Single magnetic clusters embedded in matrix

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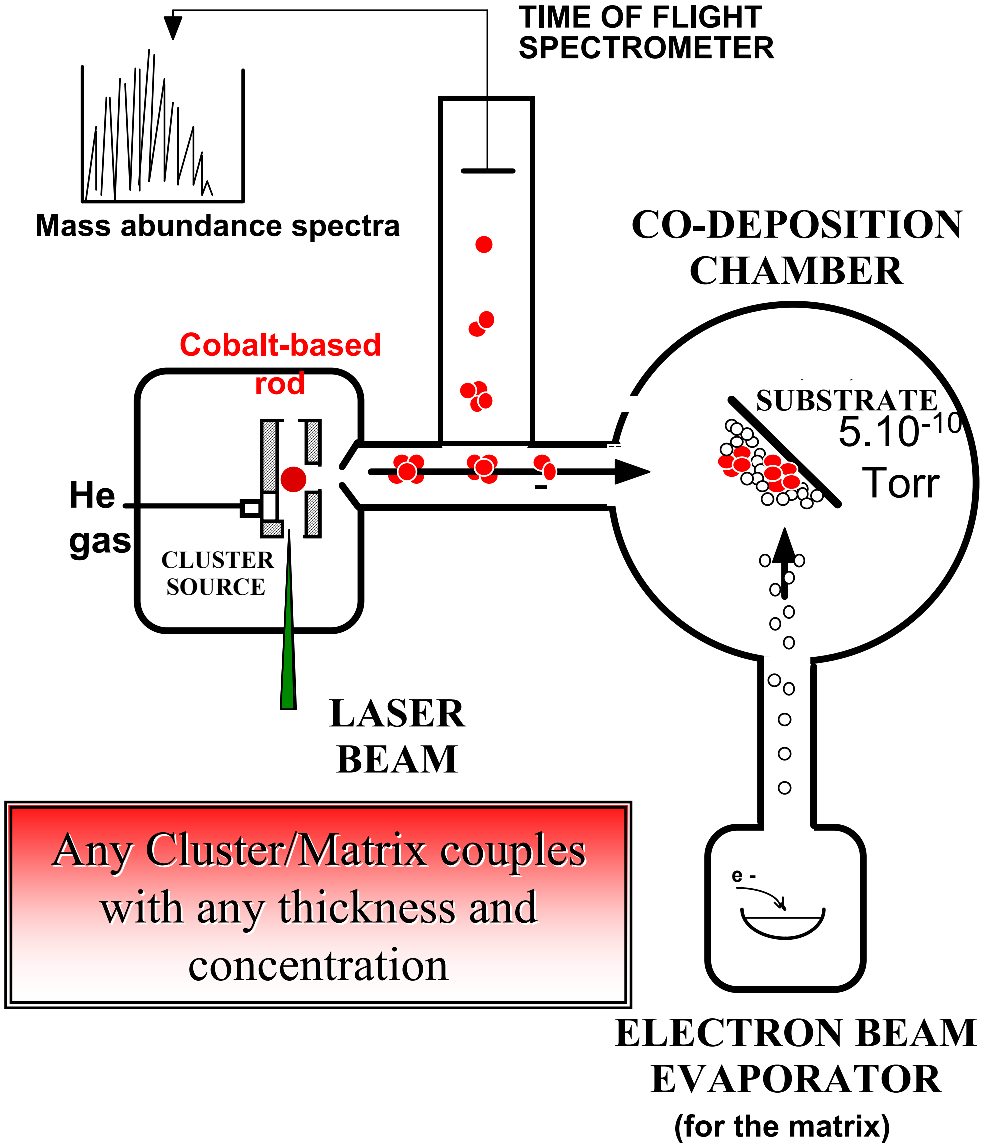
- **Synthesis, Structure and Superparamagnetism on Assembled clusters films**

- **Measurements one single nanoparticle**

co-deposition of clusters

Low Energy Clusters Beam Deposition

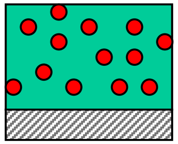


Any Cluster/Matrix couples with any thickness and concentration

D_1 **Thick samples** :

Assembled clusters films

500 nm matrix + < 5% cluster concentration



D_2 **Thin samples** :

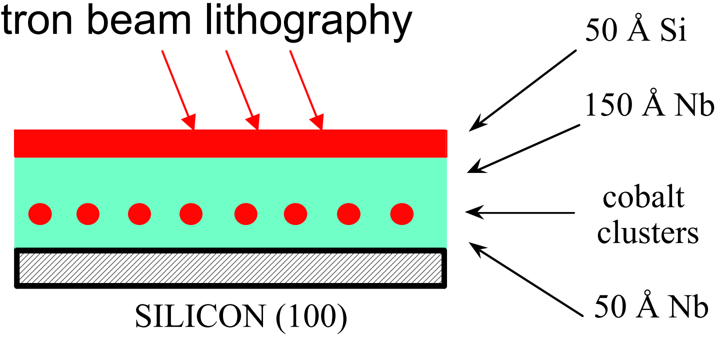
One single particle

ex : MicroSQUID :

20 nm Nb + < 0.1% cluster conc.

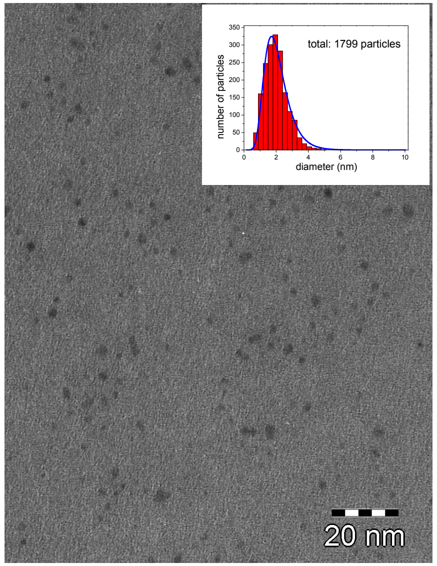
(< 5 clusters/micro-bridge)

Electron beam lithography



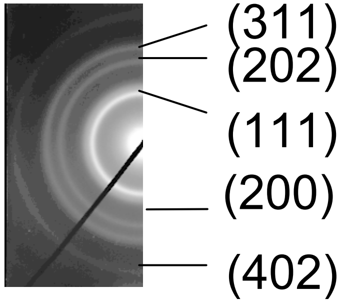
M. Jamet, V. Dupuis et al. PRB (2000)

TEM observations on mixed CoPt clusters

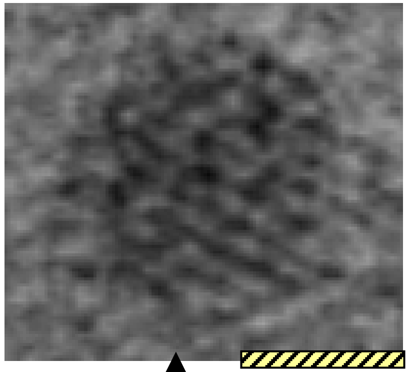


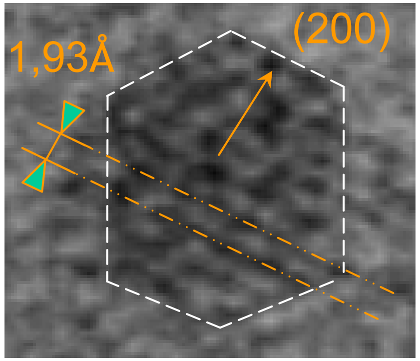
Log-normal size distribution

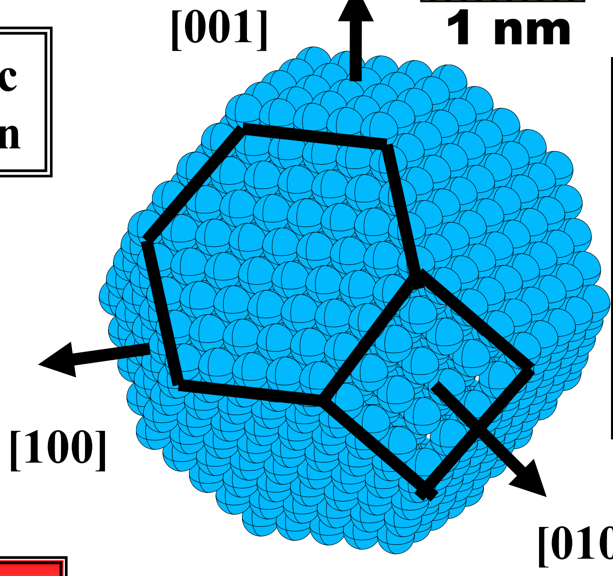
$$f(D) = \frac{1}{D\sqrt{2\pi\sigma^2}} \exp\left(-\ln^2\left(\frac{D}{D_m}\right) . \frac{1}{2\sigma^2} \right)$$

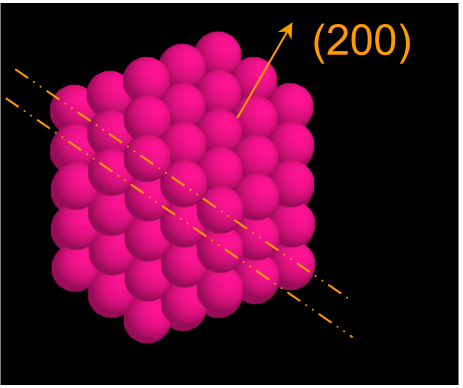


Electronic diffraction









Isolated cluster along [110]

Truncated octoahedron with (100) and (111) faces

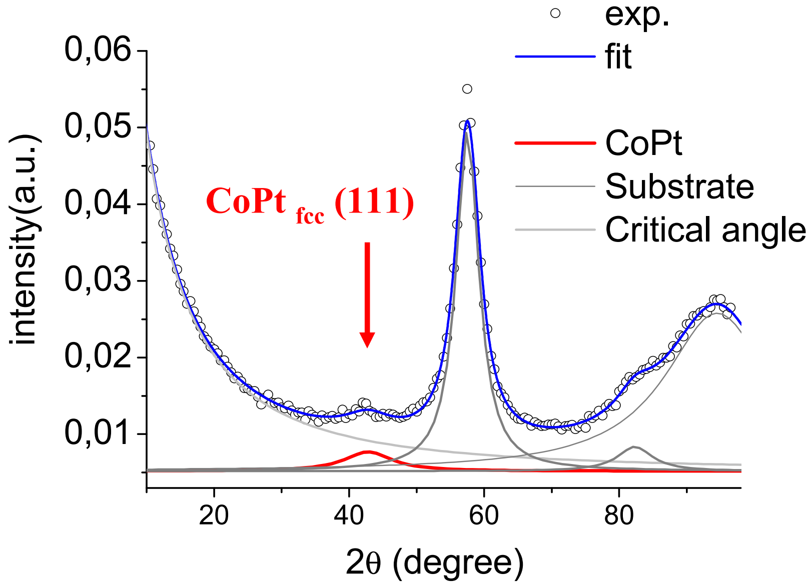
⇛ Supported CoPt cluster are fcc
With a mean diameter ϕ CoPt ≈ 2 nm

V. Dupuis, L. Favre et al. J Phys. Cond. Mat. (2004)

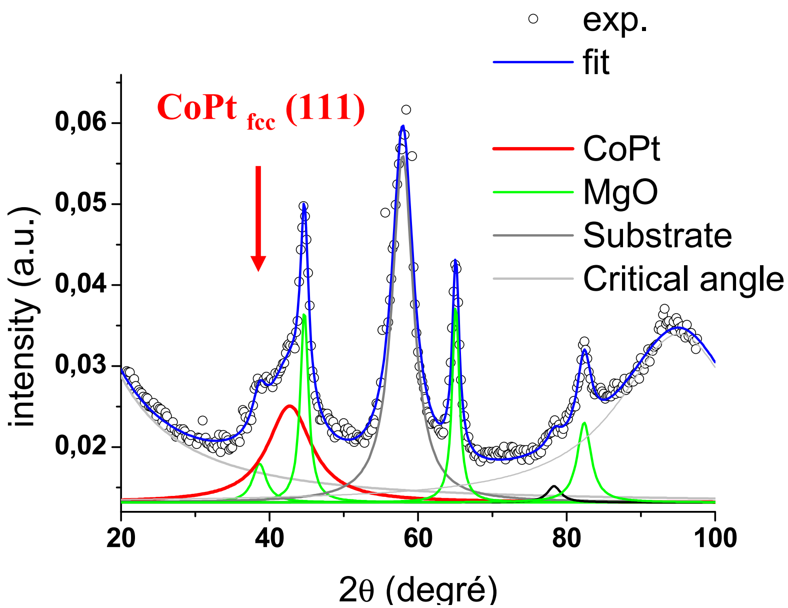
GIWAXS on mixed CoPt clusters

D2AM
(ESRF, Grenoble)

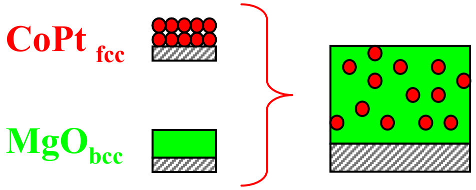
Supported CoPt clusters (without matrix)



CoPt clusters in MgO matrix



Embedded in MgO matrix
fcc CoPt is conserved



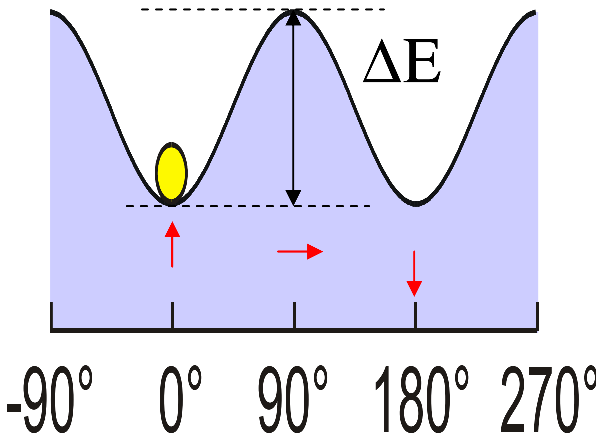
But from Debye Scherrer,
diameter ϕ CoPt ≈ 1.3 nm
is reduced : ⇒ Diffuse interface
in MgO

L. Favre, V. Dupuis et al. Submitted to Phys. Rev. B (2005)

One magnetic nanoparticle

Stoner and Wohlfarth model

ΔE is the energy barrier
at $T=0K$ and $H_{appl}=0T$



$$\boxed{\Delta E = K\, D^{\alpha}}$$

Anisotrpy constant

Cluster diameter

$\alpha = 2$, **surface anisotropy**
$\alpha = 3$, **volume anisotropy**

Superparamagnetism :

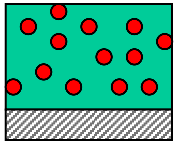
τ is the relaxation time
at $T \neq 0K$ and $H_{appl}=0T$

$$\boxed{\tau = \tau_0\, e^{\Delta E/\kappa_B T}}$$

with $\tau \approx 10^{-9}$ s for cluster
If $\tau_{mes} \gg \tau$: $\langle \mathbf{M} \rangle = 0$, superparamagnetic state
When $\tau_{mes} = \tau$: One define
T_B (resp. D_B), Blocking Temperature (resp. Diameter)

Possible to extand to a clusters assembly without interaction

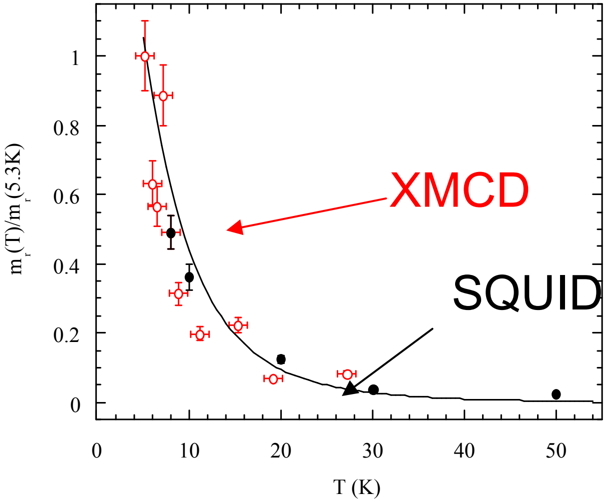
Magnetic clusters assembly in matrix : Effective Anisotropy



$\Delta E = K_{eff}\, D^{\alpha}$

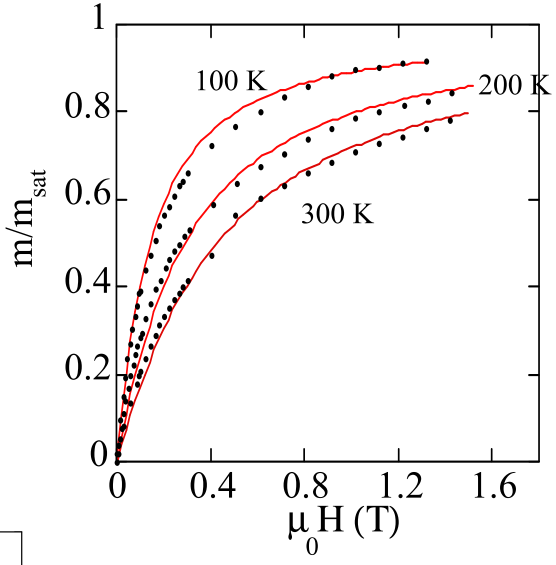
At low temperatures

- From M_r (T)



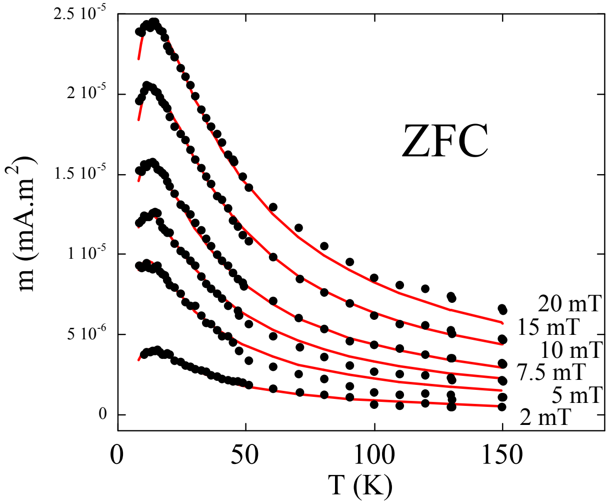
In the superparagnetic state

-From $M/M_{sat}(T)$



- From ZFC

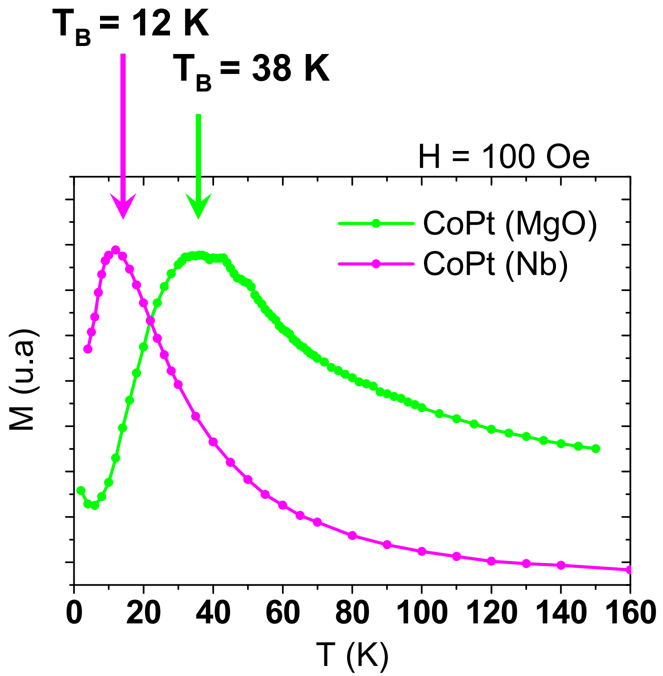
T_B

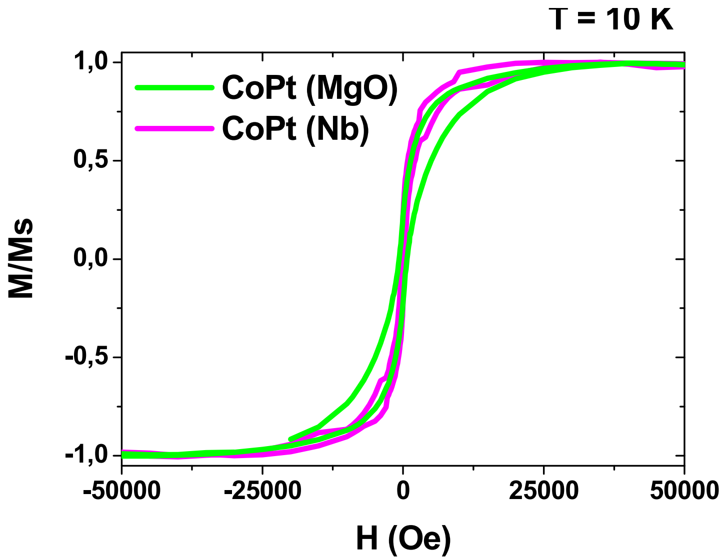


$$K_{eff} = \frac{6k_B T}{\pi D_B^{\alpha}(T)} \ln\left(\frac{\tau_{mes}}{\tau_0}\right)$$

M. Jamet et al. PRB (2000)

Magnetic Anisotropy of CoPt clusters in various matrices:





Interface effects

Blocking Temperature : **T_B α K D $^{\alpha}$** :

⇛ **Higher MAE in MgO than in Nb**

From ZFC simulations:

$K_{\text{Surf CoPt}}$ (in MgO) > $K_{\text{Surf CoPt}}$ (in Nb)

From XMCD and GIWAXS experiments:

D_{mag} (in Nb) < D_{mag} (in MgO) < D_{TEM}

Matrix	H_C	T_B
Nb	150 Oe	12 K
MgO	750 Oe	38 K

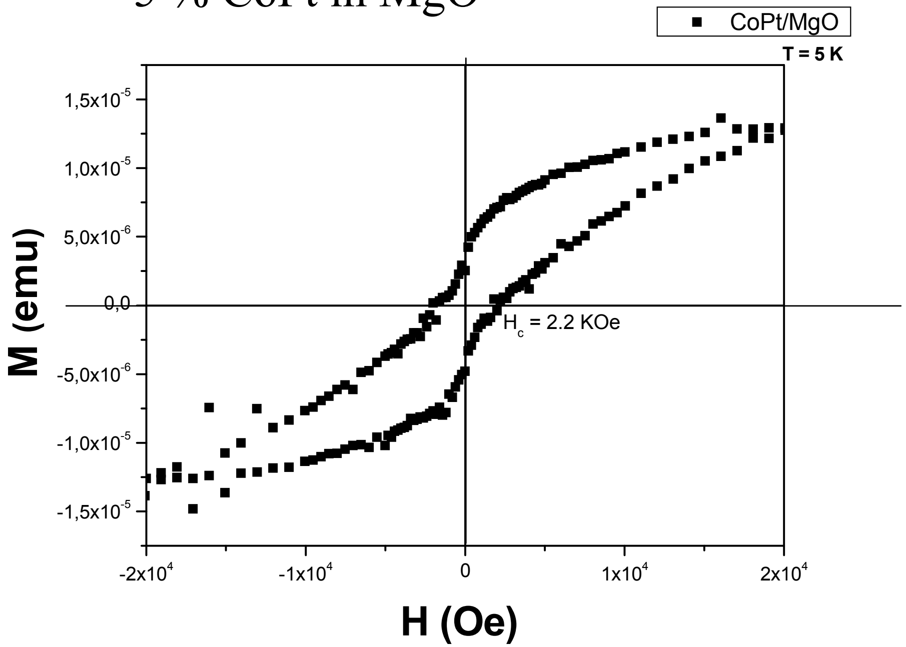
***Cf Poster**:*

«Structural and magnetic properties of Co_xPt_{1-x} mixed clusters… »

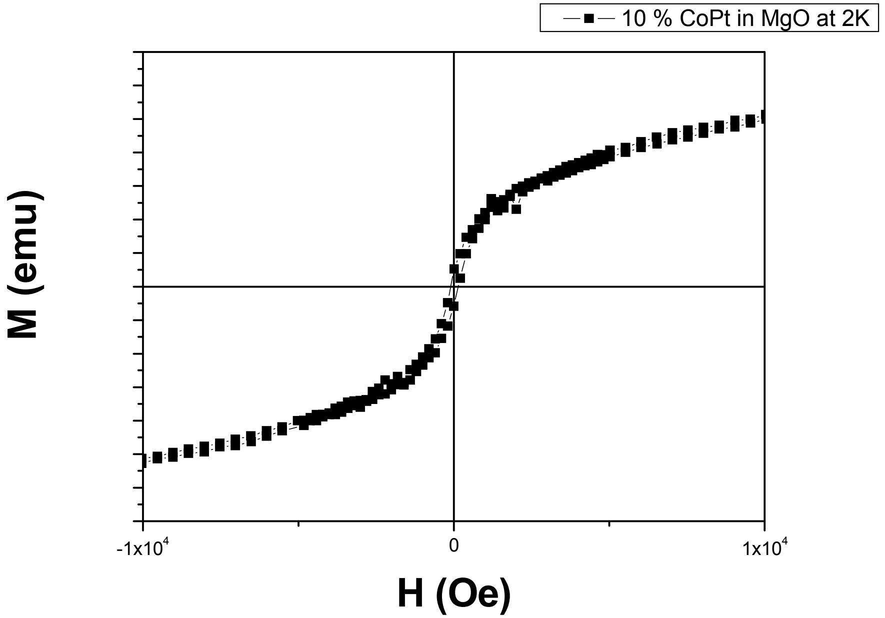
Stanislas Rohart, Cécile Raufast et al.

Magnetization of CoPt clusters in MgO versus concentration

5 % CoPt in MgO



10 % CoPt in MgO



MgO	H_C (at 2K)	T_B
5% CoPt	2.2 kOe	23 K
10% CoPt	750 Oe	38 K

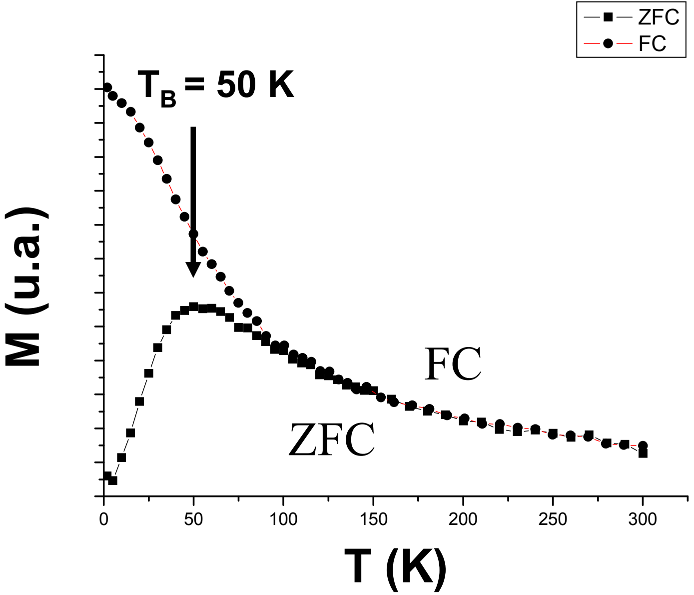
T_B ↗ and **H_C** ↘ versus CoPt concentration ↗

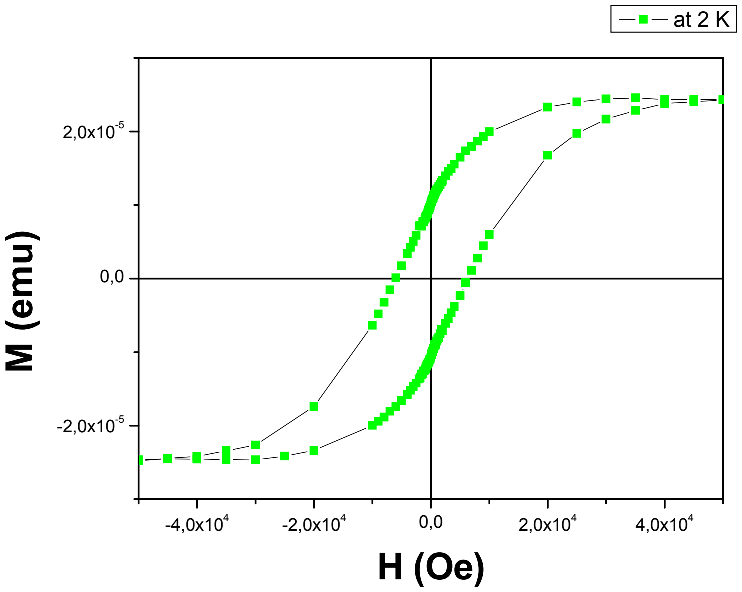
⟹ Dipolar interactions between clusters ↗
(~ Super-cluster)

Inter-particles effects

Magnetization of diluted Co$_x$Pt$_{1-x}$ clusters in MgO matrix

4 % Co$_3$Pt in MgO





Interface effects

in MgO	H_C (at 2K)	$T_B \alpha K D^{\alpha}$	Structure and diameter
5% CoPt	2.2 kOe	23 K	CoPt fcc : 2 nm
4% Co$_3$Pt	6 kOe	50 K	Core CoPt + Shell Co : 2 nm
2.5% Co	5 kOe	87 K	Co fcc : 3 nm

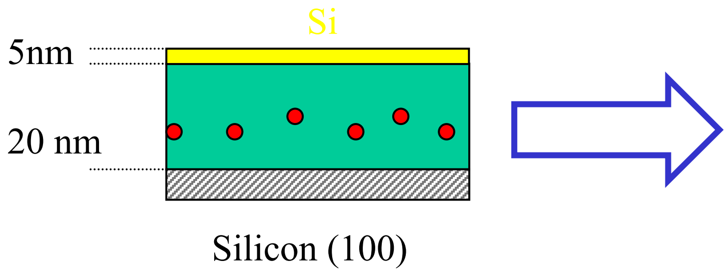
in Progress…

- **Synthesis, Structure and Superparamagnetism on Assembled clusters films**

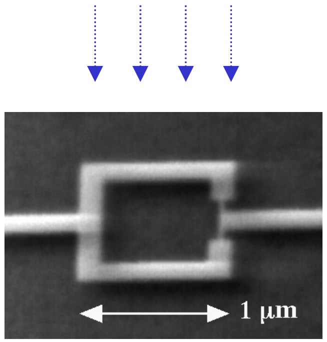
- **Measurements one single nanoparticle**

MicroSQUID measurements on single clusters

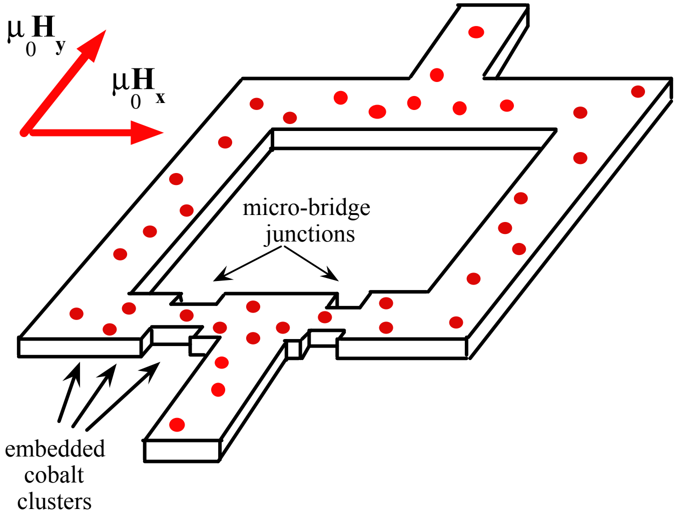
Thin Co 0.2% / Nb Film

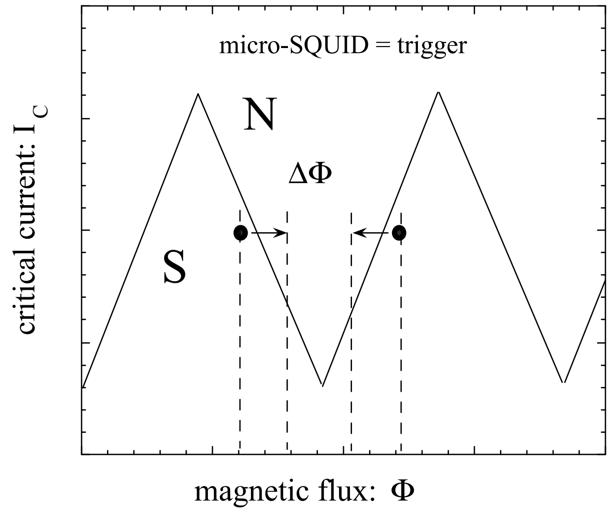


Lithography

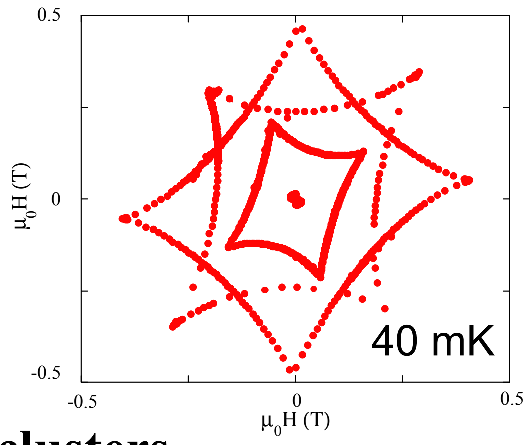


In-plane magnetic Field





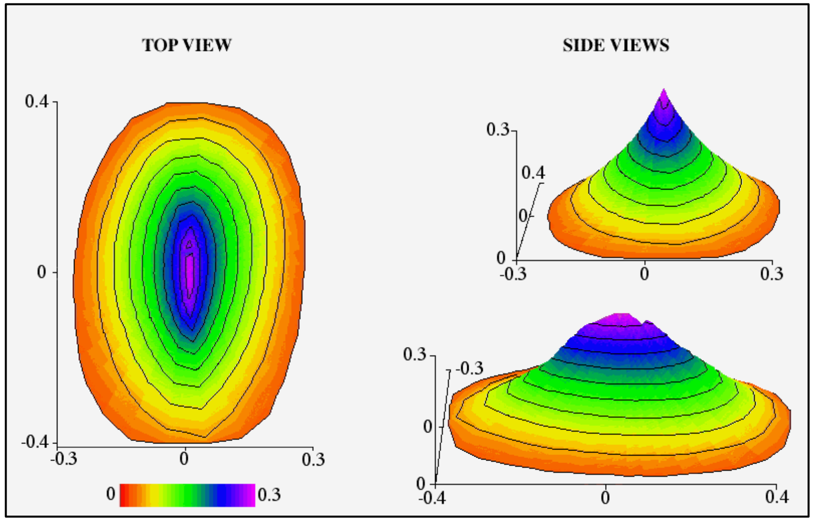
Cold mode



3 Co-clusters in the micro-bridge

Anisotropy energy:

$$\boxed{G\,(\vec{m}) = K_1 m_z^2 + K_2 m_y^2 + K_4 (m'^2_x\, m'^2_y + m'^2_x\, m'^2_z + m'^2_y\, m'^2_z) + K_6 m'^2_x\, m'^2_y\, m'^2_z + \ldots}$$



From 3 D Astroïd simulations：Experimental anisotropy constants

K_1= - 2.1*10^5 J/m^3

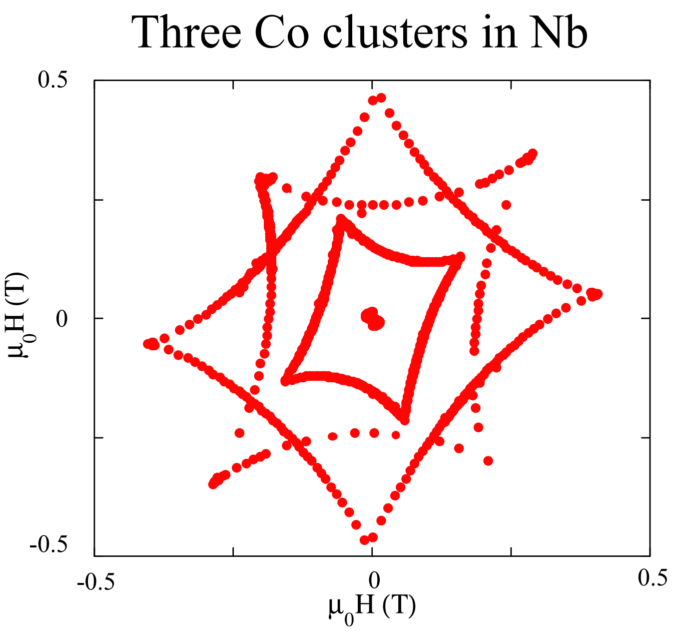
K_2= 0.8*10^5 J/m^3

K_4= - 0.1*10^5 J/m^3

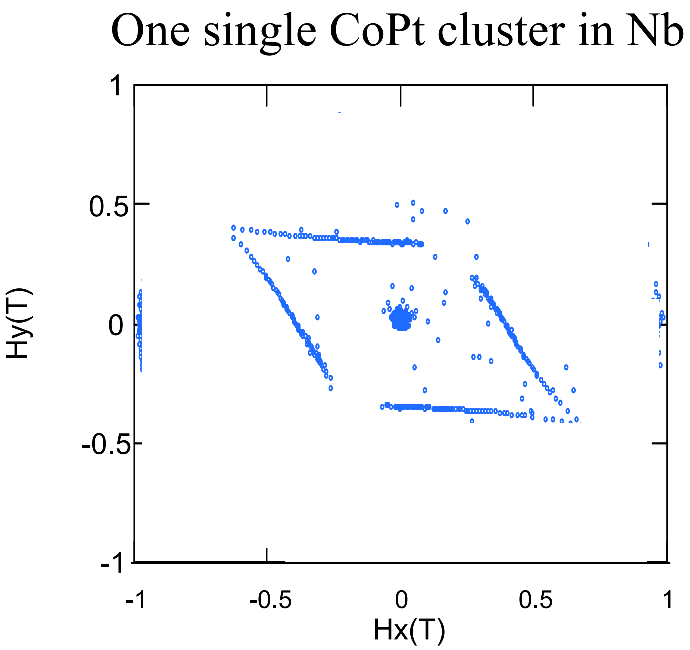
- **Second order terms dominate for pure Co clusters : bi-axial Surface Anisotropy**

M.Jamet, W. Wernsdorfer et al. PRL (2001)

Comparative 2D astroïd on Co and CoPt clusters



M. Jamet et al. Phys. Rev. Lett. 86 (2001) 4676



C. Raufast et al. (2005) unpublished

With equivalent Blocking Temperature : **T_B ~ 12 K**

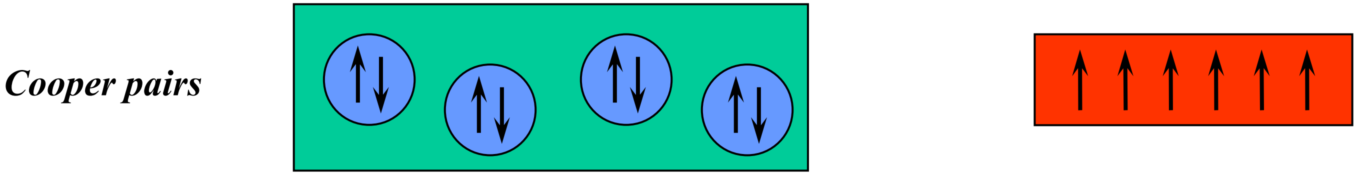
For $\varnothing_{Co}$ ~ 3nm and $\varnothing_{CoPt}$ ~ 2nm,

H_{sw} (CoPt) >> H_{sw} (Co)

Thus **K_{CoPt} (in Nb) > K_{Co} (in Nb)**

Proximity Effects : F cluster in S matrix

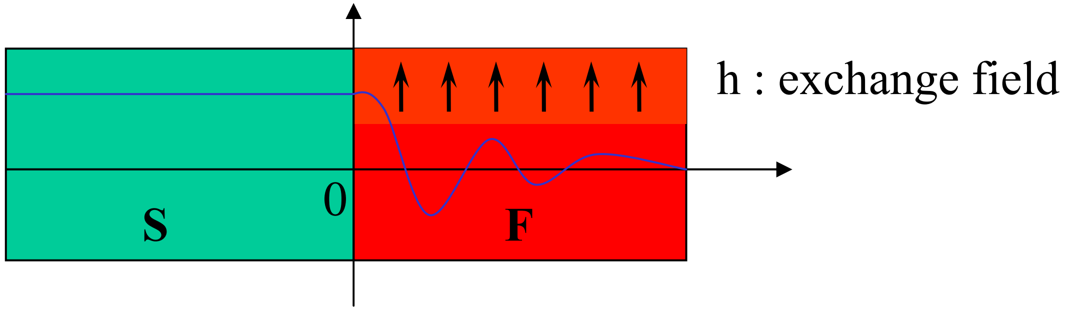
Superconductivity/Ferromagnetism: Two antagonist orders of Spin



	Type II Superconductor (Nb)	Ferromagnetic metal (Co)
Coherence length:	$\xi_S \approx$ 30 nm	$\xi_F \approx$ 2 - 4 nm
Order temperature:	$T_{critical} \approx$ 9 K	$T_{Curie} \approx$ 1388 K

⇨ **Coexistence: Mutual Influence on Electronic properties ?**

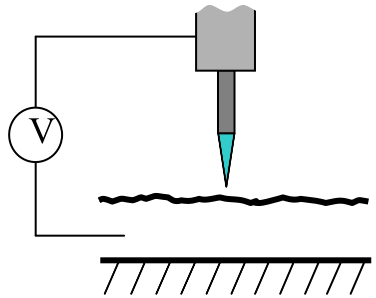
Superconductivity order parameter on the S/F interface

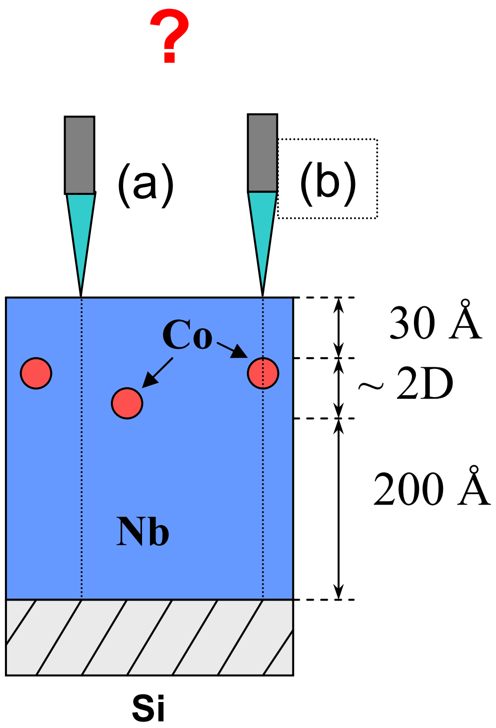


The cooper pair entering in the F region becomes an oscillating evanescent state

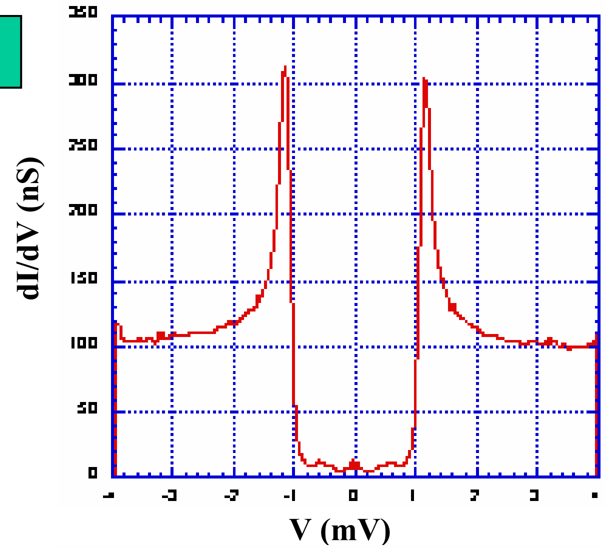
Local density of State

Very low temperature STM measurements





(a)

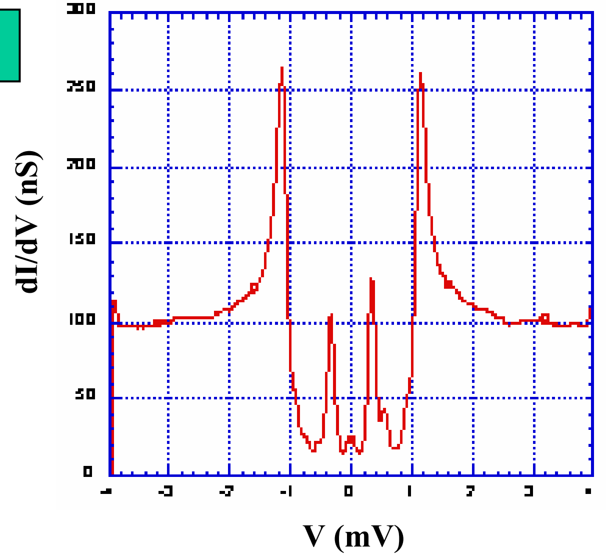


Density of state of Nb :
Superconducting gap

2Δ ≈ 2 meV

T_{mes} = 60 mK

(b)



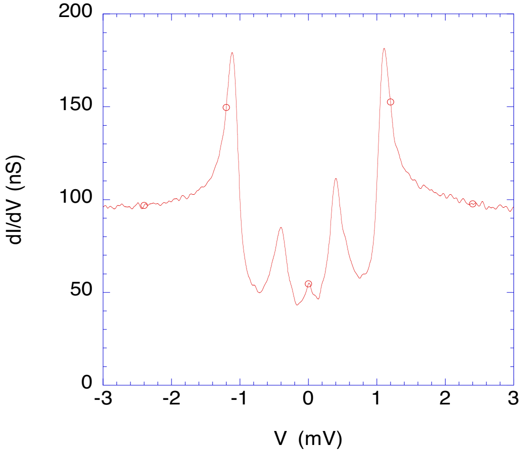
Asymetric peaks
in S gap to correlate
with F clusters

STREP ***SFINX***
(2004-2007)

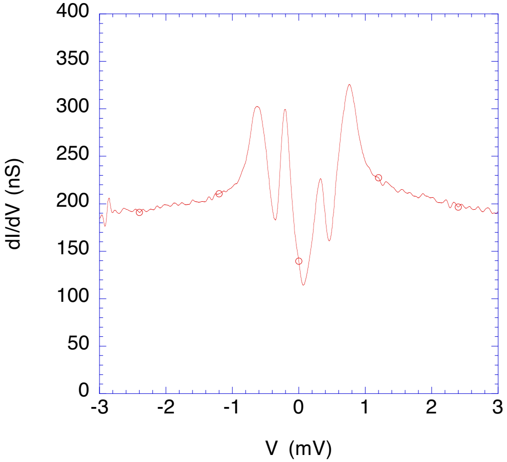
Perspectives : Theorical and experimental works to explain S/F proximity effects

. Systematic and reproductible experiments

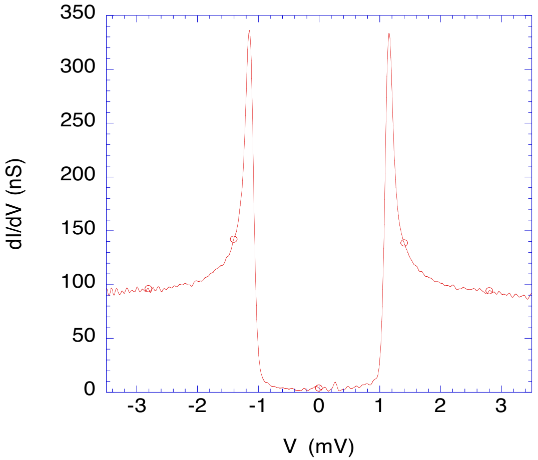
(Co) clusters in Nb
(150 clusters/µm²)



(Co) clusters in Nb
(12000 clusters/µm²)



(Ag) clusters in Nb
(370 clusters/µm²)

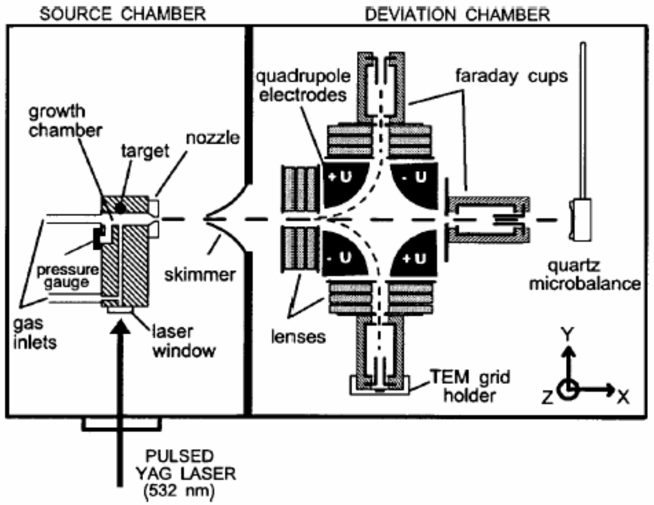


. Improvement in Matrix cristallinity and Monodisperse clusters

New UHV M.B.E chamber
(Heating sustrate, RHEED,…)

UHV Transfer suitcase
(Compatible with very low T STM)

and



Electrostatic quadrupole deviator:

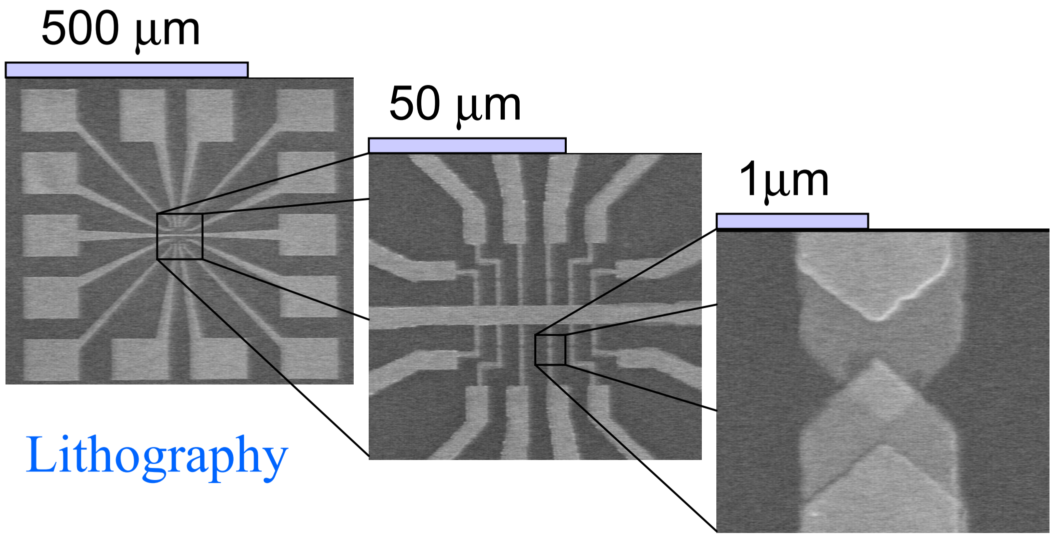
Δd/<d> = 25% → 5 %

Rev. Sc. Instrum. **75**, 2461 (2004)

Since October 2005 :
SFINX Post doc
Stanislas Rohart

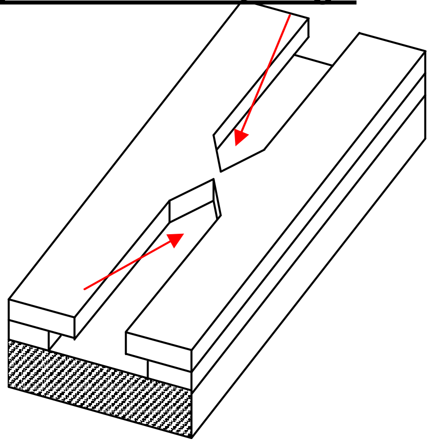
Magnetic cluster embedded in MgO matrix

Tunnel junction with one CoPt cluster

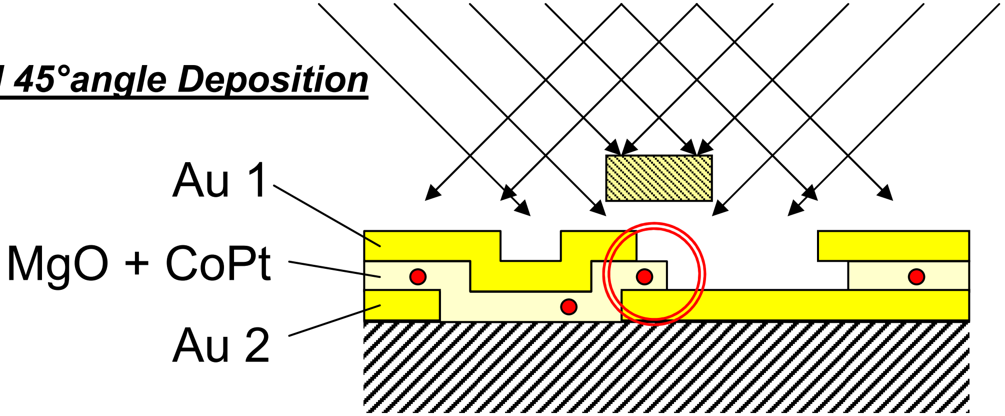


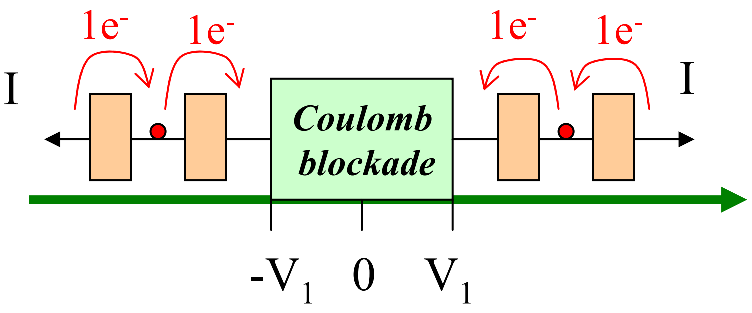
Lithography

Using a Suspended nano-bridge



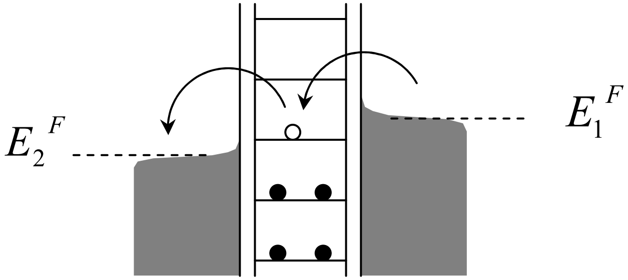
And 45°angle Deposition





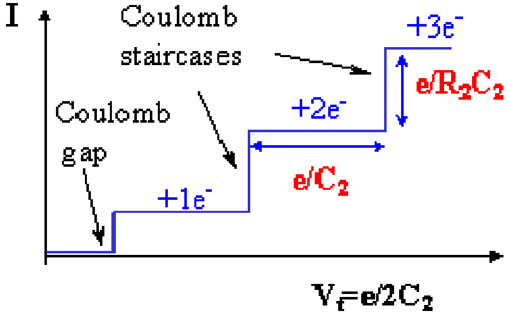
Spin-dependent tunneling and Coulomb Blockade

Principle



Coulomb Blockade

$$E = E_0 + \frac{e^2}{2C}$$

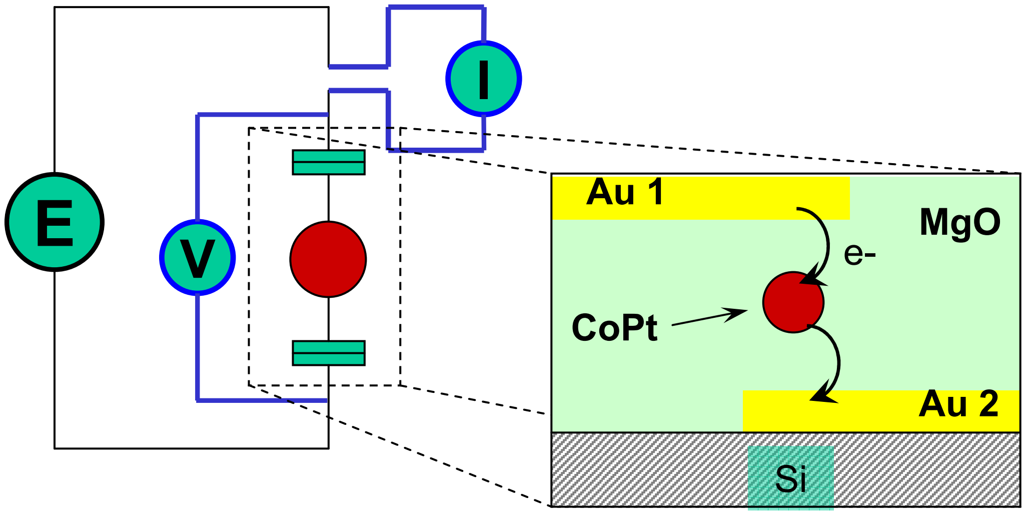


Charge Quantification

Nano-junction

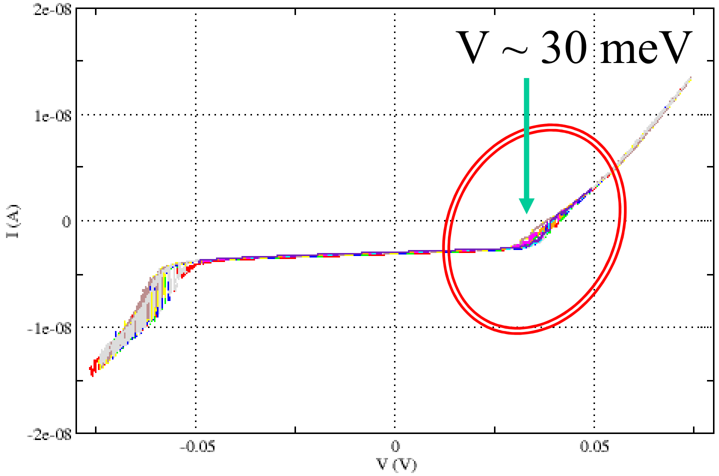
Charge transfer of one single e^- from Au_1 to Au_2 electrode via one CoPt cluster in MgO insulator

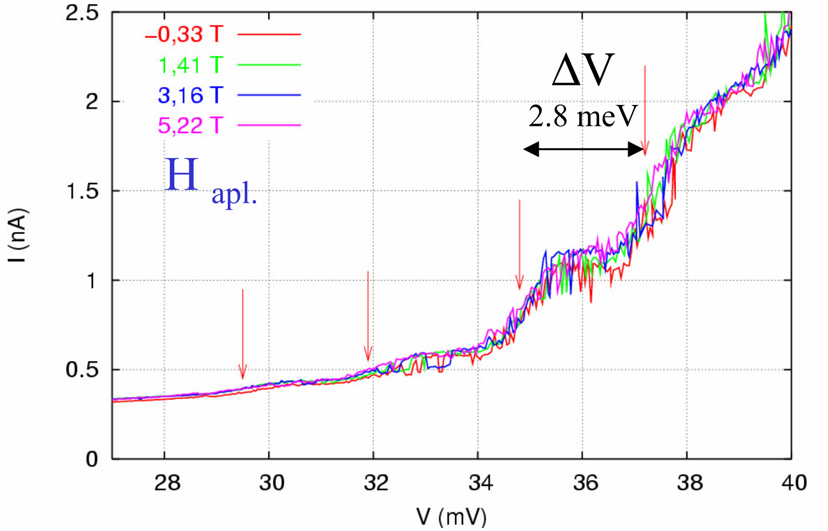
Measurement I = f(V,H)



- For a fixed bias and various external magnetic fields, energy levels must be spin-depedent → magnetic propertie of one cluster

Quantum size effect but Spin-independent tunneling





Coulomb blockade :
Energy Step due to
Tunnelling via one cluster

Zoom on the first Energy Step

- Elementary Energy Step due to Tunnelling via discrete electronic levels in one 2nm-diameter CoPt cluster (300 atoms)

- But Independent on aplied magnetic Fields H_{apl} for CoPt cluster in MgO: nonmagnetic cluster?

in progress with
Cécile Raufast' thesis…

Aknowledgments

Main results from the M. Jamet (2001) and L. Favre (2004) Thesis, Lyon, France

In progress, results from the C. Raufast PhD thesis and S. Rohart SFINX post Doc

Close collaborations:

- micro-squid and tunnel junction measurements
(W. Wernsdorfer and E. Bonet, LLN Grenoble, France)

- density of state STM measurement at very low temperature
(H. Courtois, CRTBT Grenoble, France)

- Tunneling Magneto-transport measurement
(C. Marrow, Leeds, UK)