Nanyang Technological University
Division of Physics and Applied Physics

Academic Year	2023/24	**Semester**	1
Course Coordinator	Ranjan Singh		
Course Code	PH4608		
Course Title	Plasmonics and Metamaterials		
Pre-requisites	PH2102 Electromagnetism		
No of AUs	3		
Contact Hours	Lecture: 26 hours; Tutorial: 13 hours		
Proposal Date	14 November 2023		

Course Aims

The course will be interdisciplinary in nature where the students would expand their knowledge base in the areas of nanophotonics, solid state physics, and spectroscopy. The aim would be focused at delivering the current state of the art research topic in the field of plasmonics and metamaterials. This course would encourage undergraduate students to apply their fundamental knowledge of optics and solid state physics into new area of nanophotonics.

Intended Learning Outcomes (ILO)

By the end of this course, you (as a student) would be able to:

Fundamentals (FUNDA)

1. explain the common terms used in the discussion of light-matter interaction;
2. cite examples of the applications of photons at micro-nanoscale in Science and conversely identify the appropriate phenomena and experiments;
3. apply the basic concept of photon coupled with electron resulting in the concept of plasmonics based applications and devices;
4. apply metamaterial concepts to manipulate light in different novel material systems at extremely small scale with ultrafast, and ultra-low power functionalities;
5. apply basic concepts of micro-nanophotonics to solve practical technological problems such as designing ultrasensitive sensor systems;

Plasmonics (PLASMON)

6. apply the concept of light matter coupling in photon-electron systems and derive formulas for the dispersion of surface plasmon polaritons;
7. apply the plasmonics dispersion relationship to to solve the problem of diffraction leading to super focusing enabled by plasmonics;
8. provide a graphical interpretation of coupling schemes and apply the appropriate techniques for momentum matching between free space photons and the surface plasmon polaritons;
9. apply the boundary conditions in Maxwell's equation to solve the exact conditions for the excitation of surface plasmon polaritons;
10. cite examples of the applications of plasmons in Science (such as beyond diffraction limit imaging) and conversely discuss the relevant scientific phenomena and experiments;

Metamaterials (META)

11. explain the need for a completely new set of material system by discussing the limitations in the naturally occurring materials and the fundamental electric and magnetic property of existing natural materials;

12. apply the Maxwell's equations to a new form of electromagnetic materials known as metamaterials and predict their unique properties such as negative refraction and backward wave propagation;
13. cite examples of the applications of metamaterials in Science and engineering and the methods to design application specific metamaterial devices;
14. apply nearest neighbor coupling to illustrate the effective properties of metamaterial resonators in different lattices;

Novel Material Systems in Micro-Nanophotonics (NMS)

15. apply different exotic material systems to design active metamaterial photonic devices for different functionalities;
16. select the appropriate material systems that empower the performance of metamaterials including superconductors, semiconductors and low dimensional material systems; and
17. discuss the physics of novel material system and illustrate its impact on the manipulation of light at micro-nanoscale, specifically in the metamaterial and the plasmonic system.

Course Content

The course would mainly consist of the following topics:

1. Fundamentals of Surface Plasmon Polaritons
2. Dispersion relation and coupling mechanisms
3. Fundamentals of metamaterials: The material that exists beyond the nature.
4. Active Metamaterials
5. Bright and dark mode resonances in metamaterials
6. Near field coupling phenomena: Slow light in metamaterials
7. Superconductor metamaterials
8. Fano resonant high quality factor metamaterials
9. Toroidal dipole: A new class of exotic excitations in metamaterials
10. Microelctromechanical Systems (MEMS) for Active Metamaterials

Assessment (includes both continuous and summative assessment)

Component	Course LO Tested	Weighting	Team/Individual	Assessment Rubrics
1. Research Project Assignment: Simulation + Report	ALL	30%	Individual	See Appendix 1
2. Research Project Assignment: Research Presentation	ALL	20%	Individual	See Appendix 2
3. Mid-term Test 1	FUNDA / PLASMON LO 1-10	25%	Individual	Point-based marking (not rubrics based)
4. Mid-term Test 2	FUNDA / PLASMON	25%	Individual	Point-based marking (not rubrics based)

	LO 1-10, META 11-14/ NMS 15-17			
Total		100%		

Formative feedback

This course would be an interactive course where the inputs of each students would be taken for some of the open questions asked during the class and the tutorial session. The two mid-term tests would be another indicator of how each student is progressing through the course. The research study and presentation would also allow the course instructor to provide feedbacks to the students.

Learning and Teaching approach

Approach	**How does this approach support students in achieving the learning outcomes?**
Lectures	The interactive lecture session where there is ample opportunities for open discussion on the conceptual questions raised in the class allows the student to think critical and share their ideas and concept with the class. This also allows me to get the concepts clearly through the entire class by involving each student there and ensure that the targeted learning outcomes are being achieved
Tutorials	This would allow the students to crack some intriguing problems and thus help me achieve the learning outcome.

Reading and References

Text Book

Plasmonics: Fundamental and Applications, First Edition, Stefan Alexander Maier, Springer, 978-0387331508, 2007

Course Policies and Student Responsibilities

(1) General

Students 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. Students are expected to take responsibility to follow up with course notes, assignments and course related announcements for seminar sessions they have missed. Students are expected to participate in all seminar discussions and activities.

(2) Absenteeism

An important component of the course is the research project presentation where students learn from each other. Both the presenter and the audience contribute to the discussion and learning. Therefore, both research presentation and contribution to class discussion will be assessed [See Appendix 3]. 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. There will be no make-up opportunities for in-class activities.

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

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.

Course Instructors

Instructor	Office Location	Phone	Email
Ranjan Singh	SPMS-PAP-03-13	63162965	ranjans@ntu.edu.sg

Planned Weekly Schedule

Week	Topic	Course LO	Readings/ Activities
1	Introduction to plasmonics	FUNDA 1-5 PLASMON 6	Text book: Chapter 1
2	Coupling mechanisms in plasmonics	PLASMON 6-10	Text book: Chapter 2
3	Maxwell's equations: A review; Introduction to metamaterials	META 11-14	Problem solving in class on the concept of displacement current from Maxwell's equations.
4	Passive and Active Metamaterials	META 11-14	Read lectures/ publications on active metamaterials
5	Bright and dark mode resonances in metamaterials	META 12, Mid-Term 1 (1.5 hrs)	Reads journals on bright and dark mode resonances in metamaterials and plasmonics
6	Near field coupling in metamaterials	META 13	Lecture notes/ Journal publication
7	Fano resonances in metamaterials	META 12-14	Lecture notes
8	Superconductor Metamaterials	NMS 15-17	Lecture notes/ Journal publications
9	Toroidal Metamaterials	META 14 NMS 15-17	Lecture notes/ Journal Publication
10	MEMS Metamaterials	NMS 16, Mid-Term 2 (1.5 hrs)	Lecture notes/ Journal Publications
11	Review of plasmonic metamaterials	FUNDA 1-5 PLASMON 6-8	Text book/ Lecture notes
12	Review of metamaterials	META 11-14	Lecture Notes
13	Review of Course: Final takeaways	FUNDA/PLASMON 1-10/ META 11-14/ NMS 15-17	Text book

Appendix 1: Assessment rubrics for Research Project Assignment (30%): Simulation project and report

Project Report (Adapted from https://www.cte.cornell.edu/documents/Science%20Rubrics.pdf), adapted to include ideas of SOLO taxonomy)

Criteria	**Does not meet standard (0 - 2) (Prestructural)**	**Nearly Meets Standard (3 – 4) (Unistructural)**	**Meets Standard (5 - 6) (Multistructural)**	**Exceeds Standard (7 - 8) (Relational)**	**Far Exceeds Standard (9 - 10) (Extended Abstract)**
Problem or Research Statement	Unclear and inaccurate or illogical statement.	Somewhat unclear or unable to accurately portray the problem.	Mostly clear and accurately communicated for the focused reader.	Clearly and accurately communicated, and gives most background or context and motivation.	Comprehensive description and overview of the topic, satisfactory to the expert reader.
Correctness and appropriate description of the physics	Incorrect or inappropriate use of physics in most areas.	Mostly correct and appropriate use of physics. But flawed in parts.	Correct and appropriate use of physics, with some clarity on assumptions, approximations, experimental techniques, and derivations.	Correct and appropriate use of physics, with assumptions, approximations, experimental techniques, and derivations that are accurate and detailed.	Correct and appropriate use of physics, with assumptions, approximations, experimental techniques, and derivations that are accurate and detailed. With further details of their limitation and how these could be improved.
Development of Ideas	Does not clearly introduce the topic. Does not establish or maintain focus on the topic.	Introduces the topic. Somewhat maintains focus on the topic, but lost in some parts. Development of some of the ideas.	Introduces the topic clearly. Maintains focus on the topic. Development of and/or connection between ideas are clear and correct.	Introduces the topic clearly and creatively. Maintains clear focus on the topic throughout. Development of and connection between ideas are clear and correct.	Introduces the topic clearly and creatively. Maintains clear focus on the topic throughout. Development of and connection between ideas are clear and correct. Gives detailed outlook on how ideas could be further developed in the future.
Use of secondary material	Improper and unclear citations and attribution of	Partly proper and clear citations and attribution of	Proper, accurate and clear citations and attribution of	Proper, accurate and clear citations and	Proper, accurate and *complete* referencing and
(references and citations)	others' work in most part, and with major errors.	others' work, with some errors.	others' work in most parts.	attribution of others' work throughout.	attribution of others' work in the field.

Appendix 2: Assessment Rubrics for Research Project Assignment (20%): 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 fourth-year 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.