Center for Spintronics & Biodetection

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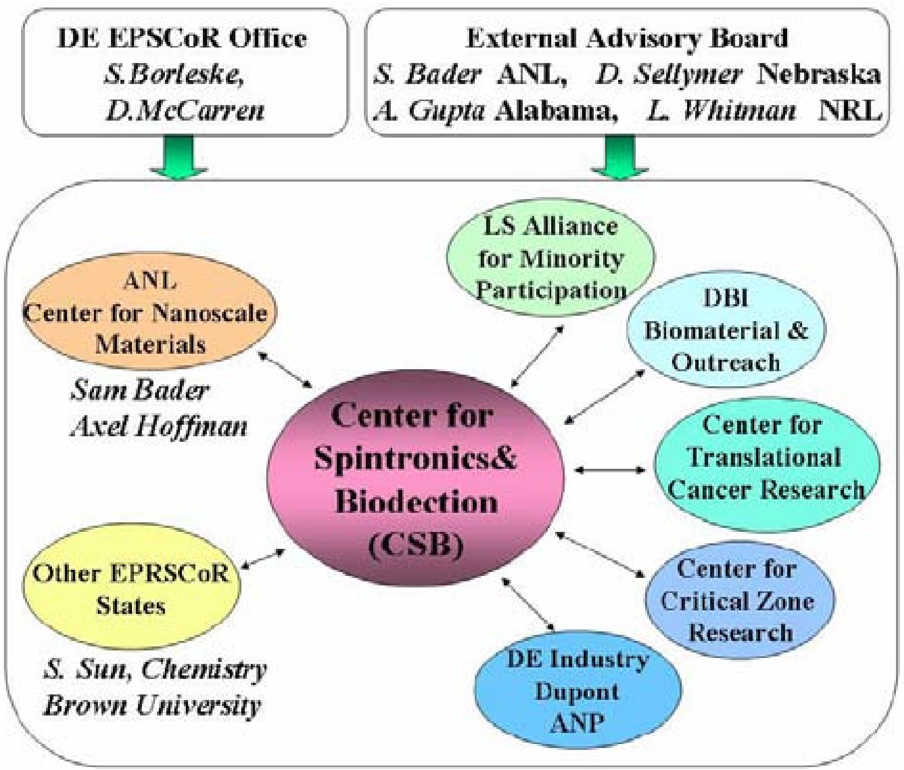
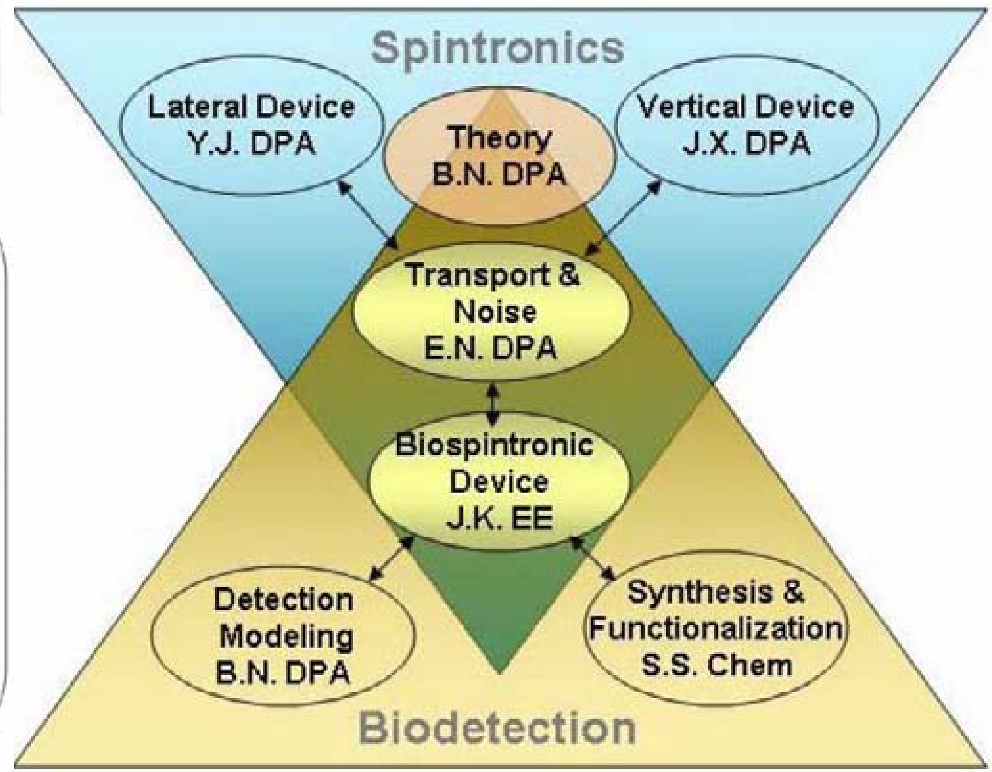
Outlines:

- **Center Overview**
- **Research Project**
- **Outreach & Education**

Center Structure





Participants

Yi Ji (Phys.)
B. Nikolic (Phys.)
J. Xiao (Phys.)
D. McCarren (DE State)
E. N. Nowak (Phys.)
J. Koldzey (EE)
S. Sun (Chem)

Collaborators:

S. Bader (ANL)
Axel Hoffmann (ANL)

CSB Objectives

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1. **Revealing fundamental physics of generation, manipulation, and detection of low dissipation spin current.**
   - spin transport across interfaces, through materials, and the effects of spin-orbit coupling, exchange interaction, electron-electron interactions, and radio-frequency fields
2. **Identifying and controlling fluctuations and noise in magnetic nanostructures**
   - attaining pico-Tesla magnetic field detectivity at low frequencies
3. **Advancing magnetic nanotechnology for sensitive biodetection**
   - synthesizing of stable monodisperse magnetic nanoparticles (NPs) with high moments for improved signal/noise ratio,
   - interactions between functionalized NPs and the magnetic sensor's surface and biological molecules.
4. **Education and mentoring of students**
5. **Supporting State's science and technology developments**

Scheme I: Generation, Transport, and Detection of Pu
Spin Current

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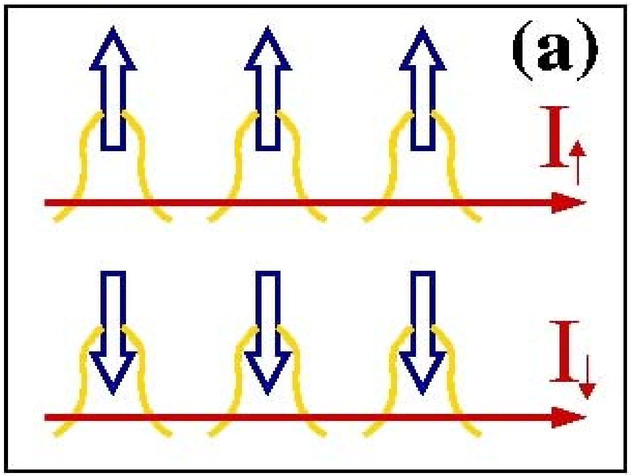
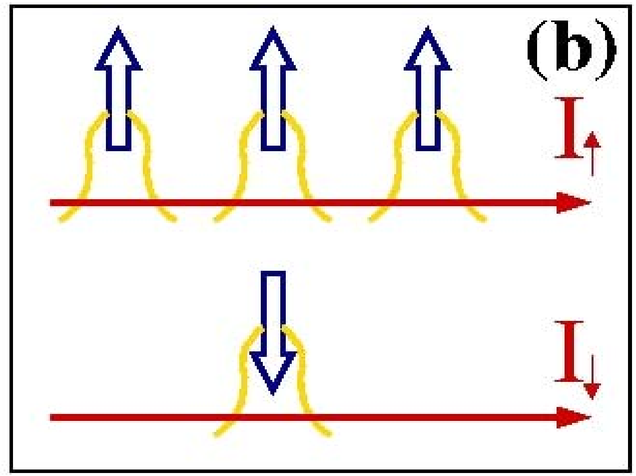
What is Pure Spin Current?

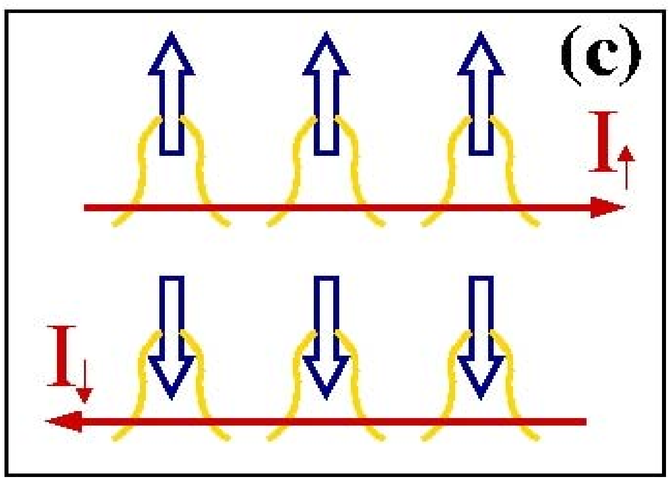


$I \neq 0$ $I_s = 0$



$I \neq 0$

$I_s \neq 0$



$I = 0$

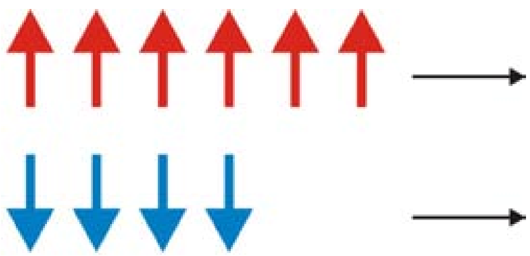
$I_s \neq 0$

$$I = I^{\uparrow} + I^{\downarrow}$$

$$I_s = \frac{\hbar}{2e}(I^{\uparrow} - I^{\downarrow})$$

Why Pure Spin Currents

(a)

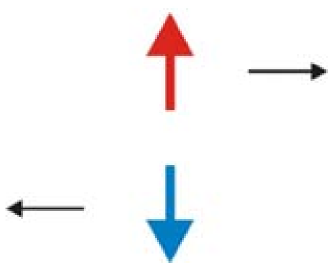


$$j_{\uparrow} = 6\, a.u.$$

$$j_{\downarrow} = 4\, a.u.$$

20% polarized current

(b)



$$j_{\uparrow} = 1\, a.u.$$

$$j_{\downarrow} = -1\, a.u.$$

Pure spin current

$$j_M = (j_{\uparrow} - j_{\downarrow})\frac{\mu_B}{e}$$

Spin current in (b) is the same as in (a)

$$P = \rho_{\uparrow} j_{\uparrow}{}^2 + \rho_{\downarrow} j_{\downarrow}{}^2$$

Joule heating in (b) is 4% of that in (a)

Generating pure spin current in NLSV

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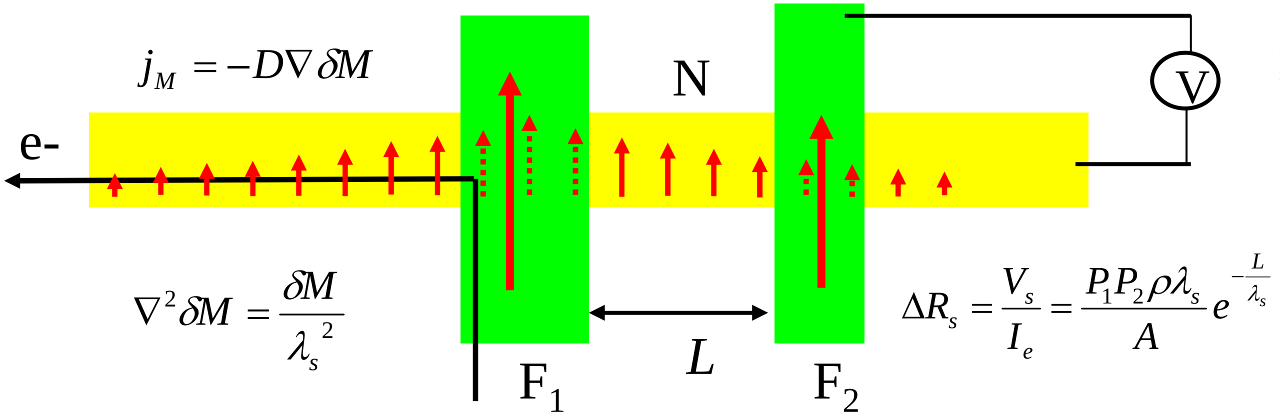
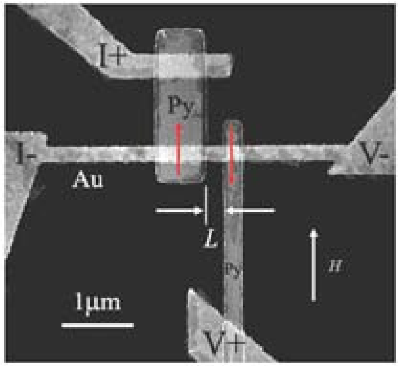


$$j_M = -D\nabla \delta M$$

$$\nabla^2 \delta M = \frac{\delta M}{\lambda_s^2}$$

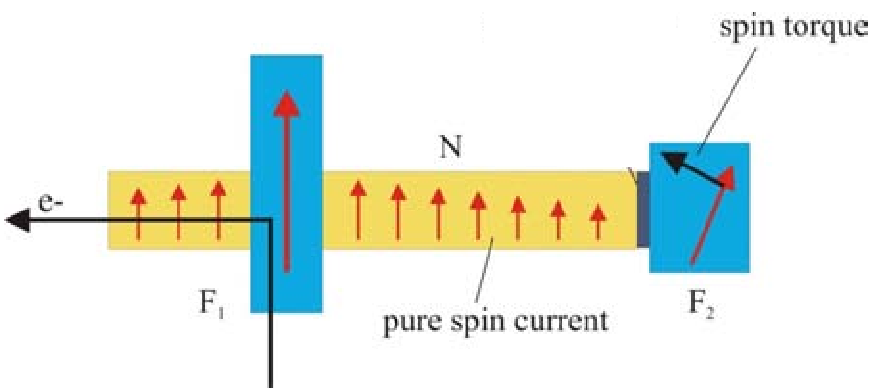
$$\Delta R_s = \frac{V_s}{I_e} = \frac{P_1 P_2 \rho \lambda_s}{A} e^{-\frac{L}{\lambda_s}}$$

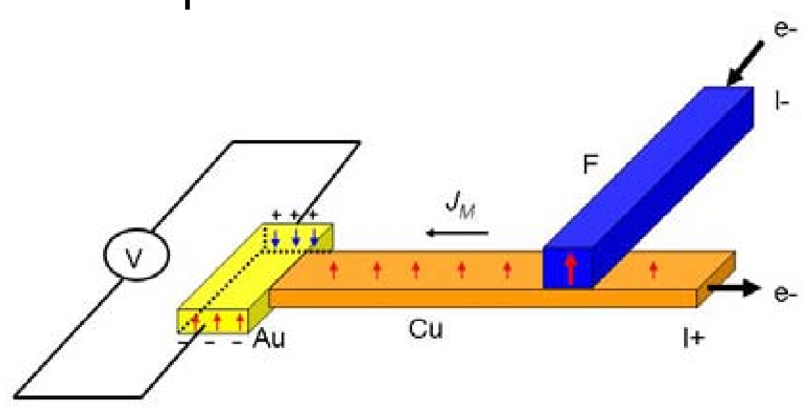
(a)



Physics to be explored in nonlocal spin valves (NLSV)

- Spin transfer switching with a pure spin current
- Direct measurement of spin Hall effect
- Exploration of multi-terminal spintronic devices





Generating pure spin current via external rf field: Spin Battery

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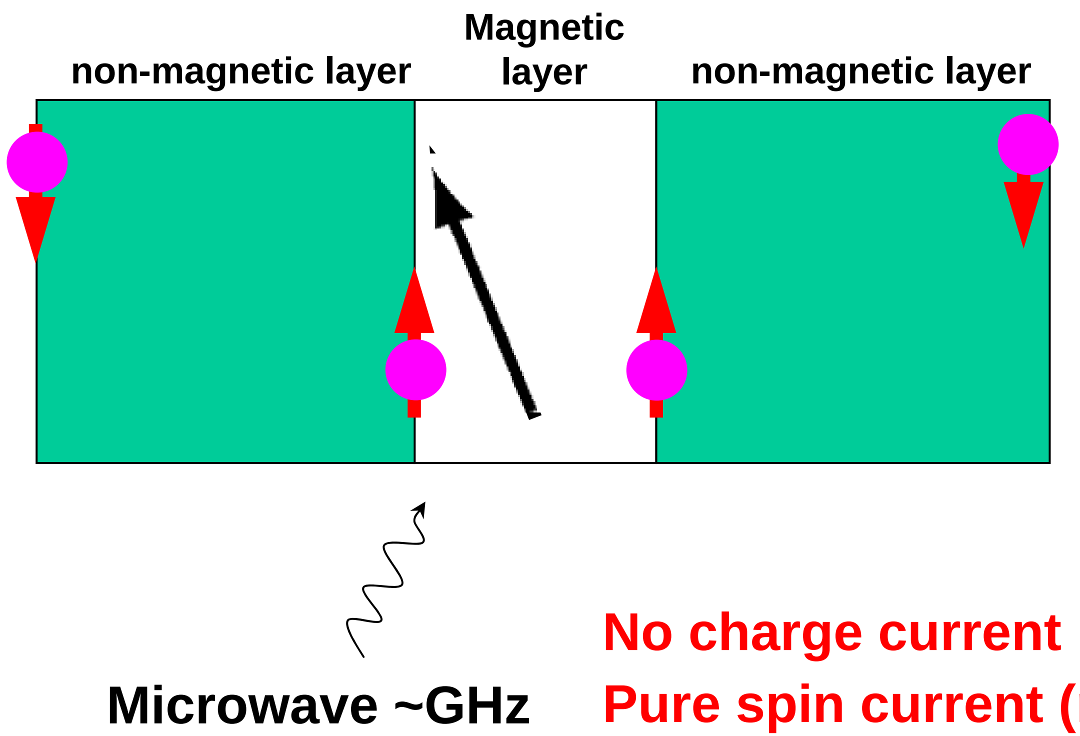


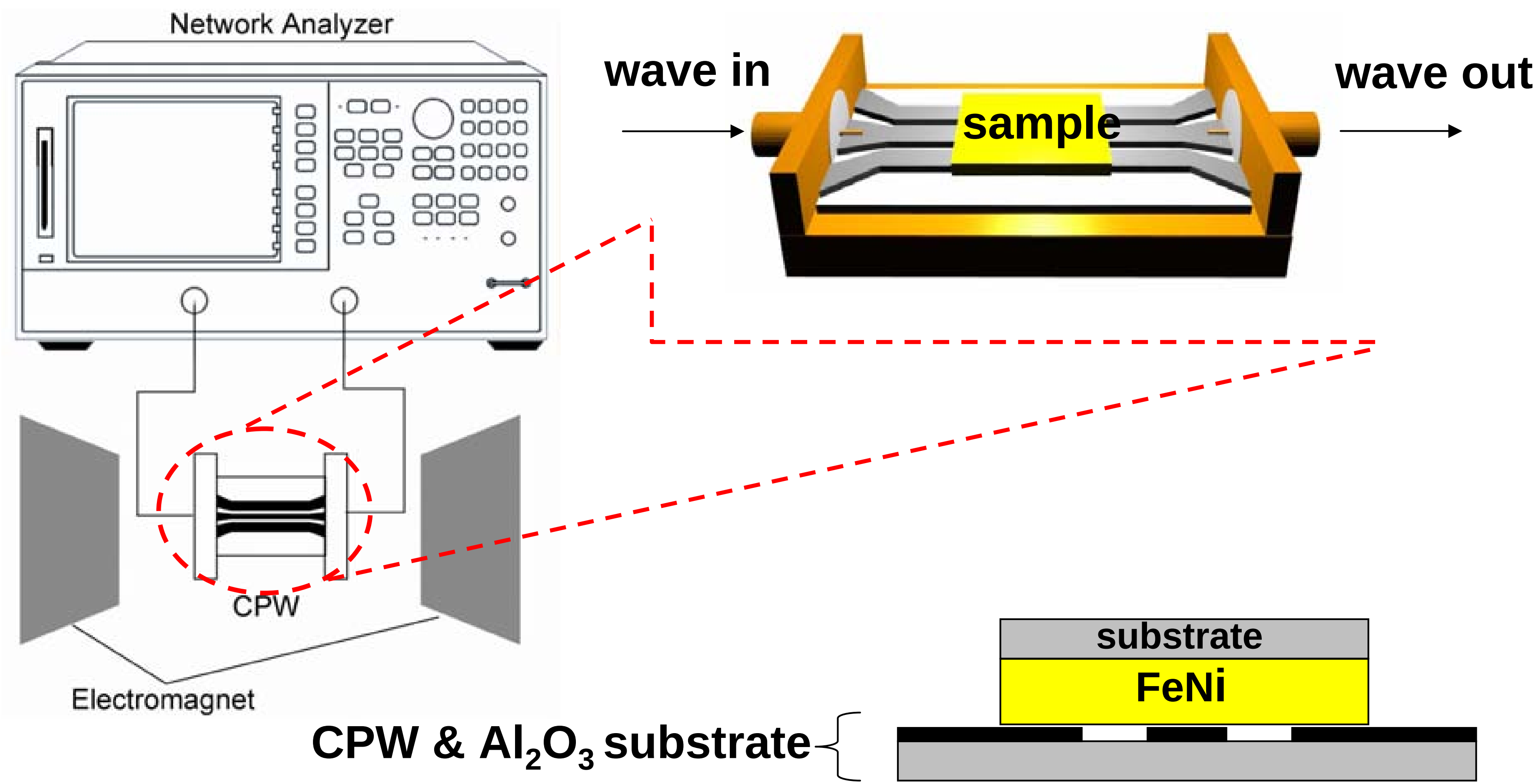
No charge current
Pure spin current (momentum flow)

Y. Tserkovnyak et al. PRL 88 117601 (2002)

Y. Tserkovnyak et al. cond-mat 0208091 (2002)

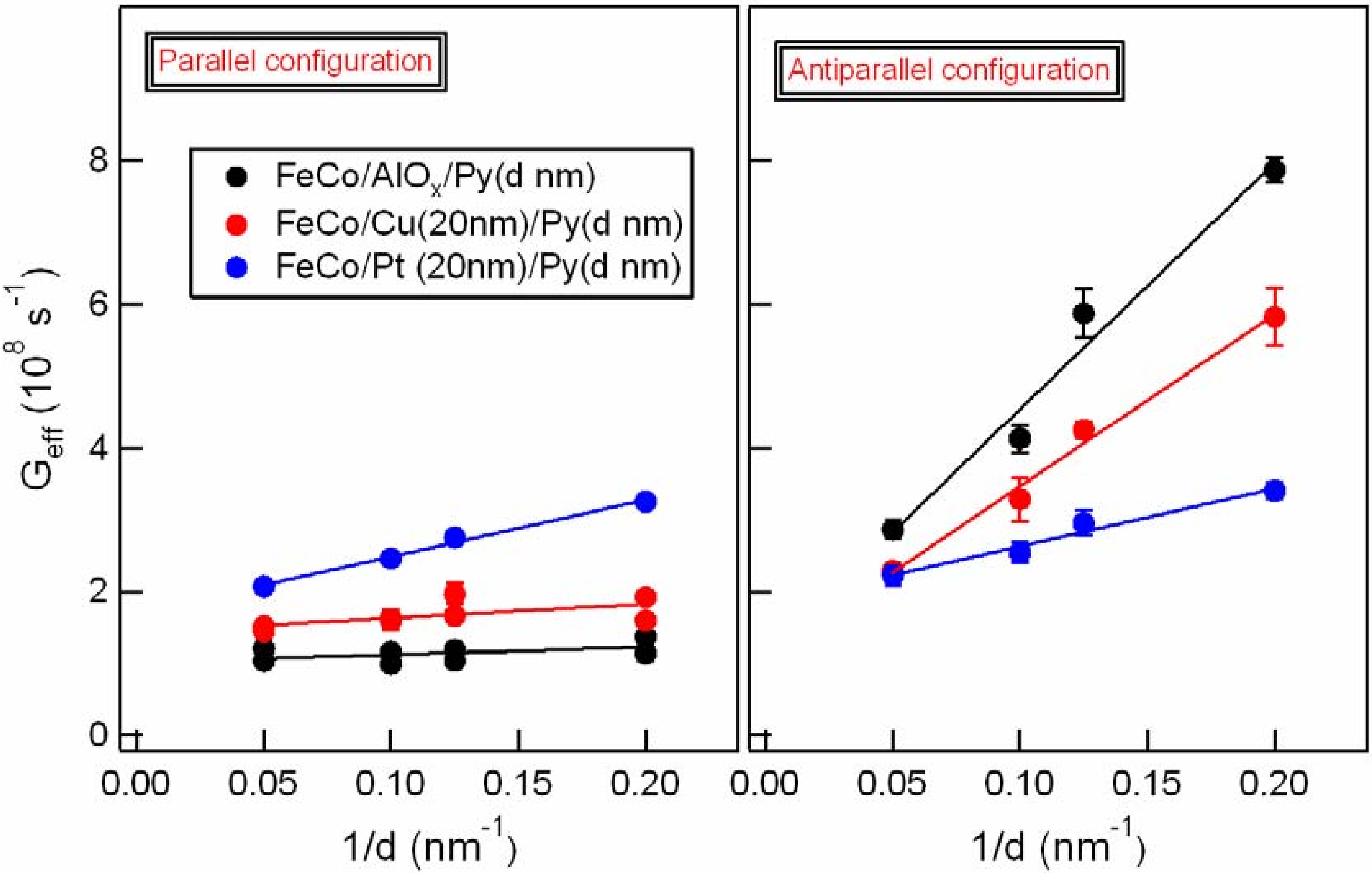
Indirect Detection: FMR Damping Enhancement

Performed by filp-chip coplanar waveguide (CPW)

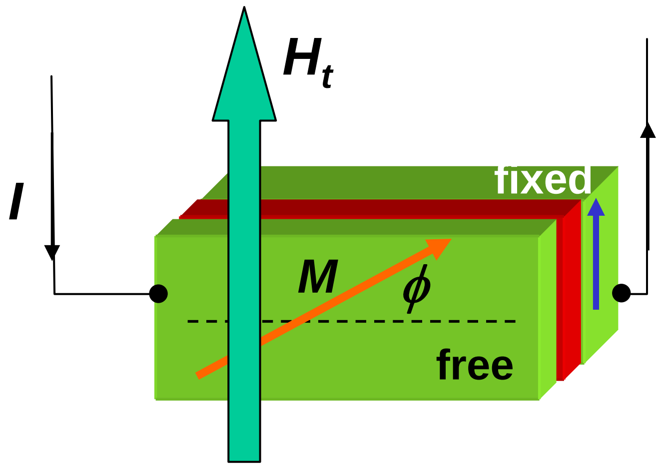


Microwave is absorbed at FMR

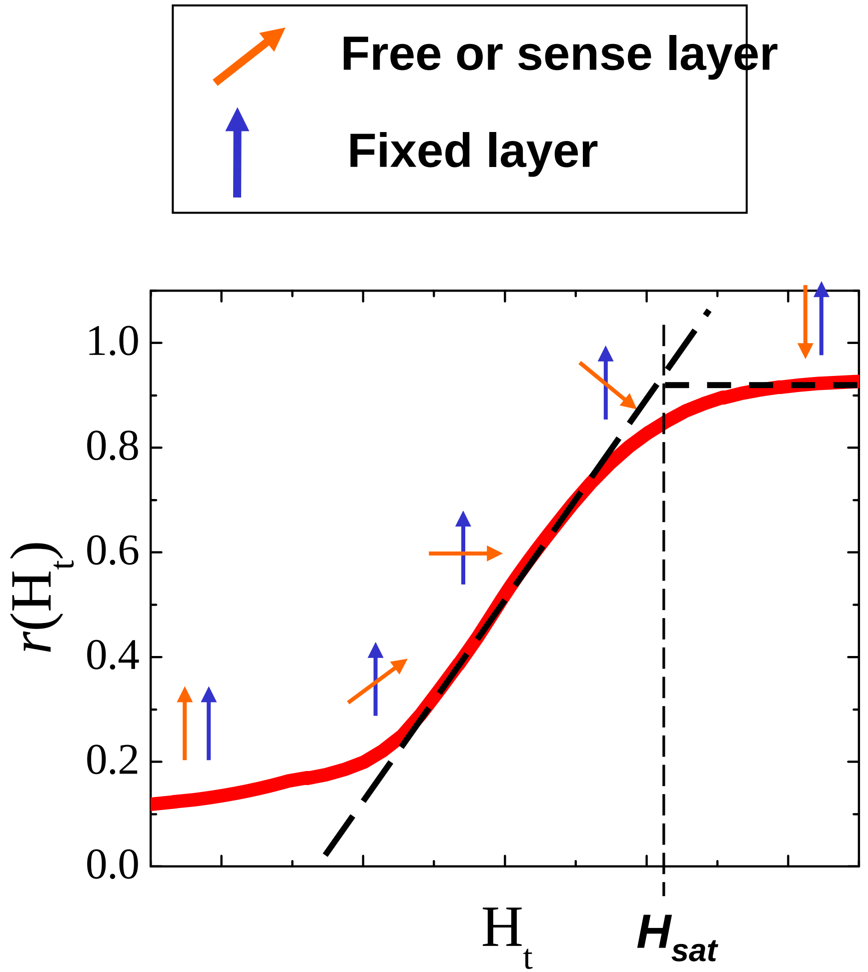
Spin Dependent Damping Enhancement



Scheme II: Signal and Noise in MTJ Sensors



$$r(\phi) = \frac{R(\phi) - R_P}{\Delta R} = \frac{1}{2}\left(1 - \sin\phi\right)$$



Magnetic Nanoparticle (MNP) Immobilization and Detection

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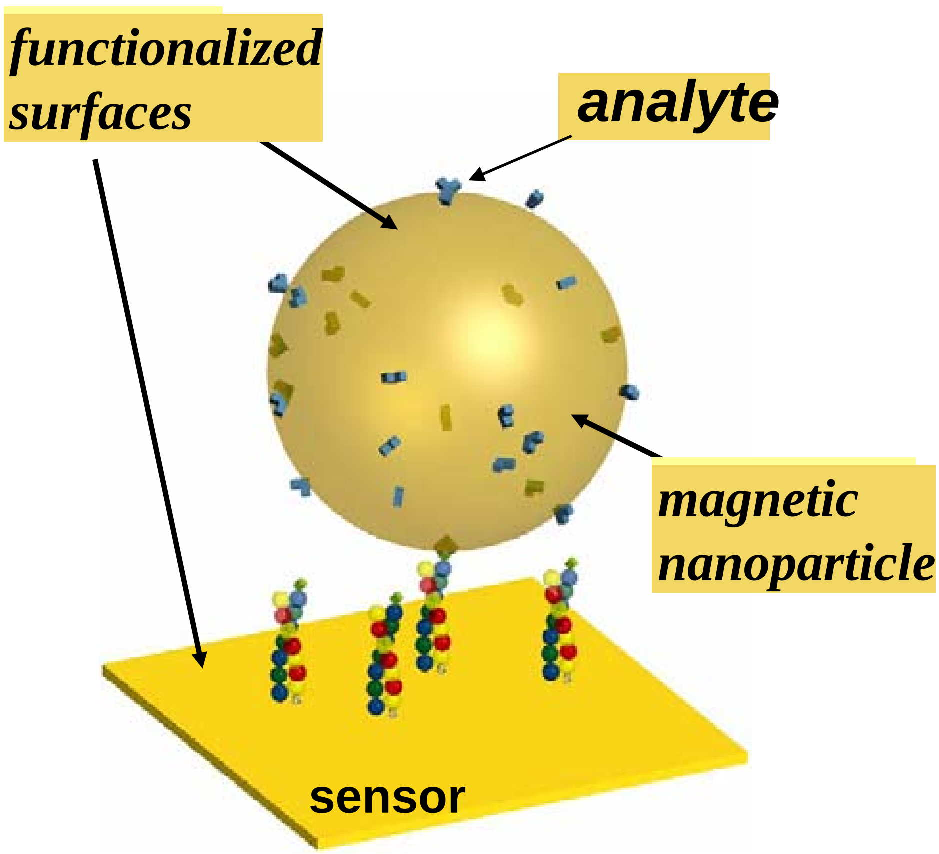
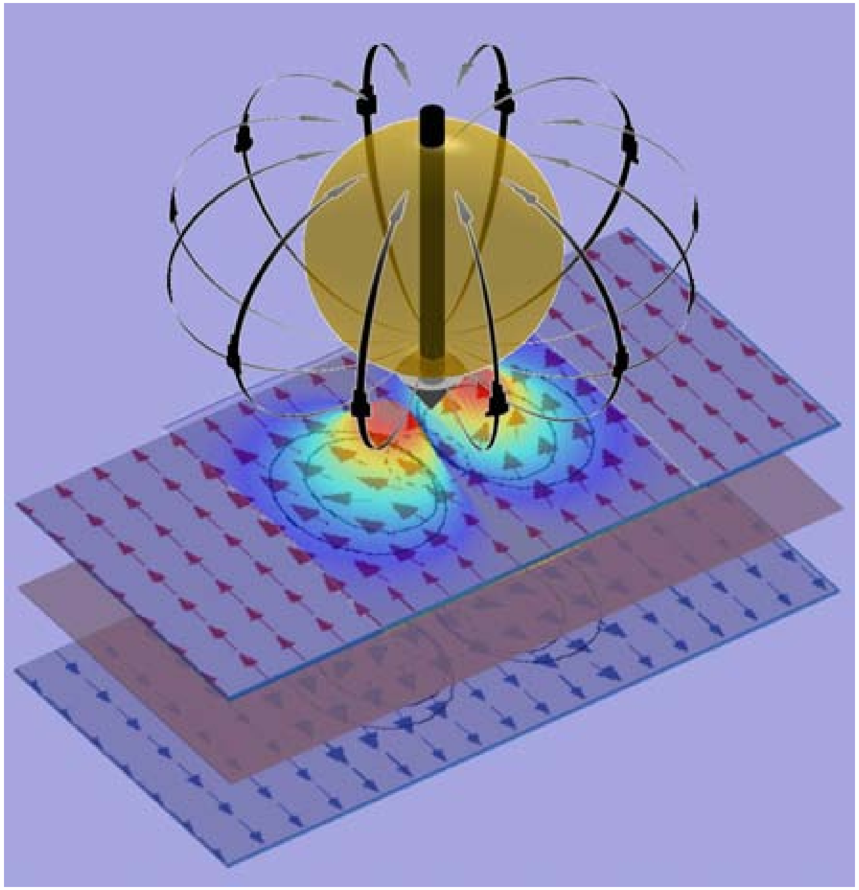


Not to scale!



MNP fringe field sensed by small portion of sensor area. [Courtesy of BRL]

Sensor Performance Parameters

- Transfer characteristics
  - Output voltage vs. applied magnetic field
    - Linear response, shape anisotropy
- Sensitivity (V/Oe or V/V-Oe)
  - Obtained by numerical differentiation of transfer curve
    - MgO barriers and soft magnetic free layers
- Intrinsic Noise (V/√Hz)
  - Measured with spectrum analyzer
    - Size matters!
- Detectivity (T/√Hz)
  - Noise/Sensitivity, approximates minimum detectable field
    - Requirements depend on MNP and separation
- Other parameters
  - Drift, dynamic range

Challenges

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- Increase Signal
  - Integrate soft magnetic layers with high-TMR MgO-based MTJ stack
  - Identify soft magnetic films: Ni77Fe14Cu5Mo4 (Conetic)
  - Overcome effects of orange peel coupling, magnetization ripple, shape anistropy: pre-oxidation treatment, ion beam assisted deposition, single crystal AFM pinning layers, synthetic AFM layers, elliptical shapes

- Reduce low frequency noise
  - Reduce medium-energy charge traps in barrier/interface
  - Reduce domain wall hopping
  - Reduce effects of drifting in temperature, power supply: Wheatstone bridge
  - Up-convert signal above sensor and electronics 1/f noise corner

Scheme III: Magnetic NPs & Interfacing with MTJ Sensors

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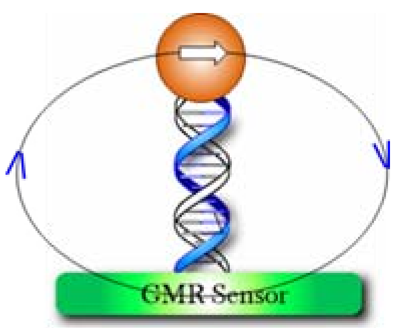
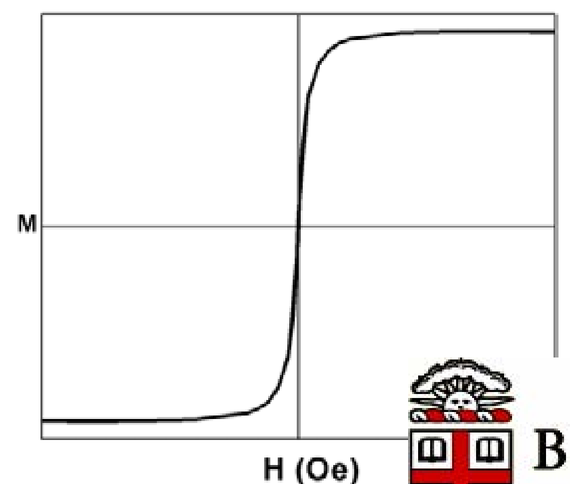
Dynabeads (> 1 micron) ⇒ ~10 emu/cc
(Particles too big, low moment density)

γ-Fe_2O_3 ⇒ ~340 emu/cc
Fe_3O_4 ⇒ ~420 emu/cc
MFe_2O_4 ⇒ up to 450 emu/cc
(Medium moment density; chemical and magnetic stability)

Co ⇒ ~1422 emu/cc
Fe ⇒ ~1714 emu/cc
CoFe ⇒ ~1950 emu/cc
(High moment density but air sensitive)

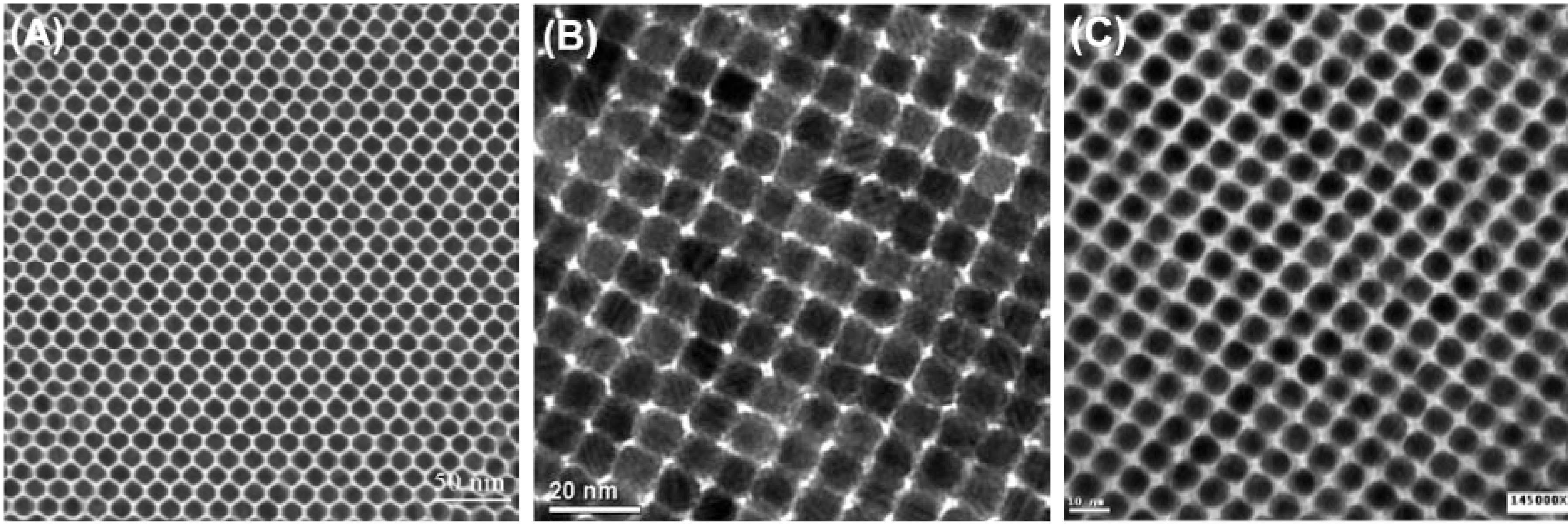
- **High saturation moment per particle.**
- **Superparamagnetic.**
- **Uniform size.**
- **Specific binding.**
- **Stable in physiological conditions.**





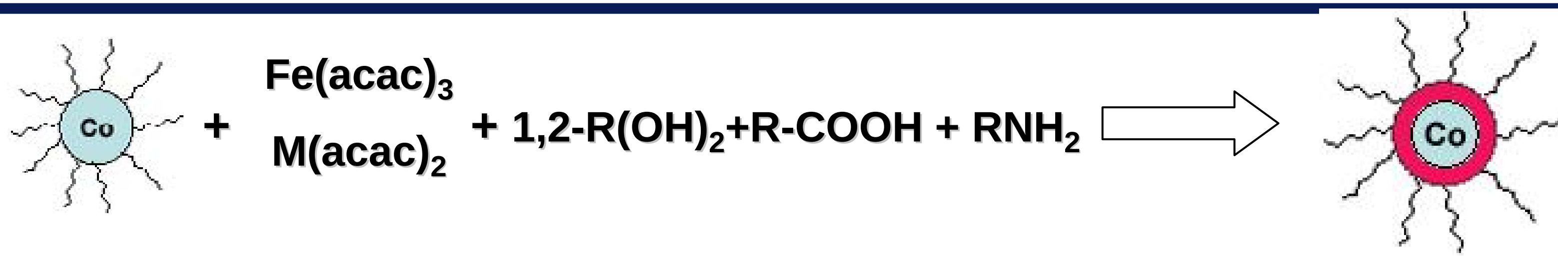
BROWN

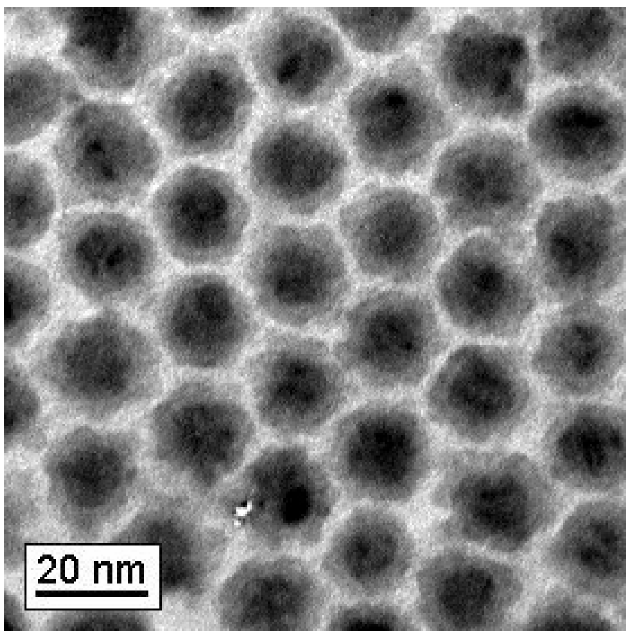
Examples of Magnetic Nanoparticles



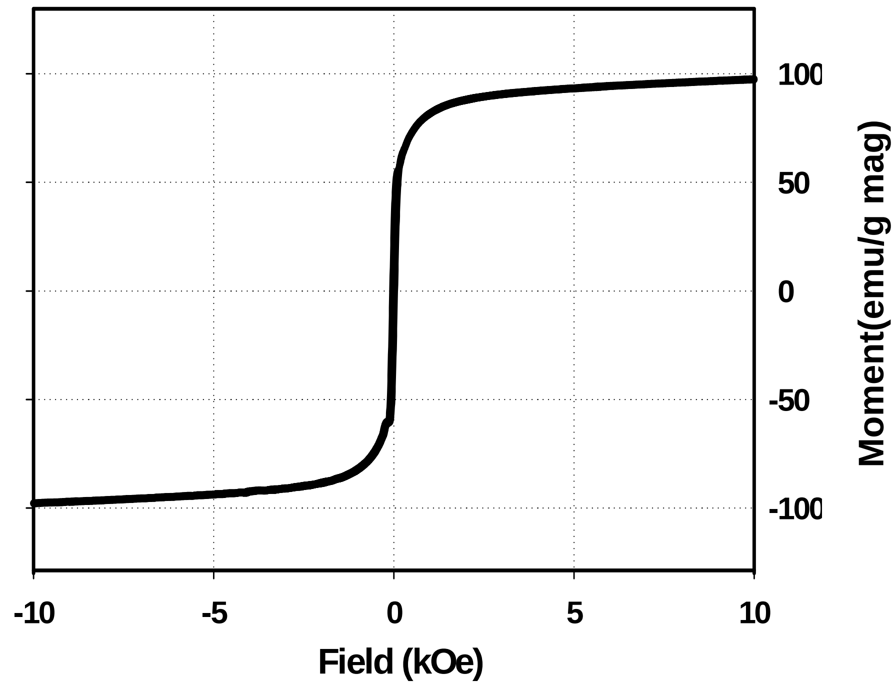
(A) 11 nm Co NPs
(B) 10 nm Fe3O4 NPs
(C) 6 nm FePt NPs

Co/MFe$_2$O$_4$ Core-Shell NPs





10 nm/3 nm Co/MnFe$_2$O$_4$
Core/shell NPs

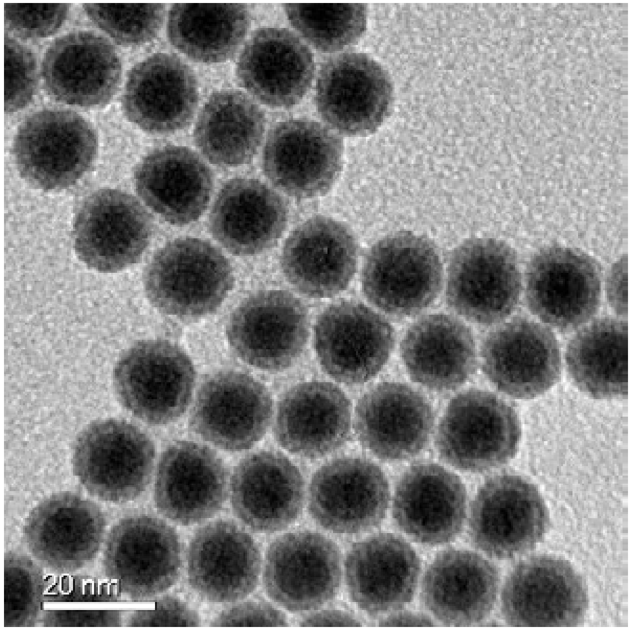


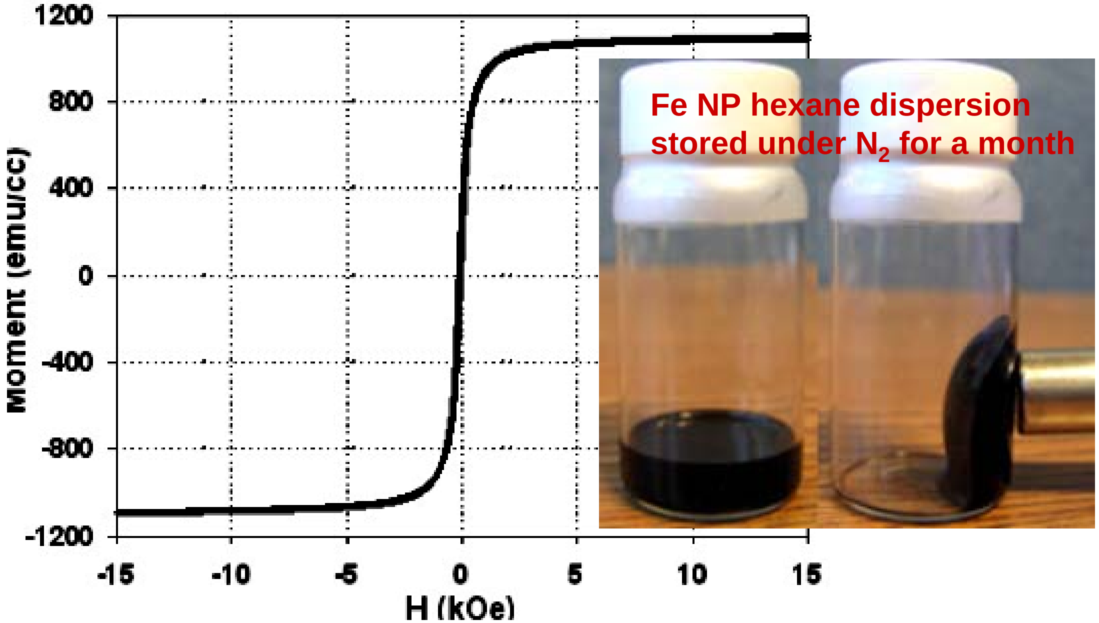
Saturation moment 100 emu/g mag

Tunable shell thickness : 1nm~5 nm

High Moment Fe Nanoparticles

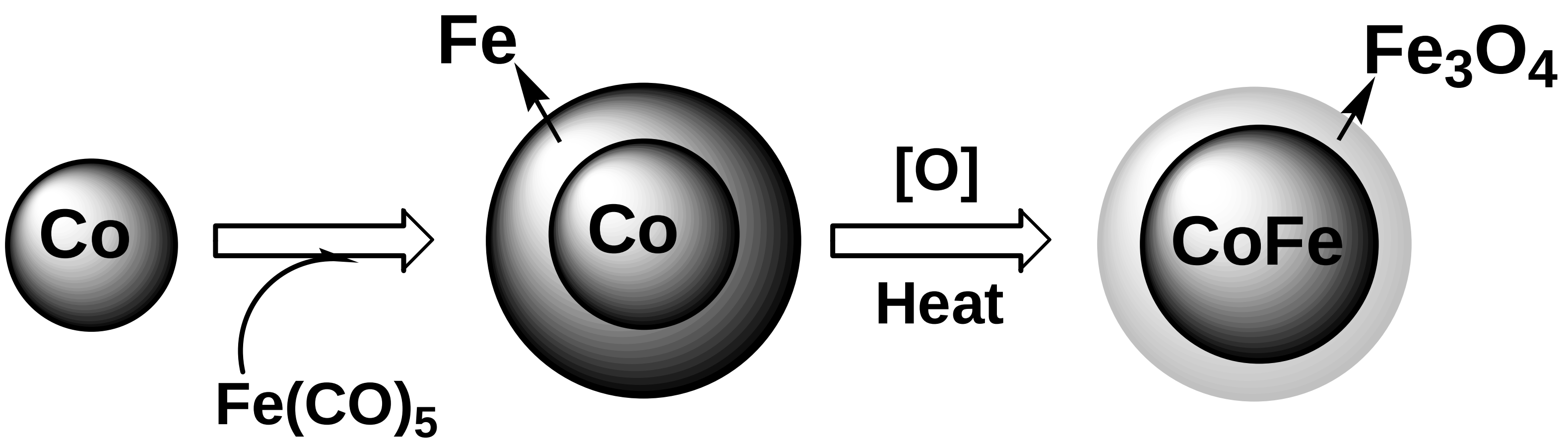
Oleylamine + Alkane + $Fe(CO)_5$ → Fe NPs





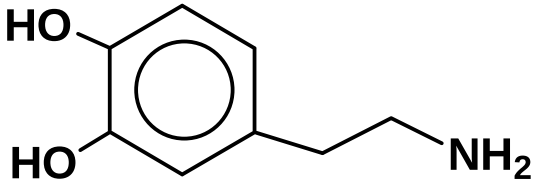
Superparamagnetic with high saturation moment
~140emu/g Fe = ~1100emu/cc

High Moment CoFe Nanoparticles - Proposed Synthesis

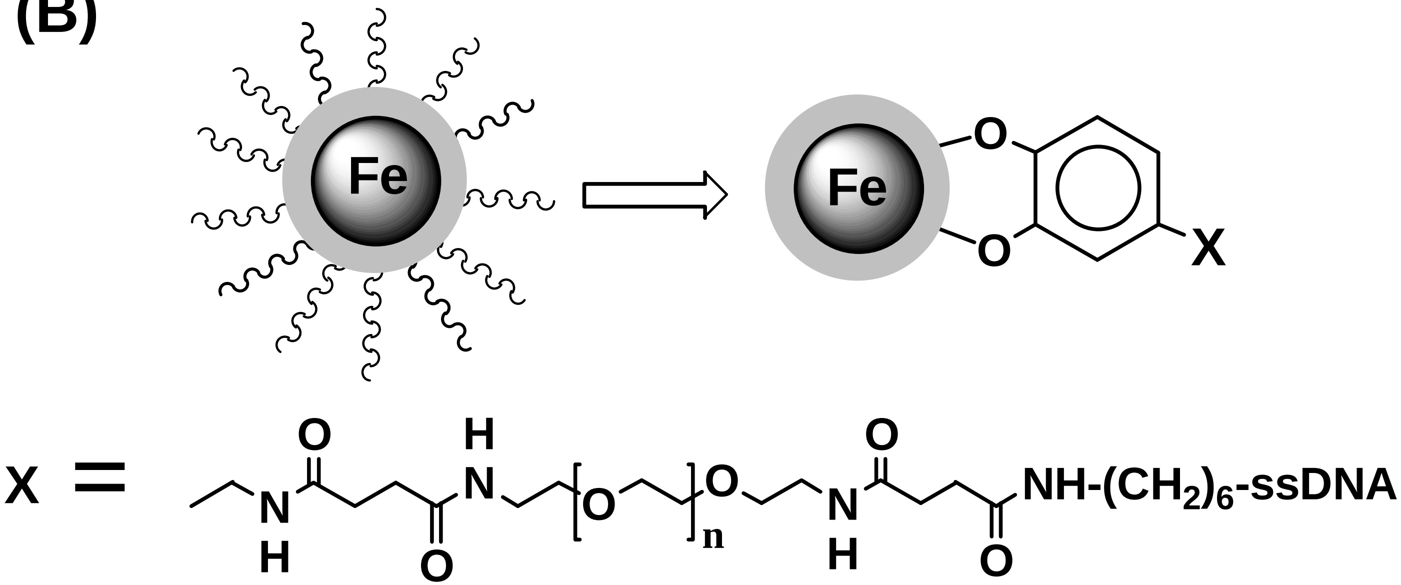


Surface Modification of Fe/Fe_3O_4 nanoparticles

(A)



(B)



Proposed Magnetic Nanoparticle Binding to Sensor Surface via DNA Hybridization

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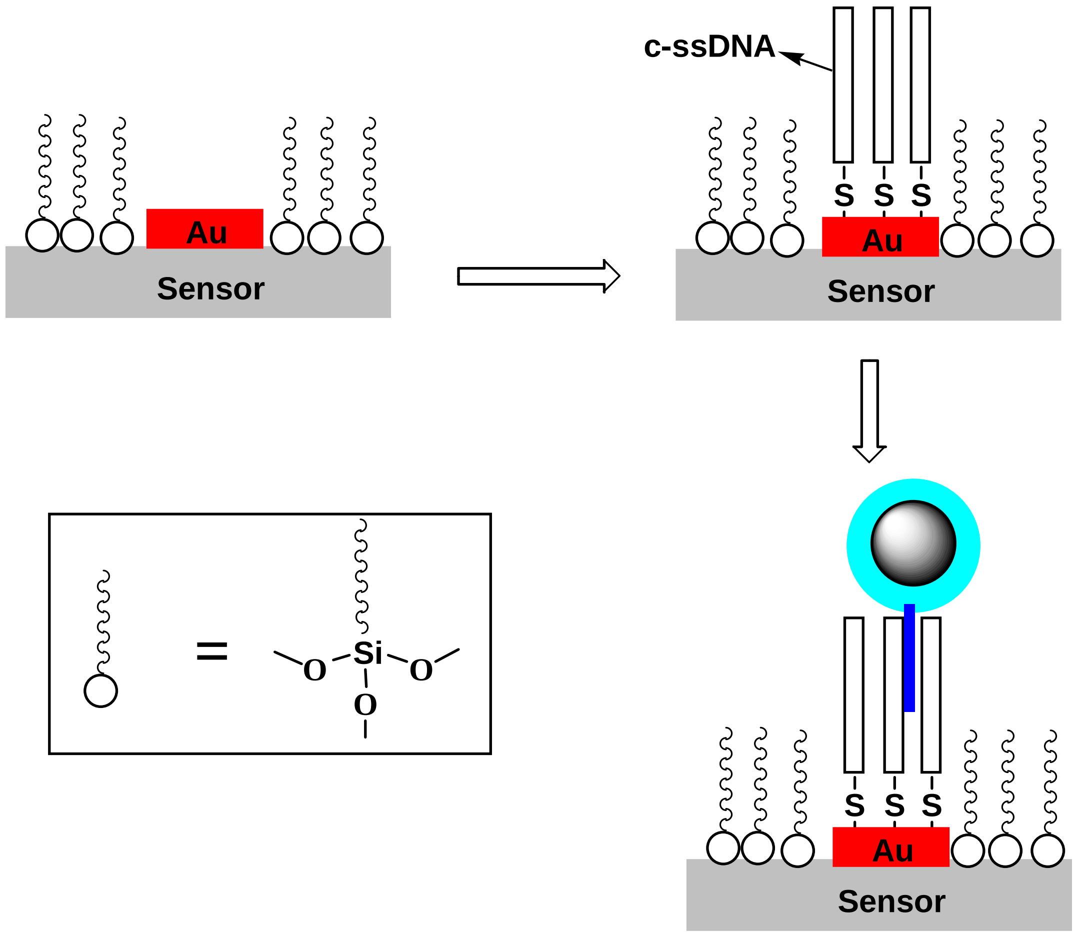
Non-specific binding is avoided by coating the rest of the surface with alkyl-Si-O



Scheme IV: Outresearch

- Underrepresented groups
  - Project 1000, the GEM Consortium,
  - *Louis Stokes Alliances for Minority Participation (LSAMP)*
  - *the Ronald E.* McNair Program, and relationships with faculty from HBCU and MI institutions (e.g., Cheney Univ., Delaware State Univ. and Lincoln Univ.).
  - developing an assessment and evaluation data set
- Undergraduate student
  - Delaware EPSCoR network.