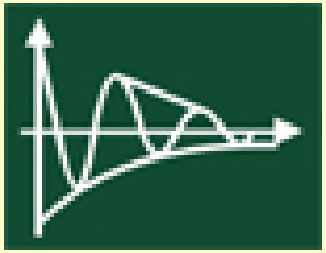
Nanomagnetismo

Parte 4

Escola do CBPF 2008



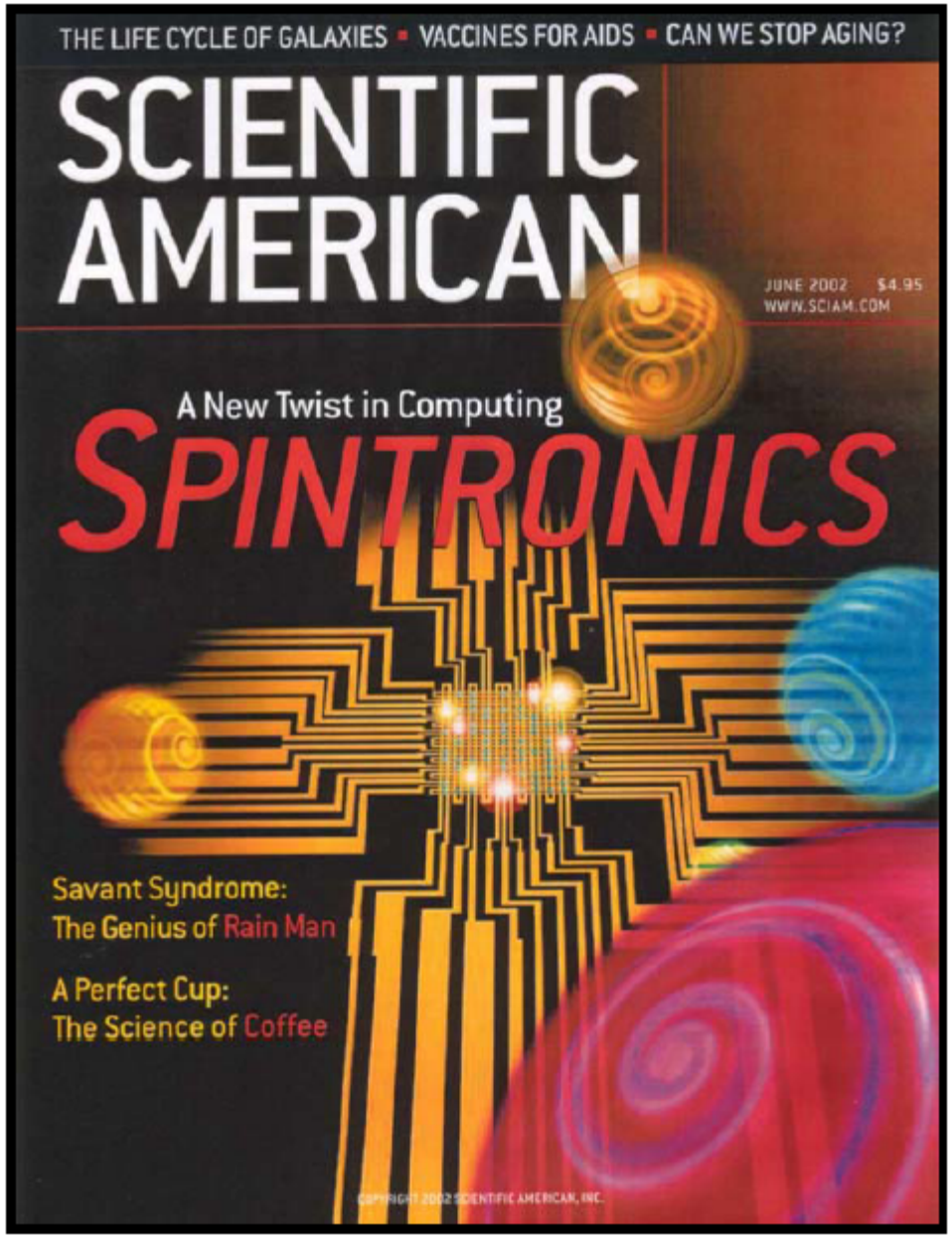
ftp://ftp2.biblioteca.cbpf.br/pub/apub/2006/mo/mo_zip/mo00206.pdf

Nanomagnetismo

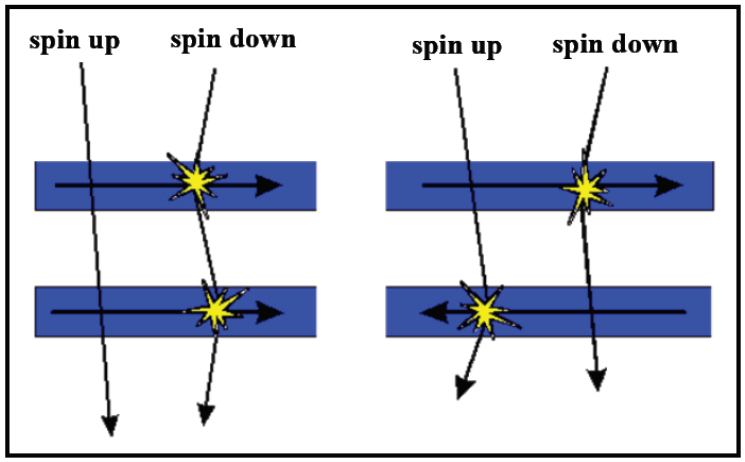
Escola do CBPF – 2008

Alberto P. Guimarães
Renato A. Silva

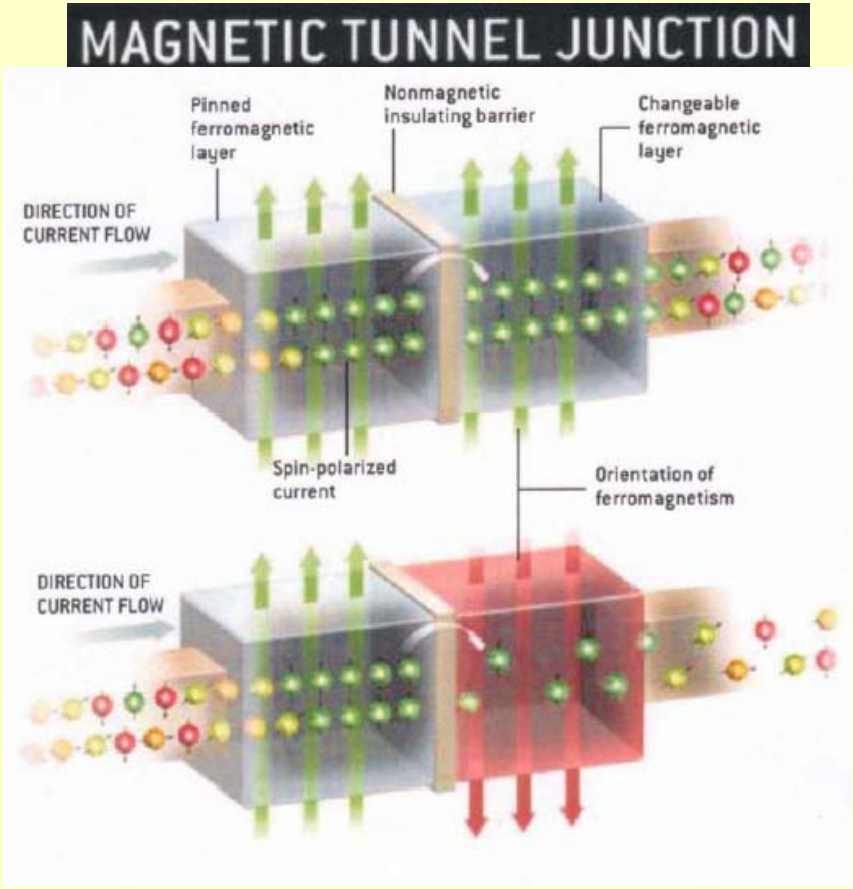
1	• **Introdução**	14/07
2	• **Magnetismo de Pequenas Partículas**	15/07
3	• **Filmes Finos e Multicamadas**	16/07
4	• **Outros Sistemas de Baixa Dimensionalidade**	17/07
5	• **Propriedades de Transporte**	18/07


THE LIFE CYCLE OF GALAXIES ▪ VACCINES FOR AIDS ▪ CAN WE STOP AGING?
SCIENTIFIC AMERICAN
JUNE 2002 $4.95
WWW.SCIAM.COM
A New Twist in Computing
SPINTRONICS
Savant Syndrome:
The Genius of Rain Man
A Perfect Cup:
The Science of Coffee
COPYRIGHT 2002 SCIENTIFIC AMERICAN, INC.

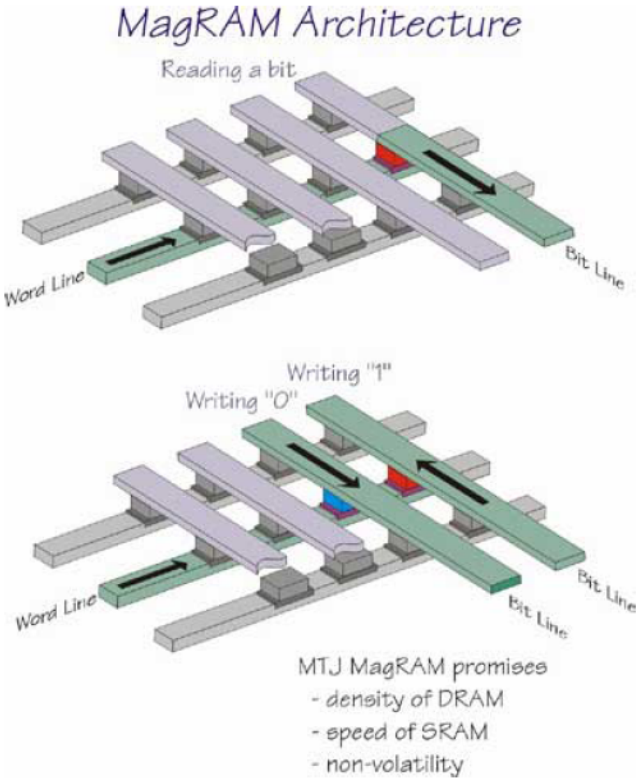
Giant Magnetoresistance (GMR)



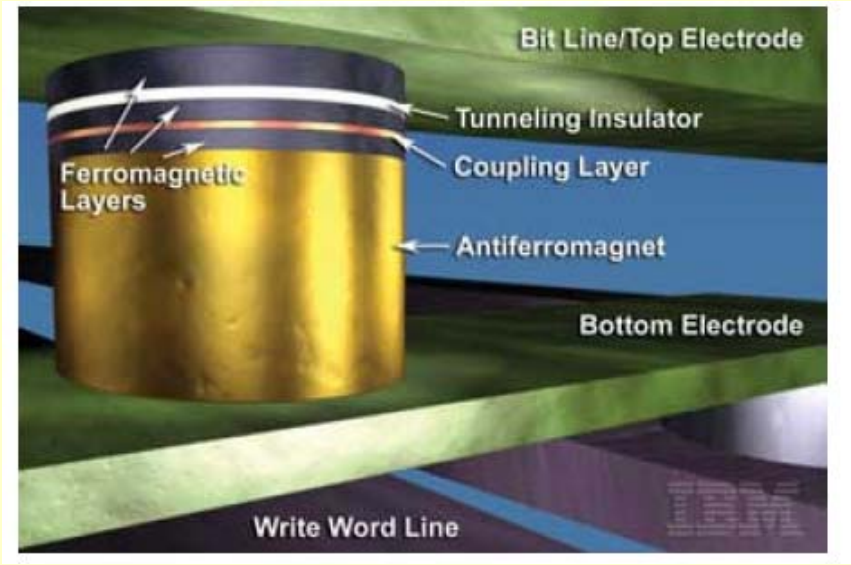
http://www.stoner.leeds.ac.uk/research/gmr.htm

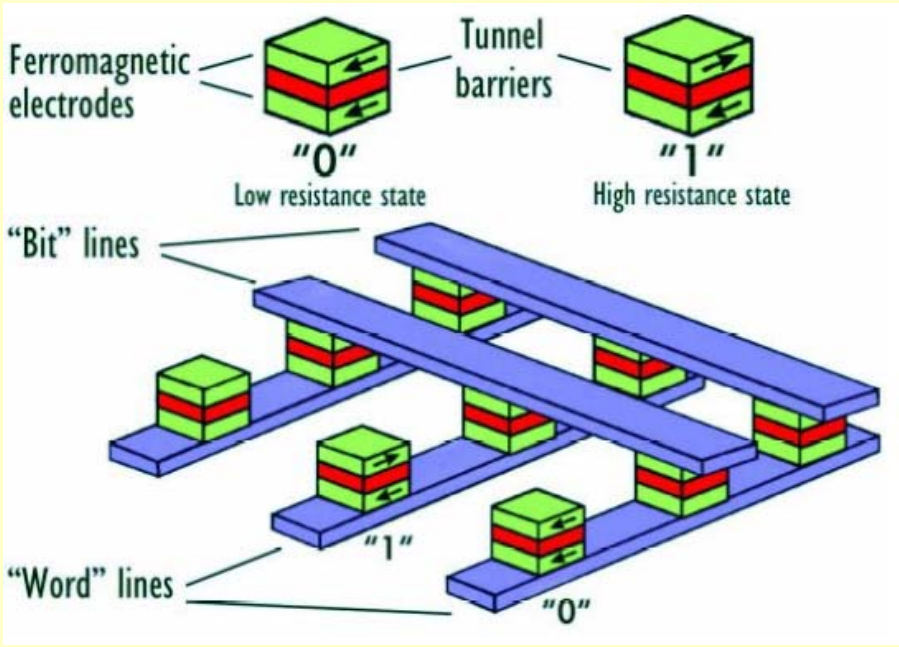


Magnetic RAM

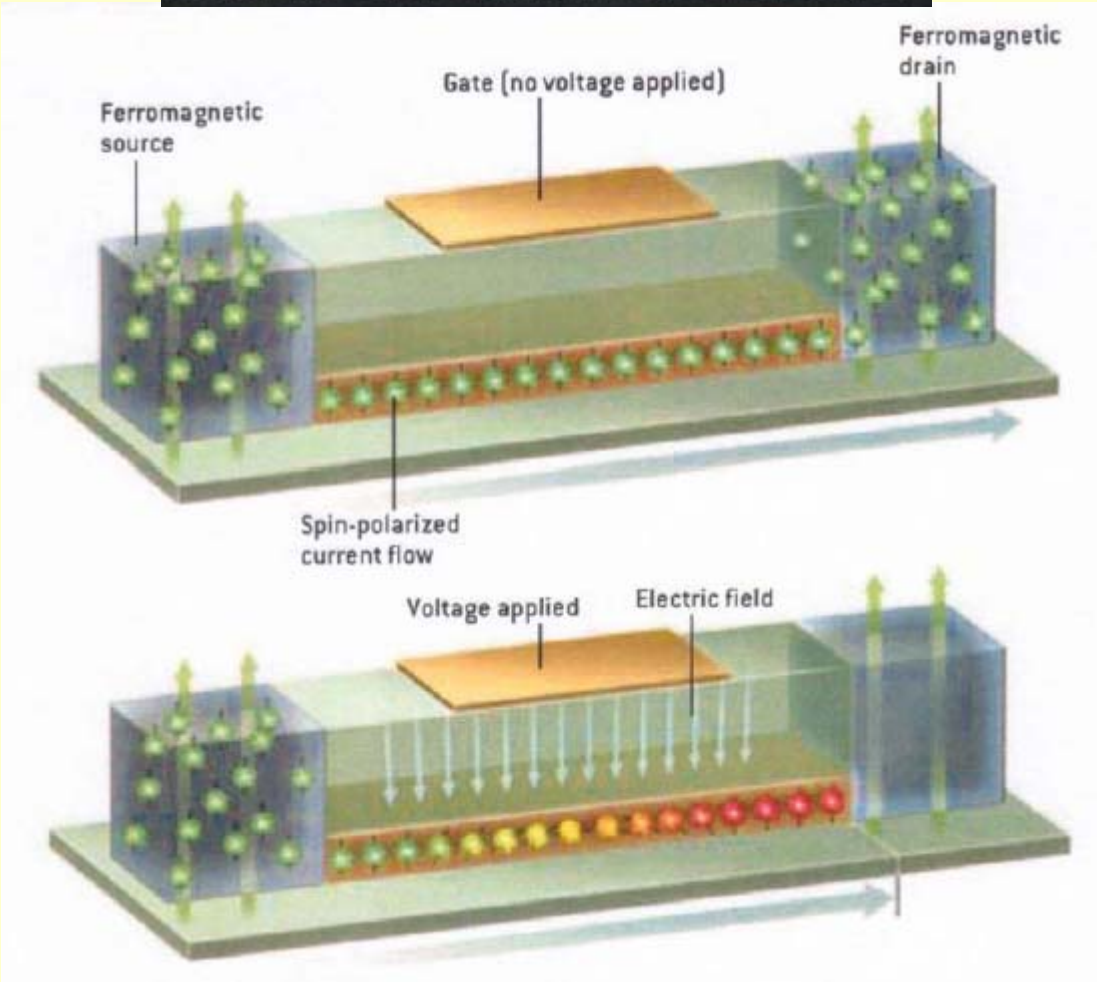


http://www.research.ibm.com/resources/news/20001207_mramimages.shtml





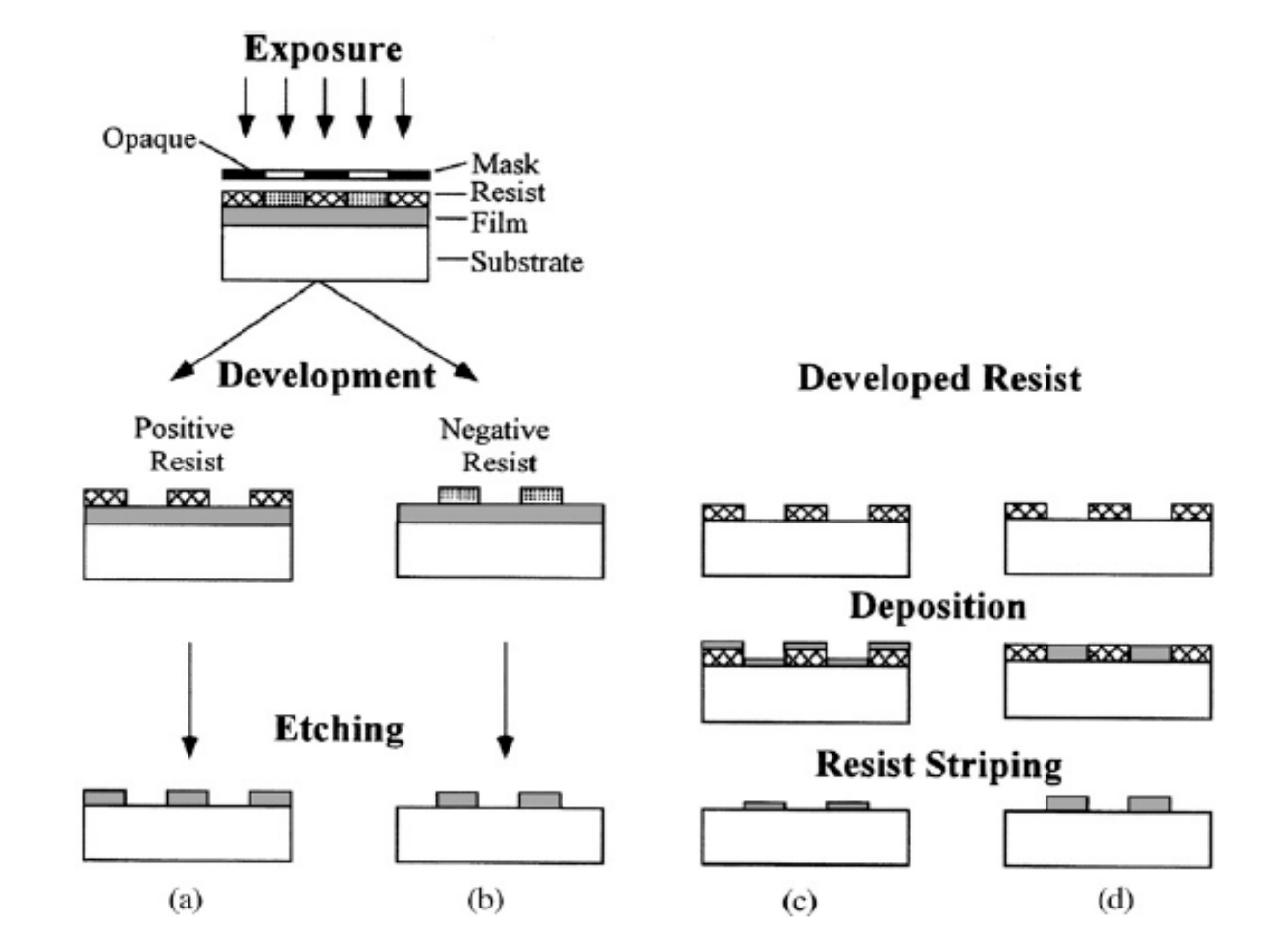
A SPIN TRANSISTOR CONCEPT

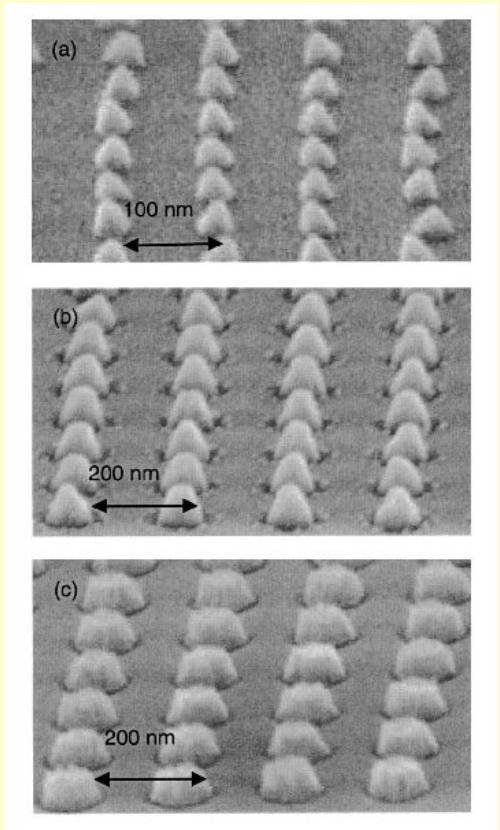


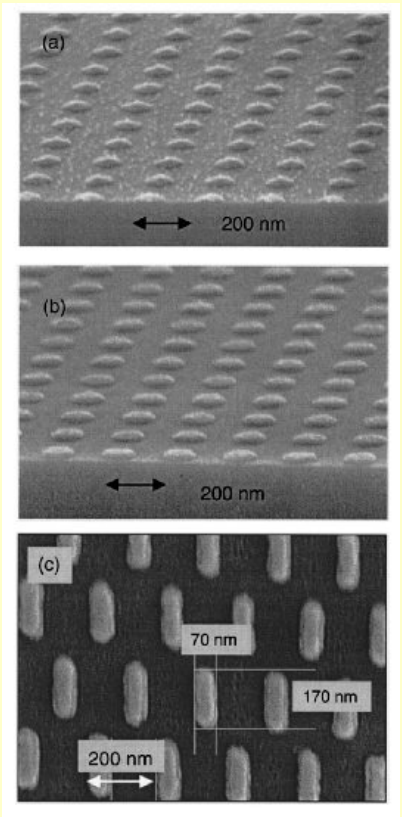
Outros sistemas de baixa dimensionalidade

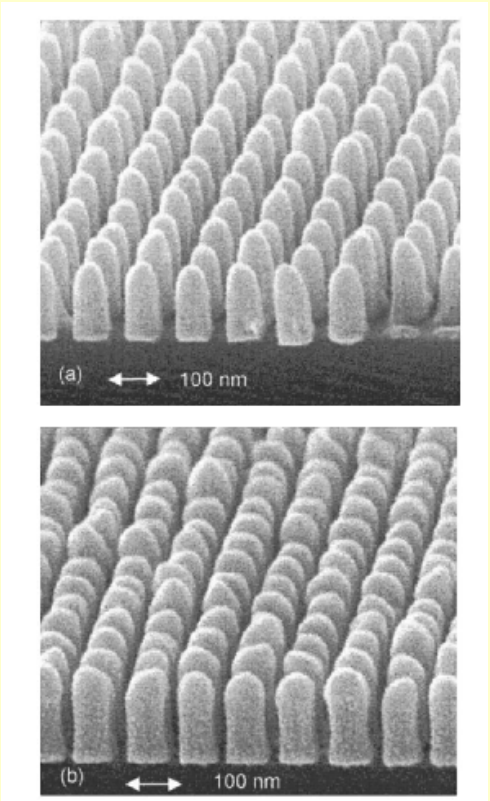
- Nanodiscos
- Nanoanéis
- Nanofios

Litografia


Exposure
Opaque
Mask
Resist
Film
Substrate
Development
Positive Resist
Negative Resist
Developed Resist
Deposition
Etching
Resist Striping
(a)
(b)
(c)
(d)

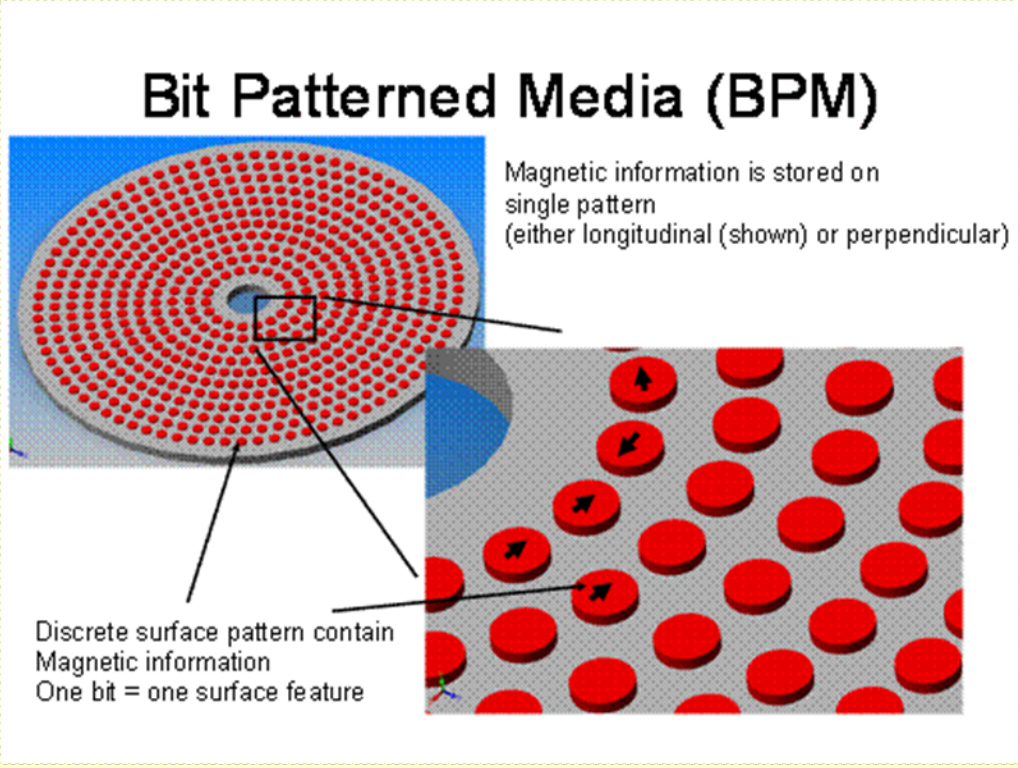

(a)
100 nm
(b)
200 nm
(c)
200 nm


(a)
200 nm
(b)
200 nm
(c)
70 nm
170 nm
200 nm

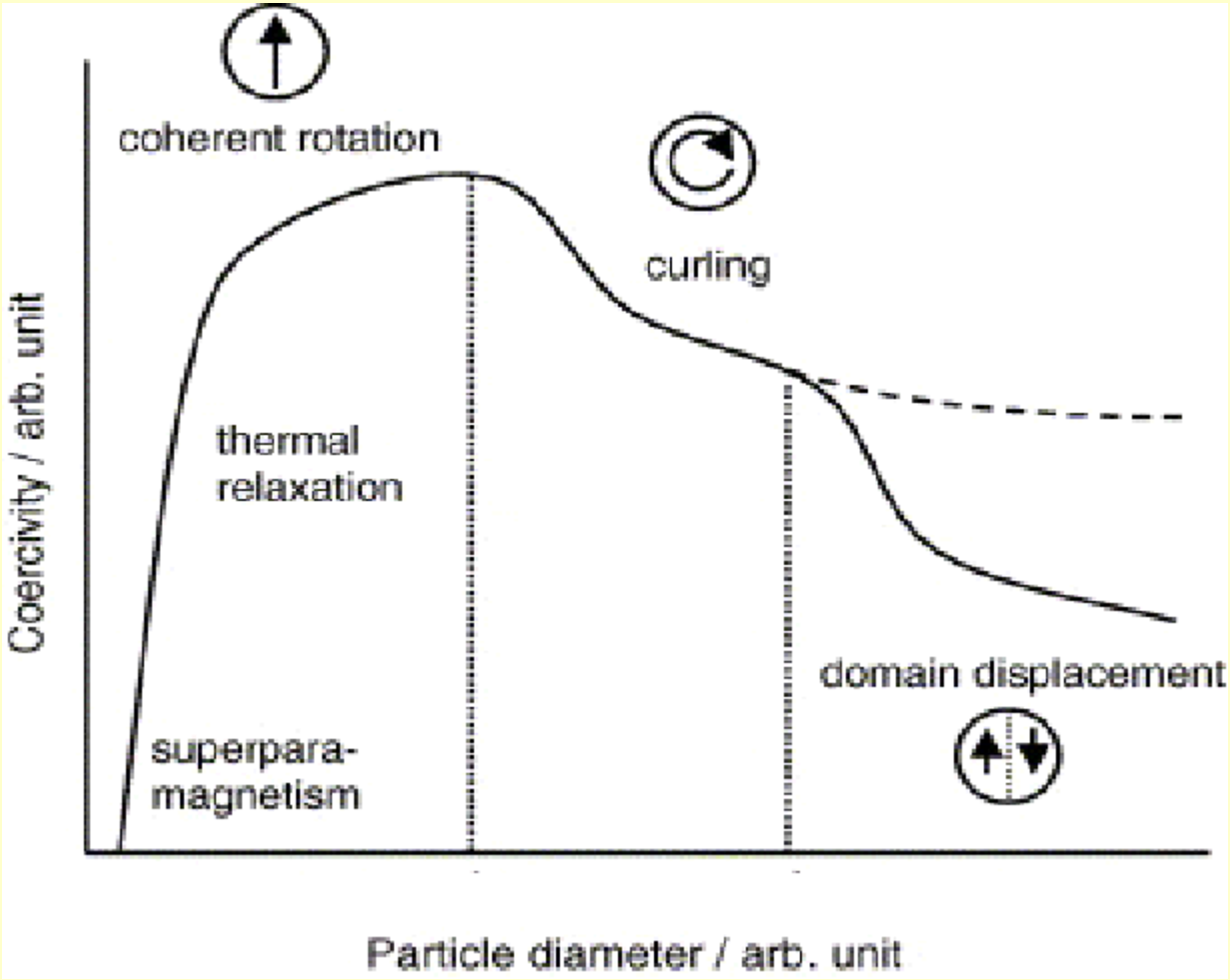

(a)
100 nm
(b)
100 nm

Gravação em meios com padrões

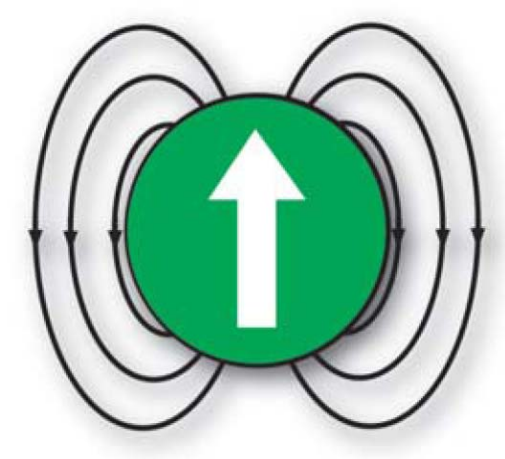
- Superfície de disco rígido com padrões criados por litografia (‘bit-patterned’)



Dependendo do material existe um estado de vórtice intermediário aos regimes monodomínio e multidomínio



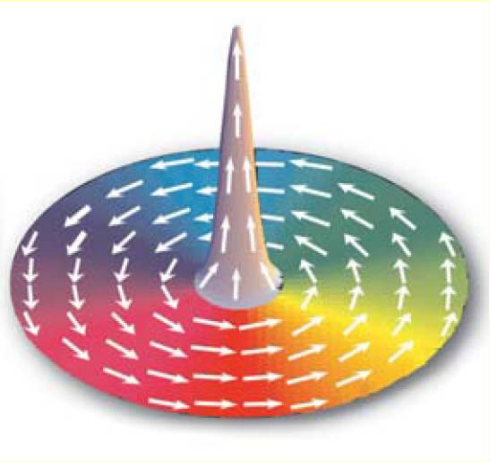
Nanodiscos



Monodomínio

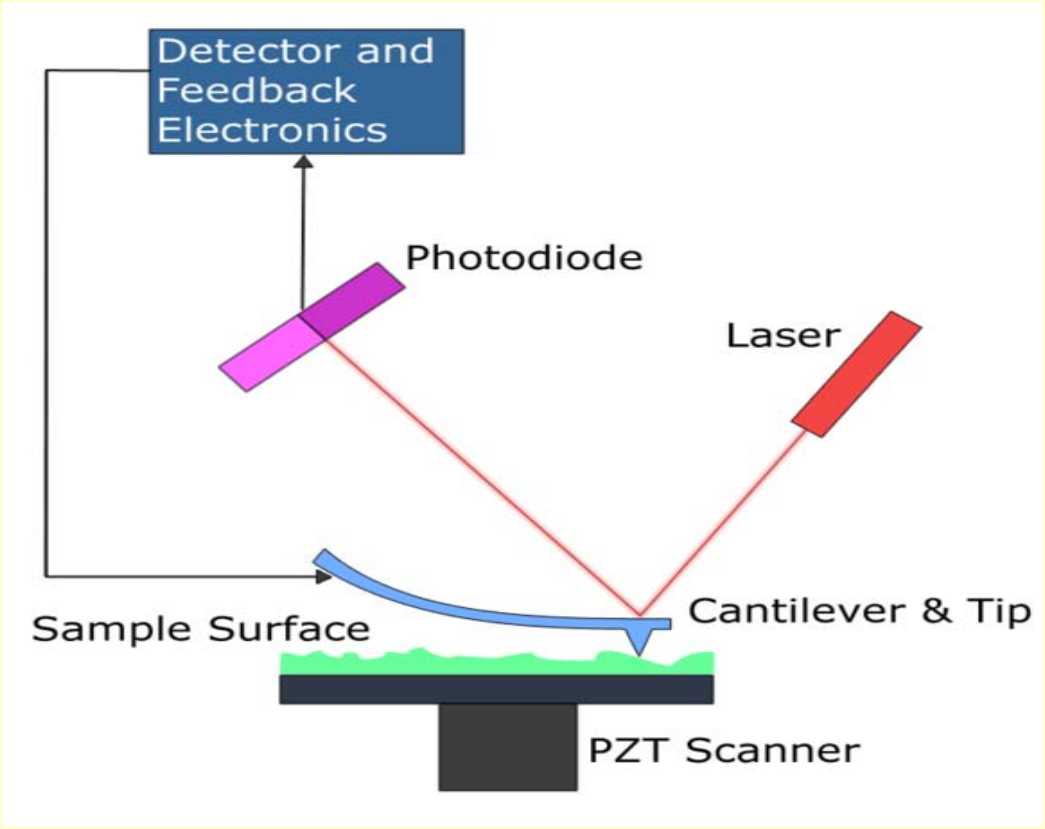


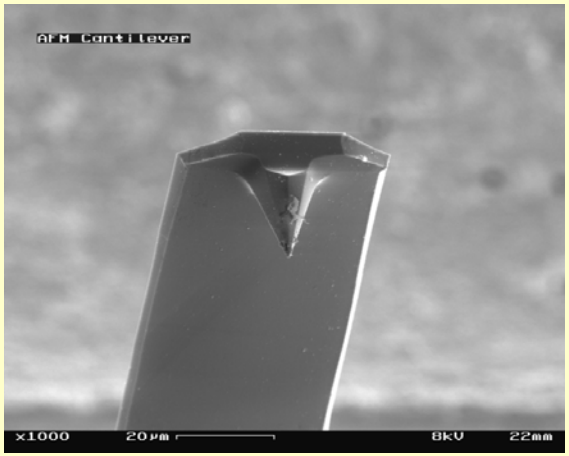
vórtice

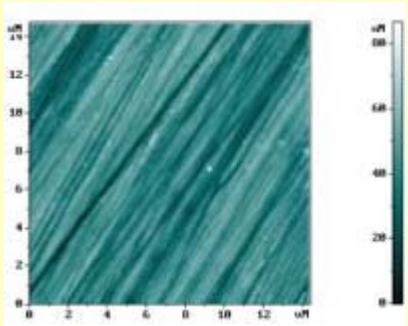


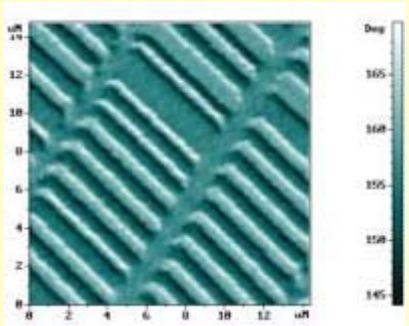
Há o aparecimento de um núcleo com magnetização perpendicular!

Microscopia de Força Magnética



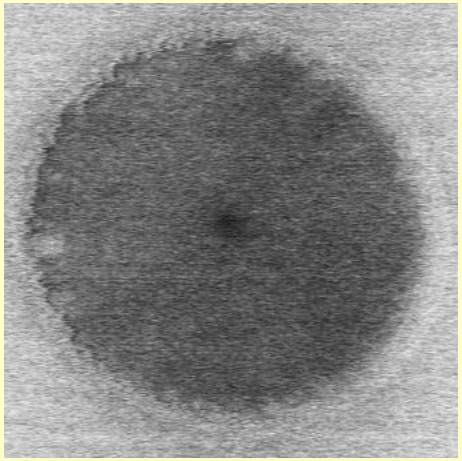


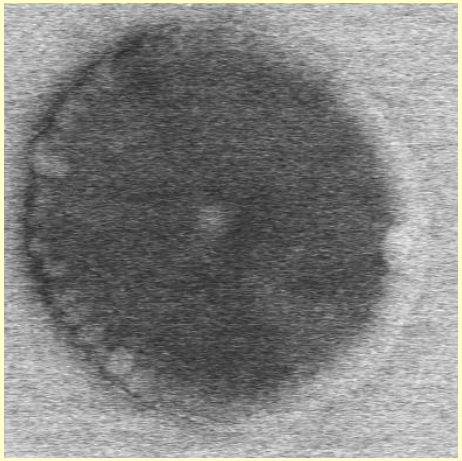


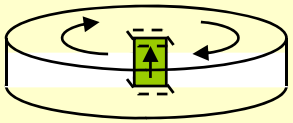


Imagens de MFM

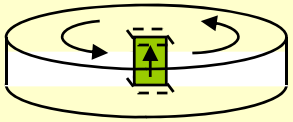
d = 400nm



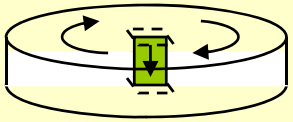




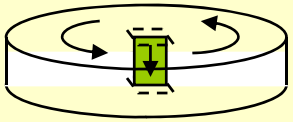
p = +1, chirality = +1 (CW)



p = +1, chirality = -1 (CCW)



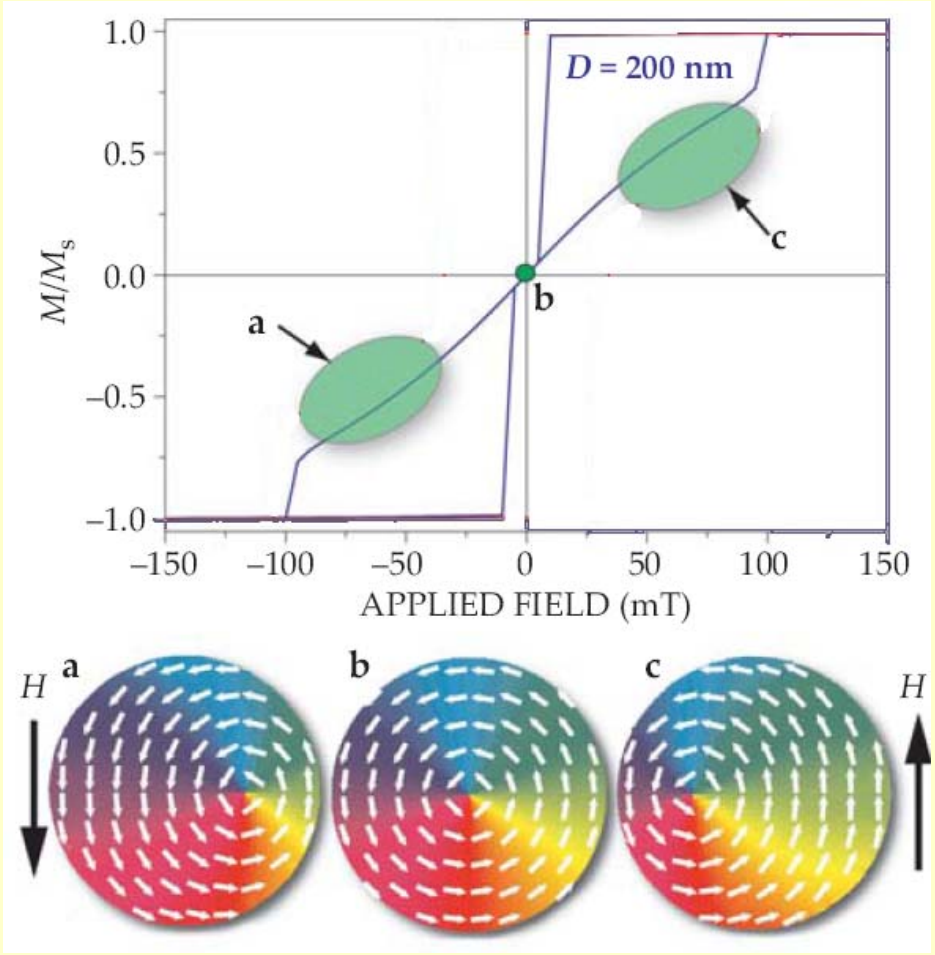
p = -1, chirality = +1 (CW)



p = -1, chirality = -1 (CCW)

J. M. García-Martín et al., J. Phys. D: Appl. Phys. **37**, 965 (2004)

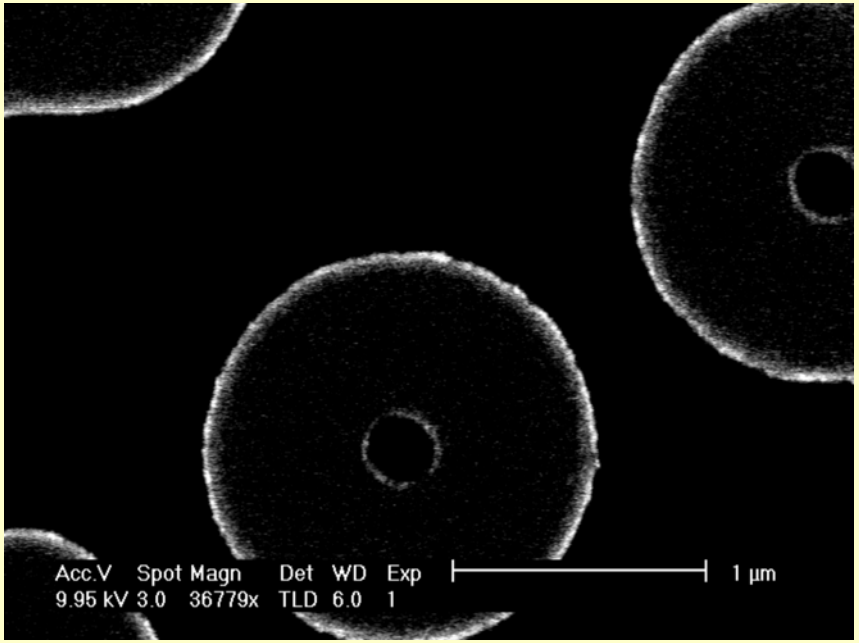
Dinâmica dos vórtices



C. L. *Chien*, et al, "*Patterned Nanomagnets*", Physics Today 60, 40 (2007)

Anéis magnéticos

Estruturas planas que têm interesse como futuros meios de gravação magnética.

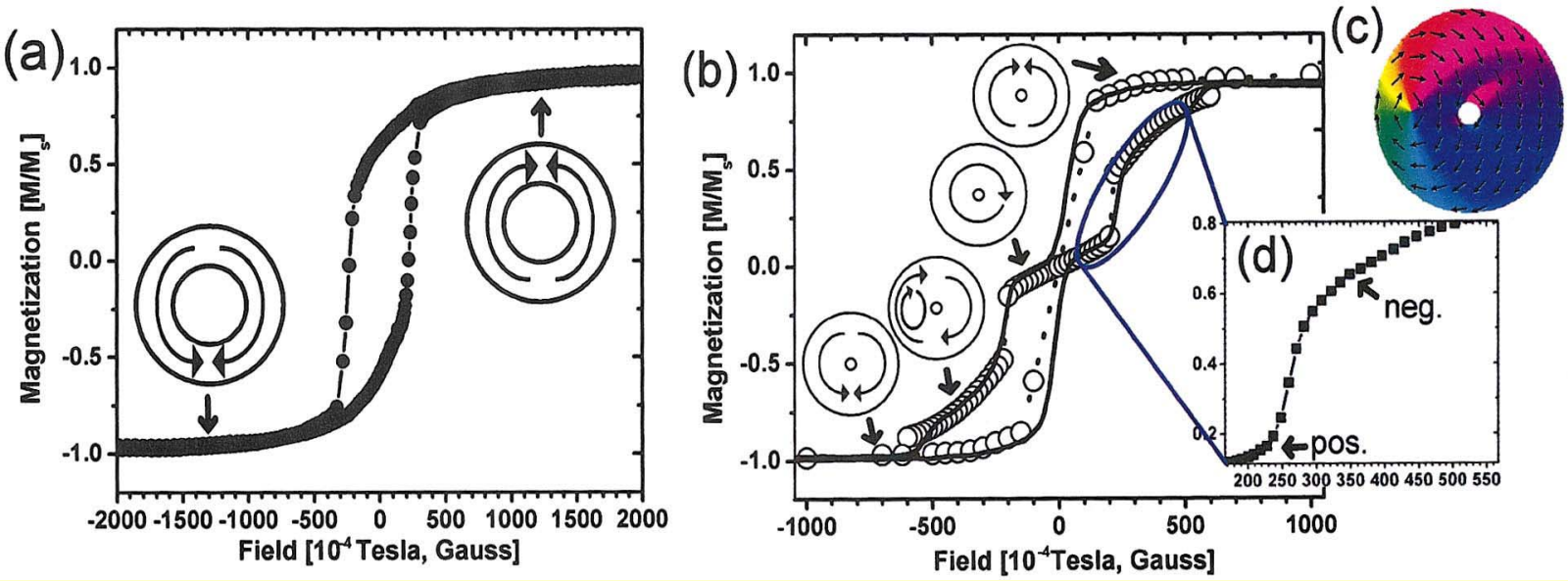


O mecanismo de inversão da magnetização depende da relação entre os raios interno e externo!

Anéis magnéticos

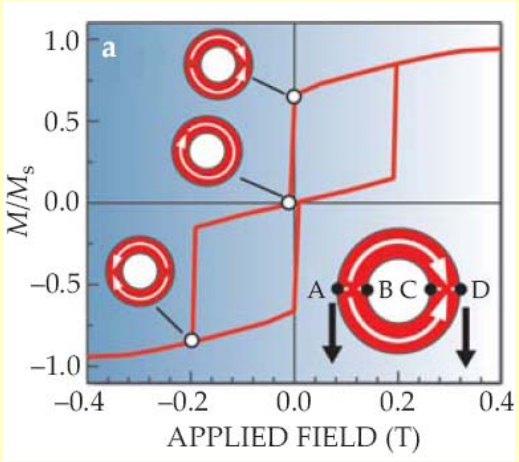
Dois exemplos de inversão da magnetização em anéis magnéticos.

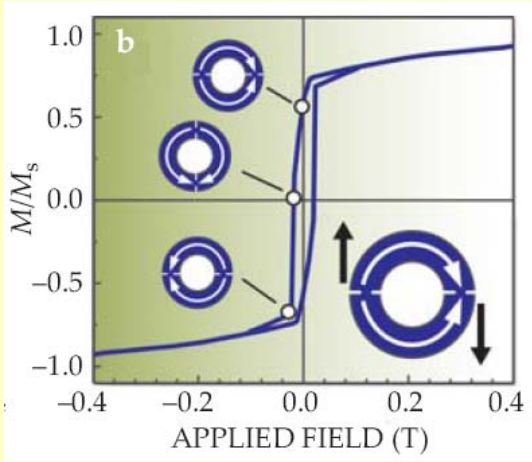
a) inversão da magnetização de um anel com diâmetro interno grande. A magnetização segue a forma “cebola”
b) inversão em anel com diâmetro interno pequeno. Forma-se um vórtice.

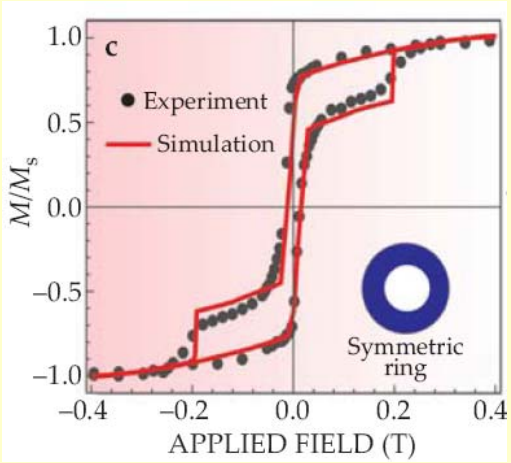


Klaui, et al, App Phys. Lett 84, 951 (2004)

Dinâmica de magnetização



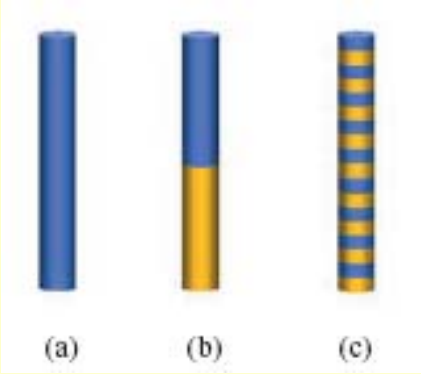


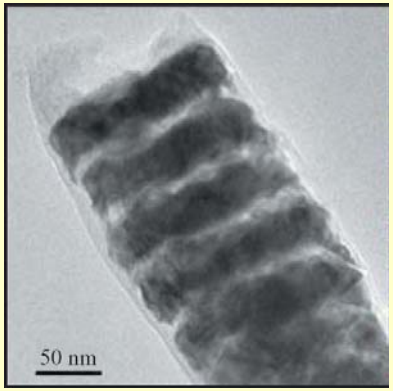


C. L. *Chien*, et al, "*Patterned Nanomagnets*", Physics Today 60, 40 (2007)

Nanofios magnéticos

Características
•Anisotropia de forma
•Possibilidade de produzir nanofios com diferentes componentes ao longo do comprimento
•Possibilidade de ajustar propriedades (diferentes de materiais bulk, filmes finos, nanopartículas)

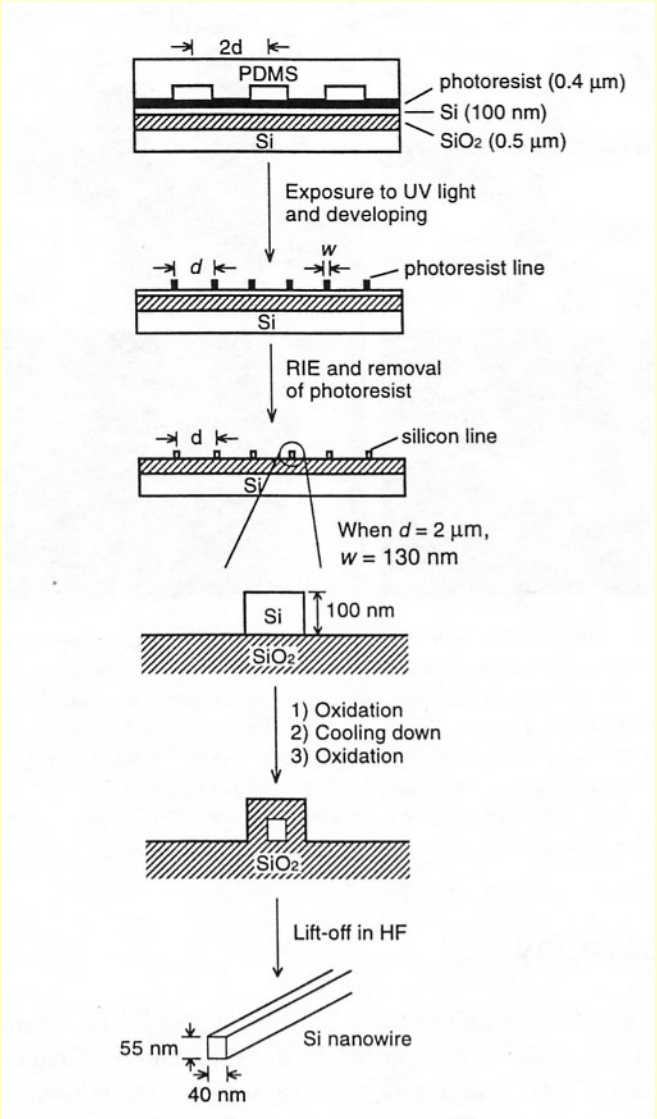




Nanofio: preparação por litografia

Preparação de nanofio de Si

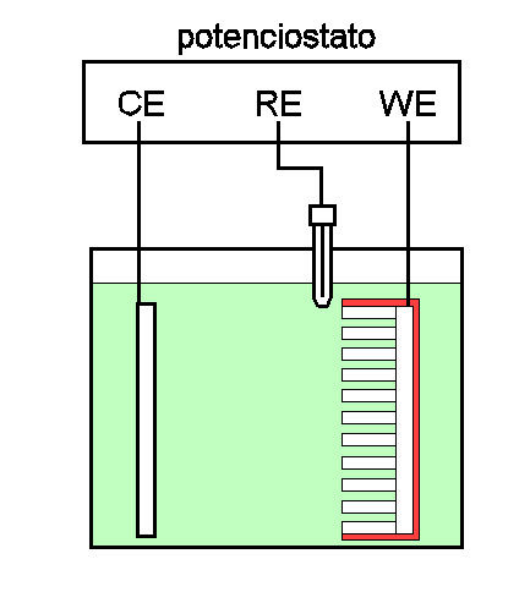
1) exposição do resist e revelação
2) ataque químico
3) oxidação
4) remoção

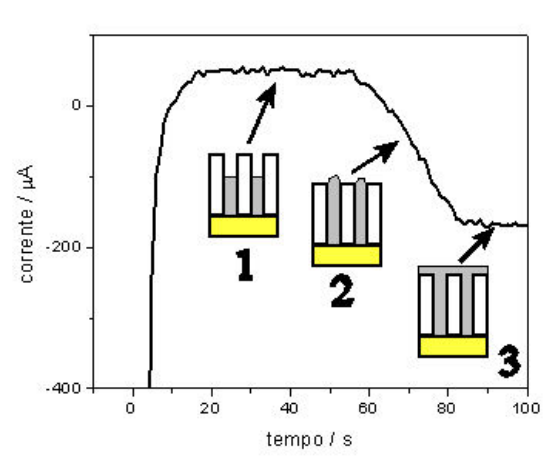


G. Cao, *Nanostructures & Nanomaterials*, Imperial College Press, London, 2004.

Nanofio: preparação por litografia

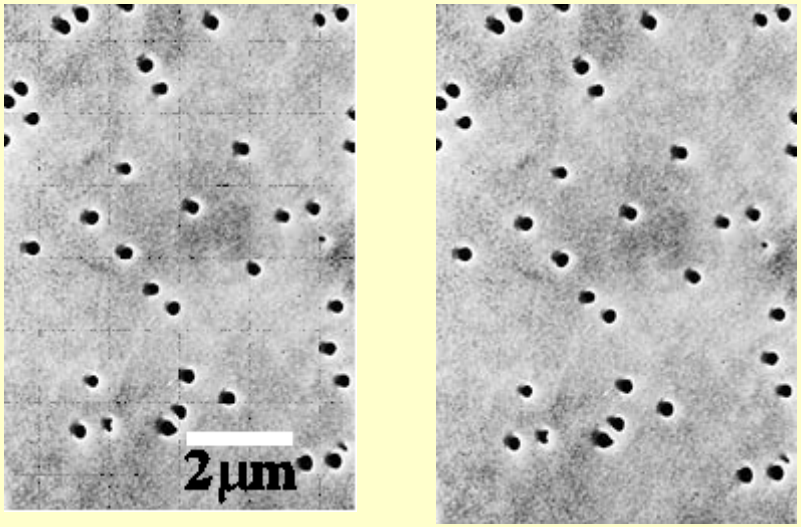
Template synthesis



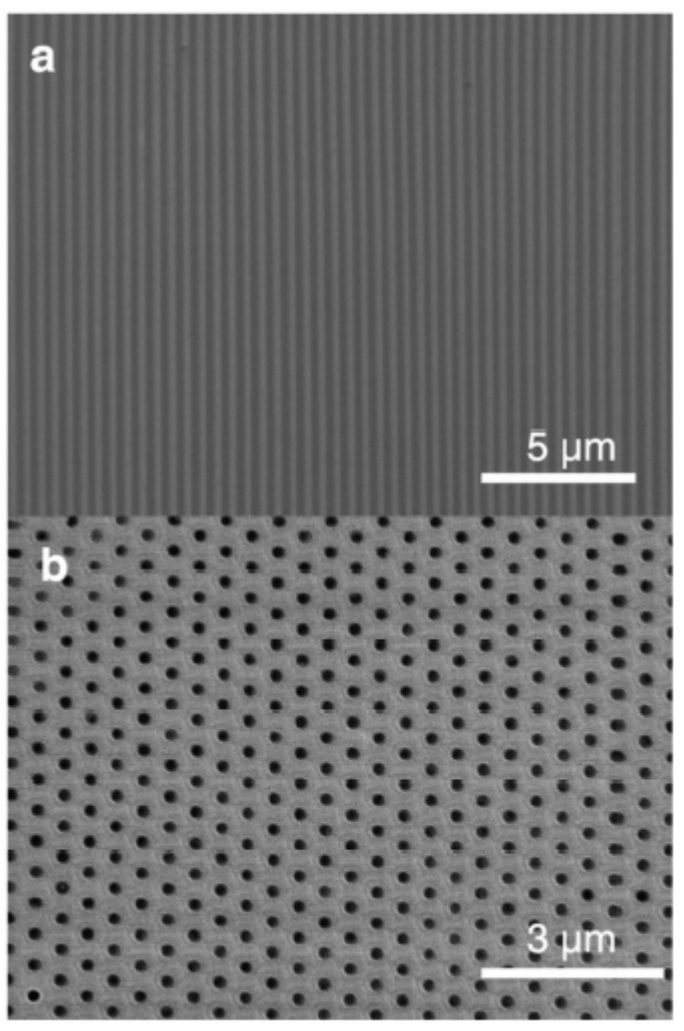


Templates

policarbonato



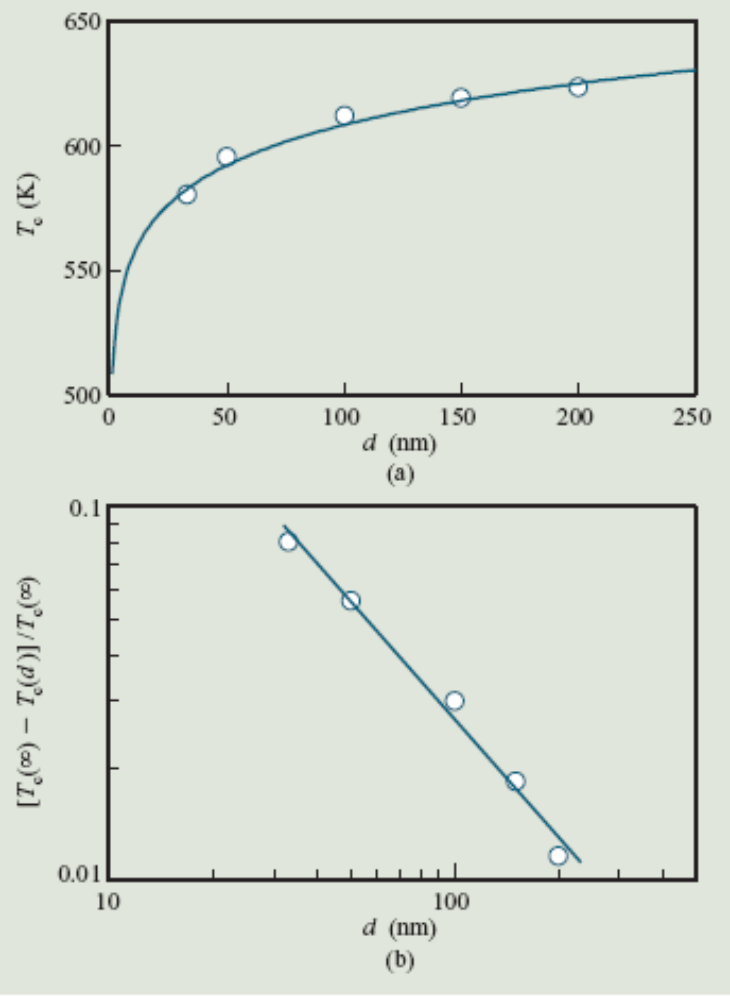
Alumina anodizada



Ordem magnética em nanofios

TC de Nanofios de Ni vs. diâmetro

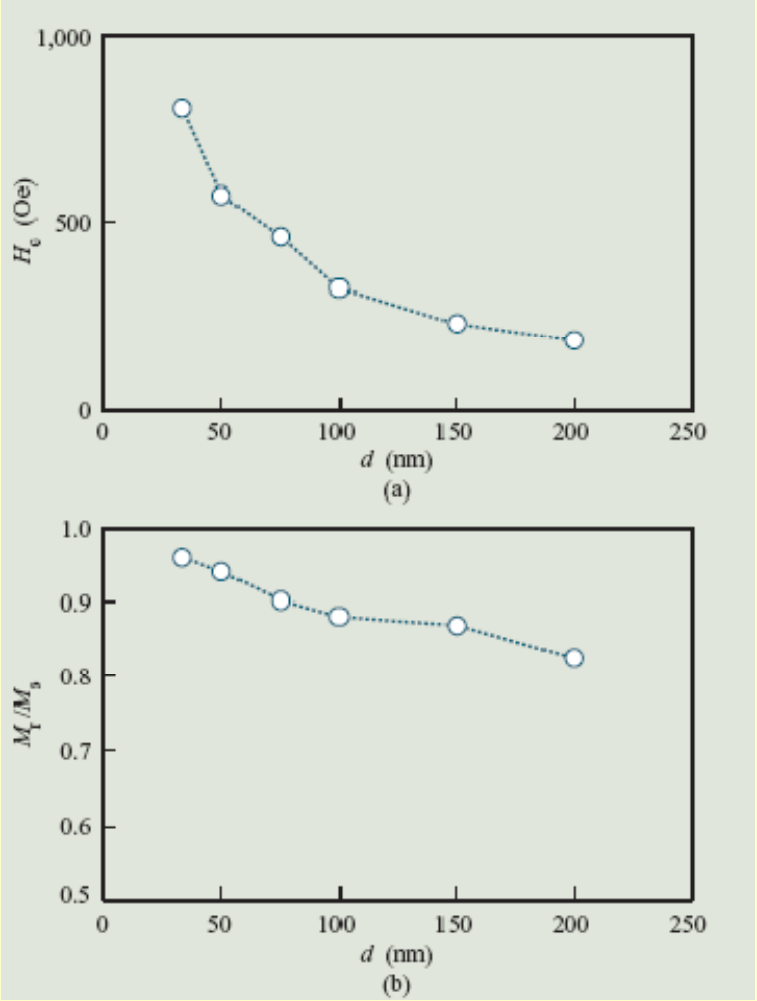
Gráfico log-log de TC(∞)-TC(d)/TC(∞)



L. Sun, et al, Tuning the properties of magnetic nanowires. *IBM J. of Res. Dev.*, 49 (2005) 79.

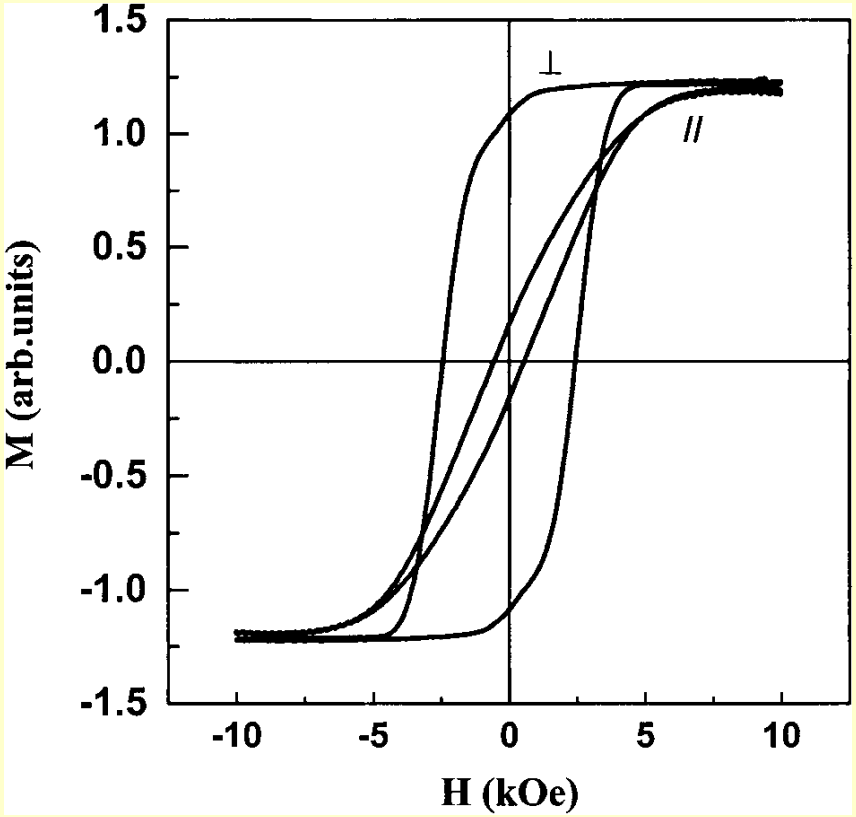
Coercividade e remanência de nanofios

Coercividade e remanência/M_s de nanofios de Ni em função do diâmetro



L. Sun, et al, Tuning the properties of magnetic nanowires. *IBM J. of Res. Dev.*, 49 (2005) 79.

Propriedades magnéticas dos nanofios

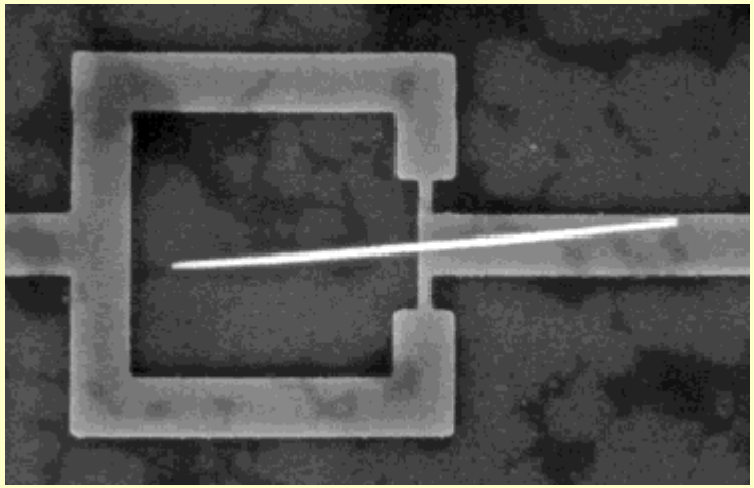


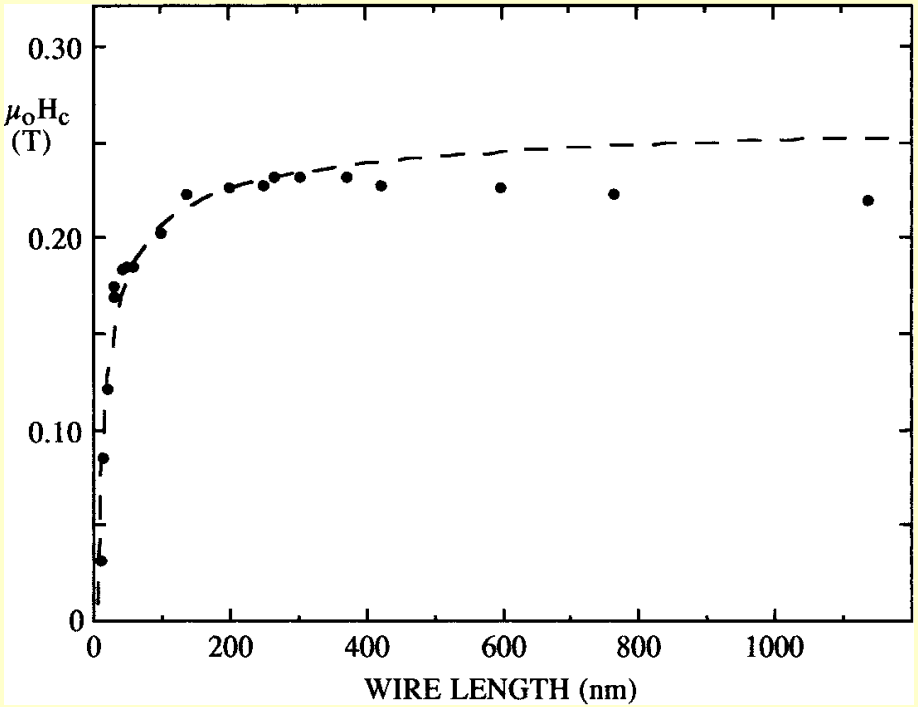
Curvas de magnetização de nanofio de Fe com diâmetro de 10 nm, para duas direções de H (note que as direções na figura são as direções relativas ao plano da membrana).

D.J. Sellmyer, et al, J Phys Cond Matt 13, R433 (2001)

Coercividade vs. comprimento

Nanofio em um microSQUID

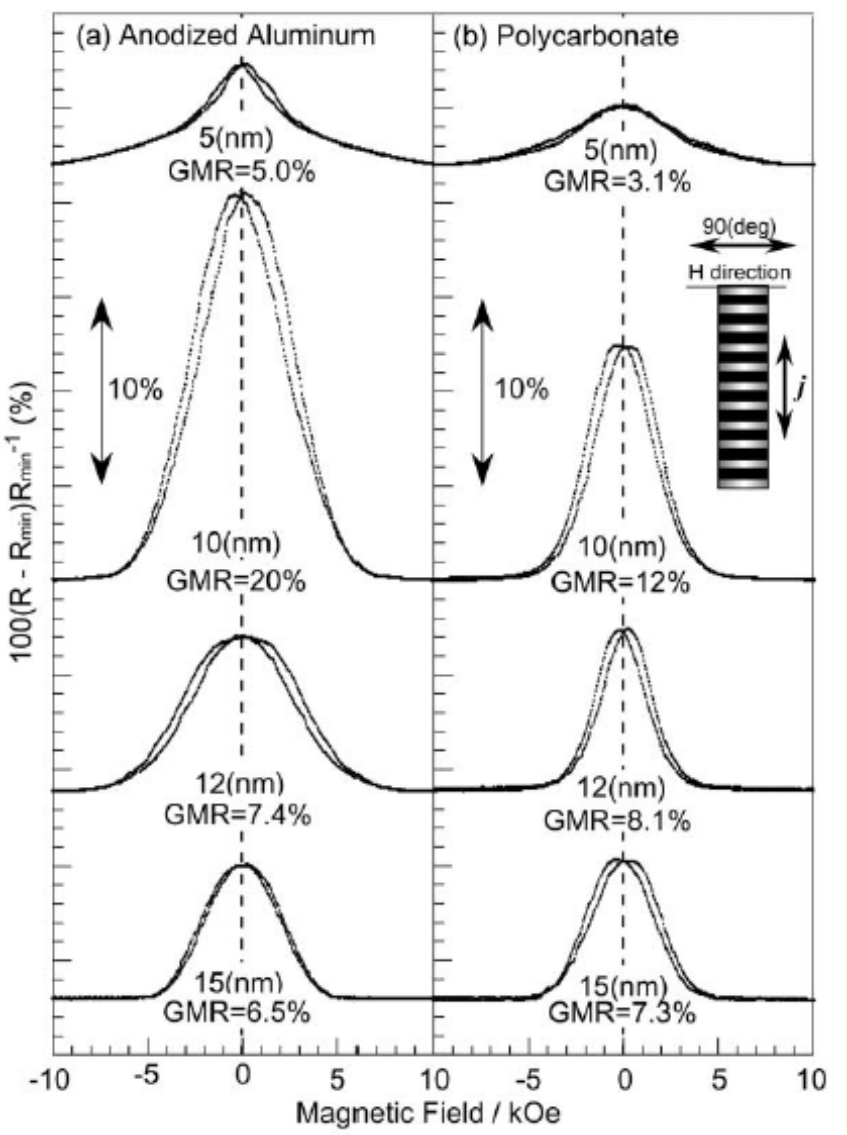




Coercividade de nanofios de Co de 10 nm de diâmetro em função do comprimento do fio. A linha pontilhada é o comportamento previsto pela teoria.

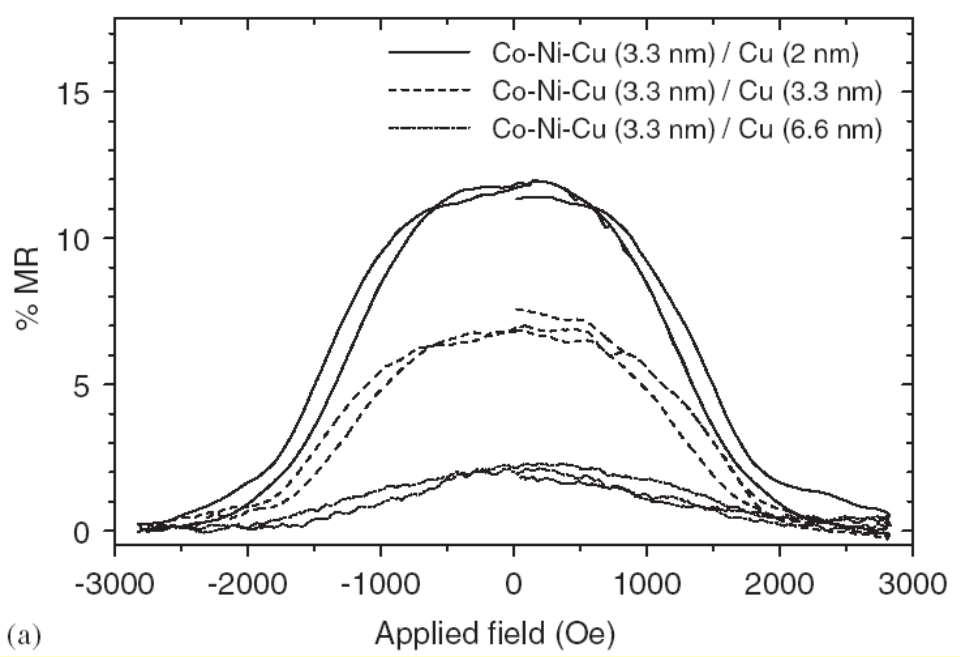
D.J. Sellmyer, et al, J Phys Cond Matt 13, R433 (2001)

Multicamada Co/Cu variando-se a espessura das camadas



T. Ohgai, et al, J. Mater. Chem. 13 (2003) 2530.

Multicamada Co/Cu variando-se a espessura da camada não magnética



F. Nasirpouri, et al, Journal of Magnetism and Magnetic Materials 308 (2007) 35.

Conclusão

- Técnicas com litografia e electrodeposição possibilitam o desenvolvimento novas estruturas nanométricas
- Estas novas estruturas apresentam propriedades dependentes da geometria das amostras
- Fios monocomponente e multicomponentes são de interesse em aplicações, uma vez que as propriedades magnéticas (temperatura de Curie, coercividade, magnetização remanente, magnetoresistência) podem ser ajustados modificando-se o diâmetro, material e espessura das camadas em fios multicamadas.

Bibliografia

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- ‘Tuning the properties of magnetic nanowires’, L. Sun, Y. Hao, C.L. Chien e P.C. Searson, IBM J. Res. & Dev. 49 (2005) 79-102.
- ‘Magnetism of Fe, Co and Ni nanowires in self-assembled arrays’, D.J. Sellmyer, M. Zheng e R. Skomski, J. Phys.: Condens. Maatter 13 (2001) R433-R460.
- ‘Domain wall diodes in ferromagnetic planar nanowires’, D.A. Allwood, G. Xiong, R.P. Cowburn, Appl. Phys. Letters 85 (2004) 2848-2850.
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