UE Nanomagnetism, spintronics

Level
Baccalaureate +5

ECTS
3 credits

Component
UFR PhITEM (physique, ingénierie, terre, environnement, mécanique)

Semester
Automne

- **Teaching language(s):** English
- **Open to exchange students:** Yes
- **Code d'export Apogée:** PAX9NPAF

Presentation

Description

Teachers : Hélène Béa (UGA) Vincent Baltz (CEA)

Objectives :

This lecture is an introduction to the field of nanomagnetism, also providing basic ideas in spin electronics. The continuous progress in patterning, instrumentation and simulation over the past decades has made possible the investigation of low-dimensional magnetic elements such as thin films and nanostructures. New properties arise in these due to the reduction of dimensionality and the ability to built artificial stackings. Beyond the development of fundamental knowledge, these bring new functionalities of interest for technology. Such is the case for Giant Magneto-Resistance, an effect combining together electronics and magnetism, as the resistance of a stacked device may strongly depend on the arrangement of magnetization in the sub-stacks. It was discovered in the mid 80's and led to the Nobel prize in Physics in 2007, and enters many applications such as magnetic sensors and encoders, data storage and processing, bio- and heath devices. Grenoble has played an active role in the development and magnetism from fundamentals to permanent magnets and currently spin electronics. Several large laboratories and research teams are devoted to these, with links to companies in Information/Communication technology or Health / Biology.

The lecture remains mostly at the phenomenological and materials level, and does not cover fundamental aspects of magnetism related to quantum mechanics and magnetism in compounds. The first chapter provides general notions about magnetism such as fields and moments, units and magnetostatics. The second chapter focuses on ground-state effects arising when the dimensions of a magnetic system are reduced, either as a thin film or nanostructure. These properties differ from those known at the macro scale, and thus must be taken into consideration when designing systems with nanometer dimensions. The third chapter pertains to magnetization processes, which means how a system reacts against a magnetic field. This aspect is crucial, as it determines how one is able to address a material or device. The fourth chapter considers high-speed magnetization processes, which happen to involve precessional processes. This aspect is crucial for current developments in spintronics for data storage and processing, where GHz operation may be required. Finally the fifth chapter will shortly present the basic phenomena arising coupling electronic transport and magnetism, both in terms of magnetoresistance (the arrangement of magnetization affects the resistance of a device) and magnetization actuation through spin-polarized transport (for example, programming a magnetic cell through a current flowing directly through the cell).

Program :

Chapter 1 : *Reminders on magnetism*

1. Magnetic induction, Maxwell equations and their consequences
2. Magnetic induction vs magnetic field
3. Magnetic materials
4. Units in magnetism
5. Magnetic energies
6. Bloch domain wall
7. Magnetometry and magnetic imaging

Chapter 2 : *Magnetism and magnetic domains in low dimensions*

1. Magnetic ordering in low dimensions
2. Magnetic anisotropies in low dimensions
3. Domains and domain walls in thin films
4. Domains and domain walls in nanostructures

Chapter 3 : *Magnetization reversal*

1. Macrospin, uniform magnetization
2. Magnetization reversal in nanostructures
3. Magnetization reversal in extended systems (thin films)

Chapter 4 : *Precessional dynamics of magnetization*

1. Ferromagnetic resonance and Landau-Lifshitz-Gilbert equation

2. Precessionnal switching of macrospin by magnetic field

3. Precessionnal motion of domain walls by magnetic field

4. Extra-torques in the presence of current: impact on precession

Chapter 5 : *Spintronics and beyond*

1. Brief overview of the field of spintronics and its applications
2. First notions to describe electron and spin transport - CIP-GMR, AMR
3. Spin accumulation - CPP-GMR
4. Transfer of angular momentum - STT
5. Berry curvature, parity and time symmetries - QHE, AHE

6. Brief non-exhaustive introduction to current topics
7. Exercices - AMR, ISHE
Bibliography :

Solid state physics textbook (Ashcroft/Mermin, Kittel,…)
Magnetism: Fundamentals (I), Tremolet de Lacheisserie (2004)
Magnetism and Magnetic Materials, J. M. D. Coey (2010)
Nanomagnetism and spintronics, T. Shinjo (2009)
Lecture notes of Olivier Fruchart
The basics of electron transport in spintronics, EDP Sciences, V. Baltz (2023)

Course parts

UE Nanomagnetism, spintronics - CMTD	Lectures (CM) & Teaching Unit (UE)	24h

Recommended prerequisites

Electrodynamics, Statistical physics, basic mathematical skills.

Period : Semester 9

Useful info

Place

- Grenoble

Campus

- Grenoble - University campus