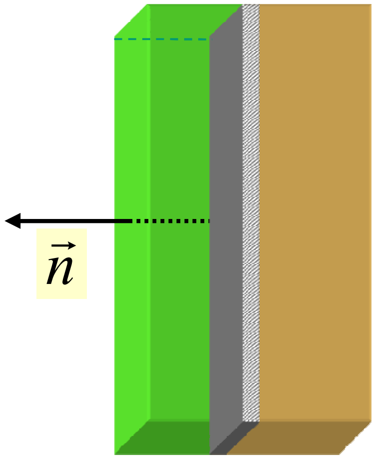
8a Anisotropía de Intercambio

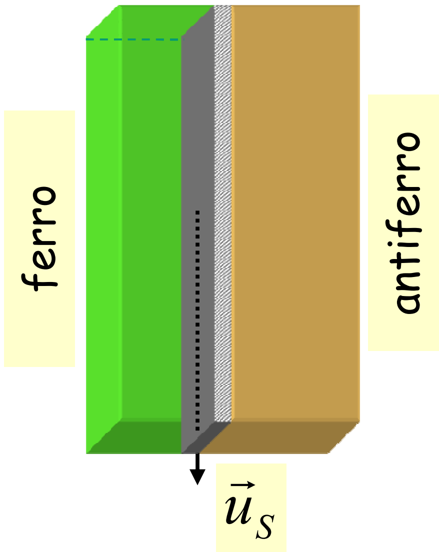
Otros usos: superficies e interfaces

Anisotropía de interfaz



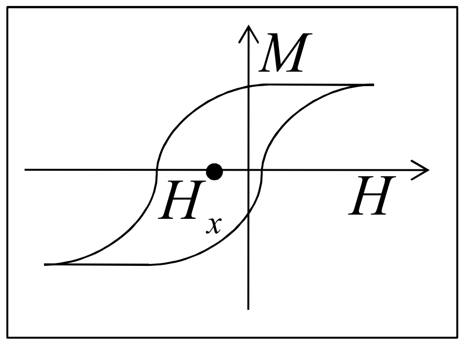
$$e_K = K_S\left[1-(\vec{m}\cdot\vec{n})^2\right] \begin{cases} K_S > 0 \Rightarrow \vec{m} \,//\, \text{sup} \\ K_S < 0 \Rightarrow \vec{m} \perp \text{sup} \end{cases}$$

Anisotropía de intercambio*



$$e_K = K_S \vec{m}\cdot\vec{u}_S = \frac{H_x}{2}\vec{m}\cdot\vec{u}_S$$

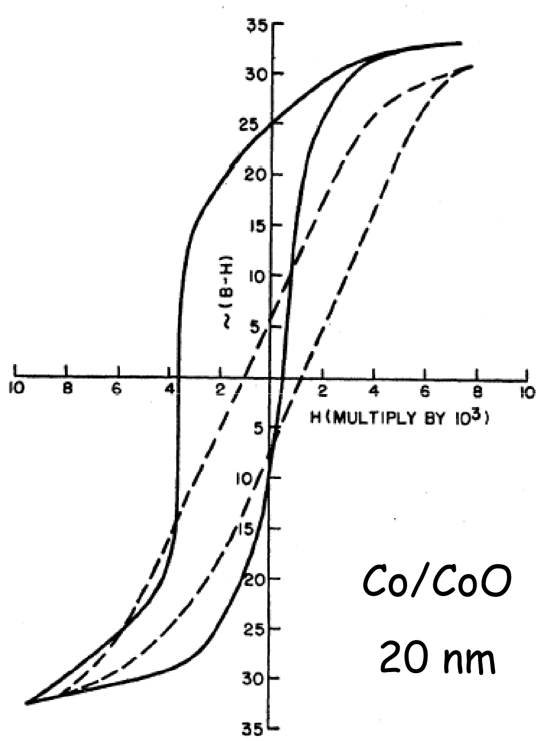
$$e_K = \frac{H_x}{2} m\cos\varphi$$



Exchange bias field

*también llamada unidireccional

Anisotropía de intercambio



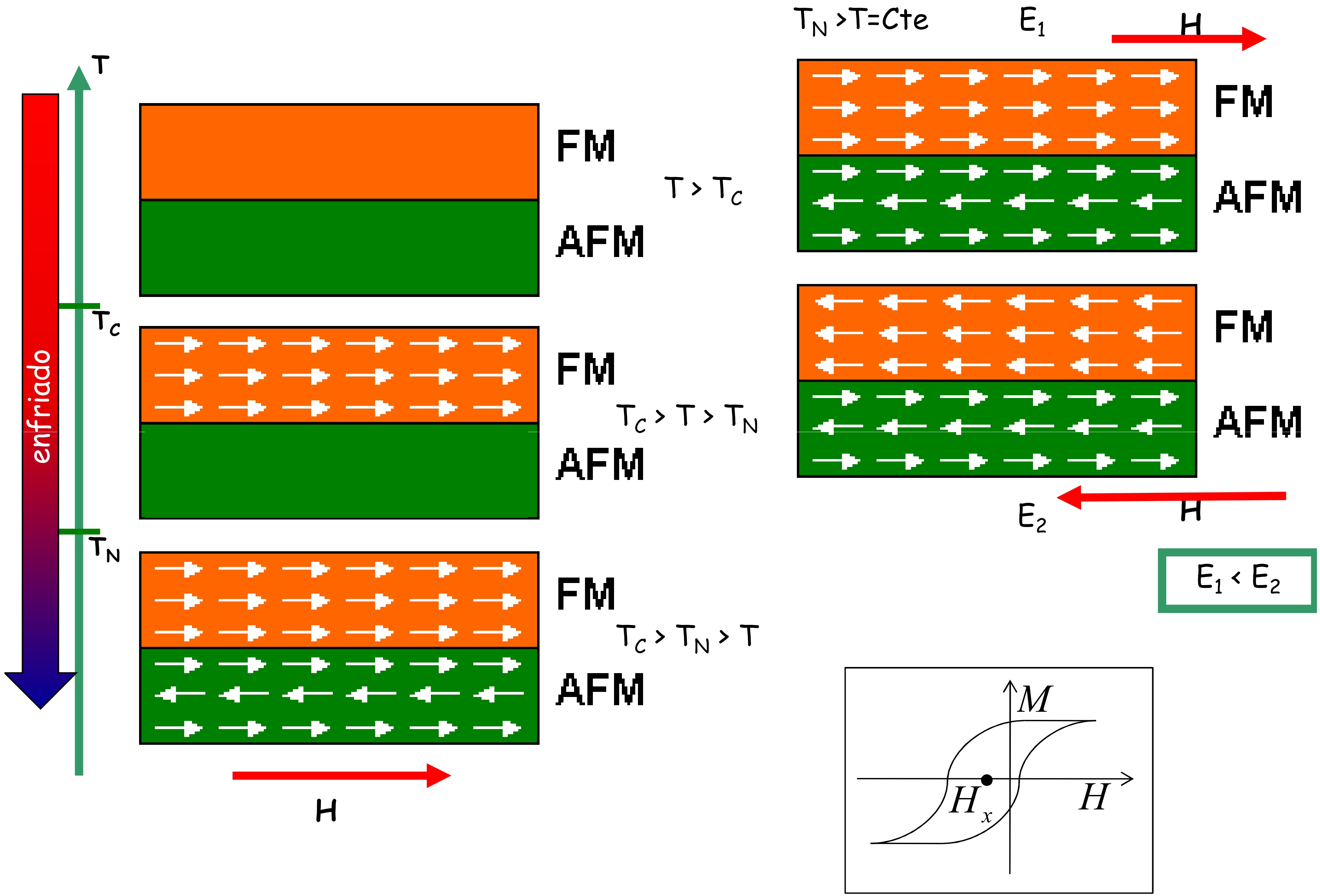
Letters to the Editor

New Magnetic Anisotropy

W. H. Meiklejohn and C. P. Bean
General Electric Research Laboratory, Schenectady, New York

(Received March 7, 1956)
PHYSICAL REVIEW
VOLUME 102, NUMBER 5
JUNE 1, 1956

Anisotropía de intercambio



Anisotropía de intercambio

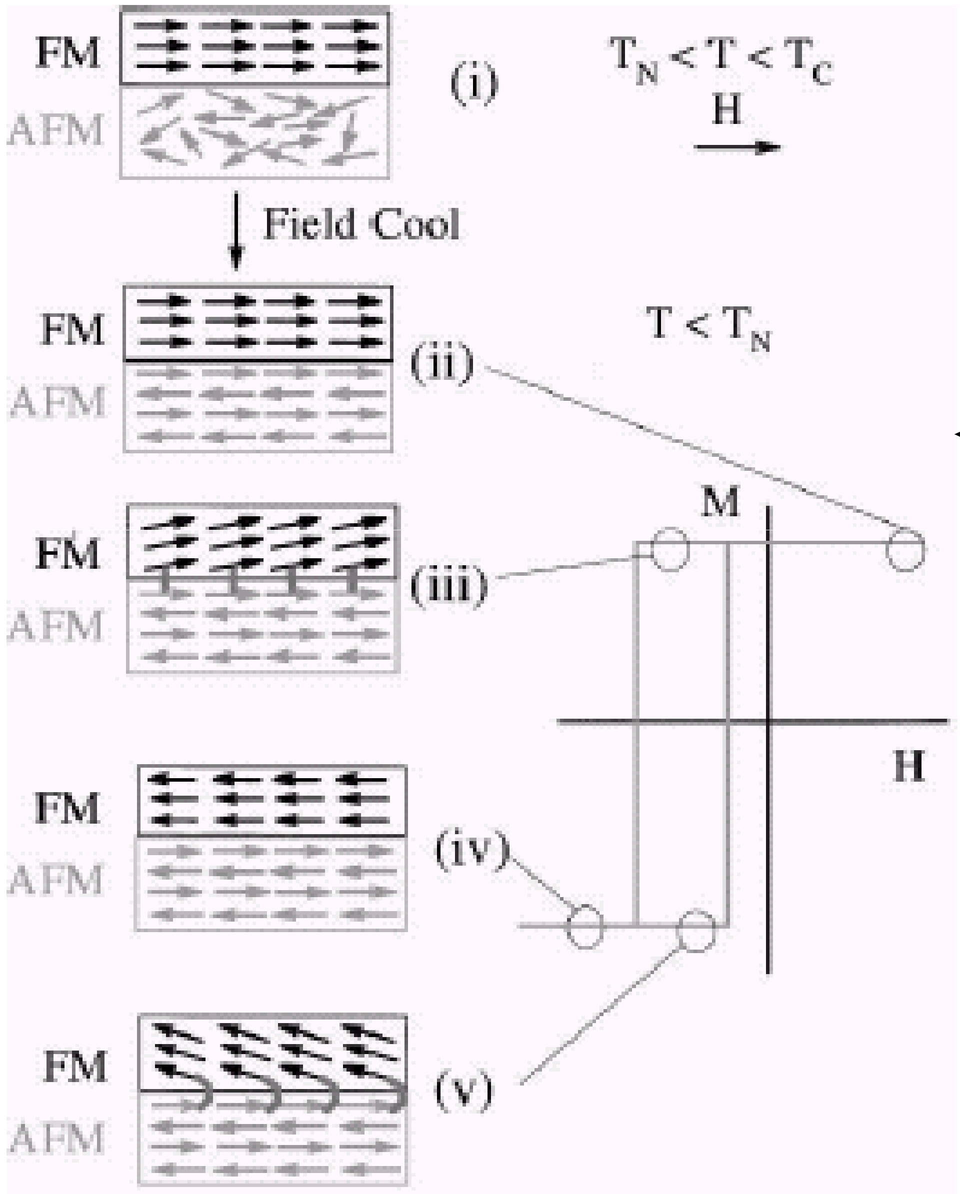
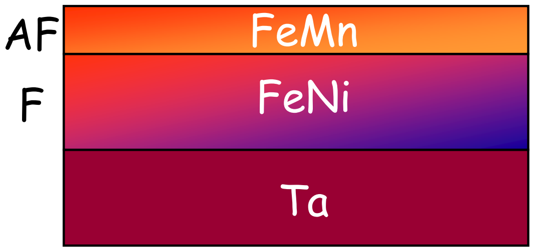


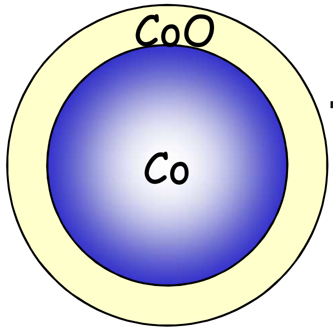
Diagrama esquemático de una configuración de spin FM /AFM.

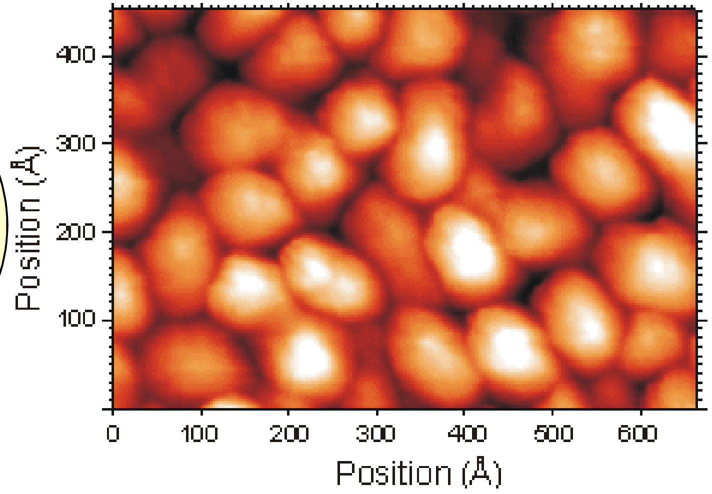
Observación de la anisotropía de intercambio

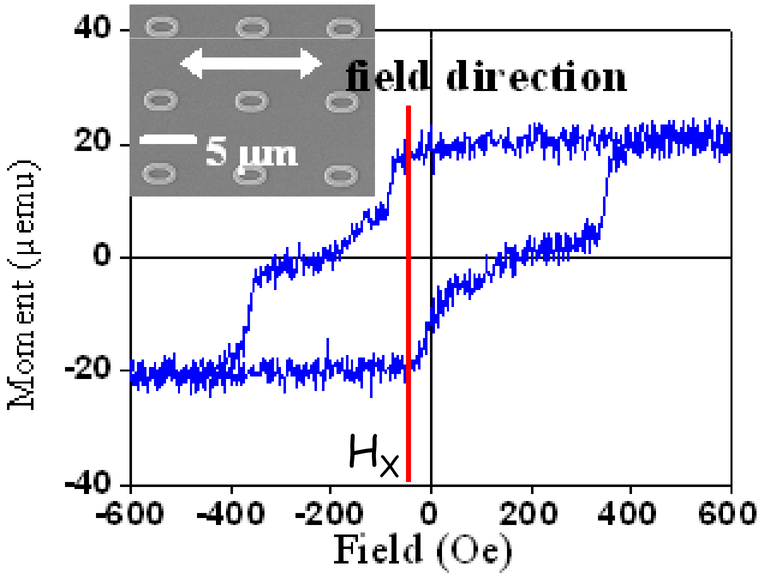
Exchange bias



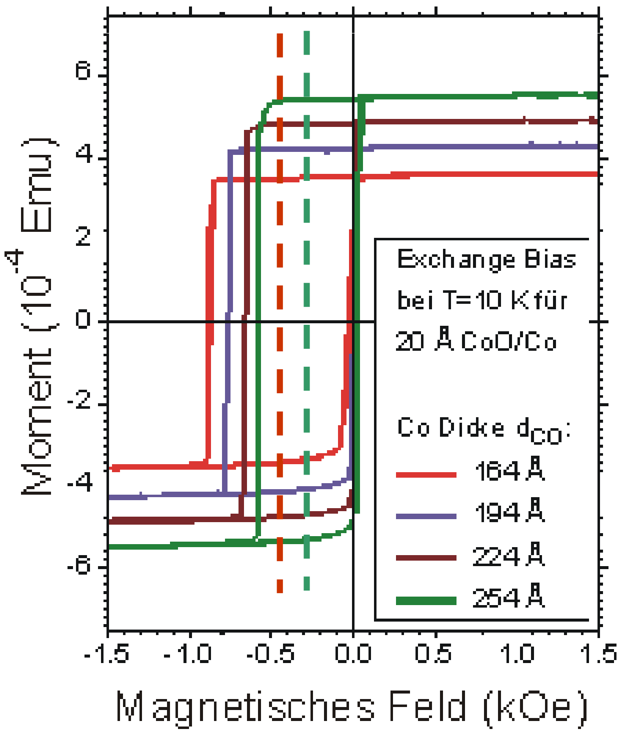
CoO/Co







Ta 20nm / NiFe 20nm/ FeMn 10 nm film



Exchange Coupling in the Paramagnetic State

J. W. Cai, Kai Liu, and C. L. Chien, *The Johns Hopkins University, Baltimore, MD 21218*

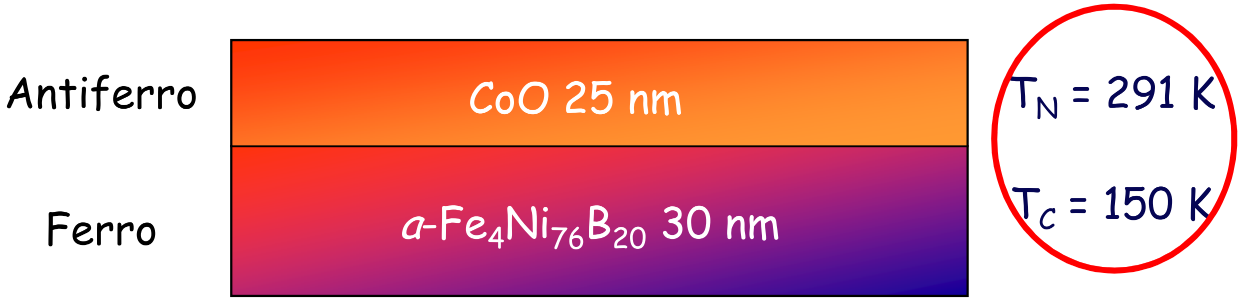
I. Introduction

When a ferromagnet (FM)/ antiferromagnet (AF) bilayer, with the Curie temperature (T_C) of the FM higher than the Néel temperature (T_N) of the AF, has been field-cooled across T_N, an exchange bias is set in. The resultant hysteresis loop of the FM is now shifted by an amount termed the exchange field (H_E), accompanied by an enhanced coercivity (H_C). In the cases thus far reported, T_C has always been much higher than T_N. During field cooling across T_N, the FM layer is in the single-domain state while the exchange coupling is being locked in. It has been generally accepted that $T_C > T_N$ is a prerequisite for establishing FM/AF exchange coupling. In this work, we have studied an FM/AF bilayer of *a*-$Fe_4Ni_{76}B_{20}$ (T_C ~ 150 K) and CoO (T_N = 291 K) with T_C *much lower* than T_N, a hitherto unexplored regime where the FM ordering is absent when the exchange coupling is being established. We have observed exchange coupling in this system, which persists well into the paramagnetic (PM) state ($T > T_C$).

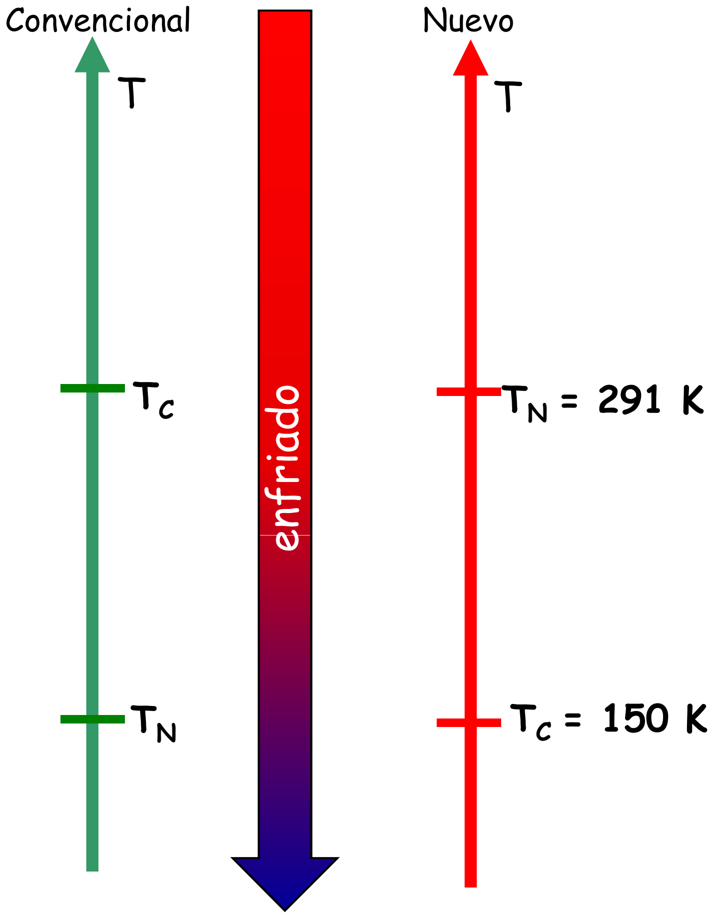
II. Results

The hysteresis loop of a single 300 Å *a*-$Fe_4Ni_{76}B_{20}$ layer at 80 K is shown in Fig. 1a, exhibiting a square loop with a small coercivity of only 0.4 Oe, which are characteristics of a soft FM. However, a bilayer of *a*-$Fe_4Ni_{76}B_{20}$(300 Å)/CoO (250 Å), field-cooled in a field of 10 kOe to 80 K, shows a shifted hysteresis loop with large values of H_E and H_C, which are clear signatures of exchange coupling. The hysteresis loops measured at successively higher temperature from 80 K to 290 K are shown in Fig. 1c — 1h. At higher temperatures, the coercivity progressively decreases and vanishes near T_C. Most strikingly, the *collapsed* loop at $T > T_C$ continues to be shifted with an exchange field H_E, which first increases to a maximum before decreasing progressively to zero at 290 K, the T_N of CoO. Thus, we not only have observed exchange coupling at $T < T_C$ in a bilayer where T_C is much less than T_N, but also at $T > T_C$, when the FM layer is in the PM state.

Exchange Coupling in the Paramagnetic State



Exchange Coupling in the Paramagnetic State



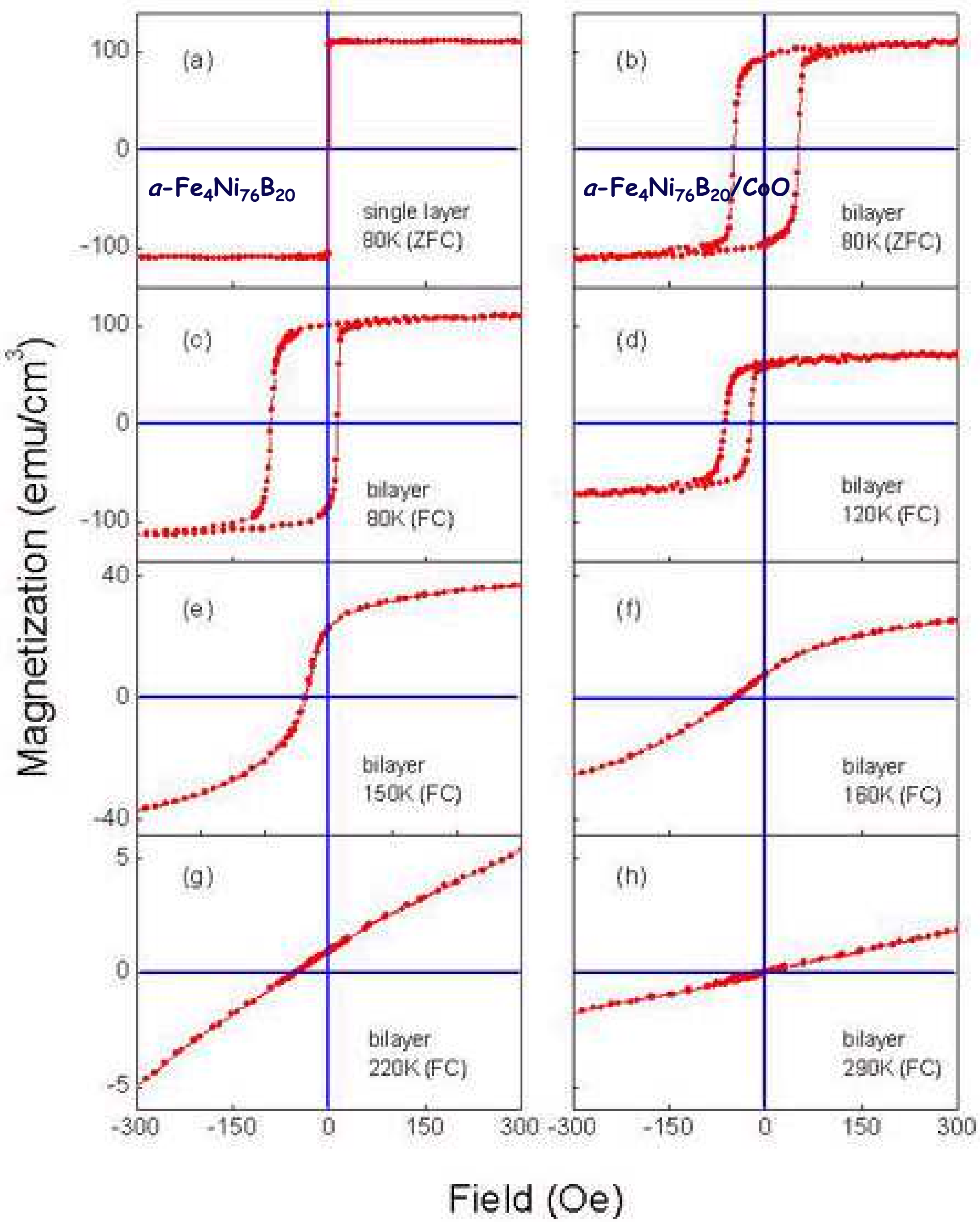


Figure 1: Hysteresis loops of a single layer a-$Fe_4Ni_{76}B_{20}$ at 80 K (a) and a bilayer of a-$Fe_4Ni_{76}B_{20}$(300 Å)/CoO (250 Å) at 80 K after zero-field cooling to 80 K (b), after field cooling in 10 kOe to 80 K and measured at 80 K (c), 120 K (d), 150 K (e), 160 K (f), 220 K (g), and 290 K (h). 0

Exchange Coupling in the Paramagnetic State

The temperature dependence of H_E and H_C, obtained from the hysteresis loops shown in Fig. 1c-1h, are presented in Fig. 2. A number of striking features are evident. First of all, H_E and the enhanced H_C do not both vanish at T_N, completely different from what has been universally observed in bilayers with $T_C > T_N$. Instead, while H_E vanishes at T_N, H_C vanishes at a lower temperature near T_C. This indicates vividly that in exchange-coupled FM/AF bilayers, the exchange field is dictated by the AF ordering, but the coercivity, although significantly enhanced by the exchange coupling, is intrinsic to the FM ordering. Most importantly, the collapsed loop continues to be shifted from H = 0 at $T > T_C$, i.e., the exchange coupling persists when the FM layer is already in the PM state. It is noted in Fig. 2 that, while H_C decreases monotonically with temperature and reaches the terminal value at T_C, H_E shows a sharp rise near T_C before decreasing towards zero at T_N.

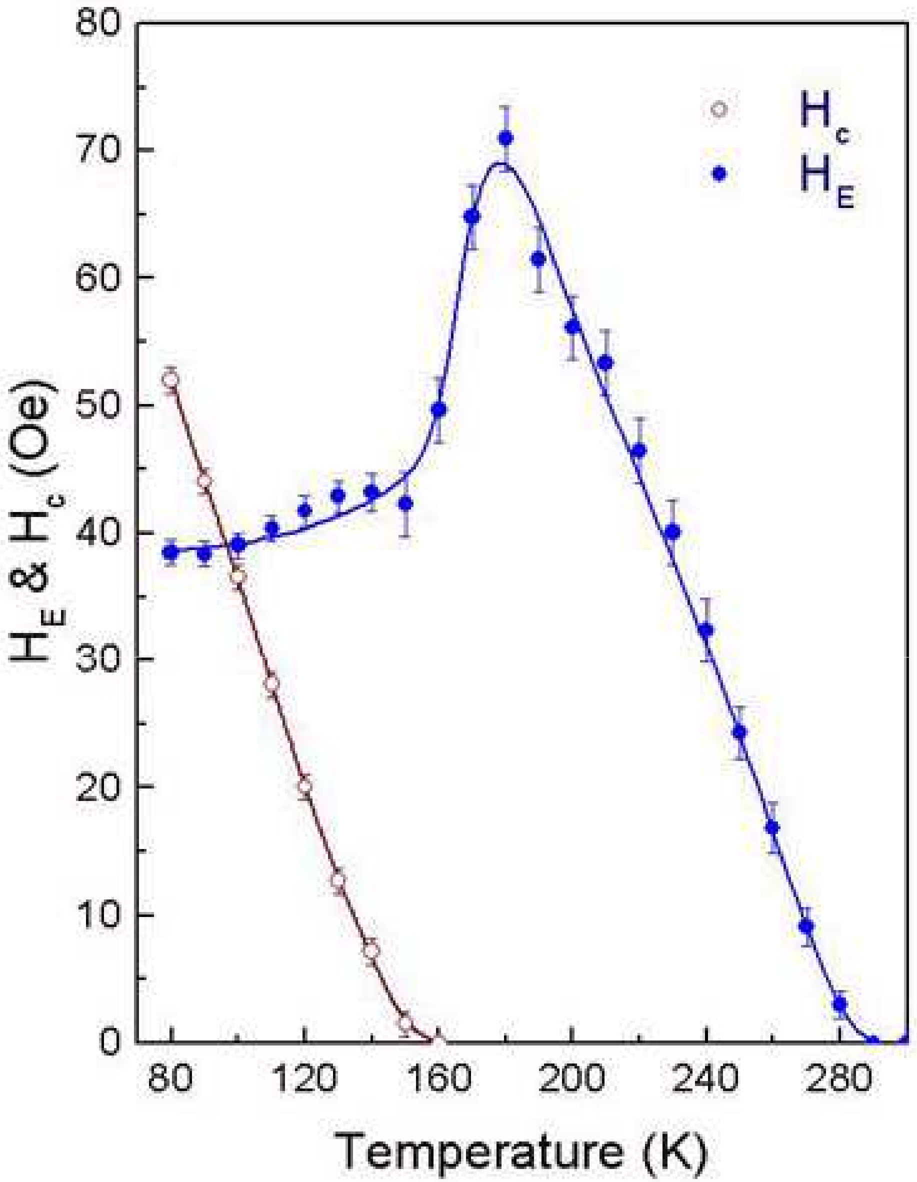


Figure 2: Temperature dependence of exchange field H_E and coercivity H_C of *a*-$Fe_4Ni_{76}B_{20}$(300 Å)/CoO (250 Å) after field cooling in 10 kOe to 80 K.

Exchange Coupling in the Paramagnetic State

The realization of exchange coupling in bilayers with T_C<< T_N also has important implication in technological application of exchange coupling in spin-valve devices. For FM/AF bilayers with optimized performance, one can broaden the search to a greater variety of FM and AF materials to realize suitable values of H_E and H_C near room temperature without regard to the condition of $T_C > T_N$.

III. Summary

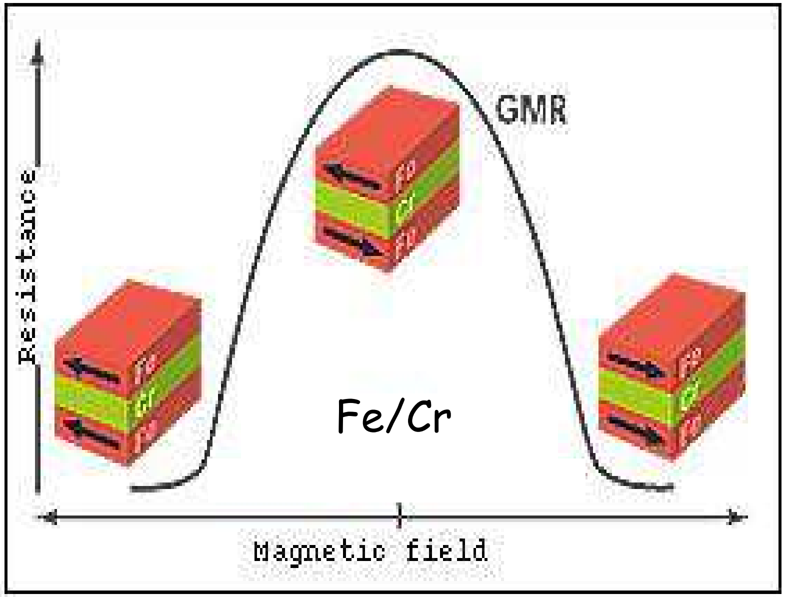
Contrary to the common perception of $T_C > T_N$ as a prerequisite for exchange coupling between a FM and an AF layers, we have demonstrated exchange coupling where $T_C \ll T_N$. The exchange coupling exists not only in $T < T_C$, but also in $T_C < T < T_N$, where the bulk of the FM layer is in the PM state. With increasing temperature, H_C vanishes at T_C, whereas H_E persists to T_N. The results show that the exchange coupling can be established in FM/AF bilayers regardless of the relative values of T_C and T_N.

Reference

J. W. Cai, Kai Liu, and C. L. Chien, Phys. Rev. B 60, 72 (1999).

Anisotropía de intercambio – válvula de spin

Magnetoresistencia gigante



Giant Magnetoresistance of (001) Fe/(001) Cr Magnetic Superlattices

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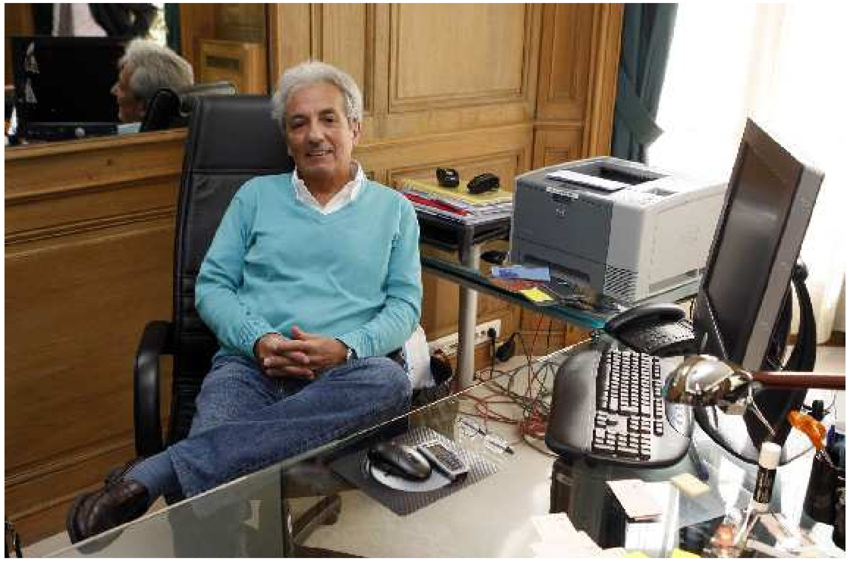
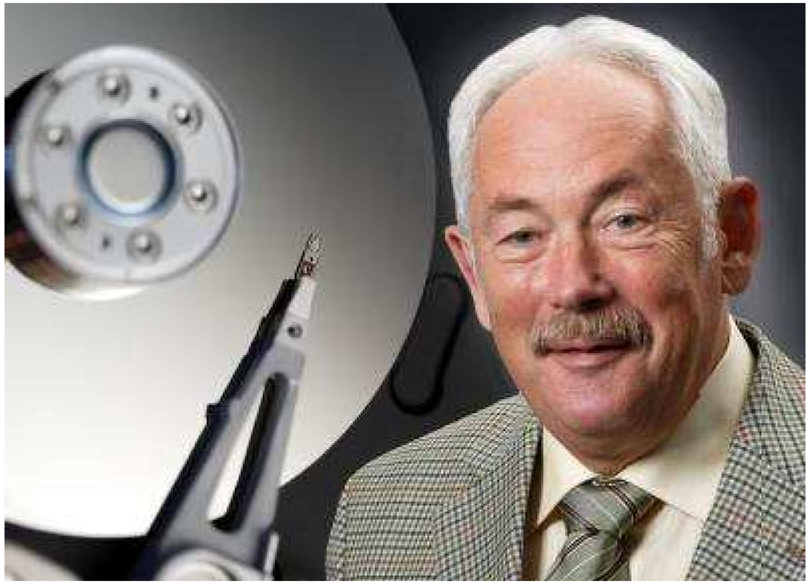


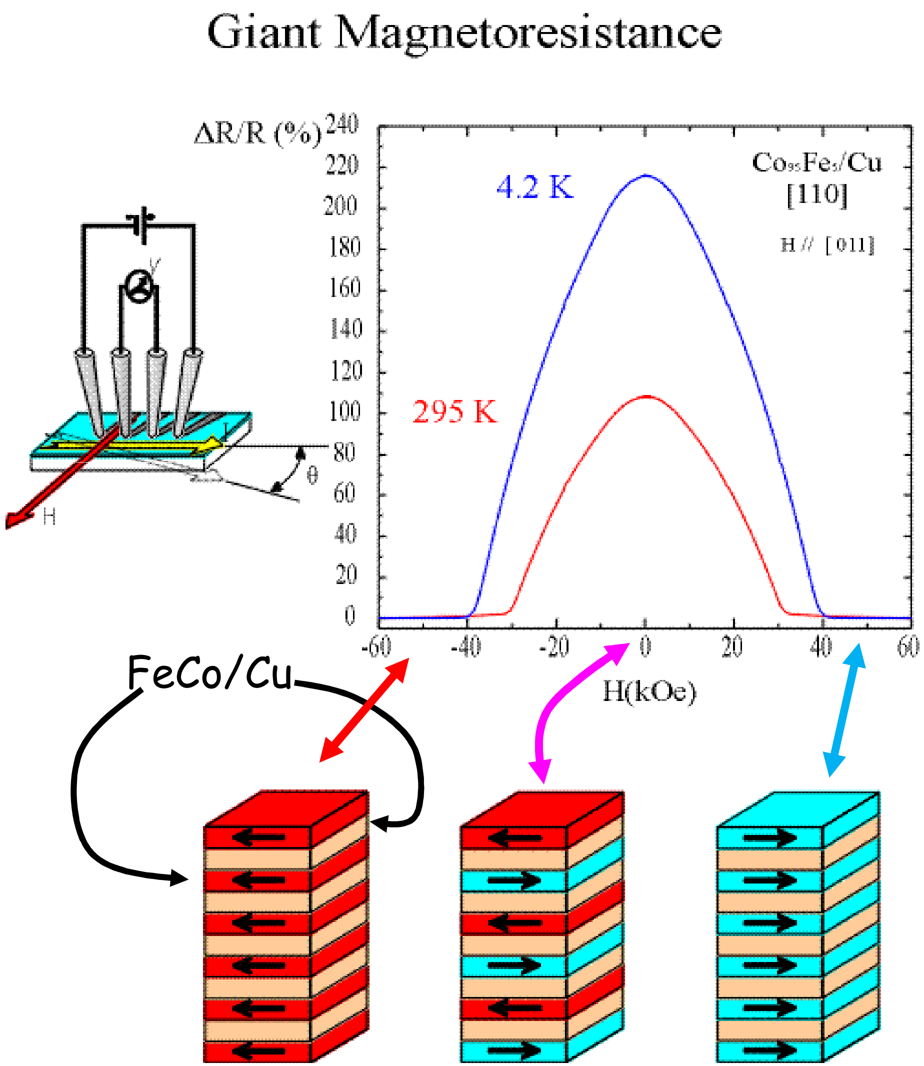
Albert Fert, Nobel Prize in Physics 2007



Peter Grünberg, Nobel Prize in Physics 2007

Anisotropía de intercambio – válvula de spin

Magnetoresistencia gigante

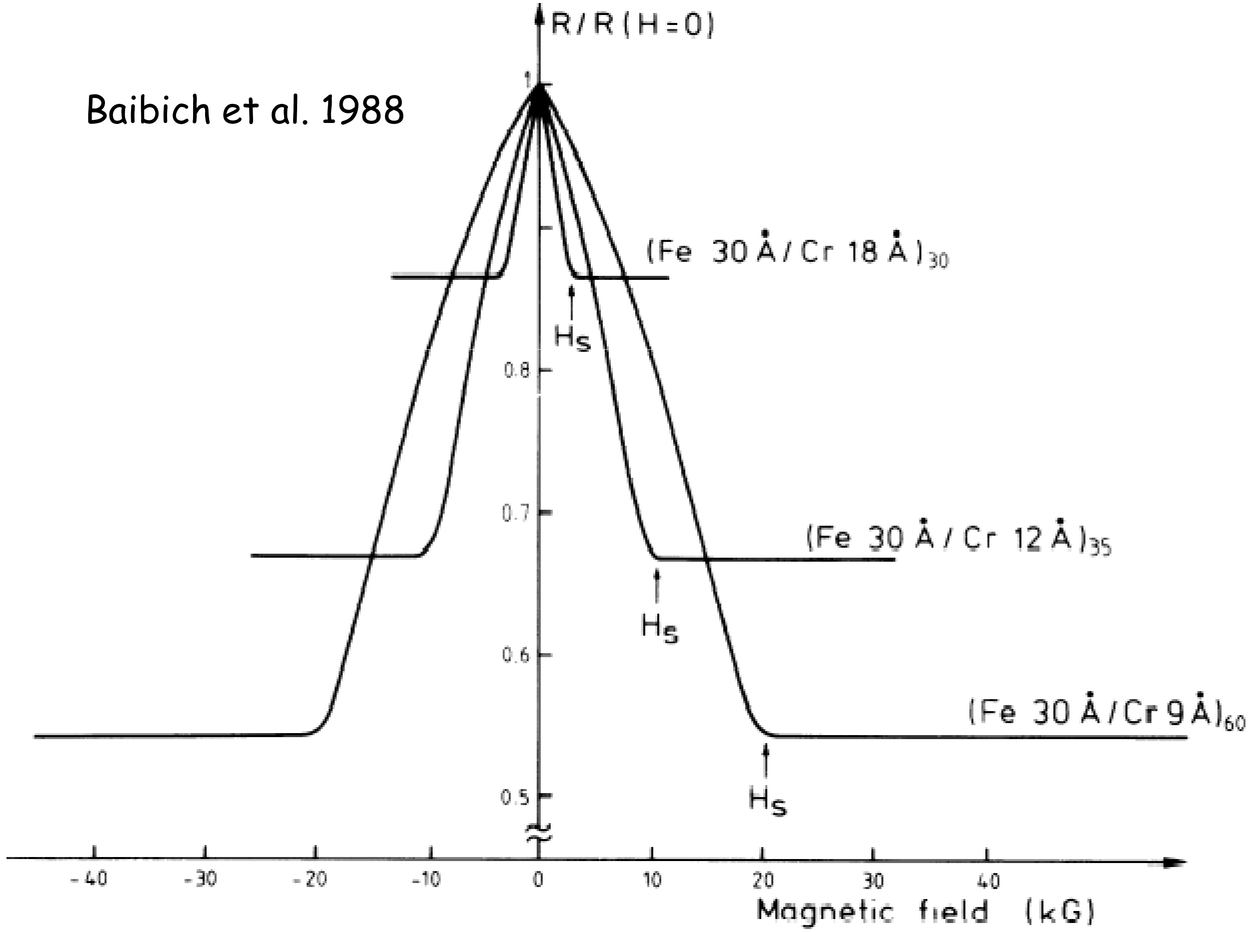


Anisotropía de intercambio – válvula de spin

Magnetoresistencia gigante

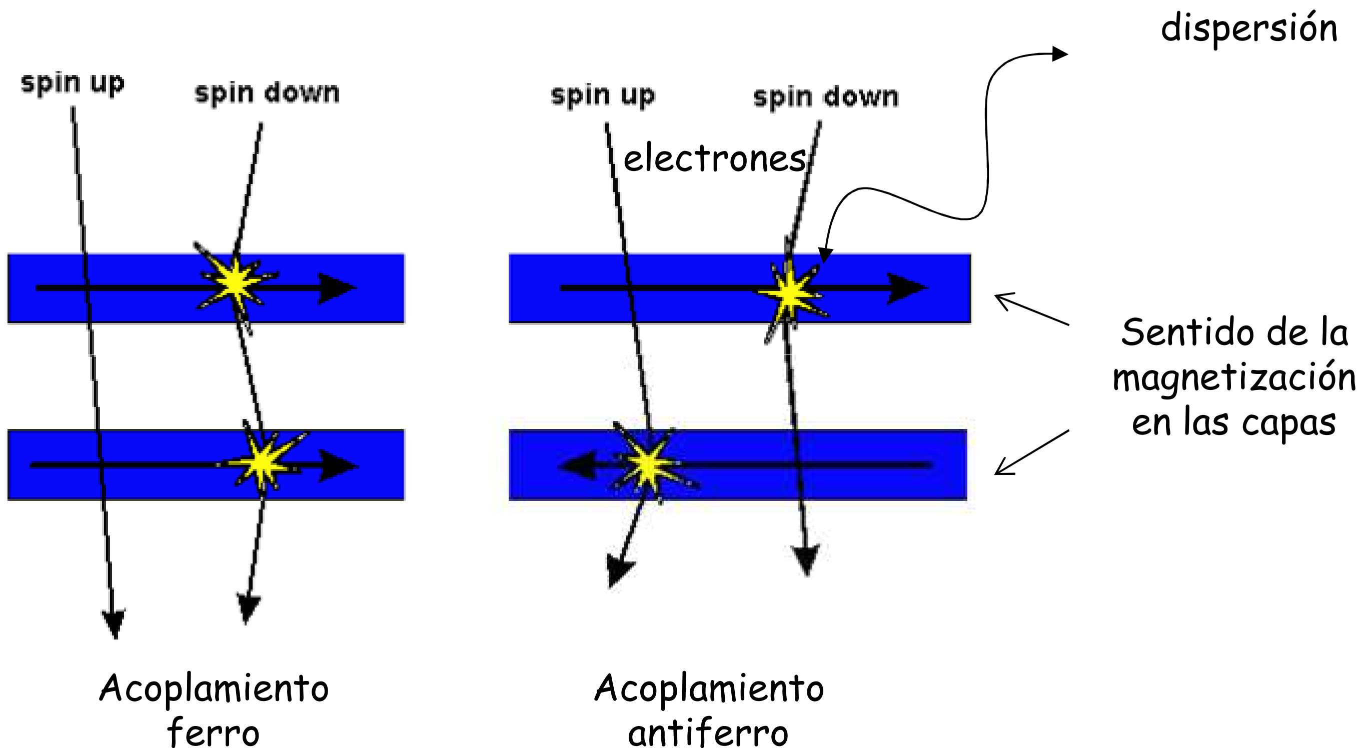
Resultados experimentales

Baibich et al. 1988



Anisotropía de intercambio – válvula de spin

Magnetoresistencia gigante



Baja resistencia

Alta resistencia

Anisotropía de intercambio – válvula de spin

Magnetoresistencia gigante

Magnetoresistance - spin valve

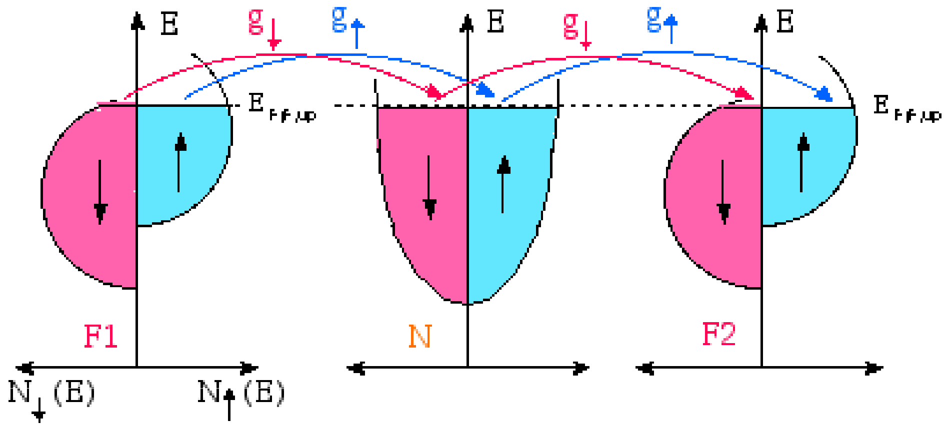
$g \propto N(E_F)$

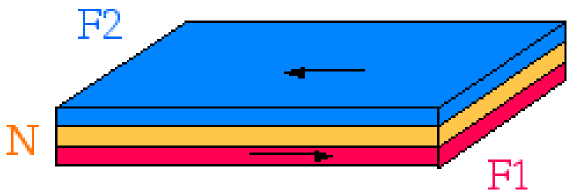
F1 and F2 parallel:

$g_{\uparrow} > g_{\downarrow}$

$g_{\uparrow}$ dominates

Low R state

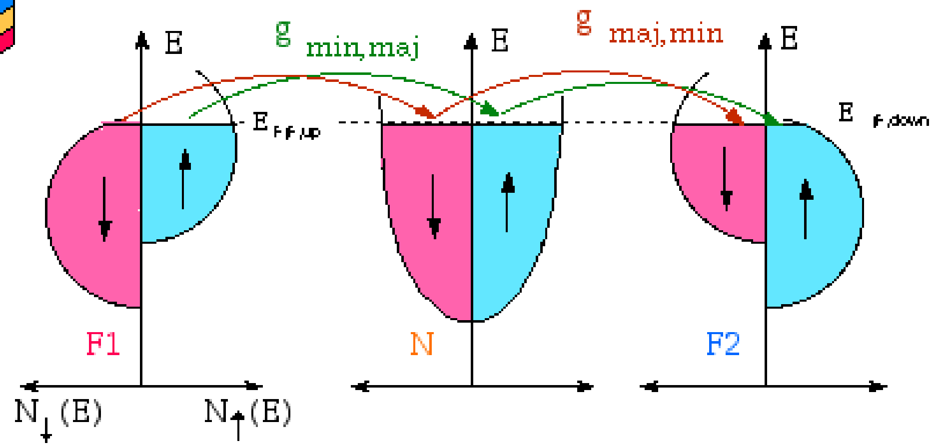




F1 and F2 antiparallel:

$g_{min,maj} = g_{maj,min} < g_{\uparrow}$

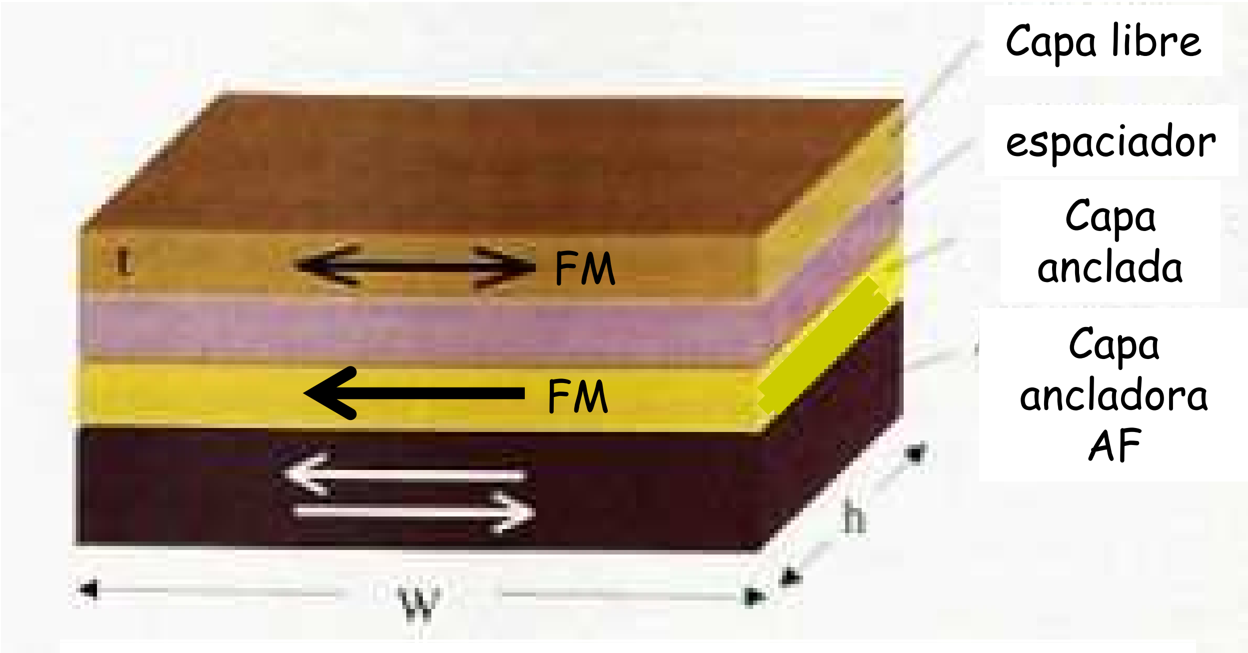
High R state

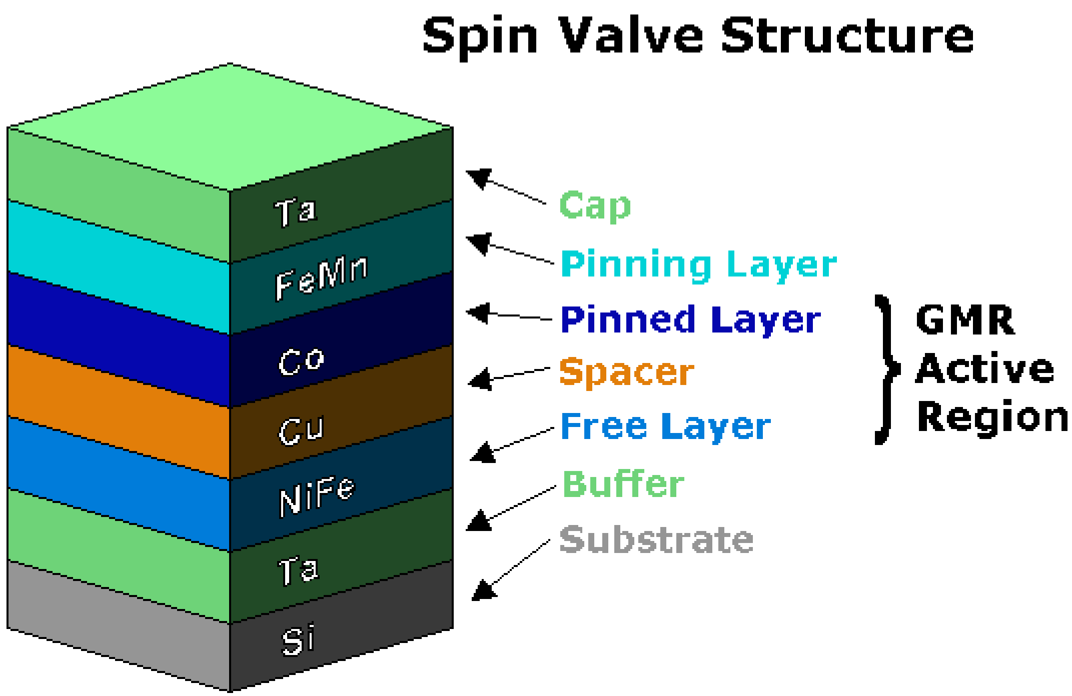


Grunberg PRB (89), Fe/Cr spin valve MR=1.5%

Baibich et al., PRL (88), Fe/Cr multilayer

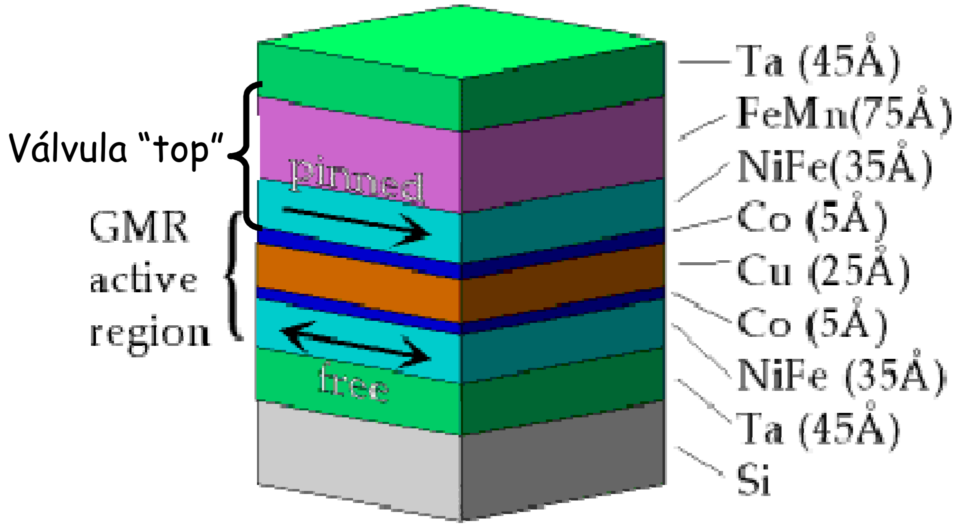
Anisotropía de intercambio – válvula de spin

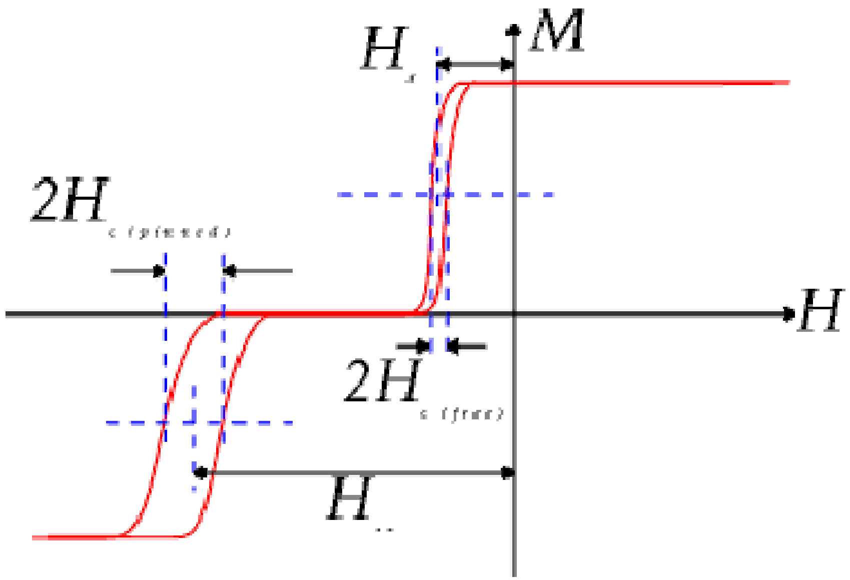


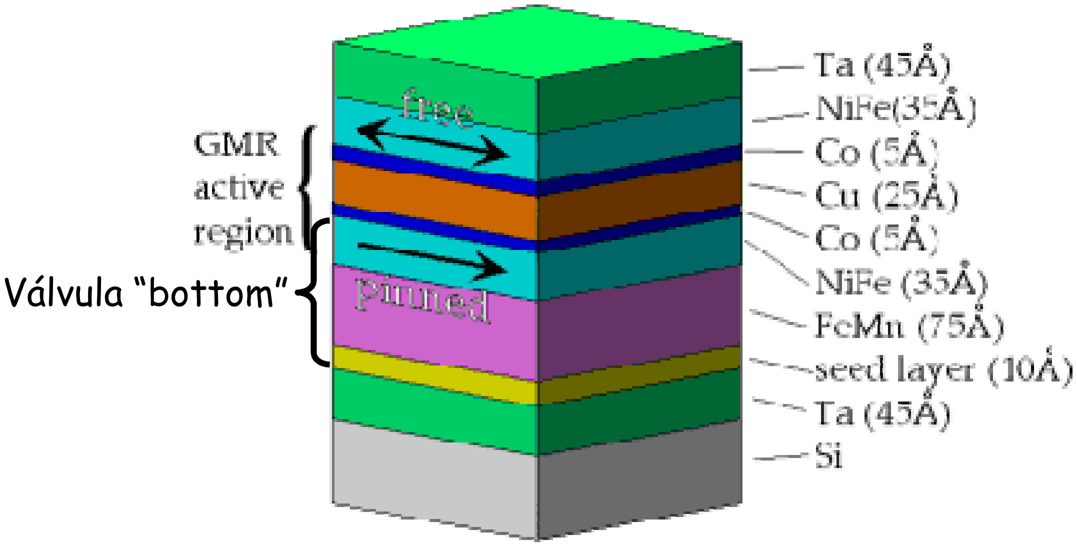


Magnetoresistencia y válvulas de spin - adenda

Válvulas de spin

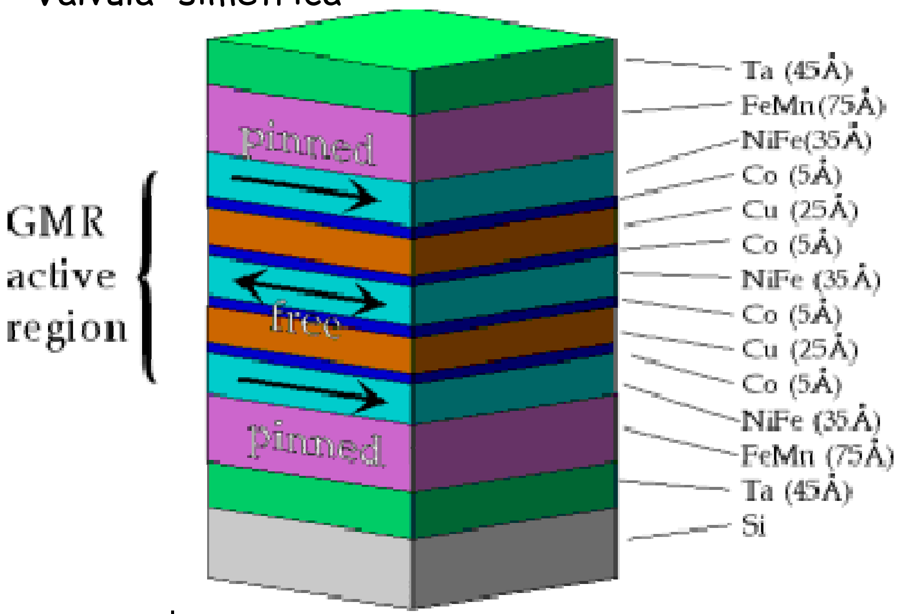


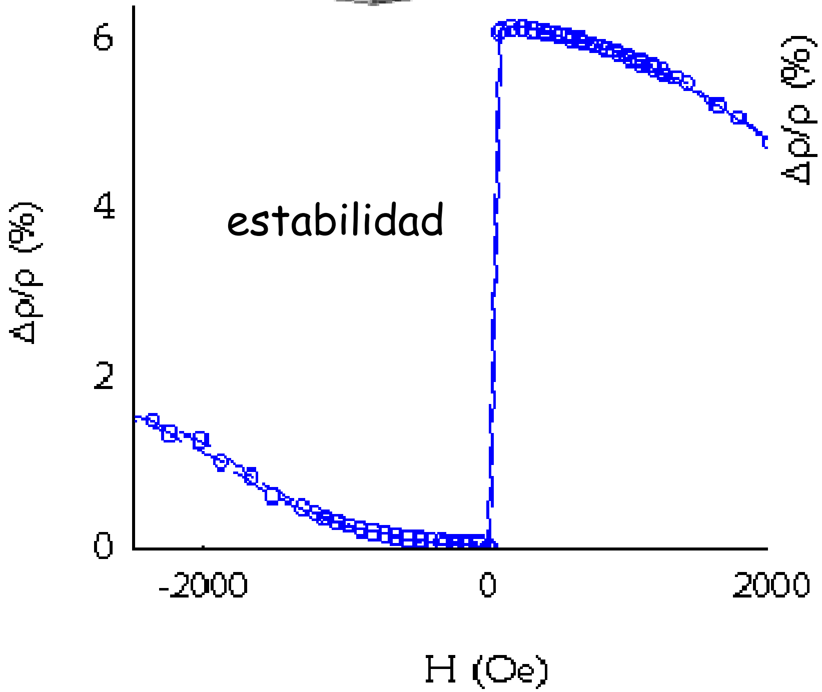




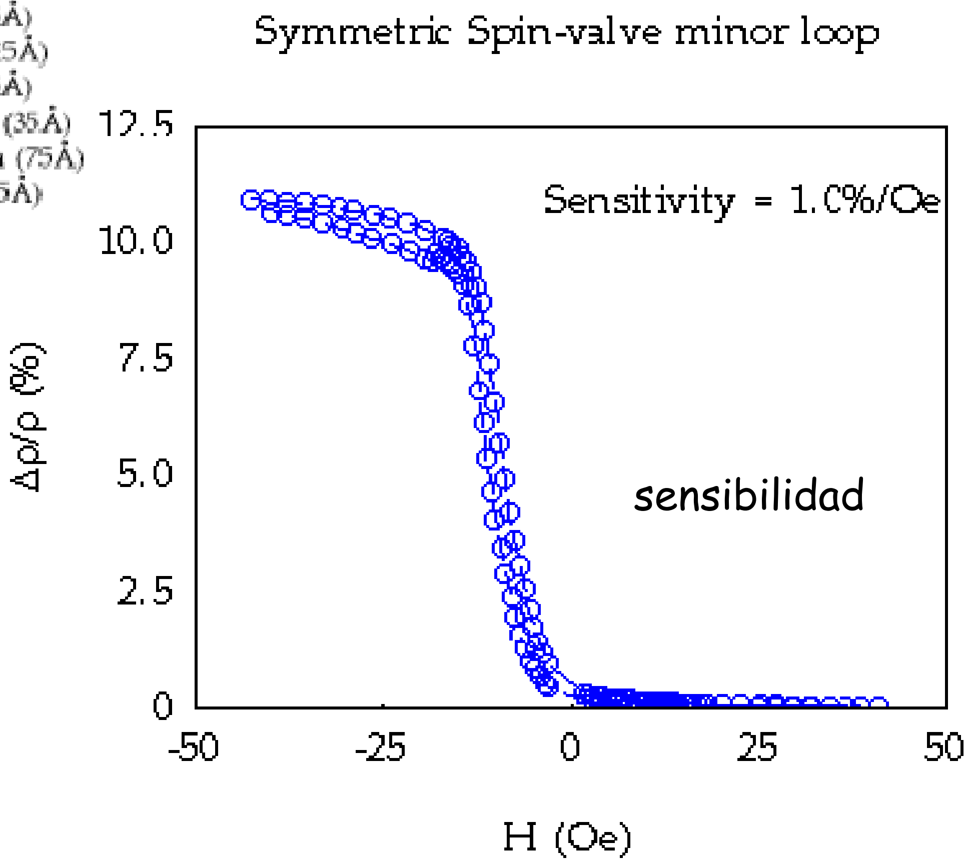
Magnetoresistencia y válvulas de spin - adenda

Válvula "simétrica"





Válvulas de spin

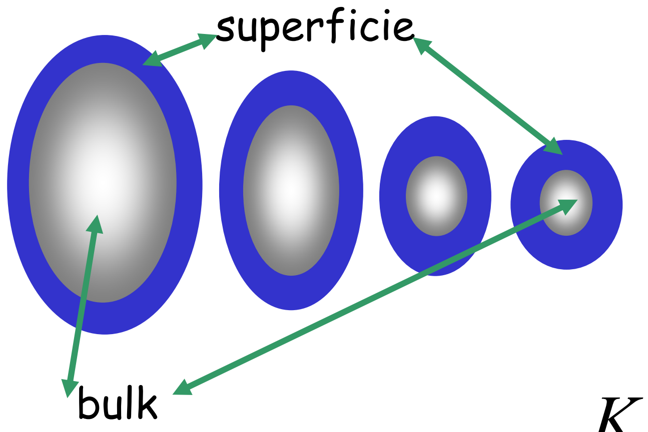


animación

Anisotropía de Superficie en Nanopartículas

Partículas ferromagnéticas pequeñas – efectos dinámicos

Anisotropía de superficie



Las superficies/interfaces presentan características especiales. Existe una discontinuidad composicional y configuracional, lo cual modifica las propiedades magnéticas. Se ha observado un **mayor efecto anisotrópico** en las superficies libres, frecuentemente con dirección radial. Por otro lado se ha observado una tendencia a menores efectos de intercambio en los átomos "superficiales" lo cual favorece el comportamiento paramagnético en esa región, incluso es frecuente la referencia a una capa superficial magnéticamente "muerta".

$$K_{ef} = K_B + K_{V_S}^{ef}$$

K_S = 10^{-4}-10^{-3} J/m^2, energía de anisotropía por unidad de área superficial

$$K_{V_S}^{ef} \approx \frac{SK_S}{V} \approx \frac{4\pi r^2}{\frac{4}{3}\pi r^3} K_S = \frac{3}{r} K_S = \frac{6}{d} K_S$$

Partícula esférica

$$K_{ef} = K_B + \frac{6K_s}{d}$$

$$K_{ef} = K_B + \gamma \frac{K_s}{\bar{d}}$$

Bødker et. Al (1994)

¿Efecto de distribución de tamaños de patículas?

Partículas ferromagnéticas pequeñas – efectos dinámicos

Anisotropía de superficie - ejemplo

$$K_B(Co_{fcc}) \approx 1\times10^5\, J/m^3$$

Alúmina

$$K_S(Co/Al_2O_3) \approx 3.3x10^{-4}\, J/m^2$$

$$K_{ef} = K_B + \gamma\frac{K_s}{\bar{d}}$$

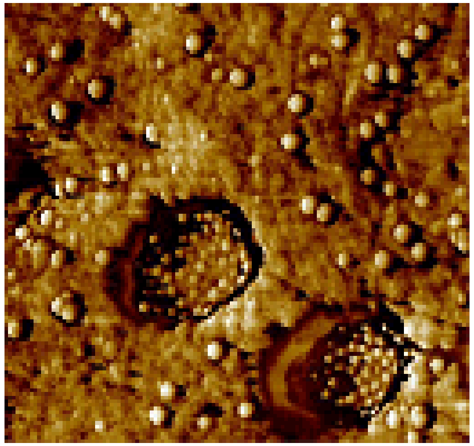


imagen MFA de nanopartículas de Co fcc en una matriz de alúmina. Las partículas son de aprox. 11 nm (diámetro).

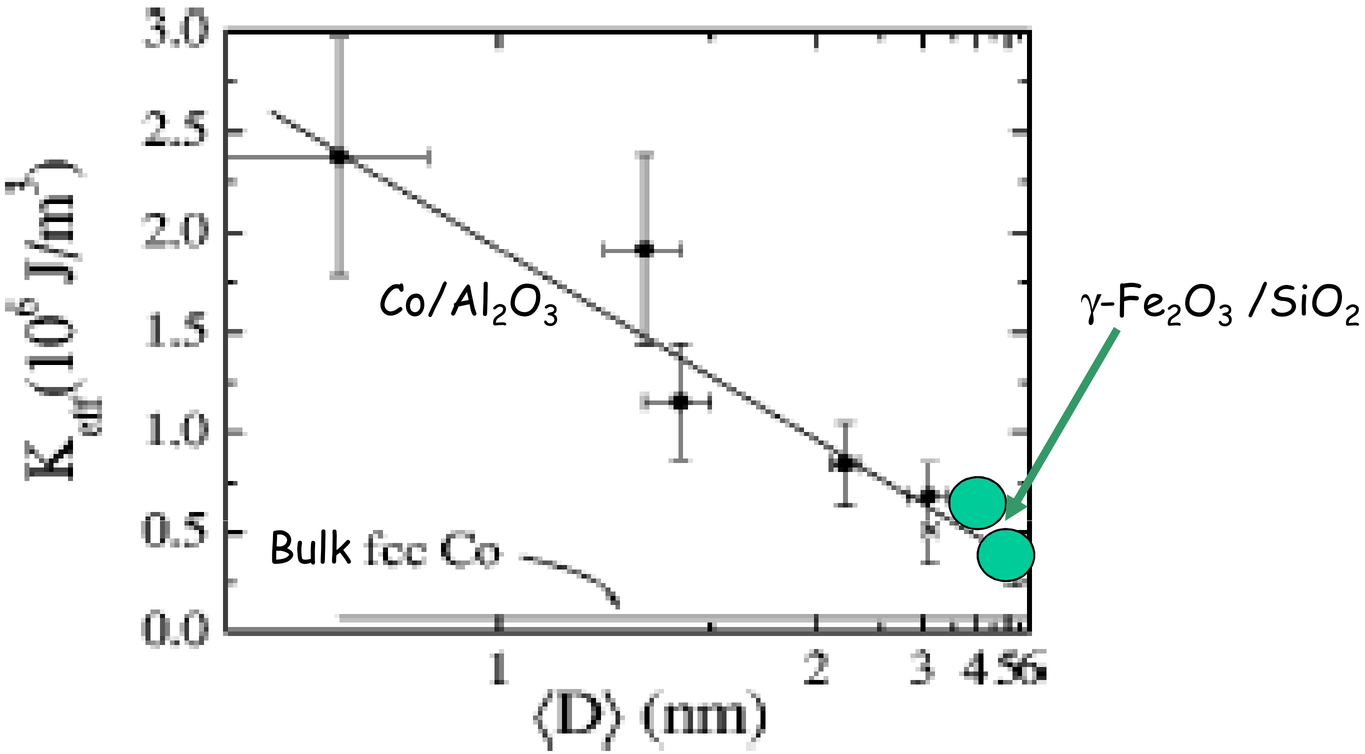
$$K_{ef}(Co/Al_2O_3) \approx \left[1\times10^5 + 6\frac{3.3\times10^{-4}}{11\times10^{-9}}\right] J/m^3 \approx 2.8\times10^5\, J/m^3$$

Si d ~ 3 nm = 3×10^{-9}m ⇒ $K_{ef}(Co/Al_2O_3) \approx 10^6\, J/m^3$

$$\tau = \tau_0 e^{\frac{K_{ef}V}{kT}}$$

Mayores tiempos de relajación

Partículas ferromagnéticas pequeñas – efectos dinámicos



F. Luis, J.M. Torres, L.M. García, J. Bartolomé, J. Stankiewicz, F. Petroff, F. Fettar, J. L. Maurice and A. Vaurés. Phys. Rev B, **65** (2002) 094409