Opportunities in Nanomagnetism

Presented by

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Argonne National Laboratory
Argonne Scientist wins Nobel Prize for Physics

NOBEL PRIZE WINNER — Argonne physicist Alexei A. Abrikosov has won the 2003 Nobel Prize for Physics, along with Anthony Leggett of the University of Illinois, Urbana-Champaign, and Vitaly Ginzburg of the P.N. Lebedev Physical Institute in Moscow. The three shared the prize for their work on superconductivity and superfluidity, explaining the nature of matter at extremely low temperatures.
400 years later

“De Magnete”, William Gilbert

William Gilbert
Oersted links Electricity and Magnetism

Oersted’s Experiment    http://www-spof.gsfc.nasa.gov/earthmag/demagint.htm
Grand Challenges in Nanomagnetism

- Ultra Strong Permanent Magnets
- Ultra High Density Media
- Spin Transistor With Gain
- ~100% Spin Polarized Materials
- R.T. Magnetic Semiconductors
- Instant Boot-Up Computer
- Magnetic Logic
- Spin-Based Qubits
- Hierarchically Assembled Media
- Computer From Test Tube
- Nano-Bio Mag Sensors
From the earliest batteries through vacuum tubes, solid state, and integrated circuits, electronics has staved off stagnation. Engineers and scientists have remade it repeatedly, vaulting it over one hurdle after another to keep alive a record of innovation unmatched in industrial history.

The mystical property of electron spin is revolutionizing the memory business. If it can do the same with logic, electronics will become "spintronics"

The Quest for the Spin Transistor
By Glenn Zorpette, Senior Editor
**Spin Injection, Diffusion, and Detection in Lateral Spin-Valves**

\[ \lambda_s = 63 \pm 15 \text{ nm} \]

\[ T = 10 \text{ K} \]

Yi Ji, et al.
Magnetic Data Storage Technologies
Magnetic Data Storage

IBM RAMAC 1956
- 2 kbits/in²
- 50 x 24-inch diameter disks
- 70 kbits/s

IBM Microdrive 1999
- 6 Gbits/in²
- 1-inch diameter disk
- 180 Mbits/s

5 Mbyte

340 Mbyte
Principles of Nanoscience

Geometric Confinement
Physical Proximity
Chemical Self-Organization
Approaches to Nano Fab . . .

Top Down

Bottom Up

Virtual Fab
Stage 1: Substrate with lithographically prepared trenches

Stage 2: Self-assembled diblock copolymer aligning within the trenches

Stage 3: 1-D nanomag array selectively adsorb on hydrophobic polymer stripes
Tibetan Sand Mandala
The Material World is Impermanent

Selfless Assembly
Arrays of Magnetostatically Coupled Dots

V. Novosad, et al. PRB

Magnetostatic interaction affects the nucleation and annihilation fields, as well as the initial susceptibility (permalloy thickness = 60 nm).
Magnetic Vortex State in disk-shaped nanomagnets

Magnetization reversal due to formation of the magnetic vortex state in circular dot
Willebrord Snell
Snell Song

• Come listen and learn, I’ve a story I tell,
• I sing of the genius of Willebrord Snell
• A mathematician who lived long ago
• In the Netherlands where the Rhine river does flow.
Snell Song

- His greatest feat came in Sixteen Twenty-one,
- When optics as science was really begun!
- While flashes of lightning illumined his page,
- He wrote down Snell’s law, his great gift to the age!

- So if you wear glasses or like to fry ants,
- Be grateful your lenses were not made by chance!
- Astronomers hail him with each new-found star!
- Microscopists toast him from each sleazy bar!

- Singin’ $n_1$ sine $\theta_{-1}$, hey, hey, hey,
- Equals $n_2$ sine $\theta_{-2}$, hip hooray!
Virtual Fab
Virtual Fab

Nakamura et al.
PRB 68, 180404 (2003)
Magnetic Virus Concept

Bio-Inspired Solution to object size and placement control
Magnetic Virus Concept

1. “Ghost phage” without DNA core is prepared by osmotic shock (uniform cavity size ~40nm)
2. Ghost phage viruses are utilized as a template for magnetic nanoparticles
3. Ligand-displayed phage viruses has recognition function for target molecules
Natural Bio-Magnetic System

Magnetic Protein

Ferritin

12 nm

Iron stored as mineral inside ferritin

Magnetic Bacteria

Magnetospirillum
Magnetotacticum

2 μm

Virus

Intermediate size (~ 50 nm)
Good for sensor application
T7 Bacteriophage

**Good confined template for material synthesis**

- Size: ~50 nm in diameter (40 nm cavity size)
- Components: Capsid shell, head-tail connector, tail, tail fibers.
- Assembly: capsid shell first, then DNA is inserted.

**Easy to construct of phage display library**

- Affinity reagent can be displayed on the capsid protein
- Library (a collection of DNA) can be constructed
Fabrication of Magnetic Virus (TEM images)

Normal T7 phage

Ghost T7 phage

Osmotic shock
(Sodium Sulfate)

Bio mineralization

(NH$_4$)$_2$Fe(SO$_4$)$_2$ + O$_2$ → Fe$_2$O$_3$

pH = 6.5

Virus with Iron Oxide Inside

Capsid Proteins
Garlic. The old superstition that garlic can destroy the magnetic power of the LODESTONE has the sanction of Pliny, Solinus, Ptolemy, Rulandus, Renodaeus, Langius and others.

Martin Rulandus saith that Onions and Garlick...hinder the attractive power of the magnet and rob it of its virtue of drawing iron, to which Renodaeus agrees; but this is all lies. (1693).


Gilbert’s "loadstone impaired by decay"
Exchange-Spring Principle for Hard Magnets

Energy Applications
Exchange-Spring Principle for Hard Magnets

Kneller and Hawig
Core-Shell Nanocrystal Spring Magnets

- Synthesize monodisperse nanomagnets with well defined shape.
- Control the magnetic functionality on a single nanocrystal level by forming core shell spring magnets.
- Form large assembly of nanocrystals

Monodispersed Co nanocrystals

Magnetic properties of single component nanocrystals.

\[ \text{Co}_2(\text{CO})_8 \xrightarrow{\Delta} \text{Co} \xrightarrow{\text{Pt(acac)}_2} \text{Co/Pt} \]

Molecular Precursor | Single-phase Nanocrystal | Core-shell Nanoalloy | 2D Array

X.-M. Lin and John Schlueter
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