Course Requisites (if applicable)

Pre-requisites	For graduate students: No pre-requisites For undergraduate students: PH2301 Physical Optics or equivalent, PH2101 Quantum Mechanics
Co-requisites	
Pre-requisite to	
Mutually exclusive to	
Replacement course to	
Remarks (if any)	

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.

Course's Intended Learning Outcomes (ILOs)

Upon the successful completion of this course, you (student) would be able to:

ILO 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.).
ILO 2	apply ray transfer matrix to simple optical components, cascaded optical components and periodic optical systems.
ILO 3	examine the solutions of the Helmholtz equation for plane waves and spherical waves.
ILO 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
ILO 5	apply wave optics to describe polychromatic & pulsed Light.
ILO 6	apply Ray-Transfer Matrix to characterize and manipulate Gaussian beams.
ILO 7	use optical components to generate Hermite-Gaussian beams, Laguerre-Gaussian beams and Bessel beams.
ILO 8	apply Gaussian optics to analyse and design laser resonators
ILO 9	apply Maxwell equations to describe and analyse nonlinear optical media.
ILO 10	use the concepts and method of wave optics to investigate the origin and manipulation of nonlinear optical processes
ILO 11	use the concepts and method of quantum mechanics to investigate the origin and manipulation of nonlinear optical processes
ILO 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

Reading and References (if applicable)

Textbook: “Fundamental of Photonics”, Bahaa E. A. Saleh and Malvin Carl Teich, Wiley-Interscience ISBN: 978-0-471-35832-9 “Nonlinear Optics”, R.W. Boyd, Academic Press, 3rd Edition, ISBN: 978-0-323-85057-5 Other references: “Quantum Electronics”, A. Yariv, 3rd Edition, Wiley, ISBN: 0471609978 (ISBN13: 9780471609971) “The principles of Nonlinear Optics”, Y. R. Shen, John Wiley, ISBN: 978-0-471-43080-3

Planned Schedule

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
1	Ray Optics	1, 2	Lecture notes – Ray Optics (I)	In-person	
2	Ray Optics, Wave Optics	1, 2, 3	Lecture notes – Ray Optics (II), Wave Optics (I)	In-person	
3	Wave Optics	3, 4, 5	Lecture notes – Wave Optics (II)	In-person	
4	Beam Optics	6	Lecture notes – Beam Optics (I), Beam Optics (II)	In-person	
5	Beam Optics, Resonator Optics	7, 8	Lecture notes – Beam Optics (III), Resonator Optics (I)	In-person	
6	Resonator Optics	8	Lecture notes – Resonator Optics (II)	In-person	
7	Revision and Midterm test			In-person	
8	Nonlinear Optical Phenomena	9	Lecture notes – NLO 1-Fundamental- NLO Susceptibility	In-person	
9	Wave Description on NLO	10	Lecture notes – NLO 2-wave description of NLO	In-person	
10	Quantum-Mechanical Theory of the Nonlinear Optical Susceptibility	11	Lecture notes – NLO 3-QM Theory of NLO-I&II	In-person	
11	Quantum-Mechanical Theory of the Nonlinear Optical Susceptibility	11	Lecture notes – NLO 3-QM Theory of NLO-II&III		

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
12	The Intensity-Dependent Refractive Index	12	Lecture notes – NLO 4- Intensity dependent Refractive Index	In-person	
13	Project Presentation, Revisions			In-person	

Learning and Teaching Approach

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.

Assessment Structure

Assessment Components (includes both continuous and summative assessment)

No.	Component	ILO	Related PLO or Accreditation	Weightage	Team/Individual	Rubrics	Level of Understanding
1	Continuous Assessment (CA): Others([group or individual projects/evaluations] Project and Presentation)	All		50	Team	Holistic	Multistructural
2	Continuous Assessment (CA): Others([assignments (e.g. term paper, essay)] Homework)	All		20	Team	Analytic	Multistructural
3	Continuous Assessment (CA): Others([quiz/test] Mid Term test)	1-8		30	Team	Analytic	Multistructural

Description of Assessment Components (if applicable)

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.

NTU Graduate Attributes/Competency Mapping

This course intends to develop the following graduate attributes and competencies (maximum 5 most relevant)

Attributes/Competency	Level
Communication	Intermediate
Creative Thinking	Advanced
Curiosity	Advanced
Learning Agility	Intermediate

Course Policy

Policy (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. On the use of technological tools (such as Generative AI tools), different courses / assignments have different intended learning outcomes. Students should refer to the specific assignment instructions on their use and requirements and/or consult your instructors on how you can use these tools to help your learning. Consult your instructor(s) if you need any clarification about the requirements of academic integrity in the course.

Policy (General)

You are expected to complete all assigned readings, activities, assignments, attend all classes punctually and complete all scheduled assignments by due dates. You are expected to take responsibility to follow up with assignments and course related announcements. You are expected to participate in all project critiques, class discussions and activities.

Policy (Absenteeism)

Absence Due to Medical or Other Reasons

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

Send an email to the instructor regarding the absence and request for a replacement class and make-up mid-terms.

Submit the original Medical Certificate* or official letter of excuse to administrator.

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.

Policy (Others, if applicable)

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