时势造英雄、英雄创时势

为何2007年诺贝尔物理学奖授予巨磁电阻效应的发现者：Albert Fert & Peter Grünberg ？

韩秀峰（X. F. Han）

2007年10月11日

磁学

国家重点实验室

中国科学院物理研究所

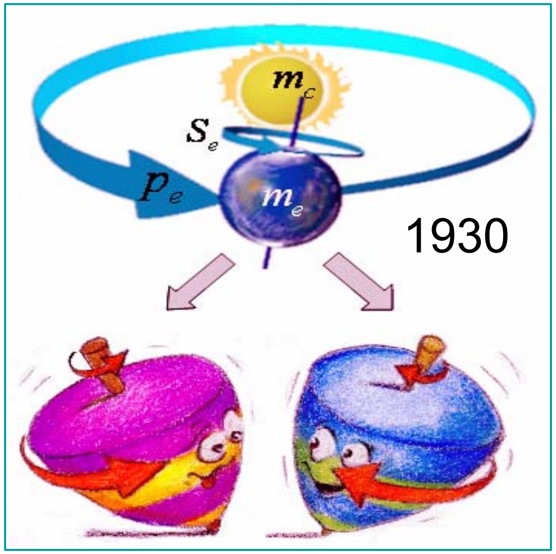
Albert Fert

1938年3月7日出。1962年在巴黎高等师范学院获数学和物理硕士学位。1970年从巴黎第十一大学获物理学博士学位，前在该校任物理学教授。他从1970年到1995年一直在巴黎第十一大学固体物理实验室工作。后任研究小组组长。1988年，他发现巨磁电阻效应，随后对自旋电子学作出过许多杰出贡献。1994年获美国物理学会颁发的新材料国际奖， 1995年至今则担任国家科学研究中心-Thales集团联合物理小组科学主管, 1997年获欧洲物理协会颁发的欧洲物理学大奖，以及2003年获法国国家科学研究中心金奖。

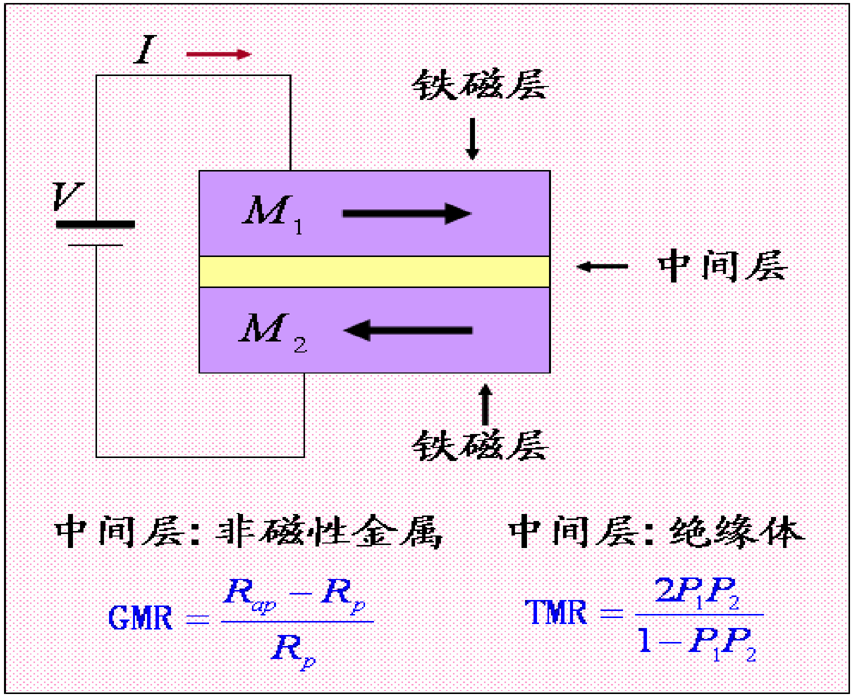
Peter Grünberg

1939年5月18日出生。从1959年到1963年，克鲁伯格在法兰克福约翰-沃尔夫冈-歌德大学学习物理，1962年获得中级文凭， 1969年在德国达姆施塔特技术大学获得博士学位。1988年，他在尤利西研究中心研究并发现巨磁电阻效应；1992年被任命为科隆大学兼任教授；2004年在研究中心工作32年后退休，但仍在继续工作。他1994年获美国物理学会颁发的新材料国际奖(Fert、Parkin共同获得)；1998年获由德国总统颁发的德国未来奖；2007年获沃尔夫基金奖物理奖(与Fert共同获得)。

磁电子学→自旋电子学



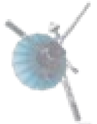
1930



中间层：非磁性金属 中间层：绝缘体

$$\mathrm{GMR} = \frac{R_{ap} - R_p}{R_p}$$

$$\mathrm{TMR} = \frac{2P_1P_2}{1 - P_1P_2}$$



- ◆电子质量
- ◆电子电荷
- ◆电子自旋

1988 GMR 巨磁电阻效应、纳米多层膜材料

1994 CMR 庞磁电阻效应、金属氧化物材料

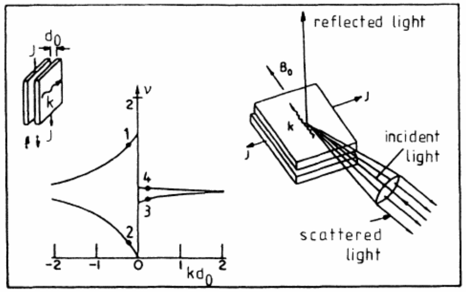
1995 TMR 隧穿磁电阻效应、磁性隧道结材料

(1) 1986 在Fe/Cr/Fe纳米磁性多层膜发现反铁磁层间耦合效应

VOLUME 57, NUMBER 19 PHYSICAL REVIEW LETTERS 10 NOVEMBER 1986

Layered Magnetic Structures: Evidence for Antiferromagnetic Coupling of Fe Layers across Cr Interlayers

REVIEW LETTERS 10 NOVEMBER 1986



P. Grünberg, R. Schreiber, and Y. Pang[(a)]
Kernforschungsanlage Jülich, 5170 Jülich, West Germany

and

M. B. Brodsky and H. Sowers
Argonne National Laboratory, Argonne, Illinois 60439

(Received 10 June 1986)

We investigated exchange coupling of Fe layers across Au and Cr interlayers by means of light scattering from spin waves. For Au interlayers we find a continuous decrease of this coupling to zero as the Au thickness is increased from 0 to ≈ 20 Å. For Cr interlayers of proper thickness we find antiferromagnetic coupling of the Fe layers. In small external fields such double layers order antiparallel with their magnetization perpendicular to the external field, in analogy to the spin-flop phase of antiferromagnets.

PACS numbers: 75.30.Ds, 75.70.Dp

(2) 1988 发现室温巨磁电阻效应(GMR)、 纳米磁性多层膜材料

[Fe/Cr]n
nano-magnetic multilayers

Fe/Cr/Fe
Sandwich structure

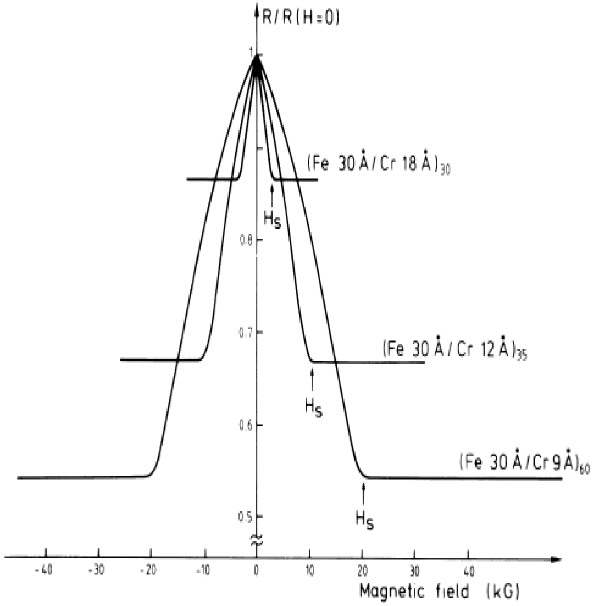


FIG. 3 Magnetoresistance of three Fe/Cr superlattices at 4.2 K. The current and the applied field are along the same [110] axis in the plane of the layers.

2473

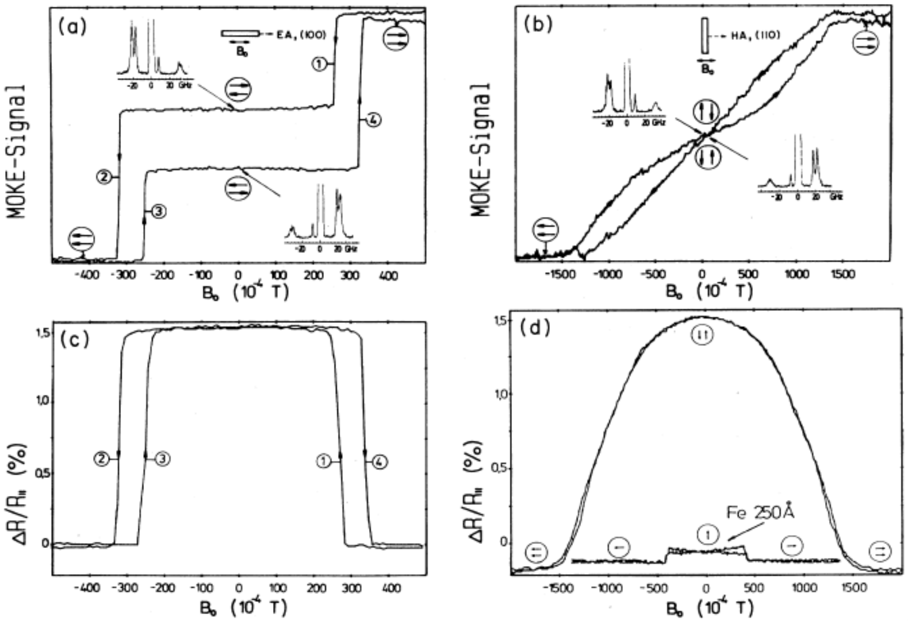
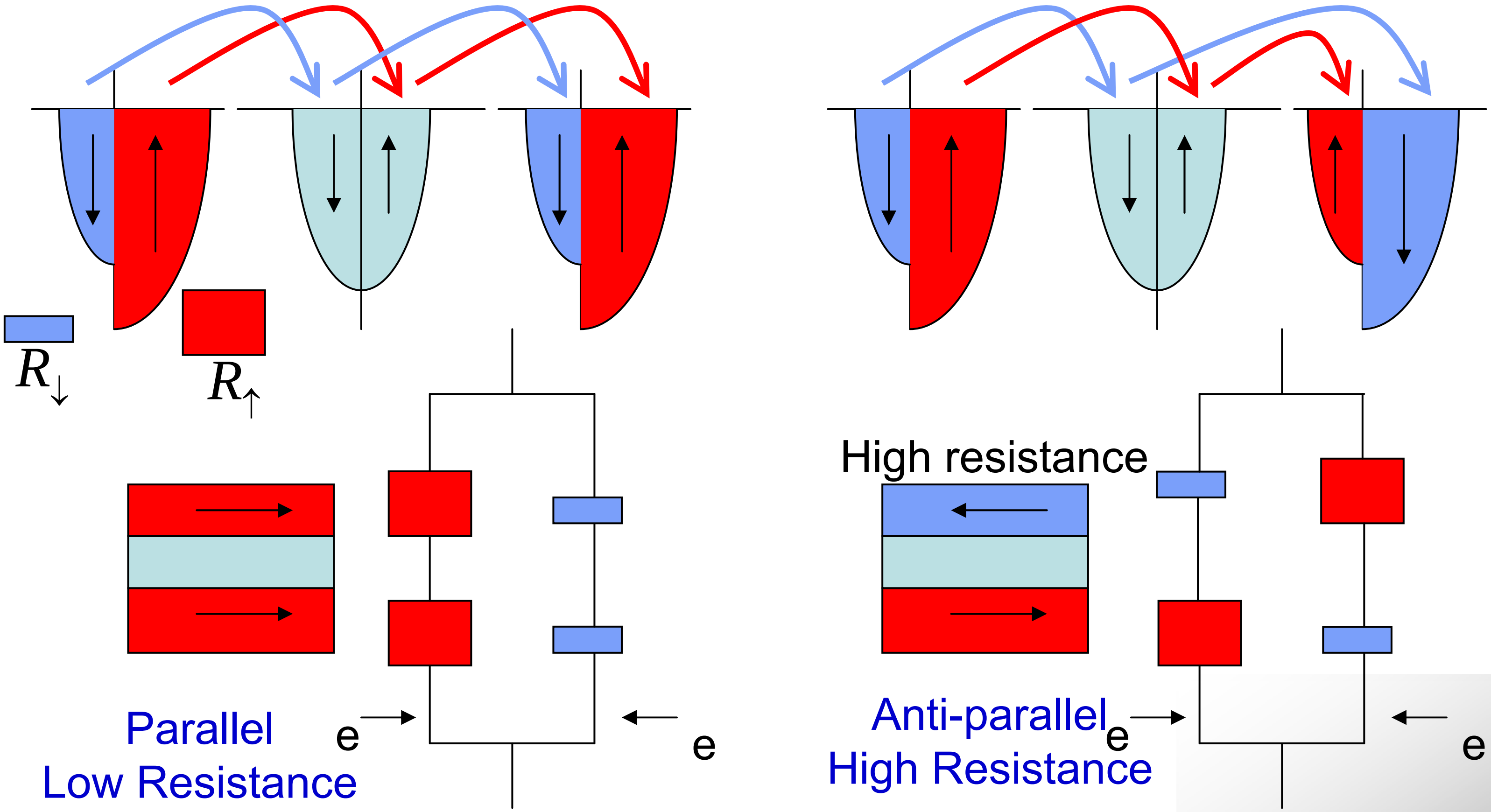


FIG. 2. (a)-(b) MOKE hysteresis curves and (c)-(d) magnetoresistance $\Delta R/R_{\parallel}=(R-R_{\parallel})/R_{\parallel}$ from Fe double layers with antiferromagnetic coupling. Also, (d) displays the anisotropic MR effect of a 250-Å-thick Fe film.

M.N. Baibich and A. Fert *et al.*, PRL 61 (1988)2472.

G. Binasch, P. Grünberg, et al., PRB 39 (1989) 4828.

Two-current series resistor model



High resistance

Parallel
Low Resistance

Anti-parallel
High Resistance

GMR= $\frac{\Delta R}{R} = \frac{R_{AP} - R_P}{R_P} = \frac{(R_\downarrow - R_\uparrow)^2}{4R_\downarrow R_\uparrow}$.

(3) Oscillations in Exchange Coupling in Metallic Superlattice Structure

Si(111)/Ru(10nm)/[Co(2)/Ru(d)]$_N$/Ru(5)

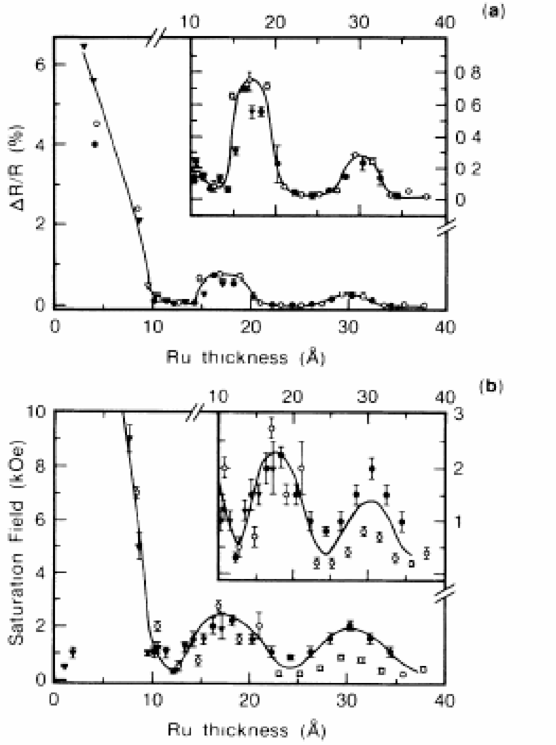
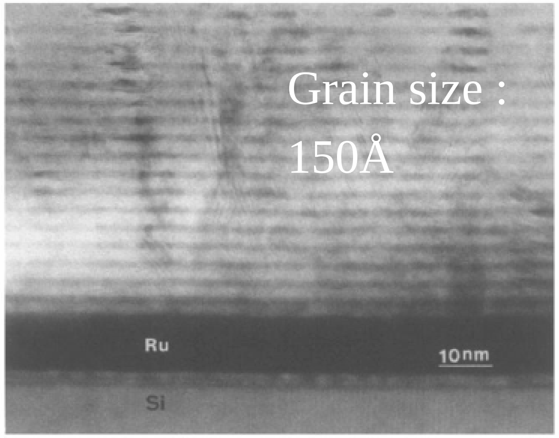


FIG. 3. (a) Transverse saturation magnetoresistance (4.5 K) and (b) saturation field (300 K) vs Ru layer thickness for structures of the form Si(111)/(100 Å) Ru/[20 Å) Co/t_{Ru} Ru]$_{20}$/(50 Å)Ru deposited at temperatures of ●, 40°C; ○, 125°C; ×, 200°C.



Grain size : 150Å

FIG. 1. High-resolution micrograph taken along the Si [11$\bar{2}$] direction from the structure, Si(111)/(100 Å) Ru/[(18 Å) Co/(8 Å) Ru]$_{20}$/(50 Å) Ru. The sample was deposited at 40°C.

Si(111)/Cr(10nm)/[Fe(2)/Cr(d)]$_N$/Cr(5)

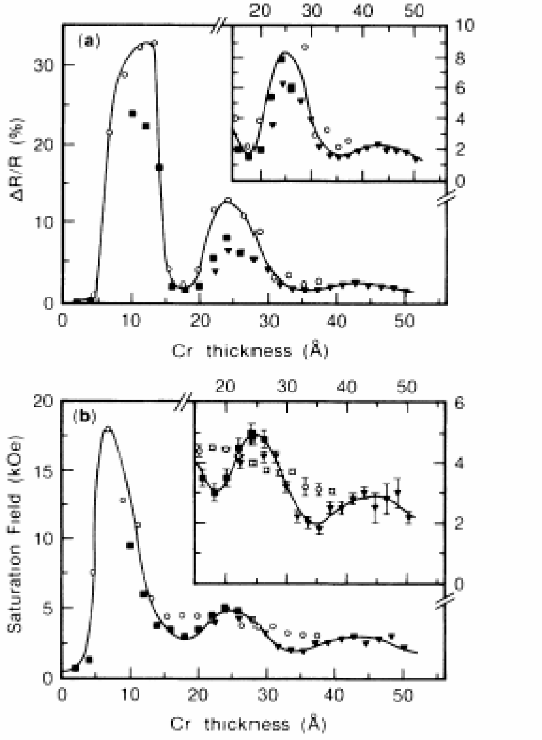
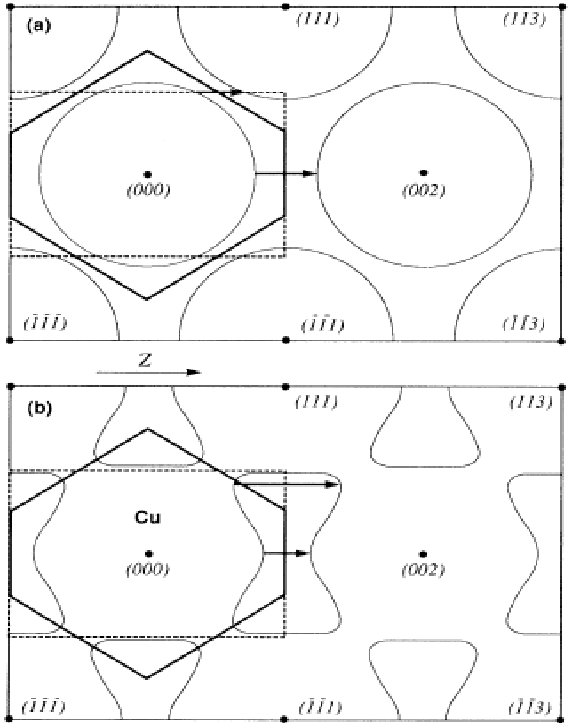


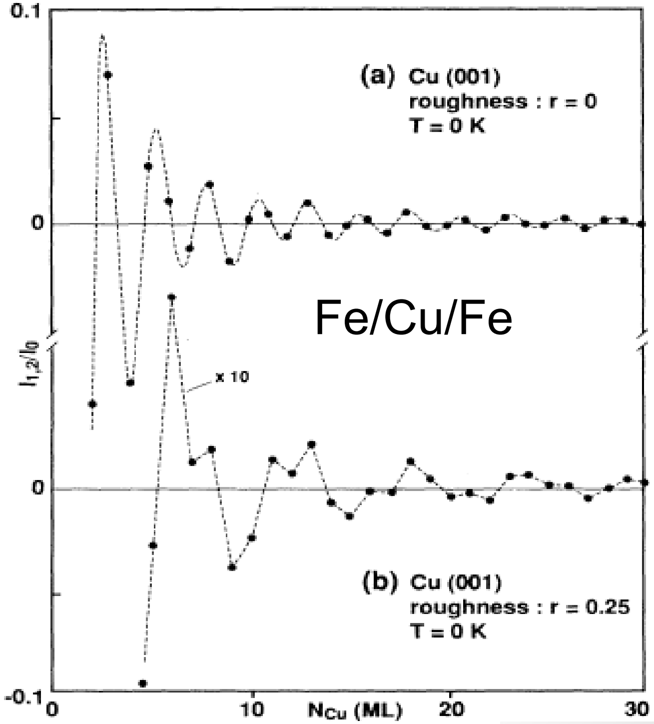
FIG. 4. (a) Transverse saturation magnetoresistance (4.5 K) and (b) saturation field (4.5 K) vs Cr layer thickness for three series of structures of the form Si(111)/(100 Å) Cr/[(20 Å) Fe/t_{Cr} Cr]$_N$/(50 Å) Cr, deposited at temperatures of △,■, 40°C (N=30); ○,125°C (N=20).

S. S. P. Parkin et. al., PRL 64 (1990) 2304

(4) Adopt RKKY-like theory to explain GMR oscillation effect

$$I_{1,2}(z) = -I_0 \sum_{\alpha} \frac{d^2}{z^2} \frac{m_\alpha^*}{m} \sin(q_\alpha^g z + \phi_\alpha) \frac{z/L_\alpha(T)}{\sinh[z/L_\alpha(T)]}$$





Fe/Cu/Fe, Bruno et.al, PRL 67 (1991) 1602

(5) Bruno set up electron-optics model to explain GMR oscillations

- **Theoretical simulation:**
- **electron-optics model given by Bruno for the interlayer AF coupling density of *J* in the stacks of FM/NM/FM**

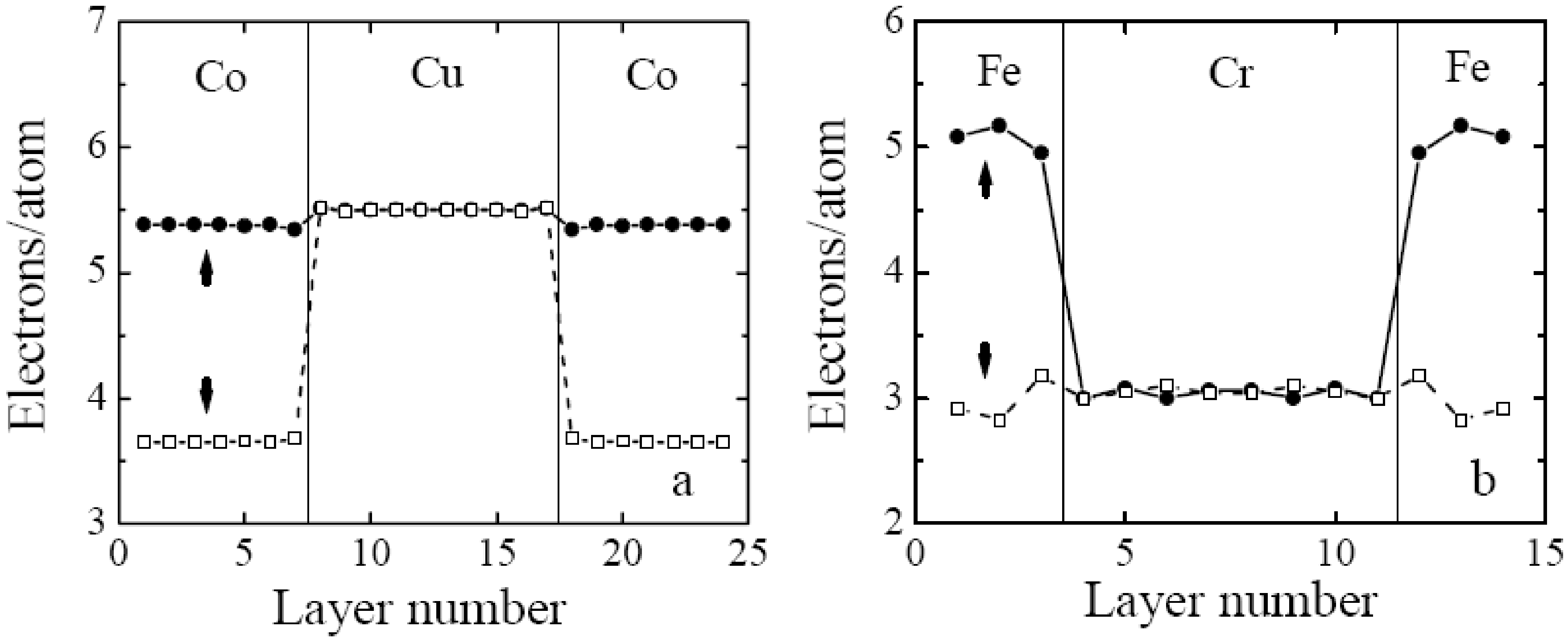
$$J \simeq (\frac{\hbar^2}{8\pi^2 m})\mathrm{Im}\{\frac{{r_\infty^\downarrow}^2}{2}e^{2ik_F d}[\frac{k_F^2}{d^2}-2(1-{r_\infty^\downarrow}^2)(\frac{d}{k_F}+\frac{h}{k_F^\downarrow})^{-2}e^{2ik_F^\downarrow h}]\}$$

- **from Fabry-Perot-like interferences of the electron Bloch waves in the** Pt(*t*)/Co(*h*)/Ru(*d*)/Co(*h*)/Pt(*t*) **stacks**

$$\begin{aligned} J \simeq (\frac{\hbar^2}{8\pi^2 m})\ \mathrm{Im}\{\ & \frac{r_\infty^2}{2}(\frac{d}{k_F})^{-2} e^{2ik_F d} - r_\infty^2(1-r_\infty^2)(\frac{d}{k_F}+\frac{h}{k_F^\downarrow})^{-2}e^{2ik_F d+2ik_F^\downarrow h} \\ & + r_\infty^2(1-2r_\infty^2)(\frac{d}{k_F}+\frac{h}{k_F^\downarrow}+\frac{t}{k_F})^{-2}e^{2ik_F d+2ik_F^\downarrow h+2ik_F t} \\ & - r_\infty^2(\frac{d}{k_F}+\frac{h}{k_F}+\frac{t}{k_F})^{-2}e^{2ik_F d+2ik_F h+2ik_F t}\}, \end{aligned}$$

- **P. Bruno, Europhys. Lett. 23,615 (1993); JMMM 121 (1993) 248 ;**
- **J. J. de Vries, et.al., PRL 75 (1995) 4306.**

(6) Electronic structure for Co/Cu/Co and Fe/Cr/Fe systems from Layer KKR first principles calculation



Co/Cu/Co系统:
majority-spin 通道匹配，电子散射弱；
minority-spin通道不匹配，电子散射强

Fe/Cr/Fe系统:
majority-spin 通道不匹配，电子散射强；
minority-spin通道匹配，电子散射弱

W. H. Butler, X.-G. Zhang, *et al.* PRB 52, 18 (1995)

(7) 1991年首次将反铁磁材料用于纳米磁性多层膜材料制备自旋阀

PHYSICAL REVIEW B VOLUME 43, NUMBER 1 1 JANUARY 1991

Giant magnetoresistance in soft ferromagnetic multilayers

B. Dieny,* V. S. Speriosu, S. S. P. Parkin, B. A. Gurney, D. R. Wilhoit, and D. Mauri†
IBM Research Division, Almaden Research Center, 650 Harry Road, San Jose, California 95120-6099

(Received 25 July 1990; revised manuscript received 21 September 1990)

We show that the in-plane magnetoresistance of sandwiches of *uncoupled* ferromagnetic ($Ni_{81}Fe_{19}$, $Ni_{80}Co_{20}$, Ni) layers separated by ultrathin nonmagnetic metallic (Cu, Ag, Au) layers is strongly increased when the magnetizations of the two ferromagnetic layers are aligned antiparallel. Using NiFe layers, we report a relative change of resistance of 5.0% in 10 Oe at room temperature. The comparison between different ferromagnetic materials (alloys or pure elements) leads us to emphasize the role of bulk rather than interfacial spin-dependent scattering in these structures, in contrast to Fe/Cr multilayers.

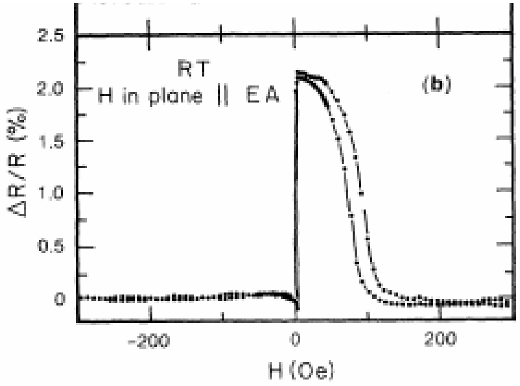
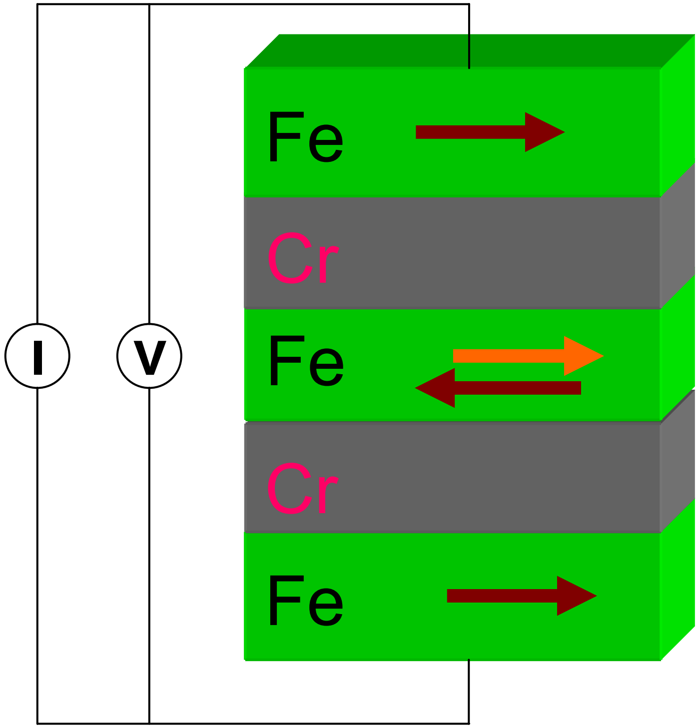


FIG. 1. Magnetization curve (a) and relative change in resistance (b) for Si/(150-Å NiFe)/(26-Å Cu)/(150-Å NiFe)/(100-Å FeMn)/(20-Å Ag). The field is applied parallel to the exchange anisotropy field created by FeMn (EA). The current is flowing perpendicular to this direction.

AMF
Spin-valve

B. Dieny et al., PRB 43 (1991)1297

(8) CPP-GMR in magnetic multi-layers



Zhang et al., JAP 69 (1991)4786

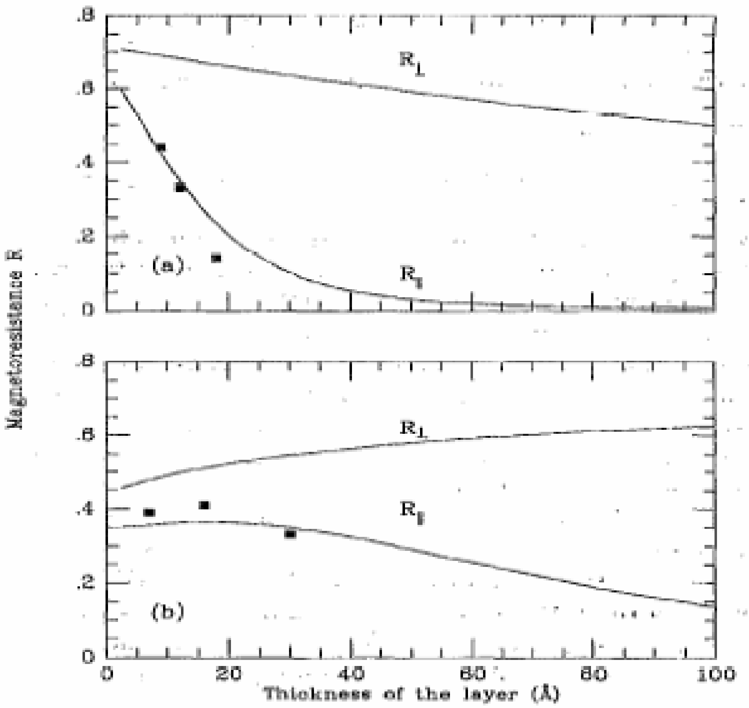
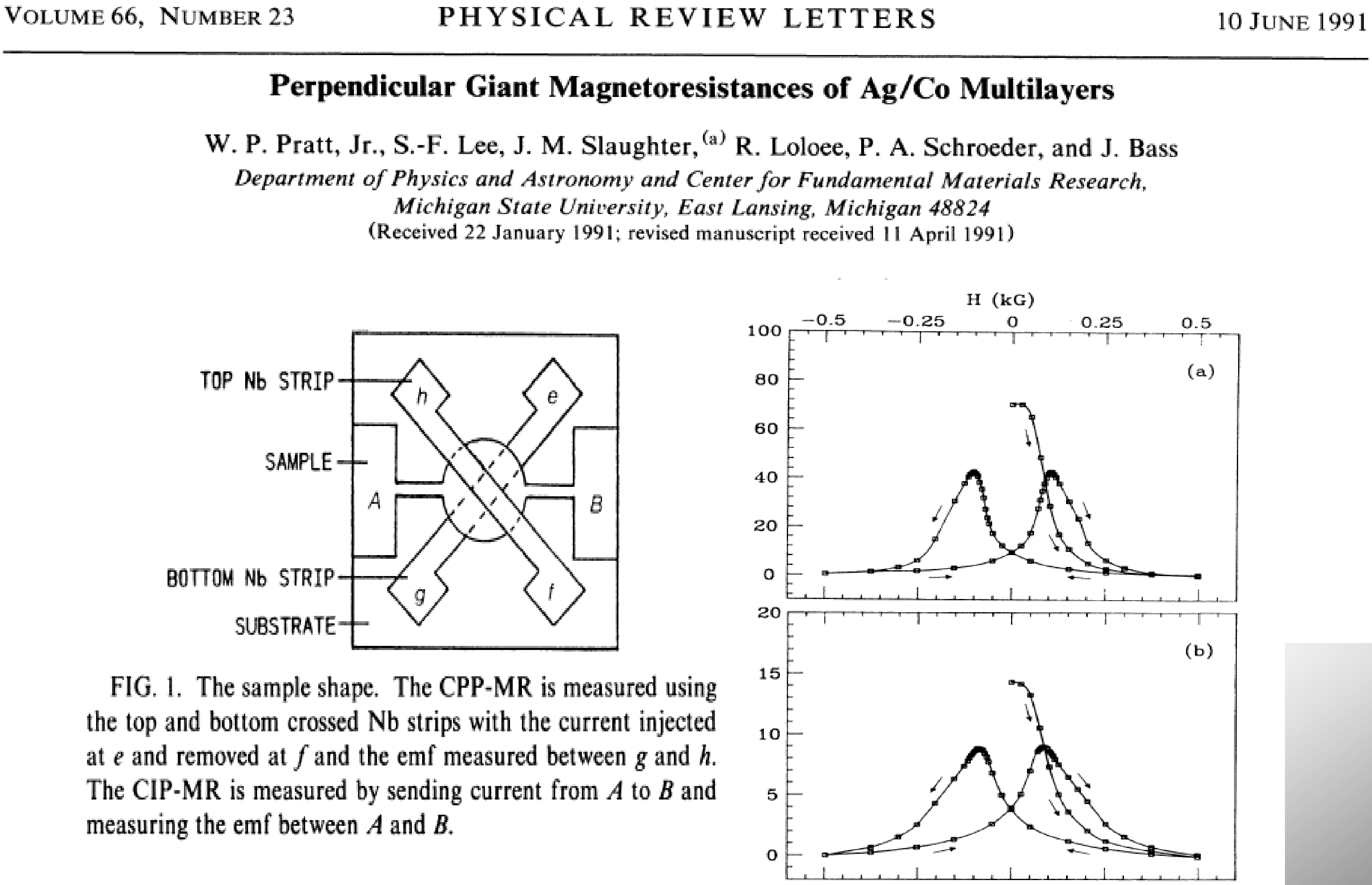


FIG. 2. The magnetoresistance ratios $R_\parallel$ and $R_\perp$ where $R = [\rho(H = 0) - \rho(H = H_s)]/\rho(H = 0)$ with the parameters that produce the best fit to the experimental data at $T = 4.2$ K given in Refs. 1 and 2, and recent results by Fert and co-workers (to be published), i.e., $\lambda_b = 19$ Å, $\lambda_s = 0.55$ $(t_{Fe} + t_{Cr})$, and $\rho_\uparrow/\rho_\downarrow = 12$: (a) as a function of thickness of the chromium layers for for fixed $t_{Fe} = 30$ Å; (b) as a function of thickness of the iron layers for fixed $t_{Cr} = 12$ Å.

W.P. Pratt et al., PRL 66 (1991) 3060.



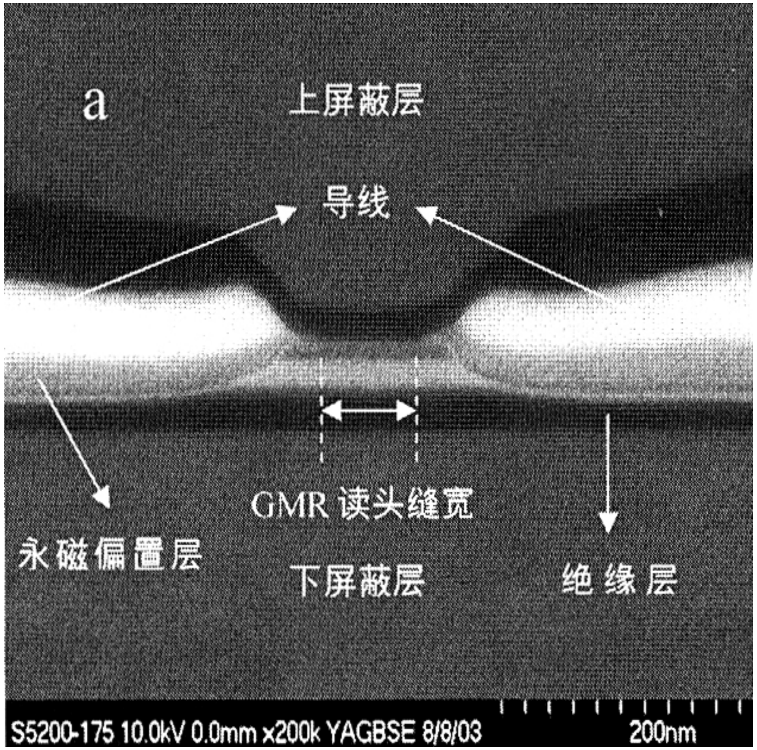
VOLUME 66, NUMBER 23 PHYSICAL REVIEW LETTERS 10 JUNE 1991

Perpendicular Giant Magnetoresistances of Ag/Co Multilayers

W. P. Pratt, Jr., S.-F. Lee, J. M. Slaughter,[a] R. Loloee, P. A. Schroeder, and J. Bass
Department of Physics and Astronomy and Center for Fundamental Materials Research,
Michigan State University, East Lansing, Michigan 48824
(Received 22 January 1991; revised manuscript received 11 April 1991)

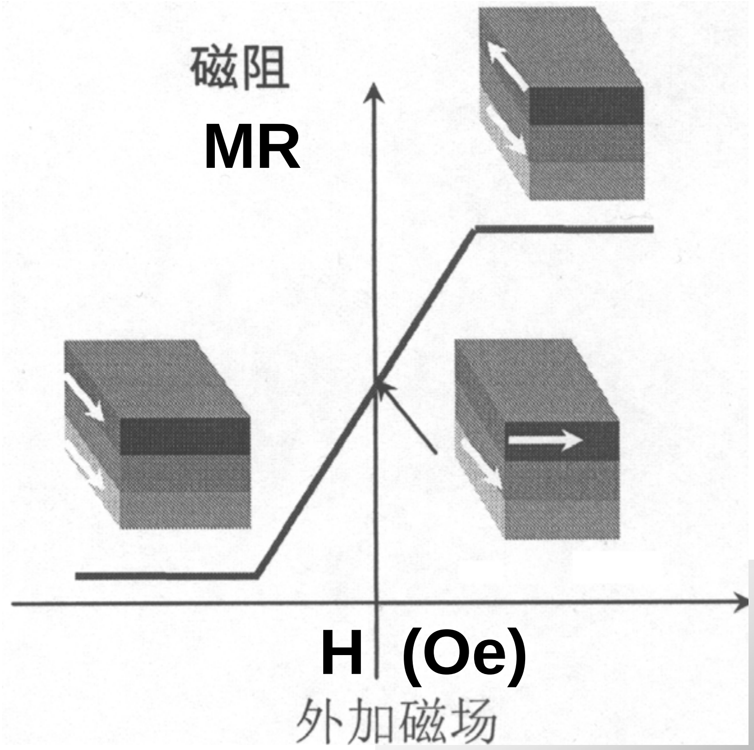
FIG. 1. The sample shape. The CPP-MR is measured using the top and bottom crossed Nb strips with the current injected at *e* and removed at *f* and the emf measured between *g* and *h*. The CIP-MR is measured by sending current from *A* to *B* and measuring the emf between *A* and *B*.

(8) GMR read head in Hard Disk Drive (HDD)



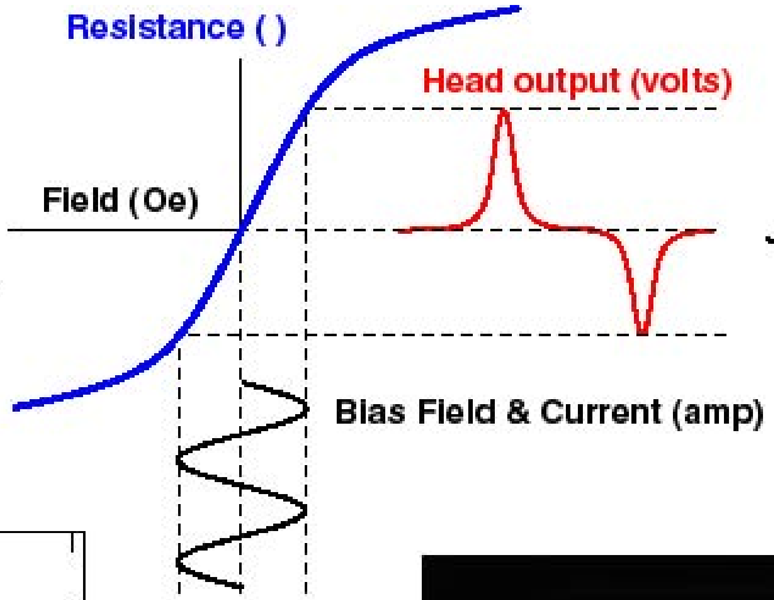
GMR 计算机磁读头

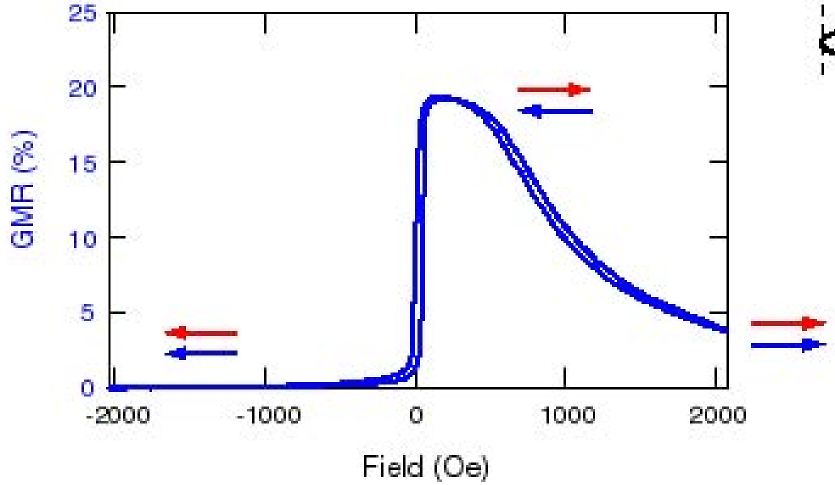
Linear output MR signal

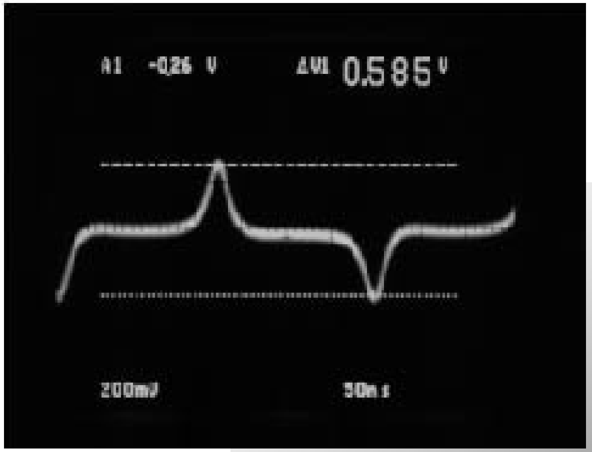


Ref：Prof. Z.C. Jiang's report of SAE

$$V_{max} = GMR \cdot \frac{C_w}{h} \cdot I_s R_p$$

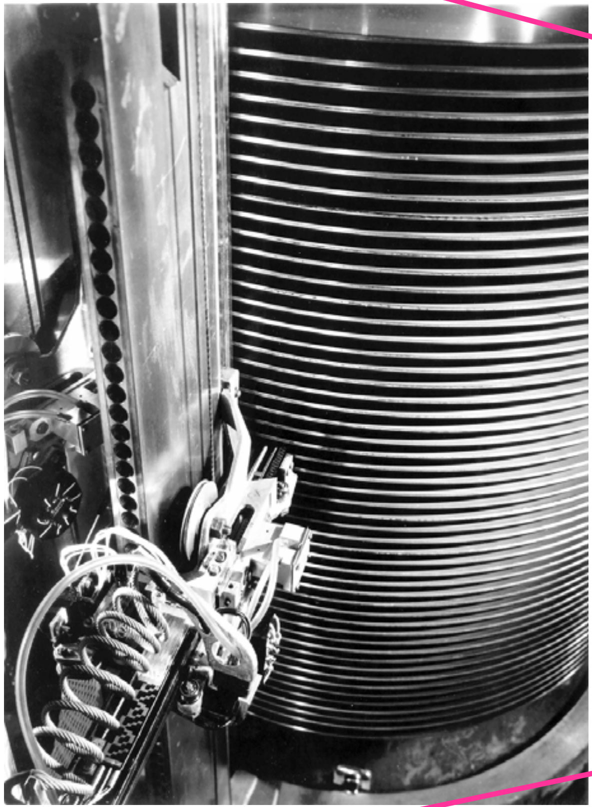






Scaling

4.4 Mbyte



80 Gbyte HDD

340 Mbyte

70 kbit/s
IBM RAMAC 1955
2 kbits/in^2
50x24" dia disks

436 Mbit/s
Seagate U series 2001
32.6 Gbits/in^2
2 x 3.5"glass disks

180 Mbit/s
IBM Microdrive
1999
6 Gbits/in^2
1 x 1" dia disk

(Supplied by Dr. Bin Lu of Seagate)

1995 发现室温隧穿磁电阻效应(TMR)、磁性隧道结材料

Fe/Al-Ox/Fe MTJ

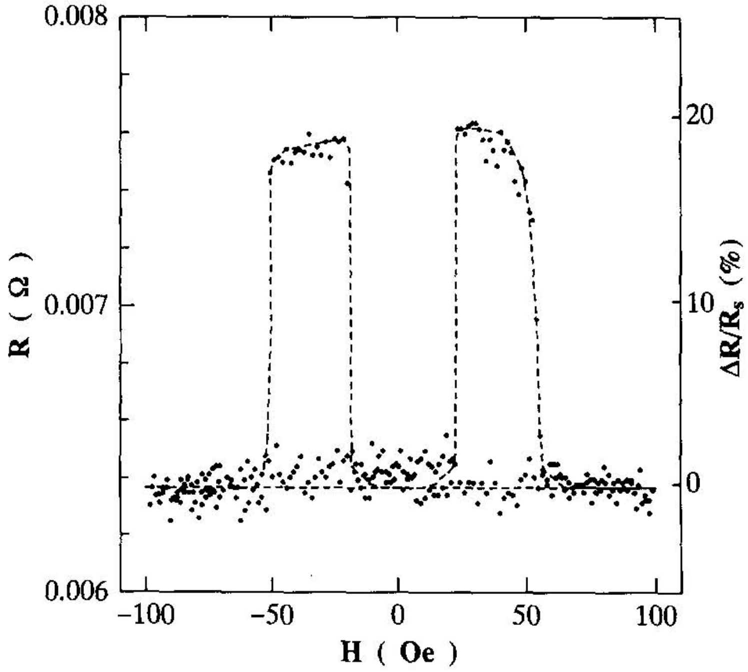


Fig. 1. Resistance as a function of the magnetic field for 1000 Å $Fe/Al_2O_3/1000$ Å Fe junction.

T. Miyazaki *et al.*, JMMM 139(1995)L231

CoFe/Al-Ox/Co MTJ

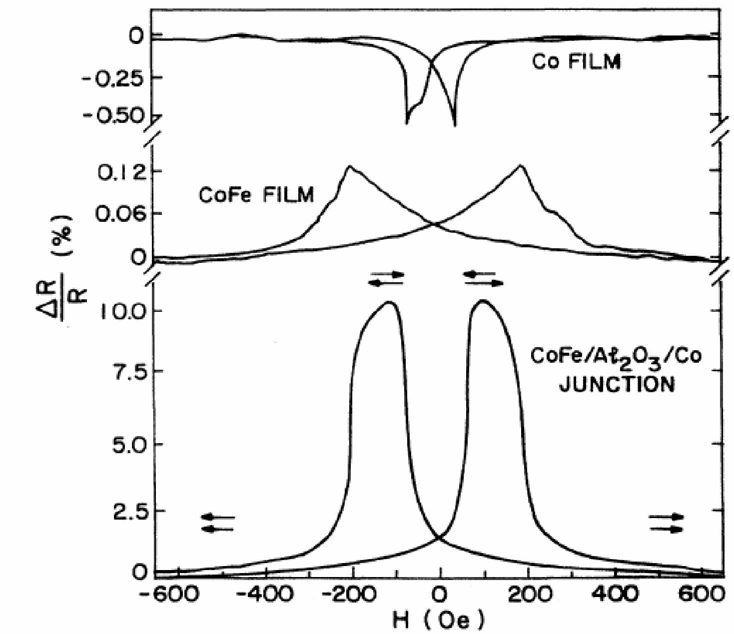


FIG. 2. Resistance of $CoFe/Al_2O_3/Co$ junction plotted as a function of H in the film plane, at 295 K. Also shown is the variation in the CoFe and Co film resistance. The arrows indicate the direction of M in the two films (see text).

J. S. Moodera et al., PRL 74 (1995) 3273

Ir-Mn AFM material, K. Imakita et al., APL 85 (2004) 3812

APPLIED PHYSICS LETTERS VOLUME 85, NUMBER 17 25 OCTOBER 2004

Giant exchange anisotropy observed in Mn–Ir/Co–Fe bilayers containing ordered Mn_3Ir phase

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Department of Electronic Engineering, Graduate School of Engineering, Tohoku University, Aoba-yama 05, Sendai 980-8579, Japan

Migaku Takahashi
Department of Electronic Engineering, Graduate School of Engineering, Tohoku University, Aoba-yama 05, Sendai 980-8579, Japan andNew Industry Creation Hatchery Center, Tohoku University, Aoba-yama

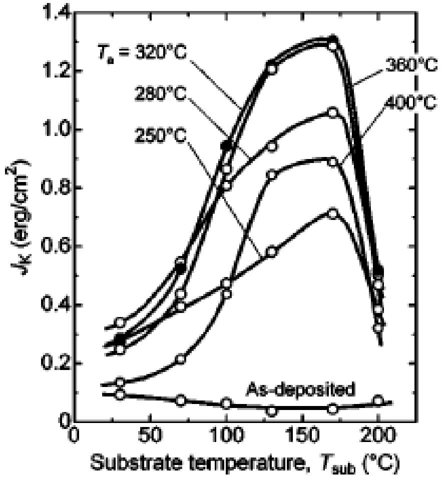


FIG. 1. Unidirectional anisotropy constant, J_K, of Mn–Ir/Co–Fe bilayers annealed at various temperature, T_a, in the in-plane magnetic field of 1 kOe. The horizontal axis corresponds to the substrate temperature, T_{sub}, during the deposition of the Mn–Ir layer.

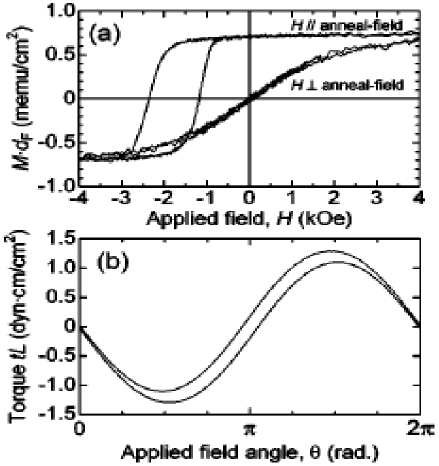


FIG. 2. In-plane (a) magnetization curves and (b) magnetic torque curve of the Mn–Ir/Co–Fe bilayer fabricated with the condition of T_{sub}=170 °C and T_a=320 °C. The strength of magnetic field applied for the torque measurement is 15 kOe.

反铁磁(AFM)钉扎材料的优化

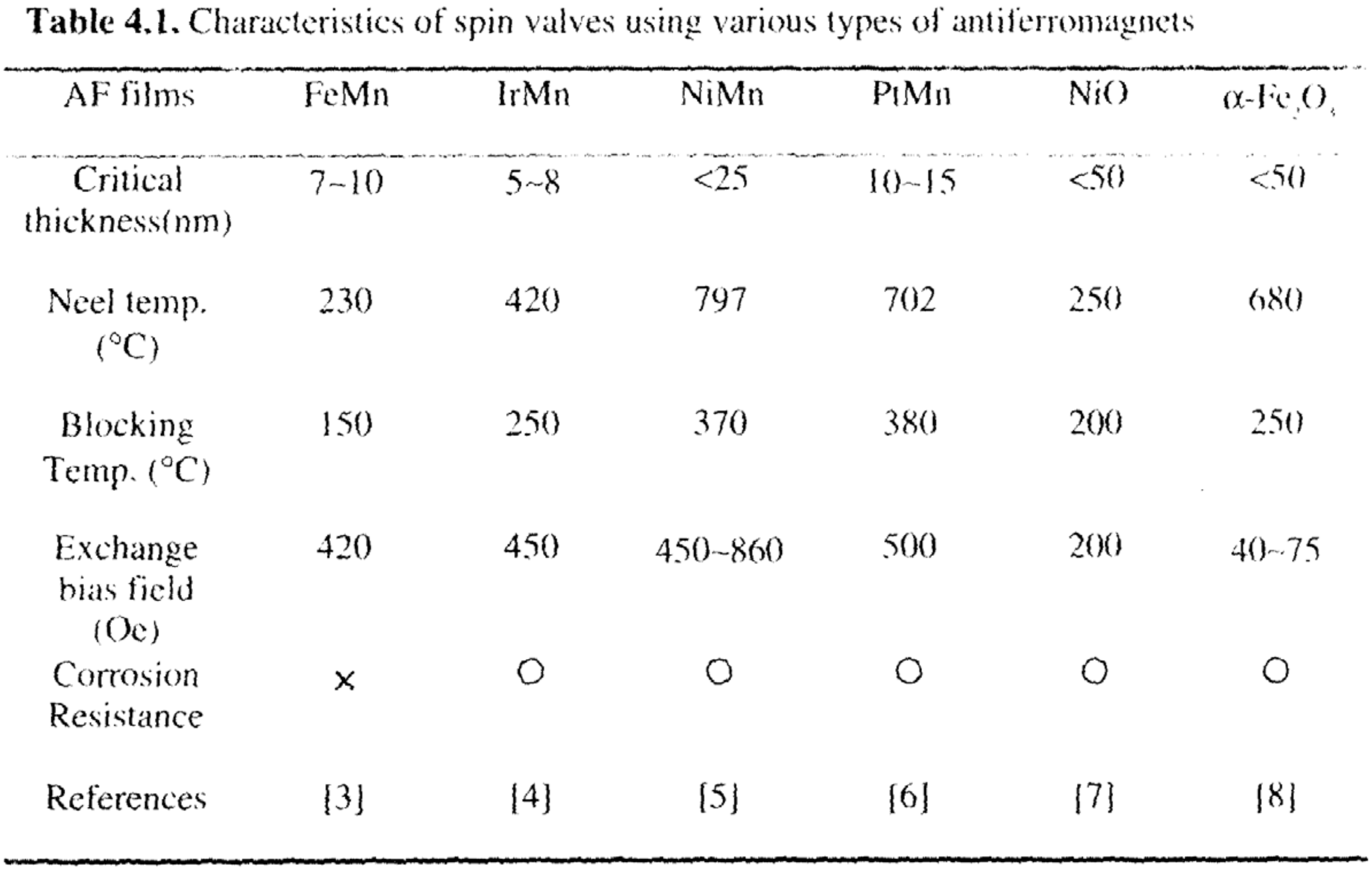
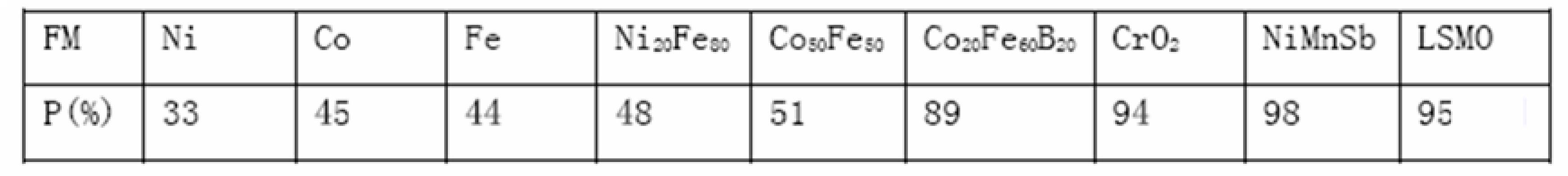


Table 4.1. Characteristics of spin valves using various types of antiferromagnets

AF films	FeMn	IrMn	NiMn	PtMn	NiO	α-Fe_2O_3
Critical thickness(nm)	7~10	5~8	<25	10~15	<50	<50
Neel temp. (°C)	230	420	797	702	250	680
Blocking Temp. (°C)	150	250	370	380	200	250
Exchange bias field (Oe)	420	450	450~860	500	200	40~75
Corrosion Resistance	×	○	○	○	○	○
References	[3]	[4]	[5]	[6]	[7]	[8]

GMR/TMR相关材料的优化

(1) 高自旋极化率铁磁材料



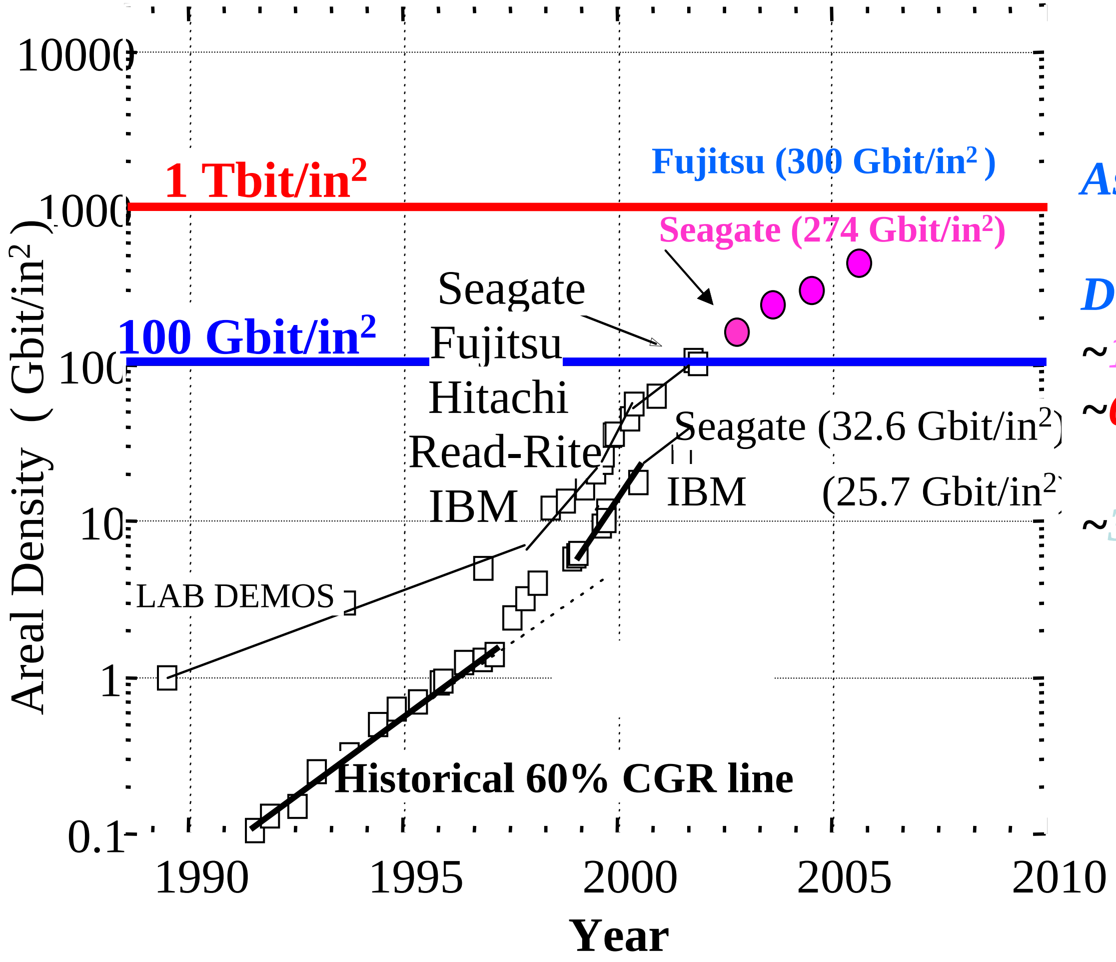
FM	Ni	Co	Fe	$Ni_{20}Fe_{80}$	$Co_{50}Fe_{50}$	$Co_{20}Fe_{60}B_{20}$	CrO_2	NiMnSb	LSMO
P(%)	33	45	44	48	51	89	94	98	95

(2) 磁性隧道结势垒材料

Barrier Materials	AlO_x	MgO_x	TaO_x	ZrO_x	AlN	CrO_x
TMR(%)	81%	361%	2.5%	20%	15.5%	8%
Journals	Wei et al., JAP 101, 09B501 (2007)	Lee et al., APL 89, 042506 (2006)	Rottlander et al., APL 78, 3274 (2001)	Wang et al., APL79, 4387 (2002)	Shim et al., APL 77, 2219 (2000)	Gupta et al., APL 78, 1894 (2001)

A real density roadmap

5x10^7 × a real density increase



As of Nov '01:

Demos:

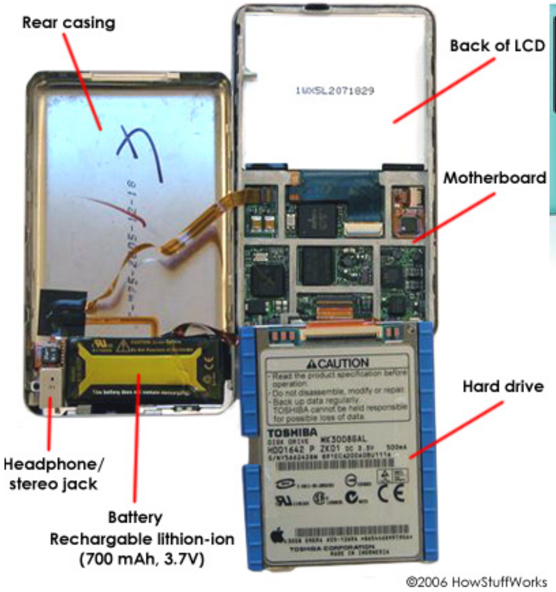
~*100 Gbpsi long*

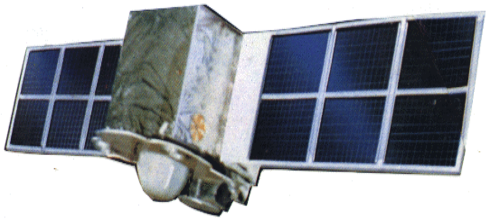
~*63 Gbpsi perp*

~*33 Gbpsi long*

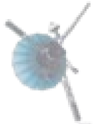
(Supplied by Dr. Bin Lu of Seagate)


131mm
67mm
HDR-CX7E


Rear casing
Back of LCD
Motherboard
Hard drive
Headphone/
stereo jack
Battery
Rechargable lithion-ion
(700 mAh, 3.7V)
©2006 HowStuffWorks



2007年诺贝尔物理学奖为何能授予巨磁电阻效应的发现者?



(1) 人工设计和合成的纳米磁性多层膜材料;

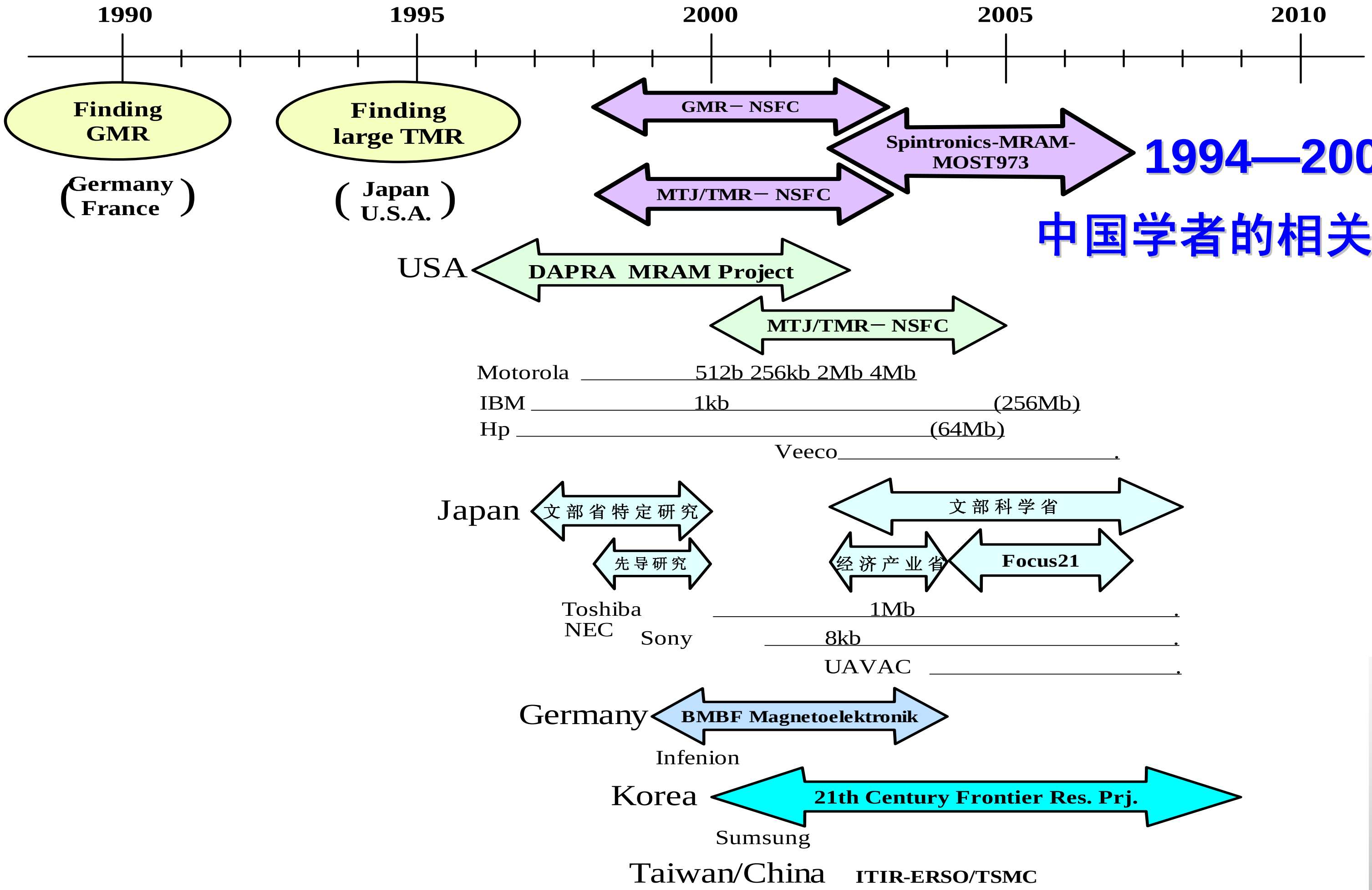
(2) 巨磁电阻效应(GMR)引发了磁电子学和自旋电子学新兴学科的形成与快速发展;

(3) 促进了与电子自旋性质相关的新型磁电阻材料和器件的研制;并在计算机磁硬盘等产品中得到广泛应用，对当代科技和信息发展起到了显著推动作用，创造了新的信息采集、存储和处理的GMR和TMR时代。

(4) 相关民用产品如：数字照相机、数字摄像机、MP3、iPod、家庭影院等等已进入千家万户，已成功地造就了每年数百亿美元产值的巨大市场，对目前人类的生活和工作方式产生了有目共睹的影响。

因此，Prof. Albert Fert 和 Prof. Peter Grünberg 能获得诺贝尔物理奖，是众望所归、意料之中的结果。

MRAM development and related spintronics Projects



1990 1995 2000 2005 2010

Finding GMR
(Germany France)

Finding large TMR
(Japan U.S.A.)

GMR－ NSFC

Spintronics-MRAM-MOST973

MTJ/TMR－ NSFC

USA **DAPRA MRAM Project**

MTJ/TMR－ NSFC

Motorola 512b 256kb 2Mb 4Mb
IBM 1kb (256Mb)
Hp (64Mb)
Veeco

Japan 文部省特定研究
先导研究
文部科学省
经济产业省
Focus21

Toshiba 1Mb
NEC Sony 8kb
UAVAC

Germany **BMBF Magnetoelektronik**
Infenion

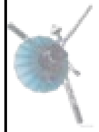
Korea **21th Century Frontier Res. Prj.**
Sumsung

Taiwan/China **ITIR-ERSO/TSMC**

1994—2006年

中国学者的相关工作介绍

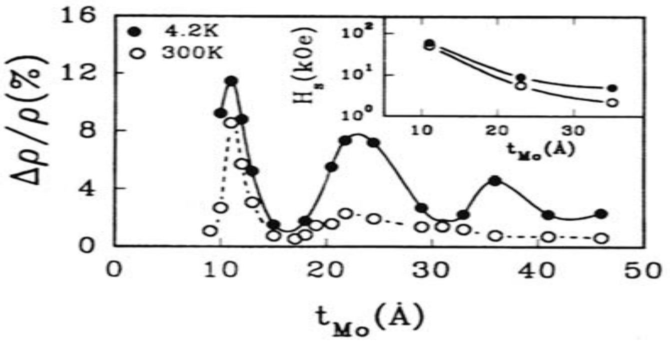
Authors (200 ~ 300 GMR related papers)	Journals	Key words
Q.Y. Jin, Y.B. Xu, H.R. Zhai, C. Hu, M. Lu, Q. Bi, Y. Zhai, G.L. Dunifer, R. Naik, M. Ahmad	PRL 72(1994)768	在 NMR 观察到的Fe/Cu多层膜中Cu层的自旋极化振荡证据
M. Li, X. D. Ma, C. B. Peng, J. G. Zhao, L. M. Mei, Y. S. Gu, W. P. Chai, Z. H. Mai, B. G. Shen, Y. H. Liu, D. S. Dai	PRB 50(1994)10323	Fe/Pb多层膜中Pb层的磁极化效应
S. S. Yan, Y. H Liu and L.M. Mei	PRB 52(1995) 1107	Co-Nb/Pb多层膜的层间耦合
L. M. Li, F. C. Pu, G. L. Yang and B. Z. Li	PRB 51(1995)12833	简化的巨磁电阻多层膜理论
J. H. Wu, B. Z. Li, G. L. Yang and F. C. Pu	PRB 53(1996) 9471	提出一种新的关于平均自由程的计算公式来阐述GMR效应
M. L. Yan, Z.S. Shan, D.J. Sellmyer, W.Y. Lai	JAP 81(1997) 4785	NiFe/Mo多层膜的层间耦和和Fe缓冲层的作
H. W. Zhao, Y. Chen, G. S. Dong, M. Lu, X. F. Jin, Y. J. Wang, H. R. Zhai, D. Yang, R. Naik, G. L. Dunifer and G. W. Auner	JAP 81(1997) 5203	Co/Mo/Co三明治结构中的反常磁输运
L. Sheng, D. Y. Xing, Z. D. Wang J. M. Dong, Y. Li, B. Z. Li, W. S. Zhang, D. S. Dai	PRB 55(1997)5908 PRB 57(1998) 1079	磁性异质结中半经典磁输运理论; TMR 三层磁性层时的磁构型



JMMM在1999年出版了专集“Magnetism beyond 2000”。其中JMMM 200(1999)571一文介绍了当时国际上发现的20多种“具有GMR效应两个特点”的多层膜材料。我们有3种金属多层膜被收录。

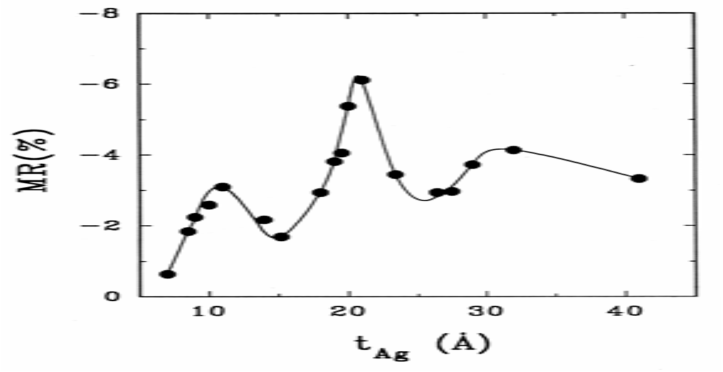
（1）Fe/Mo 多层膜的GMR振荡效应

JAP 77 (1995) 1816，阎明朗、麦正洪、赖武彦等



（2）Fe/Ag 多层膜的GMR振荡效应

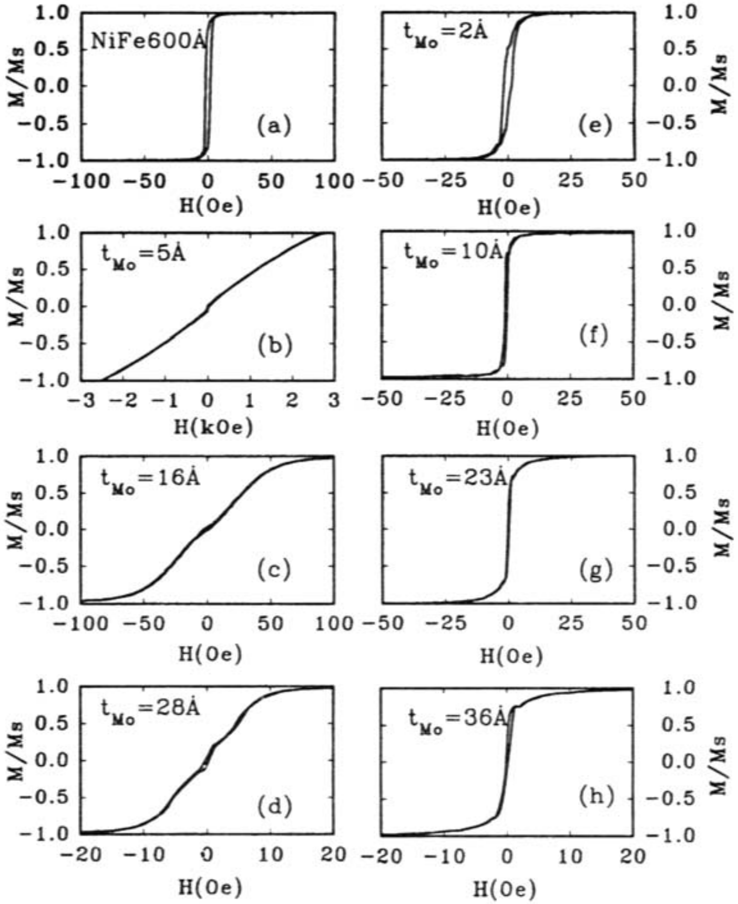
PRB 52(1995)1123，于成涛，赖武彦等

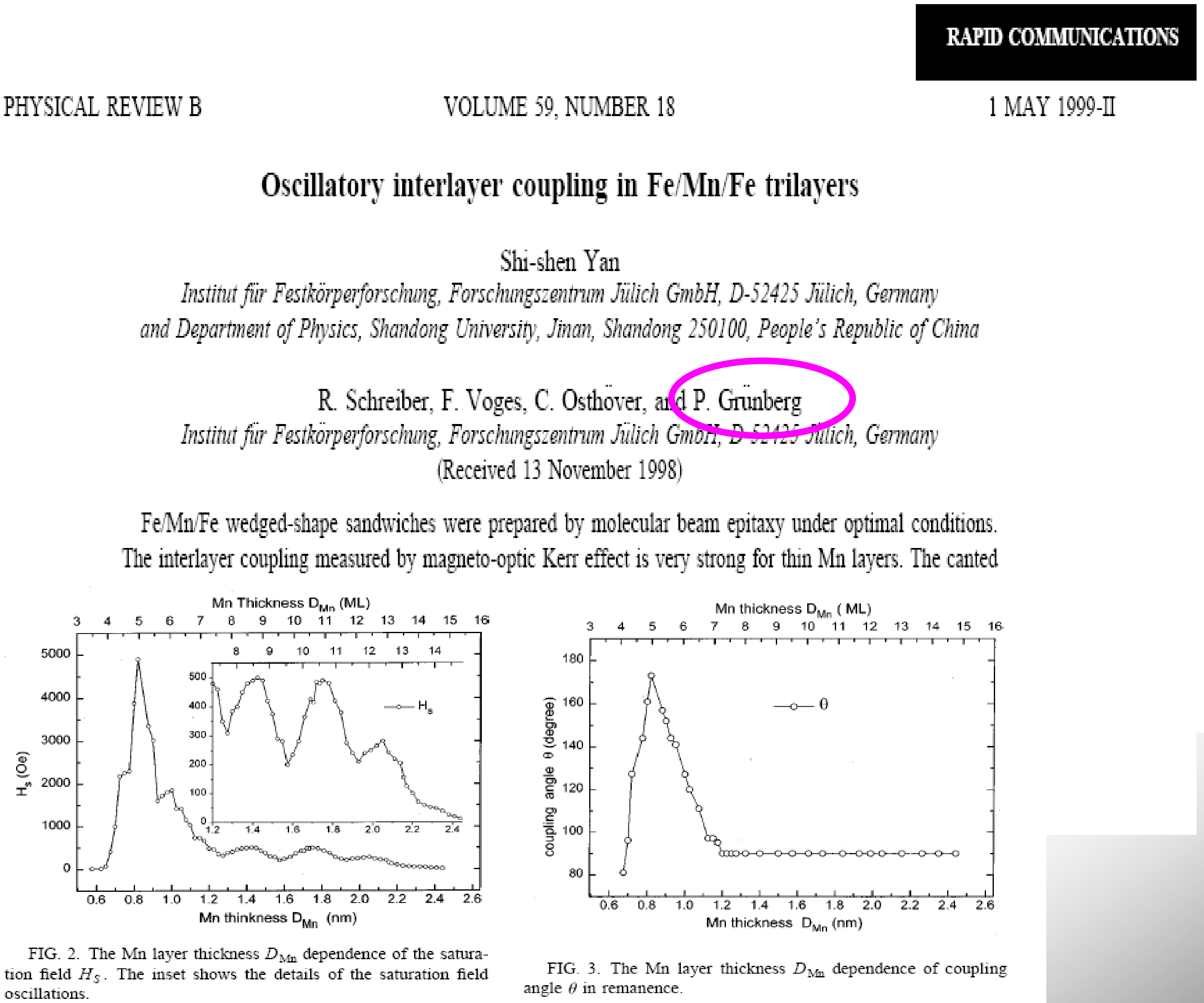


(3) NiFe/Mo多层膜的GMR振荡效应

（斜的线对应磁矩的反平行；垂直线对应磁矩的平行）

JPCM 8(1996) L711,阎明朗、麦正洪、王文魁、赖武彦等





RAPID COMMUNICATIONS

PHYSICAL REVIEW B VOLUME 59, NUMBER 18 1 MAY 1999-II

Oscillatory interlayer coupling in Fe/Mn/Fe trilayers

Shi-shen Yan
Institut für Festkörperforschung, Forschungszentrum Jülich GmbH, D-52425 Jülich, Germany
and Department of Physics, Shandong University, Jinan, Shandong 250100, People's Republic of China

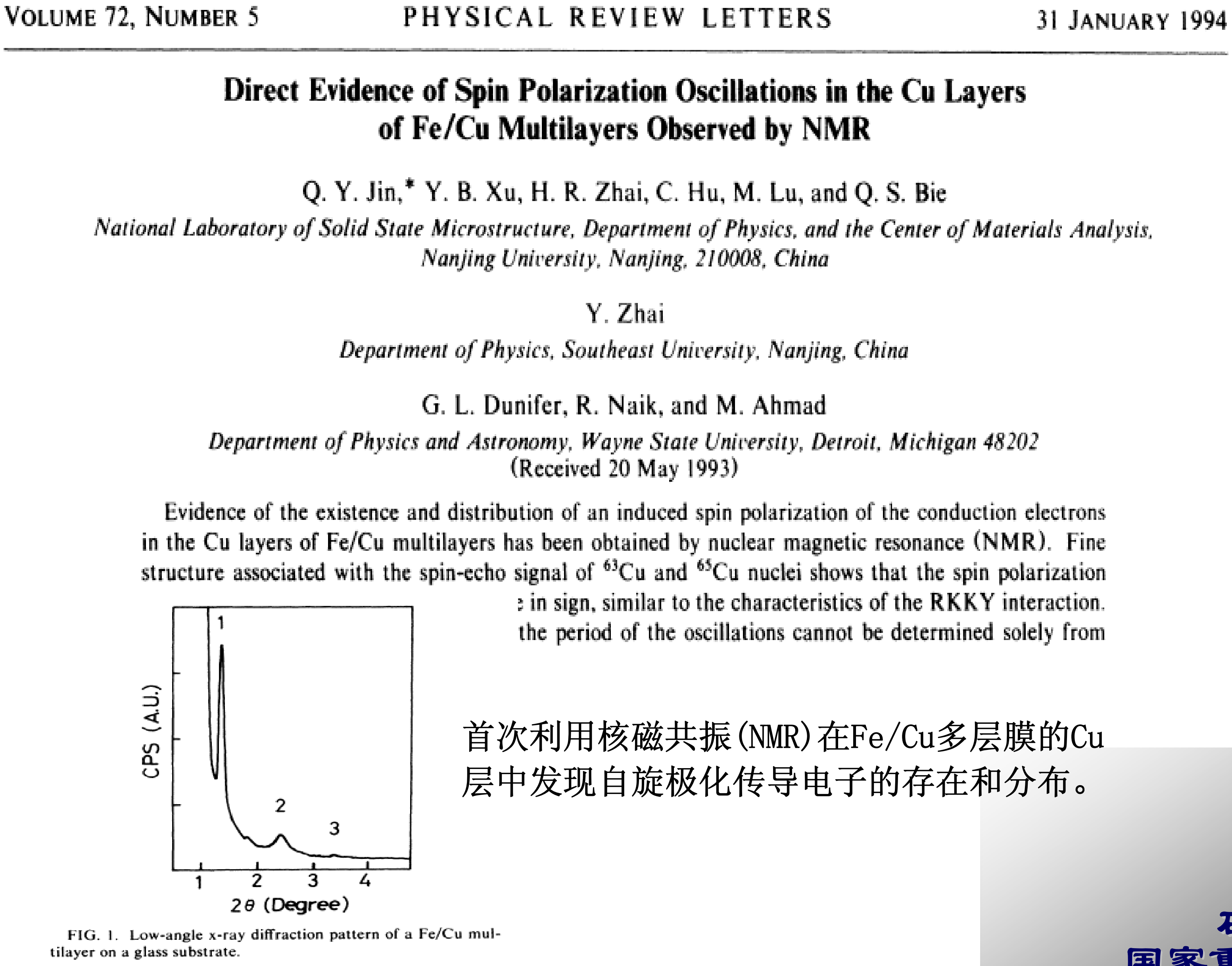
R. Schreiber, F. Voges, C. Osthöver, and P. Grünberg
Institut für Festkörperforschung, Forschungszentrum Jülich GmbH, D-52425 Jülich, Germany

(Received 13 November 1998)

Fe/Mn/Fe wedged-shape sandwiches were prepared by molecular beam epitaxy under optimal conditions. The interlayer coupling measured by magneto-optic Kerr effect is very strong for thin Mn layers. The canted

FIG. 2. The Mn layer thickness D_{Mn} dependence of the saturation field H_S. The inset shows the details of the saturation field oscillations.

FIG. 3. The Mn layer thickness D_{Mn} dependence of coupling angle θ in remanence.



VOLUME 72, NUMBER 5 PHYSICAL REVIEW LETTERS 31 JANUARY 1994

Direct Evidence of Spin Polarization Oscillations in the Cu Layers of Fe/Cu Multilayers Observed by NMR

Q. Y. Jin,* Y. B. Xu, H. R. Zhai, C. Hu, M. Lu, and Q. S. Bie
National Laboratory of Solid State Microstructure, Department of Physics, and the Center of Materials Analysis, Nanjing University, Nanjing, 210008, China

Y. Zhai
Department of Physics, Southeast University, Nanjing, China

G. L. Dunifer, R. Naik, and M. Ahmad
Department of Physics and Astronomy, Wayne State University, Detroit, Michigan 48202

(Received 20 May 1993)

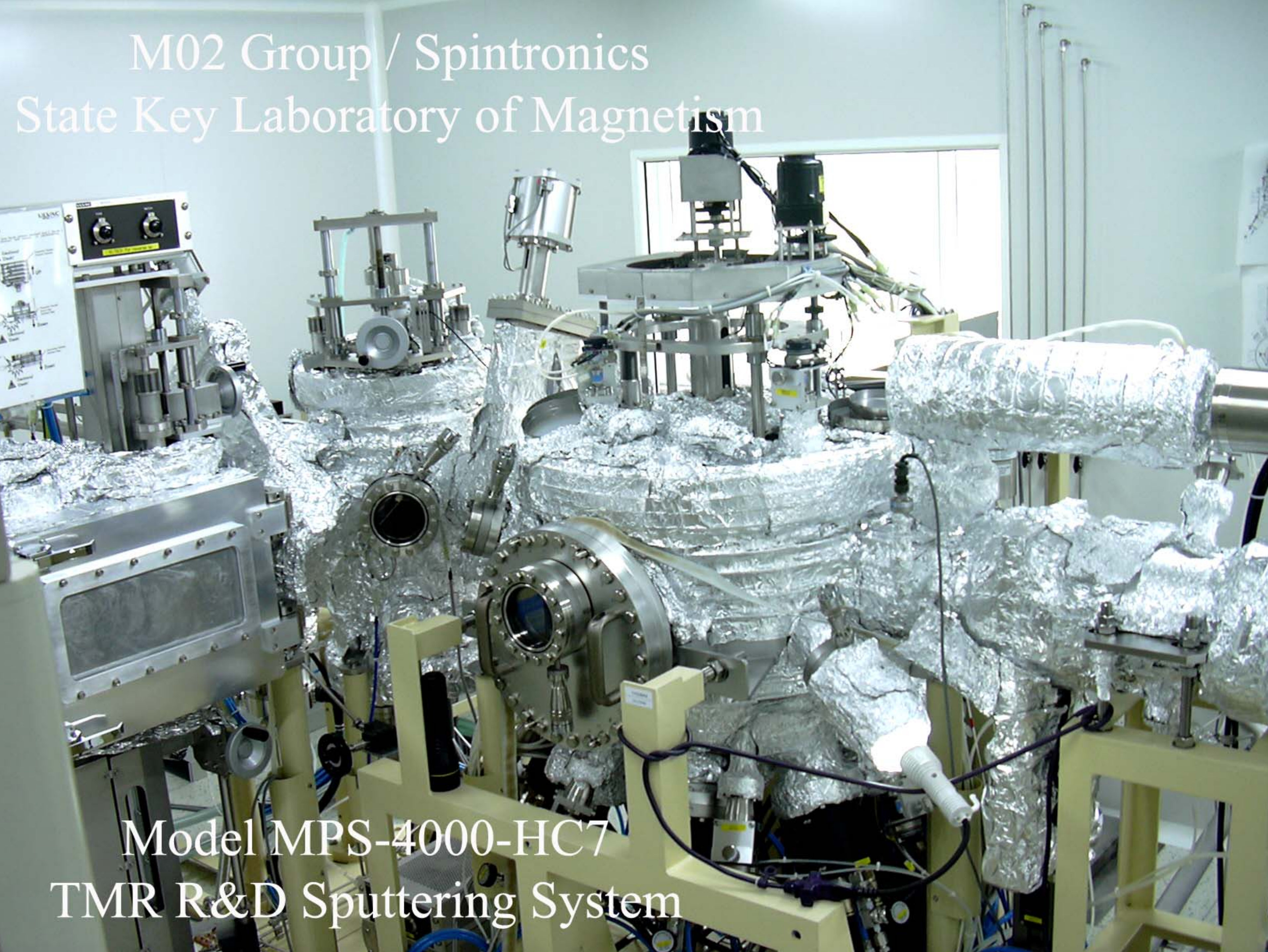
Evidence of the existence and distribution of an induced spin polarization of the conduction electrons in the Cu layers of Fe/Cu multilayers has been obtained by nuclear magnetic resonance (NMR). Fine structure associated with the spin-echo signal of ^{63}Cu and ^{65}Cu nuclei shows that the spin polarization

in sign, similar to the characteristics of the RKKY interaction.
the period of the oscillations cannot be determined solely from

FIG. 1. Low-angle x-ray diffraction pattern of a Fe/Cu multilayer on a glass substrate.

首次利用核磁共振(NMR)在Fe/Cu多层膜的Cu层中发现自旋极化传导电子的存在和分布。

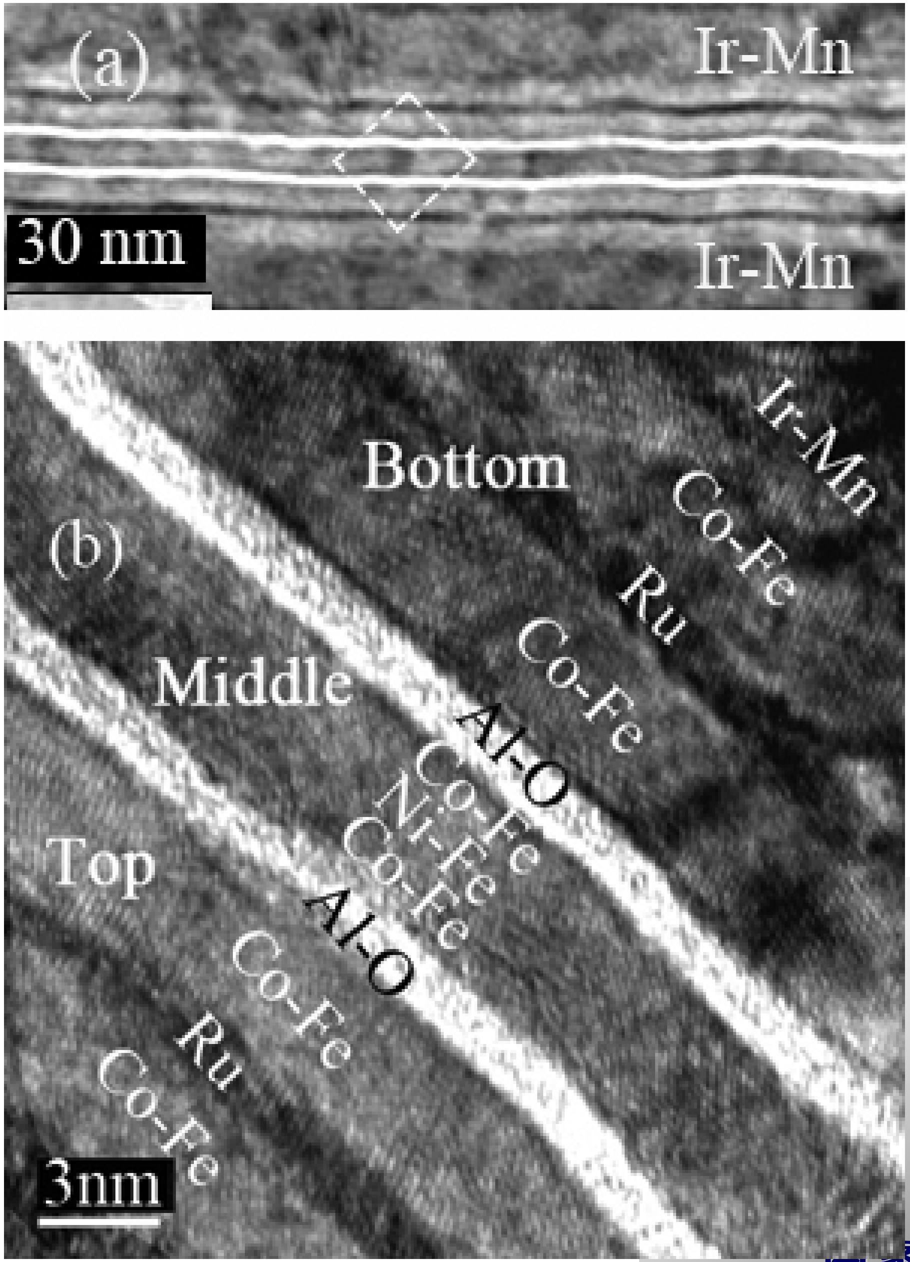
M02 Group / Spintronics
State Key Laboratory of Magnetism

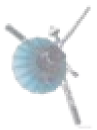


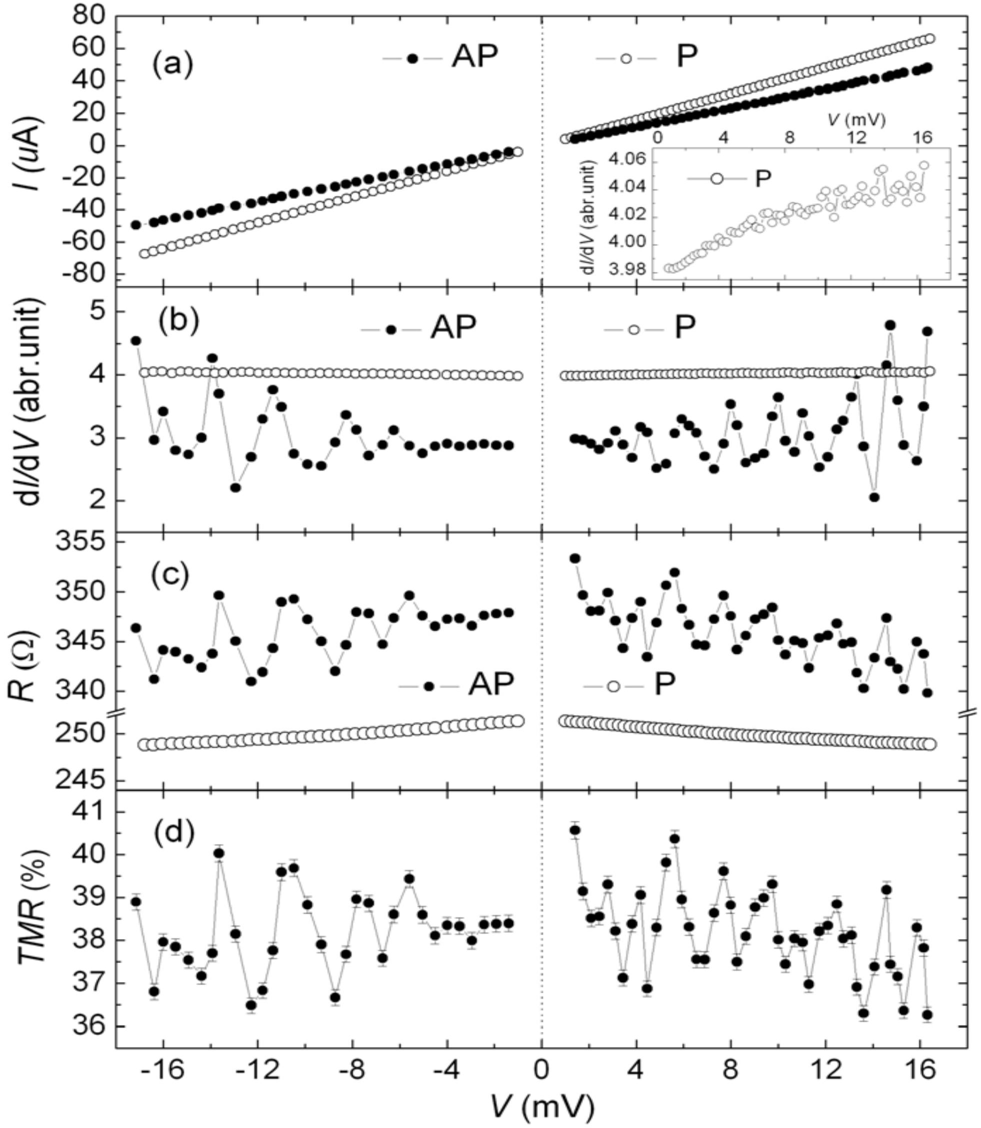
Model MPS-4000-HC7
TMR R&D Sputtering System

TEM image

1 **Cover layers**
2 **$Ir_{22}Mn_{78}$** (10)
3 **$Co_{75}Fe_{25}$** (3)
4 **Ru** (0.9)
5 **$Co_{75}Fe_{25}$** (3)
6 **Al-O** (1)
7 **CoFe(1)/Py(1)/CoFe(1)**
8 **Al-O** (1)
9 **$Co_{75}Fe_{25}$** (3)
10 **Ru** (0.9)
11 **$Co_{75}Fe_{25}$** (3)
12 **$Ir_{22}Mn_{78}$** (10)
13 **Seed layers**







TMR Oscillation Effect

at 300 K observed

in the DBMTJ

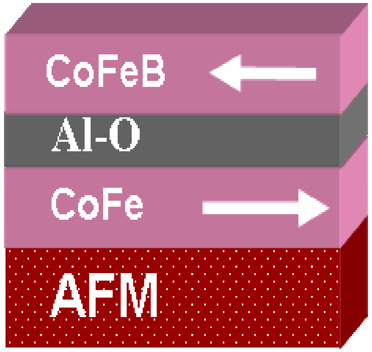
using PPMS

Z.M. Zeng, X.F. Han et al.,

PRB 72 (2005) 054419-1-5

新型反铁磁钉扎材料研究

- 发现两种新的反铁磁钉扎材料，其钉扎场和稳定性大大超越现有主流反铁磁钉扎材料的对应值，为磁电子学提供两种新的核心组元材料



新发现钉扎材料
与现有主流材料的最佳性能对照

	主流材料I $Ir_{20}Mn_{80}$	主流材料II $Mn_{50}Pt_{50}$	新型材料I $Cr_{50}Pt_{50}$ (界面添Mn)	新型材料II $Cr_{25}Mn_{25}Pt_{50}$
交换偏置场/Oe	140	255	280	370
矫顽力/Oe	15	85	90	110
钉扎截止温度/°C	280	400	600	650-700

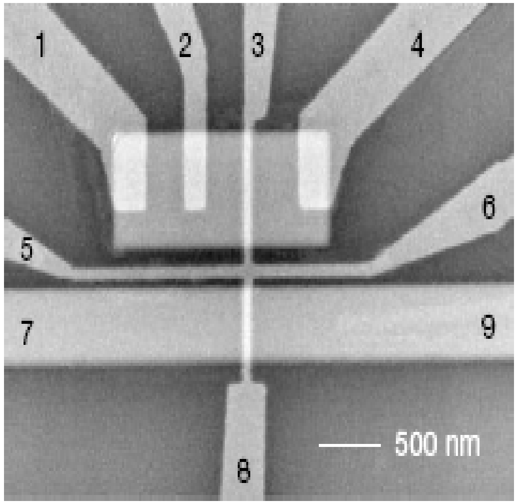
论文

- JAP 92 (2002) 5386
- APL 82 (2003) 3722
- APL 85 (2004) 5281
- APL 87 (2005) 092506
- JAP 99 (2006) 073902

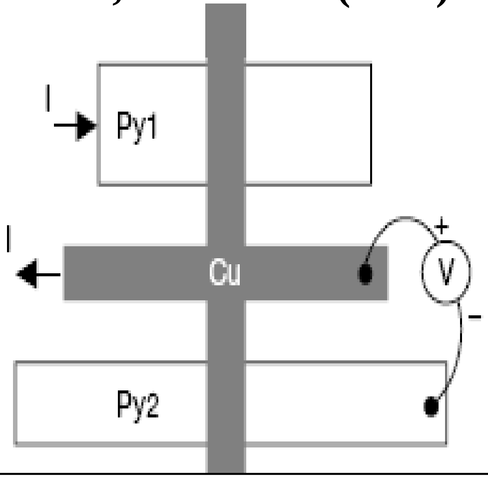
专利

- ZL02293463.4
- ZL02157977.6
- ZL200310118596.7
- 200410073654.3
- 200610056824.6

一种探测自旋散射效应和自旋翻转长度的新方法



Jedema, Nature 410(2001)345



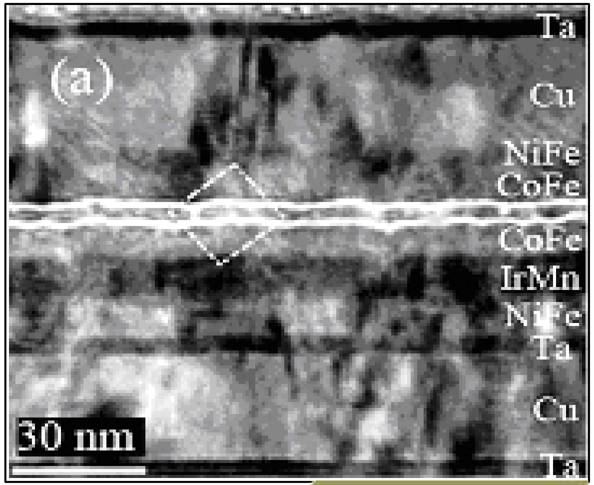
原方法

新方法的优势

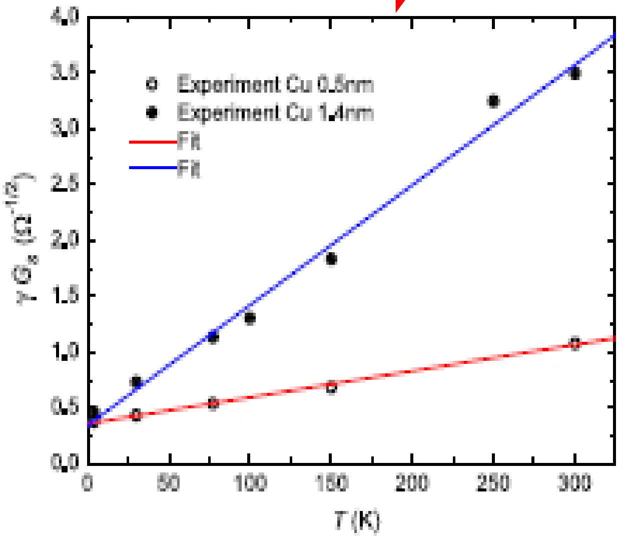
1 纳米材料体系

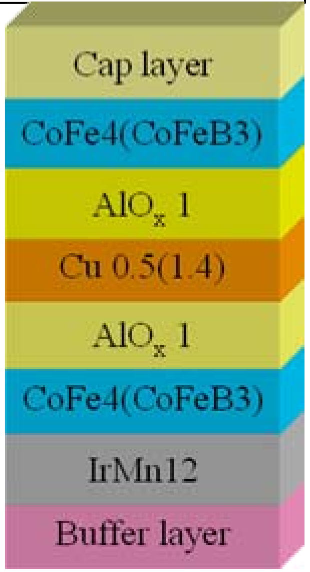
2 弹性散射机制

3 纳米器件设计

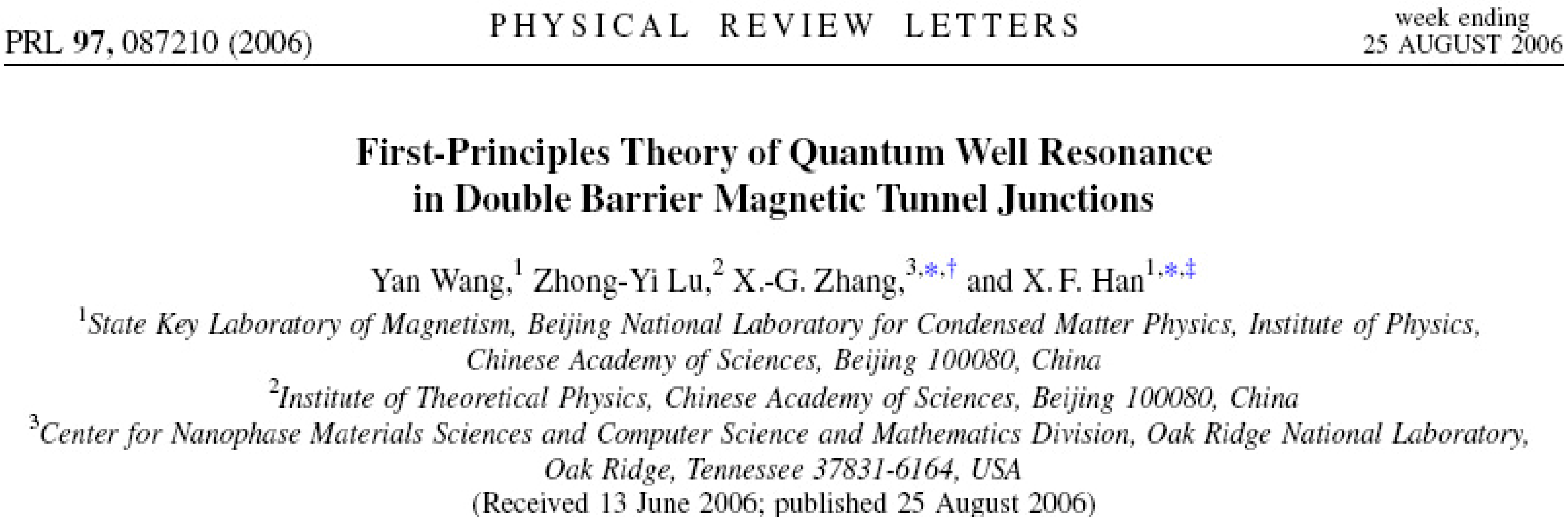


新方法





Z.M. Zeng et al., *Phys. Rev. Lett.* 97, 106605 (2006)



PRL 97, 087210 (2006) PHYSICAL REVIEW LETTERS week ending 25 AUGUST 2006

First-Principles Theory of Quantum Well Resonance in Double Barrier Magnetic Tunnel Junctions

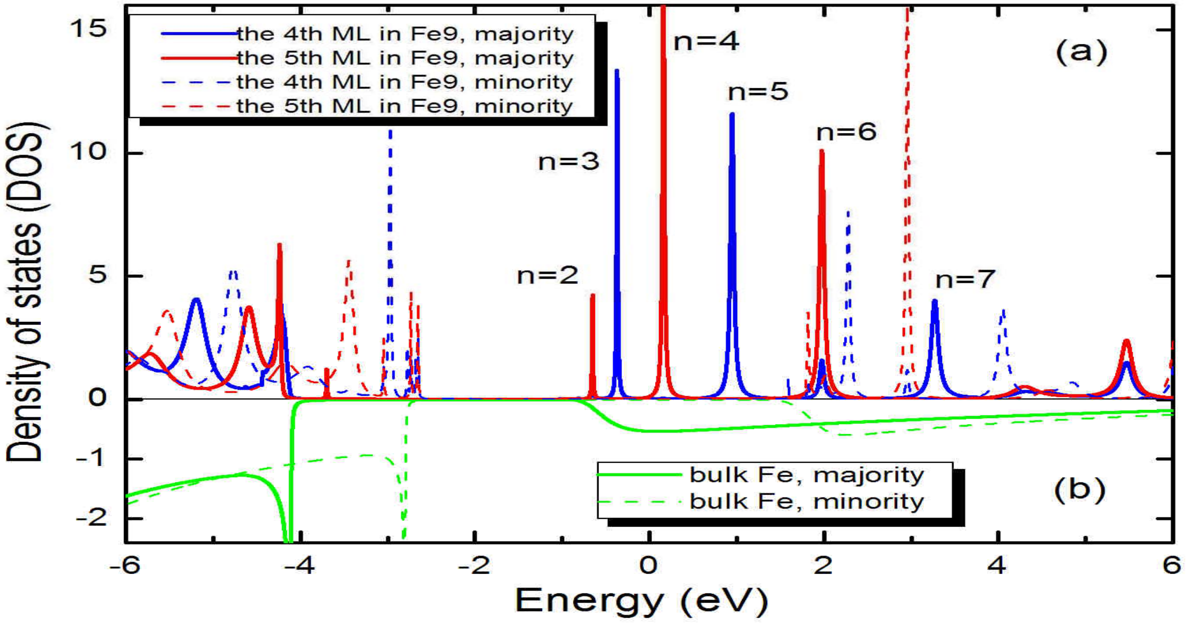
Yan Wang,[1] Zhong-Yi Lu,[2] X.-G. Zhang,[3,*,†] and X. F. Han[1,*,‡]

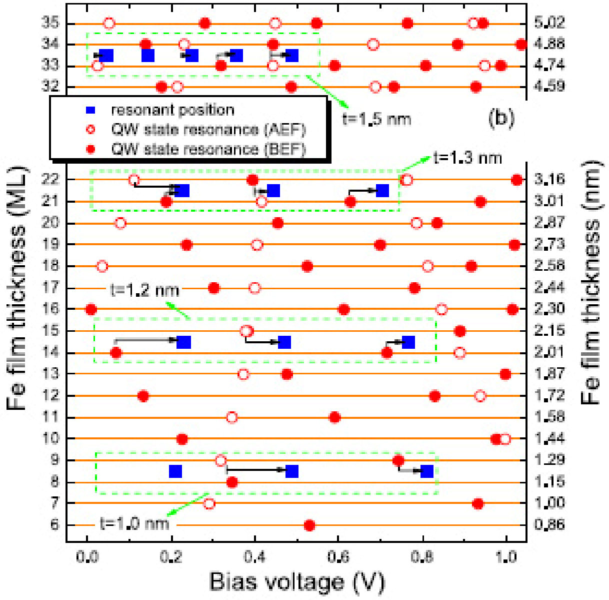
[1]*State Key Laboratory of Magnetism, Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100080, China*

[2]*Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100080, China*

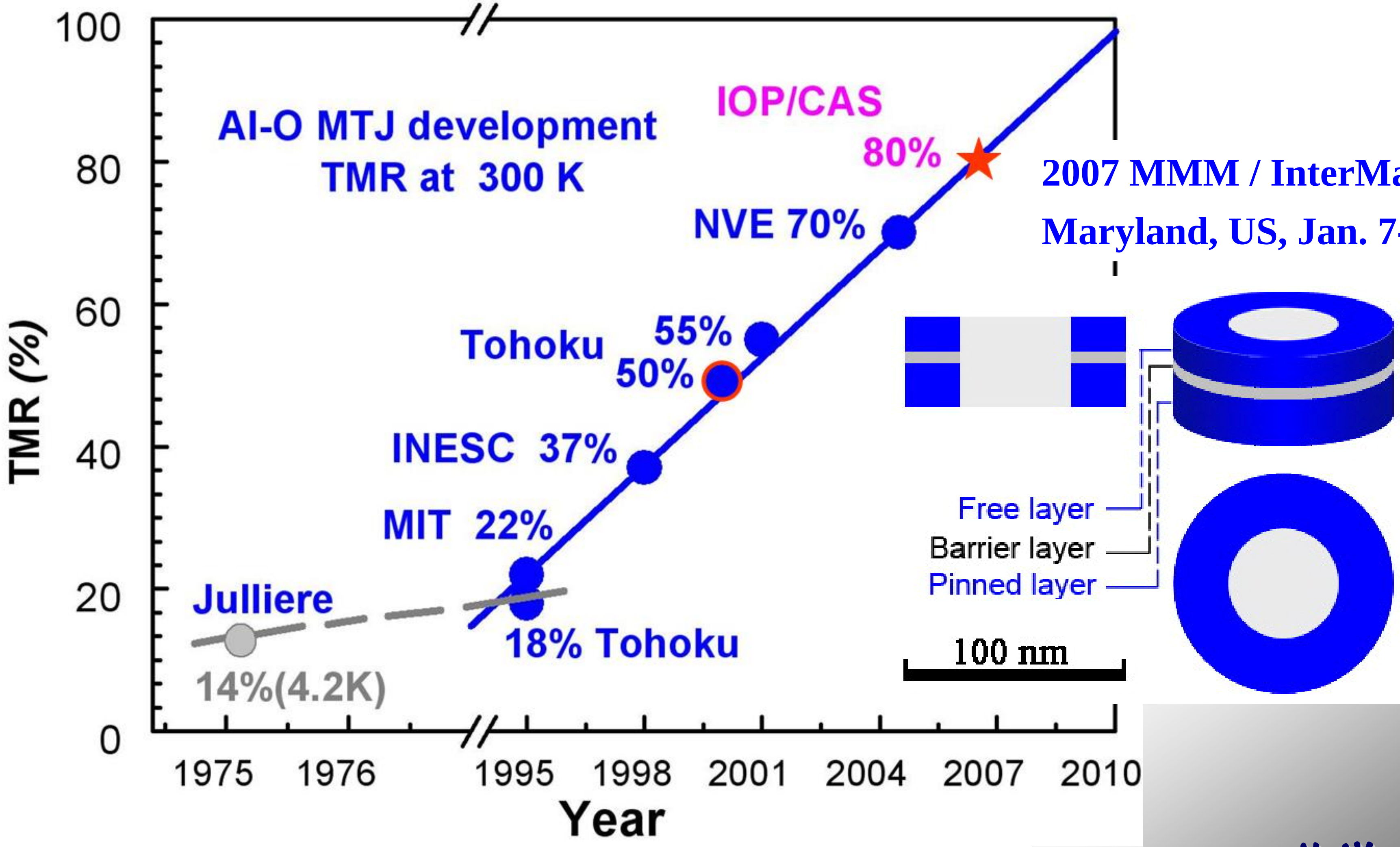
[3]*Center for Nanophase Materials Sciences and Computer Science and Mathematics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831-6164, USA*

(Received 13 June 2006; published 25 August 2006)





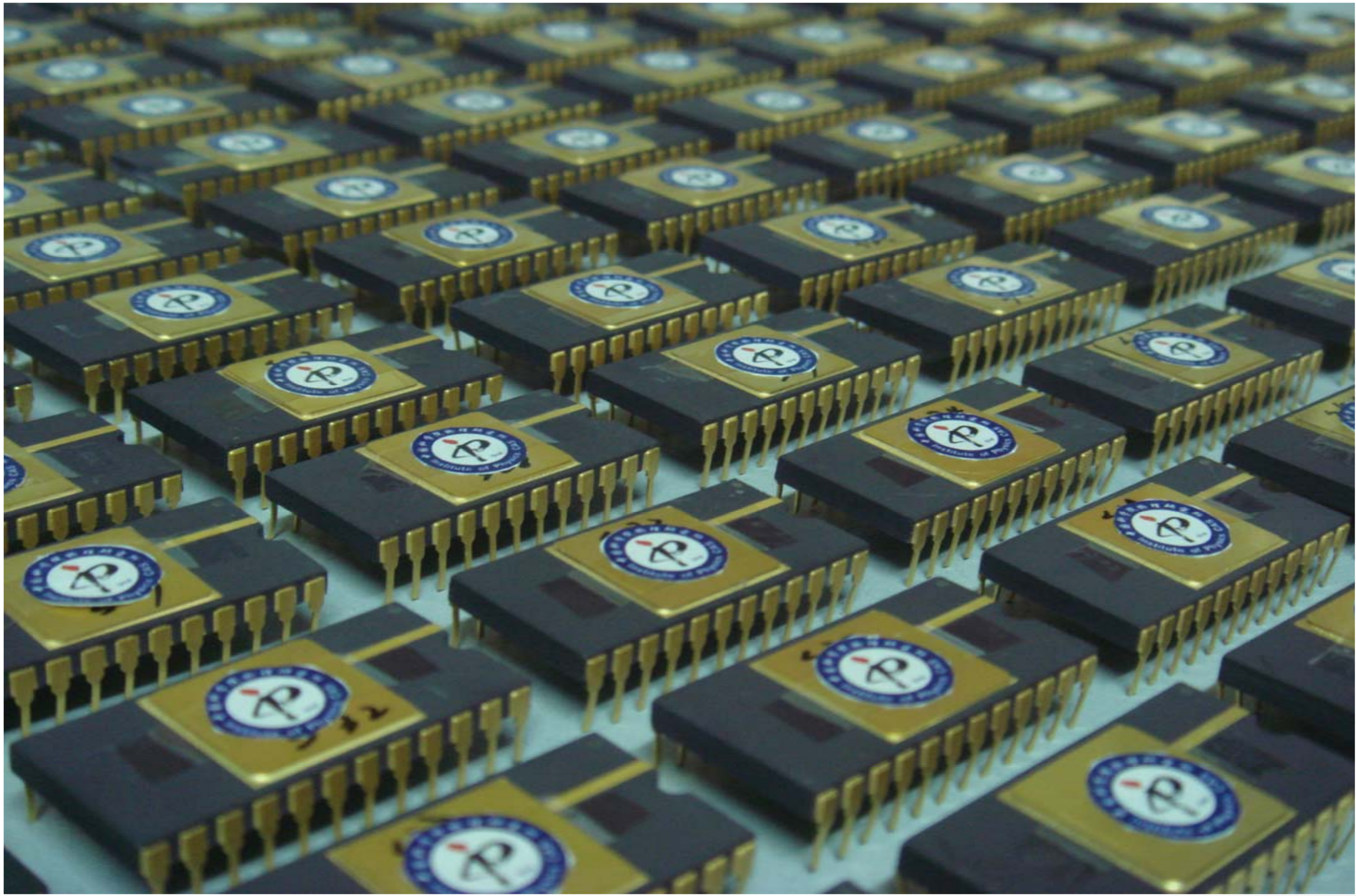
☯ 基于氧化铝势垒 TMR 磁性隧道结材料的研究



2007 MMM / InterMag

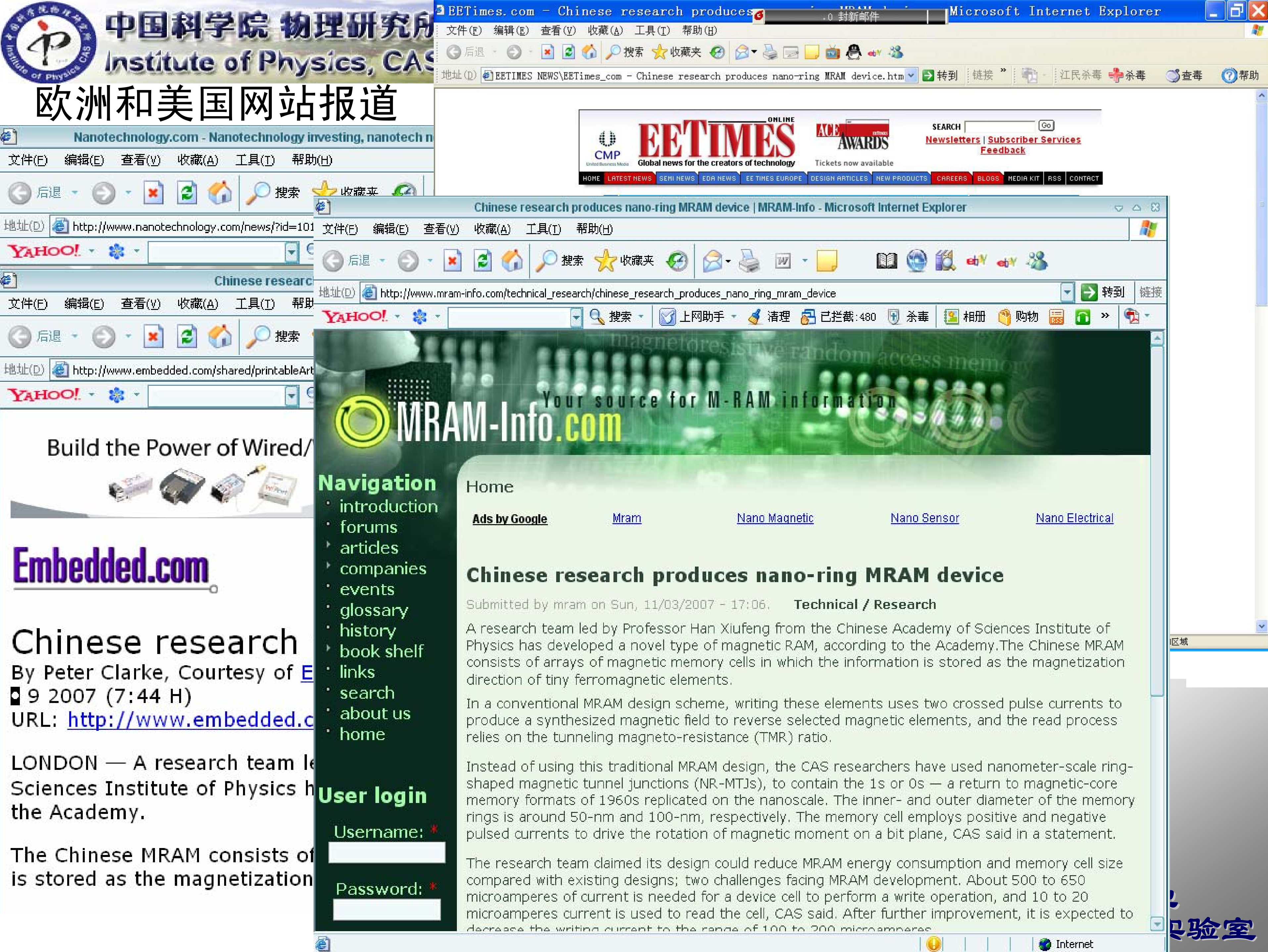
Maryland, US, Jan. 7-11

Nano-Ring MRAM using Spin Polarized Current Switching



中国科学院 物理研究所
Institute of Physics, CAS

欧洲和美国网站报道



Chinese research

By Peter Clarke, Courtesy of E

9 2007 (7:44 H)

URL: http://www.embedded.c

LONDON — A research team le

Sciences Institute of Physics h

the Academy.

The Chinese MRAM consists of

is stored as the magnetization

Chinese research produces nano-ring MRAM device

Submitted by mram on Sun, 11/03/2007 - 17:06. **Technical / Research**

A research team led by Professor Han Xiufeng from the Chinese Academy of Sciences Institute of Physics has developed a novel type of magnetic RAM, according to the Academy.The Chinese MRAM consists of arrays of magnetic memory cells in which the information is stored as the magnetization direction of tiny ferromagnetic elements.

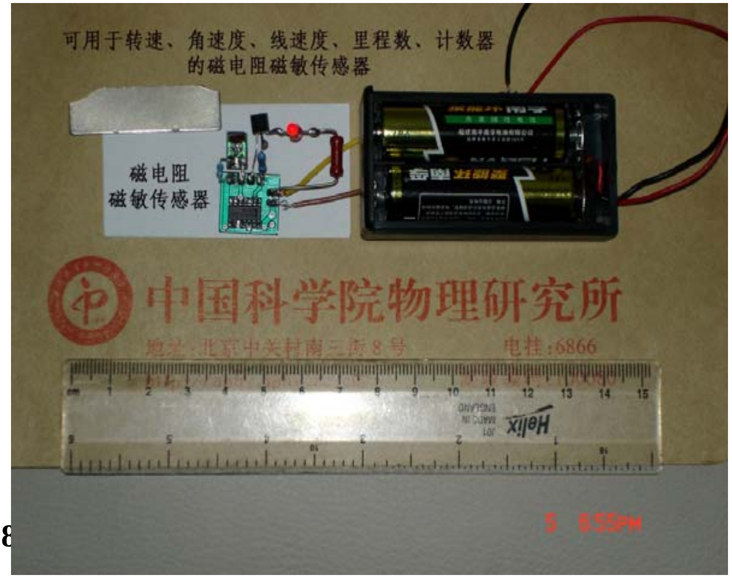
In a conventional MRAM design scheme, writing these elements uses two crossed pulse currents to produce a synthesized magnetic field to reverse selected magnetic elements, and the read process relies on the tunneling magneto-resistance (TMR) ratio.

Instead of using this traditional MRAM design, the CAS researchers have used nanometer-scale ring-shaped magnetic tunnel junctions (NR-MTJs), to contain the 1s or 0s — a return to magnetic-core memory formats of 1960s replicated on the nanoscale. The inner- and outer diameter of the memory rings is around 50-nm and 100-nm, respectively. The memory cell employs positive and negative pulsed currents to drive the rotation of magnetic moment on a bit plane, CAS said in a statement.

The research team claimed its design could reduce MRAM energy consumption and memory cell size compared with existing designs; two challenges facing MRAM development. About 500 to 650 microamperes of current is needed for a device cell to perform a write operation, and 10 to 20 microamperes current is used to read the cell, CAS said. After further improvement, it is expected to decrease the writing current to the range of 100 to 200 microamperes.

用于数控机床的精密位移传感器

二维地磁场传感器



可用于转速、角速度、线速度、里程数、计数器的磁电阻磁敏传感器

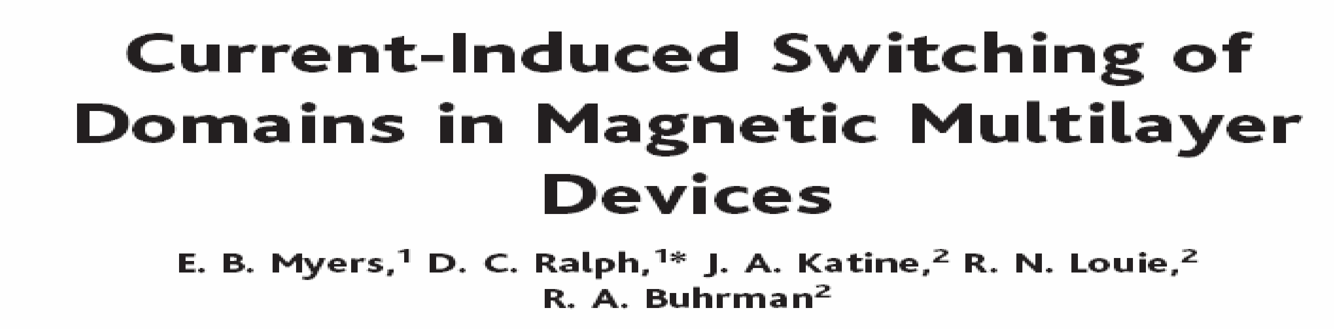
磁电阻
磁敏传感器

便携式验钞器

MTJ/
TMR
Sensor

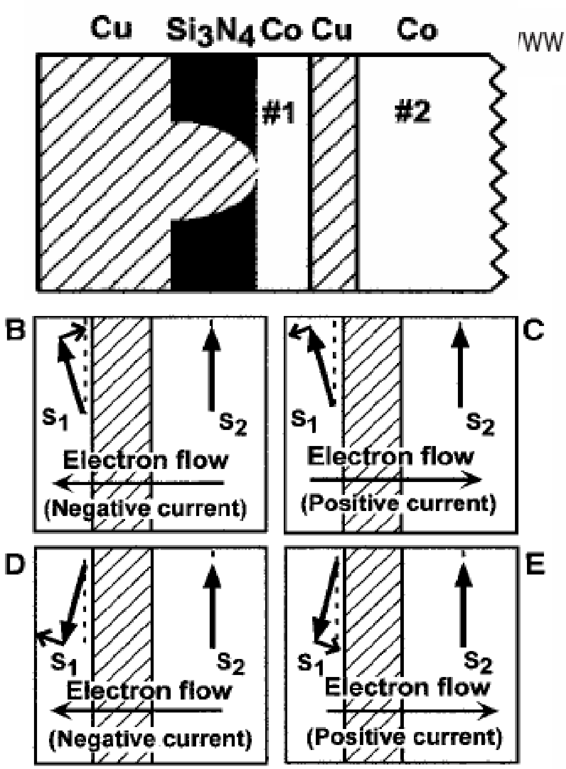
磁学室M02课题组
惠州三川电子

目前GMR和TMR相关的热点前沿课题

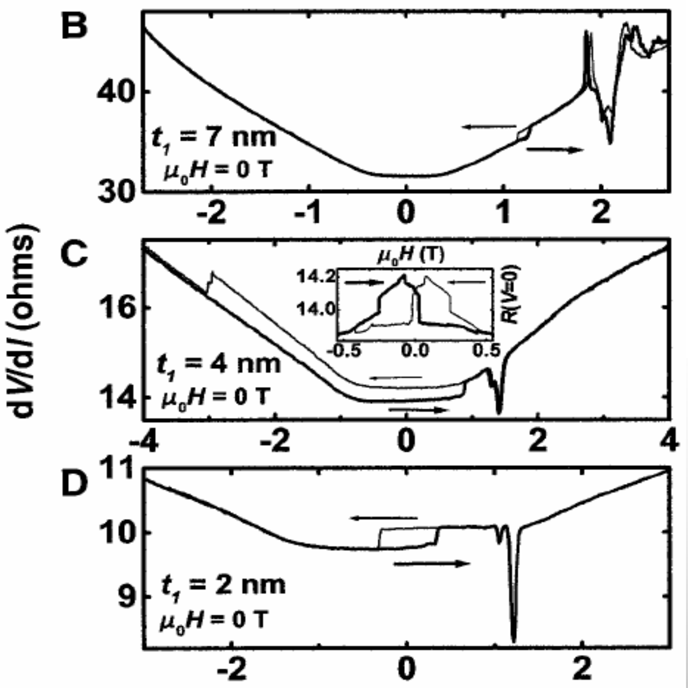


Current-Induced Switching of Domains in Magnetic Multilayer Devices

E. B. Myers,[1] D. C. Ralph,[1*] J. A. Katine,[2] R. N. Louie,[2]
R. A. Buhrman[2]



www.sciencemag.org SCIENCE VOL 285 6 AUGUST 1999 **P.867**



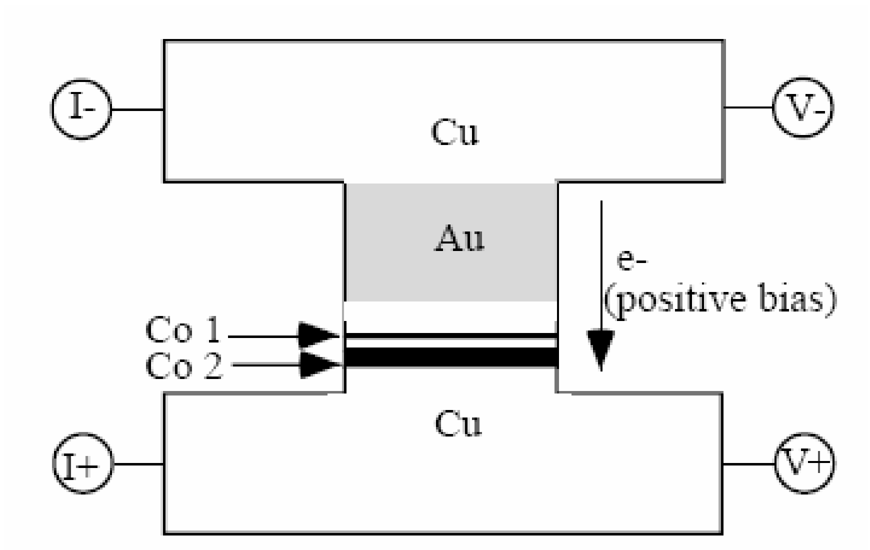
VOLUME 84, NUMBER 14 PHYSICAL REVIEW LETTERS 3 APRIL 2000

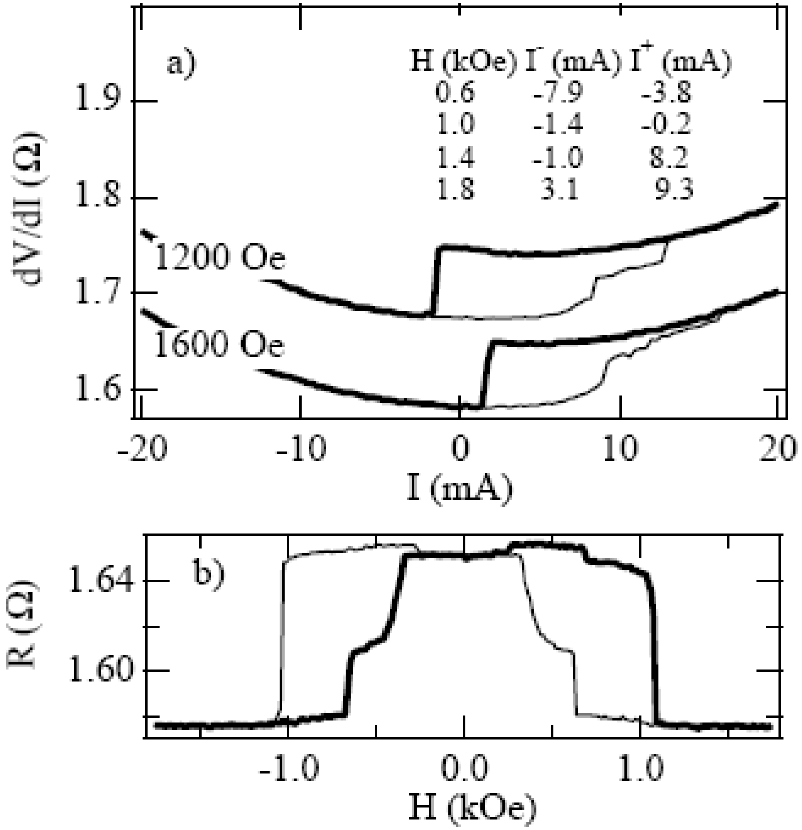
Current-Driven Magnetization Reversal and Spin-Wave Excitations in Co/Cu/Co Pillars

J. A. Katine, F. J. Albert, and R. A. Buhrman
School of Applied and Engineering Physics, Cornell University, Ithaca, New York 14853

E. B. Myers and D. C. Ralph
Laboratory of Atomic and Solid State Physics, Cornell University, Ithaca, New York 14853

(Received 12 July 1999)





VOLUME 93, NUMBER 21 PHYSICAL REVIEW LETTERS week ending 19 NOVEMBER 2004

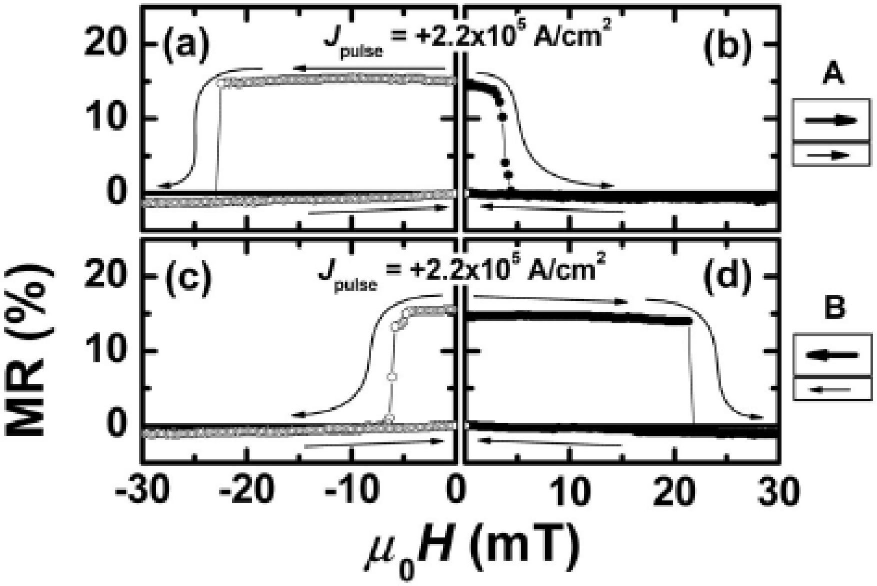
Current-Driven Magnetization Reversal in a Ferromagnetic Semiconductor (Ga, Mn)As/GaAs/(Ga, Mn)As Tunnel Junction

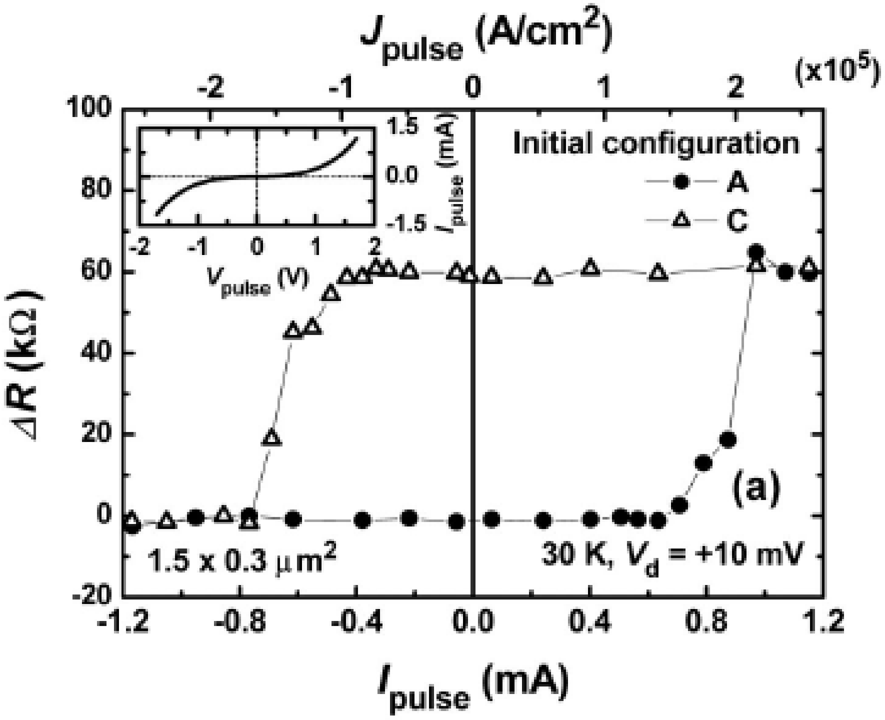
D. Chiba,[1,2,†] Y. Sato,[1] T. Kita,[1,2] F. Matsukura,[1,2] and H. Ohno[1,2,*]

[1]*Laboratory for Nanoelectronics and Spintronics, Research Institute of Electrical Communication, Tohoku University,*
Katahira 2-1-1, Aoba-ku, Sendai 980-8577, Japan

[2]*Semiconductor Spintronics Project, Exploratory Research for Advanced Technology, Japan Science and Technology Agency, Japan*

(Received 15 March 2004; published 18 November 2004)





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Mutual phase-locking of microwave spin torque nano-oscillators

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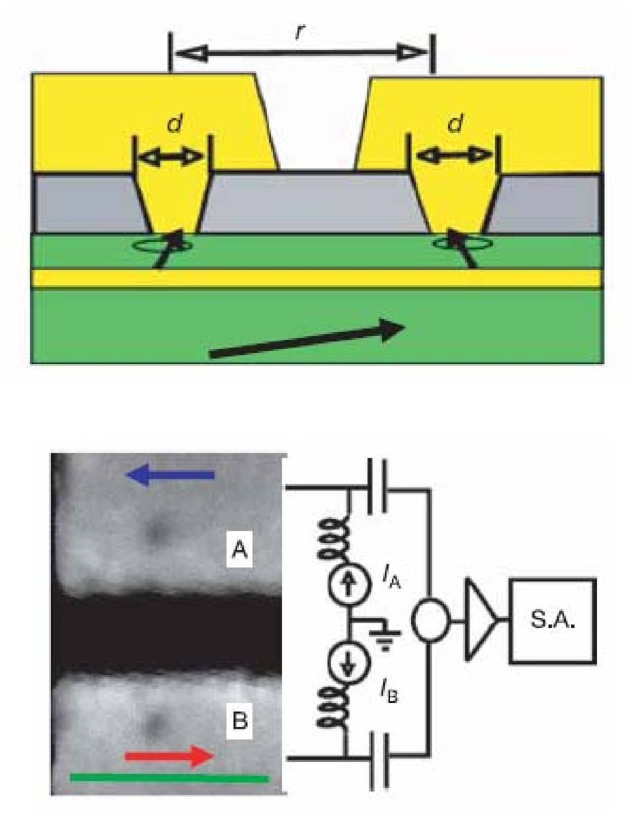

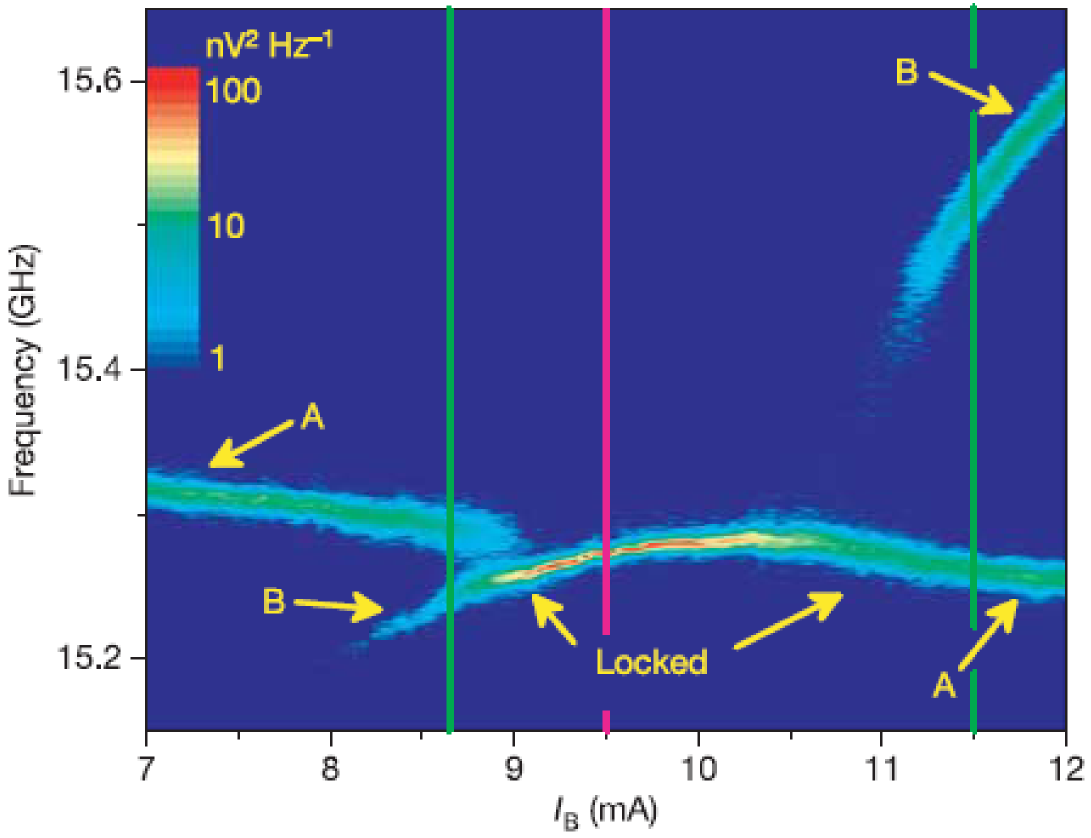

Thanks for your attendance!