Magnetic Nanostructures

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Bottoms up approaches:

- Chemically synthesized FePt nanoparticle arrays (Faculty: Nikles, Harrell, Visscher)
- Dendrimer-mediated growth of acicular Co nanoparticles (Faculty: Street)
- Synthesis of magnetic nanowires using liquid crystal templating (Faculty: Bakker)
Motivation

• Ultra-high density magnetic media

• Fundamental studies of interacting nanoparticles near the superparamagnetic limit
Superparamagnetic Limit in Magnetic Media

traditional media

⇒ small grain size
⇒ magnetization decay
("superparamagnetism")
⇒ need higher magnetic anisotropy, more uniform volumes

patterned or self-assembled

\[ \frac{1}{\tau} = f_0 \exp\left( -\frac{KV}{k_B T} \right) \]

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Chemically Synthesized L1₀ FePt Nanoparticle Arrays

Faculty: Dave Nikles (Chemistry - synthesis)  
Pieter Visscher (Physics – modeling)  
J.W. Harrell (Physics – magnetic properties)

Postdocs: Shishou Kang, X.C. Sun

Students: Shoutao Wang, Zhiyong Jia, Xuebing Feng

Support: NSF-MRSEC
High anisotropy FePt nanoparticle arrays

• Superparamagnetic as prepared
• Anneal at T ~ 550 °C → chemically ordered high-anisotropy L1₀ fct phase.
• Particles ≥ 3.5 nm thermally stable for > 10 years.
• Potential storage density > 1 Tb/in² as conventional medium (using heat assisted recording)
• Potential storage density ~ 40 Tb/in² if 1 bit/particle recording can be achieved.
Materials Issues

• Switching fields too large for writing using conventional magnetic heads (heat-assisted recording)
• Non-uniform chemical ordering
• Randomly oriented easy axes
• Surface oxidation
• Film uniformity
• Particle aggregation during high-temperature annealing
TEM Image of Self-Assembled FePtCu Nanoparticles

Monolayer

Bilayer

Mutilayer

Dr. Z. L. Wang’s TEM Lab, Georgia Tech.
Effect of Annealing on Coercivity of Chemically Synthesized FePtCu Nanoparticles

Unlike sputtered FePt films, additive Cu is ineffective in reducing the ordering temperature.
Additive Au is very effective in lowering the chemical ordering temperature. Au segregates from the FePt nanoparticles during ordering.
Reduction in Ordering Temperature in FePt by Addition of Au and Ag

![Graph showing the reduction in ordering temperature in FePt by addition of Au and Ag](image-url)
Thermal stability factor versus intrinsic switching field in annealed FePtAu nanoparticles

![Graph showing thermal stability factor versus intrinsic switching field](image)

- 8% Au
- 12% Au
- 15% Au
- 24% Au

Temperature range: 350°C - 500°C

Center for Materials for Information Technology
A NSF Materials Research Science and Engineering Center
Large Switching Volumes

\[ V_{SW} = C \frac{kT}{M_s H_0}, \quad C = \left( \frac{KV}{kT} \right)_{\text{meas}} \]

assumes \( H_0 \approx \frac{1}{2} H_k = \frac{K}{M_s} \)

\( M_s = 1100 \text{ G} \)

\[ \bar{d} = 2 \times 3 \sqrt{\frac{3}{4\pi}} V_{SW} \approx 10 \text{ nm} \]

\( d \approx 3.5 \text{ nm} \ (TEM) \)
Anisotropy Distribution

• Large coercivity ratio (CR = \( H_{CR}/H_C \)) in annealed FePt arrays evidence of large \( H_k \) distribution

• Previous modeling showed CR dependence on distribution with and mean field interactions.

• Chantrell has modeled CR using Monte-Carlo method to include thermal effects and dipolar and exchange interactions.
Future Work (FePt)

HRTEM: Georgia Tech, Glasgow, Sony

- Where does the Au and Ag go?
- Why does Cu not promote ordering?
- What is the extent of aggregation in annealed FePtAu and FePtAg arrays?
Future Work (FePt)

Better magnetic characterization. Oxford MagLab VSM just installed (9 T, 1.5K – 1000 K)

- Temperature dependence of intrinsic switching field and energy barrier to reversal
- Curie temperature

Plasmon resonance (Tom Ferrell – ORNL)
Future Work (FePt)

Chemical Ordering in Solution

• Heat FePtAu nanoparticle dispersion in a pressure reactor

• Preliminary results show partial chemical ordering, but particle growth

• Pathway to easy-axis alignment?
Synthesis of Nanostructured Thin Films using Liquid Crystal Templating

Martin G. Bakker and Roger Campbell

MINT Center and Department of Chemistry
The University of Alabama

Supported by NSF-MRSEC
What are Liquid Crystals?

Cylindrical Micelle

Hexagonal Packed Liquid Crystal Phase
Growth of Metal Particles within Mesoporous Matrix
Cobalt electrodeposited into SBA-15 grown on copper

Washed silica

Cobalt grown into silica
The Orientation Problem
Dendrimer-mediated Solution Phase Growth of Acicular Co Nanoparticles

Interdendrimer Magnetic Nanoparticles

Shane C. Street
Dr. Junyan Zhang
Dr. M. Shamsuzzoha

Supported by NSF-MRSEC
UV Irradiation of Co(II)/G4-OH System

\[ \text{CoCl}_2 \text{ aqueous} \quad + \quad \text{Dendrimer aqueous} \quad \rightarrow \quad \text{Mixed Amine-coordinated Co}^{2+} \quad \text{hv} \]
TEM image of Acicular Co Nanoparticles

Dr. M. Shamsuzzoha
TEM Image of Single Co Nanoparticle
Magnetic Hysteresis Loop of Co Nanoparticles

\[ H_c = 300.6 \text{Oe} \]
Conclusions

Interdendrimer Magnetic Nanoparticles

• Metal ions can be reduced under UV irradiation in the presence of the dendrimer, forming interdendrimer particles
• The Co particles produced are relatively monodisperse, acicular, magnetic, and apparently metallic.
Future Work?

• Are particle morphologies a function of dendrimer chemical functionality? -COO⁻, -OH, others available
• Changes in the dendrimer as a function of irradiation: NMR, IR, chromatography
• Is particle shape evolution dependent on dendrimer structure? Can use other amine reducing agents (n-acetyl ethanolamine)