Magnetization reversal in Co/Cu/Co pillars by spin injection

G. Faini
LPN-CNRS Marcoussis, France

J. Grollier, V. Cros, H. Jaffrès, A. Hamzic, J.M. George, A. Fert
UMR CNRS/THALES Orsay, France

J. Ben Youssef, H. Legall
LMB Brest, France

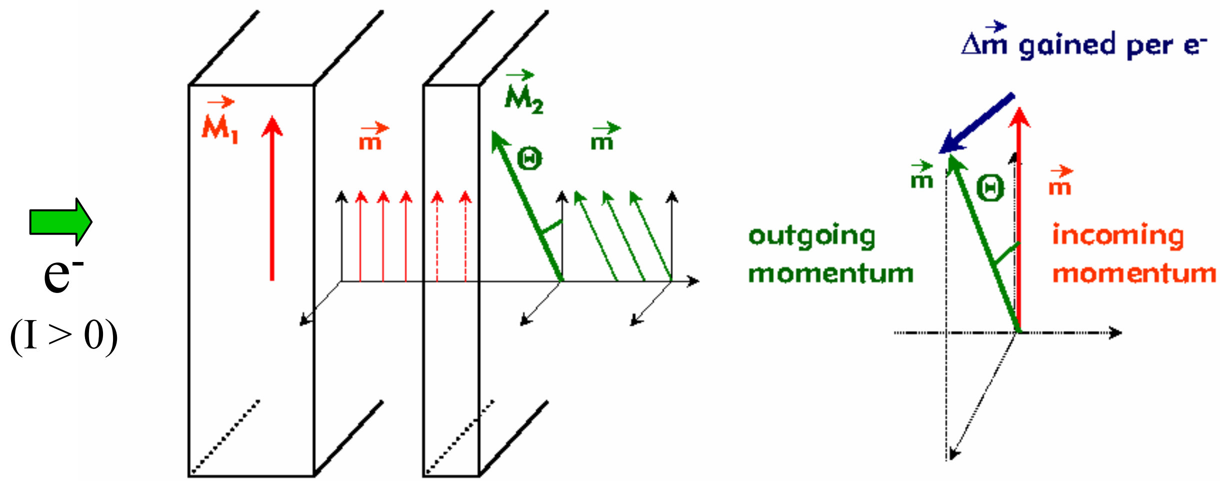
I Experiments on current-driven magnetization reversal

Test of models : field dependence

II Spin transfer in current-induced domain wall drag

Spin transfer models

J.C. Slonczewski, JMMM 159 (1996)



relaxation of TRANSVERSE polarization

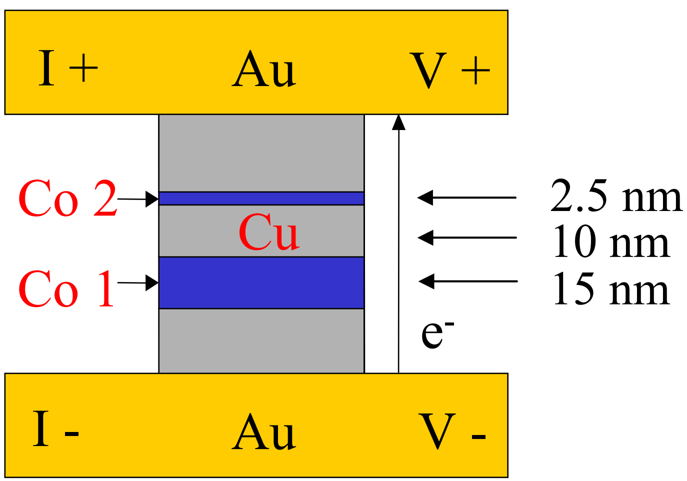
$$\left(\frac{d\vec{m}}{dt}\right)_{layer}^{injection} = -P_I \frac{I}{e} \Delta\vec{m}_{\perp}$$

Conclusions : **current density ≈ 10^7 A.cm^{-2}**
torque : odd function of current

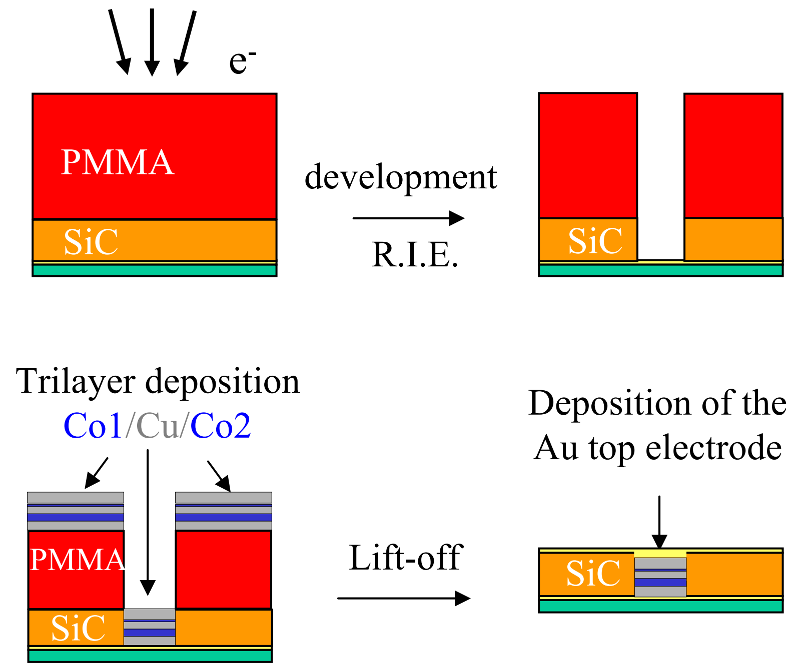
Sample fabrication

Trilayer Co/Cu/Co (dot size section : 200 x 600 nm^2)

Co 2 — Thin ferromagnetic layer : current sensitive



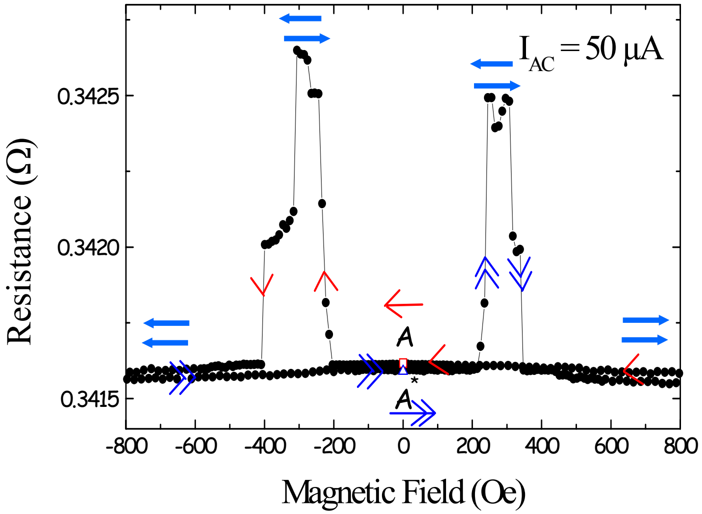
Co 1 — Thick ferromagnetic layer : current polarizer

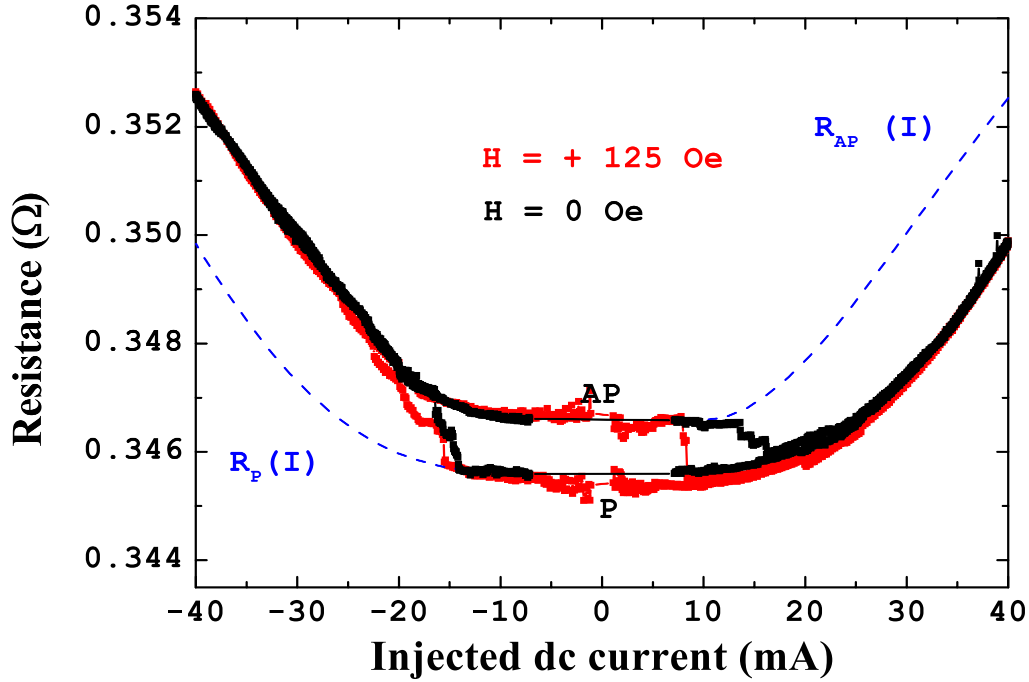


Measurements at high DC current with Happ < Han

T = 30 K

GMR = sensor





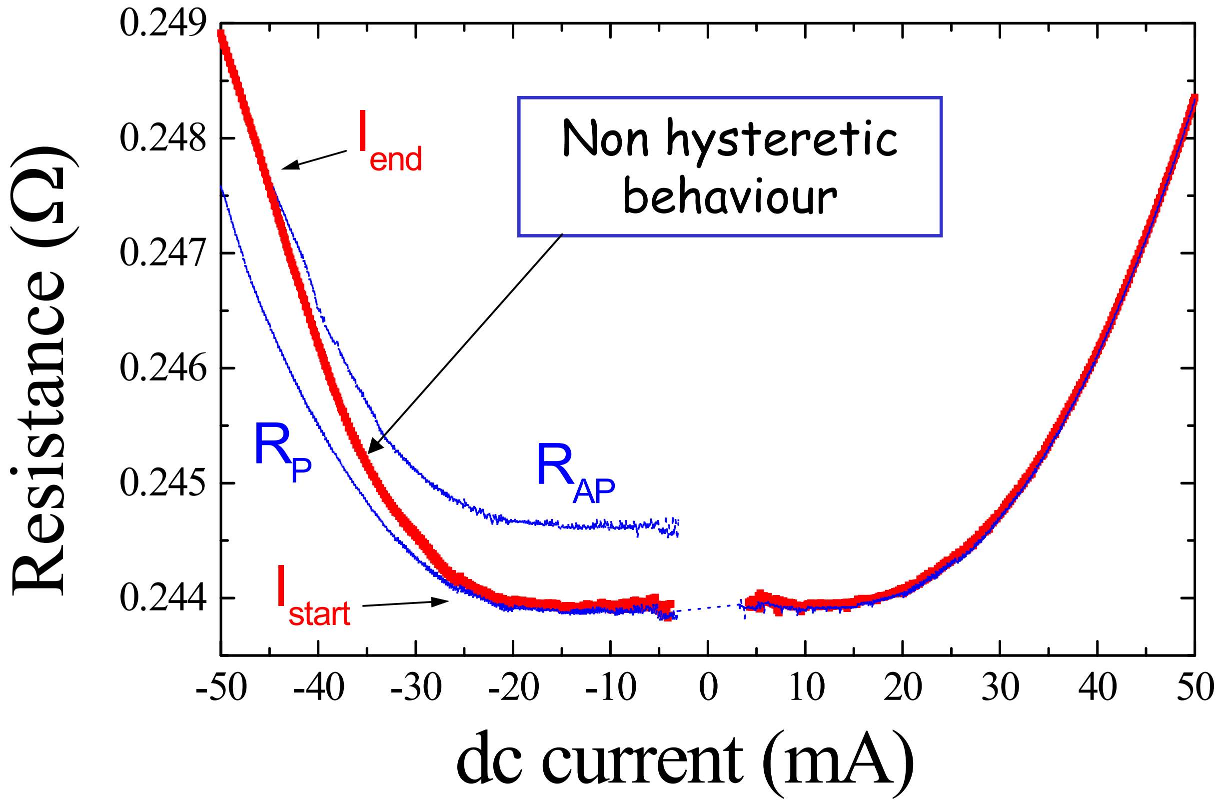
$|J_c| \approx 10^7$ **A/cm²**

A small magnetic field favors the P configuration

$\Rightarrow |J_c^{P\text{->}AP}|$ increases and $|J_c^{AP\text{->}P}|$ decreases

Measurements at high DC current with Happ > Han

T = 30 K Co (150A)/Cu(100A)/Co(25A) dot size : 200 x 600 nm²



H_{app} = 500 Oe

Calculation of the torque : LLG equation

$$\frac{d\vec{m}}{dt} = -\gamma_0\, \vec{m} \times [H_{eff}\vec{u}_x - H_d(\vec{m}.\vec{u}_z)\vec{u}_z] + \alpha\, \vec{m} \times \frac{d\vec{m}}{dt} - \Im\, \vec{m} \times (\vec{m} \times \vec{u}_x)$$

$$\Im = P_m \frac{g\mu_B}{etM_S} j$$

General case : coupled equations

m close to P and AP : uncoupled ⟶ $m_y, m_z = Ae^{x_1 t} + Be^{x_2 t}$

Ex : for a P to AP reversal

❶ Instability of P state

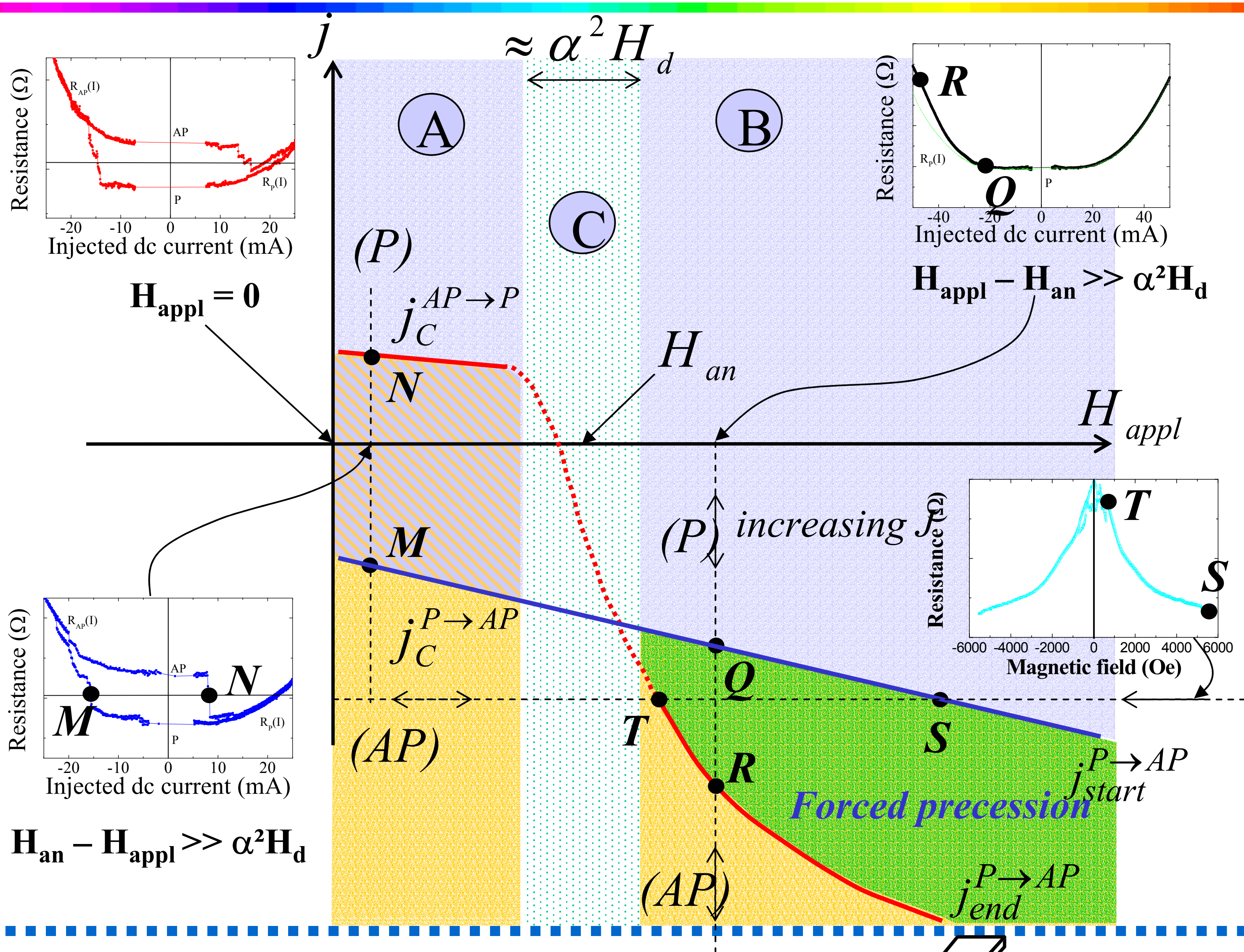
❷ Stability of AP state

⟷ sign of the real part of x_1 and x_2

holds for precessional and non precessional modes

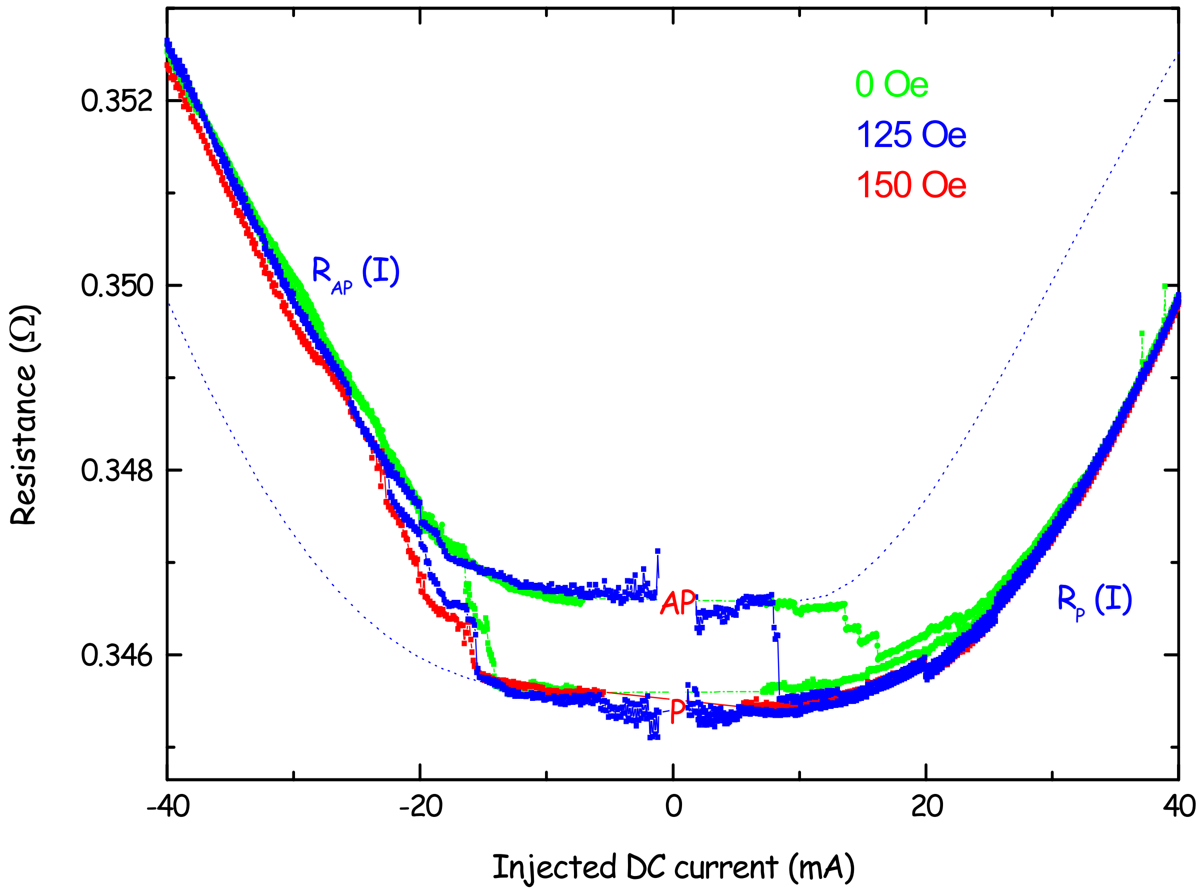
(Katine *et al* : discussion of stability limited to the field range of periodic precession)

Summary

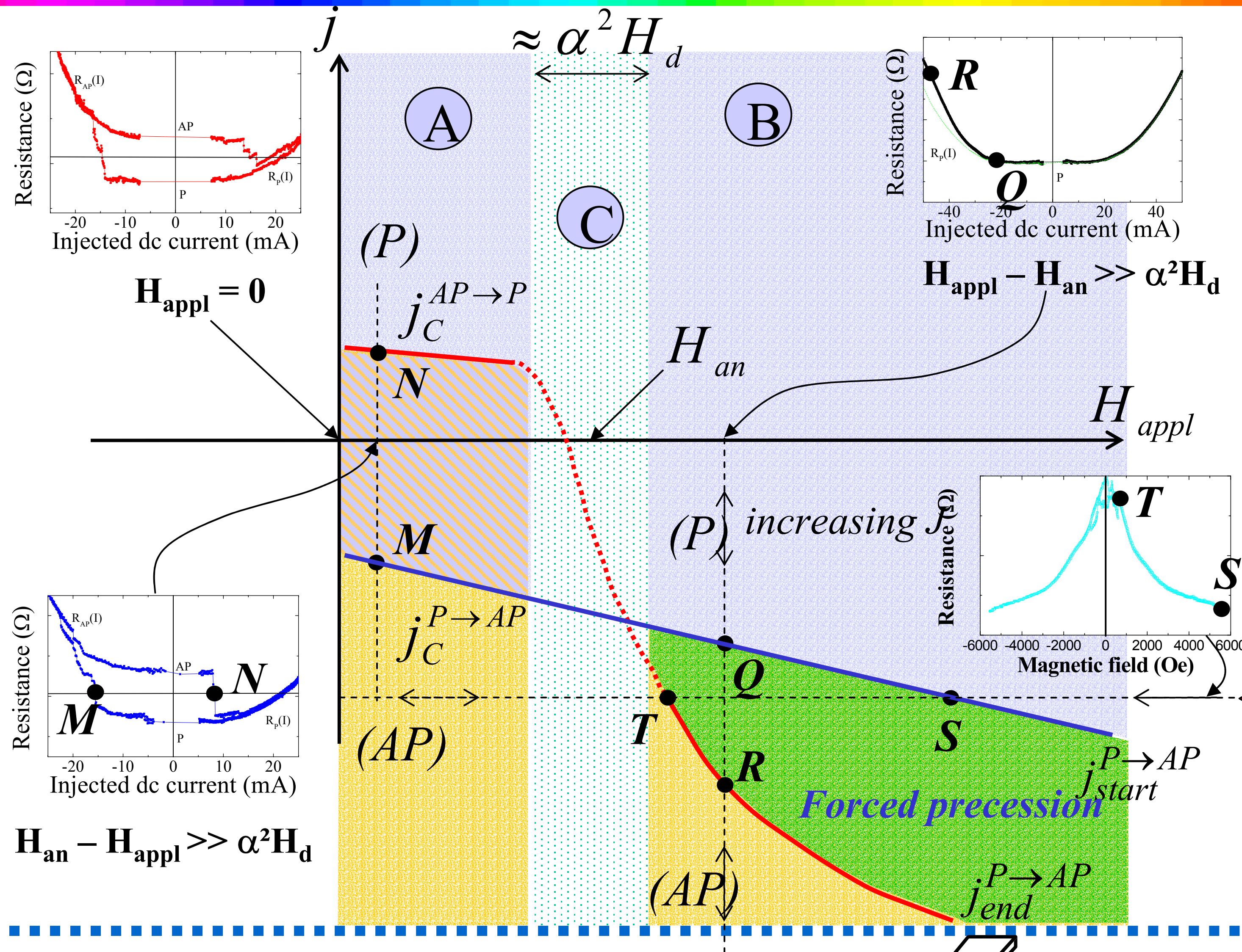


j
≈ α²H_d
A
B
C
(P)
H_appl = 0
j_C^{AP→P}
N
H_an
H_appl
M
(P)
increasing J
j_C^{P→AP}
(AP)
Q
T
S
R
j_start^{P→AP}
Forced precession
(AP)
j_end^{P→AP}
H_appl – H_an >> α²H_d
H_an – H_appl >> α²H_d
Resistance (Ω)
Injected dc current (mA)
R_AP(I)
R_P(I)
AP
P
-20
-10
0
10
20
-40
40
Resistance (Ω)
Magnetic field (Oe)
-6000
-4000
-2000
0
2000
4000
6000

Transition between the two regimes : Happ ≈ Han

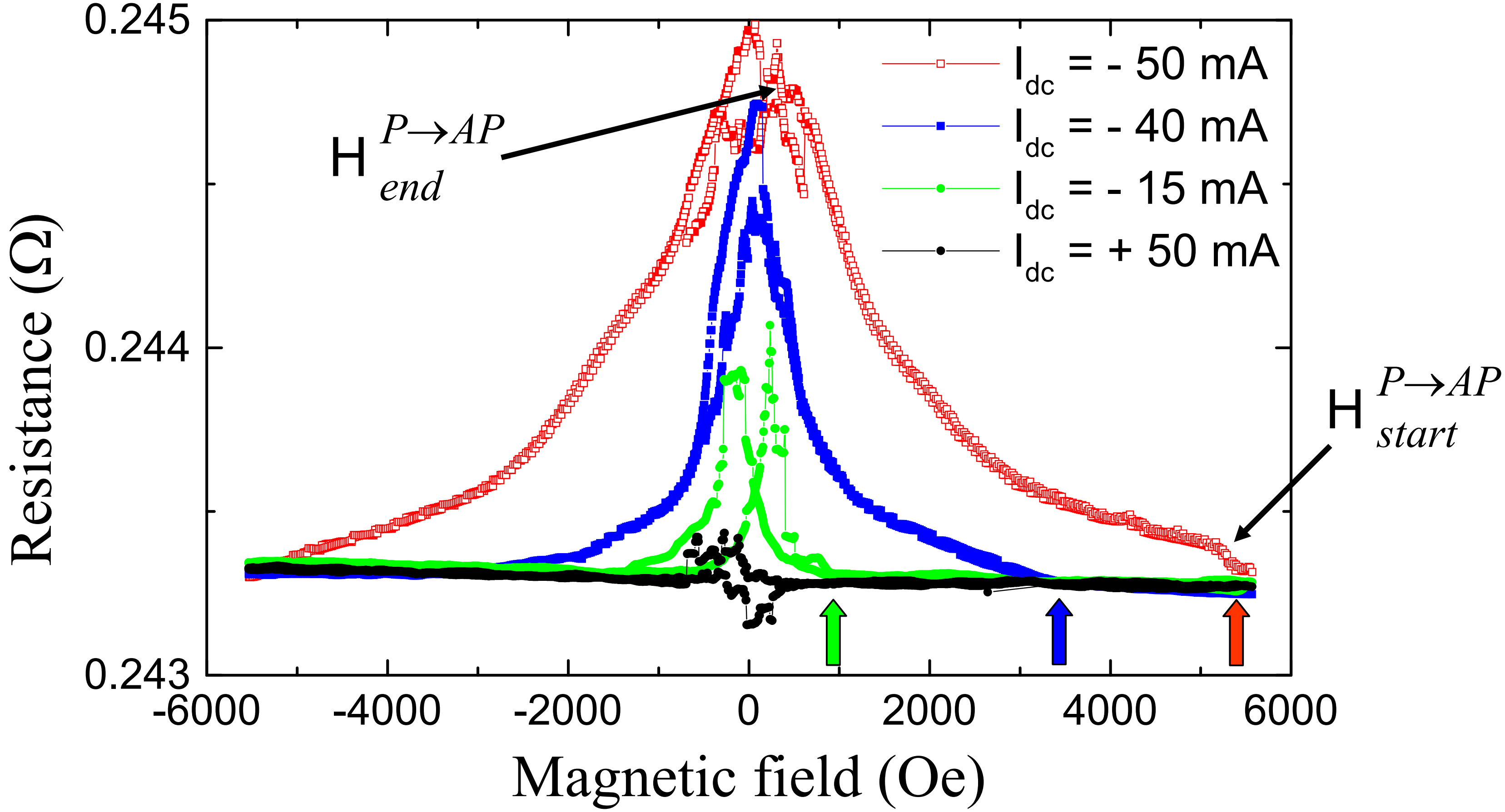


R(H) at fixed high I_{inj}



Measurements at high DC current : R(H)

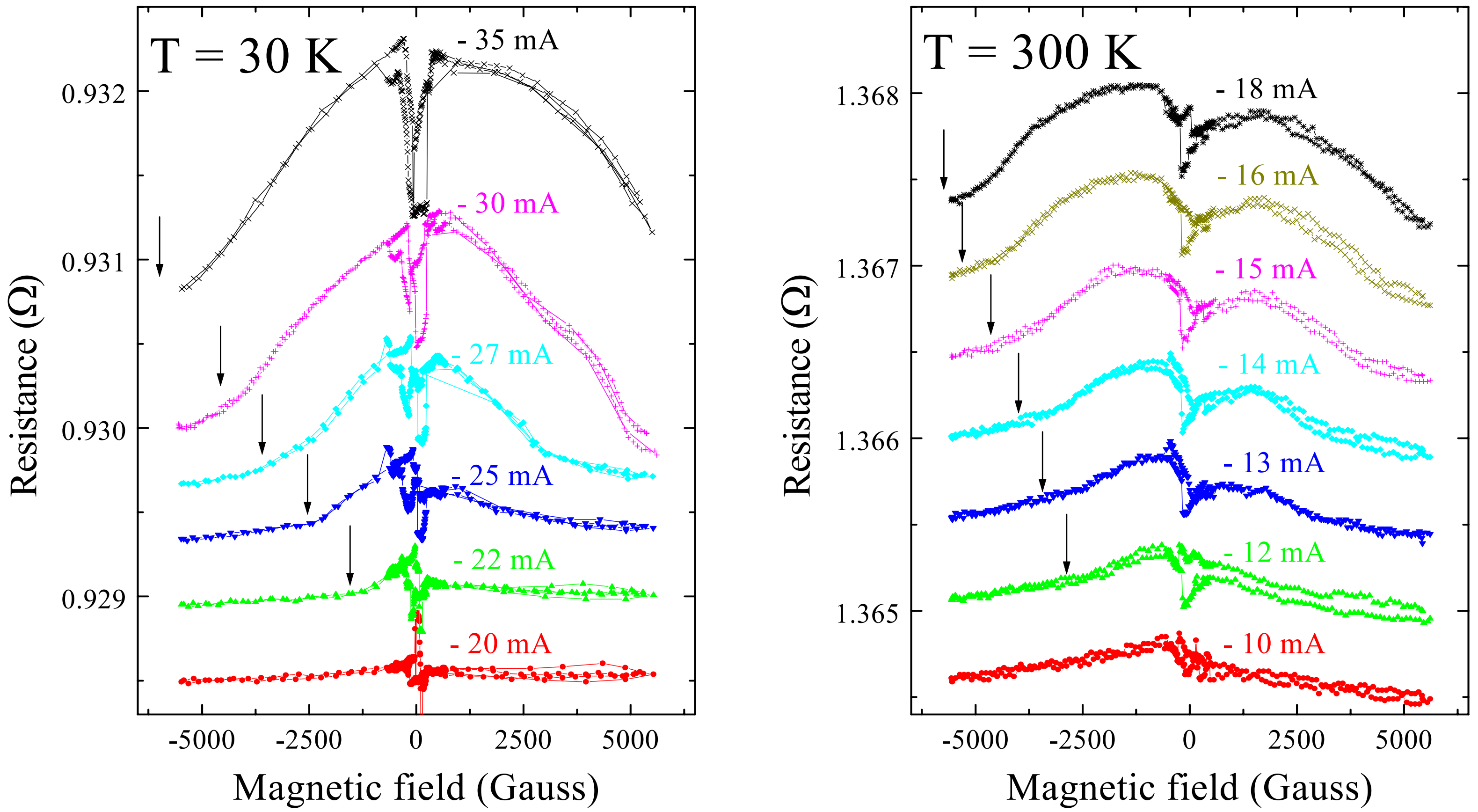
T = 30 K Co (150A)/Cu(100A)/Co(25A) dot size : 200 x 600 nm²



J. Grollier et al., ***Appl. Phys. Lett. 78, 3663 (2001)***

Field dependence of the critical current : exp.

Example for other samples :
200 x 400 nm² Co(300A)/Cu(100A)/Co(50A) pillar



Field dependence of the critical current density

- Spin transfer model (cf. Slonczewski)

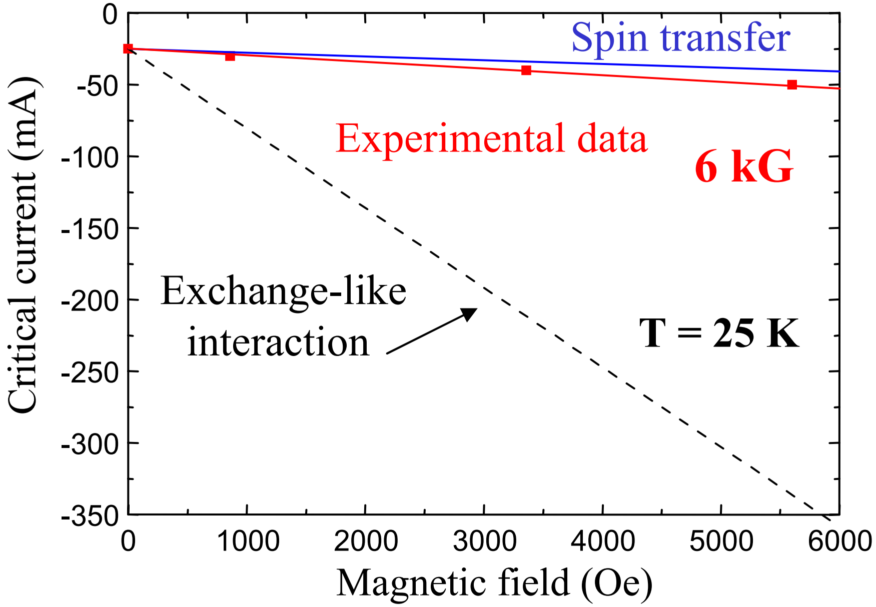
$$j_C^P = j_C^P(H = 0) \times \left[1 + \frac{H_{app}}{H_{an} + H_d / 2} \right]$$

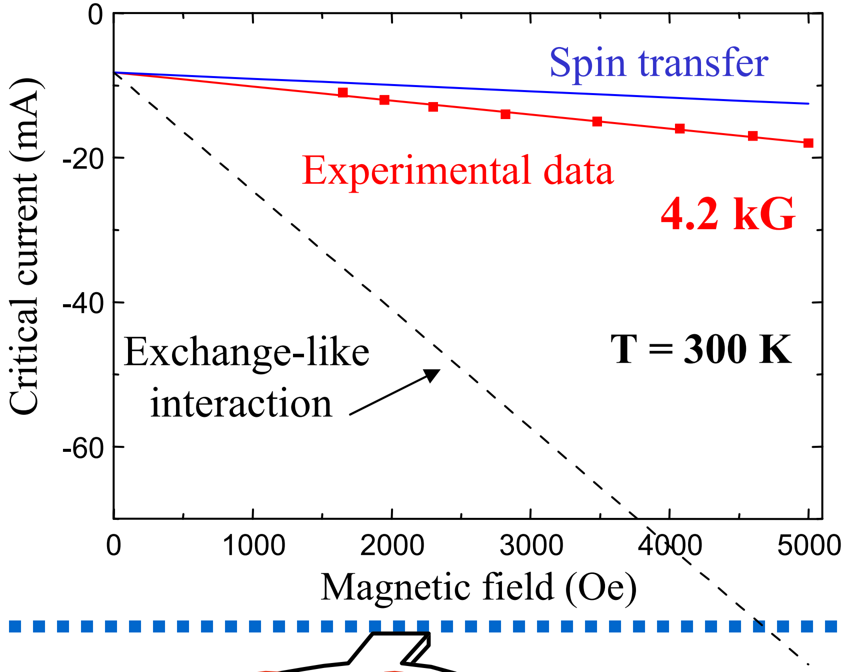
8.5 kG

- Interaction picture (cf. Heide)

$$j_C^P = j_C^P(H = 0) \times \left[1 + \frac{H_{app}}{H_C} \right]$$

0.4 kG





CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

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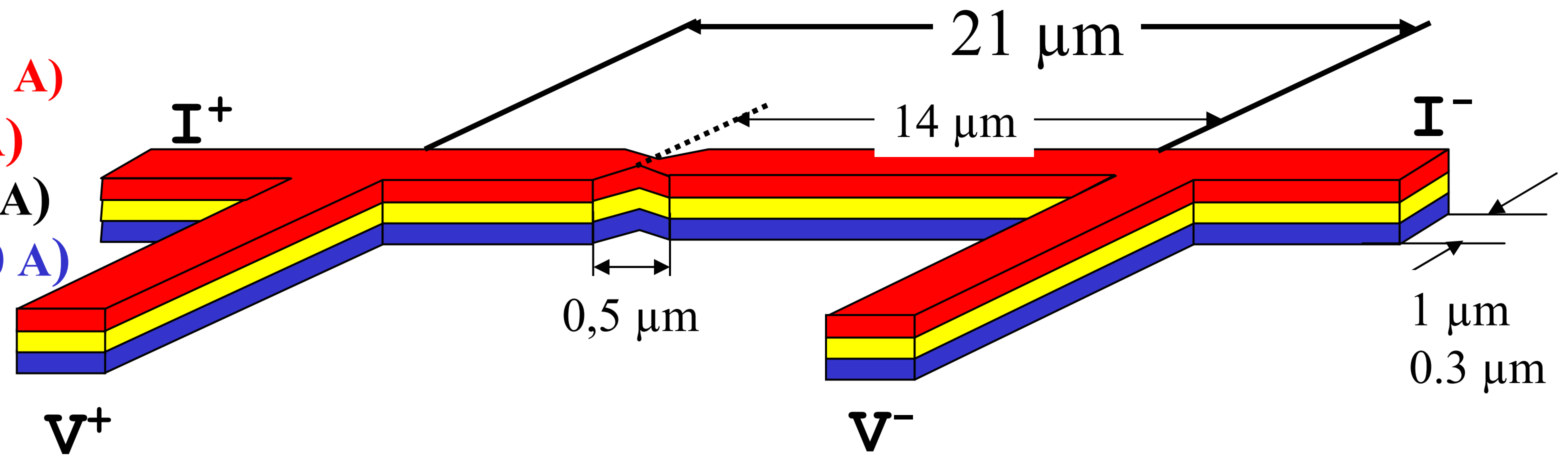
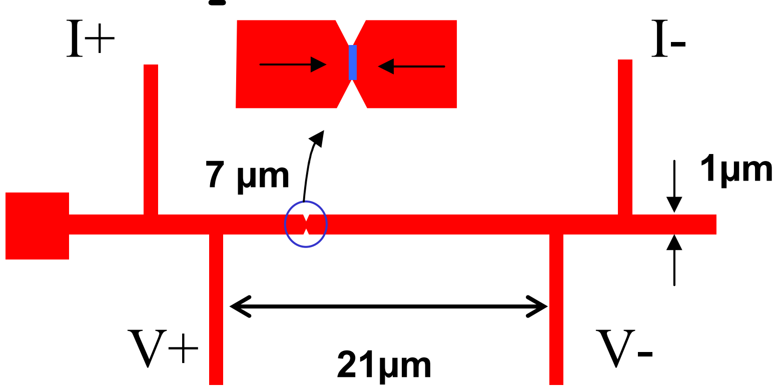
Switching a spin valve by current-induced DW drag

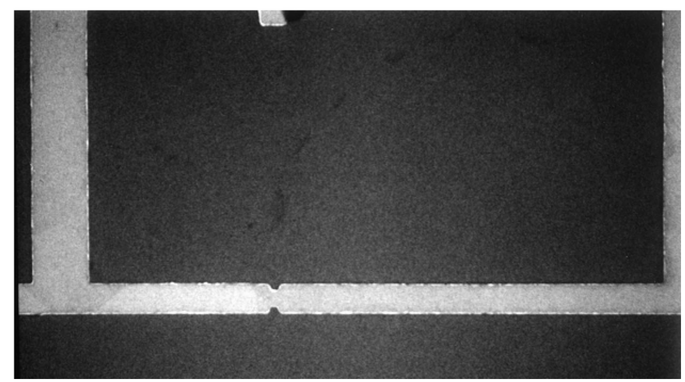
CoO (30 A)
Co (70 A)
Cu (100 A)
NiFe (70 A)



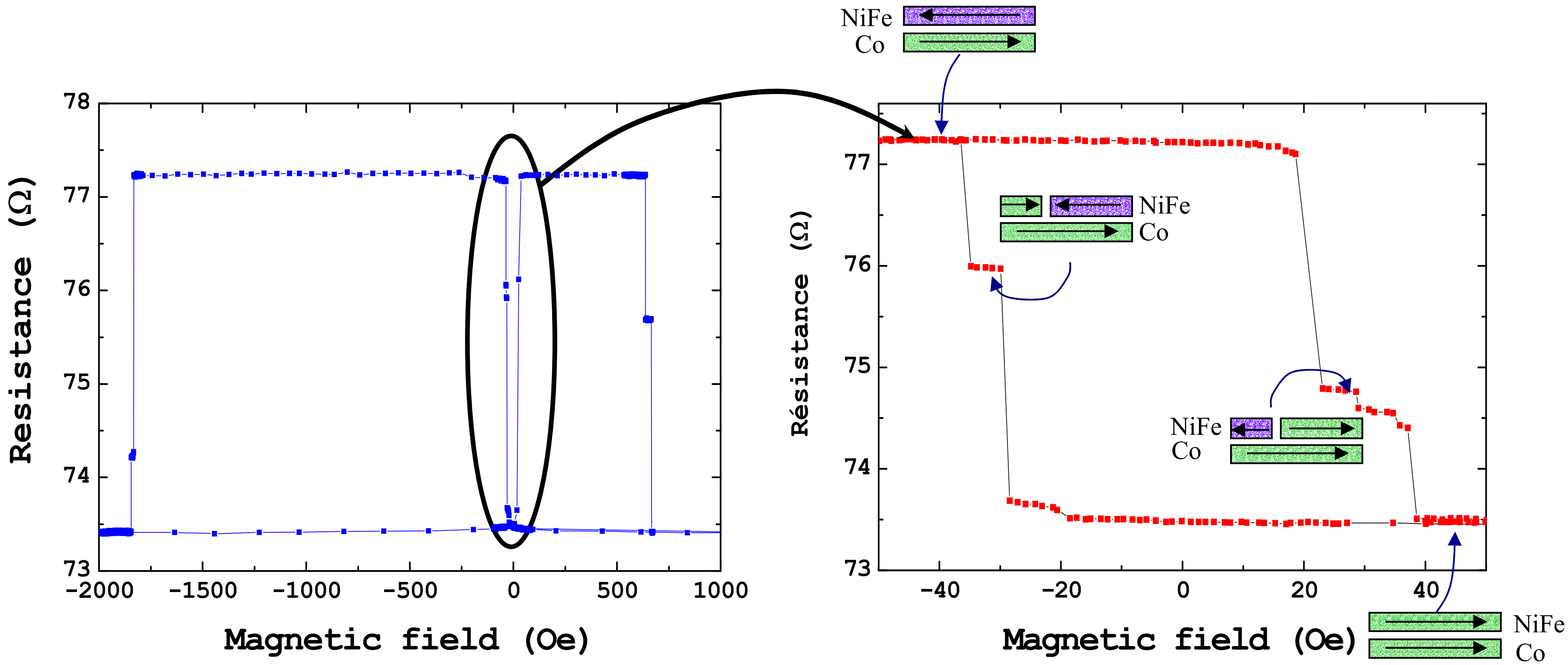
Top view :



S.E.M.image :



GMR at low temperature



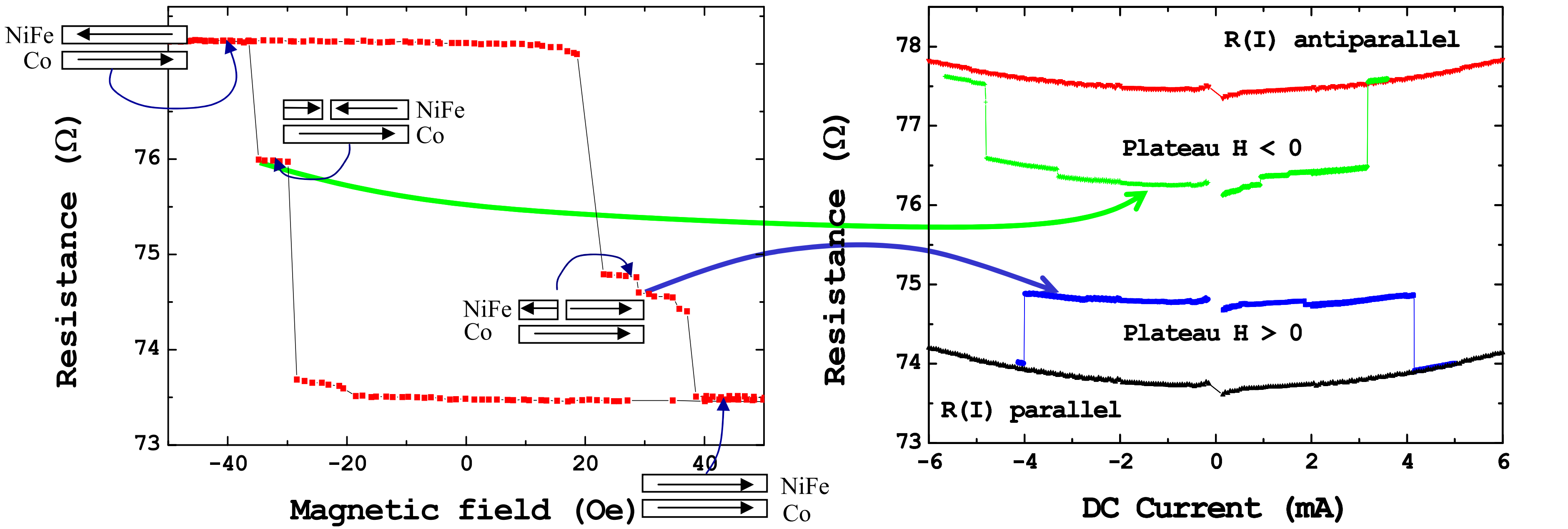
I = 5 µA and T = 3 K

GMR ≈ 5 %

Stripe width = 1µm

Domain wall motion induced by a high dc current

Stripe width = 1μm

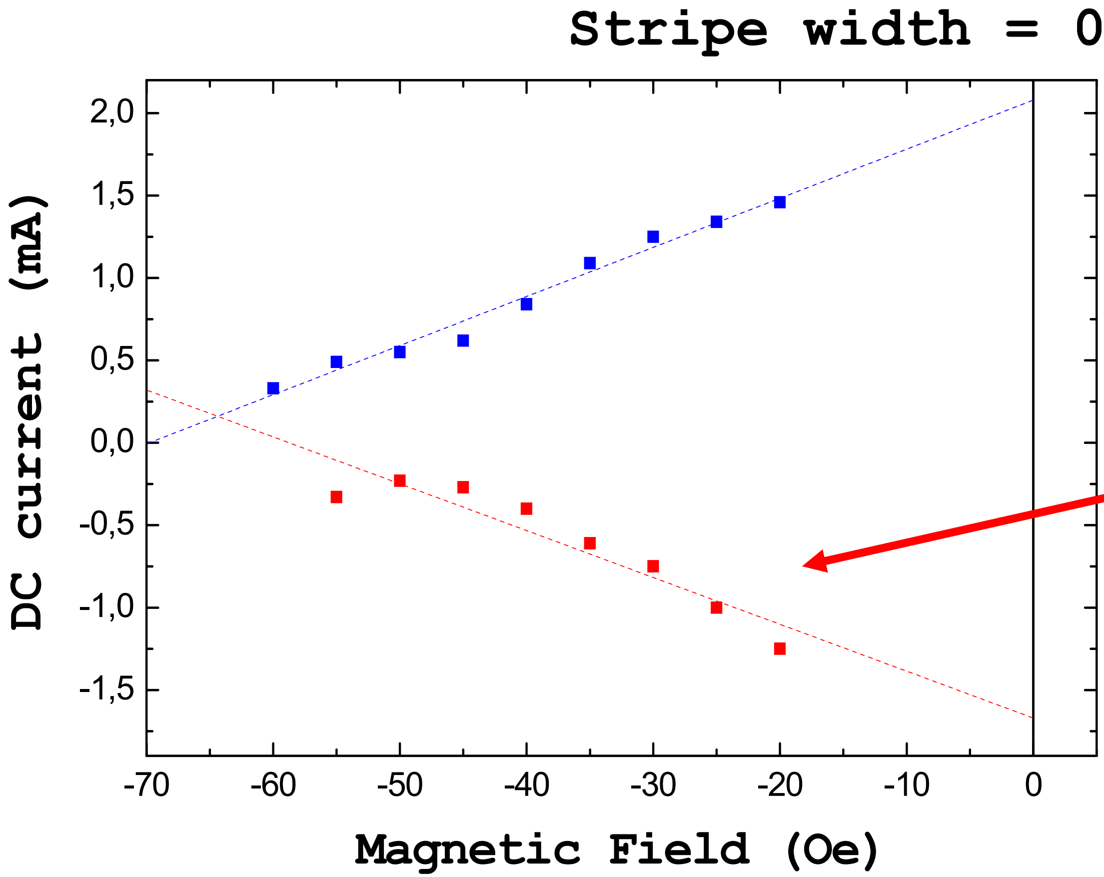


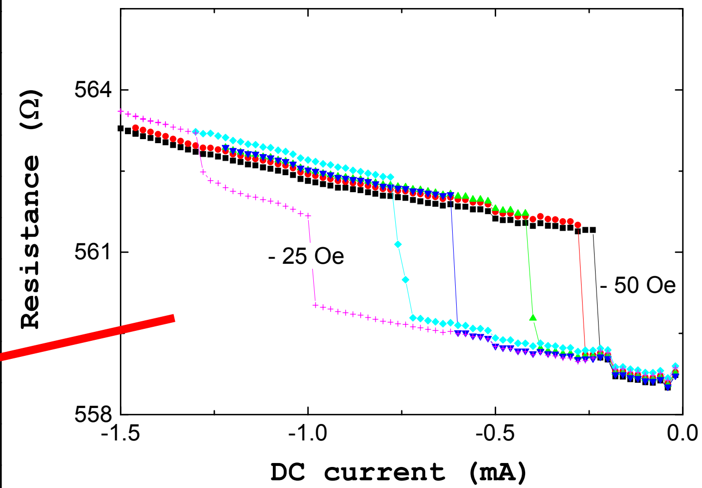
➢ motion in the same direction whatever the current direction

Critical current density ≈ 2.6 10^7 A/cm²

J. Grollier et al., Appl. Phys. Lett. 92, 4825 (2002)

Field dependence of the critical current





Critical current density :

≈ 2.10^7 A/cm² for H_{appl} = - 60 Oe

≈ 2.10^8 A/cm² for H_{appl} = 0 Oe

Origins of the effect ?

3) Spin tranfer

pros : critical current densities in agreement with spin transfer models

cons : the effect is independent of the current sign

2) Oersted field

pros : locally, $H_{longitudinal}$ reaches about 30 Oe

cons : the longitudinal component is in average zero in the sample

DW distortion and destabilization by one of these mechanisms ?

1) Heating ?

Conclusions and perspectives

• Reversal of magnetization by spin injection in pillar-shaped Co/Cu/Co tri-layers

• Spin transfer vs. interaction model (field dependence)

• Spin transfer : qualitative agreement with experiments

• Decrease the critical currents : interface resistances, spin diffusion length, sample section ...

• Study of spin transfer effect on other structures: case of the DW motion induced by a DC current

• Dynamics ?

• Promising applications (commutation of spin electronic devices)