Subject:	**Nanomagnetism and Spintronics**
Semester:	**Spring**
Credits ECTS:	**2.5**
Professors:	**Xavier Batlle**
	xavierbatlle@ub.edu
Department / Faculty:	**Dept. Física Fonamental**
	Facultat de Física, UB

Objectives:

General objectives and competences that the students should obtain at the end of course.

The main goal of this subject is to introduce the most up-date, *hot* topics in both magnetism and charge transport at the nanoscale. New frontiers in magnetic nanomaterials will be also discussed. During most of the XX century, microelectronics (charge transport) and magnetism (electron spin) were treated as independent research fields. In the last two decades, spin-electronics (spintronics) has emerged as a new discipline that aims at producing, manipulating and detecting spin-polarized currents, that is, a new discipline that handles the current depending on the electron spin. The Nobel Prize in Physics 2007 was awarded to the first experimental realization of spintronics in nanomaterials. In this course some of the new physical phenomena appearing when charge transport takes place in magnetic materials of nanometre dimensions will be briefly reviewed. At the end of the course, the student should be able to get into the new frontiers of magnetism and transport at the nanoscale by himself.

Recommendations / Previous Requisites

There are no previous requisites; however the student should hold some knowledge of quantum physics/chemistry, (atomic energy levels, orbital angular momentum, etc...), and solid state physics/chemistry (energy bands, electron localization, metals, insulators, etc…). However, the course is designed to be self-consistent.

Topics:

First Lecture.

The Nobel Prize in Physics 2007: Giant magnetoresistance or the art of manipulating the electron spin.

And…

Why nanoscience and nanotechnology? Correlation lengths.

1. Introduction to magnetism (very briefly)

Atomic magnetism. Atoms in solids: Non-cooperative phenomena. Diamagnetism and paramagnetism;

Magnetic interactions: Heisenberg hamiltonian. Direct exchange, superexchange and indirect exchange;

Localized electron model. Cooperative phenomena: ferromagnetism and antiferromagnetism;

Itinerant electron model. Pauli paramagnetism and Stoner ferromagnetism. Stoner criterion;

Magnetic anisotropy.

Magnetism and magnetic materials for applications.

2. Nanomagnetism: a trip from 3 to 0 dimensions … and coming back.

The key to nanoscience: correlation lengths.

Magnetic domains and single domain particles. Magnetic nanoparticles. Superparamagnetism. Biomedical applications.

Ordered arrays of magnetic nanoelements; Nanofabrication of magnetic structures: lithography and self-assembly methods. Patterned media. High density magnetic recording. The future: the (tens of) terabit per inch square.

Relevant phenomena (a few): Exchange bias… a wear proximity effect; Magnetism with non magnetic elements. Orbital contribution to the magnetism: magnetic Gold, the new alchemy of the XXI century? Spin resonant tunnelling effect …

3. Spintronics or why the charge and spin of the electrons matter.

What's spintronics? Combining electron charge and spin.

Electron transport in nanostructured materials. The asymmetry problem. Spin diffusion length. Magnetoresistance (MR) combining metals and insulators: Ordinary MR, anisotropic MR, giant MR (read heads in computers), tunnelling MR (new magnetic random access memory).

The spin transistor: combining ferromagnets and semiconductors: The Rasha effect. The Datta and Das transistor; Spin injection into a semiconductor. The conductivity mismatch problem; Diluted magnetic semiconductors.

Spin-polarized current-induced phenomena. Spin torque transfer: Current-induced domain switching and current-induced domain wall motion.

4. New frontiers of magnetism and spintronics.

Plan:

Lectures:	22 hours
Independent work:	10 hours
Study:	37 hours

Bibliography

1. Spintronics - a review.
J.F. Gregg et al.; Journal of Physics D: Applied Physics **35**, R121 (2002)
2. Finite size effects in fine particles: magnetic and transport properties
X. Batlle and A. Labarta,
Journal of Physics D: Applied Physics **35**, R15 (2002)
3. Spin-polarised currents and magnetic domain walls
C.H. Marrows, Advances in Physics **54**, 585 (2005).
4. Nanomagnetics
R. Skomski, Journal of Physics: Condensed Mater. **15**, R841 (2003).
5. Colloquium: Opportunities in nanomagnetism
S.D. Bader, Review on Modern Physics **78**, 1 (2006).
6. Magnetoelectronics
G.a. Prinz, Science **282**, 1660 (1998)
7. Spintronics: a spin-based electronics vision for the future
S.A. Wolf et al.; Science **294**, 1488 (2001)
8. Spintronics
D. A. Awschalom et al.; Scientific American, June 2002 (pag. 67)
9. Electronic analog of the electron-optic modulator
S. Datta and B. Dass; Applied Physics Letters **56**, 665 (1990)
10. Exchange bias (a review)
J. Nogués and I.K. Schuller, Journal of Magnetism and Magnetic Materials **192**, 203 (1999).
11. Patterned media (a review)
C.A. Ross, Annual Review on Materials Research **31**, 203 (2001)
12. Nanofabrication (a review)
J.I. Martin et al, Journal of Magnetism and Magnetic Materials **256**, 449 (2003).
13. From finite-size and surface effects to glassy behaviour in ferrimagnetic nanoparticles
A. Labarta ,X. Batlle and O. Iglesias; Surface effects in magnetic nanoparticles
D. Fiorani Editor; Springer (2006)
14. Exchange bias phenomenology and models of core/shell nanoparticles
O. Iglesias, A. Labarta and X. Batlle
Journal of Nanosciences and Nanotechnology (2008)
15. Modern Magnetic Materials,
R. C. O'Handley
Chapter 16 (Surface and thin film magnetism) and Chapter 15 (Electronic transport in magnetic materials)
16. Magnetic properties and spin disorder in nanocrystalline materials
A. Hernando, Journal of Physics: Condensed Mater. **11**, 9455 (1999).

17. Toward a Universal Memory
J. Akerman, Science **308**, 508 (2005)
18. The attraction of Magnetism
Science **294**, 1483 (2001)
19. Advances in magnetic microscopy
M.R. Freeman and B.C. Choi, Science **294**, 1484 (2001)
20. Advances in nanomagnetism via X-ray techniques
G. Srajer et al, Journal of Magnetism and Magnetic Materials **307**, 1 (2006).
21. Nanofabricated and self-assembled magnetic structures as data storage media
B.D. Terris and T. Thomson; Journal of Physics D: Applied Physics **38**, R199 (2005)
22. Magnetic recording: advancing into the future
A. Moser et al.; Journal of Physics D: Applied Physics **35**, R157 (2002).
23. Spintronics: 6th Heraeus Summer School, Lutherstadt Wittemberg (2005)
http://www.tp3.ruhr-uni-bochum.de/~koenig/Summerschool/lectures.html
24. European School on Nanoscience and Nanotechnology (2004, 2005, 2006, 2007): http://www.esonn.inpg.fr/
25. Web page on Nanoscience: http://www.nanohub.org/
26. Les houches summer School 2003 on Nanoscience:
http://www-lpm2c.grenoble.cnrs.fr/nanosciences/houches_nano.html