Annexe A: New/Revised Course Content in OBTL+ Format

Course Overview

Expected Implementation in Academic Year	AY2025-2026
Semester/Trimester/Others (specify approx. Start/End date)	Semester 1
Course Author * Faculty proposing/revising the course	Cesare Soci
Course Author Email	csoci@ntu.edu.sg
Course Title	Optical Spectroscopic Techniques
Course Code	PH7014
Academic Units	4
Contact Hours	52
Research Experience Components	

Course Requisites (if applicable)

Pre-requisites	For graduate students: No pre-requisites; For undergraduates: PH3602 Photonics and PHY (PPHY) or PHY (APHY) programme
Co-requisites	
Pre-requisite to	
Mutually exclusive to	
Replacement course to	
Remarks (if any)	

Course Aims

This course aims to teach students optical spectroscopic and imaging techniques that form an important class of non-destructive, state-of-the-art material characterization methods which have been extensively used in traditional bulk and thin film studies as well as in nanoparticles, nano-devices and bio-molecular research. The topics covered include Raman and Brillouin scattering, Fourier transform infrared spectroscopy and imaging, photoluminescence and photo-excitation spectroscopy. A brief introduction to nonlinear optics and basics of lasers will also be given. The course will cover ultrafast spectroscopic techniques, e.g. pump-probe transient absorption, fluorescence up-conversion etc. This module deals with theoretical treatment, instrumentation as well as real examples from original publications of how these techniques can be applied in various fields of research.

Course's Intended Learning Outcomes (ILOs)

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

ILO 1	Formulate and examine interactions between photons with acoustic and optical phonons, and with electronic states in different material systems
ILO 2	Use the interactions to probe various properties of the samples non-destructively
ILO 3	Illustrate the working and design principles of related instrumentation
ILO 4	Analyse and interpret the results of these techniques to study actual samples.

Course Content

Topics of the course include reflection and transmission spectroscopy, Fourier transform infrared spectroscopy, Raman scattering, photoluminescence and ultrafast spectroscopy. A brief introduction to nonlinear optics and the basics of lasers will also be given.

The module deals with theoretical treatment, instrumentation, as well as examples from original research publications, illustrating how these techniques can be applied to various fields of research.

You will choose additional presentation topics based on your interest. Possible topics include, but are not limited to: ellipsometry, circular dichroism, fluorescence anisotropy, magneto-optic Kerr effect, atomic spectroscopy, photoinduced absorption detected magnetic resonance, photoacustic spectroscopy, surface enhanced Raman scattering, hyperspectral/multidimensional imaging, near-field/confocal spectroscopy, fluorescence up-conversion, multi-dimensional femtosecond spectroscopy, femtosecond coherence spectroscopy, Terahertz time-domain spectroscopy, attosecond spectroscopy.

Reading and References (if applicable)

- Optical Spectroscopy, Methods and Instrumentations, Nikolai V. Tkachenko, Elsevier Science, DOI: 10.1016/B978-0-444-52126-2.50048-4
- The photophysics behind photovoltaics and photonics, Guglielmo Lanzani, Wiley-VCH, DOI: 10.1002/9783527645138
- Principles of Fluorescence Spectroscopy, Joseph R. Lakowicz, ISBN 978-0-387-46312-4
- Molecular Fluorescence: Principles and Applications, Bernard Valeur, DOI: 10.1002/3527600248
- Modern Molecular Photochemistry of Organic Molecules, Nicholas J. Turro, V. Ramamurthy and Juan C. Scaiano, ISBN: 978-1891389252
- Laser Spectroscopy 1 (Basic Principles), Wolfgang Demtröder, Springer, Online ISBN: 978-3-540-73418-5
- Laser Spectroscopy 2 (Experimental Techniques), Wolfgang Demtröder, Springer, Online ISBN: 978-3-540-74954-7
- Physics of Nonlinear Optics, G. S. He and S. H. Liu, World Scientific, ISBN: 978-9-810-23319-8
- Handbook of Nonlinear Optical Crystals, V.G. Dmitriev, G.G. Gurzadyan, D.N. Nikogosyan, Springer, ISBN: 3-540-65394-5

Several original research articles will also be provided for reference during the module.

Planned Schedule

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
1	COURSE PRESENTATION AND INTRODUCTION: Optics, spectroscopy, photonics. Light, radiation. Photophysics, photochemistry.	1,2	Suggested books and journal references		
2	LIGHT ABSORPTION. Absorption parameters: transmittance, Beer-Lambert law and absorption coefficient, absorptance, absorption cross-section, absorbance, molar absorption coefficient. Composite samples. Dispersive absorption spectroscopy (UV-Vis): types of spectrophotometers, sources, monochromators, detectors.	1-4	Suggested books and journal references		

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
3	RADIATION-MATTER INTERACTION. Absorption in atoms and molecules: polarization, susceptibility and absorption coefficient. Two-level system: Einstein coefficients, rate equations, absorption cross-section.	1,2	Suggested books and journal references		
4	INFRARED ABSORPTION SPECTROSCOPY. Fourier transform infrared (FTIR) spectroscopy: principles of multiplexing spectroscopy; FTIR spectrometers: spectral range and resolution, advantages over dispersive spectroscopy, IR sources, detectors and beam splitters. Vibrational spectroscopy: IR active molecular transitions, transition strength; examples.	1-4	Suggested books and journal references		

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
5	OPTICAL PROPERTIES OF SOLIDS. Macroscopic fields and Maxwell's equation: general wave equation and complex dielectric functions, Kramers-Kronig relations and sum rules. Lorentz oscillator model: single and multiple resonances, anomalous dispersion. Drude model: plasmas. Optical properties of semiconductors: intraband and interband transitions, excitonic and defect absorption.	1,2	Suggested books and journal references		

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
6	EMISSION SPECTROSCOPY: Principles of photoluminescence: excitation selection rules, intersystem crossing, Franck-Condon principle; non-radiative relaxation: internal conversion, delayed fluorescence; emission: Stokes shift, Kasha's rule, mirror-image rule, Jablonski diagram. Photoluminescence instrumentation and measurements: spectrofluorometer, calibration, quantum yield, emission and excitation spectra, excitation-emission matrix.	1-4	Suggested books and journal references		

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
7	LIGHT SCATTERING. Electromagnetic scattering: elastic and inelastic scattering. Elastic scattering: Rayleigh scattering, Mie scattering, diffuse reflectance and transmittance. Inelastic scattering: Raman scattering: induced dipole moment, selection rules, group frequencies, anisotropy, intensity, instrumentation. Brillouin scattering.	1-4	Suggested books and journal references		
8	MID-TERM test and discussion of results.	1-4	Notes and suggested books/readings		
9	INTRODUCTION TO LASERS. General properties, TEM mode, Gaussian beam, examples of lasers, types of lasers. Working principles of lasers: three and four levels systems, Fabry – Perot resonator, rate equation and threshold, Q-switching, mode-locking, chirp pulse amplification.	3	Suggested books and journal references		

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
10	TIME-RESOLVED SPECTROSCOPY: Population dynamics: thermalization, internal conversion, energy migration. Transient fluorescence: lifetime and quantum yield. Stroboscopic methods: flash-photolysis, TCSPC, streak camera. Transient absorption: ground state bleaching, photoinduced absorption, stimulated emission, IRAV modes. Quasi-static PIA: continuous-scanning differential absorption, lock-in techniques. Ultrafast spectroscopy: transient absorption spectroscopy, fluorescence up-conversion, characterization of short pulses.	1-4	Suggested books and journal references		

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
11	NONLINEAR OPTICS: Second-order nonlinear effects. Three wave interaction. Nonlinear susceptibilities. Optics of uniaxial and biaxial crystals. Phase-matching. Formulas for the calculation of phase-matching angles. Third order nonlinear optical effects: four wave interactions, two-photon absorption, self-focusing, Stimulated Raman scattering, self-phase modulation, self-trapping, Kerr and Pockels effects, photon echo, coherent anti-Stokes Raman scattering (CARS).	1-4	Suggested books and journal references		

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
12	NONLINEAR LASER SPECTROSCOPY: Second order autocorrelation, instrument response function, two-photon fluorescence, pump-probe technique, fluorescence up-conversion. Examples: singlet fission, quasiparticle dynamics in graphene, surface enhanced metal organic frameworks. inhomogeneous and homogeneous broadening, saturation of absorption, hole burning, two-photon laser spectroscopy.TWO-QUANTUM PROCESSES: quantum yield, definition; singlet-singlet and triplet-triplet excitation. Rate equations. Nonlinear transmission/propagation.	1-4	Suggested books and journal references		

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
13	ENERGY TRANSFER: Radiative energy transfer. Non-radiative energy transfer: Dexter ET, triplet-triplet annihilation; Förster ET, rate and efficiency. Application examples: determination of distance, molecular conformation, association reactions, orientation effects; molecular beacons; energy upconversion. CHARGE TRANSFER: Marcus theory: solvent reorganization, transition and reorganization energy, electron transfer rate, inverted region. Application examples: verification of the inverted region; ultrafast electron transfer in bulk heterojunction solar cells.	1-2, 4	Suggested books and journal references		

Learning and Teaching Approach

Approach	How does this approach support you in achieving the learning outcomes?
Teacher-centred + inquiry-based learning	The course adopts a teacher-centred approach to introduce fundamental concepts and working principles of the most common optical spectroscopic techniques and their instrumentation, combined with an inquiry-based learning approach to develop critical thinking and problem-solving skills through preparation and delivery of individual presentations and solution of practical exercises.
Technology-Enhanced Learning (TEL)	Use of Powerpoint with embedded videos and animations, use of technical software for data analysis,use of external databases for data retrieval, use of search engines end electronic libraries for literature search.

Assessment Structure

Assessment Components (includes both continuous and summative assessment)

No.	Component	ILO	Related PLO or Accreditation	Weightage	Description of Assessment Component	Team/Individual	Rubrics	Level of Understanding
1	Continuous Assessment (CA): Presentation(Presentation and Group Discussion)			35		Individual	Holistic	Multistructural
2	Continuous Assessment (CA): Test/Quiz(Mid-term test)			35		Individual	Analytic	Multistructural
3	Continuous Assessment (CA): Assignment(Quiz/Homework)			20		Individual	Analytic	Multistructural
4	Continuous Assessment (CA): Class Participation(Participation)			10		Individual	Analytic	Multistructural

Description of Assessment Components (if applicable)

Presentation and Group Discussion: You will give a presentation on an optical spectroscopic technique of your interest. The instructor will guide you to choose relevant readings and preparing the seminar. The presentation and the following Q&A session will be evaluated by both, your peers and the instructor based on rigour and accuracy of the technical content, background knowledge, examples and references provided, understanding of the topics, clarity of organization and timing of the presentation, as well as audience engagement.

Mid-term Test: An open-book examination on actual or plausible research problems that will test your overall understanding of the topics and your problem-solving skills.

Quiz/Homework: You will be given some quizzes and homework that will test your understanding of specific topics and your problem-solving skills.

Participation: You are expected to actively and respectfully participate in class discussions and seminar peer-evaluation.

Formative Feedback

Feedback is central to this course. You will receive both written and verbal feedback from the course instructor about your mid-term test and presentation. You will also receive peer-evaluations and comments about your presentation in consolidated (anonymized) form at the end of the module.

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
Learning Agility	Advanced
Information Literacy	Advanced
Critical Thinking	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 pre-class readings and activities, attend all seminar classes punctually and take all scheduled assignments and tests by due dates. You are expected to take responsibility to follow up with course notes, assignments and course related announcements for seminar sessions they have missed. You are expected to participate in all seminar discussions and activities.

Policy (Absenteeism)

Absence from class without a valid reason will affect your overall course grade. Valid reasons include falling sick supported by a medical certificate and participation in NTU's approved activities supported by an excuse letter from the relevant bodies.

If you miss a lecture, you must inform the course instructor via email prior to the start of the class.

Policy (Others, if applicable)