

<b>Academic Year</b>	2022-23	<b>Semester</b>	1
<b>Course Coordinator</b>	Prof Shen Zexiang		
<b>Course Code</b>	PH3602		
<b>Course Title</b>	Photonics		
<b>Pre-requisites</b>	(PH2101 and PH2301) or (PH2301 and CY1303)		
<b>No of AUs</b>	4 AU		
<b>Contact Hours</b>	3 hr – lecture; 1 hr – tutorial		
<b>Proposal Date</b>	07 December 2022		

### Course Aims

This course intends to equip you with the fundamental concept and principles of key topics in photonics. You will gain knowledge in the mechanisms of both optoelectronic systems and discrete devices. Based on this knowledge, you will be able to make both predictions and interpretation in important applications such as in optoelectronics and optical communications. In conclusion, after taking this course, your problem-solving skills will be sharpened and you will have the necessary foundation to tackle problems in Photonics research.

### Intended Learning Outcomes (ILO)

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

#### Optics (OP)

1. use physical optics concepts (such as Fresnel's equation, group velocity) to analyse and solve problems for practical applications (such as beam splitters, optical fibres, TIR microscopy and photonic crystals).
2. design anti-reflection optical thin films, spectral filters and high reflective mirrors (DBRs).
3. apply the basic dispersion principles in optical fibers to design high bit-rate optical communication systems.
4. use the birefringent crystals to design photonic devices (such as polarizers, waveplates, optical switch and modulators).
5. use nonlinear optical crystal to realize optical harmonic generation.

#### Optoelectronic Devices (OPD)

6. use the basic properties of semiconductors to design and characterize p-n junctions.
7. apply the pn-junction principles to design homo-junction LEDs and optimize high power heterojunction LEDs.
8. design and characterize semiconductor laser diodes (LDs), especially optimize heterojunction LDs based on the concepts of carrier confinement and optical confinement.
9. design and characterize various photodetectors, including, thermal detectors, pn-junction photodiodes, pin-photodiodes, and avalanche-photodiodes.
10. design and characterize high efficiency photovoltaic devices.

## Course Content

### **Light propagation in media**

Maxwell Equations  
EM wave description of light  
Phase velocity and group velocity  
Fresnel's equations  
Thin film optics  
Photonic crystals

### **Optical Fiber communication**

Plane waveguides  
Intermodal and intramodal dispersions  
Step index optical fibres  
Bit-rate, dispersion, and optical bandwidth  
Graded index fibres  
Attenuation in optical fibers  
Fiber manufacture  
Photonic crystal optical Fibres  
Fiber Bragg grating and application

### **Polarization and Modulation of Light**

Polarization states  
Light propagation in an anisotropic medium: birefringence  
Birefringent Optical Devices  
Optical Activity and Circular Birefringence  
Electro-optic effects and Electro-optic modulator  
Integrated Optical Modulators  
Acousto-Optic Modulators  
Magneto-Optic Effects  
Non-linear Optics & Second Harmonic Generation

### **Semiconductor and LEDs**

Semiconductor concept & energy bands  
Semiconductor statistics  
Extrinsic Semiconductors  
Direct and Indirect Bandgap Semiconductors: E-k  
pn Junction Principles  
LEDs

### **Semiconductor lasers**

Stimulated Emission and Photon Amplification  
Overview of Laser Operation  
Principle of the Laser Diode  
Heterostructure Laser Diodes  
Steady State Semiconductor Rate Equations  
Heterostructure and Quantum well lasers  
Laser amplifiers

### **Photodetectors**

Time Response of Thermal Detectors  
Principle of the pn Junction Photodiodes  
Pin photodiode  
Avalanche photodiode  
Heterojunction photodiodes  
Detector Noise

### **Photovoltaic Devices**

Solar Energy Spectrum  
Photovoltaic Device Principles

pn Junction Photovoltaic I-V Characteristics Series Resistance & Equivalent Circuit Temperature Effects Solar Cell Materials, Devices, and Efficiencies					
<b>Assessment (includes both continuous and summative assessment)</b>					
Component	Course LO Tested	Related Programme LO or Graduate Attributes	Weighting	Team / Individual	Assessment Rubrics
1. Final Examination	All	Competency (1,3,4)	60%	Individual	Point-based marking (not rubric-based)
2. CA1: Project and presentation	All	Communication (1,2,3) Creativity (1,2) Character (1,2,3)	6%	group	Rubrics marking- Appendix 1
3. CA2: Homework	All	Competency (1,3,4) Character (1,2)	18%	Individual	Point-based marking (not rubric-based)
4. CA3: Mid-term Test	OP 1-5	Competency (1,3,4)	16%	Individual	Point-based marking (not rubric-based)
Total			100%		
<b>Formative feedback</b>					
<p>Formative feedback is given through discussion within tutorial lessons. Feedback is always provided for your response to each question.</p> <p>Feedback is also given after each midterm on the common mistakes and level of difficulty of the problems.</p> <p>Feedback is also given during consultant discussion.</p>					
<b>Learning and Teaching approach</b>					
Approach	How does this approach support students in achieving the learning outcomes?				
<b>Use of Learning Catalytics</b> (tutorial and lecture)	This helps to engage you and serves to identify any prior misconceptions that you may have in order to better assist you in your learning journey.				
<b>Lectures</b>	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.				
<b>Tutorial</b>	You will review main concepts learned in lectures with TAs. This helps you to digest and understand better.				

<b>Homework</b>	The homework comprises standard textbook practice questions that are covered during tutorial.
<b>Reading and References</b>	
Text book:	
1. "Optoelectronics and Photonics: Principles and Practices", S. O. Kasap, Prentice Hall ISBN-13: 978-0201610871	
Other references:	
1. "Photonics: Optical Electronics in Modern Communication", A. Yariv & P. Yeh, Oxford University Press. ISBN-13: 978-0195179460	
2. "Optoelectronic Devices", S. D. Smith, Prentice Hall. ISBN-13: 978-0131437692	
3. "Photonics and Lasers: An Introduction", R. S. Quimby, John Wiley and Son. ISBN: 978-0-471-71974-8	
<b>Course Policies and Student Responsibilities</b>	
<i>Absence Due to Medical or Other Reasons</i>	
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 ( <i>subject to availability</i> ) and make-up mid-terms ( <i>subject to availability</i> ).	
* The medical certificate mentioned above should be issued in Singapore by a medical practitioner registered with the Singapore Medical Association.	

<b>Academic Integrity</b>								
<p>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.</p> <p>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 <a href="#">academic integrity website</a> for more information. Consult your instructor(s) if you need any clarification about the requirements of academic integrity in the course.</p>								
<b>Course Instructors</b>								
<table border="1"> <thead> <tr> <th>Instructor</th> <th>Office Location</th> <th>Phone</th> <th>Email</th> </tr> </thead> <tbody> <tr> <td>Prof Shen Zexiang</td> <td>SPMS-03-01</td> <td>63168855</td> <td>zexiang@ntu.edu.sg</td> </tr> </tbody> </table>	Instructor	Office Location	Phone	Email	Prof Shen Zexiang	SPMS-03-01	63168855	zexiang@ntu.edu.sg
Instructor	Office Location	Phone	Email					
Prof Shen Zexiang	SPMS-03-01	63168855	zexiang@ntu.edu.sg					

**Planned Weekly Schedule**

<b>Week</b>	<b>Topic</b>	<b>Course LO</b>	<b>Readings/ Activities</b>
1	Light propagation in media	<b>OP 1</b>	Lecture notes – Chapter 1-I
2	Light propagation in media	<b>OP 1</b>	Lecture notes – Chapter 1-II
3	Optical Fiber communication	<b>OP 2</b>	Lecture notes – Chapter 2-I
4	Optical Fiber communication	<b>OP 3</b>	Lecture notes – Chapter 2-II
5	Polarization and Modulation of Light	<b>OP 4</b>	Lecture notes – Chapter 3-I
6	Polarization and Modulation of Light	<b>OP 5</b>	Lecture notes – Chapter 3-II
7	Revision and Midterm test	<b>OP 1-5</b>	
8	Semiconductor and LEDs	<b>OPD 6</b>	Lecture notes – Chapter 4-I
9	Semiconductor and LEDs	<b>OPD 7</b>	Lecture notes – Chapter 4-II
10	Semiconductor LDs	<b>OPD 8</b>	Lecture notes – Chapter 5-I
11	Semiconductor LDs	<b>OPD 8</b>	Lecture notes – Chapter 5-II
12	Photodetectors	<b>OPD 9</b>	Lecture notes – Chapter 6
13	Photovoltaic Devices	<b>OPD 10</b>	Lecture notes – Chapter 7

**Appendix 1: Assessment Rubrics for Project Presentation**

	<b>Exceptional (5)</b>	<b>Effective (4)</b>	<b>Acceptable (3)</b>	<b>Developing (2)</b>	<b>Unsatisfactory (1)</b>	<b>Score</b>
<b>Significance of Project</b>	Absolutely significant.	Not totally significant but had made <u>non-trivial improvements</u> on existing ideas.	Not totally significant but had made <u>some minor improvements</u> on existing ideas.	Not totally significant but had made <u>modifications</u> (not necessarily improvements) on existing ideas	The project was a direct copy of existing ideas without the slightest modifications or improvements.	<b>/ 5</b>
<b>Content</b>	Provided more than <u>the required</u> information about the project; completely accurate.	Provided <u>required</u> information about the project; mostly accurate.	Provided <u>most of the required</u> information about the project; mostly accurate.	Provided <u>some of the required</u> information about the project; some major errors.	Provided <u>little to none of the required</u> information about the project; major errors.	<b>/ 5</b>
<b>Presentation Skills</b>	Ideas were presented <u>very clearly</u> and visuals were <u>very helpful</u> to audience.	Ideas were <u>presented clearly</u> and visuals were <u>helpful</u> to audience.	Ideas were presented <u>somewhat clearly</u> (i.e. generally able to follow but could be more precise, concise) and visuals were <u>somewhat helpful</u> to audience.	Ideas were <u>mostly unclear</u> and visuals were <u>mostly unhelpful</u> to audience.	Ideas were <u>not presented clearly</u> and visuals were <u>not helpful</u> to audience.	<b>/ 5</b>
<b>Discussions, Q&amp;A &amp; Contributions</b>	<u>Very productive discussions and deep analyses</u> ; critique extends beyond the requirements of the project into new scenarios.	<u>Productive discussions and analyses</u> ; critique of how different aspects of the project interact with each other and their impact on the project.	<u>Adequate discussions and analyses</u> ; critique of more than one aspect of the project, but unable to connect them.	<u>Little discussions and analyses</u> ; critique involved only a single aspect of the project.	<u>No discussions, analyses or critique.</u>	<b>/ 5</b>
					<b>Total:</b>	<b>/ 20</b>

**Graduate Attributes**

**What we want our graduates from Physics and Applied Physics to be able to do:**

Upon the successful completion of the PHY, APHY, PHME, PHMP and PHMS programs, graduates should be able to:

<b>Competency</b>	1	demonstrate a rigorous understanding of the core theories and principles of physics involving (but not limited to) areas such as classical mechanics, electromagnetism, thermal physics and quantum mechanics  [PHMS only] demonstrate a rigorous understanding of the core theories and principles of mathematical sciences involving (but not limited to) areas such as analysis, algebra and statistical analysis
	2	read and understand undergraduate level physics content independently;
	3	make educated guesses / estimations of physical quantities in general;
	4	apply fundamental physics knowledge, logical reasoning, mathematical and computational skills to analyse, model and solve problems;
	5	develop theoretical descriptions of physical phenomena with an understanding of the underlying assumptions and limitations;
	6	critically evaluate and distinguish sources of scientific/non-scientific information and to recommend appropriate decisions and choices when needed;
	7	demonstrate the ability to design and conduct experiments in a Physics laboratory, to make measurements, analyse and interpret data to draw valid conclusions.
<b>Creativity</b>	1	propose valid approaches to tackle open-ended problems in unexplored domains;
	2	offer valid alternative perspectives/approaches to a given situation or problem.

<b>Communication</b>	1	describe physical phenomena with scientifically sound principles;
	2	communicate (in writing and speaking) scientific and non-scientific ideas effectively to professional scientists and to the general public;
	3	communicate effectively with team members when working in a group.

<b>Character</b>	1	uphold absolute integrity when conducting scientific experiments, reporting and using the scientific results;
	2	readily pick up new skills, particularly technology related ones, to tackle new problems;
	3	contribute as a valued team member when working in a group.

<b>Civic Mindedness</b>	1	put together the skills and knowledge into their work in an effective, responsible and ethical manner for the benefits of society.
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