# SPIN INJECTION INTO SEMICONDUCTING NANOSTRUCTURES :

# ISSUES & PERSPECTIVES


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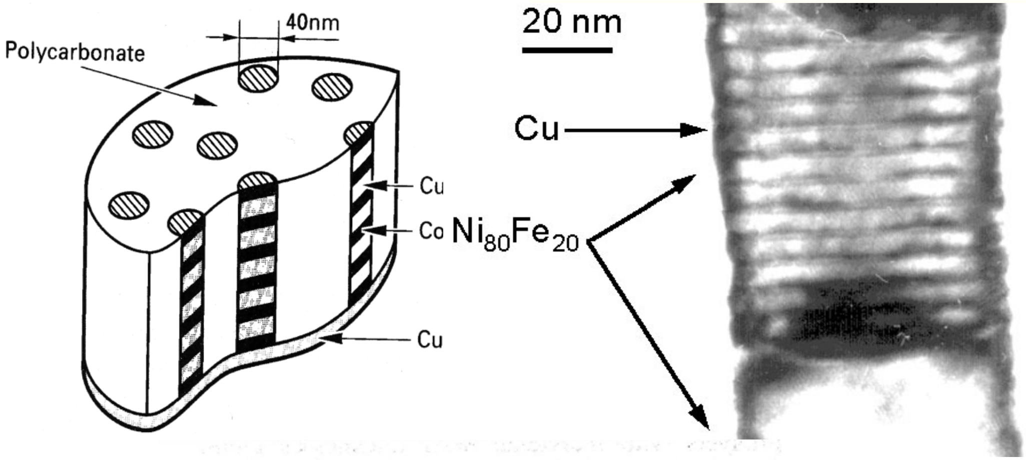
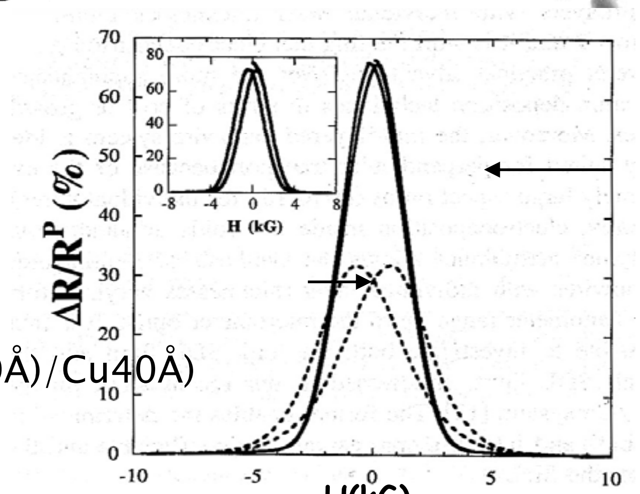
Route départementale 128, 91767 Palaiseau Cedex

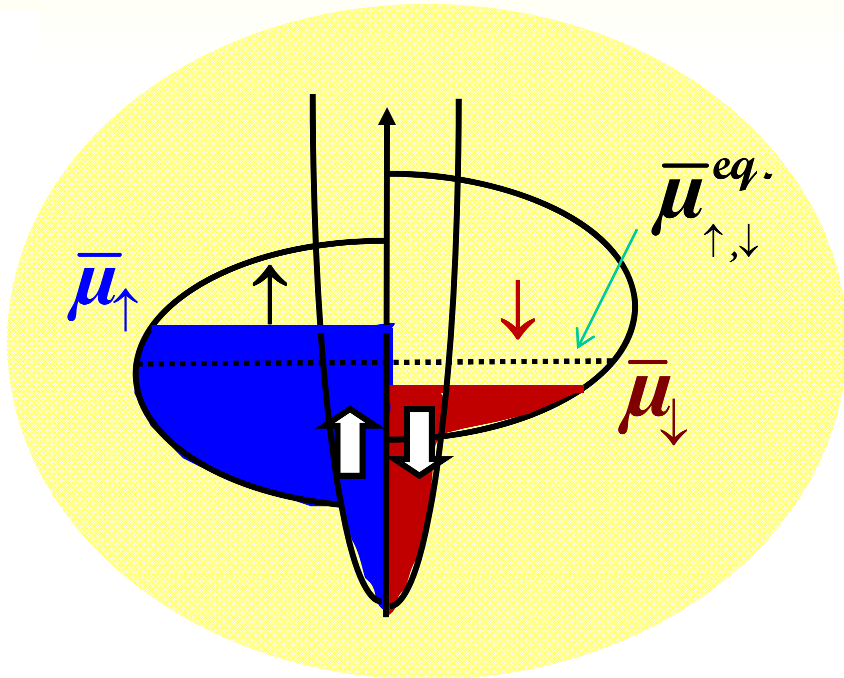
# SPIN INJECTION IN METALLIC NANOSTRUCTURES : GIANT MAGNETORESISTANCE

## NANOWIRES :




(NiFe50Å)/Cu40Å)

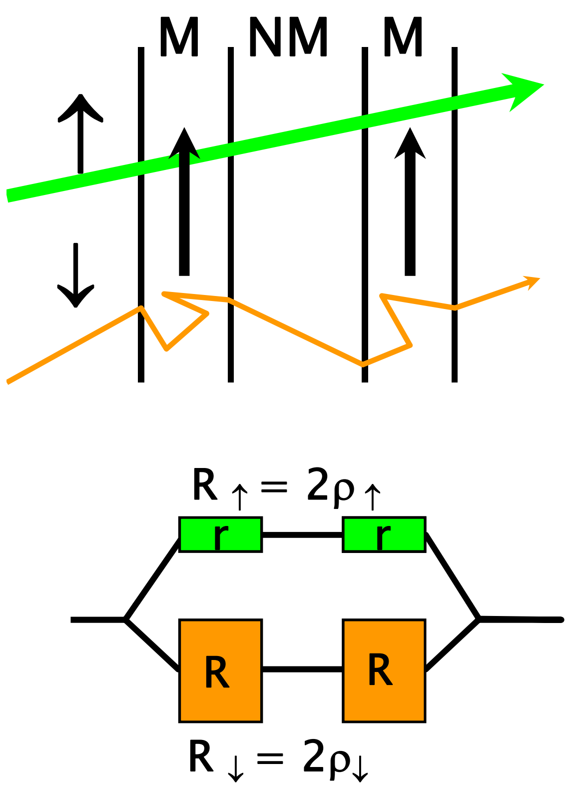



## SPIN ACCUMULATION

*Piraux et al.; Appl. Phys. Lett. 65, 2484 (1999)*

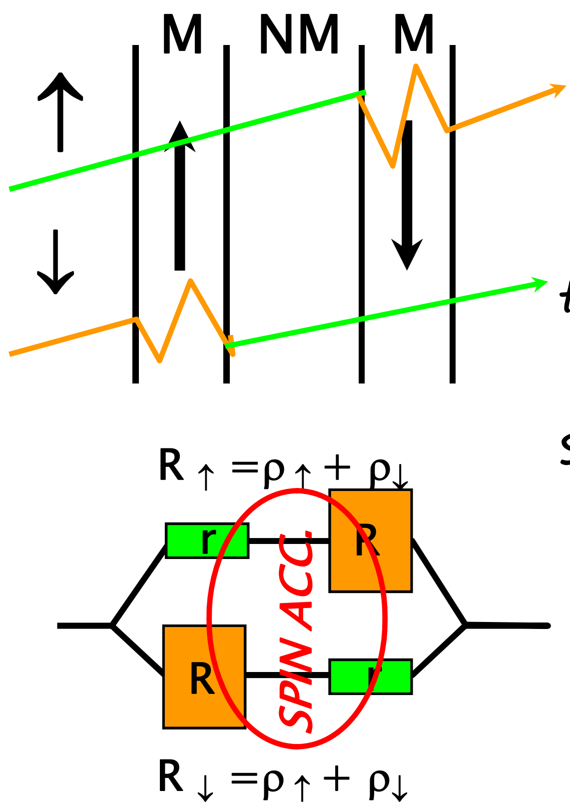
# CPP-GMR & SERIES RESISTANCE MODEL

P configuration




$$R_P = 2\rho^*\left(1-\beta^2\right)$$

AP configuration




$$R_{AP} = 2\rho^*$$

$$MR = \frac{\Delta R}{R_{AP}} = \beta^2$$

CONDITIONS :

thickness << Spin Diff. Length $l_{sf}$

&

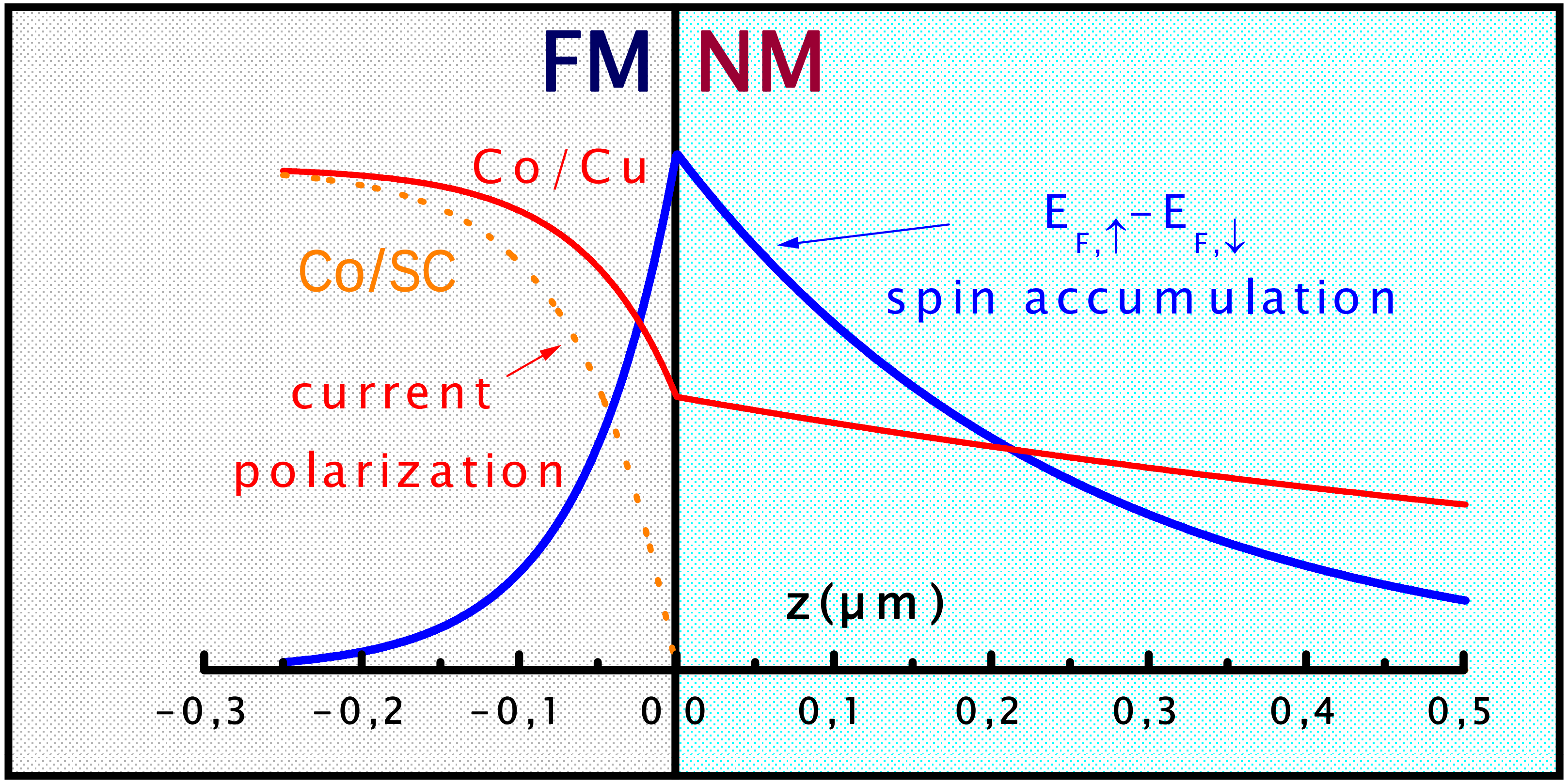
Spin relaxation negligible in Cu

$$MR \simeq \left(P^2_{\uparrow\uparrow} - P^2_{\uparrow\downarrow}\right)$$

Current spin polarization

GMR as a probe of the current spin polarization

# SPIN INJECTION INTO NON-MAGNETIC MATERIAL




*accum. spins in* ***FM*** $\propto \Delta\mu_I N_{E_F}^{FM} l_{sf}^{FM}$

*number of* ***spin flips in F***

$\propto \Delta\mu_I N_{E_F}^{FM} l_{sf}^{FM}/\tau_{sf}^{F} = \Delta\mu_I / \rho^{FM} l_{sf}^{FM}$

*accum. spins in* ***NM*** $\propto \Delta\mu_I N_{E_F}^{NM} l_{sf}^{NM}$

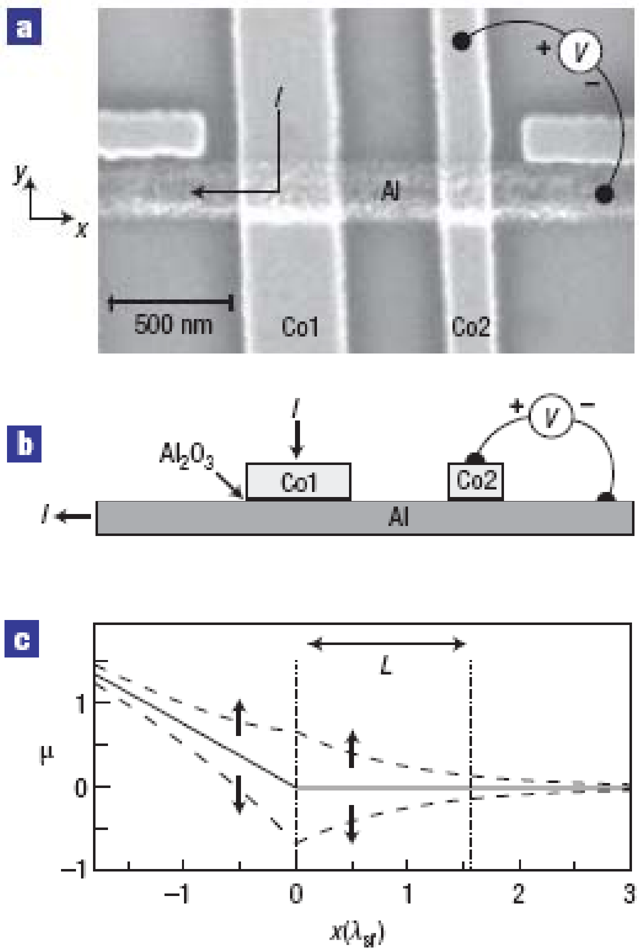
*number of* ***spin flips in NM***

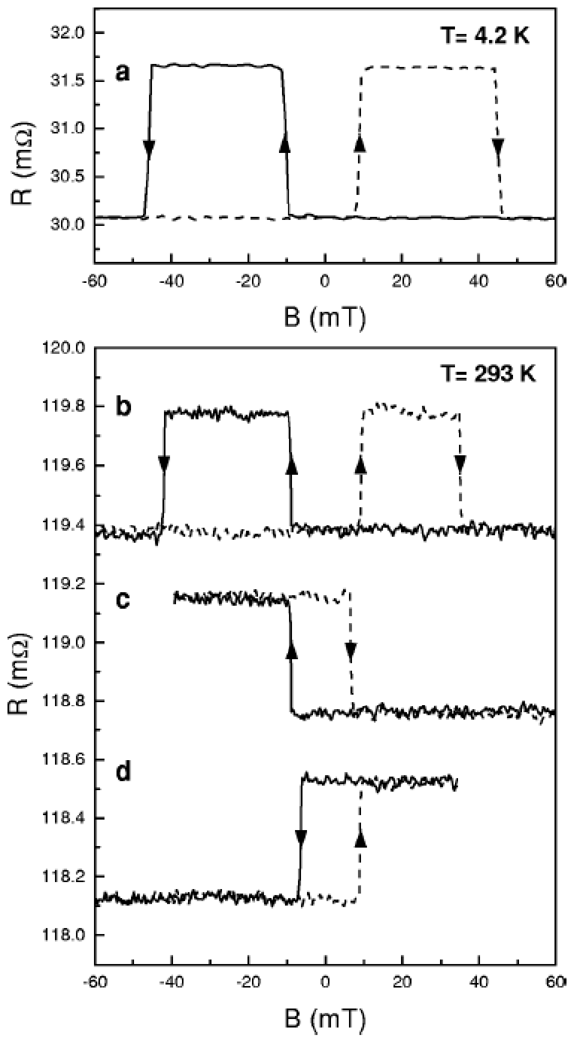
$\propto \Delta\mu_I N_{E_F}^{FM} l_{sf}^{FM}/\tau_{sf}^{F} = \Delta\mu_I / \rho^{NM} l_{sf}^{NM}$

Good conductivity matching for metals

*T. Valet, A. Fert, PRB 1993*

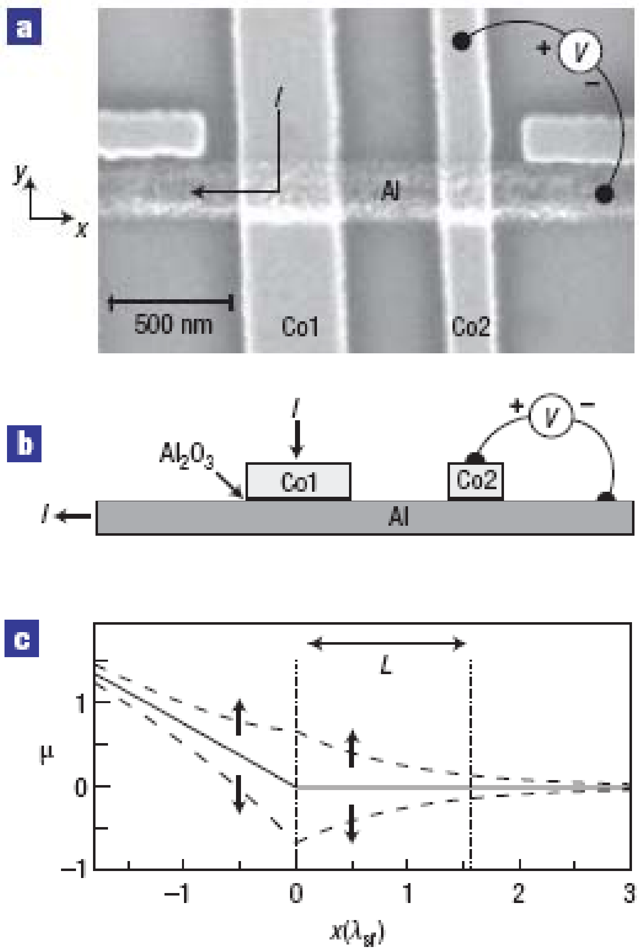
# NON LOCAL-MEASUREMENTS OF SPIN ACCUMULATION

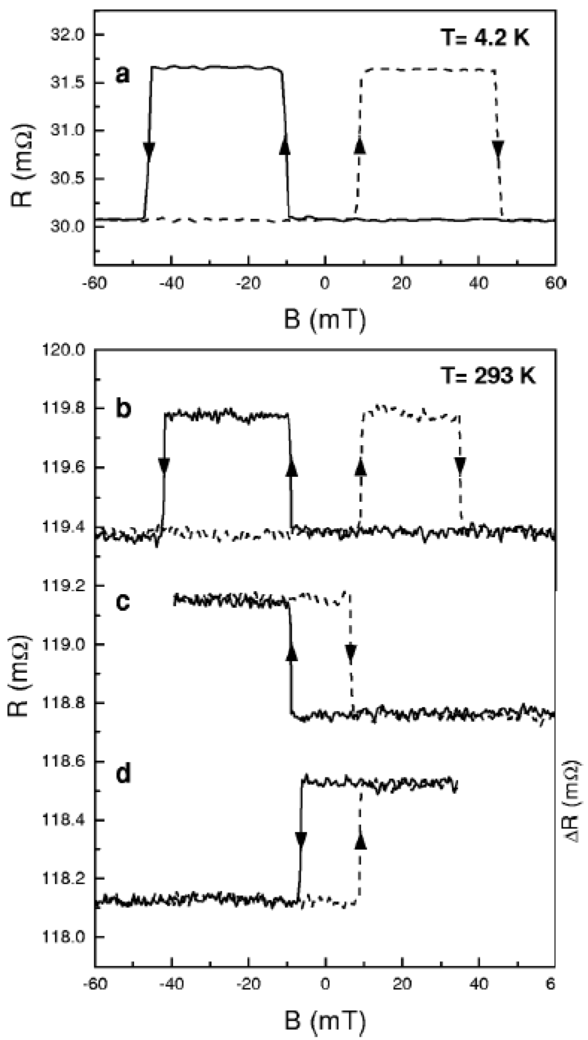


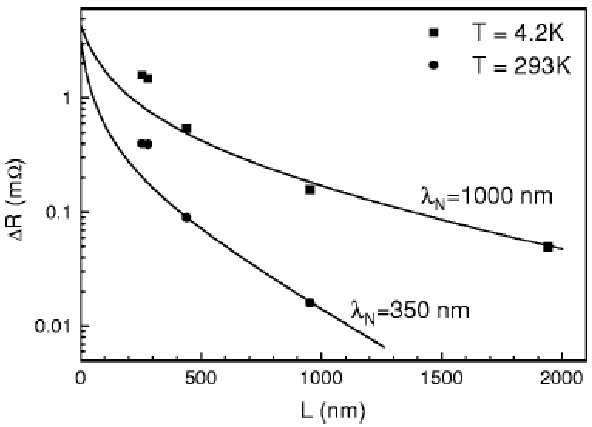




B. Van Wees, Groningen

# NON LOCAL-MEASUREMENTS OF SPIN ACCUMULATION

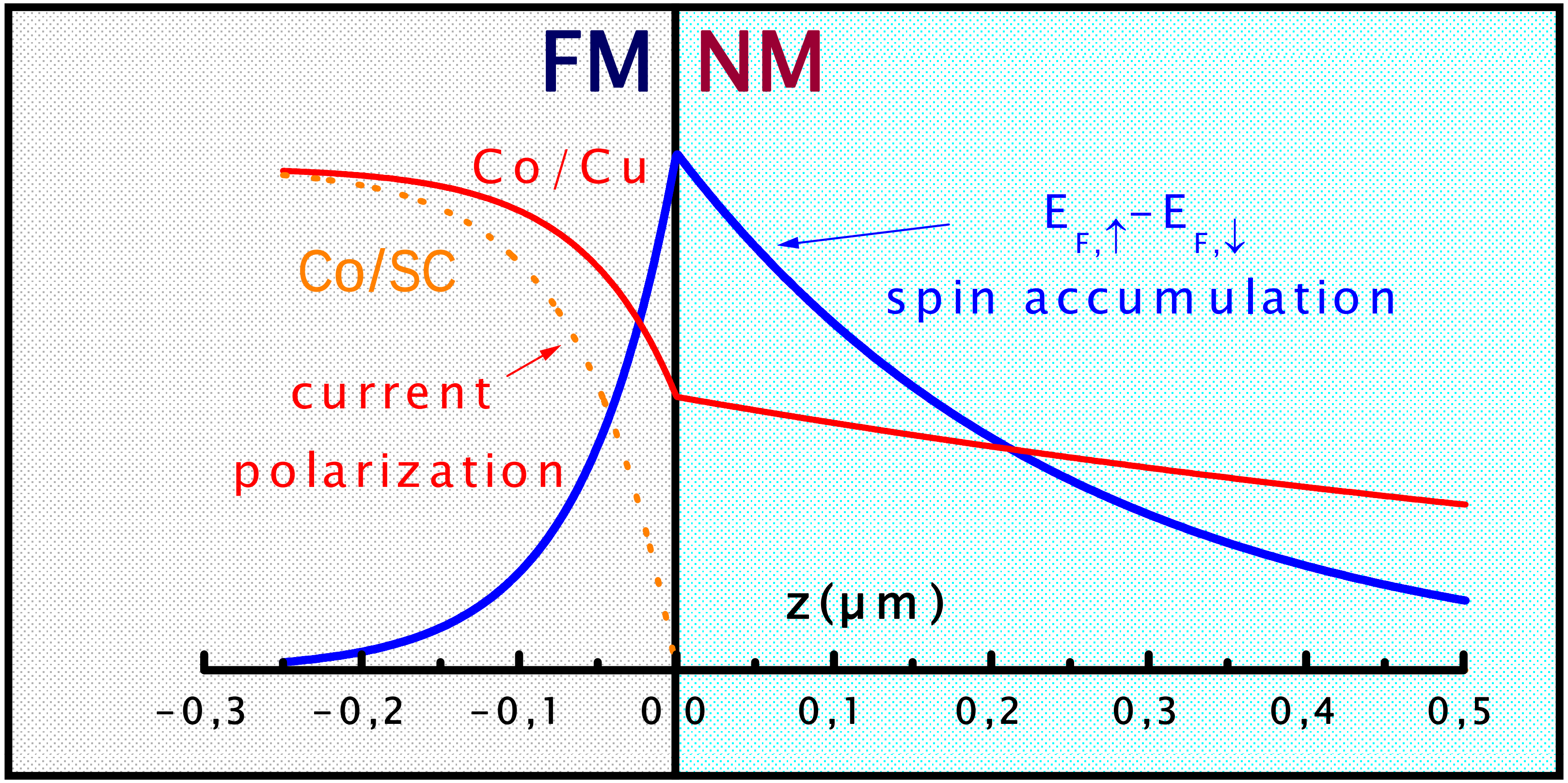



B. Van Wees, Groningen

# SPIN INJECTION INTO NON-MAGNETIC MATERIAL




T. Valet, A. Fert, PRB 1993

*accum. spins in FM* $\propto \Delta\mu_l N_{E_F}^{FM} l_{sf}^{FM}$

*number of spin flips in F*

$\propto \Delta\mu_l N_{E_F}^{FM} l_{sf}^{FM} / \tau_{sf}^{F} = \Delta\mu_l / \rho^{FM} l_{sf}^{FM}$

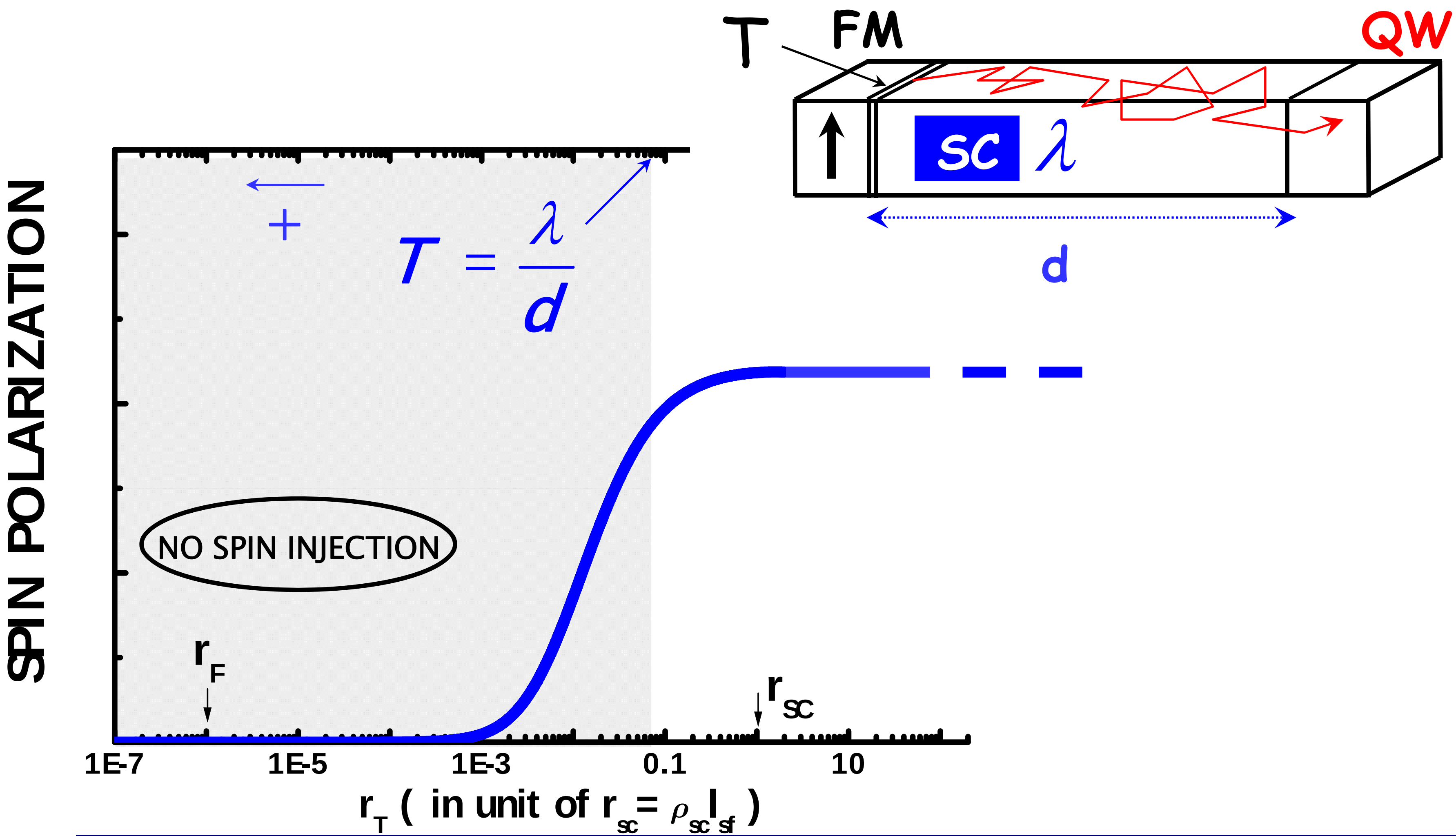
*accum. spins in NM* $\propto \Delta\mu_l N_{E_F}^{NM} l_{sf}^{NM}$

*number of spin flips in NM*

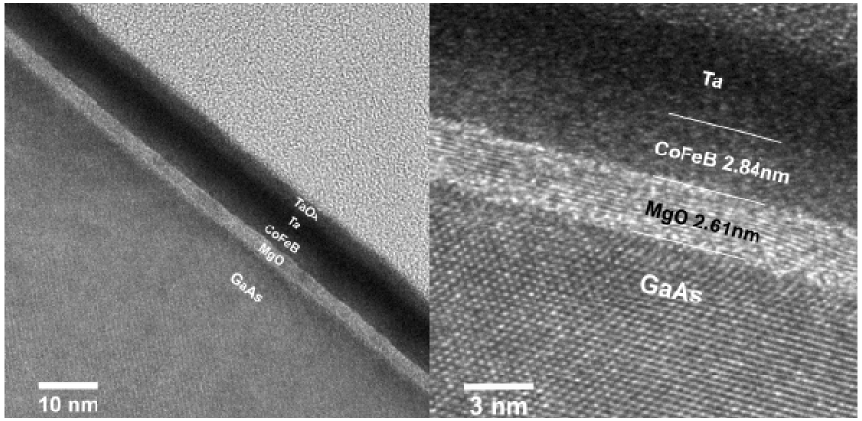
$\propto \Delta\mu_l N_{E_F}^{FM} l_{sf}^{FM} / \tau_{sf}^{F} = \Delta\mu_l / \rho^{NM} l_{sf}^{NM}$

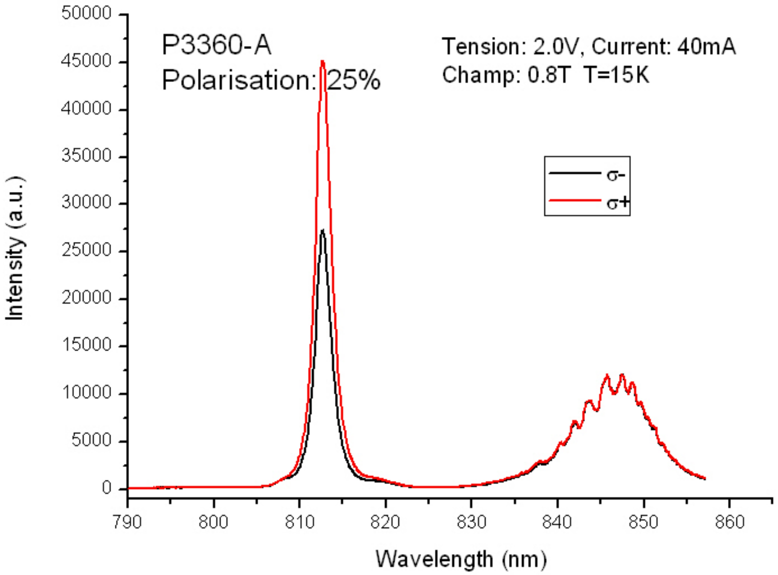
Good conductivity matching for metals

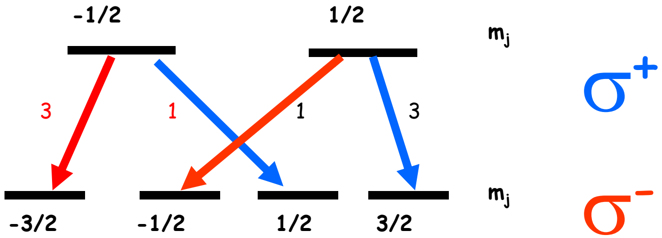
# CURRENT SPIN-POLARIZATION Vs. INTERFACIAL TRANSMISSION



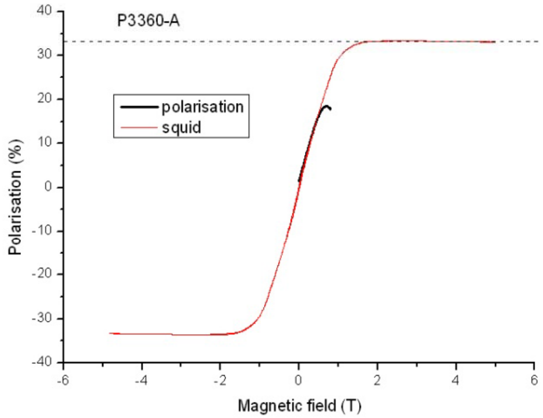
# Spin injection into a LED : optical conversion



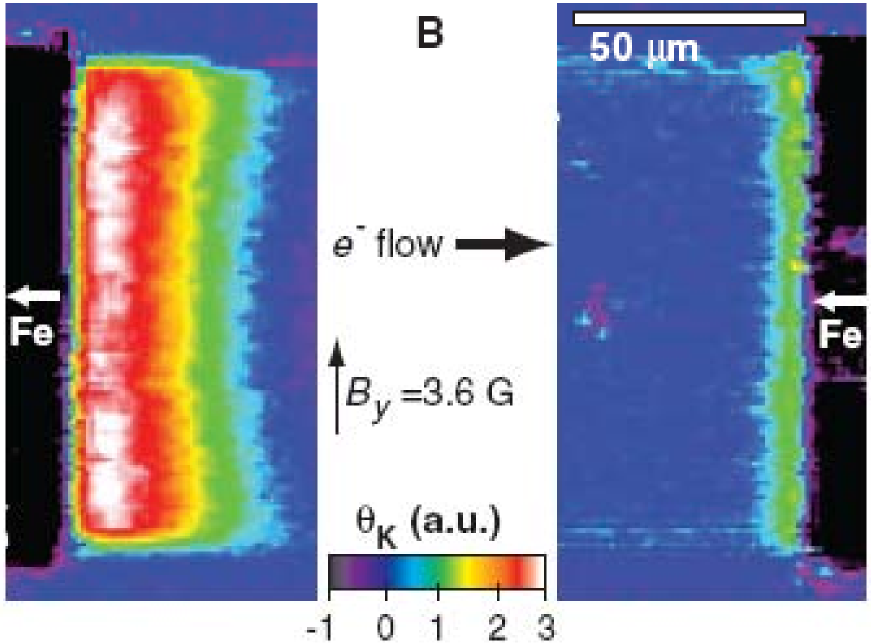

•*Aronov pickus Sov.Phys.semicond 10, 698 (1976)*



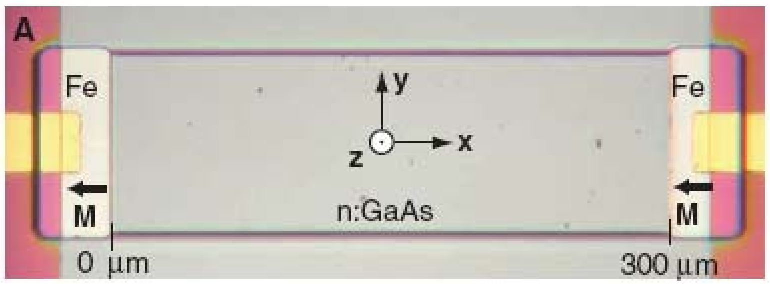
www.sciencemag.org SCIENCE VOL 309 30 SEPTEMBER 2005

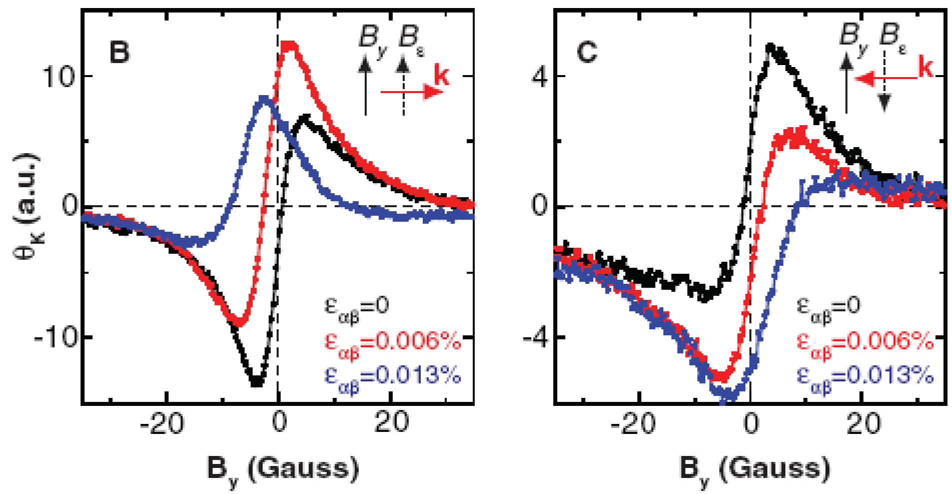
# Imaging Spin Transport in Lateral Ferromagnet/ Semiconductor Structures

S. A. Crooker,[1]* M. Furis,[1] X. Lou,[2] C. Adelmann,[3] D. L. Smith,[4] C. J. Palmstrøm,[3] P. A. Crowell[2]




## Spin Injection through a Fe/GaAs schottky junction



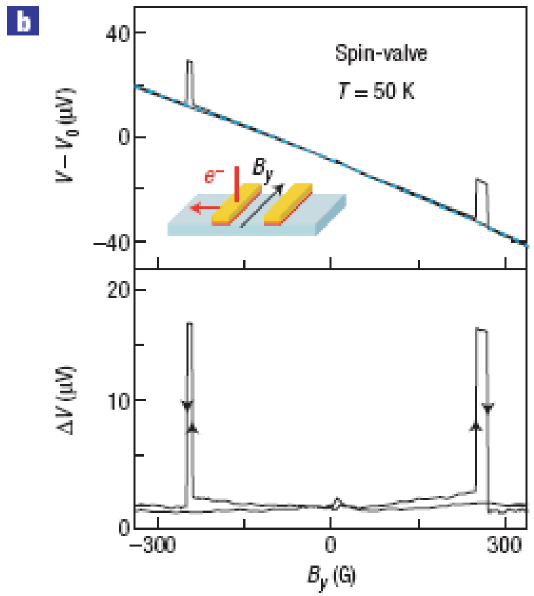

Unité mixte de Physique (UMR137)
associée à l'Université Paris-Sud

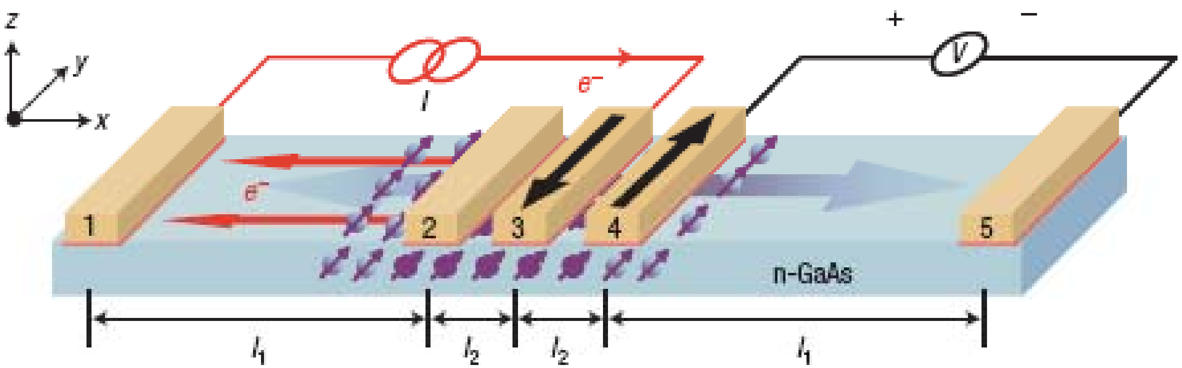
# Electrical detection of spin transport in lateral ferromagnet–semiconductor devices

XIAOHUA LOU[1], CHRISTOPH ADELMANN[2], SCOTT A. CROOKER[3], ERIC S. GARLID[1], JIANJIE ZHANG[1], K. S. MADHUKAR REDDY[2], SOREN D. FLEXNER[2], CHRIS J. PALMSTRØM[2] AND PAUL A. CROWELL[1]*

[1] School of Physics and Astronomy, University of Minnesota, Minneapolis, Minnesota 55455, USA
[2] Department of Chemical Engineering and Materials Science, University of Minnesota, Minneapolis, Minnesota 55455, USA
[3] National High Magnetic Field Laboratory, Los Alamos, New Mexico 87545, USA
*e-mail: crowell@physics.umn.edu

nature physics | VOL 3 | MARCH 2007 | www.nature.com/naturephysics



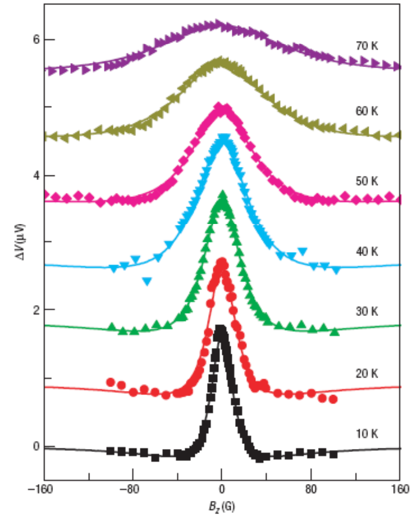




**Figure 2 Hanle curves at different temperatures.** Hanle curves for sample B obtained from $V_{3,5}$ ($\Delta V$ is $V_{3,5}$ after background subtraction) for a current $I_{1,2} = 0.6$ mA at several different temperatures. The curves are offset for clarity. The solid curves are fits to the model described in the text.

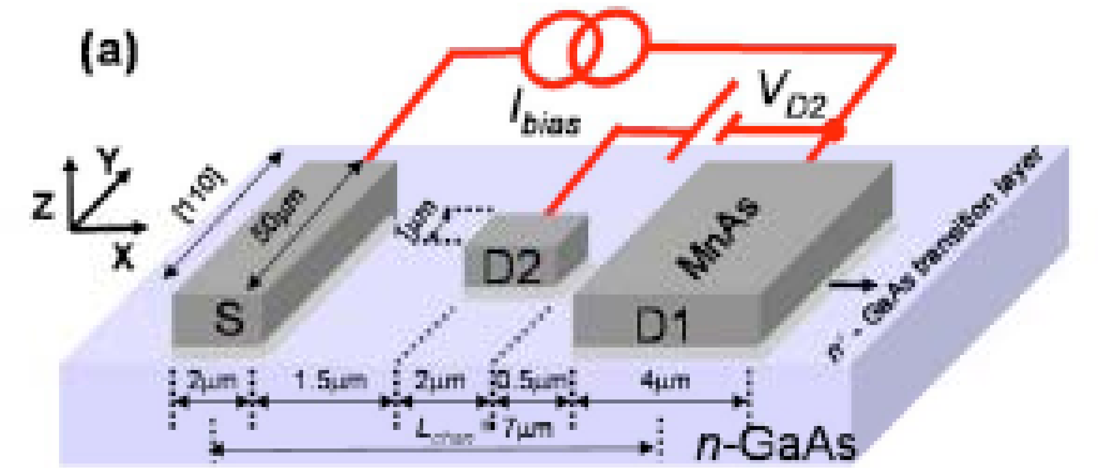
APPLIED PHYSICS LETTERS **91**, 072513 (2007)

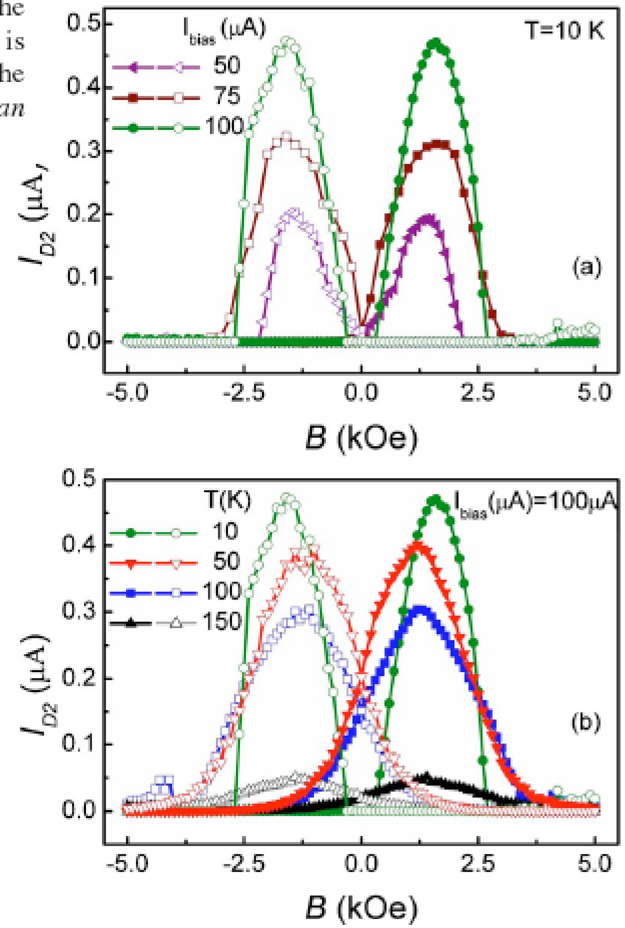
# Amplification of spin-current polarization

D. Saha,[a] M. Holub, and P. Bhattacharya[b]
*Solid-State Electronics Laboratory, Department of Electrical Engineering and Computer Science, University of Michigan, 1301 Beal Avenue, Ann Arbor, Michigan 48109-2122*

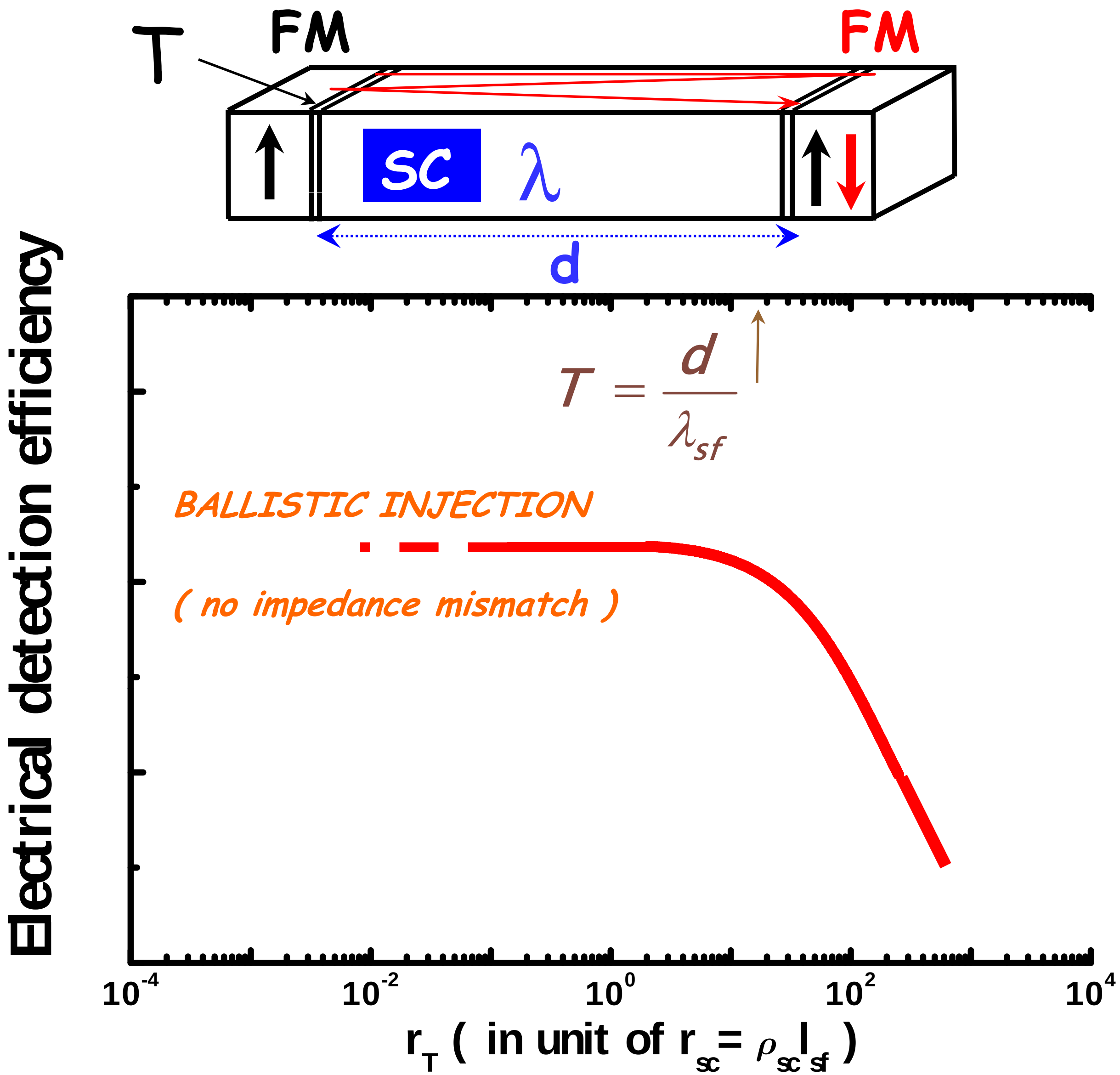
(Received 3 July 2007; accepted 24 July 2007; published online 17 August 2007)

A ferromagnet/semiconductor based electrically controlled spin-current amplifier using a dual-drain nonlocal lateral spin valve is demonstrated. The spin polarization injected by the source into the channel is amplified at the second drain contact. An amplified current spin polarization of 100% is measured. The controlled variation of amplifier gain with bias is also demonstrated. The observations are explained in the framework of the spin drift-diffusion model. © *2007 American Institute of Physics*. [DOI: 10.1063/1.2772660]

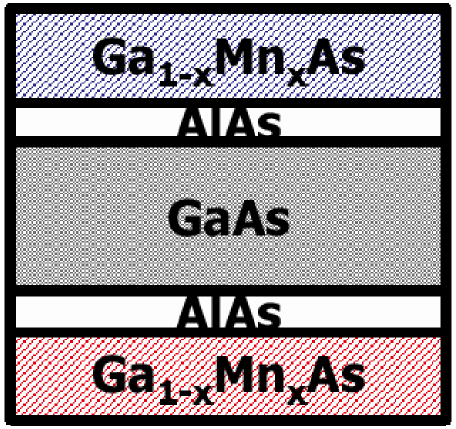


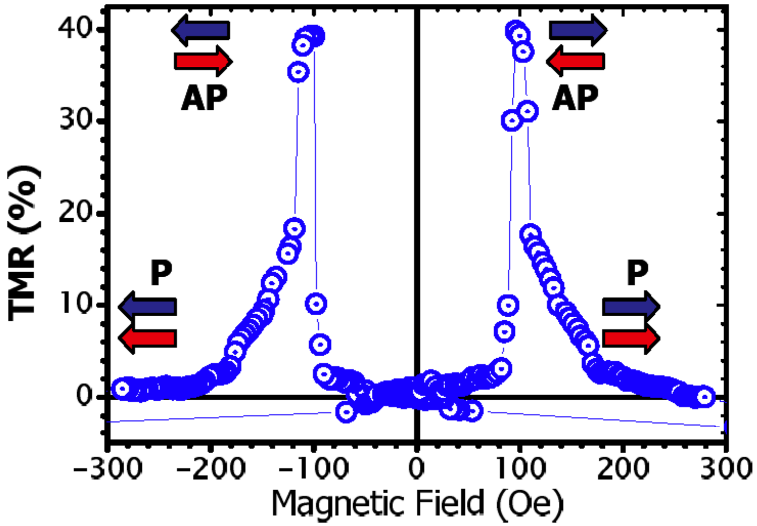



# ELECTRICAL DETECTION Vs. INTERFACIAL TRANSMISSION

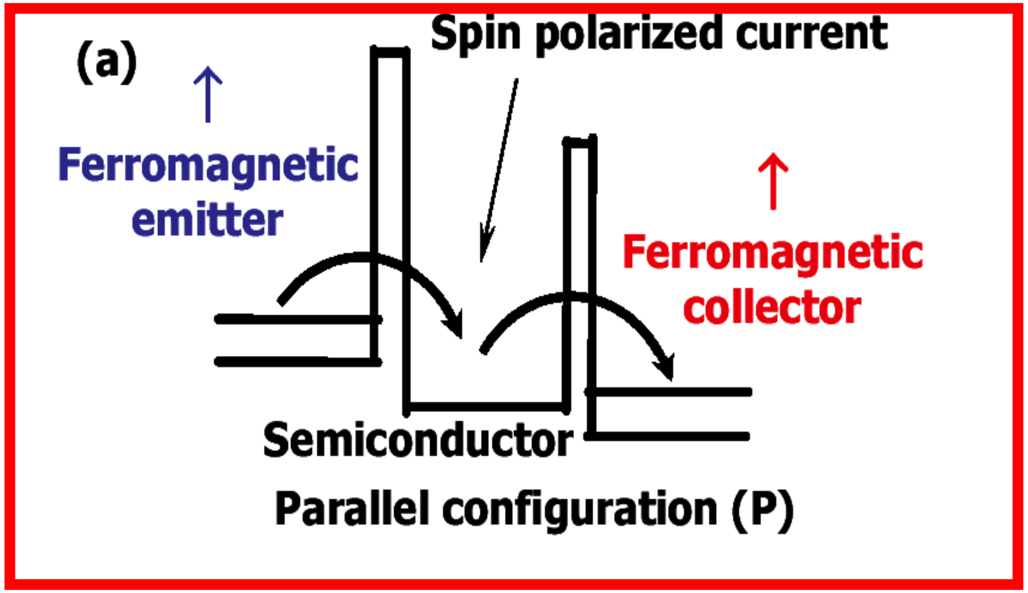


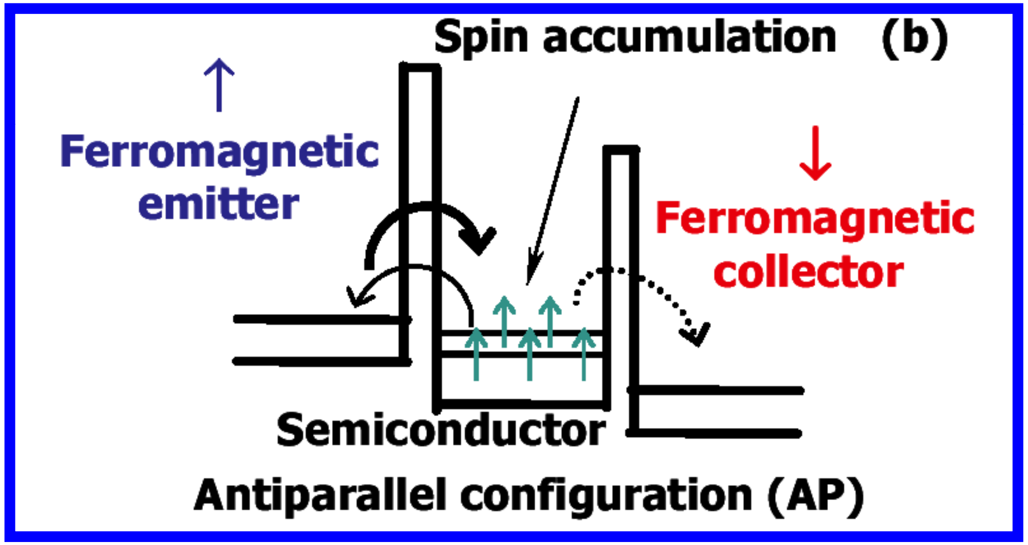
# ELECTRICAL DETECTION OF SPIN INJECTED AND ACCUMULATED IN GaAs QUANTUM WELLS



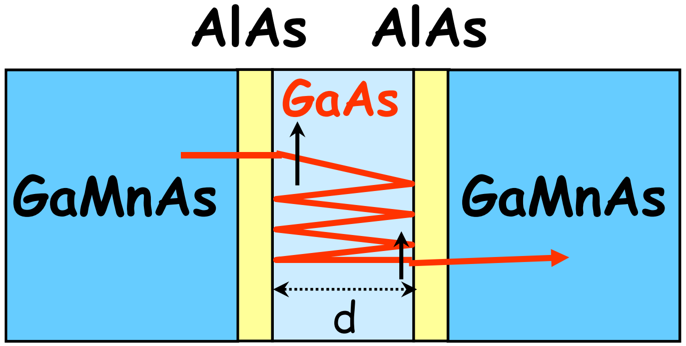




Mattana et al, Phys. Rev. Lett. (2003)



# CONDITIONS FOR NON-RELAXED SPIN ACCUMULATION

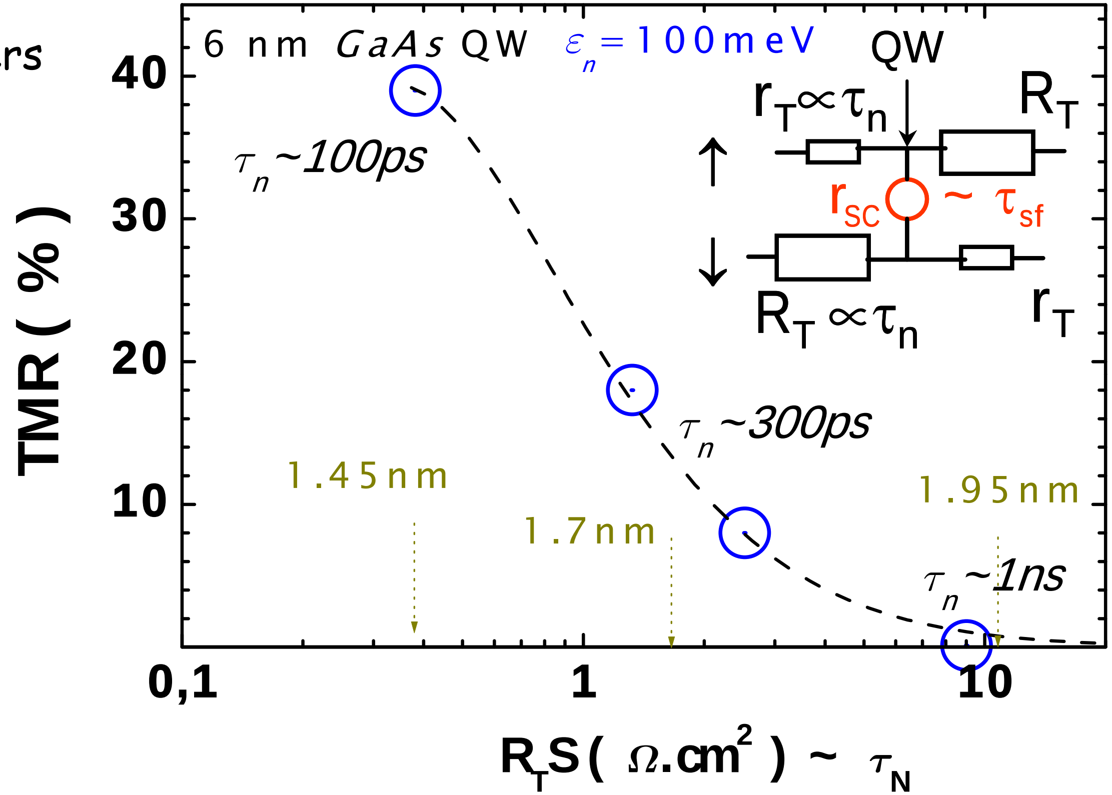



N=1/T reflections against the barriers

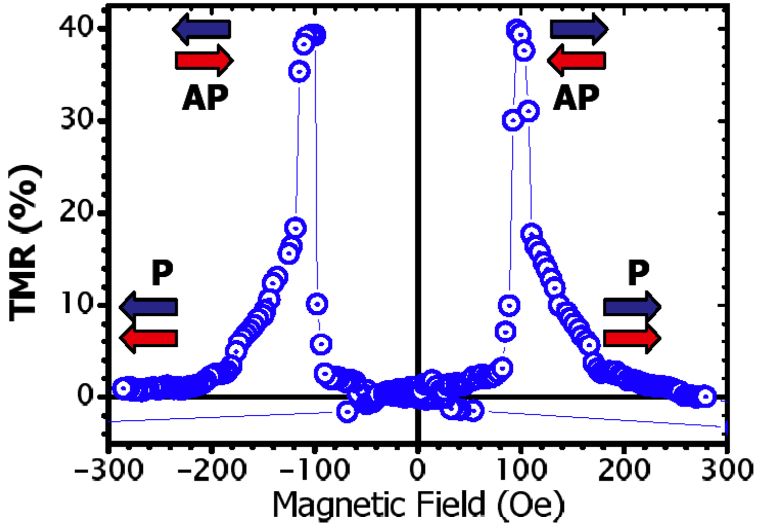
$$MR = \frac{MR_0}{1 + \frac{\tau_n}{\tau_{sf}}}$$

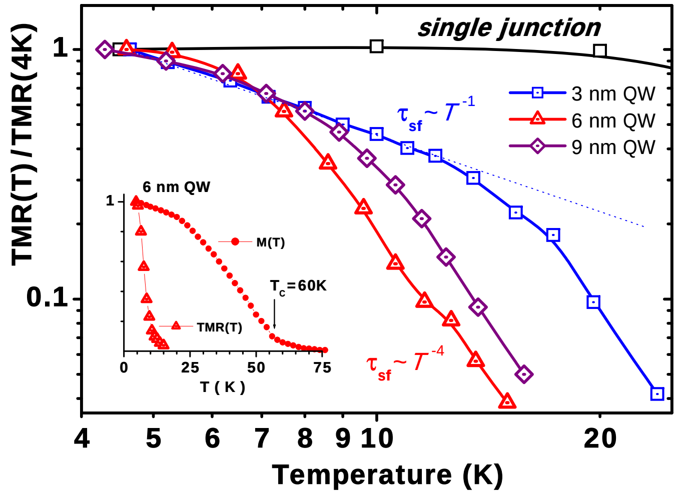
$$\tau_N \sim T^{-1} \sim r_T(\text{barriers})$$

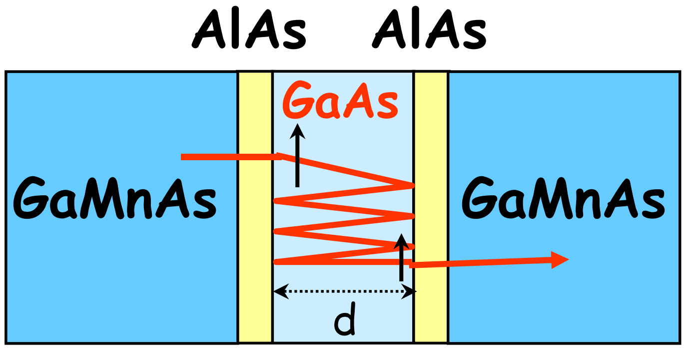
**T** = Transmission coefficient



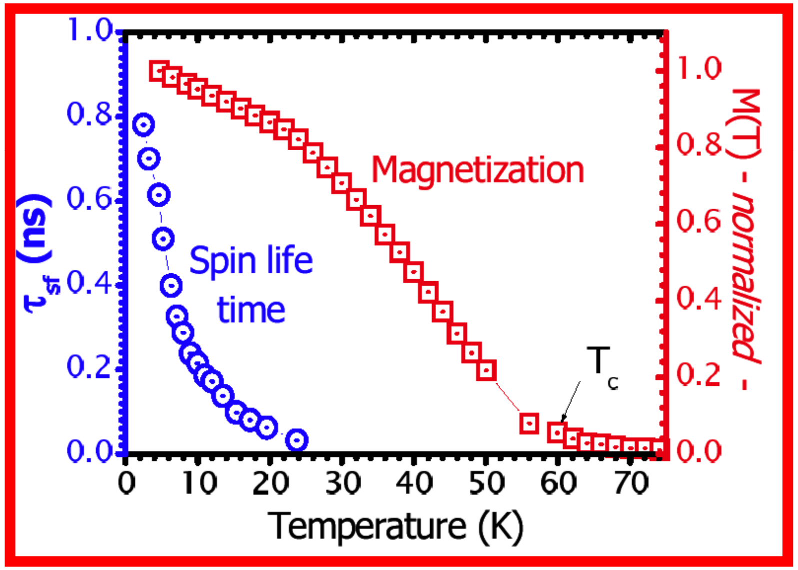
# Conditions for non-relaxed spin accumulation in temperature



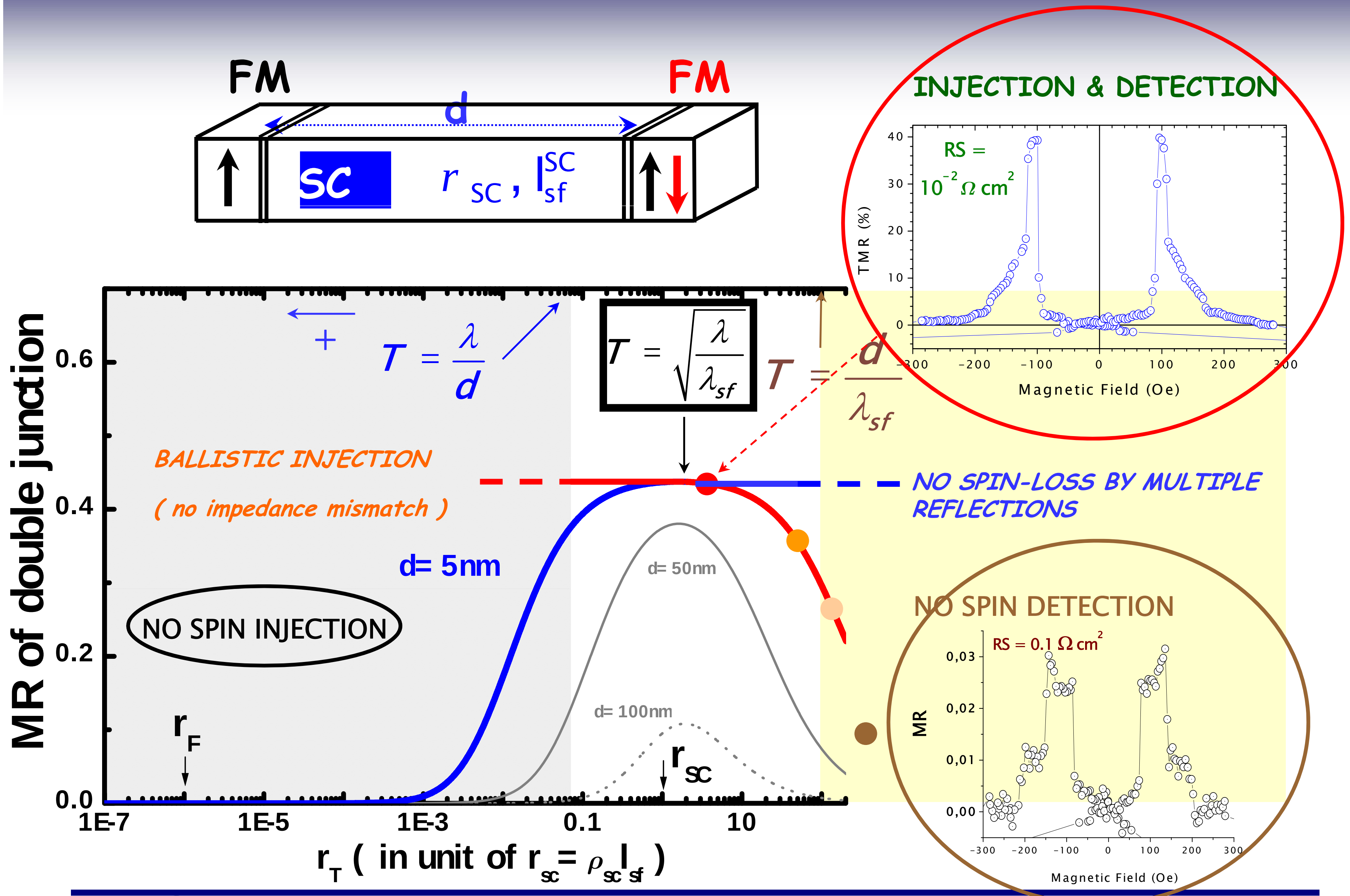




N=1/T reflections against the barriers

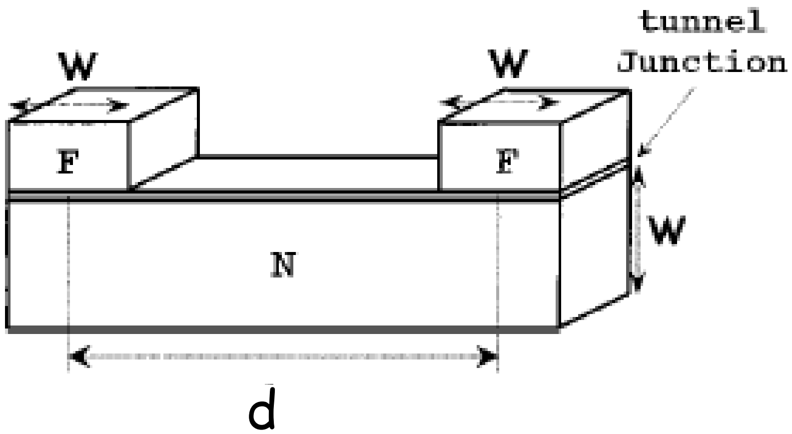


# Resume : MR Vs. INTERFACIAL RESISTANCE ( CPP GEOMETRY )



# GEOMETRICAL EFFECTS

a



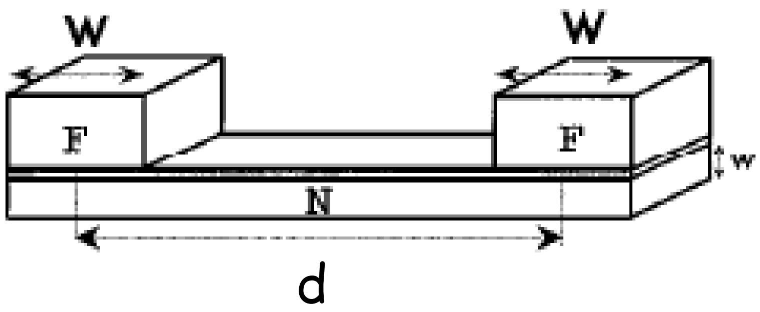

$$T = < \frac{\lambda}{d}$$

$$d < l_{sf} = \sqrt{\lambda \lambda_{sf}}$$

$$T => \frac{d}{\lambda_{sf}}$$

$$T = \sqrt{\frac{\lambda}{\lambda_{sf}}} = \sqrt{\frac{\tau}{\tau_{sf}}}$$

b



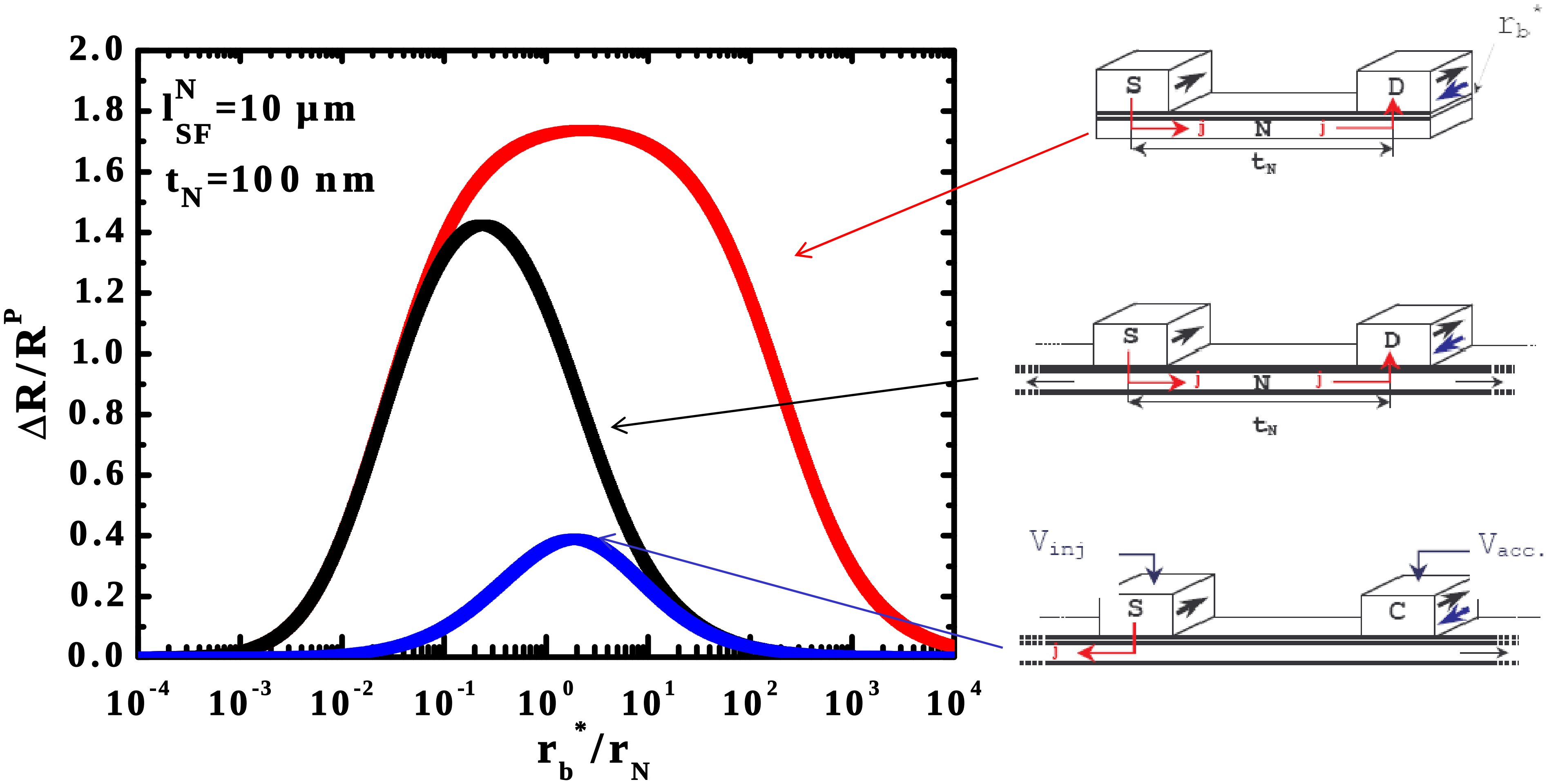

$$T = < \frac{\lambda}{d} \frac{\omega}{W}$$

$$d < l_{sf} = \sqrt{\lambda \lambda_{sf}}$$

$$T => \frac{d}{\lambda_{sf}} \frac{\omega}{W}$$

$$T = \frac{\omega}{W} \sqrt{\frac{\tau}{\tau_{sf}}}$$

# MAGNETORESISTANCE WITHIN SC CHANNELS : FROM LOCAL TO NON LOCAL MEASUREMENTS

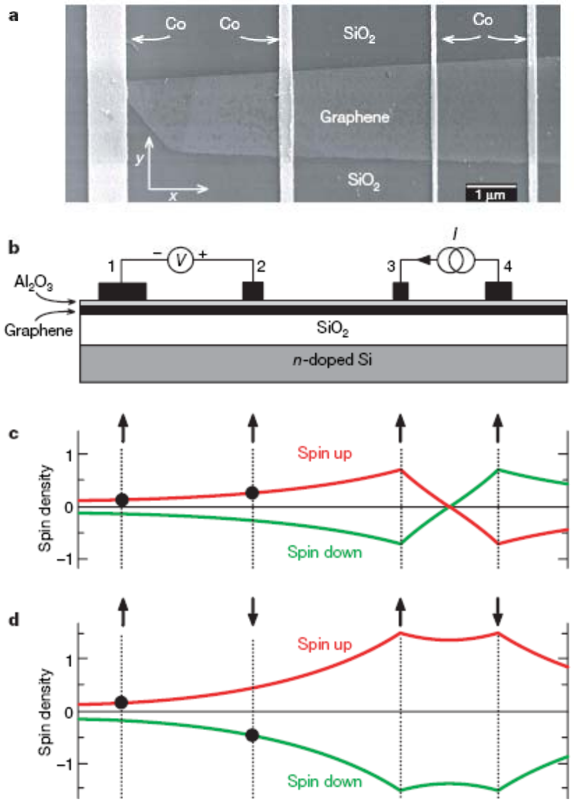


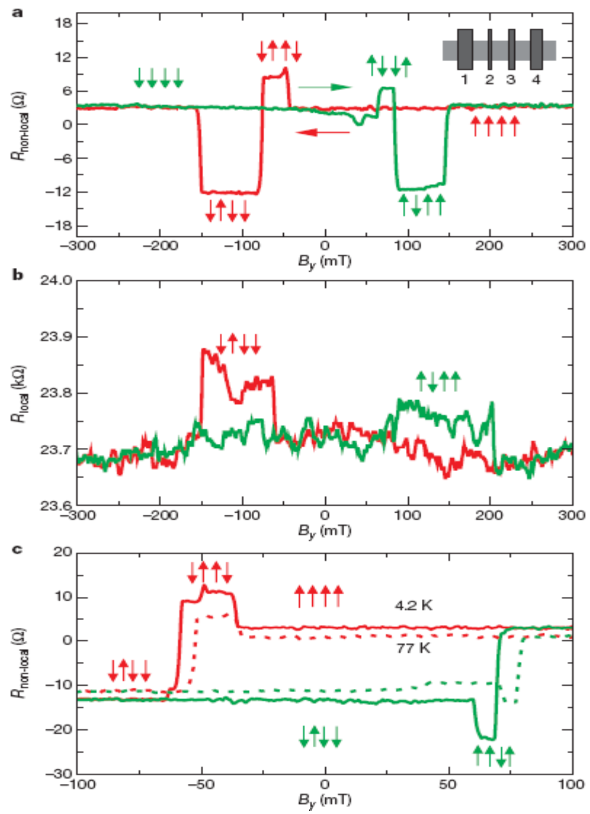
doi:10.1038/nature06037 nature

LETTERS

# Electronic spin transport and spin precession in single graphene layers at room temperature

Nikolaos Tombros[1], Csaba Jozsa[1], Mihaita Popinciuc[2], Harry T. Jonkman[2] & Bart J. van Wees[1]



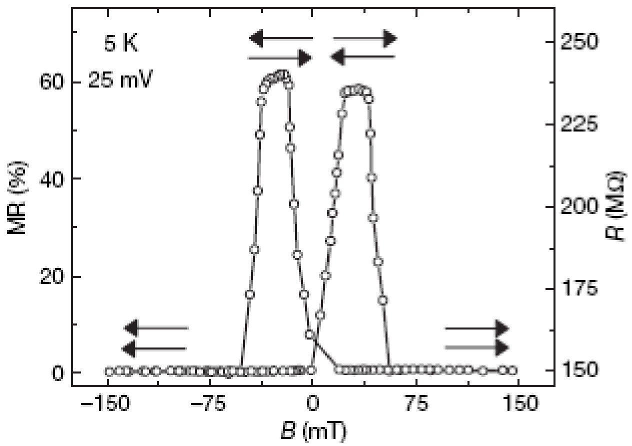



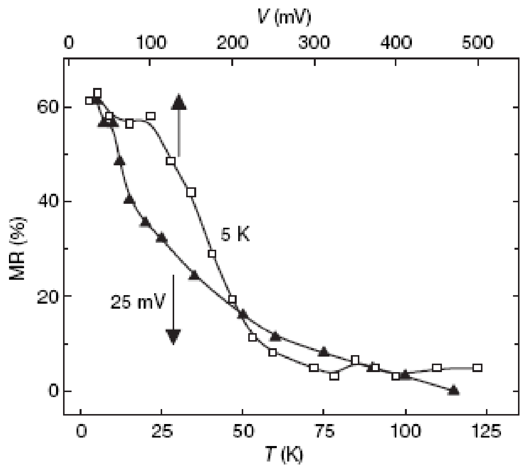
nature
Vol 445 | 25 January 2007 | doi:10.1038/nature05507

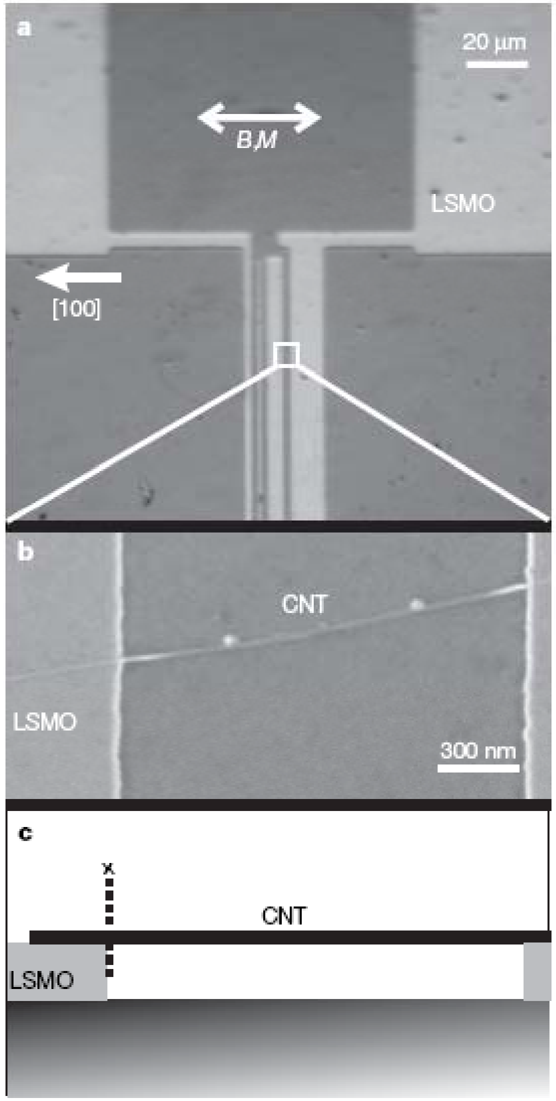
# LETTERS

## Transformation of spin information into large electrical signals using carbon nanotubes

Luis E. Hueso[1]†, José M. Pruneda[2,3]†, Valeria Ferrari[4]†, Gavin Burnell[1]†, José P. Valdés-Herrera[1,5], Benjamin D. Simons[4], Peter B. Littlewood[4], Emilio Artacho[2], Albert Fert[6] & Neil D. Mathur[1]



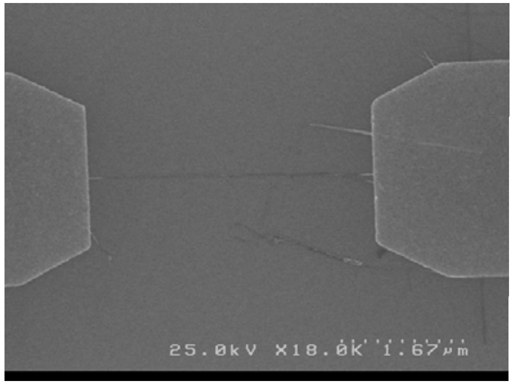



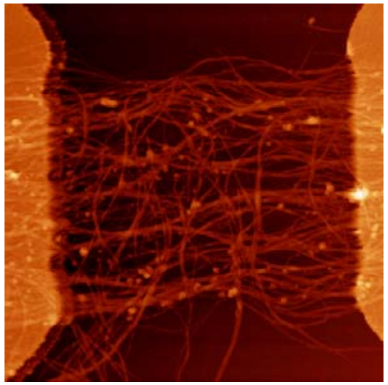

Condition for spin electrical conversion

$$\tau_{sf} > \frac{d}{v_Z . T_r}$$

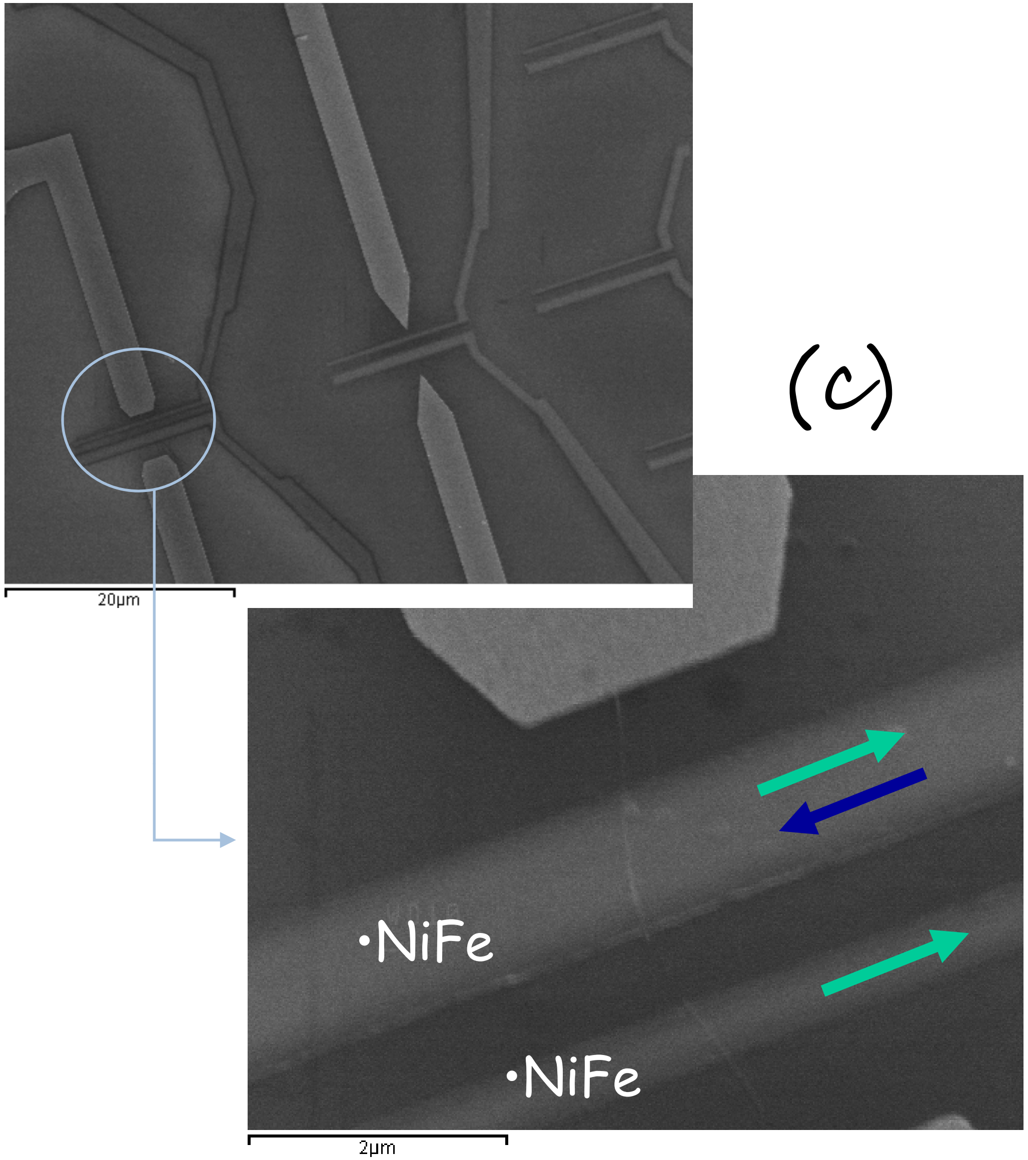
# Carbon Nanotubes (coll. CEA-SPEC V. Derrick)




(a)



(b)




(c)

# CONCLUSIONS :

Good conductivity matching in metallic multilayers :
**Giant Magnetoresistance**

Non-Local detection of spin accumulation :
small resistance leads to **low signal**

Problem of Impedance matching for FM//SC//FM semiconducting nanostructures :

-Window for interfacial transmission to obtain TMR

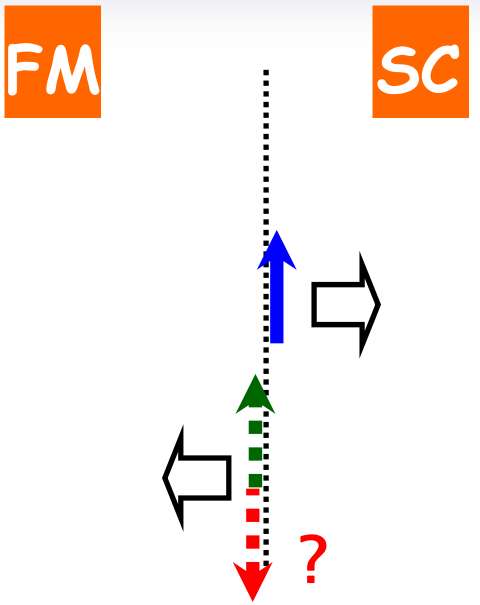
- Non Local geometry for **spin detection but unsuitable** for electrical conversion of spin accumulation

Spintronics using **Graphene and Carbon Nanotubes** :

-Higher Fermi velocity helps for spin conservation

-Higher spin lifetime due to smaller spin-orbit coupling

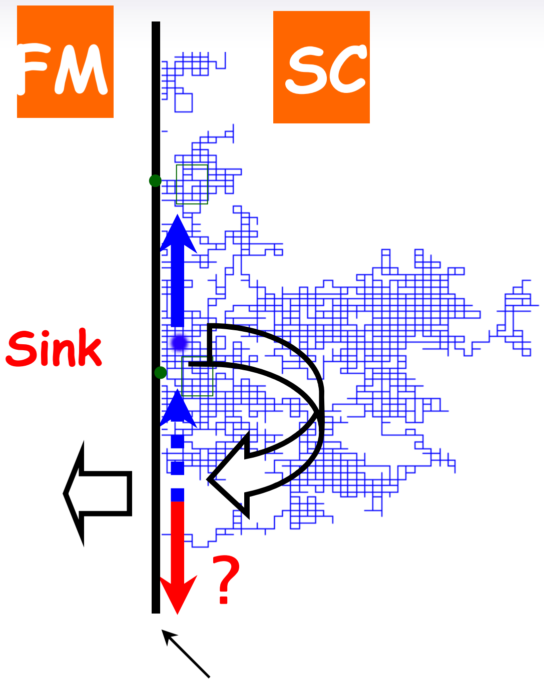
# SPIN INJECTION : MICROSCOPIC MODEL OF DIFFUSION




current polarization ?

NO

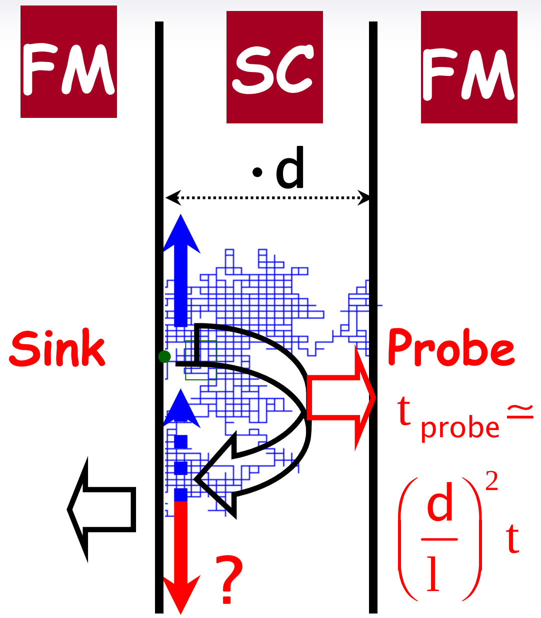
YES




$$N_{attemps} \simeq \sqrt{t_{sf}/t}$$

Current polarization :

$$T < \sqrt{\tau / \tau_{sf}} = \sqrt{\lambda / \lambda_{sf}}$$




$$t_{probe} \simeq \left(\frac{d}{l}\right)^2 t$$

$$N_{attemps} \simeq d/l$$

Current polarization :

$$T < \lambda / d$$