UNIVERSITÄT DUISBURG ESSEN

Open-Minded

CENIDE
CENTER FOR NANO INTEGRATION DUISBURG ESSEN

Lectures on Nanomagnetism

Prof. M. Farle

www.uni-due.de/agfarle

University Duisburg-Essen

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

Lecture Hall: library of faculty of physics, 5th floor

Monday, 24.03.2014

Duration		**Title of Lecture**
30 min	15:15 - 15:45	Center of NanoIntegration at University of Duisburg-Essen (Opportunities for joint research and visits)
30 min	15:45 - 16:15	Nanomagnetism: Fundamentals Ia
30 min	16:15 - 16:45	Nanomagnetism: Fundamentals Ib
	break	**Discussions and Questions**
45 min	17:00 – 17:45	Nanomagnetism: Fundamentals II
45 min	17:45 – 18:30	Nanomagnetism: Fundamentals II

Tuesday, 25.03.2014

45 min	15:15 – 16:00	Nanomagnetism: Experimental Techniques Ia
45 min	16:00 – 16:45	Nanomagnetism: Experimental Techniques Ib
	break	**Discussion and Questions**
45 min	17:00 – 17:45	Nanomagnetism: Experimental Techniques II Spin Dynamics and Magnetization Relaxation Ferromagnetic Resonance / Magnetic Damping

Wednesday, 26.03.2014

60 min	17:00 - 18:00	**How to present scientific results professionally**: Layout of Transparencies, body language, (video taped exercises for self evaluation)

Thursday, 27.03.2014

45 min	15:15 – 16:00	How to analyse a single magnetic nanoparticle ? requirements, sample preparation, structure and composition
45 min	16:00– 16:45	How to analyse a single magnetic nanoparticle ? static magnetic analysis, magnetic moments
	break	**Discussion and Questions**
45 min	17:00 – 17:45	Nanomagnetism: Spin Torque Phenomena I
45 min	17:45 – 18:30	Nanomagnetism: Spin Torque Phenomena II
30 min	18:30 – 19:00	Future Challenges in Nanomagnetism

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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

Lectures: Nanomagnetism / Spin Torque Phenomena I and II

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.