PHYS-510

Spintronics : basics and applications

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Cursus	Sem.	Type
Ing.-phys	MA2, MA4	Opt.
Physicien	MA2, MA4	Opt.
Physics		Opt.

Language of teaching	English
Credits	4
Session	Summer
Semester	Spring
Exam	Oral
Workload	120h
Weeks	14
Hours	**4 weekly**
Lecture	2 weekly
Exercises	2 weekly
Number of positions	

Summary

The course introduces the concepts necessary to understand and describe the reading and writing process of a magnetic bit. Similarities and differences between a classical and a quantum bit are addressed.

Content

Spintronics is one of the emerging fields focused on next-generation nanoelectronic devices aiming at reduced power consumption and increased memory and processing capabilities. Such devices use not only the electron charge, as traditional electronics does, but also the electron spin as an additional degree of freedom to boost performance. The course provides the basis necessary to understand and describe spin dynamics in solids and nanostructures. The time evolution of the magnetization under the torque generated by magnetic fields and spin currents is presented. Applications to devices as hard disk drive (HDD) and magnetic random-access memory (MRAM) are discussed. Finally, analogies and differences of spin dynamics in 3D/2D vs 0D (qubits) materials are shown. The content is split in four main chapters:

1) Spin dynamics in solids and nanostructures
- Continuum approximation: Landau-Lifshitz-Gilbert (LLG) equation and explanation of its microscopic origin
- Magnetization dynamics induced by magnetic field and temperature
- Bit reversal: coherent vs incoherent reversal
- Designing and writing the recording media in HDD

2) Spin transfer torque (STT)
- Giant (GMR) and tunnel (TMR) magnetoresistance, magnetic tunnel junctions (MTJ)
- Writing by means of spin-polarized currents: Landau-Lifshitz-Gilbert-Slonczewski (LLGS) equation
- GMR/TMR for reading heads in HDD, and for MRAM operation

3) Spin orbitronics
- Spin-orbit interaction
- Spin-orbit torque (SOT) in bulk (Dresselhaus effect) and at interfaces (Rashba-Edelstein effect)
- SOT- MTJ vs. STT- MTJ: opportunities and challenges for devices
- SOT in exotic materials: oxides and 2D dichalcogenides

4) From continuum approximation to quantum dynamics
- Single atom magnets and single ion molecular magnets as prototypes of spin qubits
- Quantum tunneling of magnetization
- Demagnetization induced by spin-phonon and spin-electron scattering
- Writing and reading single atom magnets with spin-polarized currents: spin polarized scanning tunneling microscopy (SP-STM)

Keywords

spin, magnetoresistance, magnetization dynamics, qubits, magnetic anisotropy, exchange

Learning Prerequisites

Recommended courses

Basic knowledge in solid state physics and in magnetism of materials is recommended

Learning Outcomes

By the end of the course, the student must be able to:

- Formulate the laws describing the macrospin dynamics of a classical magnetic bit
- Formulate the laws describing the spin dynamics of a qubit
- Assess / Evaluate the effect of a spin current on the magnetic state of a bit
- Interpret the results of a scientific experiment

Transversal skills

- Use a work methodology appropriate to the task.
- Demonstrate the capacity for critical thinking
- Summarize an article or a technical report.

Teaching methods

Ex cathedra with exercises in class

Assessment methods

Oral exam

Resources

Bibliography

1) Spintronics: fundamental and applications; P. Dey and J. N. Roy, Springer 2021
2) Introduction to spintronics; S. Bandyopadhyay and M. Cahay, CRC Press 2015

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