Physics 250

Nanofabrication & Properties of Artificially Structured Materials
What are we talking about?
Nanostructures

nm constraints
Artificially Designed & Fabricated

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# Novel & Tunable Properties

## Low dimensionality
Nanometer-scale entities

<table>
<thead>
<tr>
<th>Size</th>
<th>Characteristic Length</th>
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<tr>
<td>Non-bulk</td>
<td>Mean free path</td>
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<td>Behavior</td>
<td>Spin diffusion length</td>
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<td>Fermi wavelength</td>
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## Interplay of constituent materials
- Metal, semimetal, semiconductor, insulator
- Ferromagnet, antiferromagnet
- Superconductor
- 100% spin polarized material
  etc.

## Surface & interface
Extra degrees of freedom
Types of Nanostructures

Features:
- Unique structures
- Interplay of materials
- Interface intensive

Degrees of freedom:
- Dimensionality
- Materials
- Entity size (nm)
- Patterning

2D Layers
1D Wires
0D Particles
Patterned Structures

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Nanodots

Small area: 100µm x 100µm

E-beam lithography

Large area: 1cm x 1cm

Porous alumina shadow mask

Arbitrary shape, order

~60nm in size, ~ 10^{10}/cm^{2}, over 1cm^{2} area

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Arts and Nanoscience
Magnetization Stabilization

Enhanced Squareness & Coercivity

Combat superparamagnetic limit


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Fe Nanodots: Single Domain vs. Vortex State


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Magnetic Nanoparticles

Core / Shell Structured Magnetic Nanoparticles
- Heterostructure: Close proximity of functionally different materials
- Core (Fe): Magnetic
- Shell (Au): Oxidation and corrosion-resistant Functionalization bio-compatible
- Potential applications: MRI agent Cell tagging & sorting Hyperthermia treatment Targeted drug delivery


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Nanowires

Fabrication

Nanopore template

Electrodeposition


Arrays of 400nm Bi nanowires

A single 30nm Co-Cu nanowire

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Multilayered Nanowires

**Current Perpendicular to the Plane (CPP)**

**Current In the Plane (CIP)**

High Resistance

Low Resistance

Giant Magnetoresistance:
(Subject of 2007 Nobel Prize in Physics)

Spin dependent transport.
Direct determination of spin diffusion length.

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Semi-Metallic Nanowires

Large grain sizes

Classical & Quantum Size Effects

Large Magnetoresistance

Phys. Rev. B 58, R14681 (1998);


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Layers & Supperlattices

Growth:
- Sputtering
- Evaporation
- MBE
- Electrodeposition

Cu(5nm)/Ni(1nm) Multilayer

X-ray diffraction pattern of a FeF$_2$/Fe bilayer film

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Example: 2-Dimensional Layers

Single crystal bismuth thin film


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Magnetic Multilayers

Free FM
Exchange field $H_E=0$
Small coercivity $H_C$

Pinned FM
Large $H_E$
Large $H_C$

Spin Valves

Magnetic RAM

Read Head

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Patterned Structures

Realized over 1cm², 100 billion holes

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Thin Films with Perpendicular Anisotropy

Manipulating reversal via patterning


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Typical Steps

Fabrication -
  Sputtering
  Evaporation
  MBE
  Laser Ablation
  Electrodeposition
  Chemical reactions

Characterization -
  X-ray diffraction
  Electron microscopy
    SEM
    TEM
    AFM/STM/MFM
  Profilometry

Processing -
  Photolithography
  E-beam lithography
  Self-assembly nanolithography

Measurements
  Magnetic
    SQUID
    VSM
    AGM
    MOKE
  Transport
In-House Facilities

Fabrication

- UHV multi-source magnetron sputtering
- Electron beam evaporation
- Thermal Evaporation
- Electrodeposition
- High temperature furnaces

Characterization

- X-ray diffraction
- Electron microscopy

Measurement

- Transport w/ cryostats
- SQUID magnetometer
- VSM/AGM magnetometer
- MOKE

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On-Campus Facilities

Processing

• Class-100 cleanroom
• Photolithography
• E-beam lithography
• Reactive ion etching
• Ion milling
• Wire bonder

Fabrication

• Ion beam sputtering
• Electron beam evaporation

Characterization

• SEM
• TEM
• Profilometry
• Single-crystal diffractometer
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