

Academic Year	2018	Semester	2
Course Coordinator	S.N. Piramanayagam		
Course Code	PH4414		
Course Title	Introduction to Spintronics		
Pre-requisites	PH2102 & PH3102 or equivalent or approval by school		
No of AUs	4		
Contact Hours	52 (39 hours of Lecture, 13 hours of Tutorial)		
Proposal Date	15 November 2018		

Course Aims
<p>This course aims to introduce magnetism and spintronics technologies, which are useful in hard disk drives and the emerging field of magnetic random access memories. The course has three parts. The first part provides the fundamentals of magnetism. The second part discusses the basics and recent developments of magnetic recording. The third part discusses the basics and recent developments of spintronics, including magnetic random access memory. The course is suitable for students of Physics, Materials Science and Electrical Engineering (Microelectronics). The course equips you with relevant skills to enable you to find jobs in the electronics industry.</p>
Intended Learning Outcomes (ILO)
<p>By the end of this course, you should be able to:</p> <ol style="list-style-type: none"> 1. Explain the difference between ferromagnetic material and other types of materials 2. Explain what type of material properties are required for storing information 3. Calculate the design parameters of hard disk storage technology 4. Apply the design principle of a magnetic random access memory to achieve desired performance 5. Explain the material properties required for a memory 6. Describe the roles and utilization of MRAM layers in various designs 7. Explain the physics behind magnetic random access memory 8. Design a stack of recording medium for hard disk drives 9. Design a stack of layers for magnetic random access memory 10. Apply known properties of materials used in memory and storage devices to determine their utility in MRAM and/or hard disk drives 11. Explain newly emerging technologies for storing huge amount of information 12. Explain newly emerging topics in Spintronics 13. Summarize and critically analyse research papers 14. Present findings from the literature review
Course Content

S/N	Topic	Lecture Hours	Tutorial Hours
1	Fundamentals of magnetism <ul style="list-style-type: none"> • Introduction to the course • Magnetism in Electrodynamics perspective • Atomic magnetic moment • Exchange interaction • Ferromagnetic, ferromagnetic materials • Antiferromagnetic materials • Hysteresis loops • Domains and domain wall motion • Various types of anisotropies • Hard and Soft magnetic materials 	6 hours	2
2	Magnetic Recording Technology <ul style="list-style-type: none"> • Storage concepts • Magnetoresistance (MR) • Spin-valve sensors • Magnetic recording medium • Noise Reduction Techniques • Layered configuration of medium • Thermal Stability and Media Trilemma • Emerging Recording Technologies 	12 hours	4
3	Magnetic Random Access Memory <ul style="list-style-type: none"> • Overview of MRAM • Magnetoresistance • Various types of MRAM • Spin-Torque Switching • Challenges of MRAM • Emerging Concepts for Storing Big Data • Spintronics for other applications 	21 hours	7

Assessment (includes both continuous and summative assessment)

Component	Course LOs Tested	Graduate Attributes	Weighting	Team/Individual	Assessment rubrics
1. Final Examination	1-12	A1-A4, B2,	50%	Individual	
2. Continuous Assessment 1 (CA1): Mid-term Test	1-8	A1-A4, B2,	20%	Individual	
3. CA2: Online assignment	1-12	A1-A4,	10%	Individual	
4. CA3: Presentation	13,14	A5-A6, C1-C3, D2	20%	Individual	Appendix 1
Total			100%		

Formative feedback

1. Through the online assignment, I will regularly monitor and let you know your progress in learning
2. In the tutorial, I will give questions to test your understanding and give you feedback.

3. I will also observe how you perform in mid-term test and give you feedback.
4. In addition, I will go through your presentations, assess your presentation and give you feedback about your understanding.
5. Moreover, I will give regular feedback during the classes.

Learning and Teaching approach

Approach	How does this approach support students in achieving the learning outcomes?
Lecture	The lectures introduce condensed information on the subject, which cannot be found in text books or on the web. Class room lectures help you to achieve learning outcomes 1-12
Literature search	You would need to find relevant research articles using library database, thus addressing outcome 13
Presentations	Here, you are given a topic. You would need to go through literature and present a topic. This helps improve your self-learning and communication skills. Learning outcome 14 is achieved in this method

Reading and References

1. Developments in Data Storage: Materials Perspective, S.N. Piramanayagam and Tow C. Chong, IEEE-Wiley Press, 2011 ISBN: 9781118096833 (electronic bk.)
2. Introduction to Magnetism and Magnetic Materials, D. Jiles, Chapman & Hall, 1998 ISBN:148223887X 9781482238877

Course Policies and Student Responsibilities

Students are expected to do the online assignments and participate in the seminar discussions and activities.

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
S.N. Piramanayagam	SPMS-PAP-05-05	65923148	prem@ntu.edu.sg

Planned Weekly Schedule

Week	Topic	Course LO	Readings/ Activities
------	-------	-----------	----------------------

1	Introduction	1	Lecture Notes
2	Magnetism	1	Lecture notes, book by David Jiles
3	Storage concepts	2	Lecture notes, review paper and book
4	Magnetic Recording medium, Noise reduction techniques,	3	
5	Layered configuration of medium, Thermal Stability, Emerging recording technologies	8,10	
6	Read sensors based on giant magnetoresistance & tunnel magnetoresistance	3,5	
7	Overview of MRAM	4,5	
8	Various types of MRAM	6,7,9	
9	Spin-Torque Switching	7,10	Lecture notes, review papers and books
10	Challenges of MRAM	9,10	
11	Emerging Concepts for Storing Big Data	11	
12	Spintronics for other applications	12	
13	Seminars	13,14	Self-reading on papers provided by lecturer

Appendix 1: Assessment Criteria for Rubrics

1. Online assessment gives the students an opportunity to recollect the lecture and reinforce their understanding. This is based on answering multiple choice questions (MCQ)
2. Mid-Term test will be a mixture of MCQ and long-answer questions. The student will be tested on magnetism and magnetic recording. The student must be able to provide clear and correct answers.
3. The following is the criteria for seminar.

Criteria	Standards		
	Fail standard (8 marks and below)	Pass standard (9-14 marks)	High standard (15-20 marks)
Seminar and presentation (LO 12-14)	You demonstrated no or poor understanding on the paper that you have read. Not able to answer questions	You seem to have read the paper, understood it reasonably well by answering a few questions.	Good presentation Well prepared slides. Able to answer most of the questions accurately.

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 and PHMA programs, graduates should be able to:

Competency	A1	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;
		[PHMA 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;
	A2	read and understand undergraduate level physics content independently;
	A3	make educated guesses / estimations of physical quantities in general;
	A4	apply fundamental physics knowledge, logical reasoning, mathematical and computational skills to analyse, model and solve problems;
	A5	develop theoretical descriptions of physical phenomena with an understanding of the underlying assumptions and limitations;
	A6	critically evaluate and distinguish sources of scientific/non-scientific information and to recommend appropriate decisions and choices when needed;
	A7	demonstrate the ability to design and conduct experiments in a Physics laboratory, to make measurements, analyse and interpret data to draw valid conclusions.

<i>Creativity</i>	B1	propose valid approaches to tackle open-ended problems in unexplored domains;
	B2	offer valid alternative perspectives/approaches to a given situation or problem.

<i>Communication</i>	C1	describe physical phenomena with scientifically sound principles;
	C2	communicate (in writing and speaking) scientific and non-scientific ideas effectively to professional scientists and to the general public;
	C3	communicate effectively with team members when working in a group.

<i>Character</i>	D1	uphold absolute integrity when conducting scientific experiments, reporting and using the scientific results;
	D2	readily pick up new skills, particularly technology related ones, to tackle new problems;
	D3	contribute as a valued team member when working in a group.

<i>Civic Mindedness</i>	E1	put together the skills and knowledge into their work in an effective, responsible and ethical manner for the benefits of society.
--------------------------------	----	--