بسم الله الرحمن الرحیم

Nanomagnetism in Science and Technology

P. Kameli

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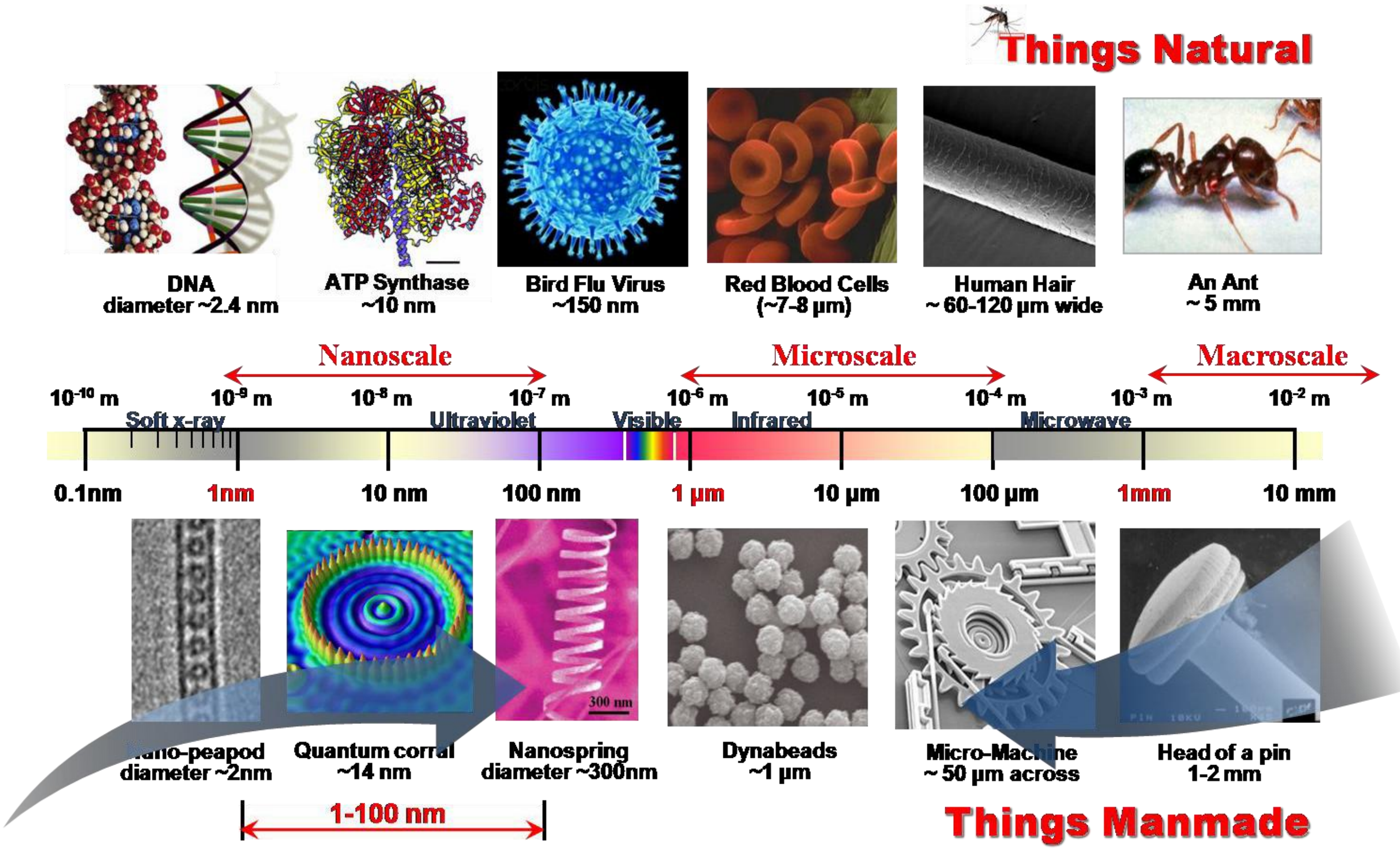
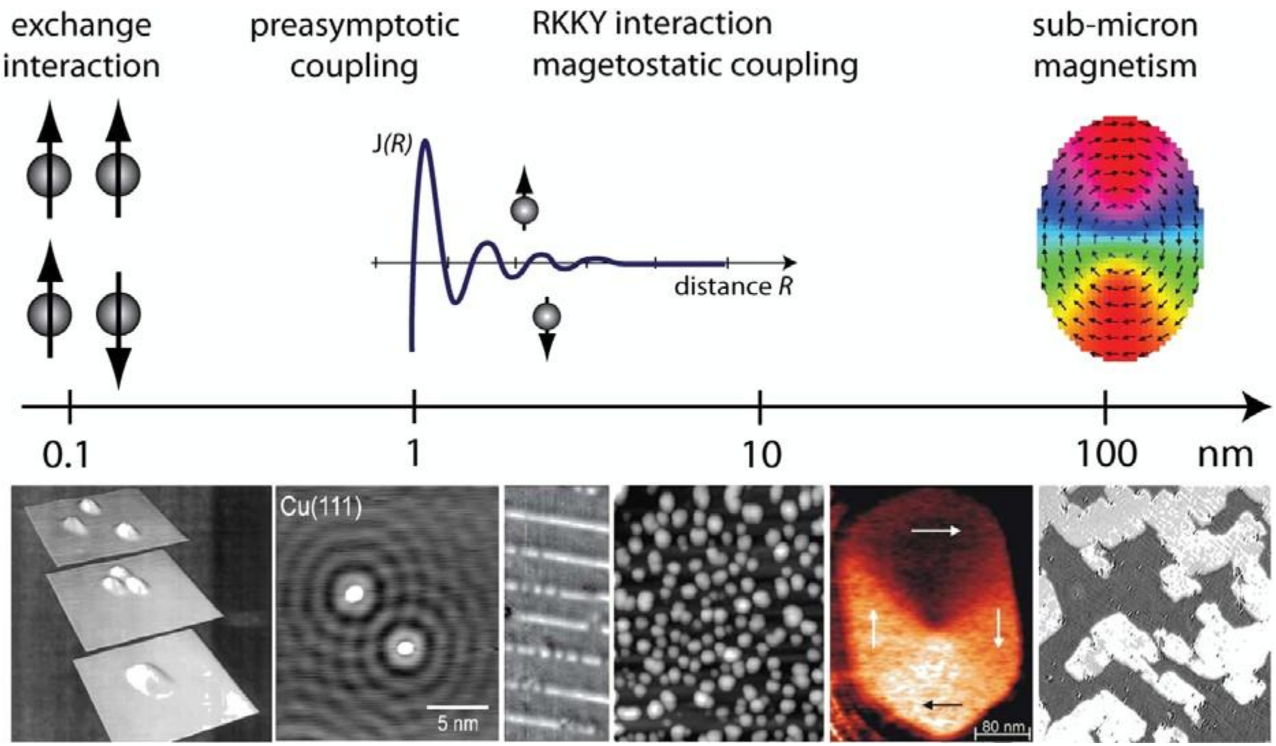
Nanotechnology



Relevant length scales in magnetism



A. Enders, et al. (2010)

Nanotechnology

There is plenty of room at the bottom.

Creation of functional (novel) materials, devices and systems through control of matter on nanometer length scale ~ 1-100 nm range.

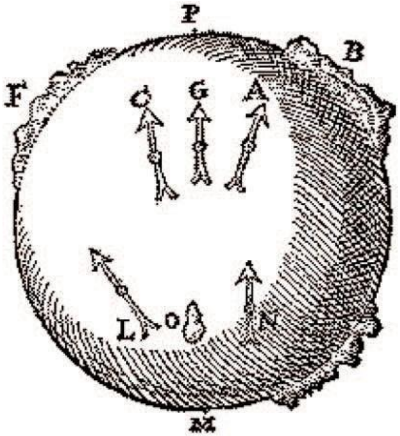
The deviation of properties of nanoscale materials from bulk materials properties are due to " surface effects ".

When characteristic length scale of microstructure is 1-100 nm it becomes comparable with the critical length scales of physical phenomena –so called "size and shape effects".

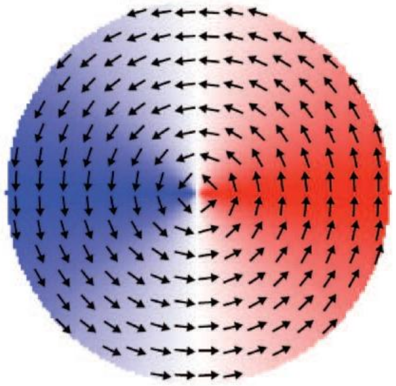
Motivations in nanoscience is to understand how materials behave when sample sizes are close to atomic dimensions.

History

Magnetism is one of the oldest scientific disciplines, but one also at the forefront of the emerging nanotechnology era.



De Magnete, published in 1600 by William Gilbert

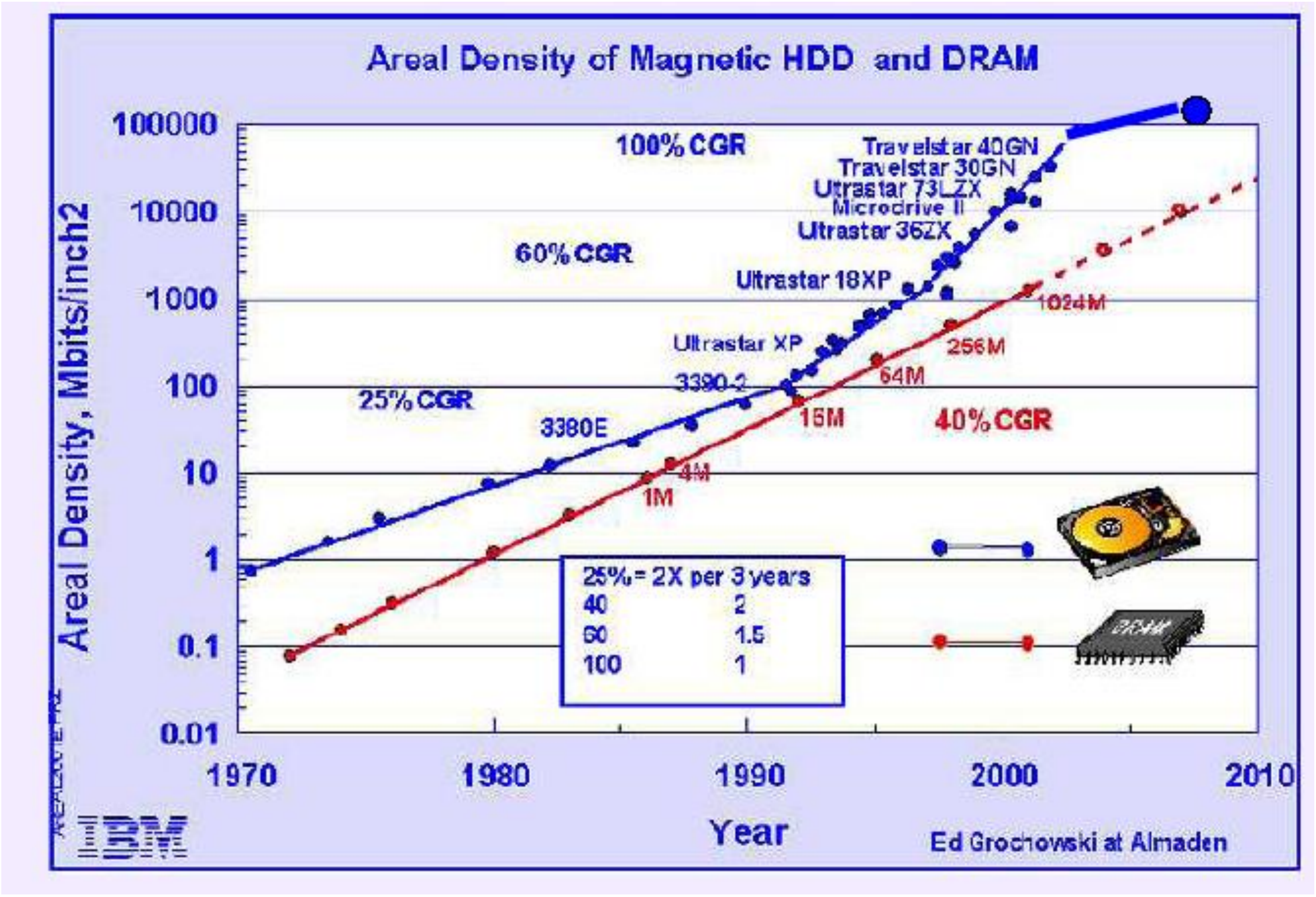


Vortex structure of submicron ferromagnetic dot of permalloy S. D. Bader (2006)

S. D. Bader (2006)

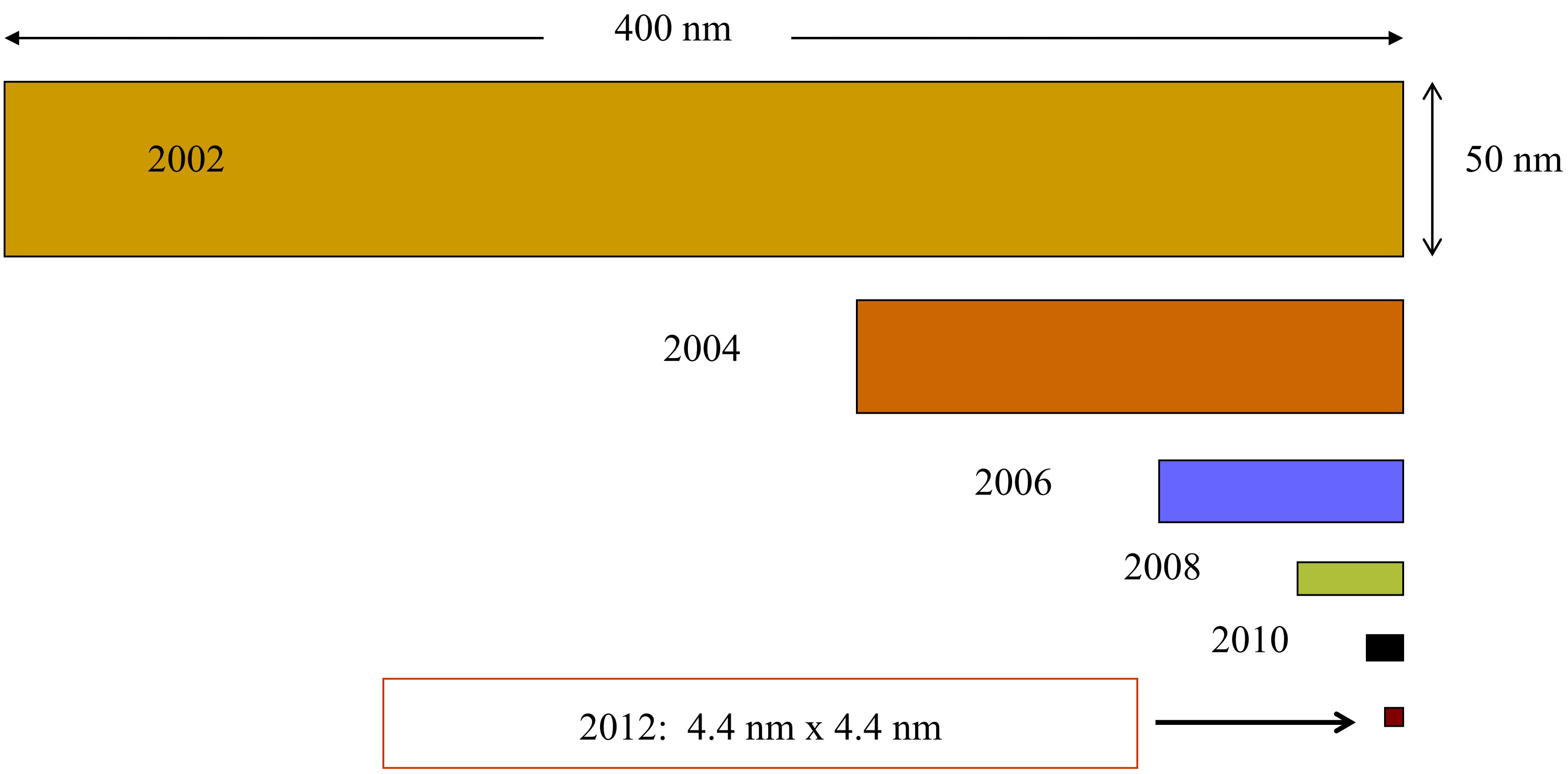
Nanomagnetism in Technology

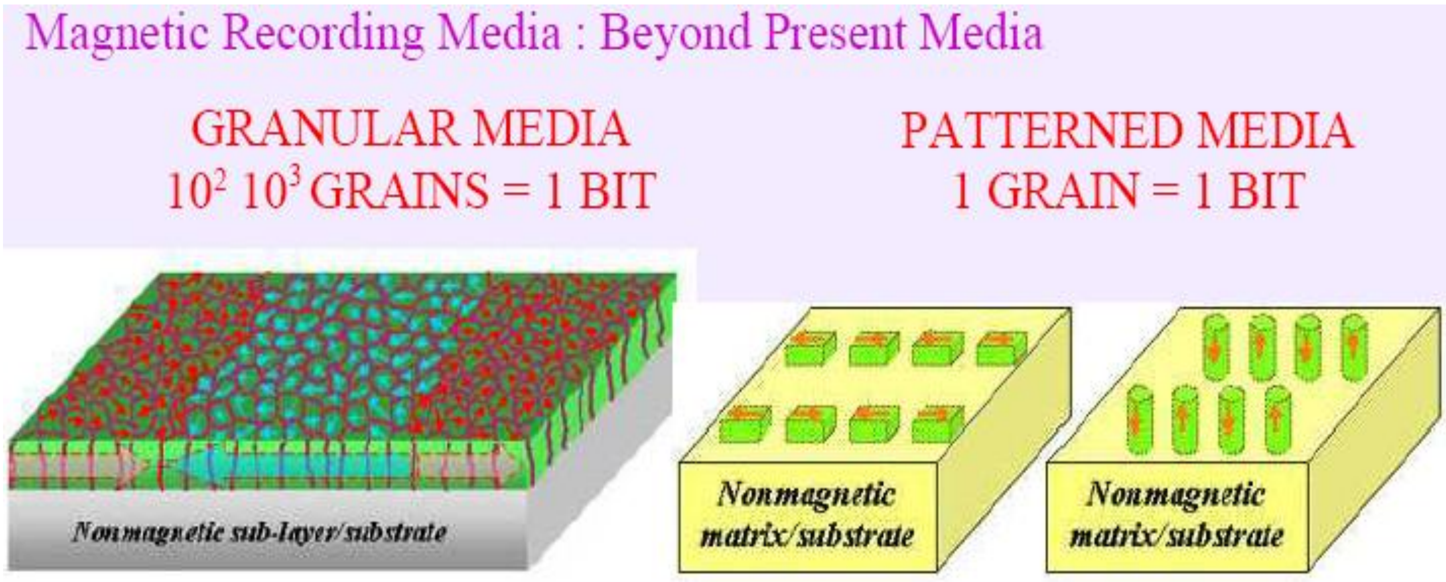
Ultra High Density Media (Hard Disk Drive)

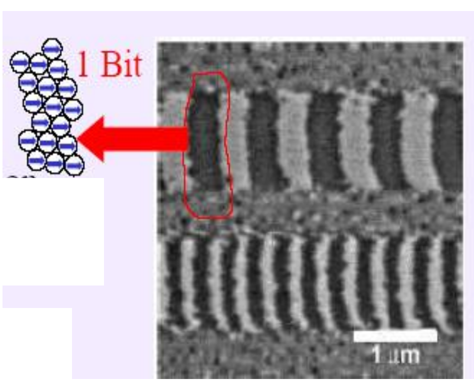


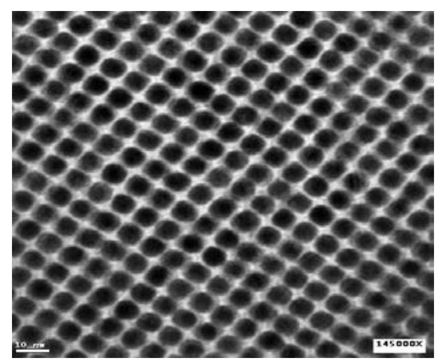
Magnetic recording media

The Incredible Shrinking Bit!
Predicted Relative Sizes of HDD Storage Bits

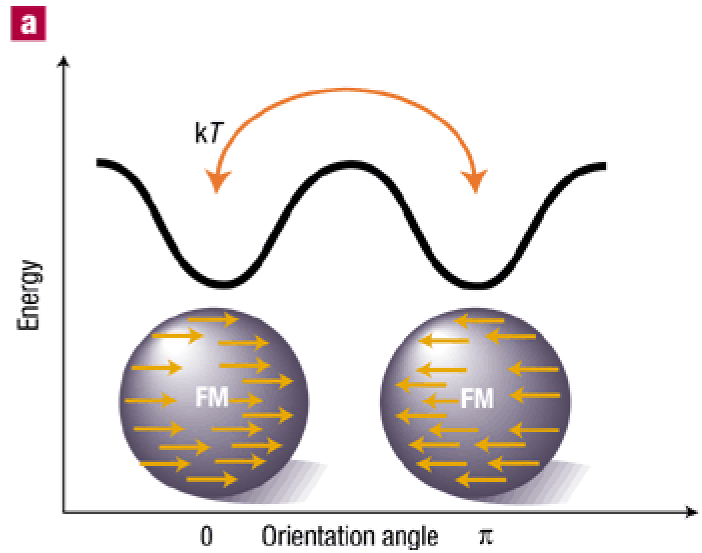


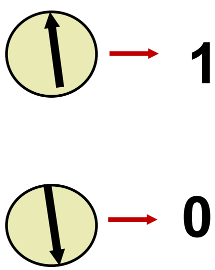

Magnetic Recording Media : Beyond Present Media
GRANULAR MEDIA
10² 10³ GRAINS = 1 BIT
PATTERNED MEDIA
1 GRAIN = 1 BIT
Nonmagnetic sub-layer/substrate
Nonmagnetic matrix/substrate
Nonmagnetic matrix/substrate


1 Bit
1 µm



CoPt





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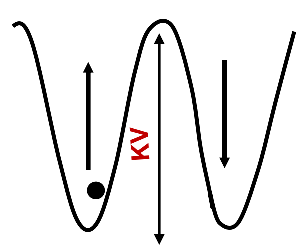
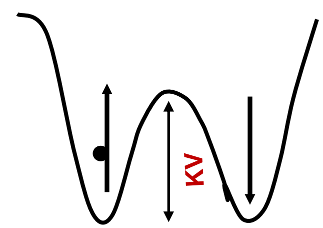
010110100011

110001011010100
001010111010011
101111010100111
110001011010100



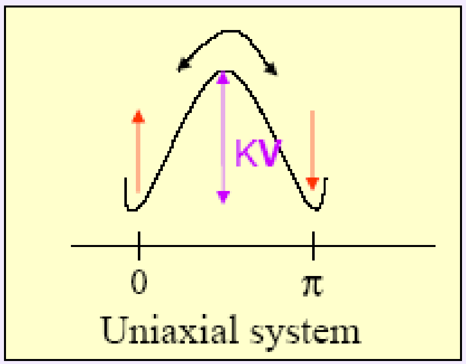


Magnetic Recording Media : A physical limit : Superparamagnetism

Remanent state is bistable

if anisotropy energy < thermal energy

i.e. $KV < kT$



thermal relaxation time, τ

$\tau = \tau_0 \exp(KV / kT)$

$1/\tau_0$ is the attempt frequency ($\tau_0 \approx 10^{-9}$ s)

Superparamagnetism

lower limit to the size of a stable ferromagnetic particle

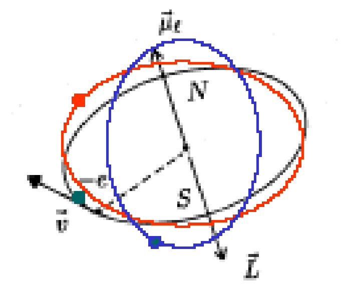
for data storage want $\tau >$ 10 years

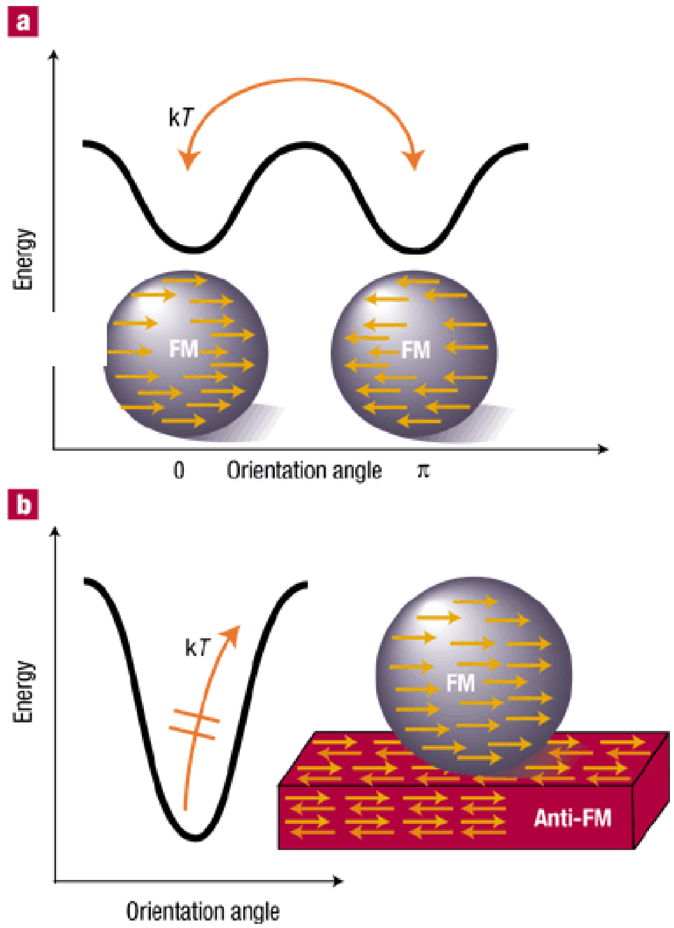
i.e. must have $KV / kT > 60$

at 300 K

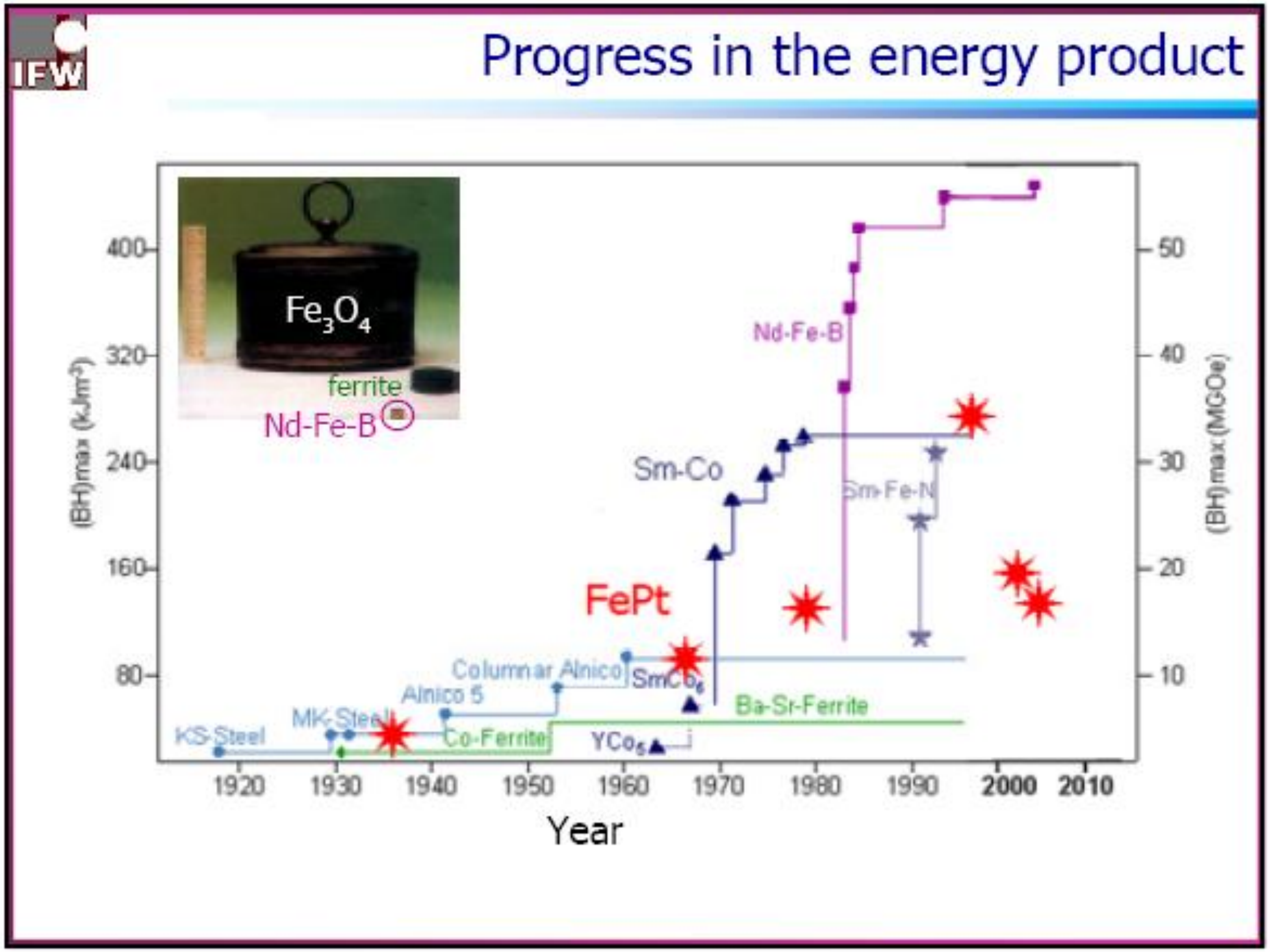
	K_1 (MJ/m^3)	ϕ_{min} (nm)
Fe	0.05	20
Co	0.5	8
$Nd_2Fe_{14}B$	5	4
$SmCo_5$	17	2

* Looking for materials with higher spin-orbit coupling

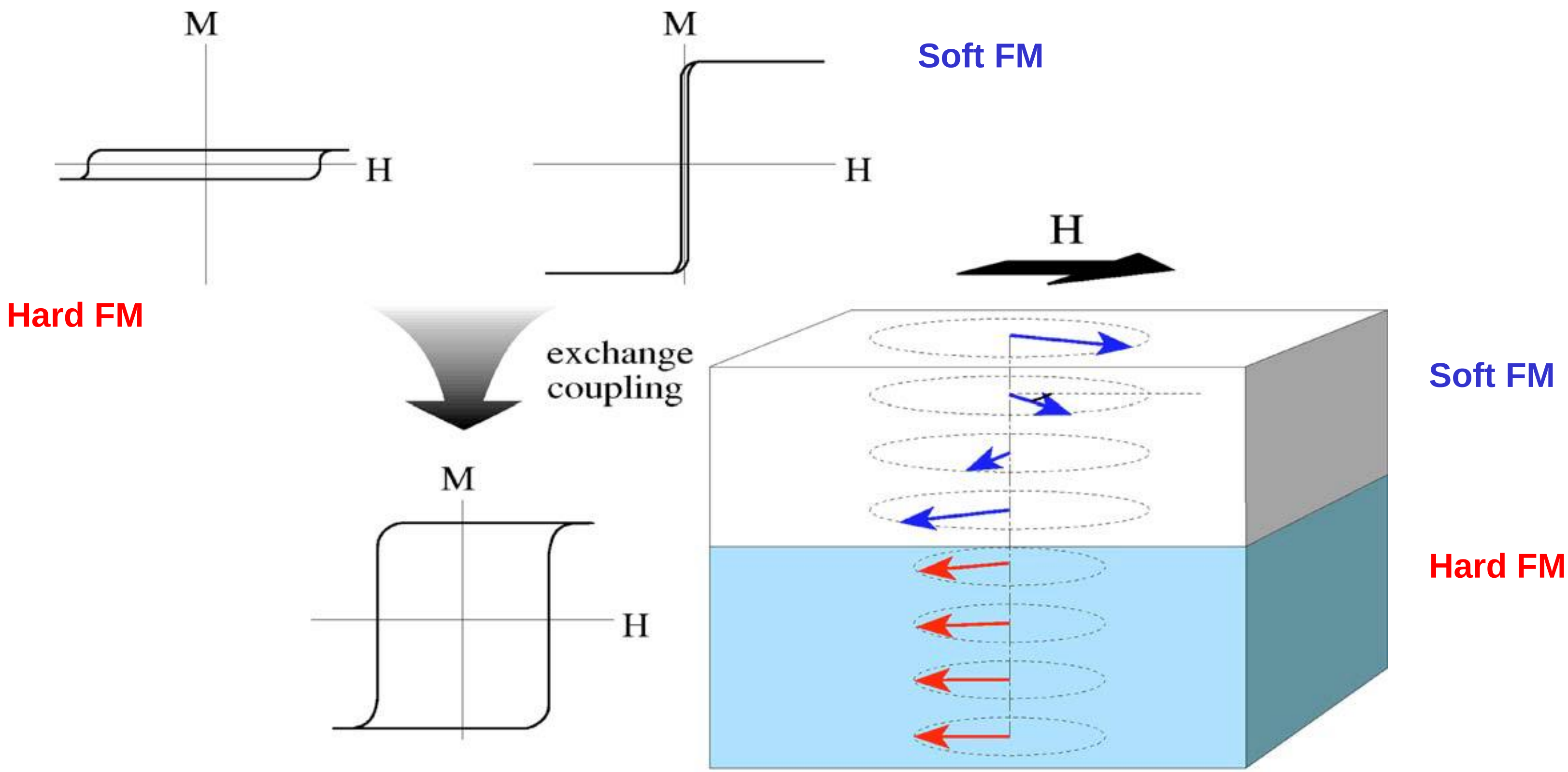




Ultrastrong Permanent Magnet



Exchange spring (Hard-Soft Nanocomposite)



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Letters to Nature

Nature **420**, 395-398 (28 November 2002) | doi:10.1038/nature01208; Received 15 July 2002; Accepted 10 October 2002

Exchange-coupled nanocomposite magnets by nanoparticle self-assembly

Hao Zeng[1,2], Jing Li[3], J. P. Liu[2], Zhong L. Wang[3] & Shouheng Sun[1]

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2. Institute for Micromanufacturing, Louisiana Tech University, Ruston, Louisiana 71272, USA
3. School of Materials Science and Engineering, Georgia Institute of Technology, Atlanta, Georgia 30332, USA

Correspondence to: Shouheng Sun[1] Correspondence and requests for materials should be addressed to S.S. (e-mail: Email: ssun@us.ibm.com).

Exchange-spring magnets are nanocomposites that are composed of magnetically hard and soft phases that interact by magnetic exchange coupling[1]. Such systems are promising for advanced permanent magnetic applications, as they have a large energy product—the combination of permanent magnet field and magnetization—compared to traditional, single-phase materials[1, 2, 3]. Conventional techniques, including melt-spinning[4, 5, 6], mechanical milling[7, 8, 9] and sputtering[10, 11, 12], have been explored to prepare exchange-spring magnets. However, the requirement that both the hard and soft phases are controlled at the nanometre scale, to ensure efficient exchange coupling, has posed significant preparation challenges. Here we report the fabrication of exchange-coupled nanocomposites using nanoparticle self-assembly. In this approach, both FePt and Fe_3O_4 particles are incorporated as nanometre-scale building blocks into binary assemblies. Subsequent annealing converts the assembly into FePt–Fe_3Pt nanocomposites, where FePt is a magnetically hard phase and Fe_3Pt a soft phase. An optimum exchange coupling, and therefore an optimum energy product, can be obtained by independently tuning the size and composition of the individual building blocks. We have produced exchange-coupled isotropic FePt–Fe_3Pt nanocomposites with an energy product of 20.1 MG Oe, which exceeds the theoretical limit of 13 MG Oe for non-exchange-coupled

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ABSTRACT
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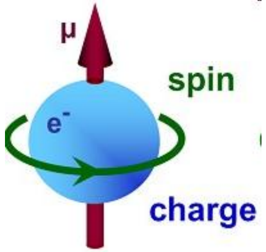
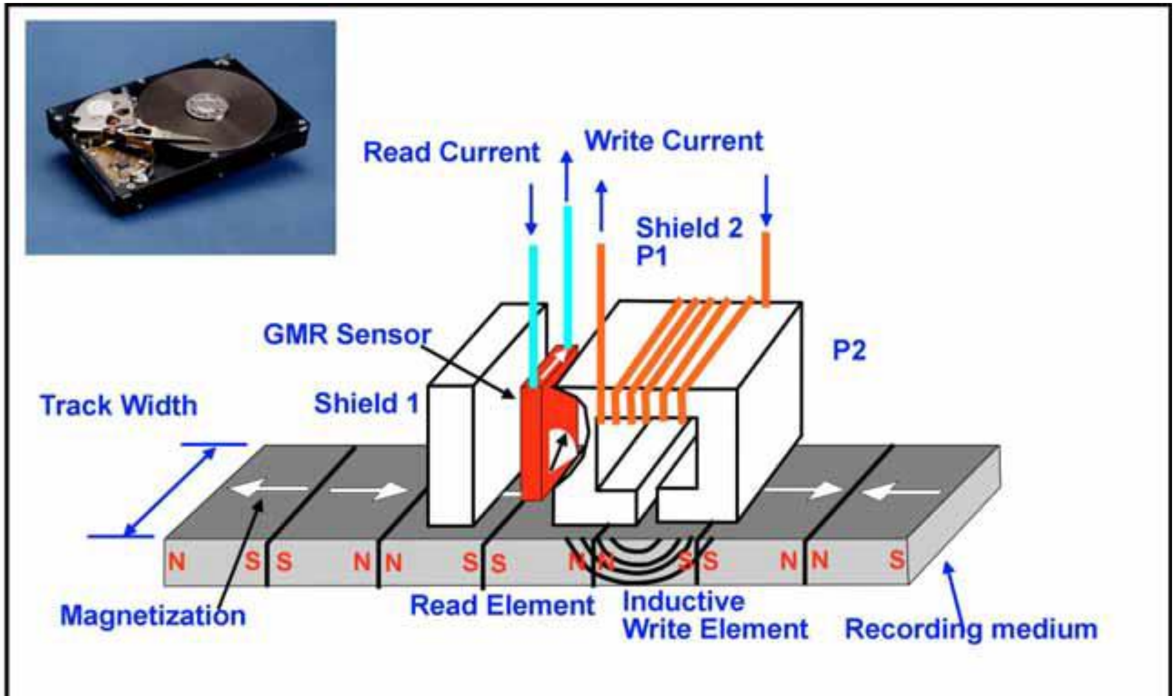
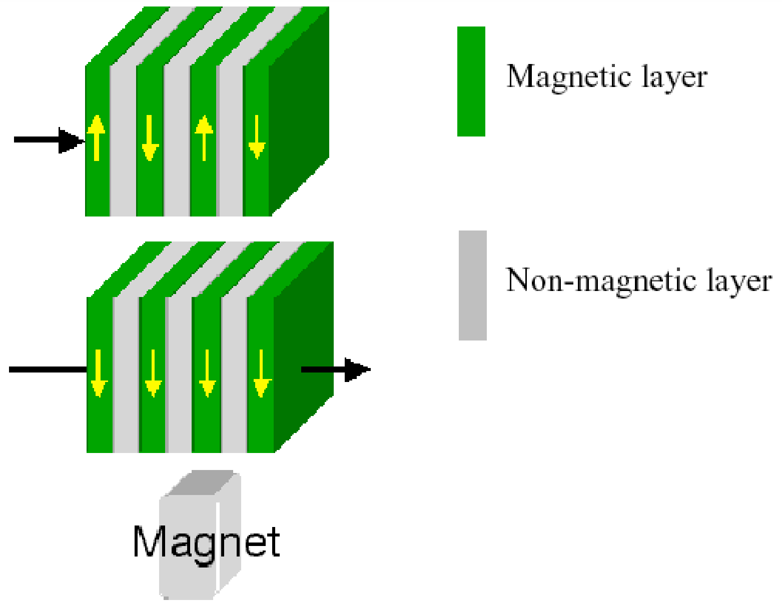


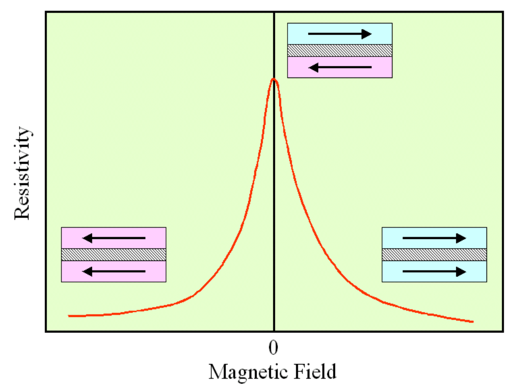


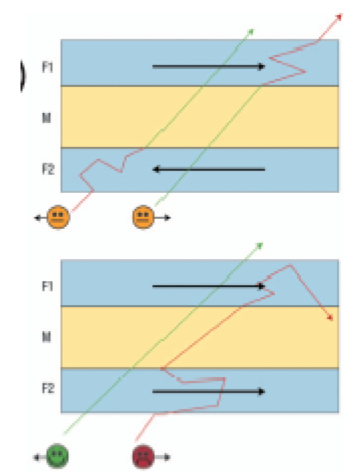
Magnetic recording process.

Ed Grochowski
IBM Almaden Research Center

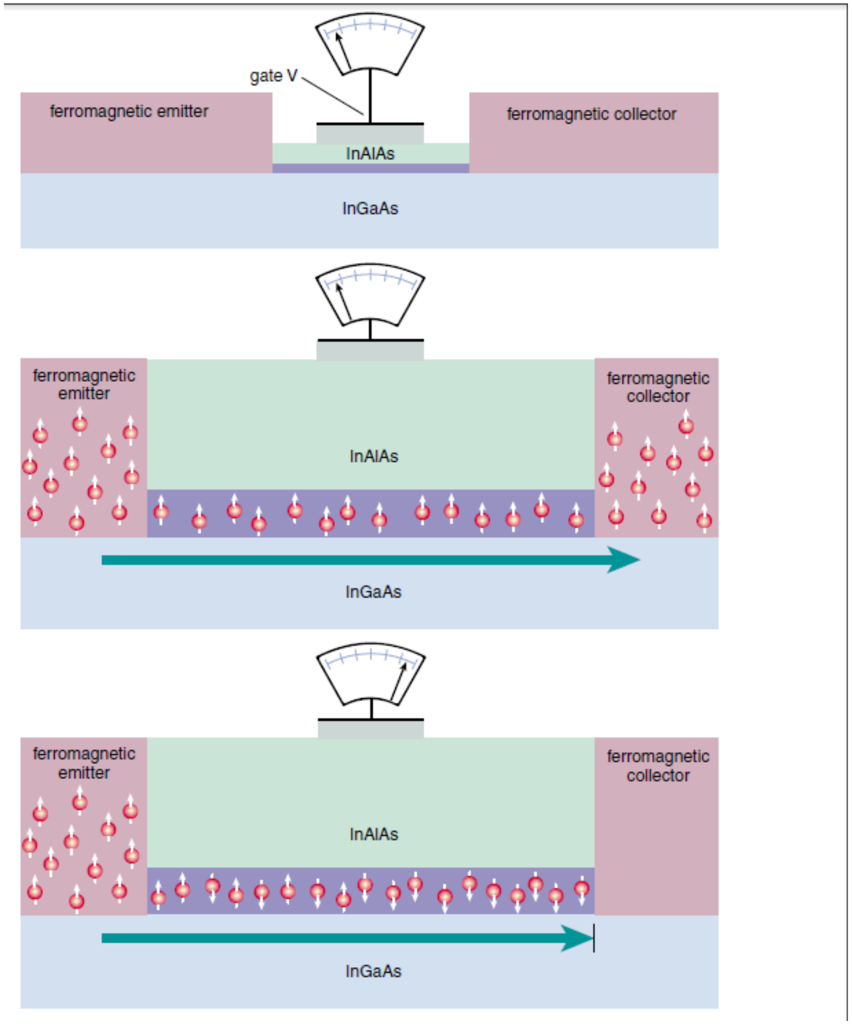
Giant magnetoresistance (GMR)



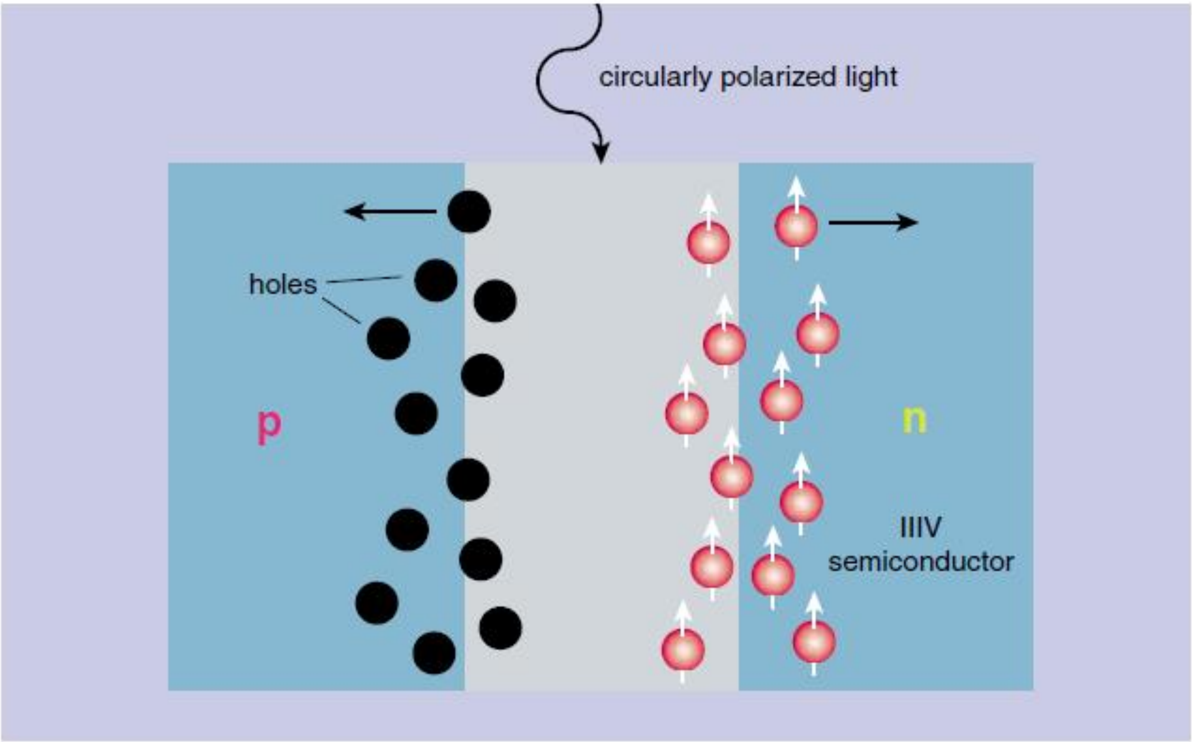




Spin Transistor



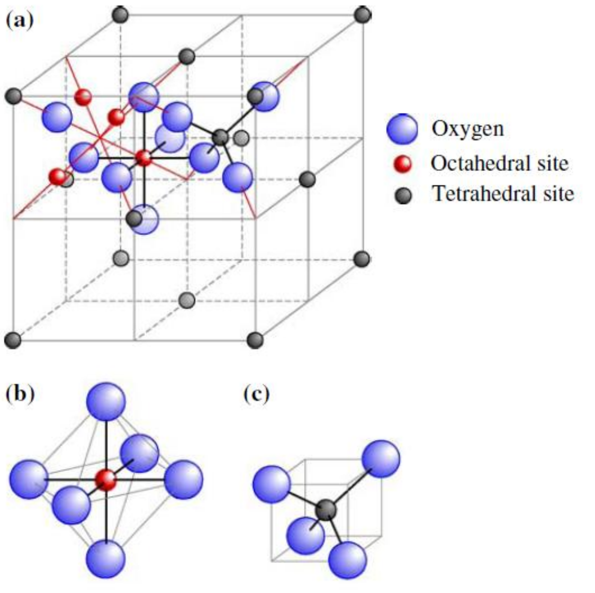
Spintronic solar Cell



Magnetic nanoparticles

1- Superparamagnetic Iron Oxide Nanoparticles (SPION)

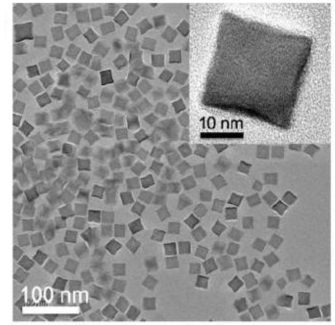
Spinel Ferrites, MFe_2O_4 M= Fe, Mn, Co, Ni, Zn



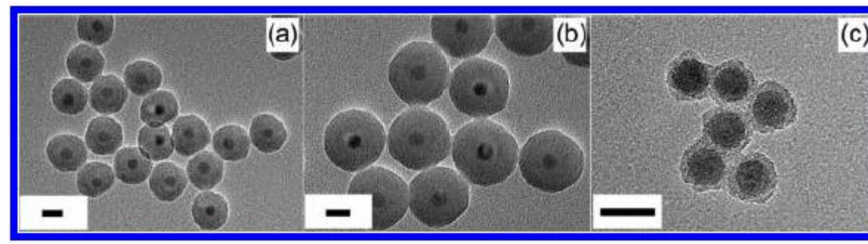
2- Transition metals and some alloys

Fe, Co, Ni, FeCo, FeNi, FePt,….

The magnetic properties of nanoparticles are determined by the:

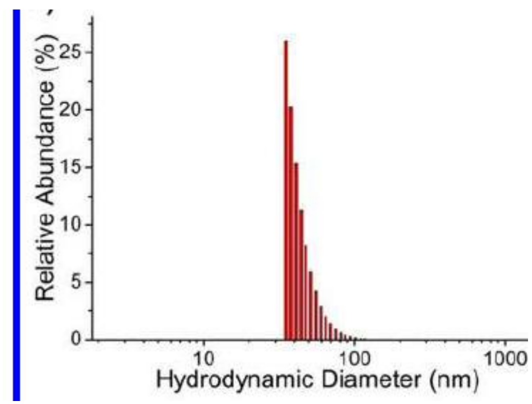


1-Chemical composition



2- Particle shape

3- Particle size



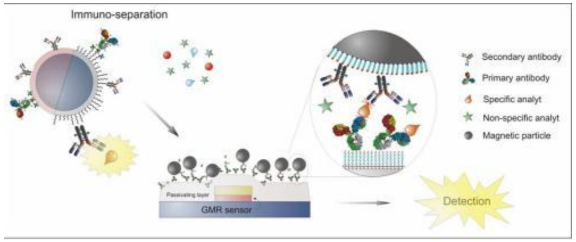
4-Size distribution

N. Lee, et al, Nano. Lett, (2012) .

Applications of magnetic nanoparticles

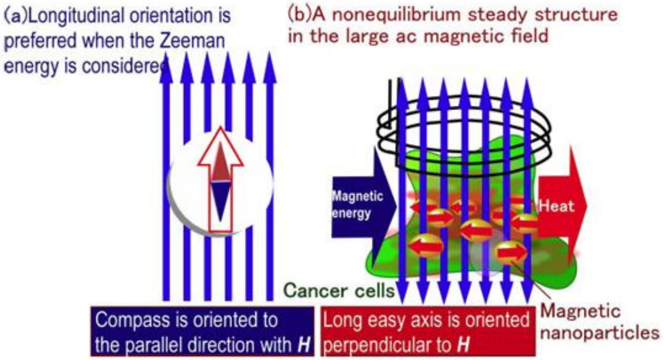
Ferrofluids

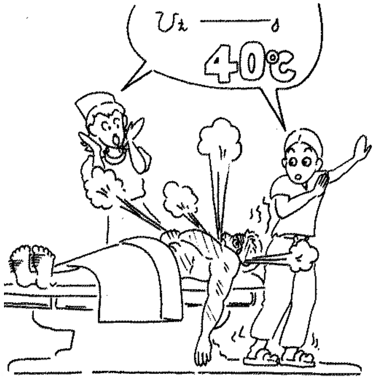
Biosensors



Contrast enhancement agents for MRI

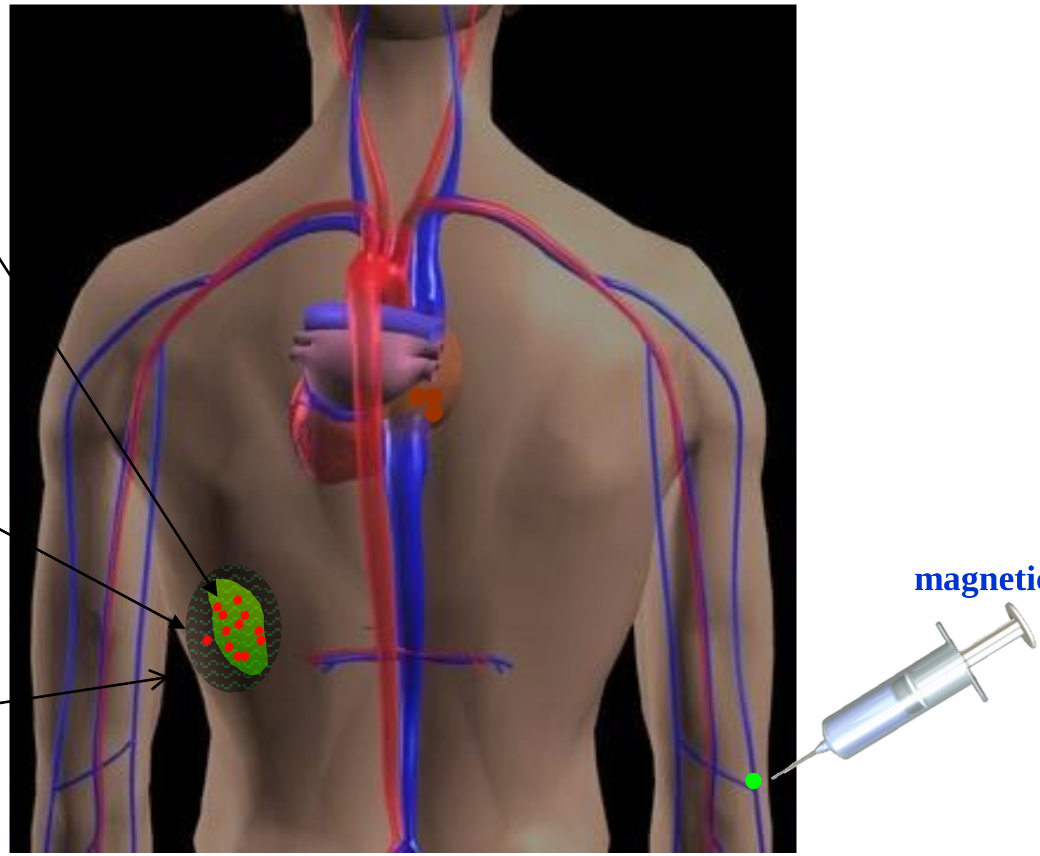
Hyperthermia





. . .

Magnetic hyperthermia



The effect of dipole interactions on magnetic losses

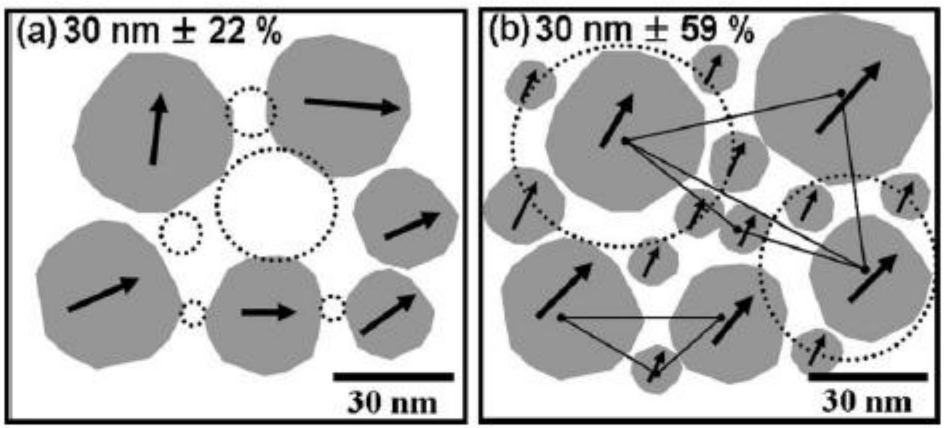
APPLIED PHYSICS LETTERS 95, 082501 (2009)

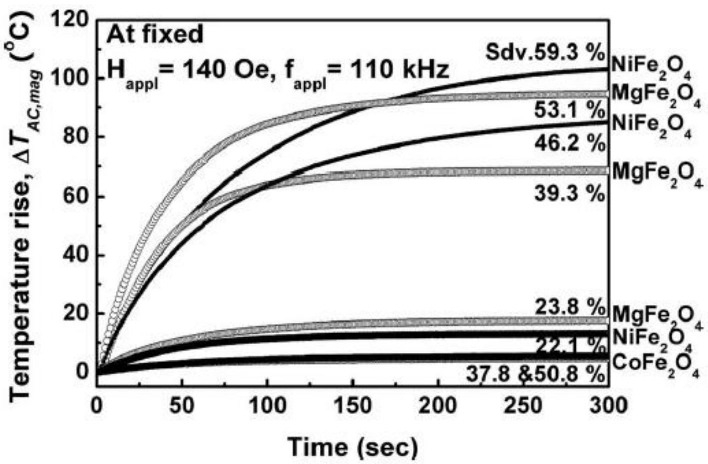
Effects of particle dipole interaction on the ac magnetically induced heating characteristics of ferrite nanoparticles for hyperthermia

Minhong Jeun,[1] Seongtae Bae,[1,a)] Asahi Tomitaka,[2] Yasushi Takemura,[2] Ki Ho Park,[3] Sun Ha Paek,[4] and Kyung-Won Chung[5]

positive

MFe2O4 (M=Mg,Ni,Co)





$$E_{\rm int} = \frac{m_1 m_2}{r^3}[\cos(\theta_1 - \theta_2) - 3\cos\theta_1\cos\theta_2], \qquad (1)$$

The effect of dipole interactions on magnetic losses

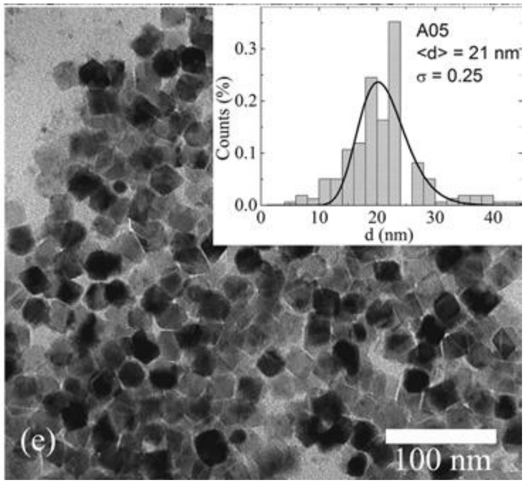
IOP PUBLISHING — JOURNAL OF PHYSICS D: APPLIED PHYSICS

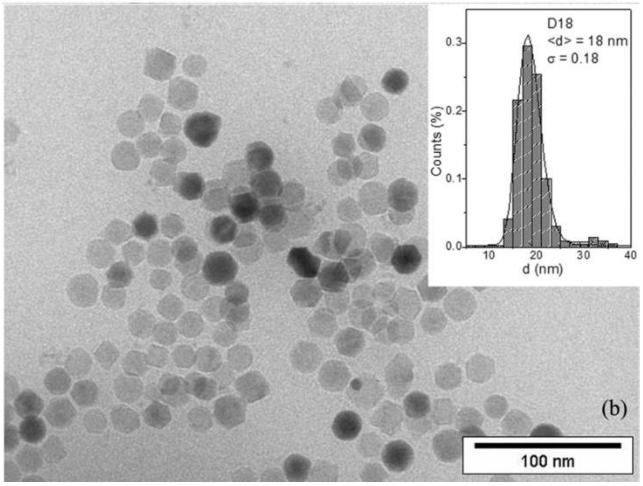
J. Phys. D: Appl. Phys. **46** (2013) 045002 (13pp) — doi:10.1088/0022-3727/46/4/045002

Heat generation in agglomerated ferrite nanoparticles in an alternating magnetic field

Negative

E Lima Jr[1], E De Biasi[1,4], M Vasquez Mansilla[1,4], M E Saleta[1], M Granada[1], H E Troiani[1], F B Effenberger[2], L M Rossi[2], H R Rechenberg[3] and R D Zysler[1]





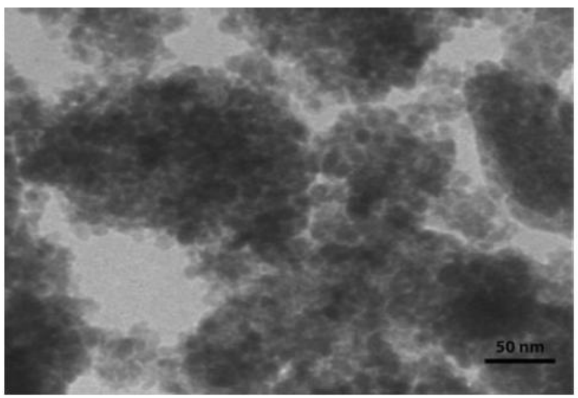
J Nanopart Res (2013) 15:1430
DOI 10.1007/s11051-013-1430-y

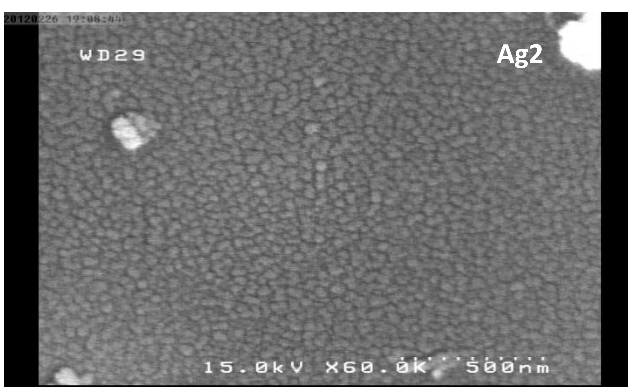
RESEARCH PAPER

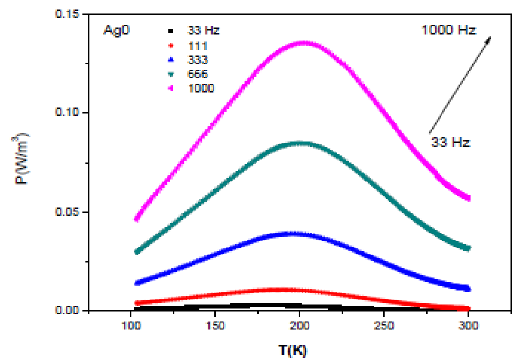
positive

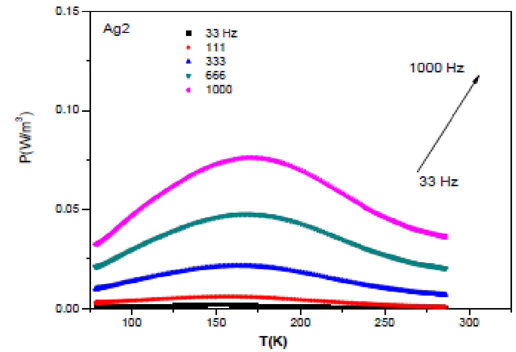
The role of Ag on dynamics of superspins in $MnFe_{2-x}Ag_xO_4$ nanoparticles

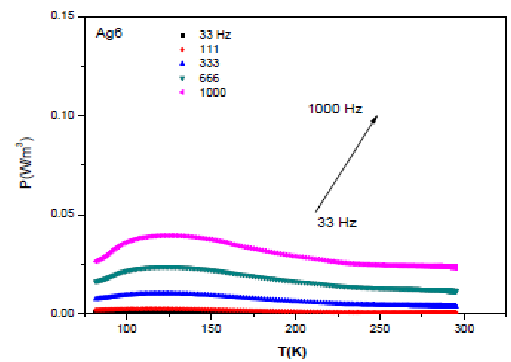
B. Aslibeiki · P. Kameli · H. Salamati











$$P = \pi\mu_0 \chi'' f H^2$$

Magnetite nanoparticles for medical MR imaging

By using ferrite nanoparticles the MRI image Contrast is modified considerably.

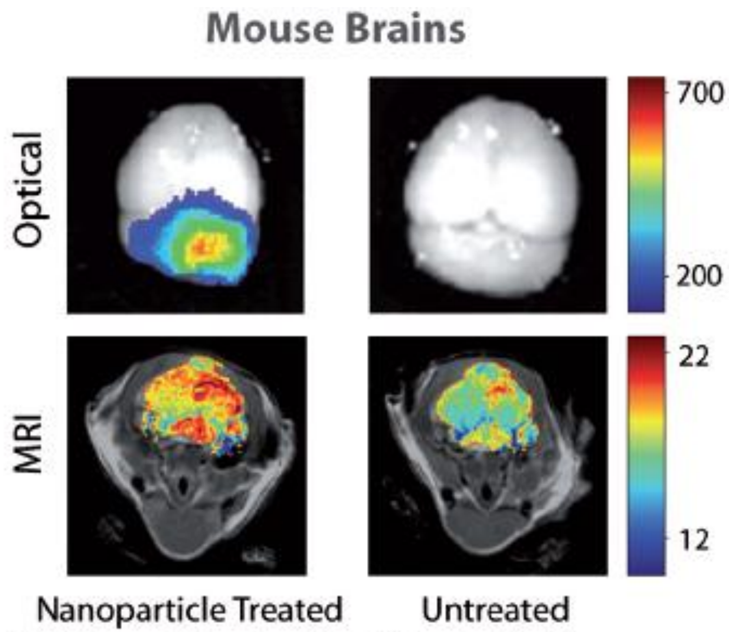
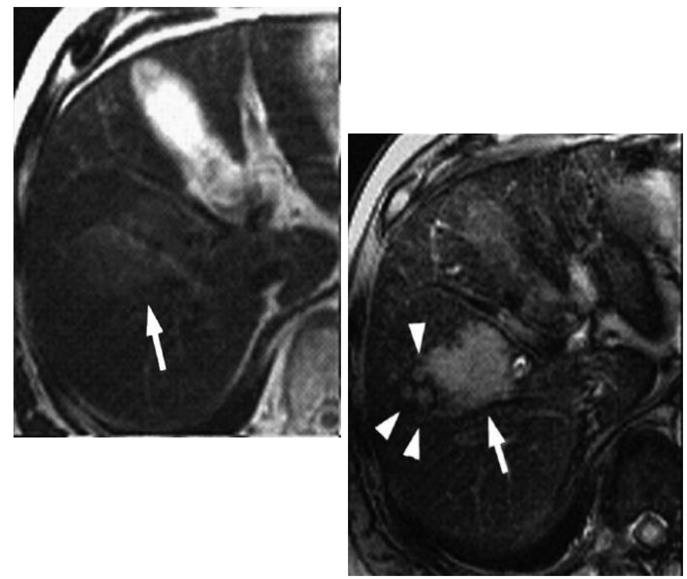


Fig. 7 Ex vivo optical imaging and in vivo MR imaging of brain tumors from a mouse treated with Cy5.5 labeled SPIONs (left) and an untreated mouse (right). The optical spectrum gradient bar corresponds to increasing fluorescent intensity. The color gradient bar for MR images corresponds to increasing r_2 values. Adapted with permission from[32], © 2010 American Association for Cancer Research.



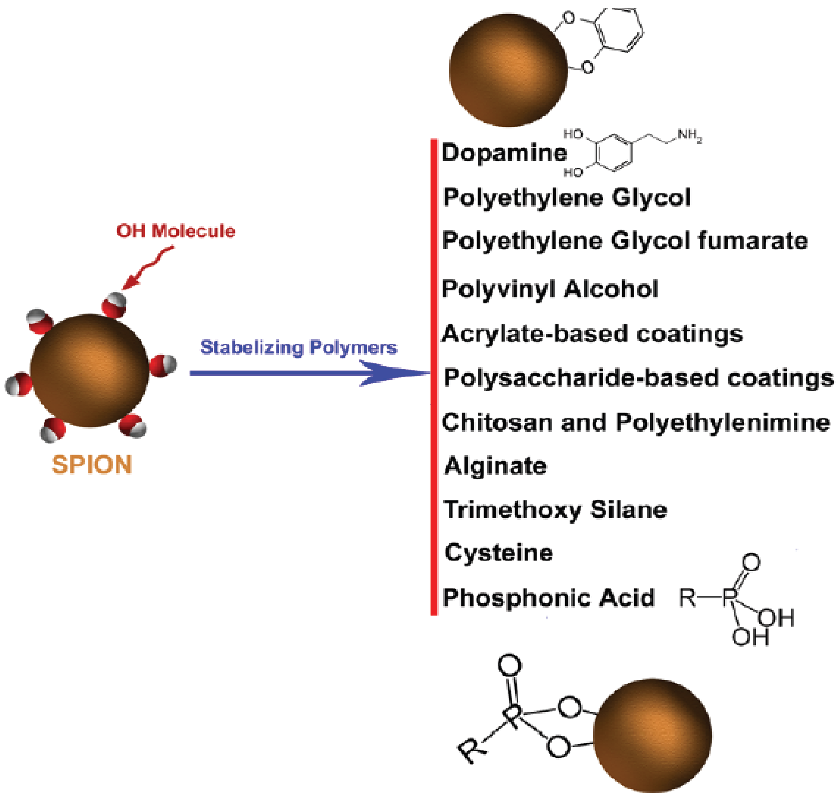
R. Zachary, Materials today ,14(2011)330.
Nanotechnology Newsletter, 170 (2011)

Int J Mol Epidemiol Genet 2011;2(4):367-390
www.ijmeg.org /ISSN1948-1756/IJMEG1111002

Review Article

Superparamagnetic iron oxide nanoparticles: promises for diagnosis and treatment of cancer

Sophie Laurent[1], Morteza Mahmoudi[2,3]



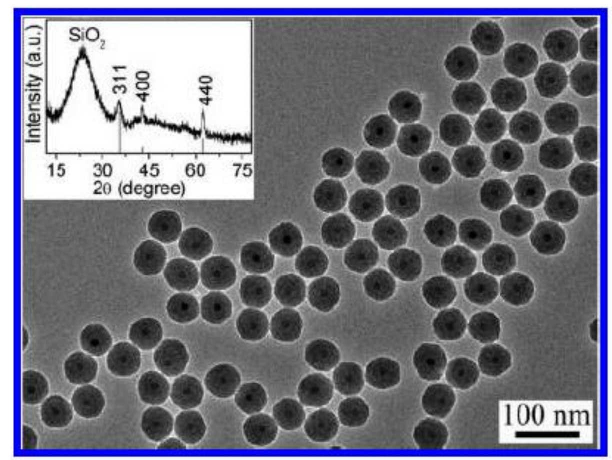


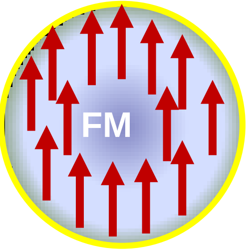
Figure 1. Scheme showing representative groups that can be used to stabilize the SPIONs.

Nanomagnetism in Science

Magnetic Nanoparticles

The magnetic properties of magnetic nanoparticles have considerable deviations from bulk behavior due to the:

a) Surface effects



$$\frac{S}{V} \approx \frac{1}{r}$$

Co : 1.6 nm

60% of atoms are on surface

b) Finite size effects

Some relevant Surface effects in the magnetic properties of magnetic fine particles:

Surface induced suppression of magnetization

$MnFe_2O_4$ nanoparticles

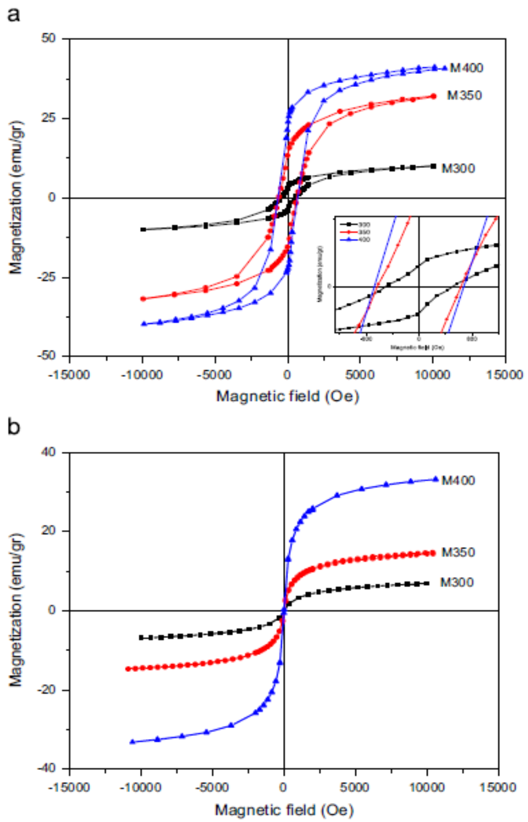
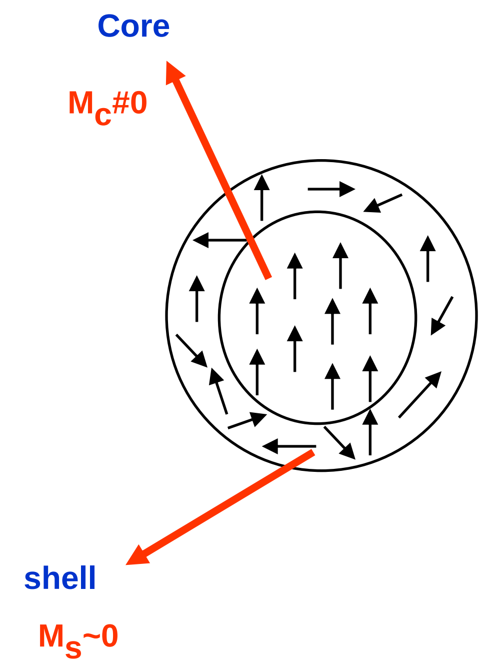


Fig. 3. (a) 5 K and (b) room temperature *M–H* curves of the samples annealed at different temperatures. The inset shows low field magnetization behavior.

B. Asli, P. Kameli, et al, J.MMM(2010).



Core-Shell Model

APPLIED PHYSICS LETTERS **95**, 043106 (2009)

Magnetic dead layer in ferromagnetic manganite nanoparticles

J. Curiale,[1,a),b)] M. Granada,[1,a),b)] H. E. Troiani,[1,a),b)] R. D. Sánchez,[1,a),b),d)] A. G. Leyva,[2,c)] P. Levy,[2,a)] and K. Samwer[3]

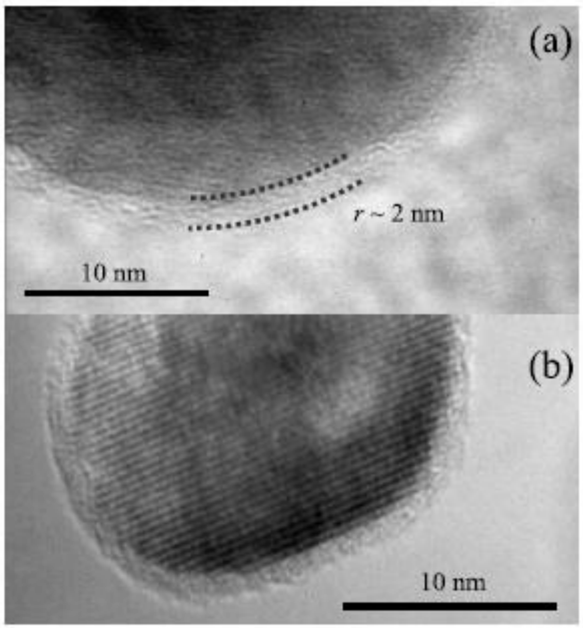
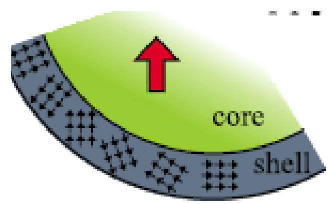
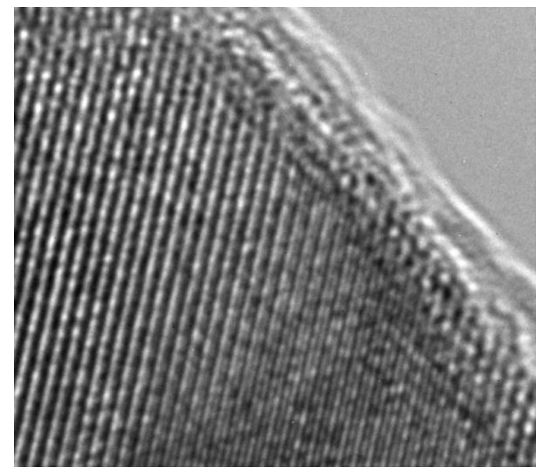


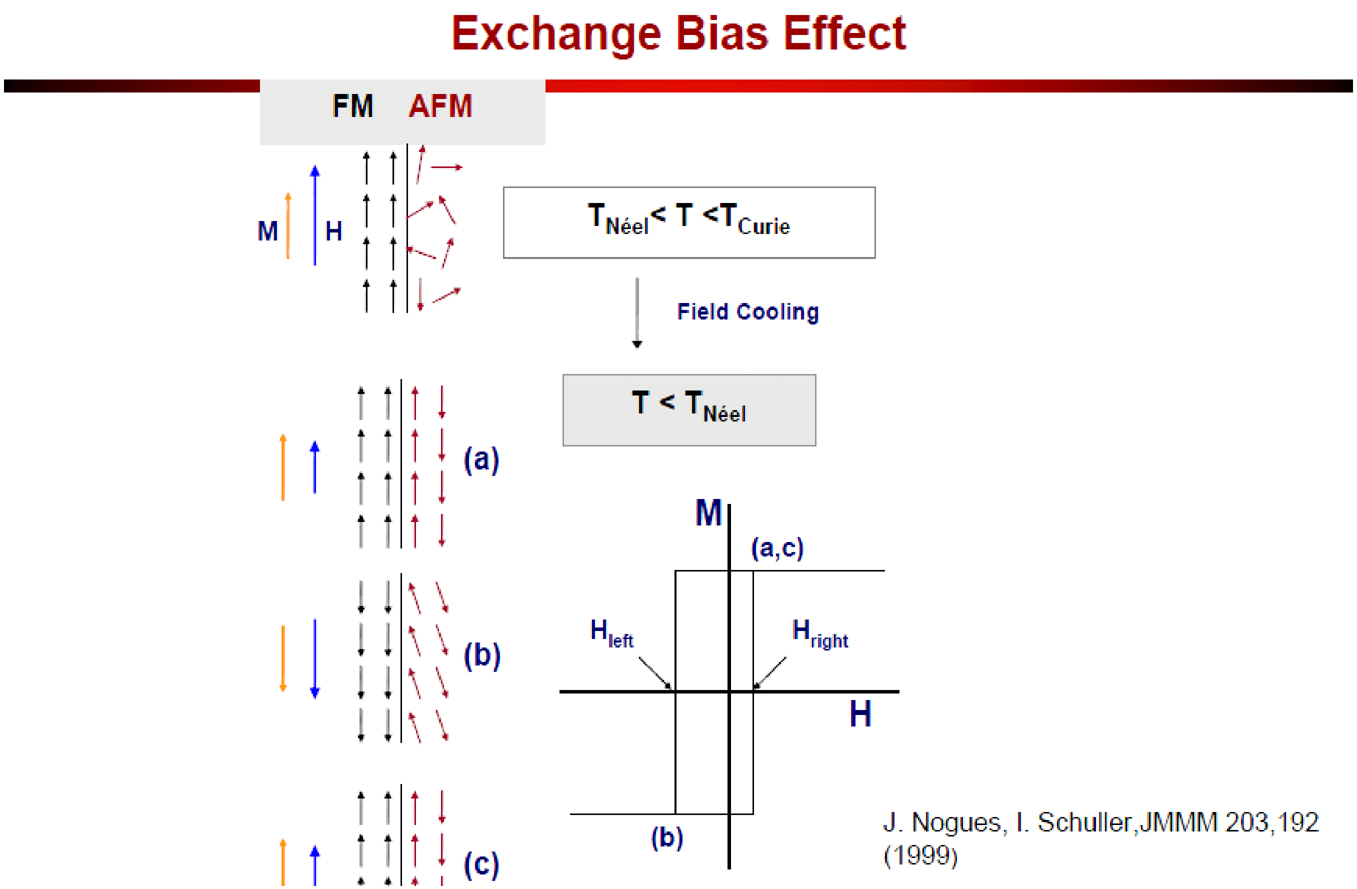
FIG. 2. HRTEM micrographs of LCMO (a) and LSMO (b) nanograins. In panel (a) the noncrystalline layer of approximately 2 nm thickness is indicated by a dot line. In panel (b), the atomic planes of the ordered core and the noncrystalline surface region are clearly distinguished.





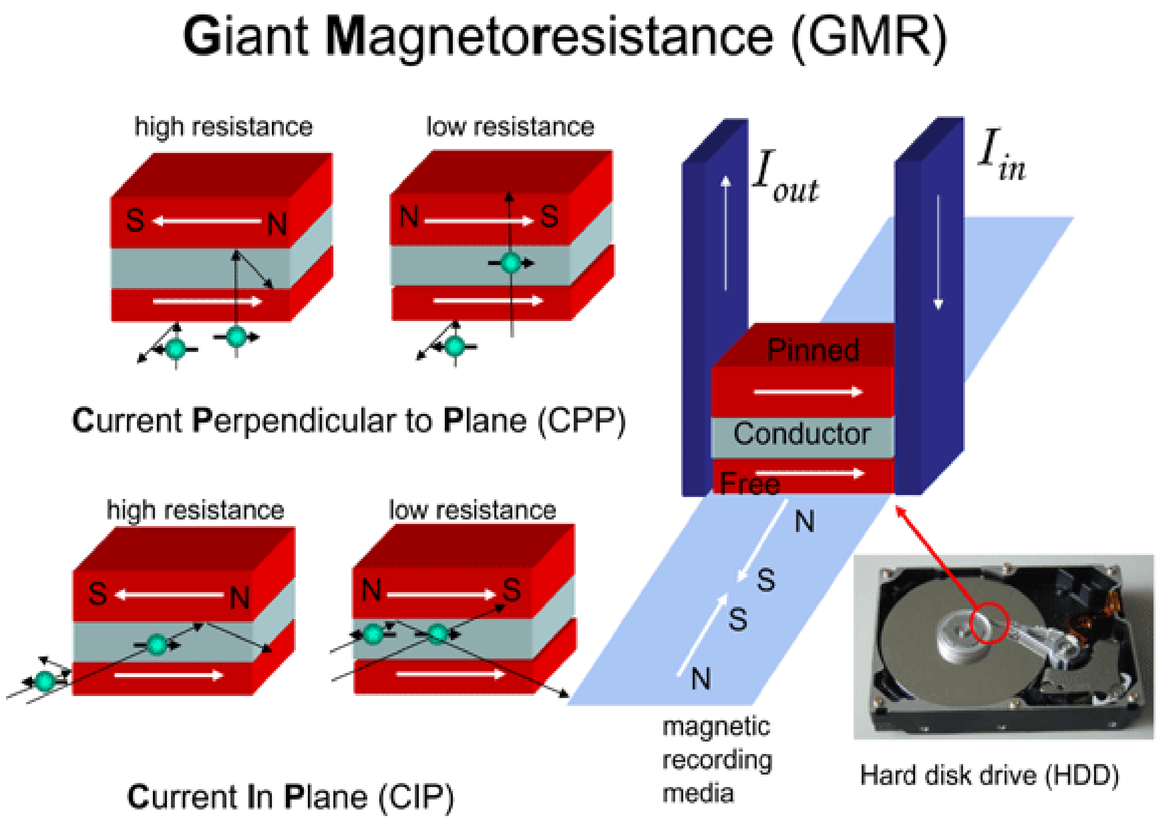
A. Rostamnejadi,et al. unpublisheded.

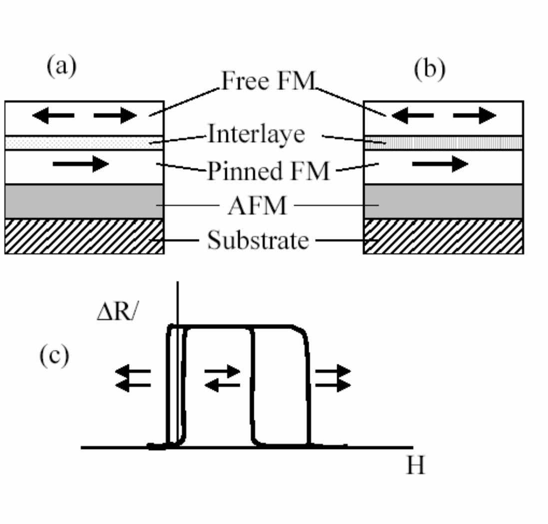
Exchange bias



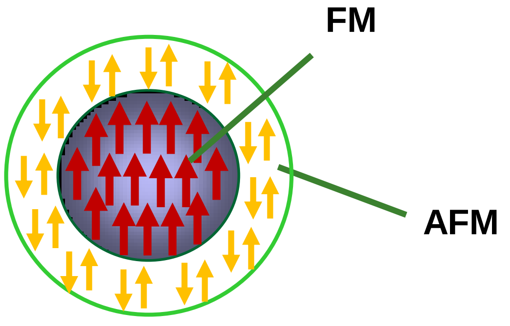
J. Nogues, I. Schuller,JMMM 203,192 (1999)

Exchange bias read head
spin valve (GMR read head)

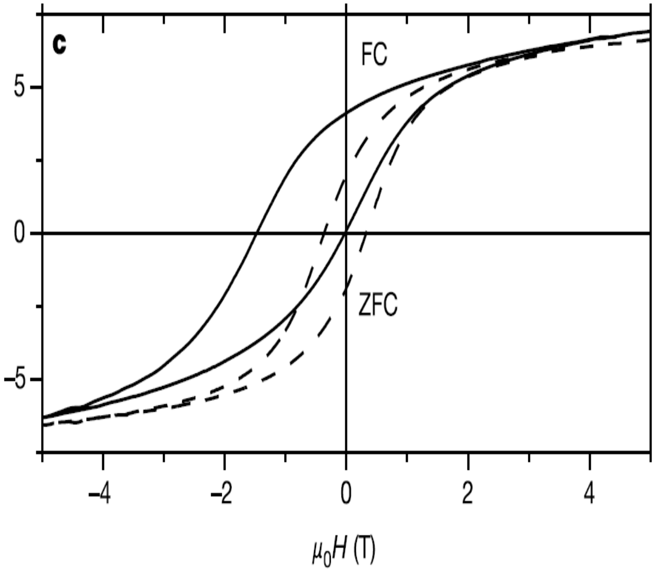




Exchange bias in nanoparticles

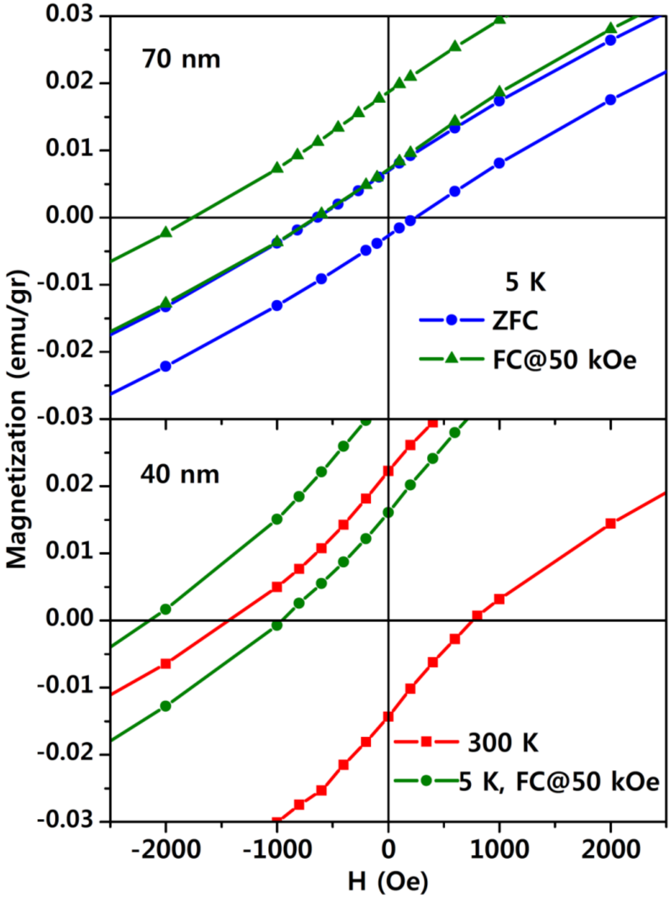


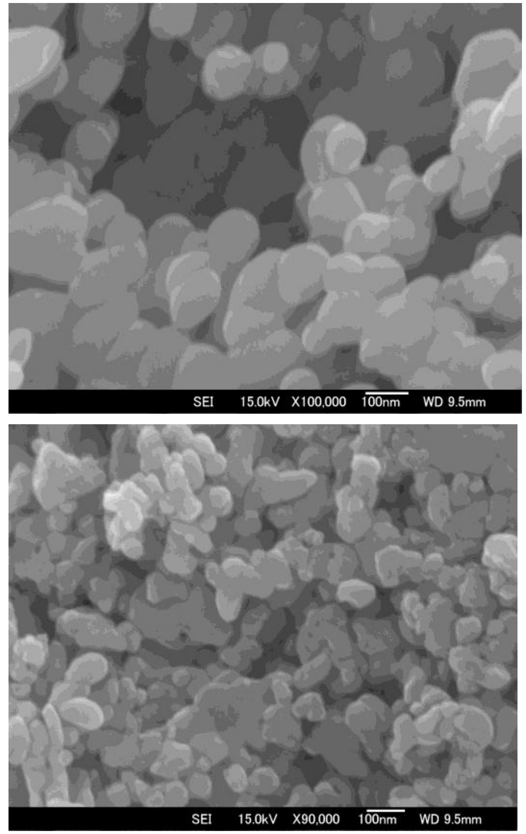
Ni/NiO , Co/CoO , …

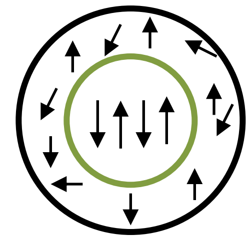


V. Skumryev, et al., *Nature*, 2003

Exchange bias in LaFeO3 AFM nanoparticles





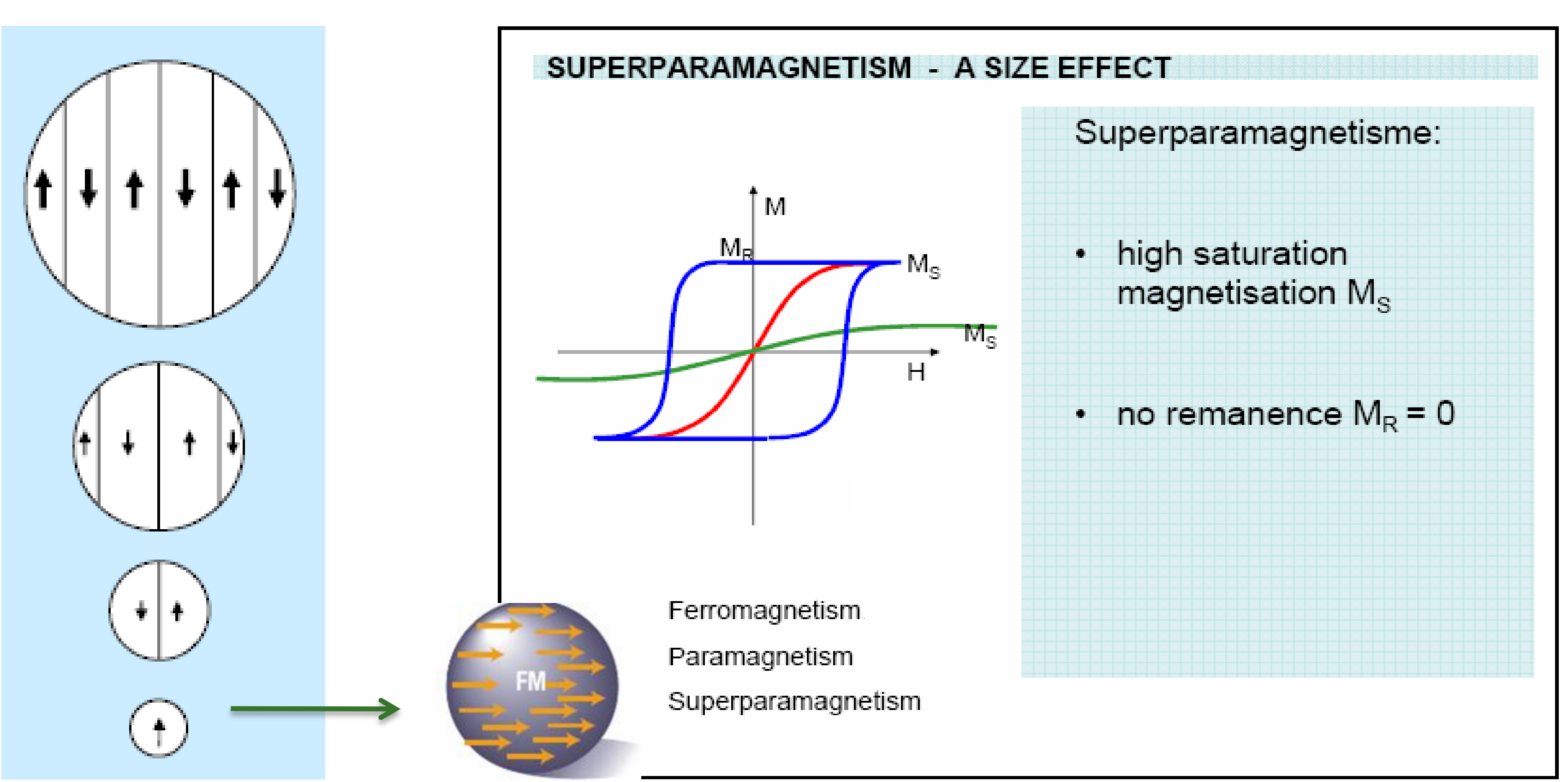


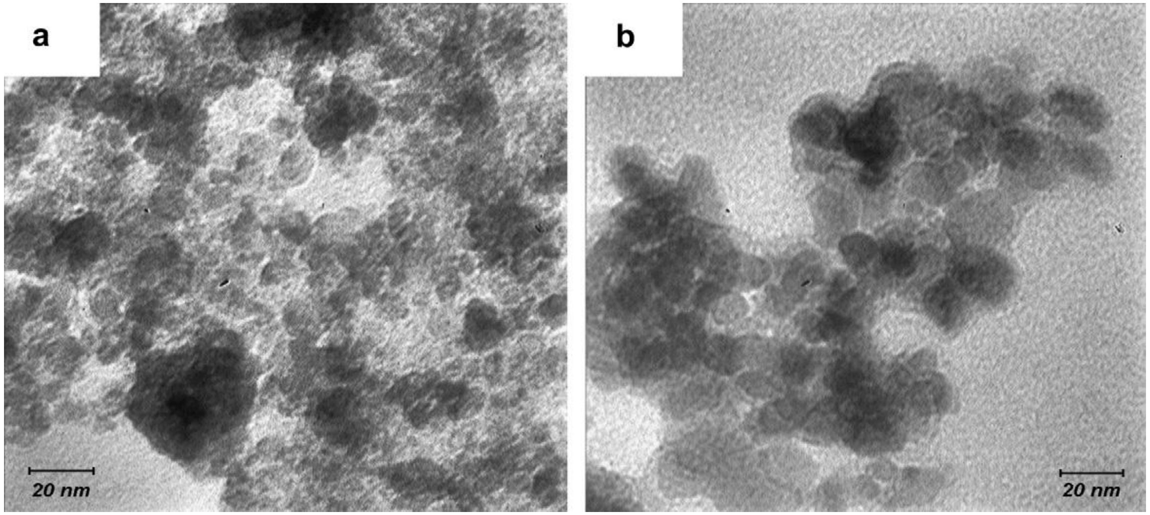
AFM nanoparticles

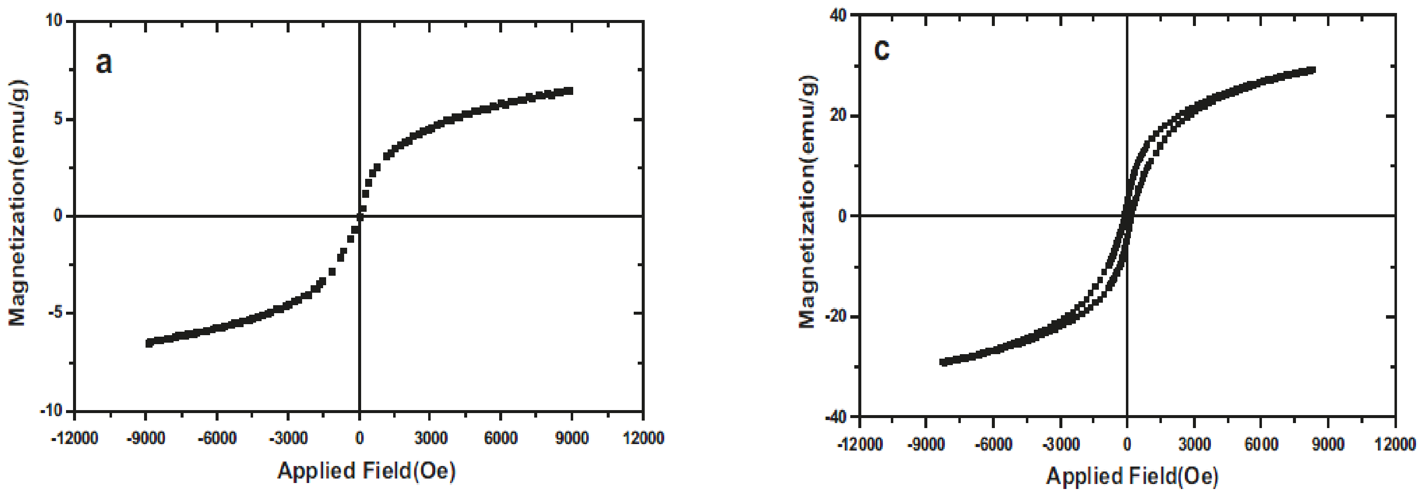
H. Ahmadvand, et al. J. Phys D: Applied Physics(2010).

Some relevant finite size effects in the magnetic properties of magnetic fine particles:

Superparamagnetism

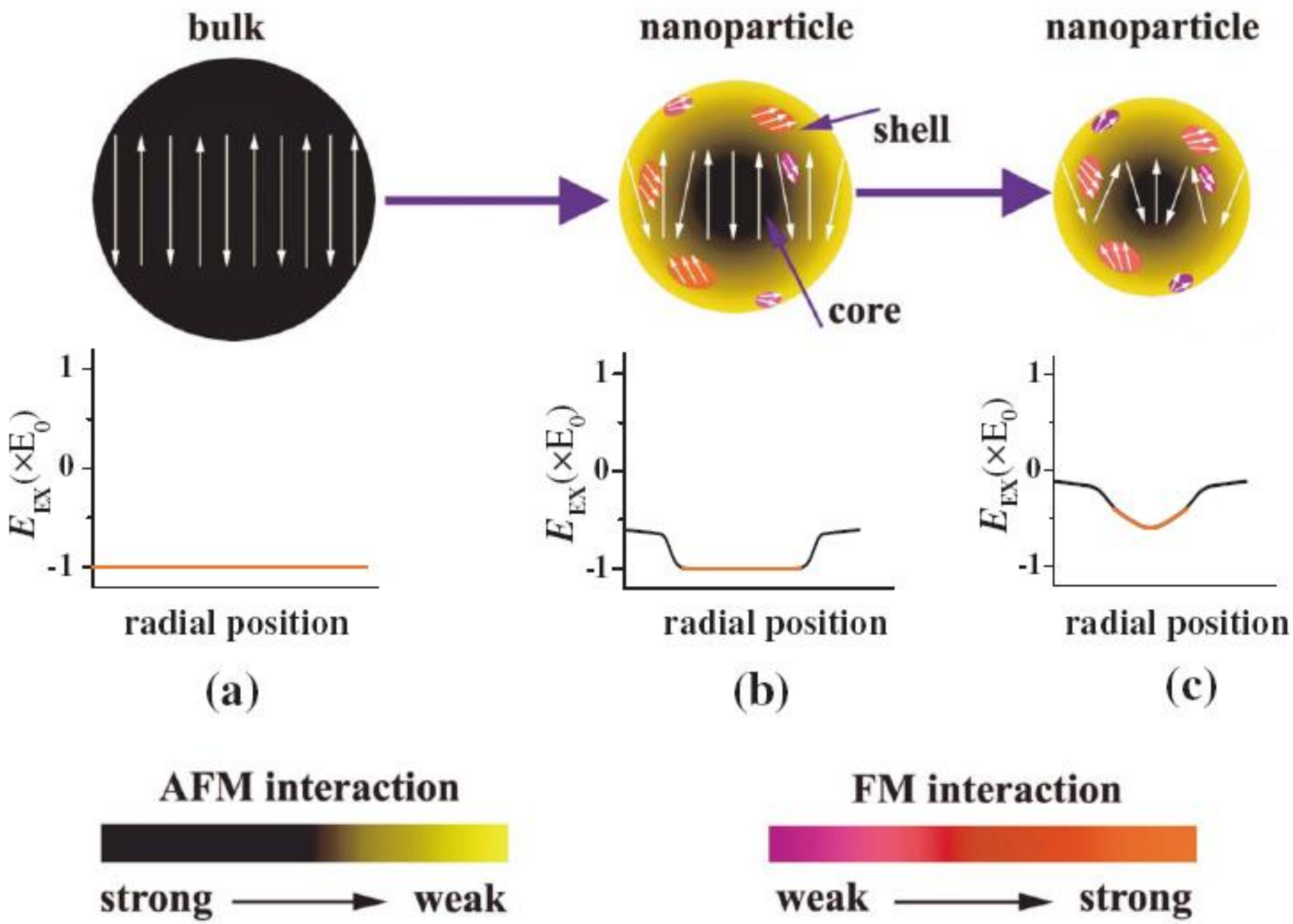






M. Eshraghi, P. Kameli, Current Applied Physics (2011).

Change of magnetic state

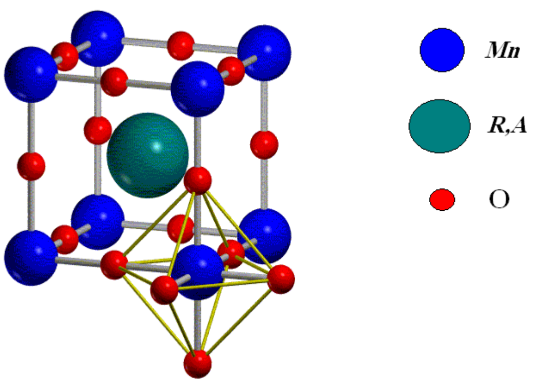


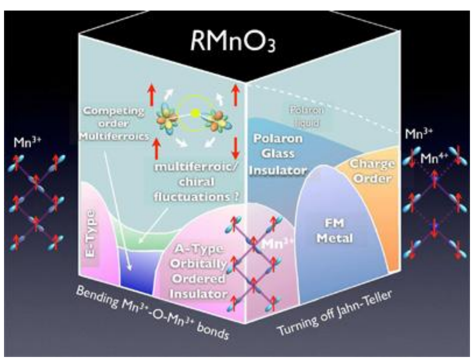
T. Zhang, PRB(2007)

Perovskite manganites

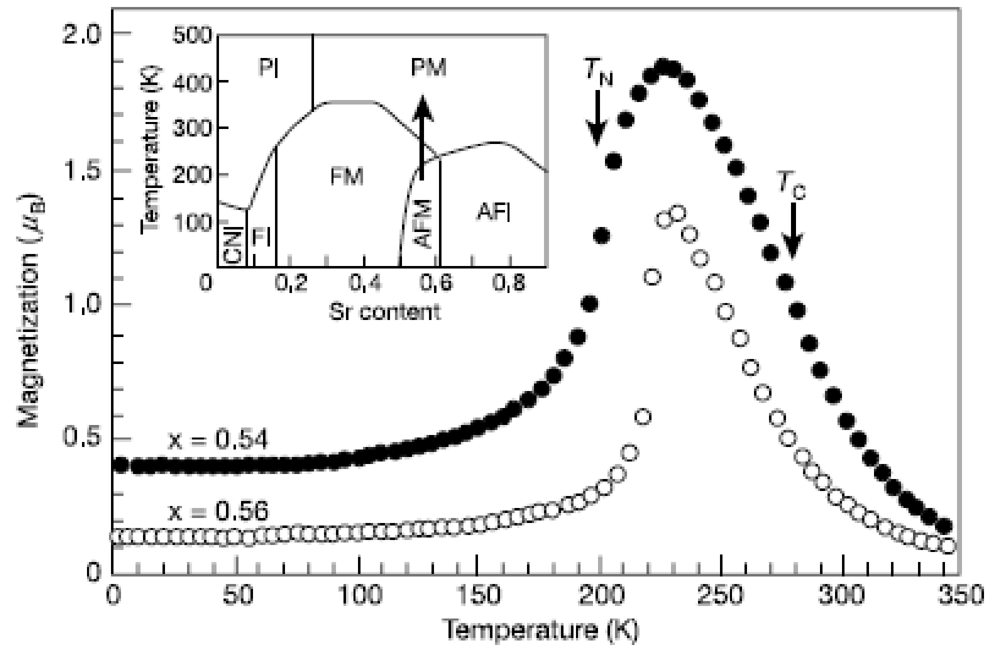
$$R_{1-x}A_xMnO_3$$

(R= La, Nd,..., A= Sr, Ca,…)





La1-x Sr x MnO3

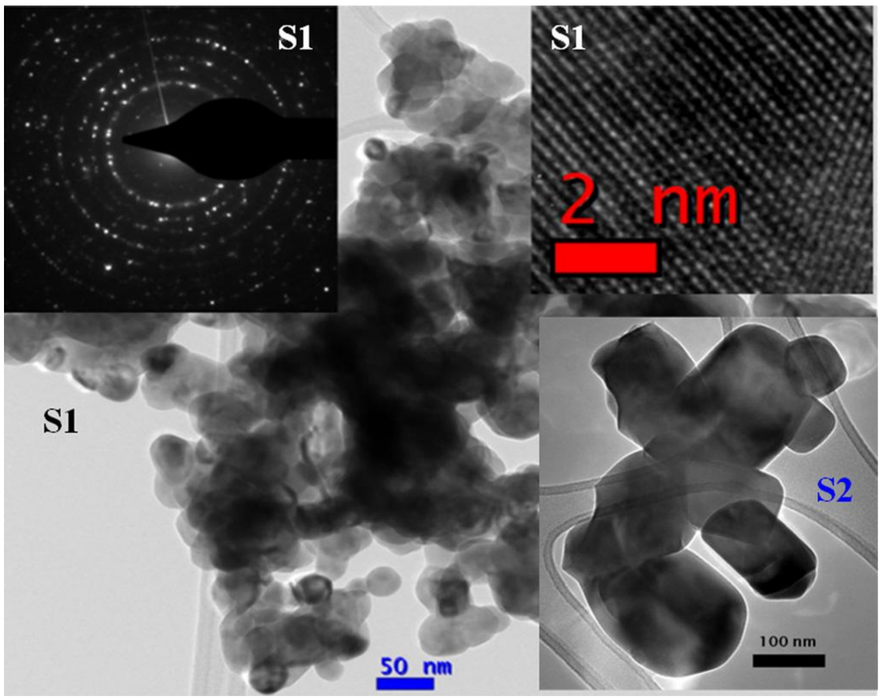


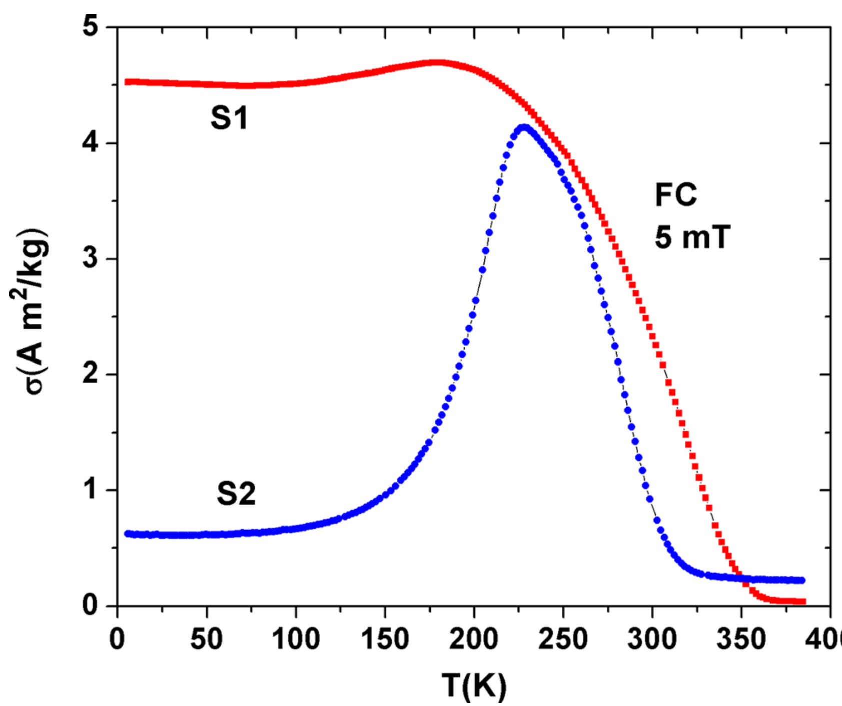
Nature 423(2003) 965.

JOURNAL OF APPLIED PHYSICS **110**, 043905 (2011)

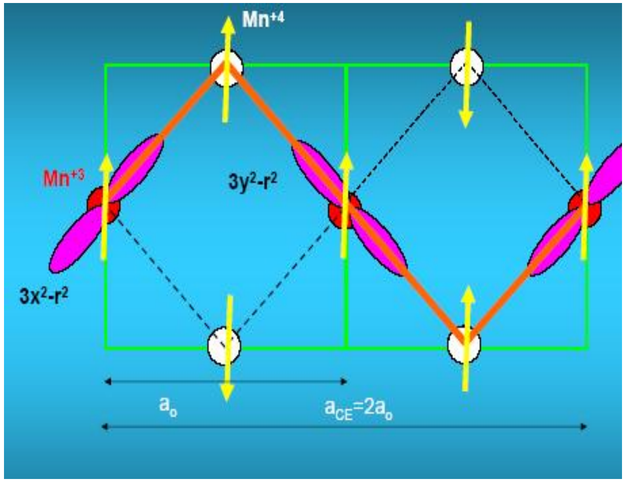
Conventional and inverse magnetocaloric effects in $La_{0.45}Sr_{0.55}MnO_3$ nanoparticles

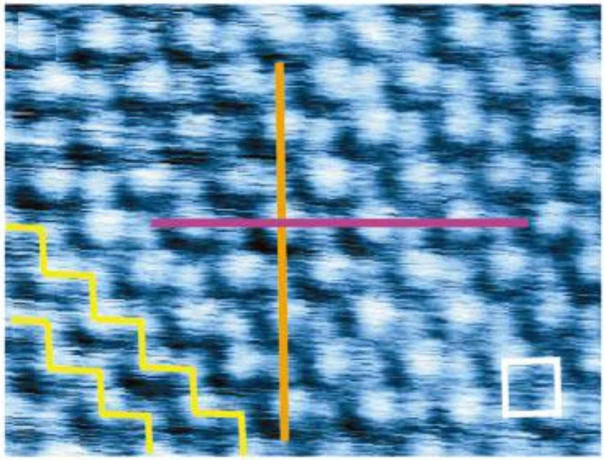
A. Rostamnejadi,[1,2,a)] M. Venkatesan,[1] J. Alaria,[1] M. Boese,[3] P. Kameli,[2] H. Salamati,[2] and J. M. D. Coey[1]
[1]*CRANN and School of Physics, Trinity College, Dublin 2, Ireland*
[2]*Department of Physics, Isfahan University of Technology, Isfahan 84156-83111, Iran*
[3]*Advanced Microscopy Laboratory, CRANN, Trinity College, Dublin 2, Ireland*





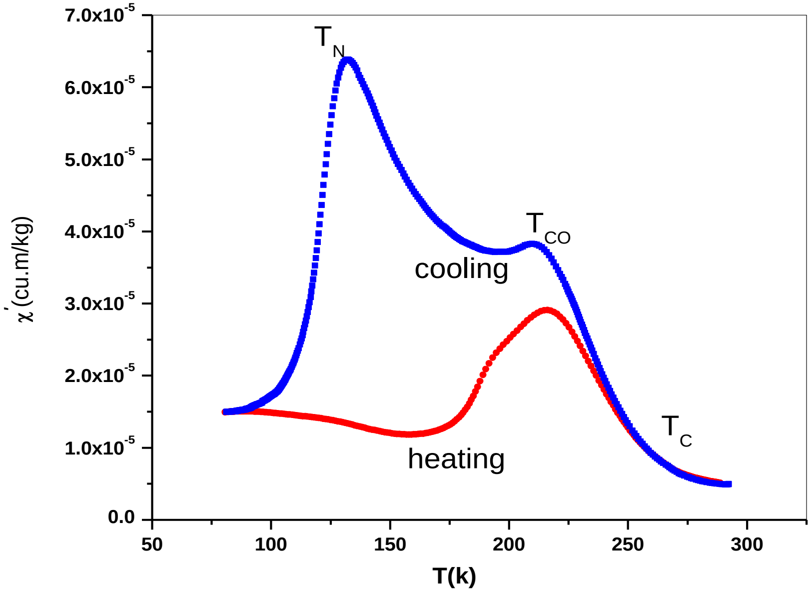
$La_{0.5}Ca_{0.5}MnO_3$ Manganite

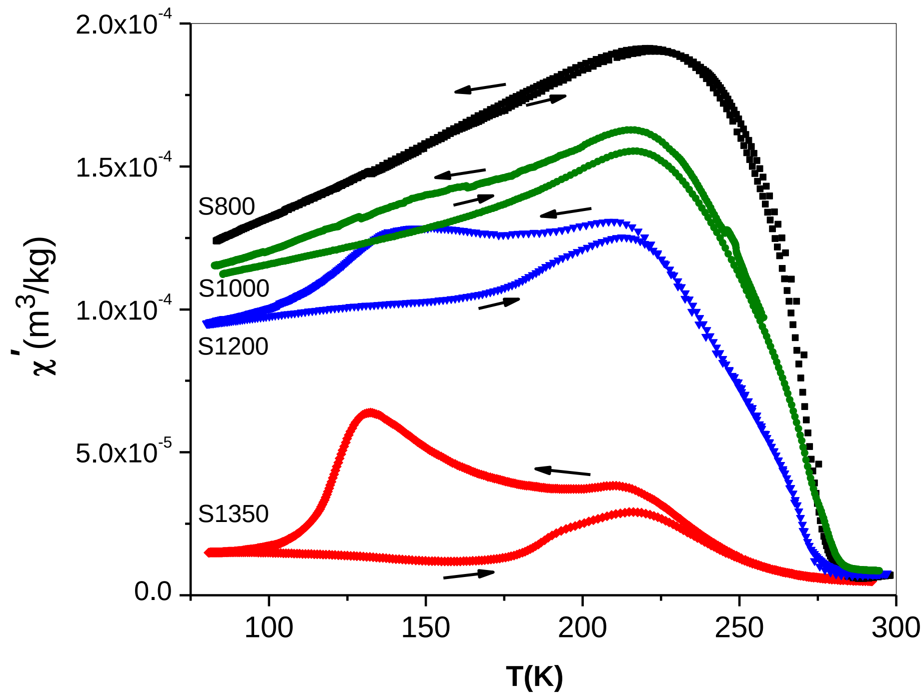




Nature 416(2002)518.

First order phase transition

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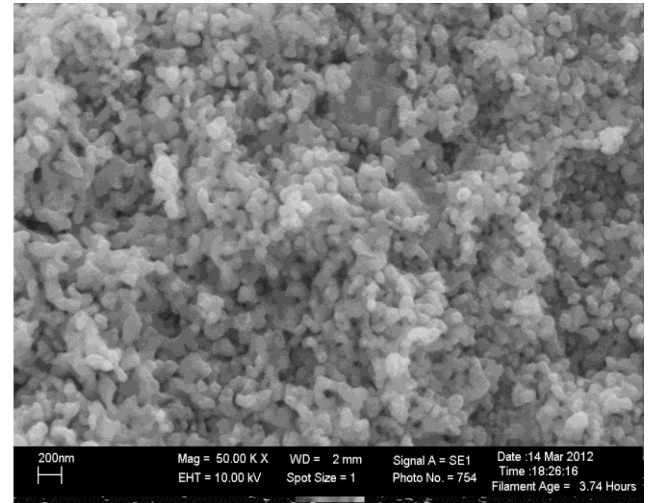
1.5x10^-4
1.0x10^-4
5.0x10^-5
0.0
χ′ (m^3/kg)
S800
S1000
S1200
S1350
100
150
200
250
300
T(K)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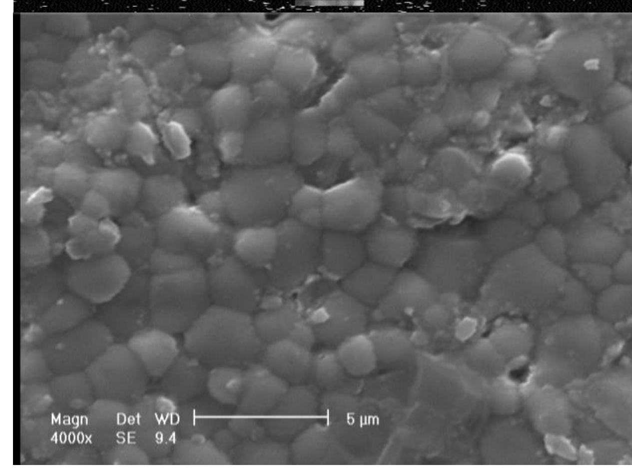
Filament Age = 3.74 Hours


Magn
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Det
SE
WD
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5 µm

28 Mar 2013

Volume 113, Issue 12, Articles (12xxxx)

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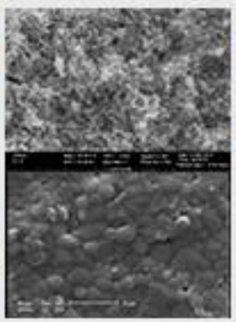

J. Appl. Phys. **113**, 123904 (2013); http://dx.doi.org/10.1063/1.4794179 (5 *pages*)

P. Amirzadeh, H. Ahmadvand, P. Kameli, B. Aslibeiki, H. Salamati, A. G. Gamzatov, A. M. Aliev, and I. K. Kamilov

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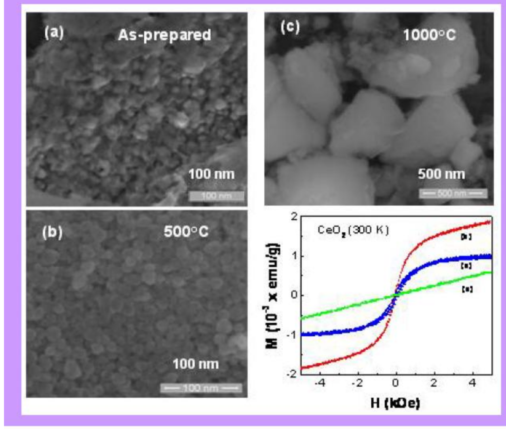
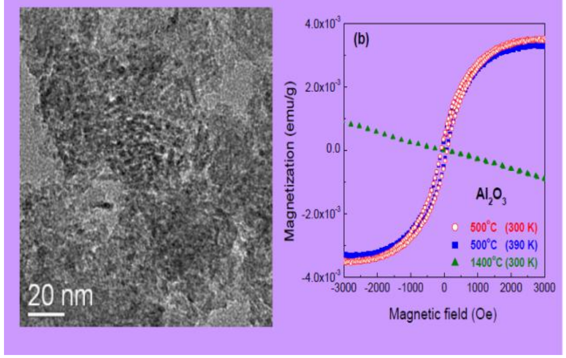
Surprising magnetism!?

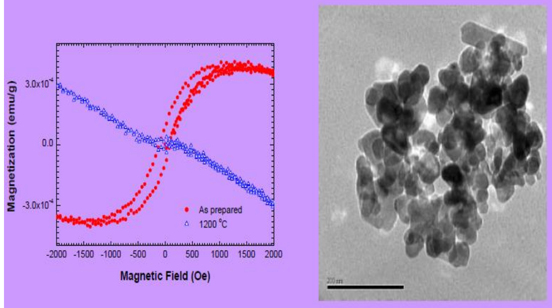
CeO_2 nanoparticles



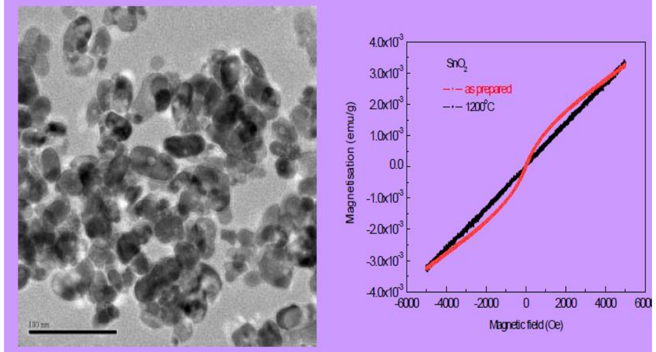
Al_2O_3



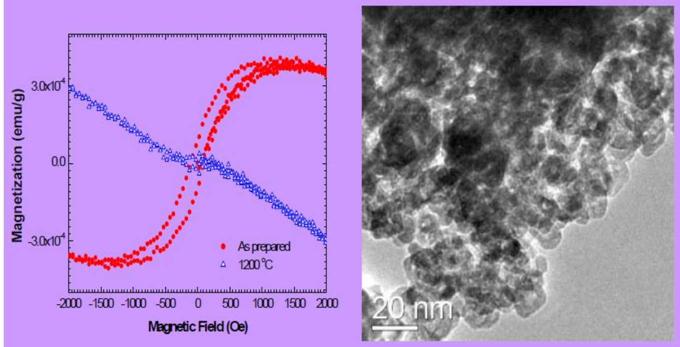
ZnO



SnO_2



In_2O_3



A. Sundaresan (2008)

Possible origin or ferromagnetism

- Surface defects due to oxygen deficiency
- Possibility of orbital contribution as suggested for thiol capped Au nanostructures

RAPID COMMUNICATIONS

PHYSICAL REVIEW B **74**, 161306(R) (2006)

Ferromagnetism as a universal feature of nanoparticles of the otherwise nonmagnetic oxides

A. Sundaresan,* R. Bhargavi, N. Rangarajan, U. Siddesh, and C. N. R. Rao
Chemistry and Physics of Materials Unit and Department of Science and Technology Unit on Nanoscience, Jawaharlal Nehru Centre for Advanced Scientific Research, Jakkur P. O., Bangalore 560 064 India
(Received 18 August 2006; published 20 October 2006)

Room-temperature ferromagnetism has been observed in nanoparticles (7–30 nm diam) of nonmagnetic oxides such as CeO_2, Al_2O_3, ZnO, In_2O_3, and SnO_2. The saturated magnetic moments in CeO_2 and Al_2O_3 nanoparticles are comparable to those observed in transition-metal-doped wideband semiconducting oxides. The other oxide nanoparticles show somewhat lower values of magnetization but with a clear hysteretic behavior. Conversely, the bulk samples obtained by sintering the nanoparticles at high temperatures in air or oxygen became diamagnetic. As there were no magnetic impurities present, we assume that the origin of ferromagnetism may be the exchange interactions between localized electron spin moments resulting from oxygen vacancies at the surfaces of nanoparticles. We suggest that ferromagnetism may be a universal characteristic of nanoparticles of metal oxides.

DOI: 10.1103/PhysRevB.74.161306 PACS number(s): 75.50.Pp, 75.50.Dd, 75.75.+a, 81.07.Wx

Thank you for your attention