT 433 – OPTICAL FABRICATION AND TESTING TECHNOLOGY

This laboratory and lecture course is designed to give a firsthand working knowledge of optical glasses, their properties, and the methods for fabricating and characterizing high quality glass surfaces and components. Lectures will emphasize the physical and optical properties of glass, methods for manufacturing glasses, the component finishing process (grinding and polishing), cleaning, finished element specification, chemical durability and optical quality evaluation methods. New glasses and their applications in laser systems and nonlinear optics will be described.

The laboratory is designed to expose the student to several varieties of optical glasses, the methods for cold working glass blanks, and the fabrication and testing of selected optical elements. Hands-on activity with grinding and polishing equipment will be required to complete one of a variety of projects. In addition to using standard test fixtures and reference standards, to evaluate their work as it progresses, each student will learn the fundamentals of interferometric testing and data interpretation, and methods for evaluating surface smoothness via noncontact, optical profilometry. An introduction, by demonstration, to continuous polishing and optical contacting techniques will be provided during the laboratory portion of the course. (continued next page)

Enrollment: 12 students maximum (priority to graduate Optics students).

Text: Instructor's notes, 450 pages provided to students in a 3-ring binder cost.

OPT 440 – FREEFORM OPTICS*

Freeform optics is an emerging technology that a broad industry community anticipates will permeate optical systems of the future. This course will define and reveal the history of freeform optics. After an overview on freeform optics that will span design, fabrication and optical testing, the course will then review the theory of optical aberrations for rotationally symmetric system with an emphasis on the field dependence of the aberrations, before introducing Nodal Aberration Theory that was developed in the 1980s for systems that depart from rotational symmetry. Design concepts will then be presented, including the aberrations of freeform optics. Examples of freeform optics designs will be presented. The sensitivity of freeform optics systems to misalignment and form errors will then be discussed. Guest lectures on the mathematics of freeform optics for manufacture, and optical fabrication and testing will be included as possible. The class is intended to be accessible to graduate students in Optics. The course will allow graduate students to learn about freeform optics and also to advance their skills in optical system design.

The format of the course will include meeting once a week and will include lectures interspersed with hands-on exercises throughout the semester. Students will be expected to conduct an independent project during the semester culminating in a written report at the end of the semester and a presentation to the class. The reading material for the class will consist of review articles and papers from the primary scientific literature. Each student will be expected to conduct an oral presentation describing the methods and conclusions of at least one paper from the primary literature as well as lead a discussion of that paper with the class.

Pre-requisites: OPT 444 Lens Design and OPT 544 Advanced Lens Design. This course is aimed at graduate students who completed OPT444, and OPT544 is required but may be taken in parallel with OPT440.

OPT 441 – GEOMETRICAL OPTICS

This course is designed to give the student a basic working knowledge of image-forming optical systems. The course is oriented toward problem solving. Material covered includes: image formation, raytracing and first-order properties of systems; magnification, F/number, and numerical aperture; stops and pupils, telecentricity vignetting; telescopes, microscopes, magnifiers, and projection systems; the Delano diagram; the eye and visual systems, field lenses; optical glasses, the chromatic aberrations, and their correction; derivation of the monochromatic wavefront aberrations and study of their effects upon the image; third order properties of systems of thin lenses; effects of stop position and lens bending; aplanatic, image centered, and pupil centered surfaces; and field flatteners.

References: Smith, Modern Optical Engineering, McGraw-Hill; Lecture notes.

OPT 442 –INSTRUMENTAL OPTICS

This course provides an in-depth understanding of the principles and practices of optical instrumentation: Optical metrology, including wavefront and surface metrology, interferometric instruments and interferogram analysis, coherence and coherence based instruments, phase measurement and phase-shifting interferometry; Spectroscopic instrumentation, including the Fourier Transform Spectrometer, the Fabry-Perot interferometer, and the grating monochromator; Image plane characterization (star test, Ronchi test, and modulation transfer function); The influence of illumination and partial coherence on image forming systems, including microscopes, systems for projection lithography, and displays.

Prerequisites: OPT 441.

OPT 443 – FUNDAMENTALS OF MODERN OPTICAL SYSTEMS

This course covers fundamental ray optics that are necessary to understand today's simple to advanced optical systems. Included will be paraxial optics, first-order optical system design, illumination, optical glasses, chromatic effects, and an introduction to aberrations.

References: Hecht, Optics (4th edition); Smith, Modern Optical Engineering; Lecture notes.

OPT 444 – LENS DESIGN

A review of geometrical optics and 3rd order aberration theory. Specification documents. Image assessment: ray intercept plots, wavefront analysis, spot diagrams, MTFs, and point spread functions. Optimization theory, damped least squares, global optimization, merit functions, variables and constraints. Glass, plastic, UV and IR materials. Aspheres, GRINs, and diffractive optics. Secondary spectrum, spherochromatism, higher order aberrations. Induced aberrations. Splitting and compounding lens elements. Aplanats and anastigmats. Refractive design forms: landscape lens, achromatic doublet, Cooke triplet, Double Gauss, Petzval lens, wide angle, telephoto, and eyepieces. Reflective design forms: parabola, Cassegrain, Schmidt, Ritchey Cretien, Gregorian, three mirror anastigmat, and reflective triplet. Computer aided lens design exercises using CodeV - includes a 4-6 week individual lens design project.

Prerequisites: Permission of Instructor

OPT 445 – PRECISION INSTRUMENTATION DESIGN

This course focuses teaching the multidisciplinary aspects of designing complex, precise systems. In these systems, aspects from mechanics, optics, electronics, design for manufacturing/assembly, and metrology/qualification must all be considered to design, build, and demonstrate a successful precision system. The goal of this class is to develop a fundamental understanding of multidisciplinary design for designing the next generation of advanced instrumentation.

OPT 446 – OPTICAL INTERFERENCE COATING TECHNOLOGY

This course addresses the design, manufacture and quality control of optic interference coatings. Topics covered include: reflection and transmission at interfaces: the vector diagram; the Smith Chart; properties of periodic media; design of high reflectors, bandpass filters and edge filter; use of

computer programs for design analysis; production techniques; thickness monitoring; thickness uniformity calculations.

OPT 447 – ADVANCED OPTICAL COATING DESIGN*

This course will cover such topics as the effects of dispersion, scatter, and inhomogeneity in multilayer interference coating designs. Attention will be given toward manufacturability of designs and meeting common optical specifications. Design assignments will address fields including, but not limited to Ophthalmic, Lighting, Display, Anti-counterfeiting, Laser, and Infrared applications. Each student will be given access to current market design, optical characterization, and post-process analysis software.

OPT 448 – VISION AND THE EYE

The human visual system is the most sophisticated imaging system known. This course will reveal the intricate optical and neural machinery inside the eye that allows us to see. It will describe the physical and biological processes that set the limits on our perception of patterns of light that vary in luminance and color across space and time. We will compare the human eye with the acute eyes of predatory birds and the compound eyes of insects. The course will also describe exciting new optical technologies for correcting vision and for imaging the inside of the eye with unprecedented resolution, and how these technologies can help us understand and even cure diseases of the eye. The class is intended to be accessible to advanced undergraduate students, especially those majoring in Optics, Biomedical Engineering, or Brain and Cognitive Science, but is recommended for anyone with a curiosity about vision or an interest in biomedical applications of optics. The course will also serve as an introduction to the study of vision for graduate students.

OPT 449 (CVS 541) – INSTRUMENTATION AND METHODS FOR VISION RESEARCH

This course describes the design, construction, and operation of optical instrumentation used in modern vision research. We discuss various techniques for delivering stimuli to the retina including Maxwellian view optics and CRT displays. Methods of calibrating these systems are described in the context of a practical treatment of radiometry, photometry, and colorimetry. The course also covers optical techniques for monitoring the retina such as optical coherence tomography, monitoring eye position such as Purkinje eye tracking, and monitoring the brain such as with infrared reflectance imaging.

OPT 450 – POLARIZATION*

This course covers the fundamentals necessary to understand the behavior of fully and partially polarized light, and the significant range of applications and optical systems in which polarization is important. Topics include foundational electromagnetic theories of propagation and scattering, polarized plane waves, polarization eigenstates, Jones and Mueller Calculii, ellipsometry, polarization in multilayers and gratings, principles of polarization ray tracing, polarization effects in focusing and imaging, polarization metrology, and topics in polarization coherence.

Prerequisites: OPT 441 or 443 and 461 or 463 or permission of the instructor.

OPT 452 (ECE 452) – MEDICAL IMAGING --THEORY AND IMPLEMENTATION

Physics and implementation of X-ray, ultrasonic, and MR imaging systems. Special attention is given to the Fourier transform relations and reconstruction algorithms of x-ray and ultrasonic-computer tomography, and MRI.

OPT 453 – QUANTUM OPTICS AND QUANTUM INFORMATION LAB

This laboratory course will expose students to *cutting-edge* photon counting instrumentation and methods with applications ranging from quantum information to biotechnology and medicine. It will be based on quantum information, the new, exciting application of photon counting instrumentation. As much as wireless communication has impacted daily life already, the abstract theory of quantum mechanics promises solutions to a series of problems with similar impact on the twenty-first century.

Major topics will be entanglement and Bells inequalities, single-photon interference, single-emitter confocal fluorescence microscopy, Hanbury Brown and Twiss correlations/photon antibunching. Photonic based quantum computing and quantum cryptography will be outlined in the course materials as possible applications of these concepts and tools.

OPT 456 – OPTICS LABORATORY

This is an intensive laboratory course. The laboratory experiments are likely to include the following:

1. Transverse and axial mode structure of a gas laser.
2. Detector calibration using a blackbody.
3. Production of a white light viewable transmission hologram.
4. Acousto-optic modulation.
5. Twyman-Green interferometry.
6. Optical Fibers Laser.
7. The Pockels cell as an optical modulator.
8. Optical beats (heterodyning) and CATV.
9. The YAG laser and second harmonic generation.
10. Fourier optics and optical filtering.
11. Lens Evaluation.
12. Modulation Transfer Function.
13. Applications and properties of pulsed dye laser.
14. Holographic optical elements.
15. Properties of Gaussian beams.

OPT 461 – FOURIER OPTICS (PHYSICAL OPTICS I)

The principles of physical optics including diffraction and propagation based on Fourier transform theory; integral formulation of electromagnetic propagation; diffraction from apertures and scattering objects; applications to optics of Fourier transform theory, sampling expansions, impulse response, propagation through optical systems, imaging and transforming, optical transfer function, optical filtering; and selected topics of current research interest.

Prerequisites: Undergraduate electromagnetic theory, advanced calculus, linear algebra.

Text: Goodman, Introduction of Fourier Optics; Class Notes.

OPT 462 – ELECTROMAGNETIC WAVES (PHYSICAL OPTICS II)

This course covers topics in electromagnetic theory that serve as a foundation for classical descriptions of many optical phenomena. A partial list of topics includes: review of Maxwell's equations, boundary conditions, and wave equations; polarization of light; crystal optics; vector, scalar, and Hertz potentials; radiation from accelerated charges; electric and magnetic dipole radiation; Lorentz atom description of the interaction of light with matter; scattering; optical waveguides.

Prerequisites: Undergraduate electromagnetic theory, advanced calculus, vector analysis.

References: Jackson, Classical Electrodynamics; Born and Wolf, Principles of Optics.

OPT 463 – WAVE OPTICS AND IMAGING

This course provides the practicing optical engineer with the basic concepts of interference, diffraction, and imaging. Each topic will be reinforced with real-world examples. The interference section will include interferometry, Fabry-Perot etalons, and multilayer thin films. The diffraction and imaging sections will include, but are not limited to, diffractive optics, Fourier series, continuous and discrete Fourier transforms, convolution theory, and Linear Systems.

Prerequisites: Advanced Calculus, Linear Algebra

References: Hecht, Optics (4th edition); Goodman, Introduction to Fourier Optics; Lecture notes.

OPT 464 – PHYSICS AND APPLICATION OF NANOPHOTONIC AND NANOMECHANICAL DEVICES*

This course aims to provide students with the understanding of fundamental principles governing optical and mechanical phenomena at micro/nanoscale, with focus on current research advances on device level. The following topics will be covered: Fundamental concepts of micro-/nanoscale optical cavities and mechanical resonators; various types of typical nanophotonic and nanomechanical structures; fabrication techniques; theoretical modeling methods and tools; typical experimental configurations; physics and application of optomechanical, quantum optical, and nonlinear optical phenomena at mesoscopic scale; state-of-the-art devices and current research advances.

Prerequisites: EM waves (ECE230 or OPT262 or OPT462); Waveguides and optoelectronics (ECE235/435 or OPT226 or OPT468); Quantum mechanics (OPT223 or OPT412 or PHY237 or PHY407).

OPT 465 – PRINCIPLES OF LASERS

This course provides an up-to-date knowledge of modern laser systems. Topics covered include quantum mechanical treatments to two-level atomic systems, optical gain, homogenous and inhomogeneous broadening, laser resonators and their modes, Gaussian beams, cavity design, pumping schemes, rate equations, Q switching, mode-locking, various gas, liquid, and solid-state lasers.

Prerequisites: undergraduate electromagnetic theory and quantum mechanics.

OPT 467 – NONLINEAR OPTICS*

Fundamentals and applications of optical systems based on the nonlinear interaction of light with matter. Topics to be treated include mechanisms of optical nonlinearity, second-harmonic and sum- and difference-frequency generation, photonics and optical logic, optical self-action effects including self-focusing and optical soliton formation, optical phase conjugation, stimulated Brillouin and stimulated Raman scattering, and selection criteria of nonlinear optical materials.

Prerequisites: Students must have completed either OPT 461 or 463 or 462.

References: Robert W. Boyd, Nonlinear Optics, Second Edition.

OPT 468 – INTEGRATED PHOTONICS

The course will cover the behavior of light in integrated waveguide devices. The course will feature in-class demonstrations, integrated photonic device design, and device testing in a laboratory setting. We will review Maxwell's Equations and cover topics such as optical modes, planar waveguides, optical fibers, rectangular waveguides, coupled-mode theory, mode coupling, resonators, modulators, and numerical methods for integrated photonic device design. During this class you will learn the fundamentals of integrated photonics, design an integrated photonic device, and test and analyze its performance.

OPT 470 – BIOMEDICAL MICROSCOPY

This course covers the principles and practice of light microscopy as applied to biological and medical questions. Topics include basic light microscopy, DIC, phase epifluorescence, confocal and multiphoton laser-scanning microscopy, and selected methods such as CARS, FRET, FRAP, FCS, etc.

OPT 476 – BIOMEDICAL OPTICS

Biomedical optics is the study of how light is used to study biological systems, to obtain medical information, and to perform clinical procedures. Major topics in this course include biomedical spectroscopy (absorption, fluorescence, Raman, and elastic scattering), propagation of photons in highly scattering media (such as tissue), and techniques for high-resolution imaging in biological media: confocal imaging, multiphoton imaging, and optical coherence tomography.

Students taking this course come from a variety of backgrounds. As such, the course is intended to be flexible in giving students depth in a few self-selected areas. In addition to the broader problem sets, there are two team-based reviews (oral and written) of recent journal articles, chosen by the team. The final project consists of a longer review paper, written individually, and a corresponding oral examination on that topic. This course is offered every second Fall (even years) and is intended to alternate with and be complementary to Biomedical Microscopy (BME 270/470, offered on the Fall semester in odd years), forming a two-semester Fall sequence that can start with either course.

Prerequisites: basic knowledge of quantum mechanics, statistical mechanics, linear algebra, differential equations, and vector calculus. Open to graduate students and upper-level undergraduates (who usually enroll in OPT 276, with fewer homework problems).

OPT 481 – TECHNICAL ENTREPRENEURSHIP

Course Objective: The course provides an opportunity to examine the management practices associated with innovation and new business development. The analysis of entrepreneurship is

evaluated from the perspective of start-up ventures and established companies. There is an appraisal of the similarities and differences in the skills and the functions required to develop successful projects in both types of situations. A range of management issues is discussed, including organizational development, analysis of market opportunities, financial planning and control, capitalization, sources of funds, the due-diligence process, and valuing the venture.

Course Approach: To expose students to various facets of new venture management and entrepreneurship, classes consist of lectures, evaluation of a current business situation, and presentations by guest speakers. Each speaker has started a business or been intimately involved in an entrepreneurial venture. The primary requirement for the course is the development of a business plan for a start-up that integrates the various organizational functions of a company. Furthermore, two (one for engineers) case studies must be prepared for credit. The first case examines a new venture in real time. The second involves an evaluation of a proposed new venture and the development of its marketing program.

OPT 482 – SYSTEM INTEGRATION AND PRODUCT DEVELOPMENT*

In this class we will explore the ISO 9000 product development process and illustrate how to use this process to develop both products and research systems that meet necessary specifications. The class will use systems such as video projectors, CD-ROM drives, bar-code scanners and scanning laser microscopes as examples to illustrate the various concepts.

Prerequisites: OPT 425, 441 or 443 and 461 or 463 or permission of the instructor.

OPT 492 – THz TECHNOLOGY AND ULTRAFast PHENOMENA*

This course has two parts: THz technology and ultrafast phenomena.

[1] THz technology covers the basic concepts of generation, propagation and detection of THz waves. It provides the fundamentals of free-space THz optoelectronics for sensing, imaging and spectroscopy applications. A THz optoelectronic system, with diffraction-limited spatial resolution, femtosecond temporal resolution, DC-THz spectral bandwidth, and mV/cm field sensitivity, will be central to the course. Examples of nondestructive testing, environmental sensing, homeland security, and biomedical applications will be highlighted.

[2] Ultrafast Phenomena covers the methods for short optical pulse and phenomena measurements, short laser pulse generation, amplification, detection, and characterization, as well as attosecond science and high harmonics generation.

Prerequisites: OPT 462 or permission of the instructor.

OPT 521 – OPTICAL INTERACTIONS IN SOLIDS*

The course consists of a sequence of lectures on topics in solid state physics which are necessary to understand the operation of optoelectronic devices. To balance the course between theoretical and experimental topics, each lecture commences with a fifteen minute overview of a specific experimental technique, or device which is related to the optical properties of solids. Lectures cover the following topics: optical constants of solids, electronic states, the role of lattice vibrations, a detailed look at optical transitions, and building devices.

OPT 511: ADVANCED MATHEMATICAL METHODS *

This course focuses on advanced numerical and analytical techniques that are likely to be useful for PhD-level Optics students. It will begin with a review of numerical errors and then develop simple

algorithms for solving nonlinear algebraic and differential equations. The later half of the course will cover several analytical techniques useful for solving ordinary and partial differential equations encountered in various areas of optics and photonics. Students will be given weekly homework problems based on the material covered each week.

Prerequisites: OPT 411 and some knowledge of MATLAB.

Course Textbook: S. Chapra, *Applied Numerical Methods with MATLAB*, 3rd edition (McGraw-Hill, 2011).

OPT 528 – ADVANCED TOPICS IN TELECOMMUNICATIONS*

The course is designed to provide the student with understanding of the recent advances in the field of lightwave technology. The following topics are covered: Dispersive and nonlinear effects in optical fibers; linear and nonlinear properties of fiber Bragg gratings, linear and nonlinear properties of fiber couplers, fiber interferometers: including Fabry-Perot resonators, nonlinear fiber-loop mirrors, Mach-Zehnder interferometers, different kinds of fiber amplifiers and lasers, pulse-compression techniques, design of modern fiber-optic communication systems, optical solitons and their applications.

Prerequisites: OPT 461 or 463, OPT 428 recommended (but not required).

Course Textbook: G. P. Agrawal, *Applications of Nonlinear Fiber Optics*

(Academic Press, San Diego, 2001); Supplementary Reading: G. P. Agrawal, *Nonlinear Fiber Optics*, 3rd ed. (Academic Press, San Diego, 2001).

OPT 535 – MODERN COHERENCE THEORY*

Theory of random process, stationarity ergodicity, the auto-correlation function and the cross-correlation function of random process. Spectrum of a stationary random process and the Wiener-Khinchine theorem, Second-order coherence theory in the space-time domain, the mutual coherence function, the degree of coherence. Second-order coherence theory in the space-frequency domain, the cross spectral density, mode representation, propagation problems, Inverse radiation problems, effects of source correlations and scattering of partially coherent light from deterministic and from random media. Phase space representations. Quantum theory of coherence.

Pre-requisite: OPT 461 or 463, OPT 425, OPT 442, or permission by instructor

OPT 544 – ADVANCED LENS DESIGN*

This course starts with a review of refractive optical design forms. The design of complex zoom lenses and multi-mirror reflective systems is discussed in detail starting with first principles. Other topics covered include: optical design and materials for the ultraviolet and infrared wavelength bands, plastic optical systems, opto-mechanical design, tolerancing, sensitivity analysis, monte carlo analysis, environmental analysis, advanced optimization techniques such as user-defined and global optimization, ghost and stray light analysis, and illumination design. Students will be required to complete two complex group design projects.

Pre-requisite: OPT 444.

OPT 551 (PHY 531) – INTRO TO QUANTUM OPTICS*

An introduction to quantum and semiclassical radiation theory with special emphasis on resonant and near-resonant interactions between atoms and optical fields. Topics covered include field quantization, Weisskopf-Wigner and Jaynes-Cummings models, the optical Bloch equations,

resonant pulse propagation, homogeneous and inhomogeneous broadening, adiabatic and non-adiabatic transitions, and dressed states.

Prerequisite: OPT 412 or PHY 407/408 or permission of instructor.

OPT 552 – QUANTUM OPTICS I*

This course is a continuation of Quantum Electronics I in which the basic theory developed in the first semester is applied to atomic and molecular systems. The topics covered include resonance fluorescence, superfluorescence, saturation spectroscopy, stimulated Raman scattering, multiphoton ionization, and other spectroscopic techniques of current interest.

Prerequisites: OPT 551 or permission of the instructor.

References: Allen and Eberly, Optical Resonance and Two-Level Atoms; Loudon, The Quantum Theory of Light; Current literature.

OPT 553 (PHY 532) – QUANTUM OPTICS II: ATOM-FIELD INTERACTIONS*

Topics covered include the resonant interaction of atoms and quantized fields including spontaneous emission, the Lamb shift, resonance fluorescence, the quantum regression and fluctuations-dissipation theorems, quantum states of the field including squeezed states, Schrodinger cat states and bi-photons, entanglement in atom-field interactions, multiphoton ionization and other strong field effects, and wave packet physics.

Prerequisite: OPT 551/PAS 531 or permission of instructor.

OPT 554 – ADVANCED TOPICS IN QUANTUM OPTICS*

Several professors from the Institute of Optics and the Department of Physics and Astronomy (Alonso, Bigelow, Boyd, Eberly, Howell and Stroud) deliver a two-double lecture sequence as an overview of their current research interests in Quantum Optics. Both experimental and theoretical topics will be discussed. In addition, students will carry out 6-hour laboratory experiments on generation and characterization of single and entangled photons (Lukishova). Grades [S (satisfactory) or E (failure)] will be based on the evaluation of a homework problem set for each section of the course.

Prerequisite: OPT 412 or PHY 407/408 or permission of instructor.

OPT 561 – ADVANCED IMAGING*

This course covers advanced topics in imaging, concentrating on computed imaging, Fourier-transform-based imaging, and unconventional imaging, with emphasis on imaging through aberrating media (particularly atmospheric turbulence), in mathematical depth. Topics are selected from the following: stellar (speckle, Michelson, and intensity) interferometry, wavefront sensing for adaptive optics, phase diversity; pupil-plane lensless laser imaging including 2-D and 3-D digital holography, imaging correlography, and X-ray diffraction imaging; Lyot coronagraphy, synthetic-aperture radar, Fourier telescopy, Fourier-transform imaging spectroscopy, structured-illumination superresolution, optical coherence tomography, extended-depth-of-field imaging, and synthetic-aperture radar. Additional topics suggested by the students are also considered. The course also explores image reconstruction and restoration algorithms associated with these imaging modalities, including phase retrieval, Wiener-Helstrom and maximum likelihood deconvolution, multi-frame blind deconvolution, de-aliasing, side-lobe elimination, and phase-error correction algorithms.

A project plus term paper, exploring an advanced imaging topic in depth, including computer simulations (or laboratory experiments) and implementing the image formation or restoration algorithms, are required.

Prerequisites: OPT 461 (Fourier Optics) or 463.

OPT 564 – THEORY OF OPTOELECTRONIC SYSTEMS*

With a definite systems orientation, we will study topics in diffraction theory, coherence, signal processing, detection theory, digital image processing, spatial and frequency domain filtering, and statistical optics as they apply to systems for imaging, digital cameras and remote sensing. Regular problem sets will be assigned together with request-for-proposal (RFP) topics so that the advanced graduate student will obtain experience in the technical aspects of preparing systems proposals. Students will prepare a final oral presentation (no other final examinations) to brief the class on a topic related to the course material. The course is a continuation of OPT 461-462.

Prerequisites: OPT 461 or 463 is a prerequisite for this course.

Texts: Selected chapters in: 1) Applications of Optical Fourier Transforms by Henry Stark; 2) Image Recovery by Henry Stark; 3) Image Science by J. C. Dainty and R. Shaw; 4) Digital Halftoning by R. Ulichney, as well as selected papers in the literature.

OPT 591 – READING COURSE IN OPTICS

Reading courses can be organized in consultation with a faculty member to cover topics not offered in existing formal courses. A typical format for a 4 credit hour reading course is the following: the supervising faculty member assigns reading material on the topic in question to the student(s), who then meet once or twice per week with the professor and give oral presentations and discuss the materials. No more than 8 credit hours of reading courses can be used towards the 60 credits of courses required for the Ph.D. degree. Reading courses cannot be used to satisfy the advanced course requirement.

Prerequisites: permission of instructor and of Graduate Dean required; special application required

RECENT M.S. THESIS TITLES

2015

Design and Illumination for a Czerny-Turner Spectrometer

On the Measurement of Quantum Entanglement of Photons from a Silicon Microdisk

2016

Estimating Organelle Size Distributions in Single Cell via Angular Scattering: Quantifying Sources of Uncertainty

A Study of Homogeneous and Spherical Gradient-Index Ball Lenses

2017

Effect of Raman Scattering on Soliton Interaction in Optical Fibers

Forward-Adjoint Monte-Carlo Photon Migration Simulation for Spatially Offset Raman Spectroscopy

Broadband High NA Objective Minimizing Total Group Delay Dispersions: A Design Study

Towards Quantitative Phase Imaging Using a Limited-Range Phase Shifter

A Study of Homogeneous and Spherical Gradient-Index Ball Lenses

Coherent Control of a Single Nitrogen-Vacancy Center Spin in an Optically Levitated Nano

Beam Quality Measurement in High Powered Femtosecond Pulsed Lasers

RECENT PhD THESIS TITLES

2008

In Vivo Imaging of the Retinal Pigment Epithelial Cells

Corrected near-infrared Spectroscopy, C-NIRS: An optical system for extracting hemodynamic signatures unique to the brain

Materials for Nonlinear Optics: Semicontinuous Gold Films and Fast Saturable Absorbers

2009

When Nano Meets Bio: Biological Molecule Detection based on Silicon Two-Dimensional Photonic Crystals

Imaging, Scattering, and Spectroscopic Systems for Biomedical Optics: Tools for Bench Top and Clinical Applications

Application of Phase Retrieval to the Measurement of Optical Surfaces and Wavefronts

Phase Diversity for Segmented and Multi-Aperture Systems

Local-Field Effects and Nanostructuring for Controlling Optical Properties and Enabling Novel Optical Phenomena

Integrated Raman and Angular Scattering of Single Biological Cells

Focused Monochromatic Fields

Integrated Raman and Angular Scattering of Single Biological Cells

Micro-processing of Polymers and Biological Material Using High Repetition Rate Femtosecond Laser Pulses

Compound Optical Arrays & Polymer Tapered Gradient Index Lenses

High-Power Single-Frequency Fiber Lasers

Compound Optical Arrays & Polymer Tapered Gradient Index Lenses

Coherence Properties of the Entangled Two-Photon Field Produced by Parametric Down-Conversion

Speckle in a Thick Diffuser

Novel Devices and Applications Based on Micro-processed Optical Fibers

Study of Nonlinear Optical Effects in Silicon Waveguides

Partition Lenses for Extended Depth of Field

Study of Continuous Variable Entanglement in Multipartite Harmonic Oscillator Systems

Fast-Electron Source Characterization and Transport in High-Intensity Laser-Solid Interactions and the Role of Resistive Magnetic Fields

2010

Polarization and Coherence-Engineered Illumination with Applications in Imaging

Generation and Applications of Multi-Partite Multi-Level Quantum Entanglement

Dimpled Planar Lightguide Solar Concentrators

Nanochannel Based Single Molecule Recycling

Methods for Coherent Lensless Imaging and X-Ray Wavefront Measurement

Characteristics of InAs-Based nBn Photodetectors Grown by Molecular Beam Epitaxy

All-fiber Faraday Devices Based on Terbium-doped Fiber

2011

Fundamentals and Applications of Slow Light

Toward an Ultra-Low Energy, CMOS-Compatible Electro-Optical Modulator for On-Chip Optical Interconnects

Nonlinear and Quantum Superresolution and Fast-Light Pulse Distortion Management

Pupil Engineered Confocal Microscopy for Investigation of Turbid Media

Confocal Raman Microscopy for Oral Streptococci

Robust Image-Based Wavefront Sensing

2012

Optical Signal Processing with Reduced Power Consumption

Antenna-coupled Photoemission from Single Quantum Emitters

Nonlinear Photonic Devices with Subwavelength Dimensions

Aberration Correction in Digital Holography

Spatial Coherence Interferometry and its Applications

Studies of Slow Light with Applications in Optical Beam Steering

2013

Interaction of Light with Metallized Ultrathin Silicon Membrane

Secure Opto-Technologies

Transcutaneous Raman Spectroscopy of Bone

Laser Breakdown of Dielectric Materials

Ultra-short Pulse Characterization and Coherent Time-Frequency Light Processing

Image Reconstruction and Discrimination at Low Light Levels

Functional Measurements of Retinal Phototoxicity using Photopigment Densitometry and Adaptive Optics

Femtosecond Laser Processing of Ophthalmic Materials and Ocular Tissues: A Novel Approach for Non-invasive Vision Correction

2014

Design Guidelines for Wavefront Coding in Broadband Optical Systems

Graphene Nanophotonics

Advanced Planar Light Guide Solar Concentrators

Subaperture Conics and Geometric Concepts Applied to Freeform Reflector Design for Illumination

Investigation of Capillary-level Blood Flow Variability Through the Application of Random Access Multiphoton Microscopy to Cerebral Blood Flow Imaging

Optical Methods for the Development of Clinical Photodynamic Therapy Dosimetry

Freeform, ϕ -Polynomial Optical Surfaces: Optical Design, Fabrication and Assembly

The Exploitation of Optical Forces Near Photonic Biosensors in Order to Improve Detection Limits

Photonic Technologies to Enable Slow Light Applications

Advances in Algorithms for Image Based Wavefront Sensing

Gradient-Index Materials, Design, and Metrology for Broadband Imaging Systems

Communicating with Transverse Modes of Light

2015

Spatial and Spectral Brightness Enhancement of High Power Semiconductor Lasers

Design and Fabrication of Large Diameter Gradient-Index Lenses for Dual-Band Visible to Short-Wave Infrared Imaging Applications

Analysis and Suppression of Dark Currents in Mid-Wave Infrared Photodetectors

Ytterbium Fiber Laser Driven, Multi-Wavelength Femtosecond Optical System Operating in the Ultraviolet, Visible, Near-Infrared and Mid-Infrared

In vivo Two-Photon Ophthalmoscopy: Development and Applications

Investigation of the Field Dependence of the Aberration Functions of Rotationally Nonsymmetric Optical Imaging Systems

Polarimetric Scatterometry using Unconventional Polarization States

Quantum information with structured light

Window-Integrated Low Concentration Planar Light Guide Solar Concentrators

2016

Design, Fabrication and Characterization of Polymer Gradient-Index(GRIN) Material

Modulation of Optical Spatial Coherence via Surface Plasmon Polaritons

Practical Invisibility Cloaking

Optical Design with Freeform Surfaces, with Applications in Head-worn Display Design

Optical Metrology by Prescription Retrieval and Transverse-Translation Diversity Phase Retrieval

Optical Coherence Tomography Metrology of Gradient Refractive Index Material and Freeform Optical Surfaces

Ultra-High Efficiency Rare-Earth-Doped Fiber Lasers in the Visible and Infrared

Applications of High-Q Microresonators in Cavity Optomechanics and Nonlinear Photonics

Generation and Detection of Pulsed Terahertz Waves with Laser Induced Microplasmas

Singular Atom Optics via Stimulated Raman Interactions in Spinor Bose-Einstein Condensates

2017

Nanophotonics with Two-dimensional Semiconductors

Surface Conduction in III-V Semiconductor Infrared Detector Materials

Resonance-Enhanced Nonlinear Optical Effects

Dynamic Characterization of Ocular Surface with Thermography and Macroscopic Imaging Ellipsometry

Design of ZnS/ZnSe Gradient-Index Lenses in the Mid-Wave Infrared and Design, Fabrication, and Thermal Metrology of Polymer Radial Gradient-Index Lenses

Applications of Space-time Duality

Improved Time-Lapsed Angular Scattering Microscopy of Single Cells

GRADUATE STUDENTS 2017 – 2018

<u>Name</u>	<u>Degree</u>	<u>Year</u>	<u>Advisor</u>
1. Agnello, Samuel	MS / pt	4	Marciante
2. Ahsan, Amira Sayyidah	PhD	2	Agrawal
3. Aleman-Castaneda, Luis Arturo	PhD	2	Alonso
4. Anthony, Drake Robert	PhD	2	
5. Antikainen, Aku	PhD	5	Agrawal
6. Banet, Matthias	PhD	1	
7. Bergkoetter, Matthew	PhD	8	Fienup
8. Berman, Rebecca	PhD	9	Moore
9. Betts, Susannah	PhD	Leave of Absence	Berger
10. Boccuzzi, Krysta	PhD	5	Marciante
11. Bodell, S. Yvonne	MS	1	
12. Brooks, Daniel	PhD	7	Knox/Ellis
13. Buch, Shaival	PhD	6	Agrawal
14. Bukowski, Leva	PhD	7	Knox / Zuegel
15. Carson, Alexander	MS	1	
16. Chaudhuri, Romita	PhD	3	Rolland
17. Chiang, Wesley	MS	1	
18. Chou, Robert Yuan Ying	MS	2	
19. Choudhary, Saumya	PhD	3	Boyd
20. DiAntonio, Andrew	MS / pt	4	
21. Draham, Robert	PhD	4	Berger
22. Dunn, Kaitlin	PhD	1	
23. Fann, Chun-Hao	MS	1	
24. Farriss, Wesley	PhD	5	Fienup
25. Feng, Guanping	MS	3	Berger
26. Feeks, James	PhD	7	Hunter / Williams
27. Fennig, Eryn	PhD	5	Moore
28. Galabada, Ashan	PhD	3	Brown
29. Gandara Montano, Gustavo	PhD	6	Knox
30. Gao, Shenghan	MS	1	
31. Gao, Yifeng	MS	3	Knox
32. Garriga, Kareem Jamaal	PhD	2	Zhang
33. Gearhart, Sara	PhD	4	Knox
34. Godat, Tyler Christian	PhD	2	Williams
35. Gold Dahl, Meredith Ellen	PhD	2	
36. Goodsell, Jeremy	PhD	1	
37. Graf, Austin Joseph	PhD	2	Lin
38. Granados Baez, Marissa	PhD	2	Cardenas
39. Granger, Charles	PhD	5	Williams
40. Greenbaum, Aaron	MS	1	
41. Guevara Torres, R. Andres	PhD	6	Jesse Schallek / Williams
42. Gutierrez, Rodrigo	PhD	5	Eberly
43. Haddad, Steven	MS / pt	3	Knox
44. Halnon, Theodore	MS	1	
45. Han, Jiashi (Maggie)	MS	2	
46. Han, Songfeng	PhD	6	Choe
47. Hart, Jacob	MS	1	
48. Hassett, Jeremy D	PhD	2	
49. He, Wenhua	MS	3	Alonso
50. Head, Stephen	PhD	8	Brown
51. Holland, Joseph	MS	1	
52. Hrdina, Janet Anne	PhD	2	Yoon
53. Hu, Shaodan	MS	2	
54. Huang, Ruiting	PhD	4	Knox
55. Hughes, William (Billy)	PhD	3	Wicks
56. Iacchetta, Alexander	PhD	7	Fienup
57. Iyer, Arjun	PhD	1	
58. Javid, Usman Ali	PhD	2	Lin
59. Jenkins, Gregory Warren (Greg)	PhD	2	Bromage

60. Ji, Qiuzhi	MS	3	Yoon
61. Jiang, Jingwei	MS	2	
62. Jin, Boya	MS	3	Marciante
63. Jin, Qi	PhD	2	Zhang
64. Joseph, Aby	PhD	5	Williams
65. Kasm, Christina	MS / pt	2	
66. Khan, Obaidullah	MS	1	
67. Khoshooniy, Nataliya	MS	2	
68. Kochan, Nicholas	PhD	1	
69. Lam, Billy	PhD	3	Guo
70. Li, Yunqi	MS	1	
71. Li, Zihao	MS	1	
72. Liang, Kevin	PhD	3	Alonso
73. Liang, Yaoyue	MS	1	
74. Linden, Joseph	MS	1	
75. Ling, Lingwei	MS	1	
76. Liu, Jianzhao	MS	2	
77. Liu, Kang	PhD	7	Zhang
78. Liu, Yuxuan	PhD	1	
79. LoMando, Joseph	MS / pt	2	
80. Lopez-Rios, Raymond	MS	1	
81. Lorenzo, Josie	PhD	1	
82. Lu (Lv), Yiming	MS	2	
83. Luo, Rui	PhD	5	Lin
84. Lyu (Lv), Jiakai	MS	2	
85. MacNeil, James	MS / pt	4	
86. Michalko, Aaron	PhD	4	Fienup
87. Morales, Angel	MS	2	
88. Morgan, Pierce	MS	1	
89. Mukherjee, Arunabh Samrat	PhD	2	Vamivakas
90. Nauriyal, Juniyali	MS	2	
91. Ni, Yunhui (Ken)	MS	1	
92. Nikolov, Daniel	PhD	5	Rolland
93. Niu, Yifan	MS	2	
94. Oloughlin, Trevor	PhD	4	Wicks
95. Ordway, Mark	MS	1	
96. Page, Taylor	MS	1	
97. Paine, Scott	PhD	5	Fienup
98. Papa, Jonathan	PhD	4	Rolland
99. Perez, Jose	PhD	5	Badolato
100. Pettit, Robert	PhD	5	Vamivakas
101. Pietsch, Christopher Mark (Chris)	MS	2	
102. Qi, Rui	MS	4	Alonso
103. Qiu, Liangyu	PhD	3	Vamivakas
104. Reimers Jacob	PhD	6	Rolland
105. Rodriquez, Michael	PhD	1	
106. Sachkouskaya, Olga	MS / pt	1	
107. Savage, Daniel	PhD	8	Knox
108. Schiesser, Eric	PhD	6	Rolland
109. Sharma, Katelynn	PhD	6	Brown
110. Shu, Chi	MS	2	
111. Siddiqui, Mahmudur	PhD	7	Boyd / Zhang
112. Slater, Jonathan Travis (Jon)	MS	2	
113. Smith, Katherine	MS	1	
114. Sonde, Aniruddha Ramakrishna	MS	2	
115. Song, Meiting	PhD	2	Vamivakas
116. Song, Wanyue (Fifi)	MS	2	
117. Steidle, Jessica	PhD	1	
118. Steven, Samuel (Sam)	PhD	3	Bentley / Dubra
119. Takaki, Nicholas	PhD	3	Rolland
120. Tang, Joseph	PhD	3	Fienup
121. Tangari, Martin	PhD	2	Ellis

122. Townley-Smith, Keeley	PhD	2	
123. Vella, Anthony	PhD	6	Brown / Alonso
124. Villegas Burgos, Carlos Mauricio	PhD	1	
125. Vijayakumar, Surendar	MS	1	
126. Wadood, Abdul	PhD	3	Stroud
127. Walters, Sarah	PhD	5	Hunter / Williams
128. Wei, Ran	MS	1	
129. Wiggins, Grayson	MS	1	
130. Will, Scott	PhD	3	Parker / Fienup
131. Wozniak, Kaitlin	PhD	6	Ellis / Huxin
132. Xu, Zhou (Joe)	MS	2	
133. Xu, Di (Charlie)	PhD	5	Rolland
134. Yang, Tianyi	PhD	3	Moore
135. Yang, Qian	MS	1	
136. Yee, Anthony	PhD	5	Moore
137. Yoon, Changsik	PhD	5	Rolland
138. Yuan, Lin	MS	1	
139. Zhang, Shurui	MS	2	
140. Zhang, Yanqi	MS	2	
141. Zhang, Yi	PhD	1	
142. Zhao, Jiapeng	PhD	4	Boyd
143. Zhao, Yang (Estel)	PhD	6	Moore
144. Zhong, Fenghe	MS	3	Ellis
145. Zhou, Yiyu	PhD	3	Boyd
146. Zhu, Huiqing (Ching)	MS	2	

PhD's: 86
MS: 60
Total: 146