Engineering Faculty Document No. 86-23
December 5, 2022

To: The Engineering Faculty

From: The Faculty of the School of Materials Engineering

Re: New graduate course – **MSE 58500– Magnetic Materials: Physical Properties and Applications:**

The Faculty of the School of Materials Engineering has approved the following new graduate course as of December 5, 2022 (see attached document of course description). This action is now submitted to the Engineering Faculty with recommendation for approval.

MSE 58500– Magnetic Materials: Physical Properties and Applications

Sem 1 or 2, Class 3, Credit Prerequisites: Junior or higher standing in Engineering or Science

This course provides an introduction of the basic physical and structural properties that determine the functionality of magnetic materials and devices. Starting from basic concepts on the physics of magnetism, materials synthesis and device fabrication, the functional requirements of magnetic materials for diverse applications will be discussed. Magnetic material properties depend on the electronic structure of the constituent elements and their electronic interactions. These interactions are controlled by their atomic arrangement, microstructure, defects, and strain fields that distort the local atomic order. Furthermore, the role of reduced dimensionality on the physical and functional properties of nanoscale materials will be discussed.

This course was taught under a temporary course number in Fall of 20 and Fall 22, with enrollments of 5 and 10 respectively. The course will be a part of emphasizing materials used in microelectronics and semiconductor systems.

____
David Bahr, Head
School of Material Engineering

Proposal for New Graduate Level Course for Academic Review
MSE 58500– Magnetic Materials: Physical Properties and Applications

Note: The detailed course proposal is intended for academic review by the appropriate area committee of the Graduate Council. It supplements the Form 40G that is intended for administrative review of the Graduate School and Registrar.

TO: Purdue University Graduate Council

FROM: Faculty Member: **Ernesto E. Marinero**
Department: School of Materials Engineering
Campus: West Lafayette

DATE: October 12, 2022

SUBJECT: Proposal for New Graduate Course

MSE 58500– Magnetic Materials: Physical Properties and Applications

2 lectures per week (Tue, Thu), 75 minutes each

1. Course Description

This course provides an introduction of the basic physical and structural properties that determine the functionality of magnetic materials and devices. Starting from basic concepts on the physics of magnetism, materials synthesis and device fabrication, the functional requirements of magnetic materials for diverse applications will be discussed. Magnetic material properties depend on the electronic structure of the constituent elements and their electronic interactions. These interactions are controlled by their atomic arrangement, microstructure, defects, and strain fields that distort the local atomic order. Furthermore, the role of reduced dimensionality on the physical and functional properties of nanoscale materials will be discussed.

2. Justification for the Course

2.1 Justification of the need for the course

The course is designed for senior undergraduate and graduate students from Materials, Mechanical, Chemical, Biomedical and Electrical engineering schools as well as Physics and Chemistry departments who are interested to learn how magnetic materials for diverse applications such as electric power generation and transmission, transportation electrification, microelectronics, biomedical and industrial applications, are designed and optimized by controlling the atomic level interactions of the constituent elements, their crystalline and magnetic order as well as their synthesis and post-processing conditions. The course will complement the topics covered in various courses such as MSE 370 (Electrical, Optical and Magnetic Properties of Materials), MSE 502 (Defects in Solids) MSE 523 (Physical Ceramics), MSE 548 (Deposition Processing of Thin Films and Coatings), MSE 597 (Solid State Materials), ECE 50653 (Fundamentals of Nanoelectronics), ME 51700 (Micro/Nanoscale Physical Processes, s), PHYS 430- Electricity and Magnetism I (Honors), PHYS 545-Solid-state Physics.

Currently there is no permanent materials engineering course that provides comprehensive understanding on how the physics of magnetism, the atomic and structural order, the role of defects and the synthesis methods and fabrication techniques determine the desired magnetic material properties for diverse applications.

2.2 Justification that course will be taught at a graduate level

MSE 59000 will be taught at the graduate level. The course builds on undergraduate topics (MSE 330, 335, 370) and complements material in MSE 502, 523, 548 and 575. Students taking this course will be expected to have a basic background of the structure of materials, electronic, mechanical, optical, magnetic properties, materials synthesis, and characterization.

2.3 Justification for online delivery

This course will be of of interest to students pursuing distance learning or online Masters degrees in engineering disciplines including the recently announced Interdisciplinary Masters in Microlectronics and Semiconductors. Engineers in the magnetic materials and device industry sectors will benefit greatly from this course.

3. Learning Outcomes and Methods of Assessment

3.1 Learning Outcomes

By the end of the course, students are expected to (a) understand the physical origins of magnetism and magnetic material properties, (b) establish the correlation between materials magnetic properties and their crystalline order, microstructure, the role of defects and secondary phases, (c) explain how synthesis and post-processing techniques are used to design and optimize magnetic materials, and (d) apply the course learnings to optimize magnetic material properties and functionality for diverse applications.

3.2 Assessment Methods

Assessment will be achieved through three components: (a) class participation and online contributions to weekly topics posted by the instructor on Brightspace, (b) open book quizzes to evaluate understanding of lecture material and the student ability to conduct independent research in answering the questions, topics and case studies comprising the quizzes, (c) execution and contributions to semester-long team research project assignments on magnetic material applications selected by the team. The research project final reports (in lieu of a final exam) will be a topical review. The technical quality of the report and the student contributions (assessed by team members) will determine the grade obtained.

3.3 Final Grading Criteria

Grading is based on a fixed scale that is familiar to advanced undergraduate and first- and second-year graduate students. The breakdown will be:

- Classroom participation and online discussion contributions 15%
- Quizzes 30 - 40%
- Research Project Execution and Contributions 40 - 50%

Final grades may be adjusted depending on class performance, quality of contributions to online discussions and the research project.

Grading Scale: In this class grades reflect the sum of your achievement throughout the semester. You will accumulate points as described in the assignments portion above, with each assignment graded according to a rubric. At the end of the semester, final grades will be calculated by adding the total points earned and translating those numbers (out of 100) into the following letters (there will be no partial points or rounding).

- A+: 97 - 100
- A: 93 - 96
- A-: 90 - 92
- B+: 87 - 89
- B: 83 - 86
- B-: 80 - 82
- C+: 77 - 79
- C: 73 - 76
- C-: 70 - 72
- D+: 67- 69
- D: 65 - 66
- D-: 60 - 64
- F: 59 or below

3.4 Methods of Instruction

Lectures: in-class, pre-recorded lectures (if necessary) and invited guest speakers will be used to achieve the learning outcomes. This will include presentation of foundational concepts and focus topics via slides and blackboard writing, as well as presentations of recently reported scientific and engineering studies of magnetic materials pertinent to the team research projects. All instructional material for the course will be posted in Brightspace.

3.5 Prerequisite(s)

Graduate Standing OR MSE 330 and MSE 370

4. Course Instructor

Ernesto E. Marinero, Professor MSE.

Prof. Marinero expertise on magnetism, magnetic materials and devices stems from his research career at the IBM Almaden Research Center in San Jose CA, where he led materials science-based programs that led to the successful development of ultra-high density magnetic storage and novel spintronic devices. His research at Purdue focuses on magnetic materials includes spin-based computing (Magnonics) and magneto-plasmonics. Magnonics takes advantage of dissipationless magnon transport and wave-based computing to develop new computer architectures. Magneto-plasmonics effort exploits the coupling of spins and plasmon to manipulate the spin orientation in fs time scales to generate ultrafast memory devices and topologically protected photon and magnonic crystals.

5. Course Outline:

1. Atomic origins of magnetism
2. The magnetic hysteresis loop and magnetization dynamics
3. Magnetic materials classification and magnetometry
4. Magnetic exchange coupling
5. Magnetic anisotropy and atomic composition and order
6. Synthesis of magnetic materials
7. Structural characterization of magnetic materials
8. 1D – 3D magnetic materials and phenomena
9. Magnetic materials for microelectronics, spintronics, computing and sensing applications
10. Magnetic materials for power generation and transmission
11. Magnetic materials for renewable energy and transportation electrification
12. Magnetic materials for biomedical applications
13. Emergent cross-over fields in magnetism

6. Reading List

Suggested Textbooks:

Purchase of the first two textbooks is encouraged but is not mandatory.

a) **Introduction to Magnetic Materials,** Second Edition, B. D. Cullity and C.D. Graham, Wiley, Print ISBN:9780471477419|Online ISBN:9780470386323 |DOI:10.1002/9780470386323. Provides foundational concepts in magnetism and magnetic materials.
b) **Magnetism and Magnetic Materials,** J.M.D. Coey, Cambridge University Press, ISBN-13 978-0-511, excellent book, available as an e-book.
c) **Magnetic Materials: Fundamentals, Products, Properties, Applications,** Rainer Hilzinger and Werner Rodewald, Ed. Vacuumschmelz GmbH & Co, Germany, ISBN 978-3-89578-352-4, this book provides a good industry perspective.
d) **Nanoscale Magnetic Materials and Applications**, J. P. Liu, E. Fullerton, O. Guttfleisch and D. J. Sellmyer, Editors, Springer, ISBN 978-0-387-85598-1 e-ISBN 978-0-387-85600-1

Additional topical reading:

a) Review on spintronics: principles and device applications, Hirohata et al., JMMM, 509 (2020) 166711.
b) Perspectives on Permanent Magnetic Materials for Energy Conversion and Power Generation, Lewis L.H and Jimenez-Villacorta F., Metallurgical and Materials Transactions, 44A (2013) S2.

c) Biological Magnetic Materials and Applications, T. Matsunaga, T. Tanaka and D. Kisailus, Editors, Springer, ISBN 978-981-10-8069-2 (eBook).
d) Development of Processes and Characterization of Ferromagnetic Materials for Manufacture of Transformer Core and Motors for Higher Efficiency, Raju, R. and Praveen, J., Materials Today: Proceedings 5 (2018) 4016.
e) **Journal publications**: selected review papers will be posted by Prof. Marinero on Brightspace and independent literature review by students on topics covered during class.

7. Course Syllabus

MSE 59700: Magnetic Materials: Fundamental Properties, Structure-Property Relationships
Fall Semester, 2022

Lectures: Tuesdays and Thursday 3:00pm – 4:15 pm, ARMS 3315

Instructor: Professor Ernesto E. Marinero, Office: WANG 4510, eemarinero@purdue.edu

Course description
This course provides an introduction of the basic physical and structural properties that determine the functionality of magnetic materials and devices. Starting from basic concepts on the physics of magnetism, materials synthesis and device fabrication, the functional requirements of magnetic materials for diverse applications will be discussed. Magnetic material properties depend on the electronic structure of the constituent elements and their electronic interactions. These interactions are controlled by their atomic arrangement, microstructure, defects, and strain fields that distort the local atomic order. Furthermore, the role of reduced dimensionality on the physical and functional properties of nanoscale materials will be discussed.

Topics
Physical origins of magnetism: from atoms to bulk magnetic materials
Structure-property relationships of magnetic materials
Synthesis and characterization of magnetic materials
Magnetic materials for renewable energy and transportation electrification
Magnetic materials for microelectronics, computing, and sensor applications
Magnetic materials for biomedical applications
Emerging fields in magnetism, magnetic materials, and convergent technologies

Suggested Textbooks:
Introduction to Magnetic Materials, Second Edition, B. D. Cullity and C.D. Graham, Wiley, Print ISBN:9780471477419 |Online ISBN:9780470386323 |DOI:10.1002/9780470386323.
Magnetism and Magnetic Materials, J.M.D. Coey, Cambridge Univ. Press, ISBN-13 978-0-511,
Magnetic Materials: Fundamentals, Products, Properties, Applications, Rainer Hilzinger and Werner Rodewald, Ed. Vacuumschmelz GmbH & Co, Germany, ISBN 978-3-89578-352-4.

Nanoscale Magnetic Materials and Applications, J. P. Liu, E. Fullerton, O. Guttfleisch and D. J. Sellmyer, Editors, Springer, ISBN 978-0-387-85598-1 e-ISBN 978-0-387-85600-1

Course Organization

The class meets twice a week for 2 lectures lasting 75 minutes (3:00 – 4:15 pm). To enhance the concepts discussed in the lectures, the instructor post on Brightspace Discussion Forum weekly topics pertinent to the material presented in the lectures. To respond to the posted topics, students need to conduct independent literature research to respond to the topics and contribute to discussion strings initiated by their peers. Open book quizzes will be given periodically to evaluate student progress and their ability to conduct independent research in answering the questions, topics and case studies comprising the quizzes. Students will participate in a semester-long team research projects on magnetic materials applications selected by the team.

Grading policy

- Classroom participation and online discussion contributions 15%
- Quizzes 30 - 40%
- Research Project Execution and Contributions 40 - 50%

Prerequisites

Students should have a basic background of the structure of materials, electronic, mechanical, optical, magnetic properties, materials synthesis, and characterization.