Lectures on Nanomagnetism

Prof. M. Farle / Dr. M. Spasova
www.uni-due.de/agfarle
University Duisburg-Essen

(Lectures will be given in English with (partial) Russian translation upon request)

Multifunctional Hall of library of faculty of Physics, MSU

Monday, 09.04.2012-Friday, 13.04.2012, 11:00-12:30&15:00-14:30.

Lectures: Nanomagnetism/ Fundamentals I and II

1. Introduction
a. Diamagnetism
b. Paramagnetism
c. Ferro-, Ferri- and Antiferromagnetism
d. Magnetic susceptibility and permeability

2. Magnetic order and magnetic interactions
a. Magnetic exchange (direct, indirect, and superexchange)
b. Dipolar magnetic interaction
c. Spin-orbit interaction
d. Local magnetic moments and spin-polarized electron band structure

3. Magnetization and magnetic anisotropy of ferromagnets
a. Magnetic hysteresis loop
b. Magnetic anisotropy energy density (surface, volume, shape)
c. Magnetic domains (competing exchange, magnetostatics and anisotropy)
d. Temperature dependent magnetization
e. Temperature dependent magnetic anisotropy

4. Superparamagnetism
a. Magnetic moment of a single atom versus the magnetic moment of a nanoparticle
b. Size dependence of the magnetization of a single nanoparticle
c. Temperature dependence of the magnetization of a single nanoparticle
d. Magnetic response of an ensemble of nanoparticles with different sizes

Abstract:

The fundamentals for understanding the magnetic response of a collection of magnetic nanoparticles and thin films are discussed. Starting with a review of the properties of dia-, para- and ferromagnetic materials an understanding for the magnetic stability of magnetic nanoparticles of different sizes, shapes, crystal structure and composition is developed. The dominating inner particles and interparticle magnetic interaction are presented. Within this frame of reference the behaviour of a nanoparticles ensemble is discussed. The concept of effective magnetic anisotropy and blocking temperature is explained. Finally, using this fundamental understanding the possibilities to tune and control the magnetic properties of nanoscale particles is presented.

Suggested Reading:

- *Ch. Kittel, "Introduction to Solid State Physics", Chapter 11,12 and 13*
- *R. C. O'Handley, „Modern magnetic materials: Principles and Applications"*

Lectures: Nanomagnetism / Experimental Techniques I, II, and III

1. Overview
a. Contributions to magnetization in a multi-element material
b. Extracting magnetic moments from magnetometry
c. Problems when analysing magnetic hysteresis of unknown magnets
d. How to measure magnetic susceptibility ?

2. Magnetometry
a. Super conducting interference device (SQUID) magnetometry
   Artifacts , sensitivity and speed of different types of measurements
b. Alternative methods of conventional magnetometry
   Vibrating sample magnetometer
   Alternating Gradient magnetometer
c) Magneto-optics

3. Magnetic anisotropy energy density
a. Torque magnetometry
b. Ferromagnetic resonance

4. Synchrotron based techniques
a. Element specific magnetic moments from X-ray magnetic circular dichroism
b. Element-specific electronic structure
c. Site-specific bonding and bond length determination

5. Examples of magnetic resonance in systems at the nanoscale
a. Ferromagnetic resonance in ultrathin films
b. Ferromagnetic resonance in coupled ultrathin films
c. Ferromagnetic resonance in ensembles of magnetic nanoparticles
d. Ferromagnetic resonance on single nanostructures

6. Overview of methods not discussed (e.g. electron and neutron spectroscopies)

Abstract:

Experimental techniques to investigate collective and individual static magnetic responses of superparamagnetic nanoparticle are presented. Problems, artifacts and sensitivity concerns are discussed. Suggestions for the best experimental techniques to address specific problems in nanomagnetism are given.

Suggested reading:

- *J. Stöhr and H.C. Siegmann, „Magnetism: from fundamentals to nanoscale dynamics", Chapter 10*
- *NanoSQUIDS: in Supercond. Technol.* ***22*** *(2009) 064001*
- *A closer look into magnetism: Opportunities with synchrotron radiation* , IEEE Transactions on Magnetics **45** (2009) 15-57
- *Magnetism at the Nanoscale: the case of FePt*, Modern Physics Letters B **21** (2007) 1111-1131

UNIVERSITÄT DUISBURG ESSEN

Open-Minded

Lectures: Nanomagnetism / Spin Torque Phenomena I and II

1. Introduction
a. Giant magneto-resistance ↔ spin-torque
b. Spin-torque and magnetic random access memory
2. Spin-torque in vertical structures
a. Basic phenomenon
b. Current-induce magnetization reversal in nanopillars
3. Mathematical description
a. Landau-Lifshitz (LL) equation of motion
b. Simple explanation of additive term to LL equation
4. Requirements for spin-torque systems
a. Electron scattering in ferromagnetic solids
b. Requirements for magnetic and non-magnetic layers in spin-torque systems
5. Detection of spin-torque damping by Ferromagnetic resonance
6. Spin-torque oscillators
a. Basic phenomenon
b. Experimental detection (Lock-In amplifier)
7. Spin-torque in lateral structures
a. Current-induced domain wall motion
b. influence of Oersted field

Abstract:

An introduction to the field of spin-torque driven processes is given. Spinpolarized currents may give rise to magnetization reversal or magnetization precession (spin-torque oscillators) within vertical nanopillar samples that consist of two magnetic layers separated by a non-ferromagnetic one. The phenomena are described using simple models, recent experimental evidence is given and a connection to possible applications is made. The effort to reduce the critical current density is reviewed.
Within lateral stripe-like systems spin-torque can be used to move domain walls. This effect is discussed and experimental evidence in polycrystalline materials as well as single crystalline materials is given.