COURSE CONTENT FOR PH7015

Academic Year	2022/2023	**Semester**	2
Course Coordinator	Prof. Sun Handong		
Course Code	PH7015		
Course Title	Advanced Optics		
Pre-requisites	For graduate students: No pre-requisites For undergraduate students: PH2301 Physical Optics or equivalent, PH2101 Quantum Mechanics		
No of AUs	4		
Contact Hours	Lecture: 39 hours; Tutorial: 12 hours (3 hr – lecture each week; 1 hr – tutorial each week)		
Proposal Date	6 April 2022		
Suggested Class Size	15		

Course Aims

This course intends to equip you with the fundamental concept and principles of key topics in advanced optics and nonlinear optics. You will gain knowledge in the mechanisms of beam manipulation, generation of ultrafast laser pulses, optical resonators, wavelength conversion, nonlinear absorption etc. Based on this knowledge, you will be able to make both predictions and interpretation in important applications such as in lasers and advanced optics. In conclusion, after taking this course, your problem-solving skills will be sharpened, and you will have the necessary foundation to tackle problems in advanced photonics related research.

Intended Learning Outcomes (ILO)

By the end of this course, you should be able to:

1. use the concepts and methods (such as postulates of ray optics) to analyse and solve problems for practical applications (such as examining various optical components (planar mirrors, parabolic mirrors, elliptical mirrors and spherical mirrors, prisms, beam splitters, lenses and light guides) and their unique properties, and apply the ray equation and paraxial wave equation to graded-index optical components.).
2. apply ray transfer matrix to simple optical components, cascaded optical components and periodic optical systems.
3. examine the solutions of the Helmholtz equation for plane waves and spherical waves.
4. apply the Fresnel approximation to spherical waves to obtain the paraboloidal wave and the validity of the Fresnel approximation and establish the relation between Wave Optics and Ray Optics.
5. apply wave optics to describe polychromatic & pulsed Light.
6. apply Ray-Transfer Matrix to characterize and manipulate Gaussian beams.
7. use optical components to generate Hermite-Gaussian beams, Laguerre-Gaussian beams and Bessel beams.
8. apply Gaussian optics to analyse and design laser resonators
9. apply Maxwell equations to describe and analyse nonlinear optical media.

10. use the concepts and method of wave optics to investigate the origin and manipulation of nonlinear optical processes
11. use the concepts and method of quantum mechanics to investigate the origin and manipulation of nonlinear optical processes
12. apply the principles of Nonlinear Optics to wavelength conversion, THz generation and detection, supercontinuum, intensity related refractive index, photorefractive effect, stimulated Raman scattering etc.

Course Content

Ray Optics
Postulates of Ray Optics
Simple Optical Components
Graded-Index Optics
The Eikonal Equation
Matrix Optics

Wave optics
Postulates of Wave Optics
Monochromatic Waves
Relation between Wave Optics and Ray Optics
Simple Optical Components
Interference
Polychromatic & Pulsed Light

Beam Optics
The Gaussian Beam
Transmission through simple optical components
Transmission through an arbitrary optical component
Hermite-Gaussian beams
Laguerre-Gaussian Beams
Bessel Beams

Resonator optics
Planar-Mirror Resonators
- Resonator Modes;
- Density of Modes
- Losses and Resonance Spectral Width
- Sources of Resonator Loss;
- Photon Lifetime;
- Q-Factor
- Off-axis Resonator Modes

Spherical-Mirror Resonators
- Ray Confinement – confinement conditions, g-parameters, planar, confocal and concentric resonators
- Gaussian Beam – a mode of the spherical mirror resonator
- Resonance Frequencies

- Hermite-Gaussian Modes

Nonlinear Optical Phenomena
Sum- and difference-frequency generation
Parametric versus nonparametric Process
Formal definition of nonlinear optical susceptibility
Anharmonic oscillator model
Properties of the nonlinear susceptibility
Time-domain description of optical nonlinearities

Wave Description on NLO
The Wave Equation for Nonlinear Optical Media
The Coupled-Wave Equations for Sum-Frequency Generation
The Manley–Rowe Relations
Sum-Frequency Generation
Second-Harmonic Generation
Phase-Matching Considerations
Optical Parametric Oscillators
Quasi-Phase-Matching

Quantum-Mechanical Theory of the Nonlinear Optical Susceptibility
Introduction of Perturbation theory
Schrödinger equation calculation of the nonlinear optical susceptibility
Density Matrix Formalism of Quantum Mechanics
Perturbation solution of the Density matrix equation of motion
Density Matrix Calculation of the Linear Susceptibility
Density Matrix Calculation of the Second-order Susceptibility
Density Matrix Calculation of the Third-Order Susceptibility
Electromagnetically Induced Transparency

The Intensity-Dependent Refractive Index
Descriptions of the Intensity-Dependent Refractive Index
Tensor Nature of the Third-Order Susceptibility
Propagation through Isotropic Nonlinear Media
Nonlinearities Due to Molecular Orientation
Thermal Nonlinear Optical Effects
Semiconductor Nonlinearities

Assessment (includes both continuous and summative assessment)

Note: It is advised that Group component and class participation should not be more than 40% and 20% respectively, unless with good justification.

Component	ILO Tested	Weighting	Team/Individual	Assessment Rubrics

1. CA1: Project and presentation	All	50%	Individual	Rubrics marking-Appendix 1
2. CA2: Homework	All	20%	Individual	Point-based marking (not rubric-based)
3. CA3: Mid-term Test	1-8	30%	Individual	Point-based marking (not rubric-based)
Total		100%		

Description of Assessment Components:
Continuous Assessment 1 (CA1): You are required to work on a selected topic. You need to submit a report and do a ~20 minutes presentation.
Continuous Assessment 2 (CA2): You are required to submit assignments.
Continuous Assessment 3 (CA3): You are required to take a midterm test covering the teaching content.

Formative feedback

Formative feedback is given through discussion within tutorial lessons. Feedback is always provided for your response to each question.

Feedback is also given after each midterm on the common mistakes and level of difficulty of the problems.

Feedback is also given during consultant discussion.

Learning and Teaching Approach

Note: Please include and indicate TEL component.

Approach	**How does this approach support you in achieving the learning outcomes?**
Use of Learning Catalytic (tutorial and lecture)	This helps to engage you and serves to identify any prior misconceptions that you may have to better assist you in your learning journey.
Lectures	Warm-up questions will be raised first, followed by lectures that further explains the physics based on the questions. Then wrap-up questions will also be provided.
Tutorial	You will review main concepts learned in lectures with TAs. This

	helps you to digest and understand better.
Homework	The homework comprises standard textbook practice questions that are covered during tutorial.

Reading and References

Textbook:

1. "Fundamental of Photonics", Bahaa E. A. Saleh and Malvin Carl Teich, Wiley-Interscience ISBN: 978-0-471-35832-9
2. "Nonlinear Optics", R.W. Boyd, Academic Press, 3rd Edition, ISBN: 978-0-323-85057-5

Other references:

1. "Quantum Electronics", A. Yariv, 3rd Edition, Wiley, ISBN: 0471609978 (ISBN13: 9780471609971)
2. "The principles of Nonlinear Optics", Y. R. Shen, John Wiley, ISBN: 978-0-471-43080-3

Course Policies and Student Responsibilities

Absence Due to Medical or Other Reasons

If you are sick and unable to attend your class / Mid-terms, you have to:

1. Send an email to the instructor regarding the absence and request for a replacement class and make-up mid-terms.
2. Submit the original Medical Certificate***** or official letter of excuse to administrator.
3. Attend the assigned replacement class (subject to availability) and make-up mid-terms (subject to availability).

***** The medical certificate mentioned above should be issued in Singapore by a medical practitioner registered with the Singapore Medical Association.

Academic Integrity

Good academic work depends on honesty and ethical behaviour. The quality of your work as a student relies on adhering to the principles of academic integrity and to the NTU Honour Code, a set of values shared by the whole university community. Truth, Trust and Justice are at the core of NTU's shared values.

As a student, it is important that you recognize your responsibilities in understanding and applying the principles of academic integrity in all the work you do at NTU. Not knowing what is involved in maintaining academic integrity does not excuse academic dishonesty. You need to actively equip yourself with strategies to avoid all forms of academic dishonesty, including plagiarism, academic fraud, collusion and cheating. If you are uncertain of the definitions of any of these terms, you should go to the academic integrity website for more information. Consult your instructor(s) if you need any clarification about the requirements of academic integrity in the course.

Course Instructors

Instructor	Office Location	Phone	Email
Prof. Sun Handong	SPMS-PAP-04-12	65138083	hdsun@ntu.edu.sg

Industry Participation

Company Name	Description of involvement (e.g., co-curation of course, speaker or instructor), include no. of course hours if known.	Contact Person	Email

Planned Weekly Schedule

Week	Topic	ILO	Readings/ Activities
Week 1	Ray Optics	1, 2	Lecture notes – Ray Optics (I)
Week 2	Ray Optics, Wave Optics	1, 2, 3	Lecture notes – Ray Optics (II), Wave Optics (I)
Week 3	Wave Optics	3, 4, 5	Lecture notes – Wave Optics (II)
Week 4	Beam Optics	6	Lecture notes – Beam Optics (I), Beam Optics (II)
Week 5	Beam Optics, Resonator Optics	7, 8	Lecture notes – Beam Optics (III), Resonator Optics (I)
Week 6	Resonator Optics	8	Lecture notes – Resonator Optics (II)
Week 7	Revision and Midterm test		
Week 8	Nonlinear Optical Phenomena	9	Lecture notes – NLO 1-Fundamental- NLO Susceptibility
Week 9	Wave Description on NLO	10	Lecture notes – NLO 2-wave description of NLO
Week 10	Quantum-Mechanical Theory of the Nonlinear Optical Susceptibility	11	Lecture notes – NLO 3-QM Theory of NLO-I&II
Week 11	Quantum-Mechanical Theory of the Nonlinear Optical Susceptibility	11	Lecture notes – NLO 3-QM Theory of NLO-II&III
Week 12	The Intensity-Dependent Refractive Index	12	Lecture notes – NLO 4- Intensity dependent Refractive Index
Week 13	Project Presentation, Revisions		

Other information(s)

Nil.

Appendix 1: Assessment Criteria for Project Presentation

Criteria	Does not meet standard (0 - 2) (Prestructural)	Nearly Meets Standard (3 – 4) (Unistructural)	Meets Standard (5 - 6) (Multi-structural)	Exceeds Standard (7 - 8) (Relational)	Far Exceeds Standard (9 - 10) (Extended Abstract)
Organization and structure	No clear structure apparent to the presentation. Ideas appear scattered and incoherent. No clear distinction between introduction of background concepts, presentation of main results, and conclusions.	Somewhat structured presentation. Distinct sections such as introduction, results, conclusions, etc. exist, but sections are incomplete and their content scattered / unstructured.	Structured presentation. Distinct sections such as introduction, results, conclusions, etc. exist, and their content is mostly organized. Key conclusions are only apparent after reading the conclusions slide.	Well-structured presentation. Distinct sections such as introduction, results, conclusions, etc. exist, their content is well-organized throughout the presentation, and the key conclusions are clear throughout.	Above standard structured presentation. Content of introduction, results, conclusions, etc. are well organized throughout the entire presentation, presenting content not only comprehensively, but efficiently.
Visual presentation (e.g., design of presentation slides)	Ineffective or no use of presentation technology (e.g., PowerPoint) at all.	Somewhat effective use of presentation technology (e.g., PowerPoint slides). Technology is used but content presented is mostly illegible and disorganized	Effective use of technology (e.g., PowerPoint slides). Information legible and well-organized throughout most of the presentation.	Effective use of technology (e.g., PowerPoint slides). Information legible and well-organized throughout the entire presentation.	Effective and creative use of technology (e.g., PowerPoint slides). Information is not legible but also well-structured. Additional technology/ applets (e.g., PPT animations are being used to further illustrate complex concepts.

Effectiveness of oral presentation and Q&A	Does not communicate ideas effectively. Uses pace, tone, and style ineffectively (monotonous style) and hence loses attention of audience through most of the presentation.	Communicates ideas somewhat effectively. Ideas are mostly comprehensible and communicated somewhat effectively by use of pace, tone, and style. Maintains attention of audience in some parts of the presentation.	Communicates ideas in an effective and understandable manner. Uses pace, tone, and style effectively, most of the time. Catches the interest of the audience through most of the presentation	Communicates difficult or complex ideas in an effective and understandable way. Uses pace, tone, and style effectively all the time, and catches the interest of the audience, or engages the audience throughout	Far exceeds expectations of a graduate student in communicating complex scientific concepts. Uses pace, tone, and style not only effectively but also creatively. Never loses interest and engagement of the audience
Individual Contribution	Little to no effective contribution in the presentation and Q&A portions, displays little knowledge in the chosen topic.	Contribution in the presentation and Q&A portions reflect only one aspect the chosen topic. Limited insights.	Contribution in the presentation and Q&A portions reflect more than one aspect of the chosen topic but does not connect them as a coherent whole. Insights may be unoriginal.	Contribution in the presentation and Q&A portions reflect depth of knowledge not only in an individual segment, but in the whole topic. Insights are thoughtful and analytical.	Contribution in the presentation and Q&A portions reflect coherence, fluency, and depth of knowledge in the whole topic. Comes across as an integral part of the team. Insights are critical and offer new or unique perspectives on the topic.