# Re-entrant antiferromagnetism in the exchange-coupled IrMn/NiFe system

**<u>L. Del Bianco</u>**, E. Bonfiglioli, F. Chinni, M. Tamisari, F. Spizzo

*Dipartimento di Fisica e Scienze della Terra, Università di Ferrara, Italy*

*lucia.delbianco@unife.it*

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# Objective

Description of the dynamic magnetic behavior of the antiferromagnet in exchange-coupled FM/ AFM **NiFe/IrMn bilayers**

**Re-entrant antiferromagnetism**

• From the continuous NiFe/IrMn film to **dot arrays**: spatial confinement and exchange coupling mechanism

We exploit the exchange coupling with a soft FM as a tool to gain an insight into the magnetic properties of the AFM

We study the magnetic properties of the AFM phase to gain an insight into the exchange coupling mechanism *(exchange bias effect)*

# NiFe/IrMn film

Si / Cu[5 nm] / **Py**[5 nm] / **IrMn**[6 nm] / Cu [5 nm]

**Py**: $Ni_{80}Fe_{20}$

**IrMn**: $Ir_{25}Mn_{75}$

*Reference film: Si / Cu[5 nm] / **Py**[5 nm] / Cu [5 nm]*

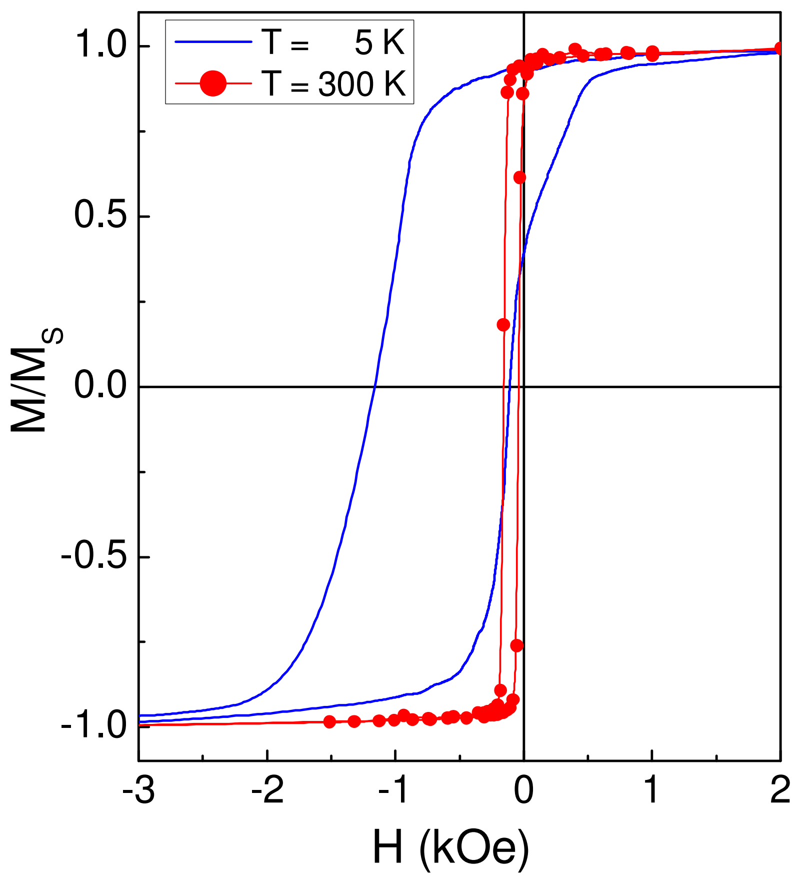
Deposition by **dc-magnetron sputtering**

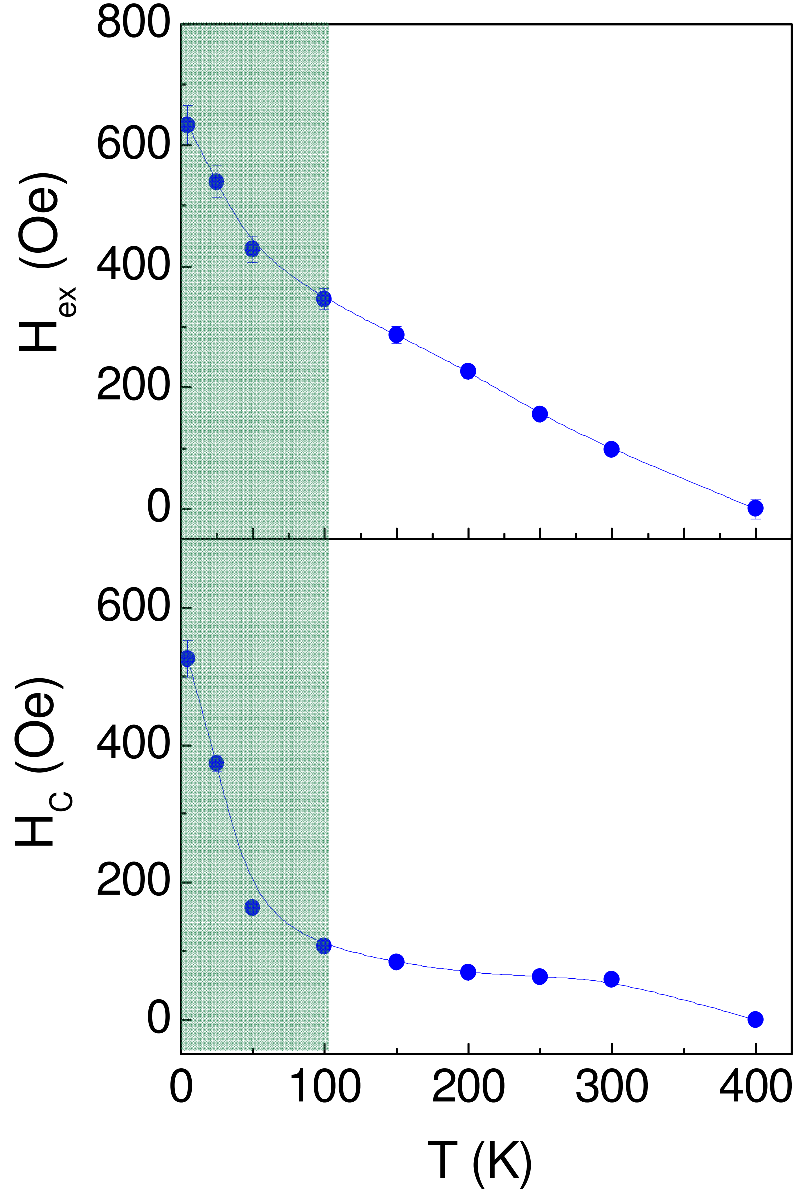
Ar atmosphere, deposition rate $\cong$ 0.2 nm/s

**$H_{dep}$ = 400 Oe**

# Hysteresis loops

***(5-400 K temperature range)***

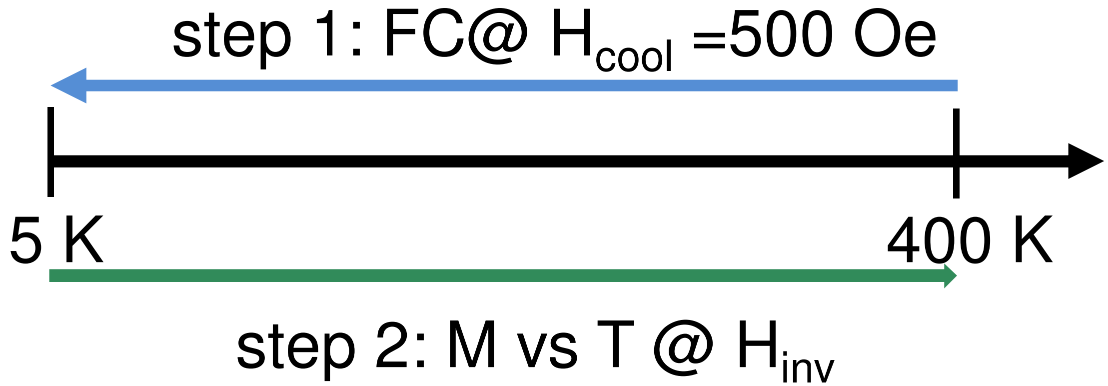


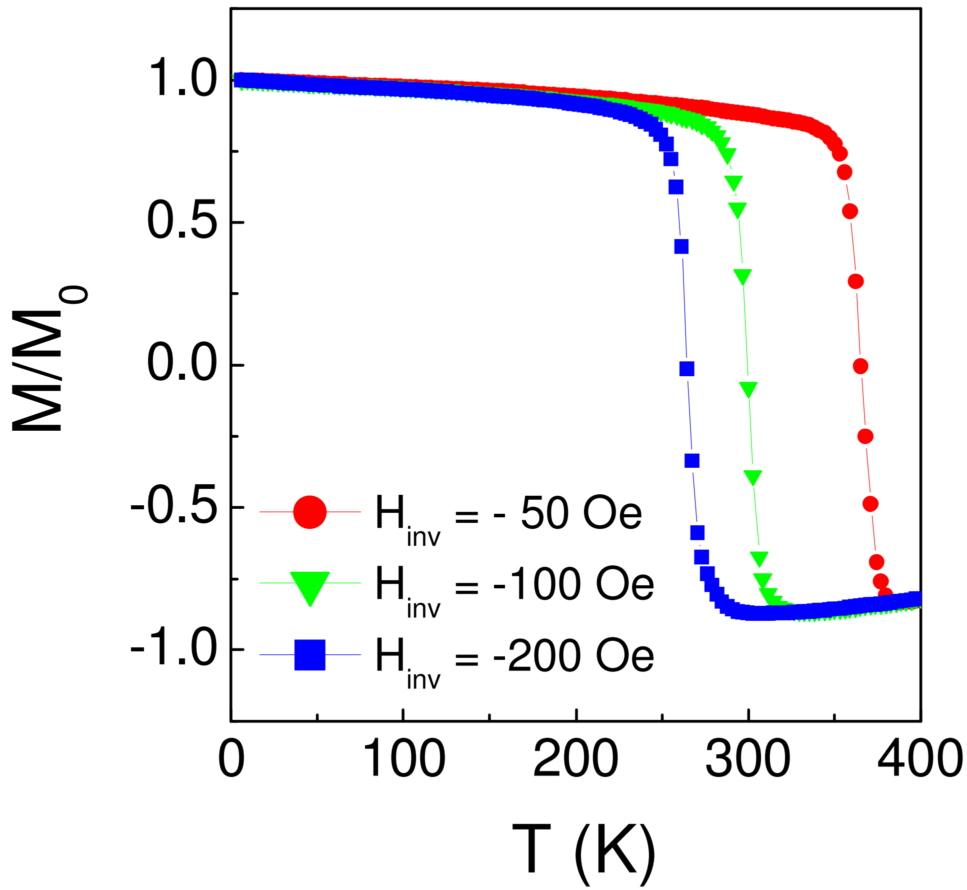



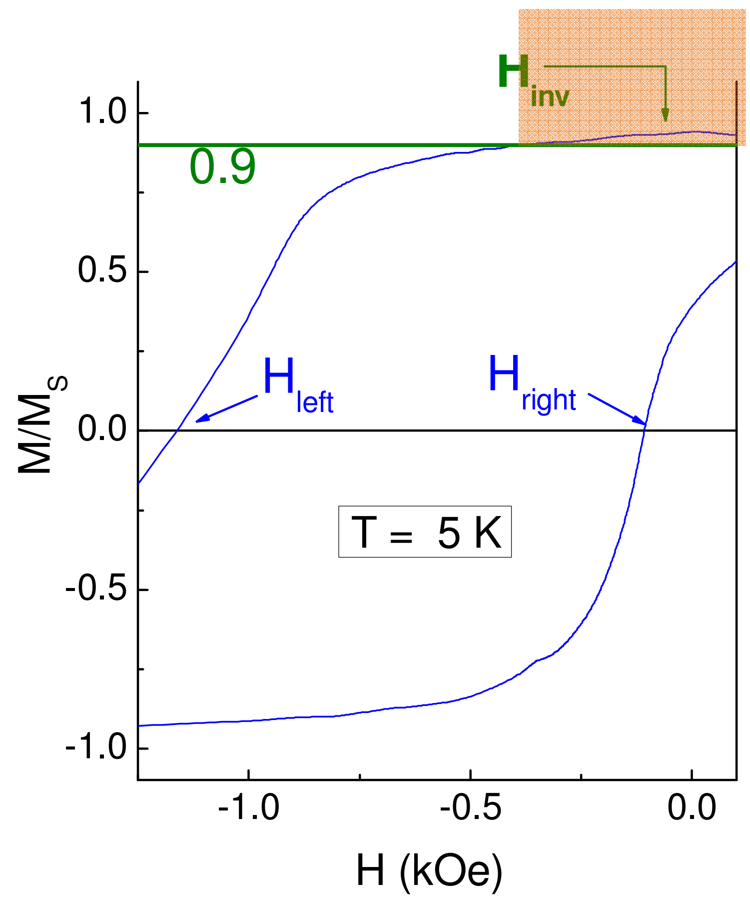

Change of magnetic regime at T ~ 100 K

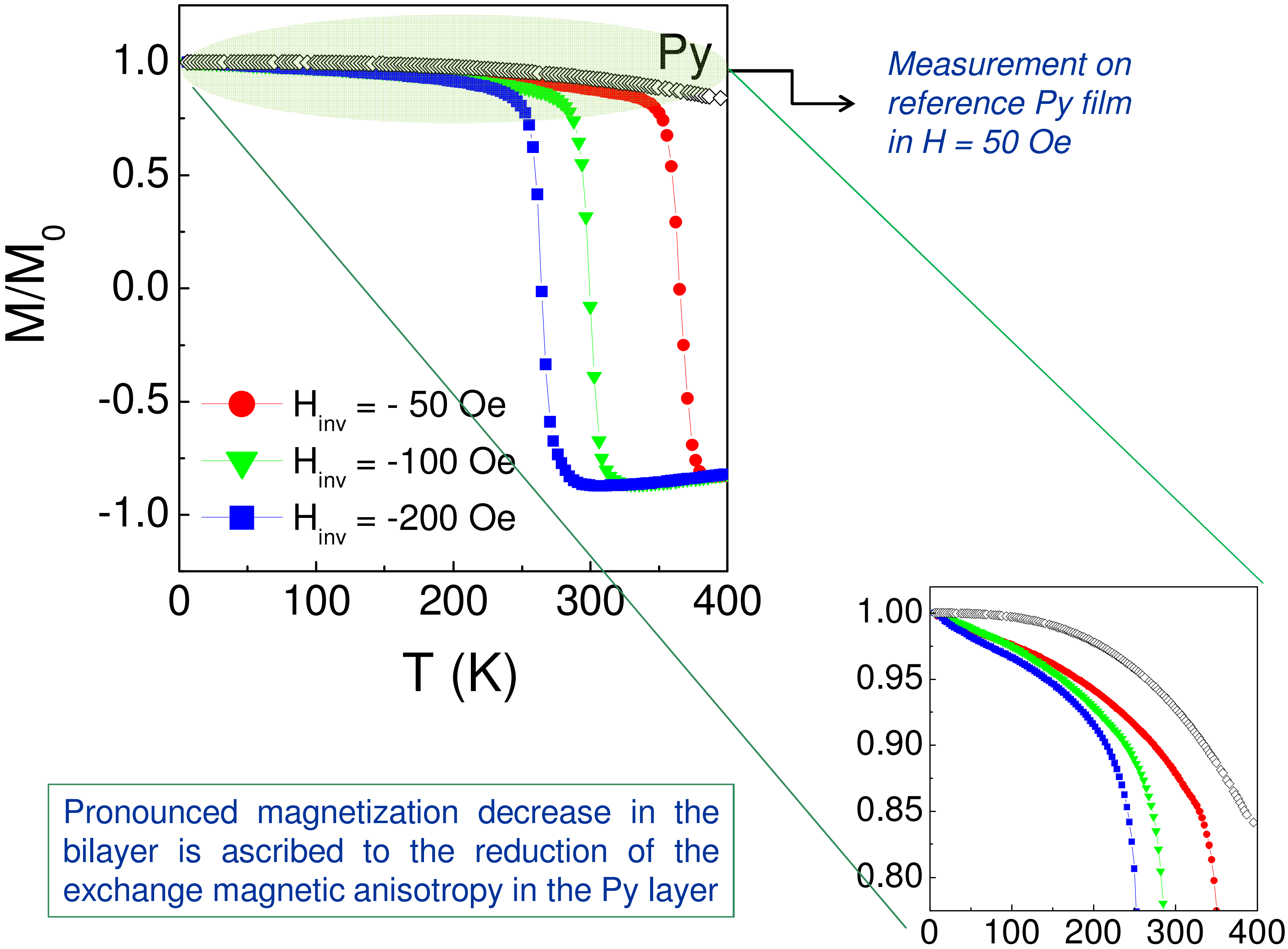
**Magnetization reversal study -**

SQUID measurement procedure



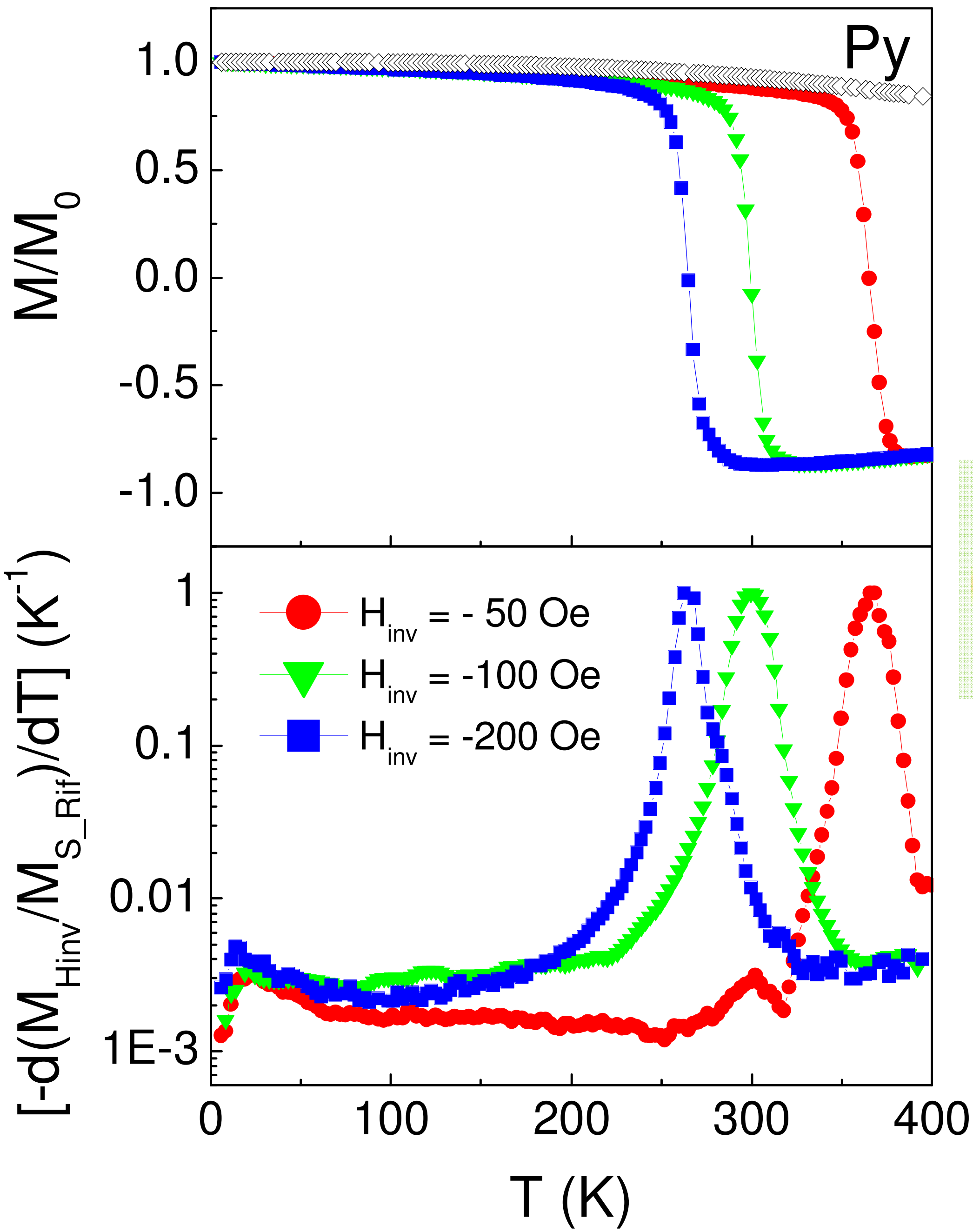






*Measurement on reference Py film in H = 50 Oe*

Pronounced magnetization decrease in the bilayer is ascribed to the reduction of the exchange magnetic anisotropy in the Py layer




**AFM film consists of non-interacting nanograins**

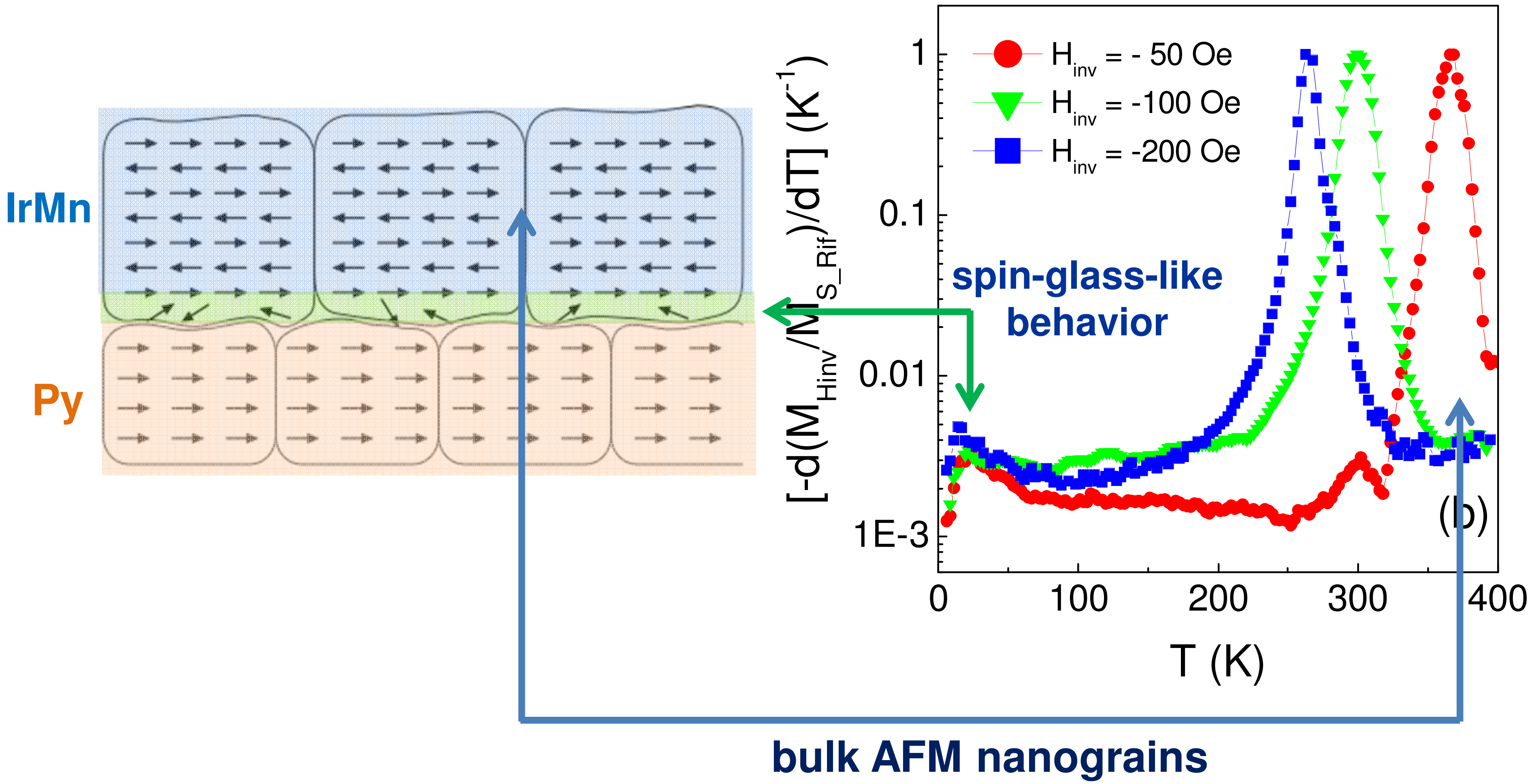
⇓

Distribution of effective anisotropy energy barriers ΔE

$$\left(\frac{M_{H_{\mathrm{inv}}}}{M_{\mathrm{S\_Rif}}}+1\right) \propto \int_{\Delta E_{\mathrm{crit}}}^{\infty} f(\Delta E)\,\mathrm{d}\Delta E$$

We obtain information on the anisotropy energy barrier distribution of the AFM as it is felt by the FM component

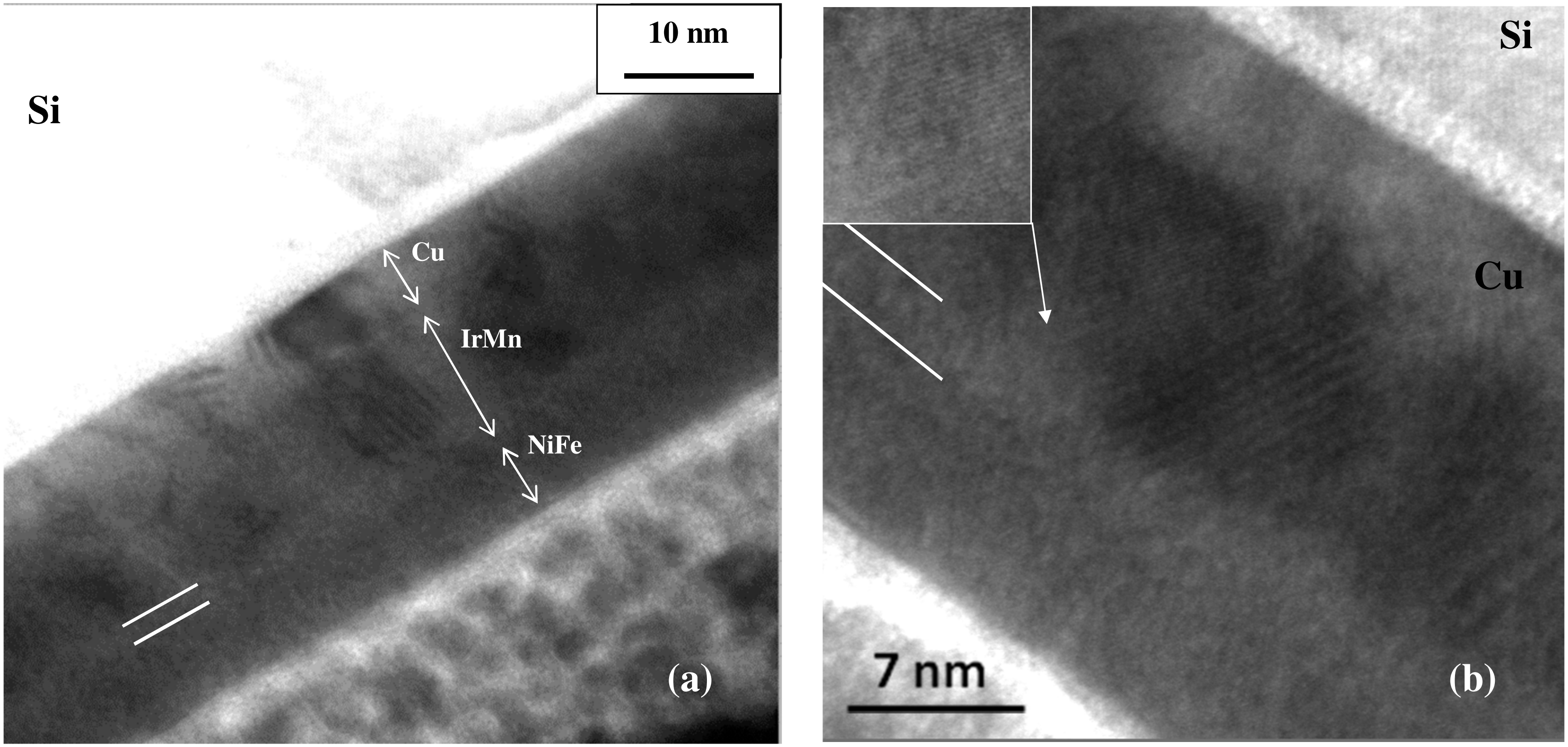
*F. Spizzo et al., J. Phys.: Condens. Matter 25, 386001 (2013)*




$V = 25\ kT_B/K_{IrMn}$

$\Rightarrow$ size ~ 10 nm

$K_{IrMn} = 1.8 \times 10^6$ erg/cm$^3$




Existence of a disordered AFM region at the interface with the NiFe phase

**TEM results confirm our prediction on the structure of the AFM phase**

**T > 100 K**

Only the interfacial AFM spins tightly anchored to the spin lattice of the bulk AFM nanograins contribute to $H_{ex}$

**T ~ 100 K**

The frozen collective state breaks up. Polarizing action of bulk AFM spins on the interfacial ones prevents the development of a paramagnetic state.

**Re-entrant antiferromagnetism**

**T< 100 K**

AFM interfacial spins are frozen and subjected to a high effective anisotropy.

T

**$H_{ex}$ decreses and finally the EB effect disappears**

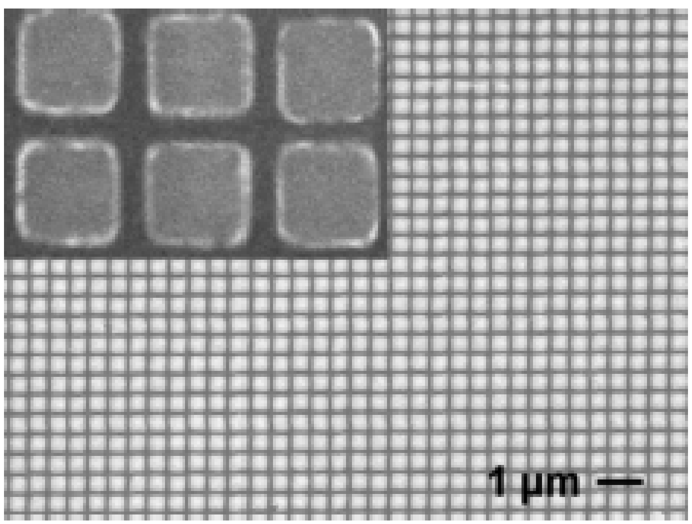
**$H_{ex}$ is maximized**

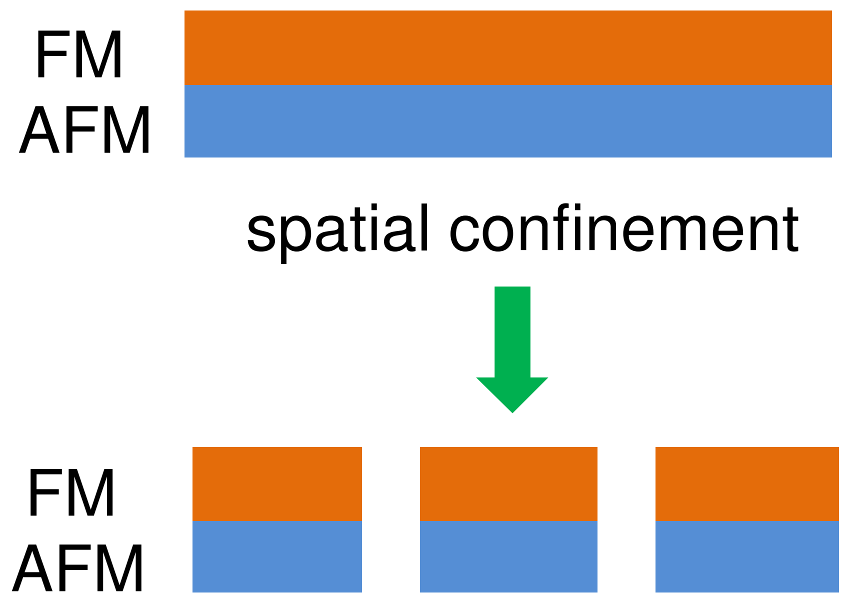
# From the continuous film to dot arrays

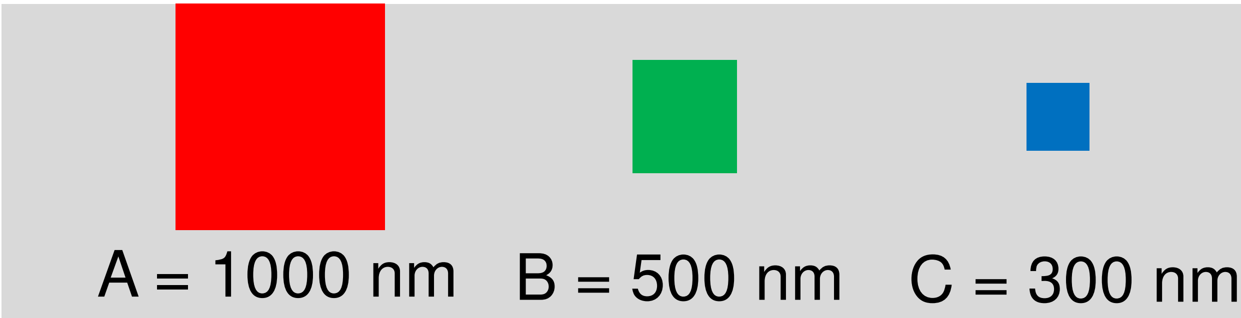
Si / Cu[5 nm] / **IrMn**[10 nm] / **Py** [5 nm]

**Electron beam lithography and lift-off**

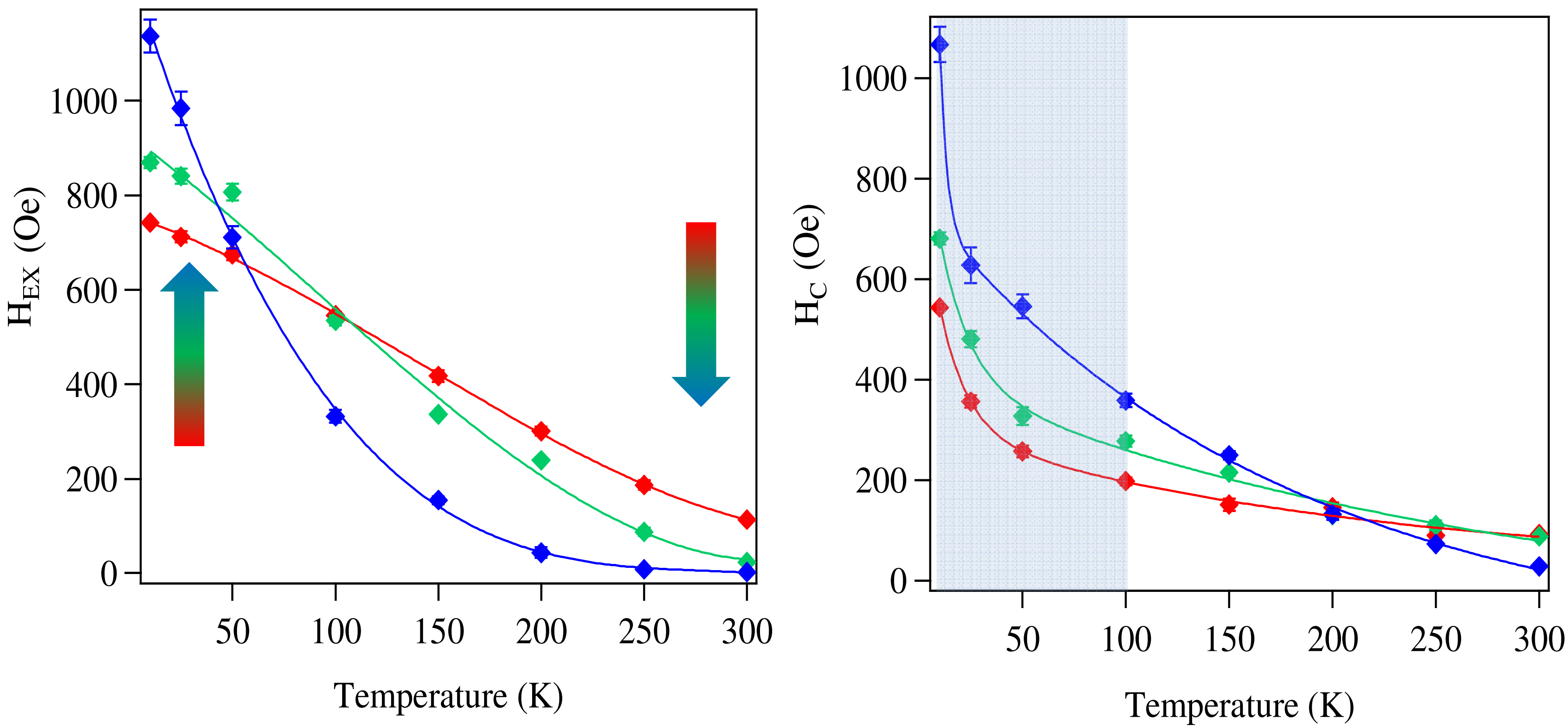
**dc-magnetron sputtering**
($H_{dep}$ = 400 Oe)

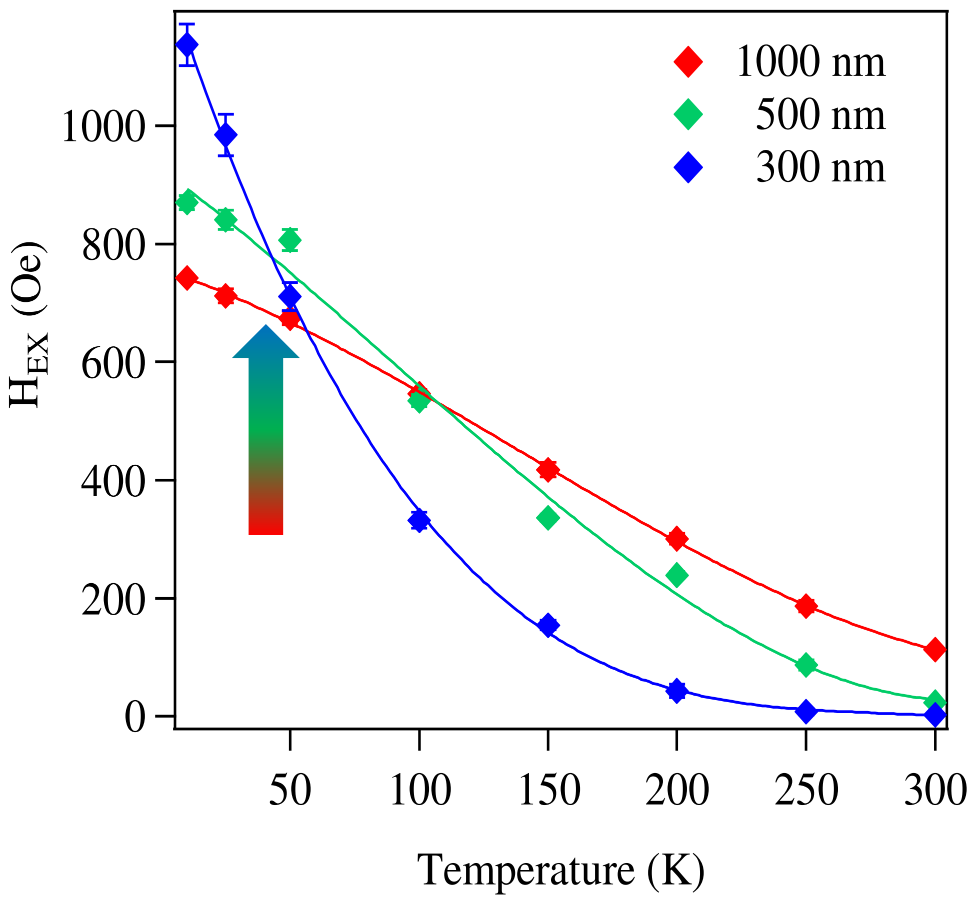





**MOKE - FC hysteresis loops**
*($H_{cool}$ = 500 Oe;*
*10-300 K temperature range)*



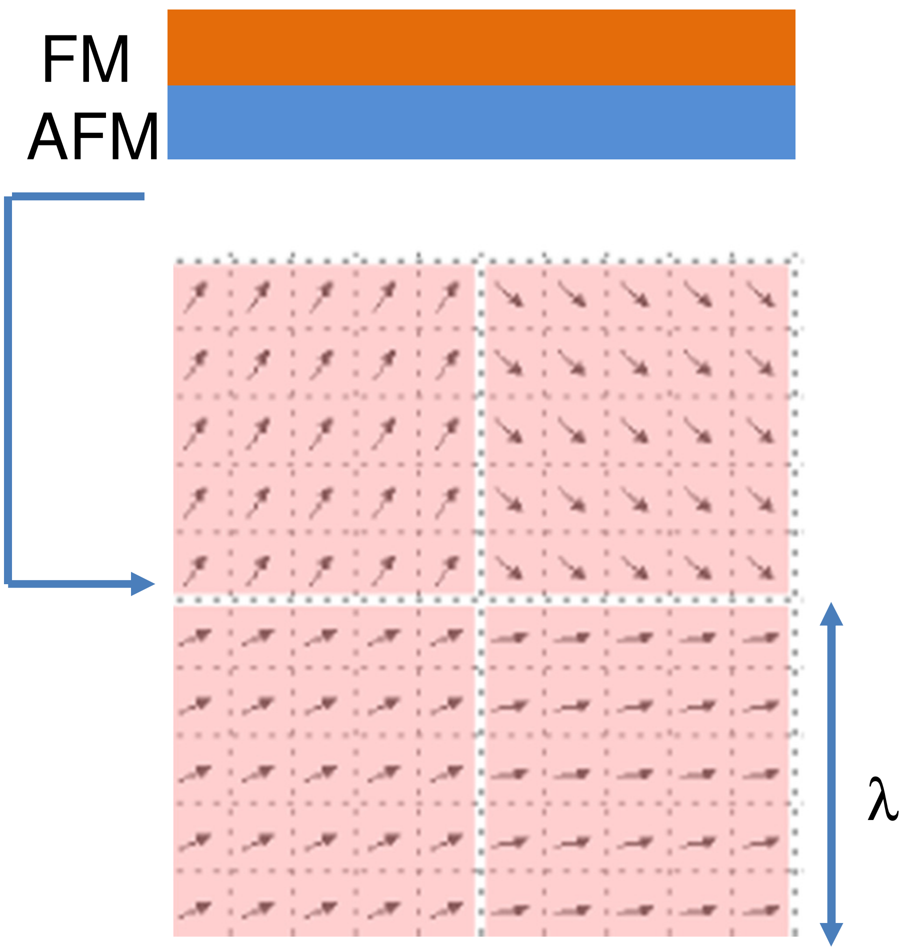



## At low temperature

The correlation length among the AFM interfacial spins increases with reducing T

Object Oriented MicroMagnetic Framework

## Dependence of $H_{ex}$ on the AFM correlation length $\lambda$




Dot size = 1200 nm

OOMMF cell size = 10 nm

$K_{AFM} = 2 \times 10^{7}$ erg/cm$^{3}$ cells:

FM/AFM exchange interaction = $10^{-7}$ erg/cm

**Different cell size:**
**10, 20, 100, 200, 300 nm**

*F. Spizzo et al., Phys. Rev. B 91 (2015) 064410*

Object Oriented MicroMagnetic Framework

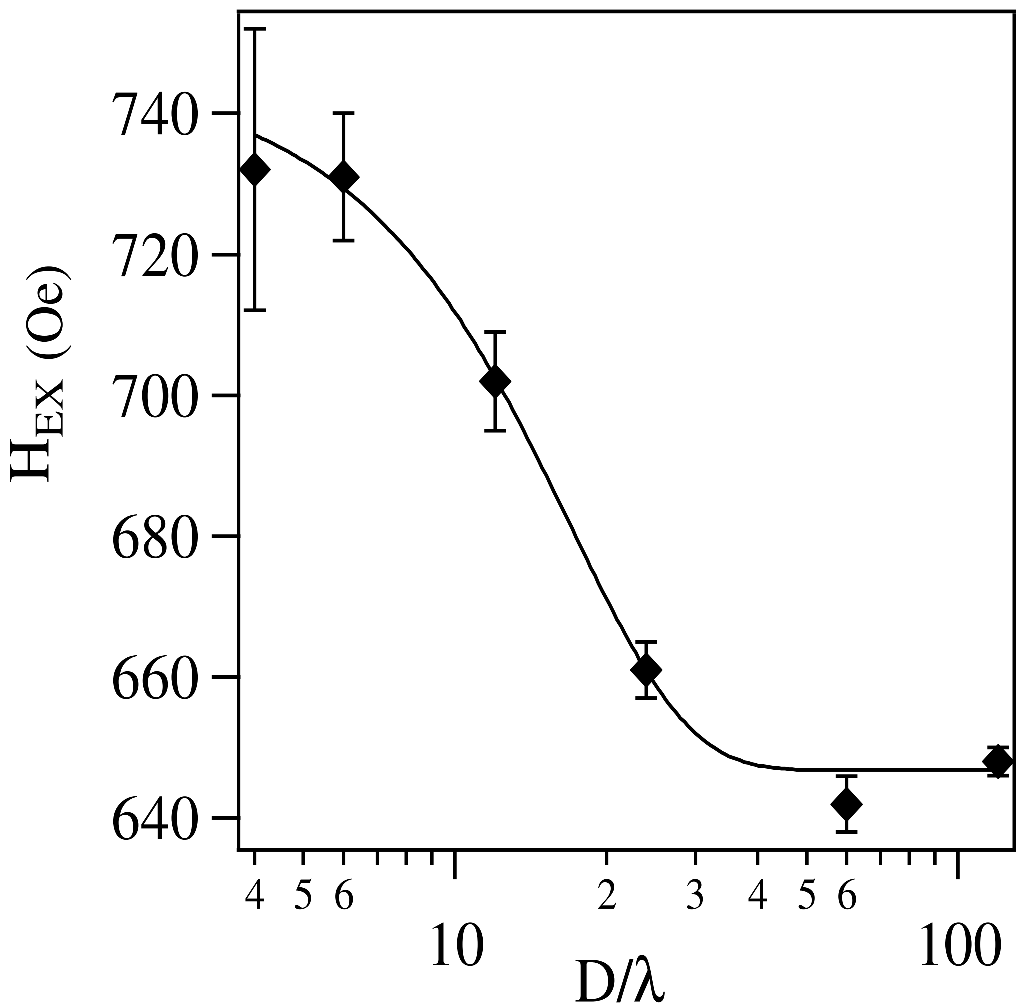
## Dependence of $H_{ex}$ on the AFM correlation length λ

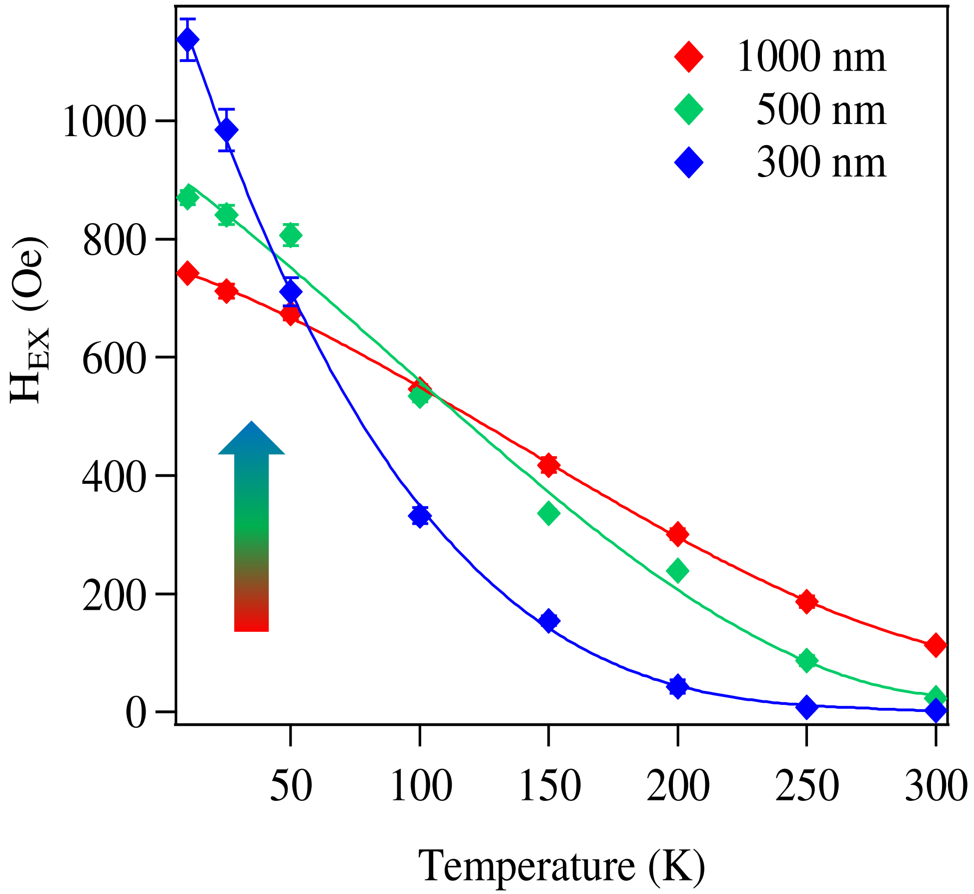
Dot size = 1200 nm

All the AFM cells with
high K (100% pinning centers)

Different cell size:
10, 20, 100, 200, 300 nm

$H_{ex}$ increases as
$D/\lambda \rightarrow 1$






At low temperature

Spin correlation effect

Correlated AFM spins exert a stronger pinning action as

$D/\lambda \rightarrow 1$

# Conclusions

**Re-entrant antiferromagnetism $\Rightarrow$ Passage from the glassy to the AFM state**

- **Re-entrant magnetic regime**: the magnetism of AFM interfacial spins is sustained by stable nanograins.

## Exchange coupling mechanism

- **Low temperature**: collective freezing of the disordered AFM spins $\Rightarrow$ high $H_{ex}$.
- **High temperature**: FM/AFM coupling governed by a fraction of interfacial AFM spins.
- **Spatial confinement** $\Rightarrow$ spin correlation effect

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A. Gerardino, A. Notargiacomo

*IFN-CNR, I-00156 Roma, Italy*

G. Barucca

*Univ. Politecnica delle Marche,*
*I-60131 Ancona, Italy*

**Thanks for attention**