Self-organization on surfaces: an overview

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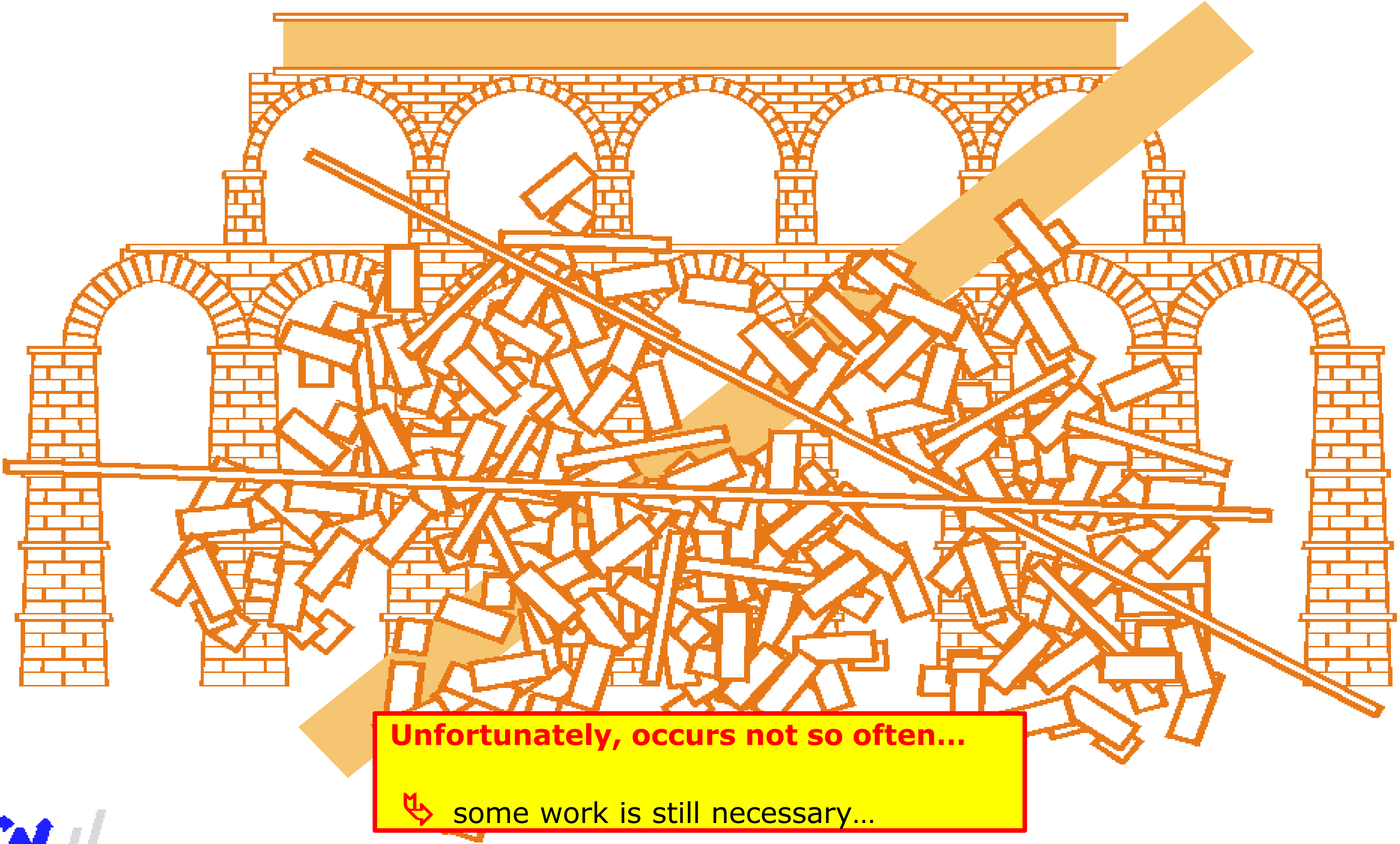
Part of the lab (Summer)

- (Grenoble)
- I. Overview of self-organization processes
- II. Self-organization for magnetism (litterature)
- III. Our contribution for magnetism

I. Overview of self-organization processes



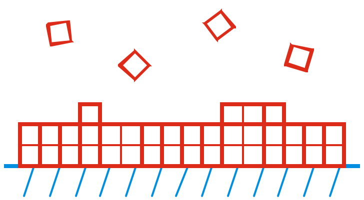
Unfortunately, occurs not so often…

some work is still necessary…

Macroscopic concept: surface energies

2D

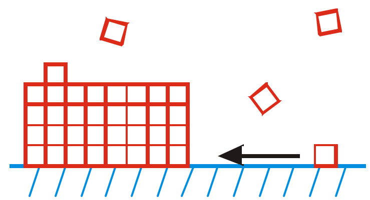
Franck van der Merwe



$ã_{substr.} > ã_{film} + ã_{interf.}$

3D

Volmer-Weber



$ã_{substr.} < ã_{film} + ã_{interf.}$

E.Bauer, Z.Kristallogr.110, 372 (1958)

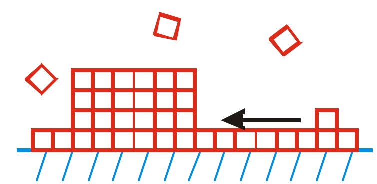
E.Bauer, Phys.Rev.B 33, 3657 (1986)

- Flat thin films: **high** substrate energy
- Islands (dots): **low** substrate energy

Another growth mode is frequently observed

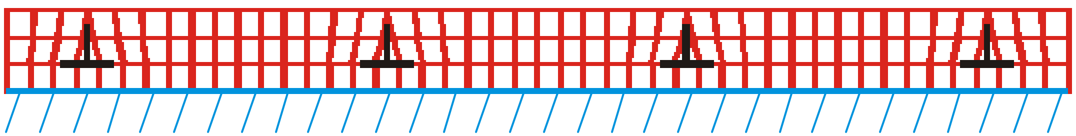
2D → 3D

Stranski-Krastanov

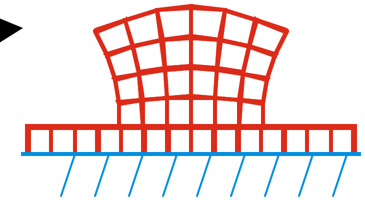


Microscopic concept: misfit accomodation

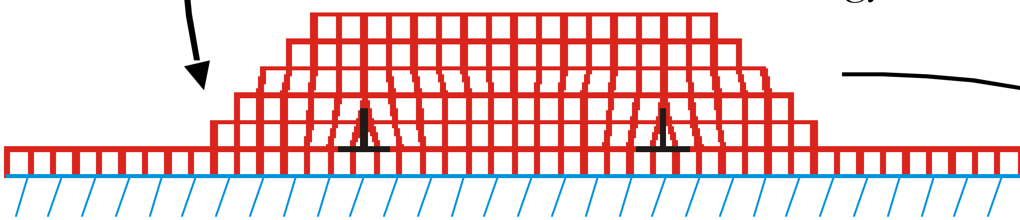
- High energy of dislocations



Misfit accomodation by elastic 3D relaxation



Additional effective interface energy



P.-O. Jubert *et al.*, Phys. Rev. B 64, 115419 (2001)

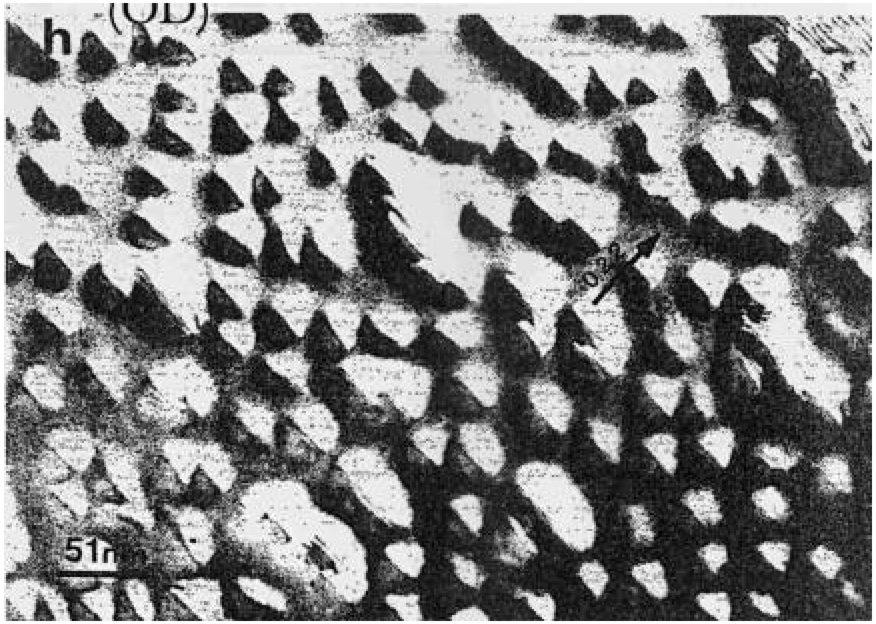
F. Tinjod *et al.*, submitted to J. Alloy Comp. (2002)

- Thickness-dependant surface stress

H.Ibach, Surf.Sci.Rep.29, 193 (1997)

- Many parameters for spontaneous island growth: Self-assembly

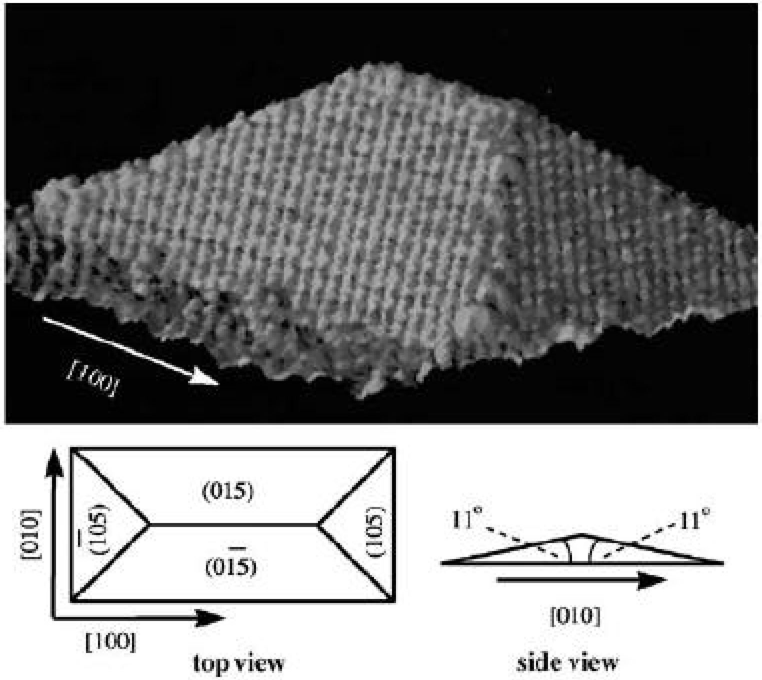
$In_xGa_{1-x}As/GaAs$ quantum dots (OD)



S.Z.Chang *et al.* ,J.Appl.Phys.73,4916(1993)

Lasing properties

Ge/Si(001): hut shape

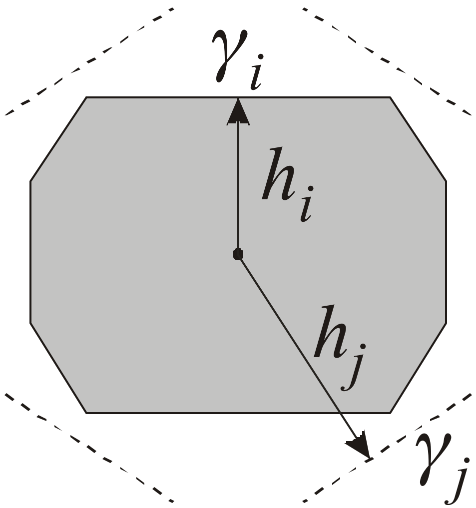


I.W. Mo et al., Phys. Rev. Lett. 65, 1020 (1990)

Wulff's theorem

Free crystal

$$\frac{\gamma_i}{h_i} = \text{Constant}$$

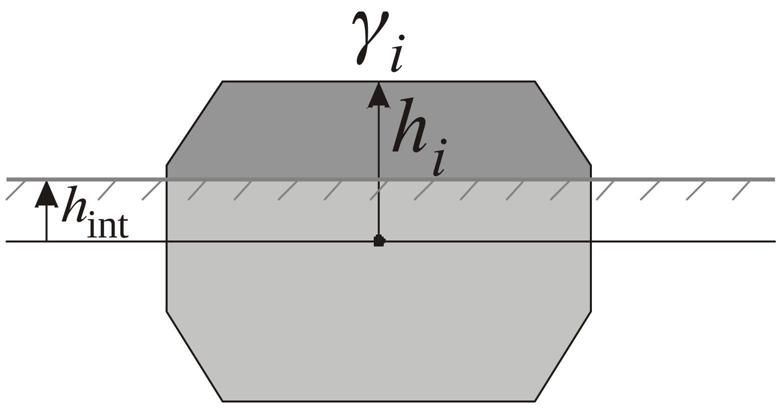


No facets with high surface energy

Wulff Kaishev's theorem

Supported crystal (growth on surfaces)

$$\frac{\gamma_i}{h_i} = \frac{\gamma_S - \gamma_{int}}{h_{int}} = \text{Constant}$$



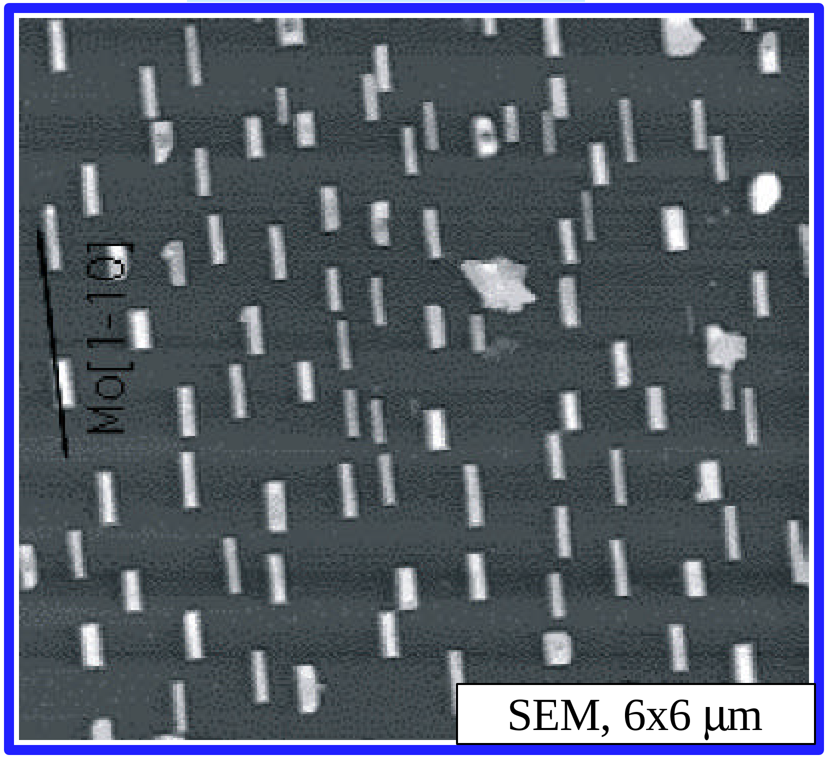
Truncated crystal

With strain:
Simulations or more complex models (e.g. small dots)

P. Müller and R. Kern, Surf. Sci. 457, 229 (2000)

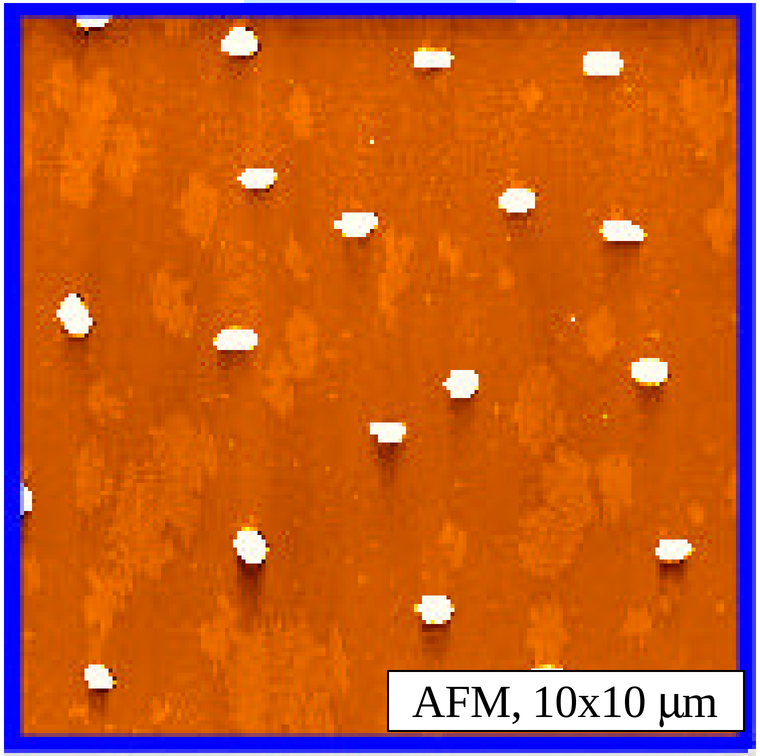
Play with surfactants

Target : $SmFe_2$



SEM, 6x6 µm

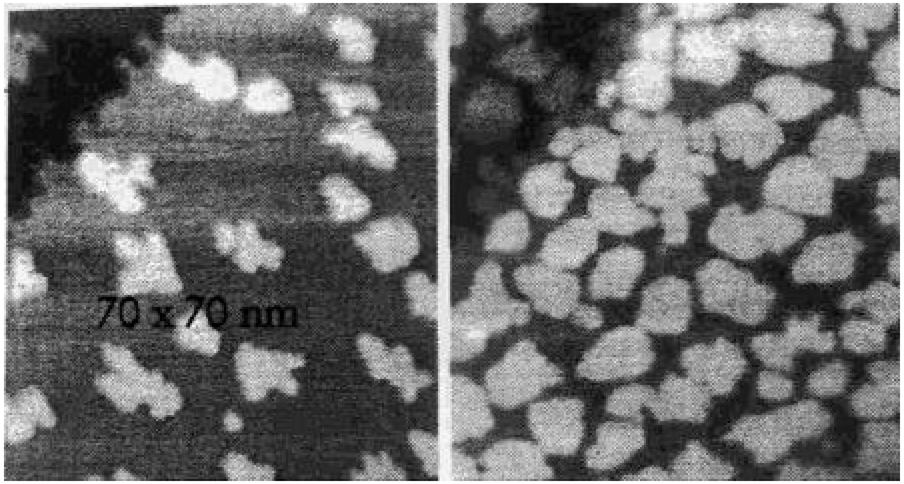
Target : Fe



AFM, 10x10 µm

Play with coverage

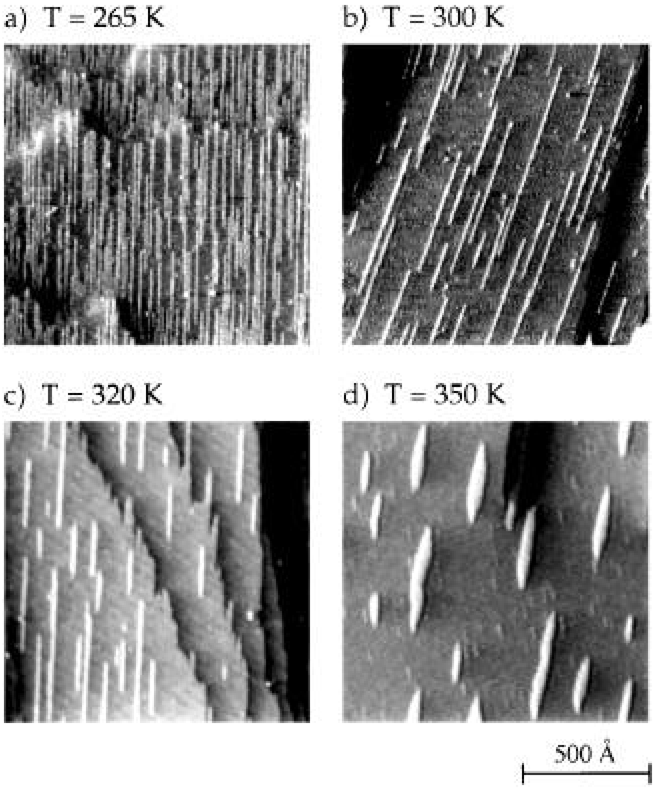
Fe/W(110)



H.J.Elmers *et al.*, Phys.Rev.Lett.73, 898(94)

Play with symmetry and temperature

Cu/Pd(110)



J.P.Bucher *et al.*, Europhys.Lett.27, 473(93)

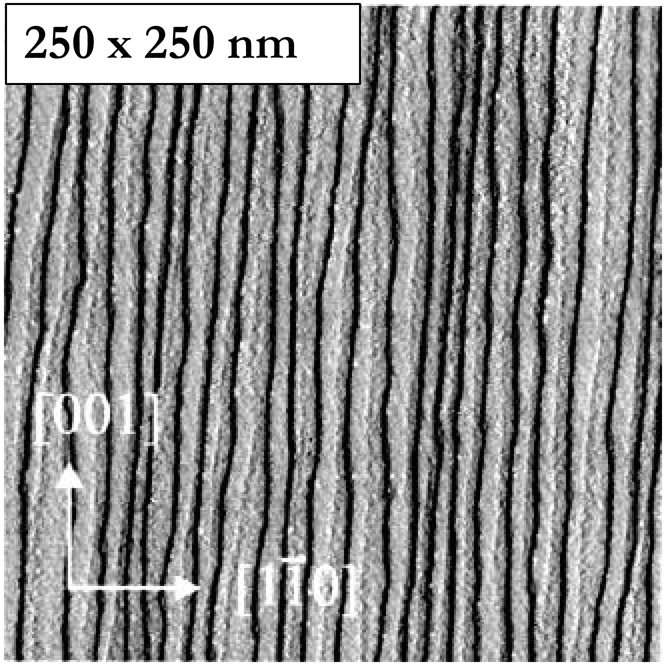
Very general phenomenon : many systems are suitable.

I. Overview of self-organization processes

Self-assembly + 'long-range' positional order between dots.

Dot-dot interactions << dot-substrate : the organization must be supplied by the substrate

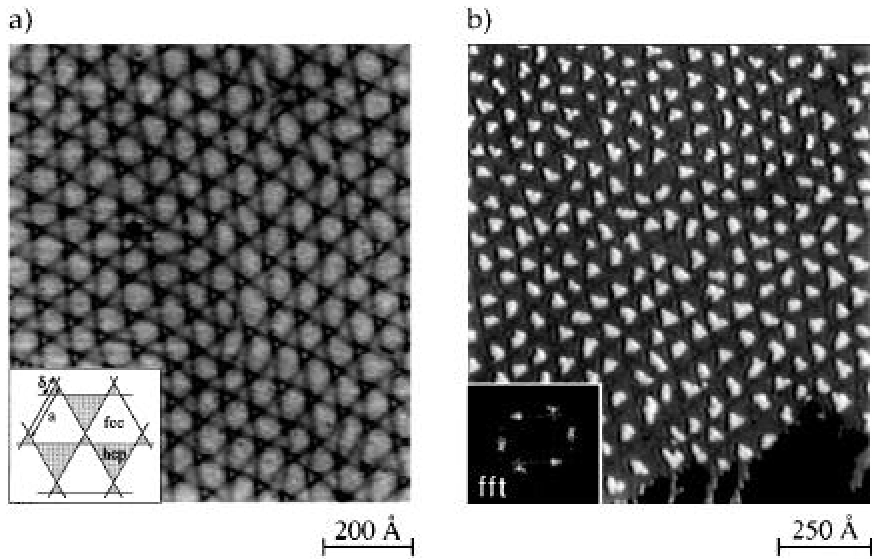
Vicinal surfaces



J.Hauschild *et al.*, Phys.Rev.B57, R677(1998)

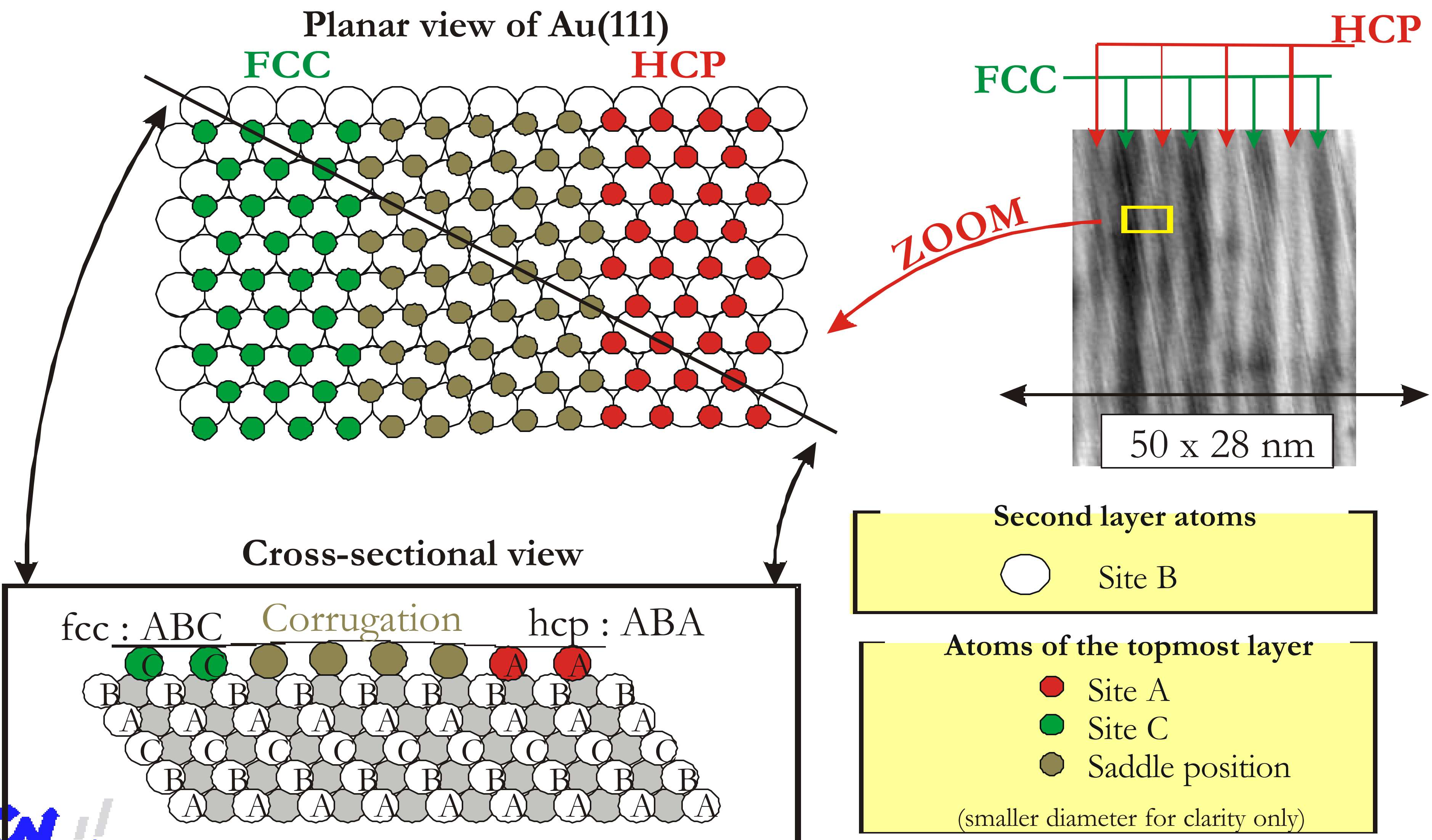
Fe(0.5ML)/W(110)

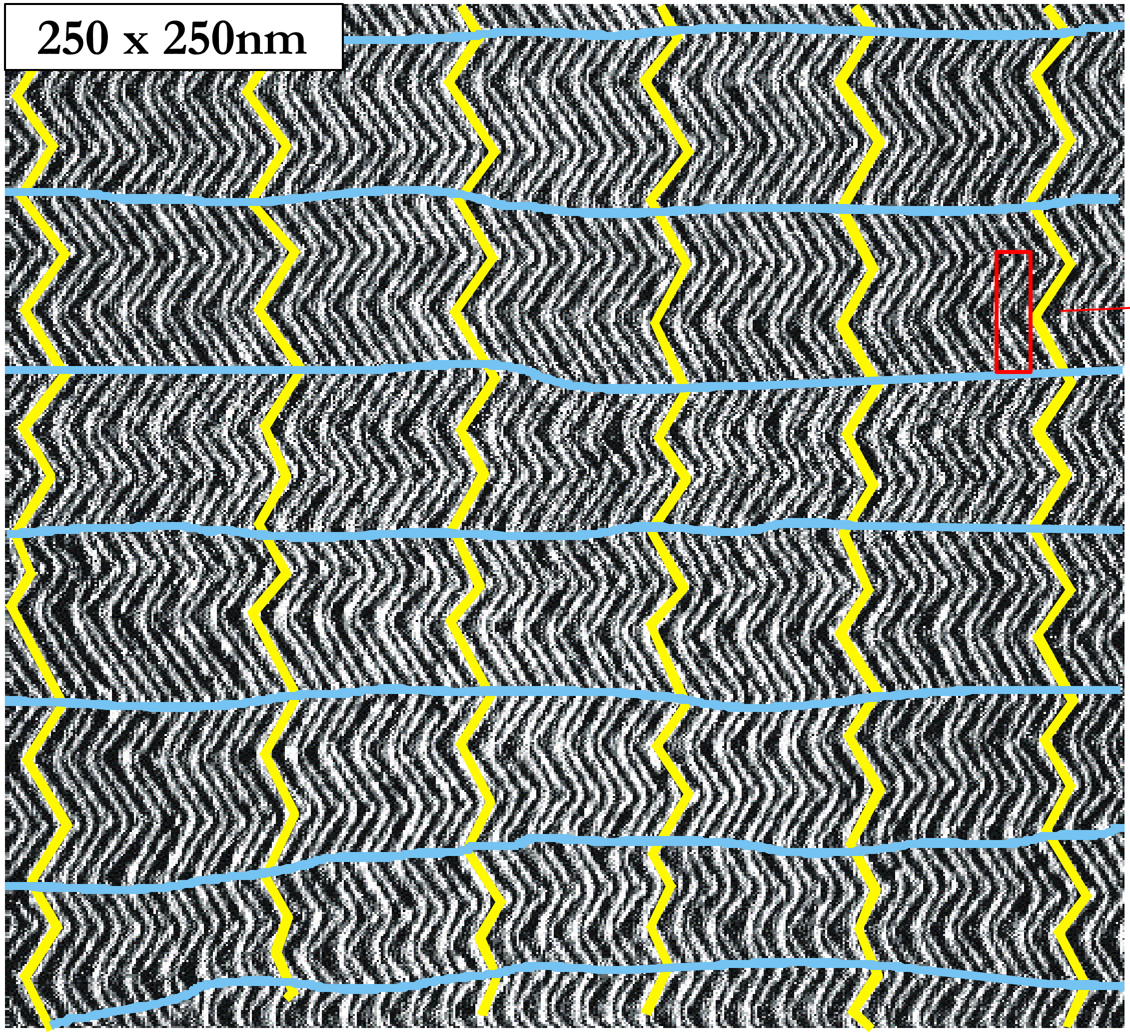
Overlayer dislocations



H.Brune *et al.*, Nature 394(6692), 451 (1998)

Ag(110K)/Ag(2ML)/Pt(111)


Planar view of Au(111)
FCC
HCP
HCP
FCC
ZOOM
50 x 28 nm
Cross-sectional view
fcc : ABC
Corrugation
hcp : ABA
C C A A
B B B B B B B B B
A A A A A A A A A
C C C C C C C C C
B B B B B B B B B
A A A A A A A A A
Second layer atoms
Site B
Atoms of the topmost layer
Site A
Site C
Saddle position
(smaller diameter for clarity only)



Corrugation ~ 0.2 Å

Unit cell size :

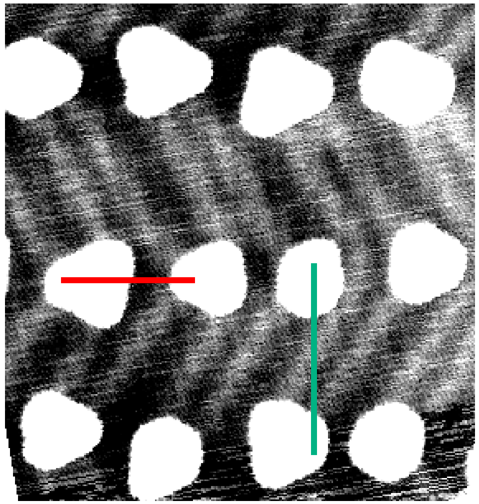
~ 7.5 x 25nm

↳ Isotropic surface relaxation

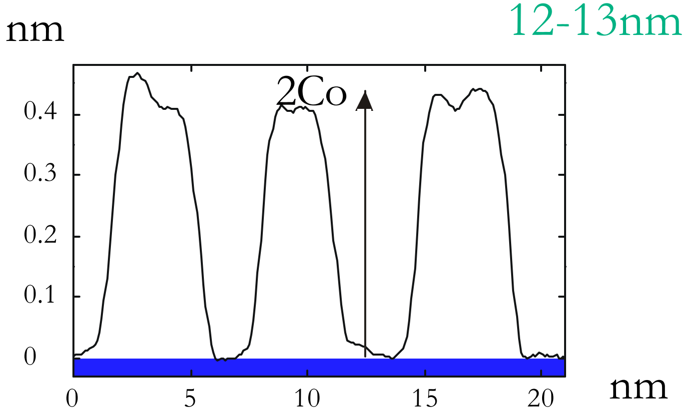
J. V. Barth et al., Phys. Rev. B 42 (15), 9307 (1990)

A.R. Sandy et al., Phys. Rev. B 43 (6), 4667 (1991)

- Co, Ni, Fe : Nucleation at the elbows of the chevrons



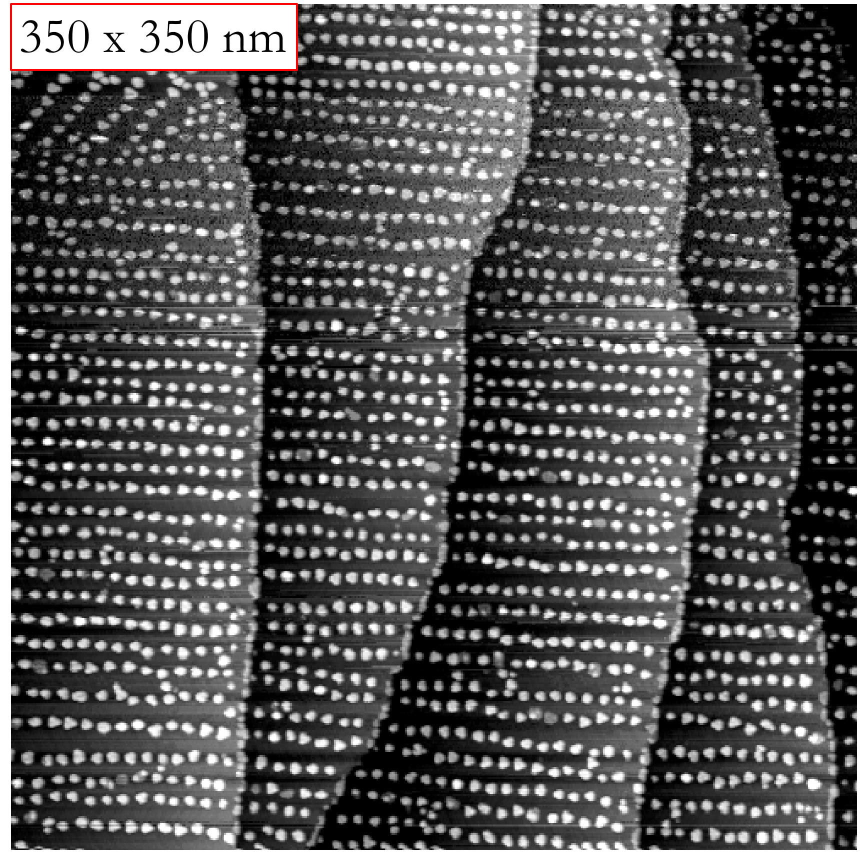
(0.20AL Co@300K)



Fe, Ni : 1 AL-high dots

D.D. Chambliss et al., PRL **66**, 1721 (1991)

B.Voigtlander et al., PRB **44**, 10354 (1991)

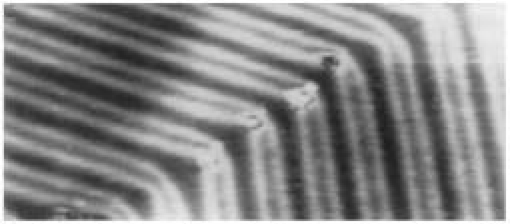


- Medium-ranged organization
- Steps do not necessarily disturb the order [see also: V.Repain, Europhys. Lett., **47** (4), 435 (1999)]

Fe, Co, Ni (etc.) nucleation: atomic place exchange mechnism with Au atoms

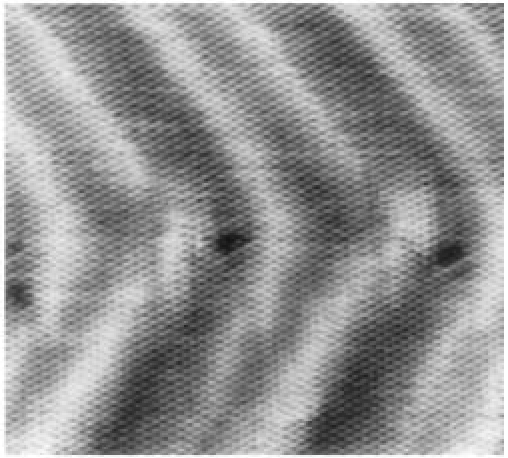
Example: 0.002ML Ni@300K

a)



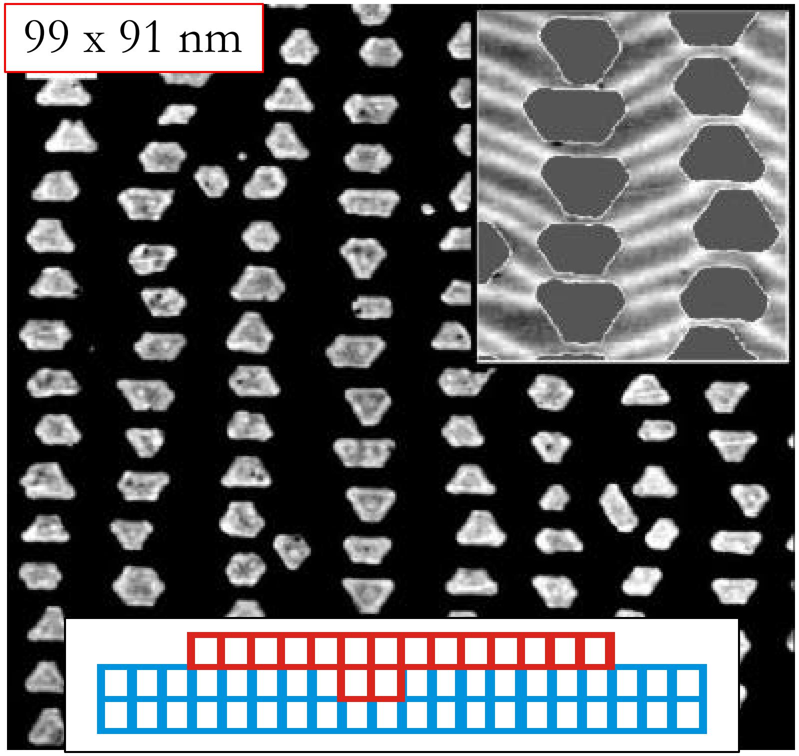
Element	Surface free energy (eV)	Heat of sublimation (eV)
Ag	0.50	2.95
Al	0.56	3.39
Cu	0.69	3.51
Au	0.72	3.79
Ni	0.90	4.45
Co	0.94	4.40
Fe	0.96	4.32

b)



J.A.Meyer et al., Surf.Sci.**365**, L647 (1996)

0.25ML Ni@300K : 1ML-high dots

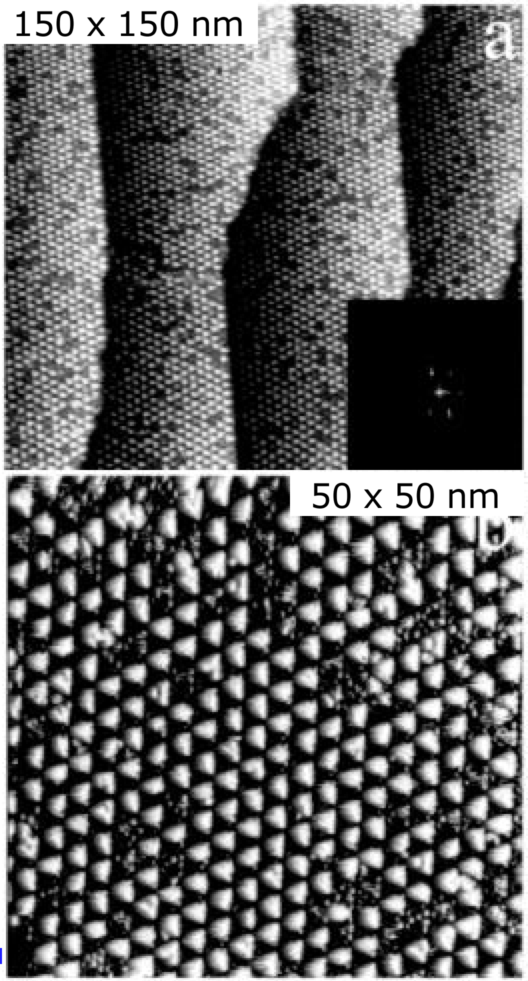


W.G.Cullen *et al.*, Surf.Sci.**420**, 53 (1999)

Leading parameter : deposit has a higher surface energy.
(and Au atoms stress near chevrons)

Intrinsic reconstruction

Tl(0.20ML) / Si(111)7x7

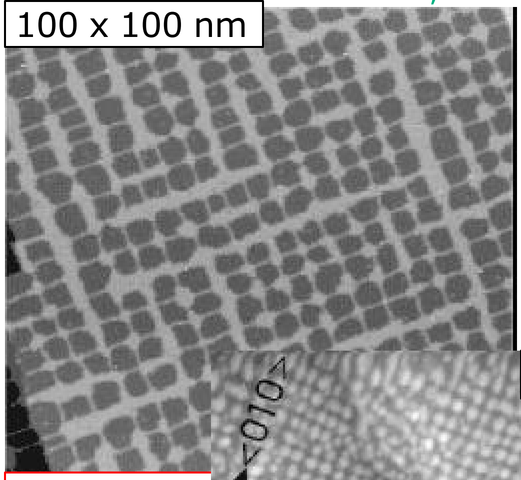


L.Vitali, Phys.Rev.Lett.**83**(2), 316 (1999)

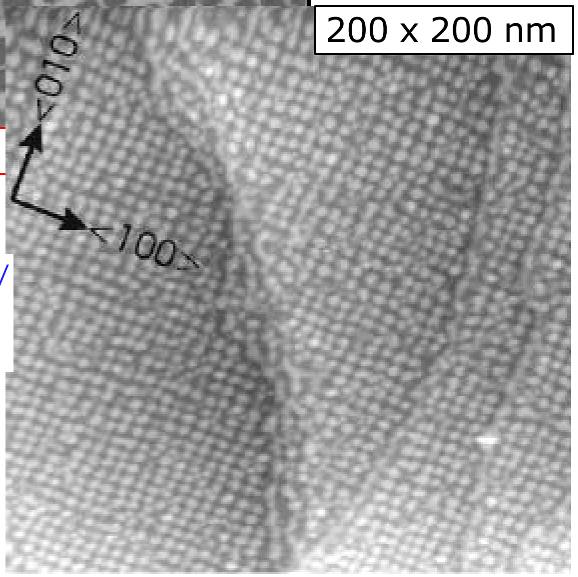
Gas adsorbtion

N on Cu(100)

T.M.Parker, Phys.Rev.**B56**, 6458(1997)

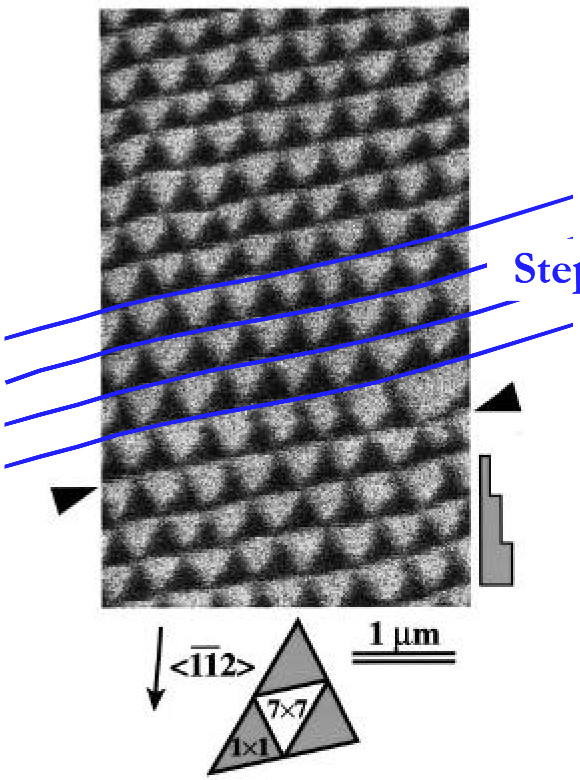


Au(0.67ML)/ N-Cu(100)



H. Ellmer et al., Surf. Sci. 511, 183 (2002)

- Superstructure of reconstructions: **7x7 and 1x1 triangles** on Si(111), misoriented along <11-2>



H.Hibino, PRB**58**(12), R7500 (1998)

- **Co on vicinal Au(111)**

Steps and reconstructions

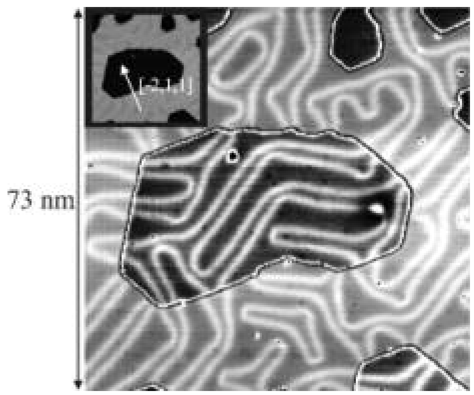
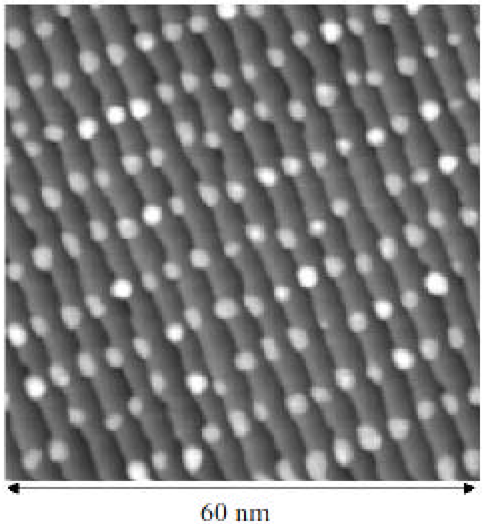


FIG. 4. STM image of a few vacancies islands. T=300 K. In inset, the raw STM image. The same image is shown where the corrugation due to the terrace levels has been sub tracted in order to enhanced the reconstruction lines.

Reconstructions lie perpendicular to steps

0.2ML Co



Nucleation both at steps and at reconstructions

V. Repain, Europhys. Lett. **47**, 435 (1999)
V. Repain, Europhys. Lett. **58**, 730 (2002)

(see also H. Brune et al.)

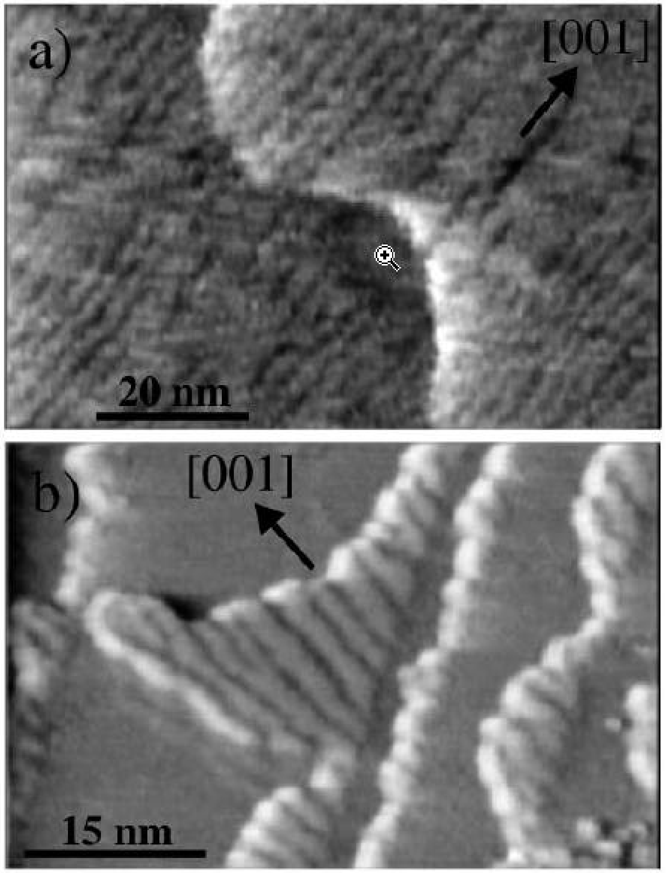
- Self-organization generally from substrate, not from deposit !
- Relies on surface science fundamental investigations

- Good pattern does not necessarily imply good overgrowth

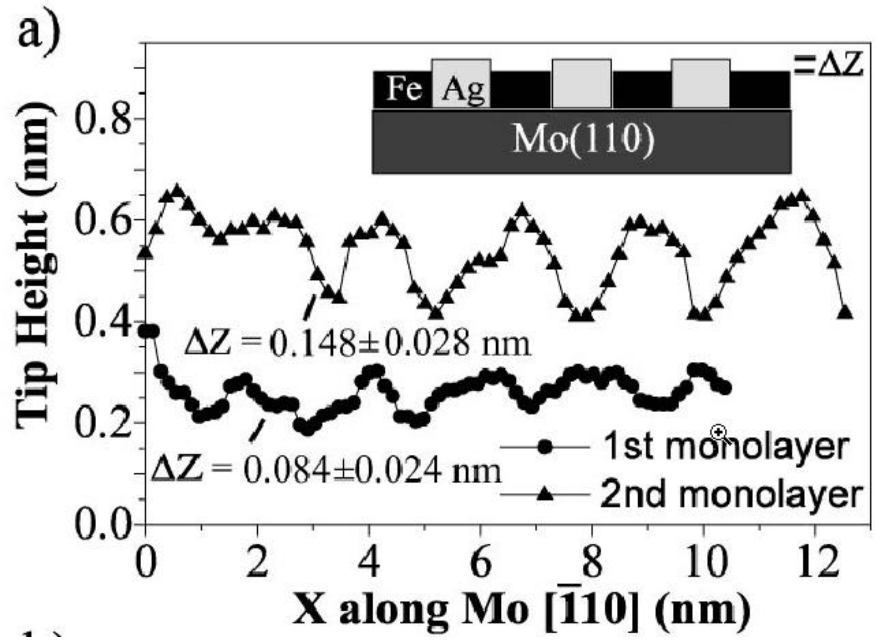
Lateral modulation in ultrathin films

FeAg/Mo(110)
1AL

CoAg/Mo(110)
0.3AL



E. D. Tober et al., PRL81, 1897 (1998)

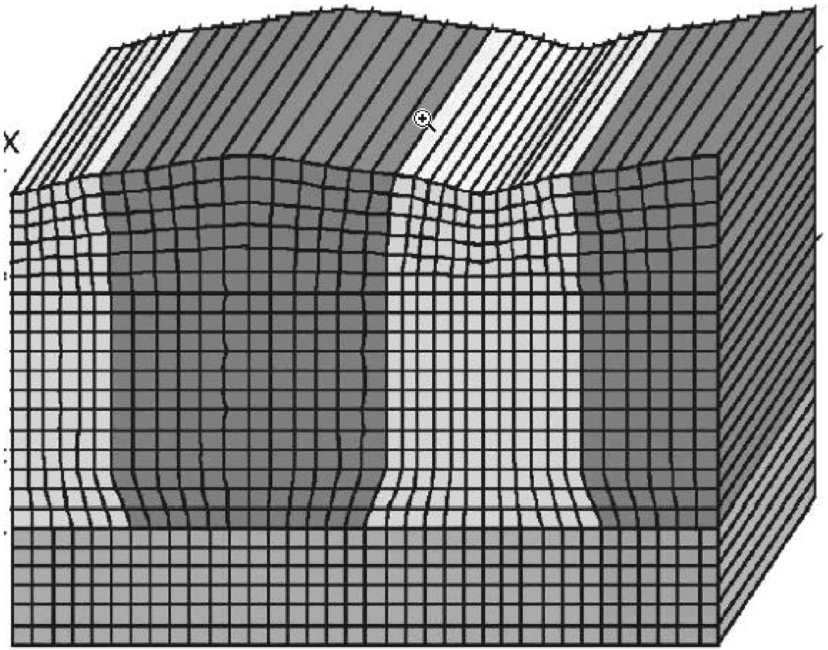


Self-organization due to strain:

- Immiscible materials
- Compensated lattice mismatch
- Period ~ thickness

Principle

Strain release
Here: accumulation during growth

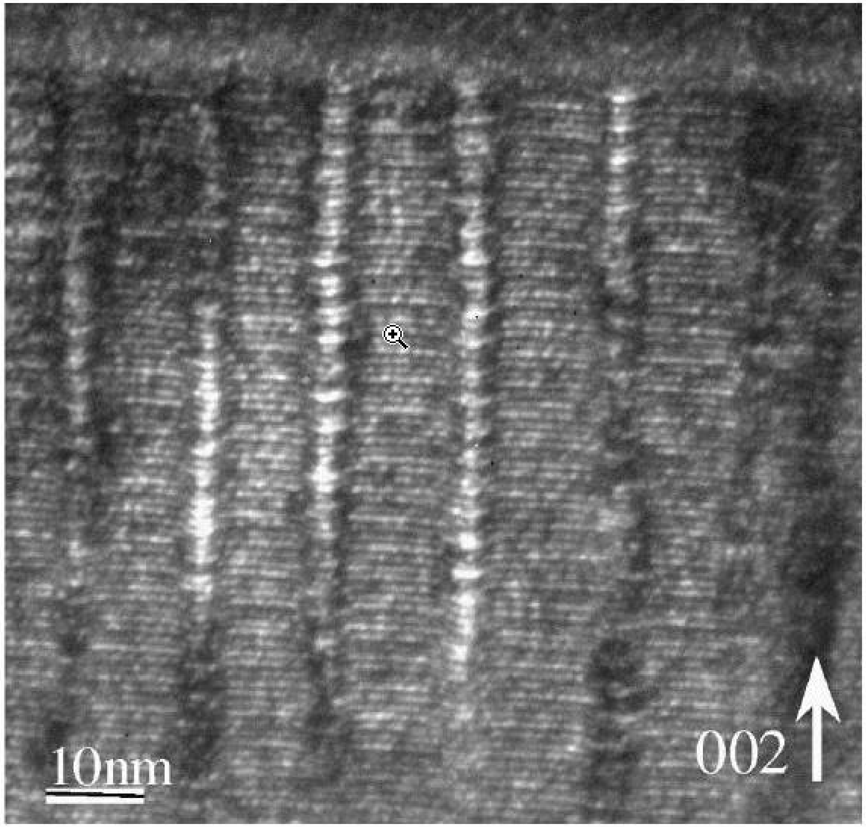


R. D. Twesten et al, PRB60, 13619 (1999)

[Cf Grinfeld instability: M. A. Grinfeld, Dok. Akad. Nauk SSSR 290, 1358 (1986)]

Experiments

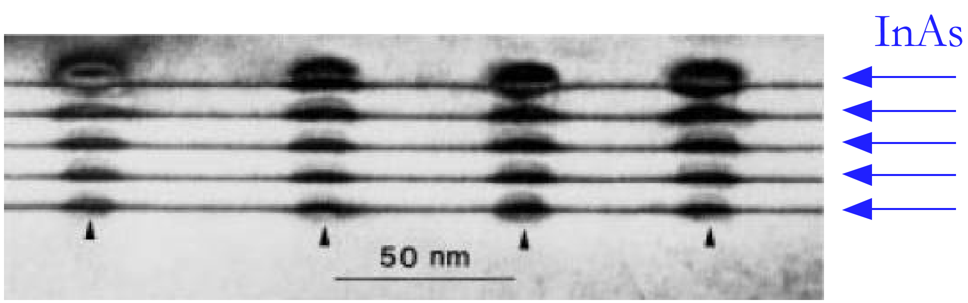
InAs/AlAs short-period multilayers



R. D. Twesten et al, PRB60, 13619 (1999)

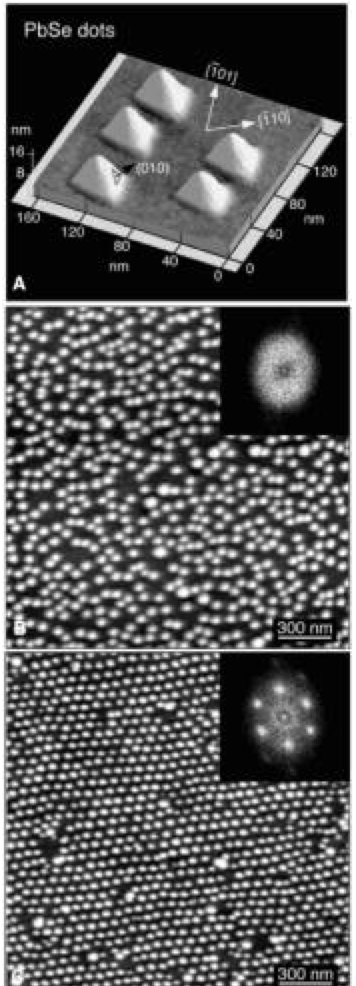
InAs / GaAs(100)

- Strain field in spacer layer :
  - vertical stacking of dots



Q.Xie, Phys.Rev.Lett.75(13), 2542 (1995)

- From 2D assembly to 3D- organization



Zoom :
facetted dots

Single layer :
Self-assembly,
no organization.

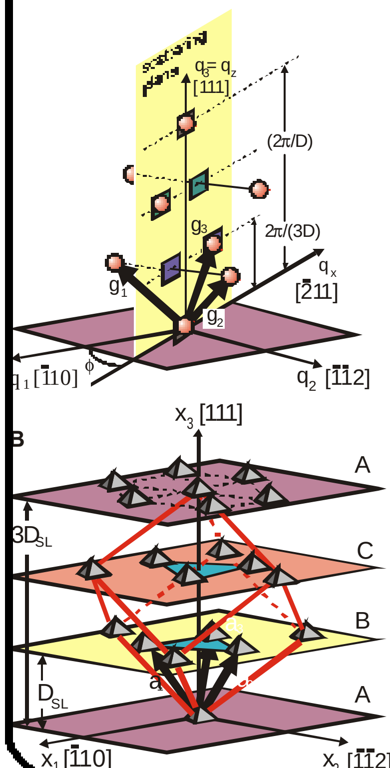
Multilayers :
improvement of
the organization.

(After 60 layers)

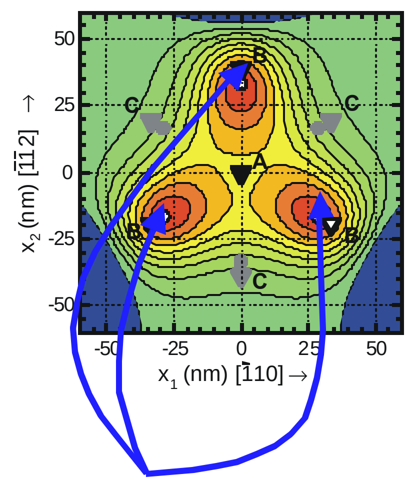
PbSe / PbTe(111)

- Anisotropic elastic media
  - f.c.c. superstacking, not vertical.

X-Ray diffraction



Anisotropic in-plane distribution of elastic energy density

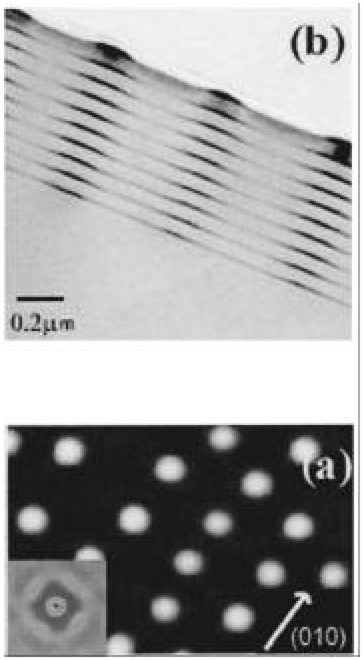


Misfit reduced by 2%
preferential nucleation

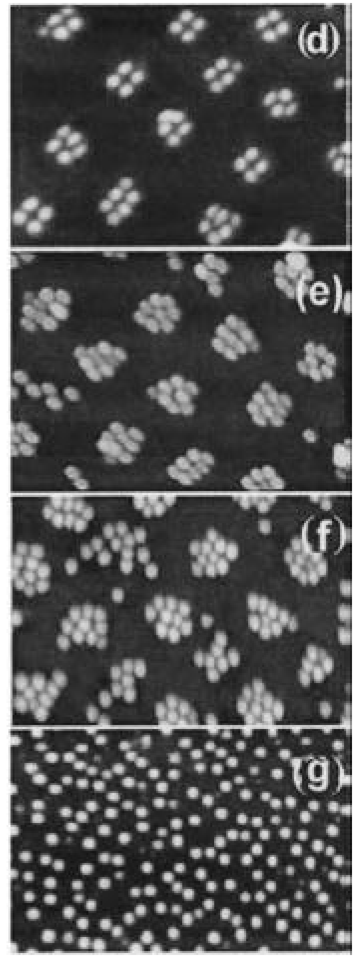
G.Springholz, Science **282**, 734 (1998)

Step 1
multilayers for organization

Ge islands/Si(001)



Step 2
use as a template



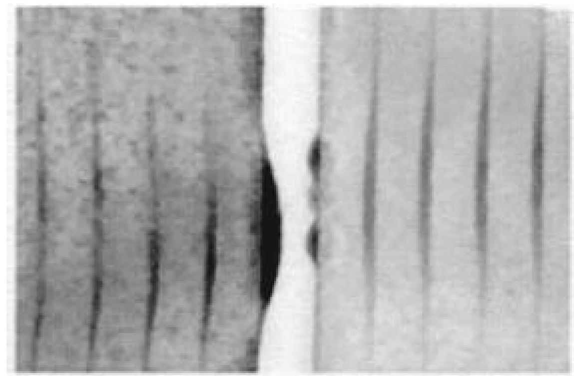
35nm

45nm

65nm

200nm

HREM view



Template Overgrowth

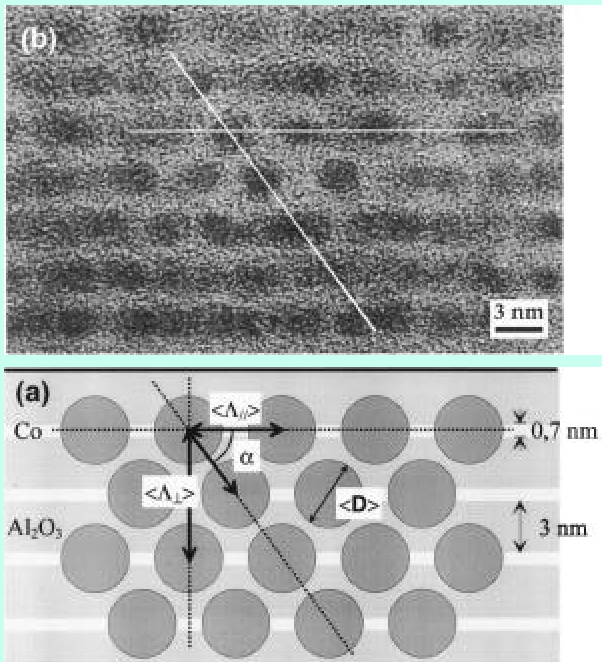
G. Capellini *et al.*, APL82, 1772 (2001)

Co/Al_2O_3 granular system (sputtering)

$(Co: 0.7\ nm/Al_2O_3: 3\ nm)_{14}$

REAL SPACE

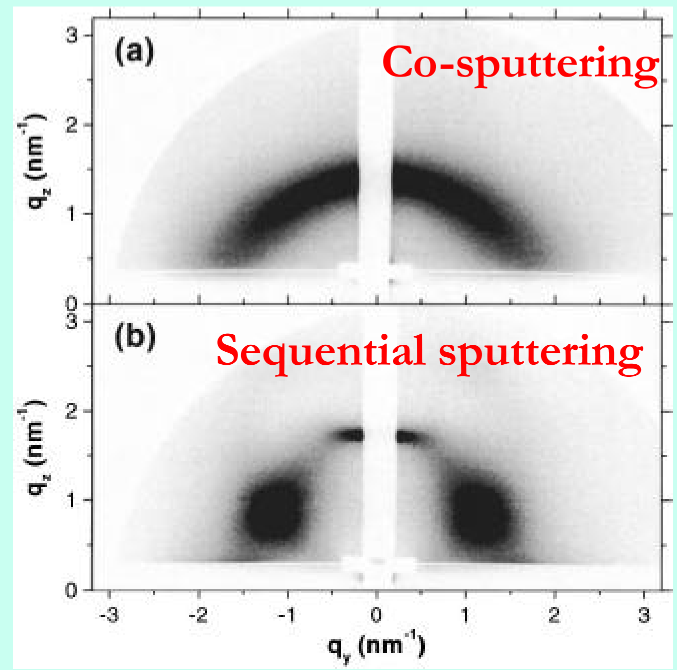
TEM cross-section (Sequential sputtering)



RECIPROCAL SPACE

GISAXS:

Grazing Incidence Small Angle X-Ray Scattering



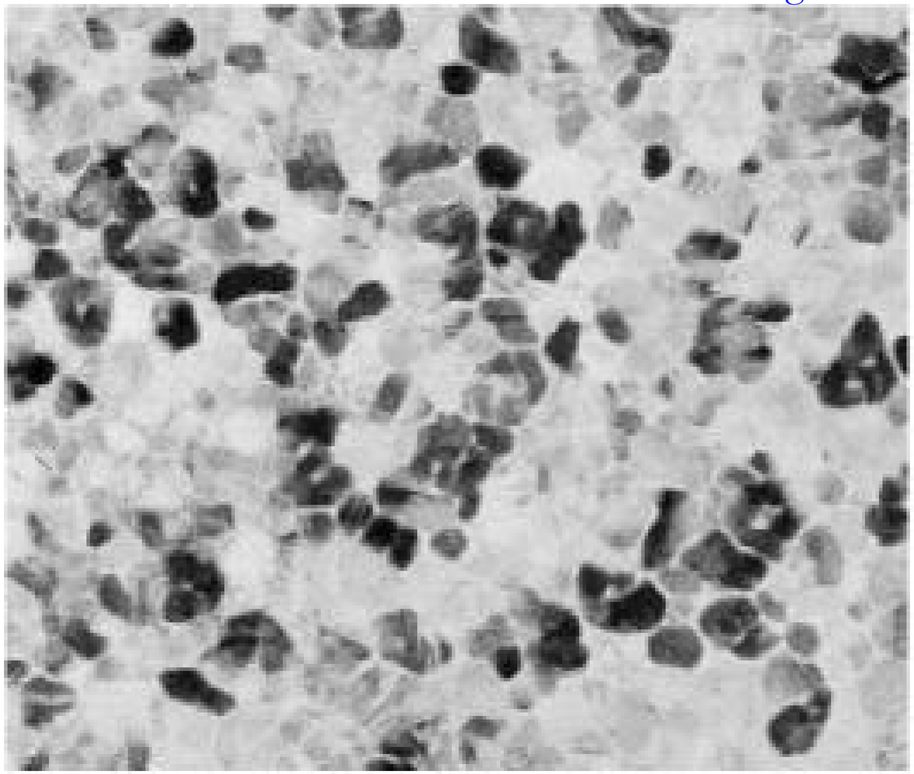
➢ FCC vertical stacking (not epitaxial !)

D. Babonneau, Appl. Phys. Lett. 76, 2892 (2000)

Hard disk media

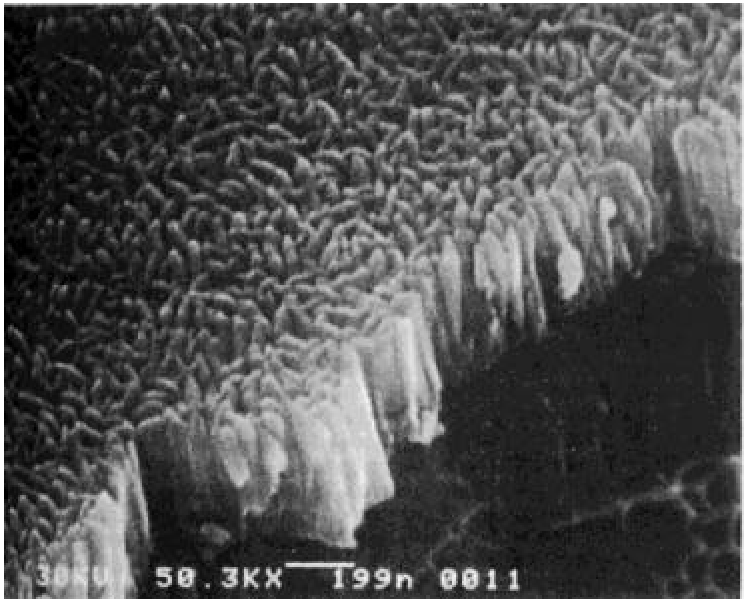
45 Gbit/in^2 demo thin film media for magnetic recording (Seagate)

8.5nm diameter grains



High Resolution Electron Microscopy (HREM), top view

Image: courtesy D. Weller - Seagate ; N. Dempsey - LLN/CNRS



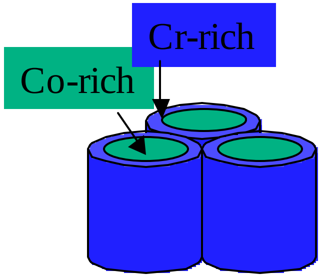


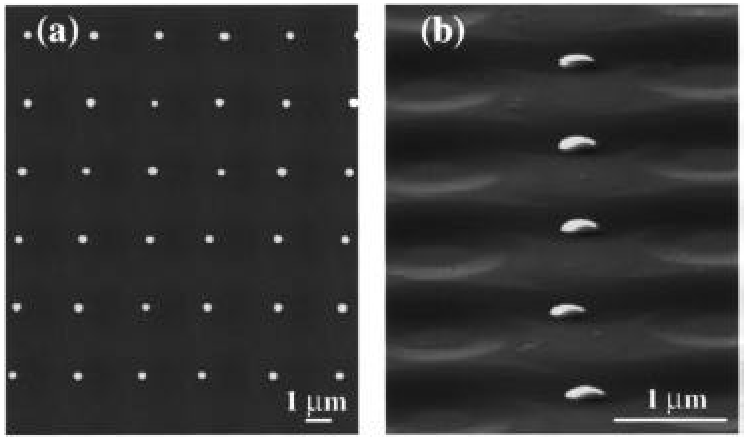
Image: courtesy L. Ranno

Cf columnar CoFe2O4-BaTiO3 (Ramesh Ramamoorthy)

I. Overview of self-organization processes

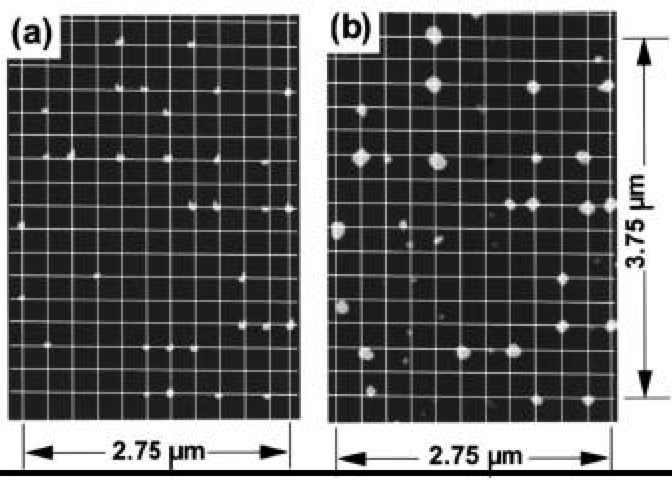
- Lithography + Etching + Annealing → holes

Au/Si



Y.Homma, Appl.Phys.Lett. **74**(6), 815 (1999)
T.Ogino, Surf.Sci.386, 137 (1997)

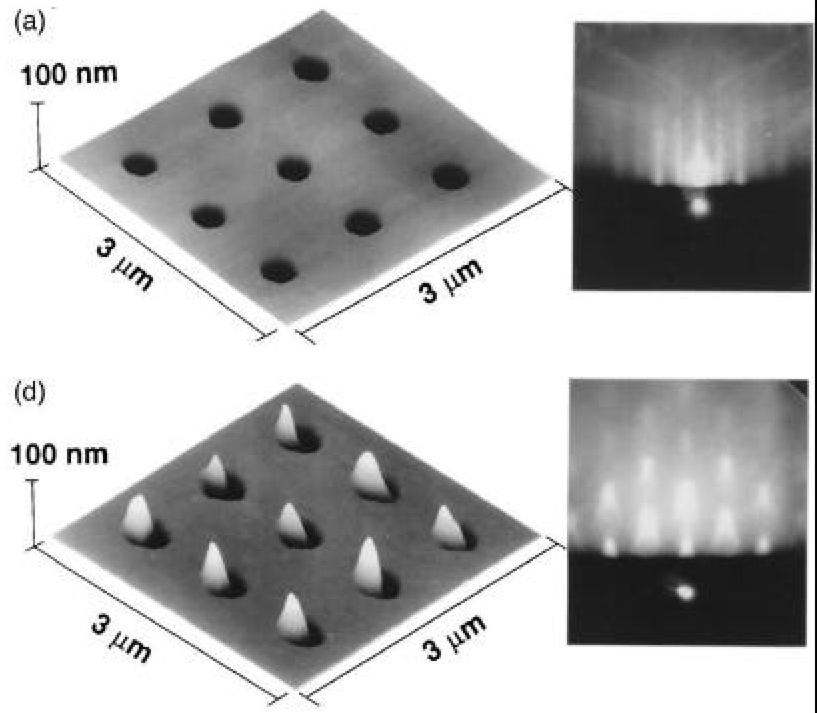
- Nanoimprint → Si mesas → Ge / Si



T.I.Kamins, Appl.Phys.Lett. **74**(12), 1773 (1999)

- In-situ lithography on oxide layer

InAs / GaAs

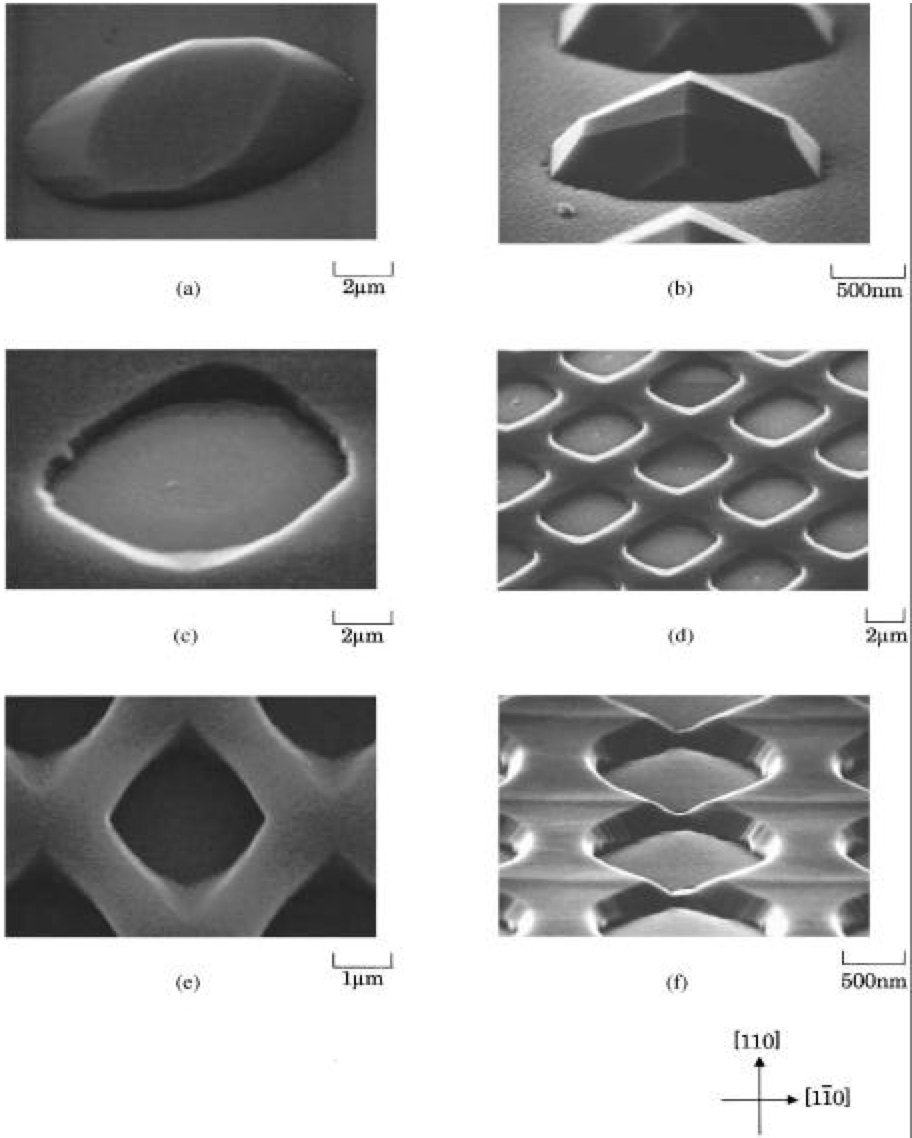


T.Ishikawa, Appl.Phys.Lett. **73**(12), 1712 (1998)

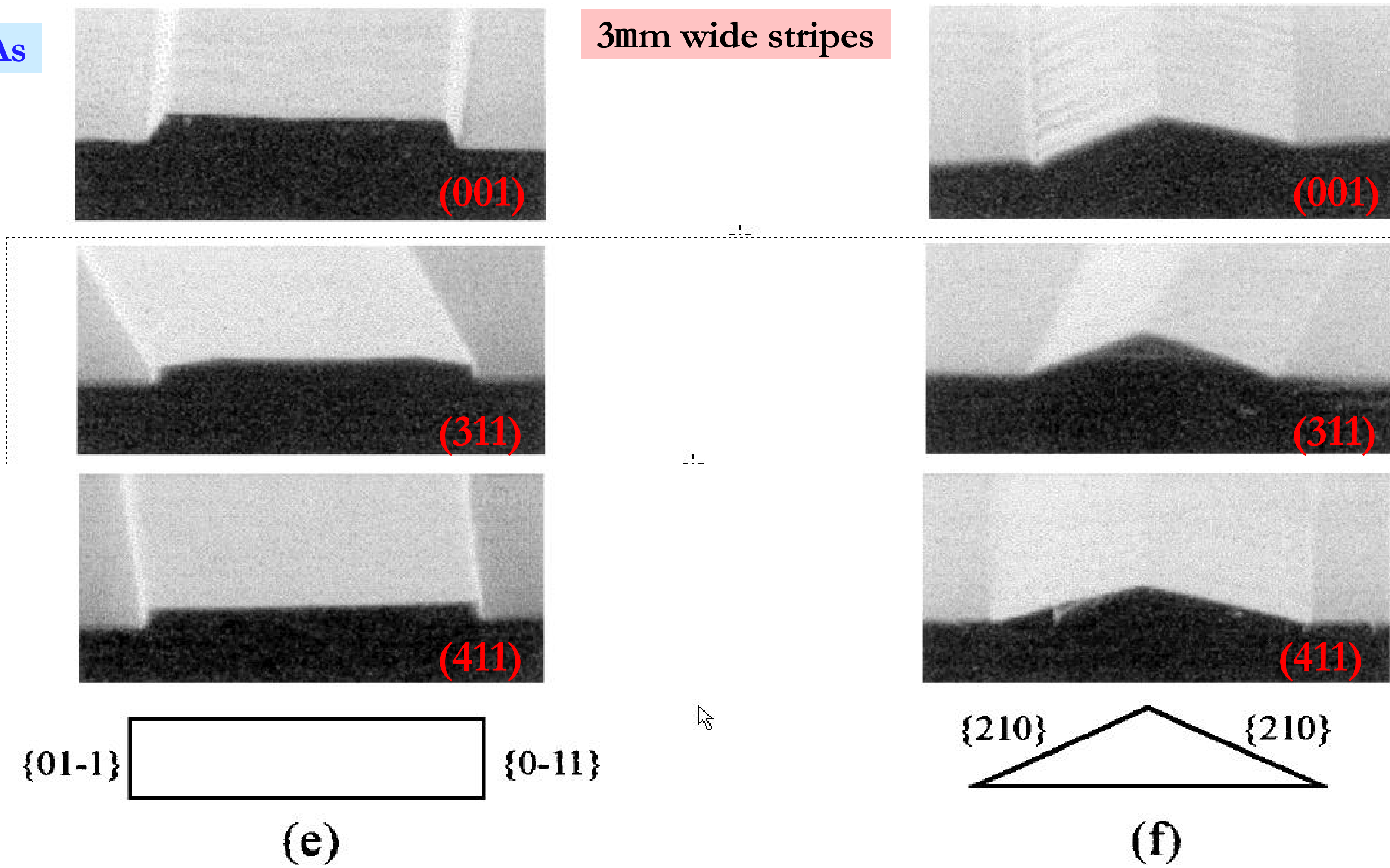
GaAs / GaAs

- **Step 1**: Deposition of SiO_2 layer
- **Step 2**: Ex-situ lithography on oxide layer, plus wet chemical etching
- **Step 3**: Growth of GaAs through windows, either in dot or antidot array.

H. Hasegawa, J. Cryst. Growth 227-228, 1078 (2001)



GaAs / GaAs



H. Hasegawa, J. Cryst. Growth 227-228, 1078 (2001)

Recently achieved for metals (Co/Ru(0001))

ELSEVIER

Surface Science 432 (1999) 37–53

surface science

www.elsevier.nl/locate/susc

How to control the self-organization of nanoparticles by bonded thin layers

A. Bourret *

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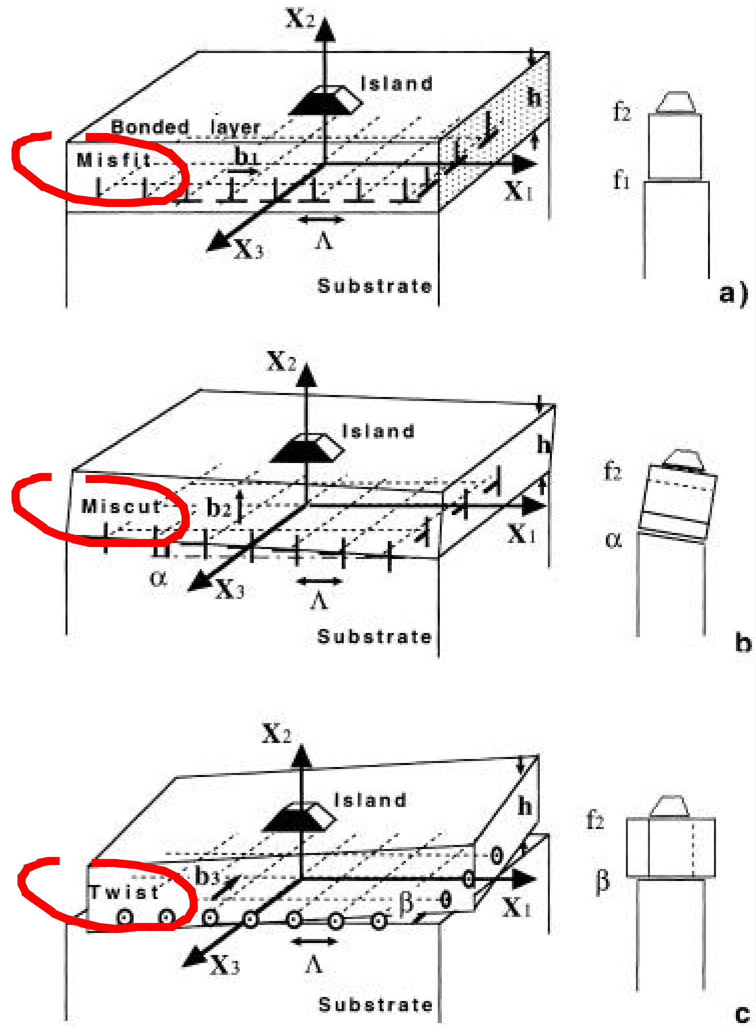
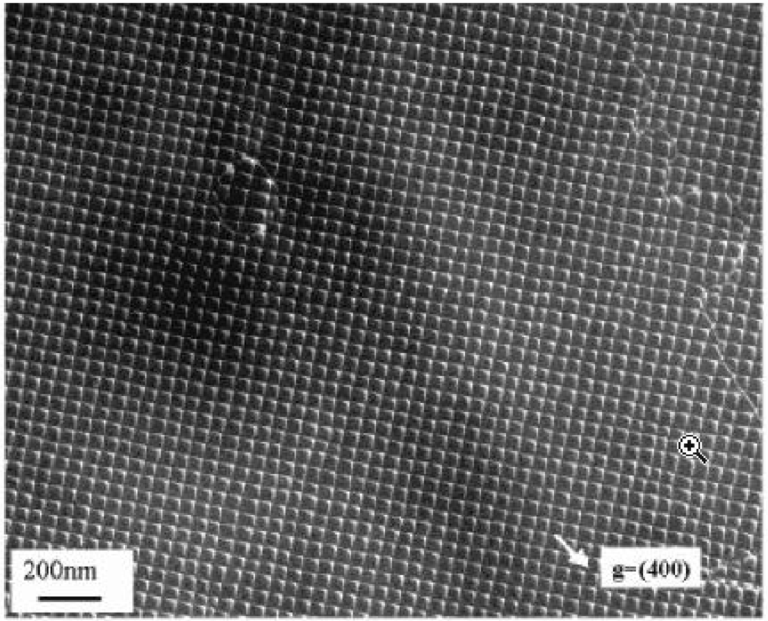
Received 21 December 1998; accepted for publication 6 April 1999



- Substrate bonding and smart cut process.
  - array of dislocations arise from either:
    - Misfit
    - Miscut
    - Twist

Step 1: wafer bonding

Screw dislocations

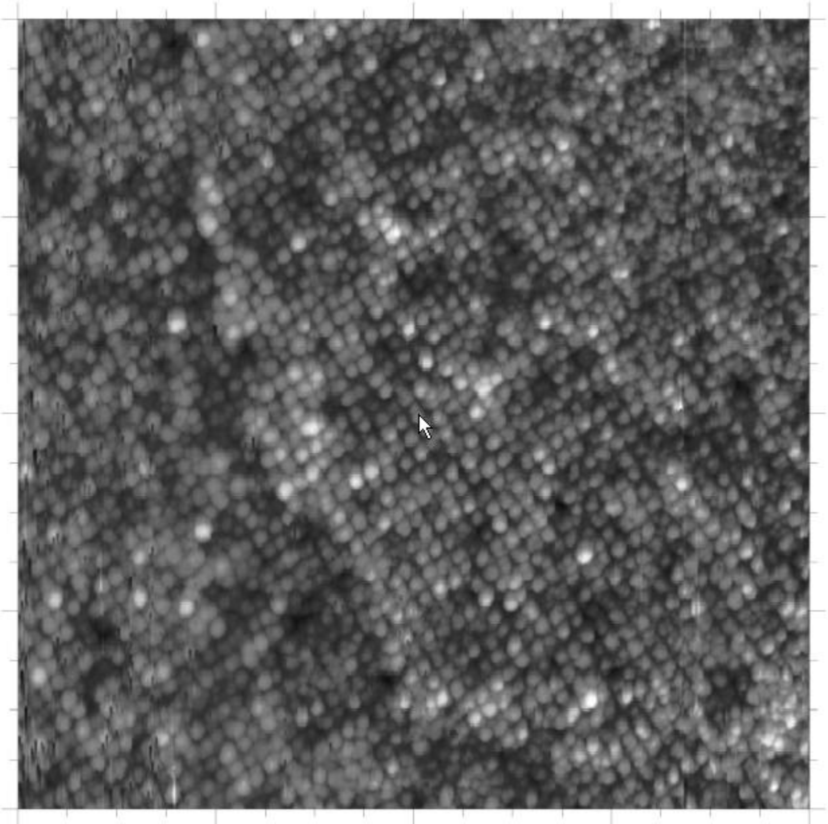


J. L. Rousseau *et al.*, APL80, 4121 (2002)

CEA-Grenoble

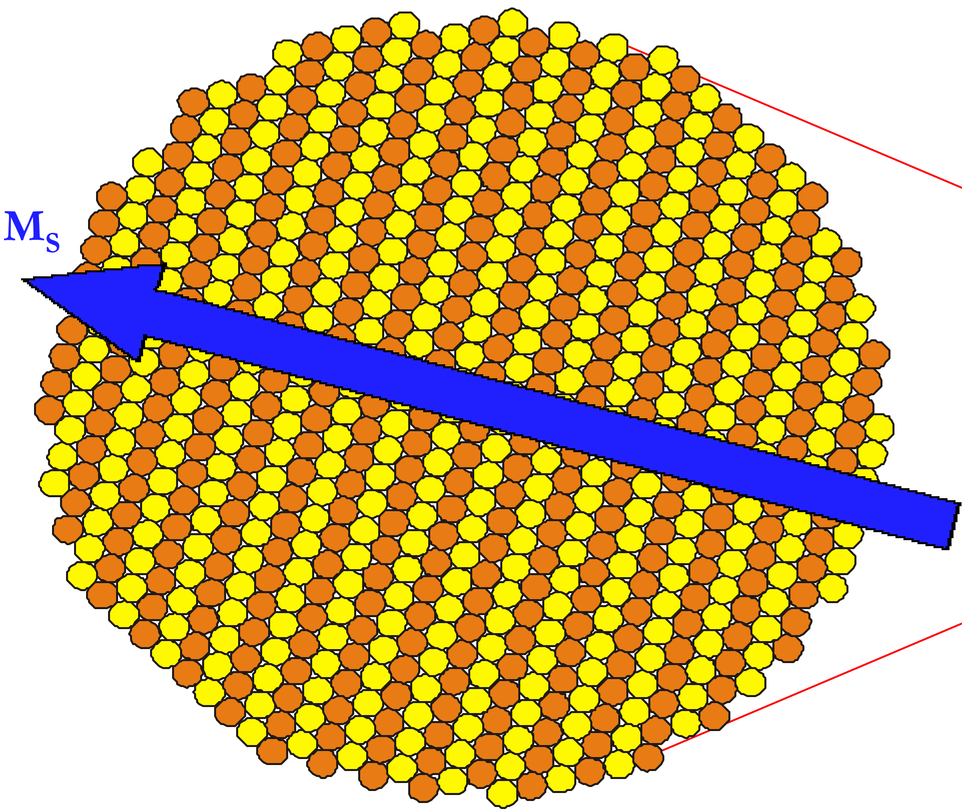
Step 2: template for growth

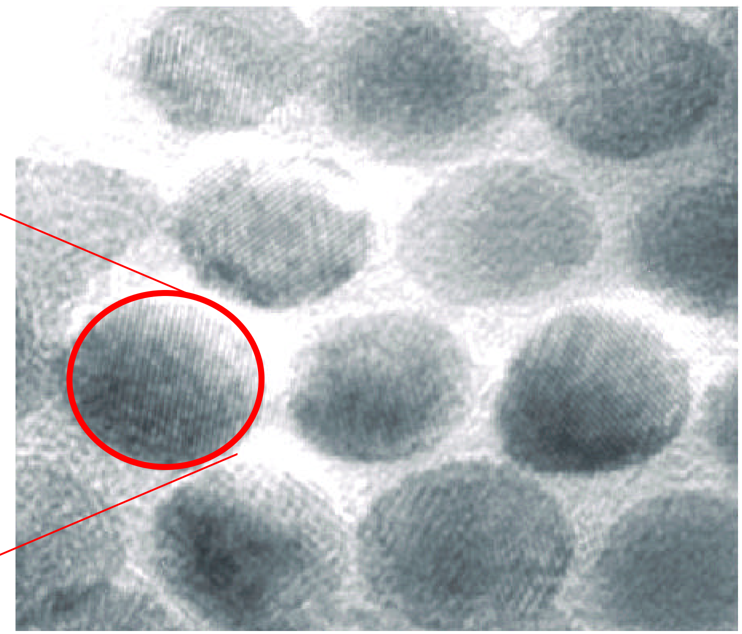
1. Chemical etching > corrugation enhanced
2. Growth (here: Ge/Si)



J. Eymery, Habilitation (2003)

$L1_0$ phase : alternation of Fe and Pt monoatomic planes
↪ extremely high magnetocristalline anisotropy K





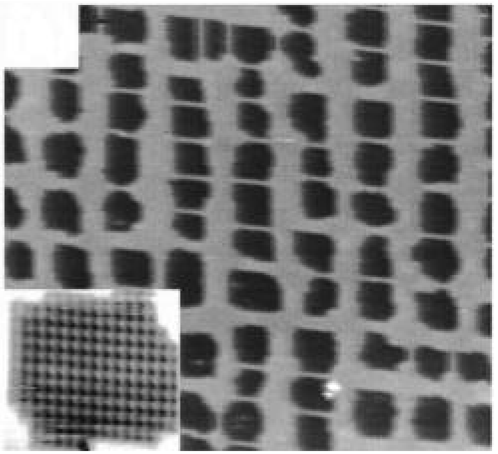
Random orientation of anisotropy axes

S. Sun, Science 287, 1989 (2000)

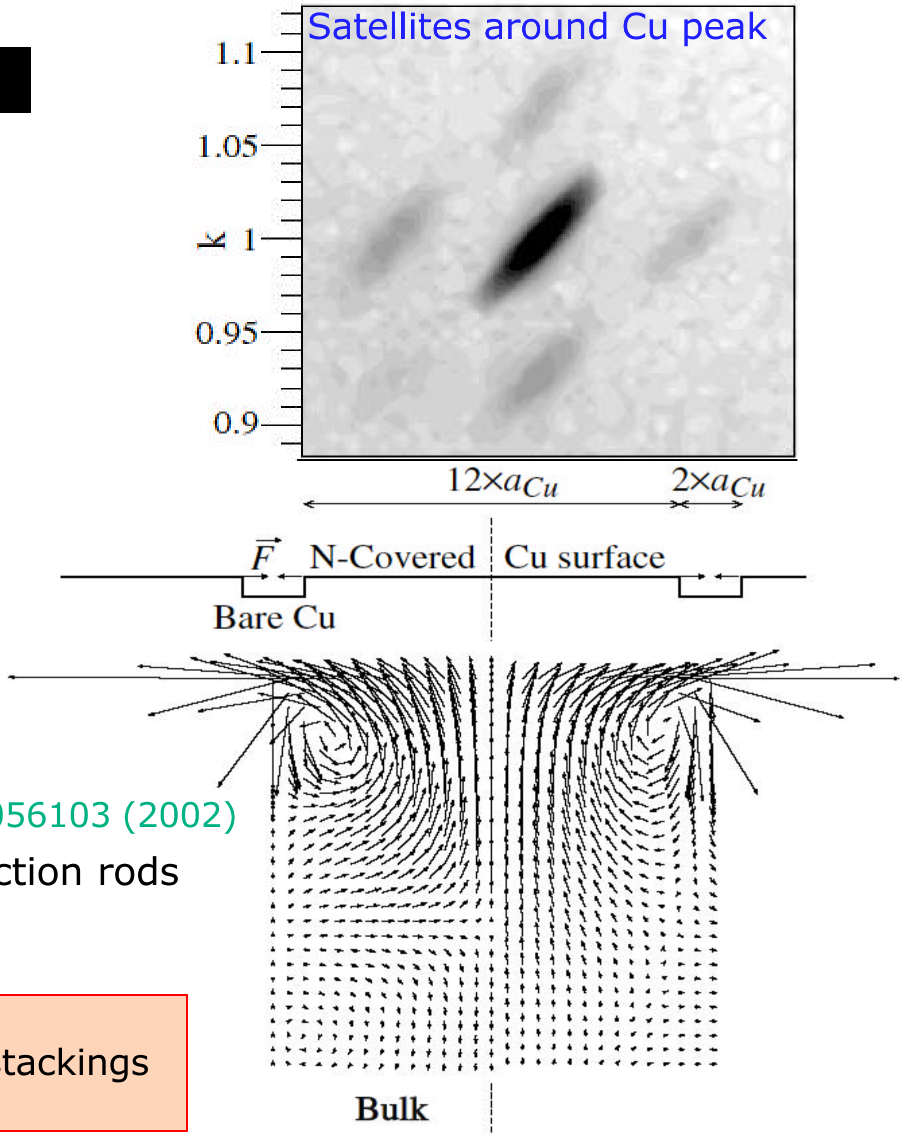
I. Overview of self-organization processes

SXRD: self-organized N/Cu(001)

0.2AL N/Cu(001)



S.L. Silva, APL76, 1128 (2000)
F.M. Leibsle, SS317, 309 (1994)



B. Croset, PRL88, 056103 (2002)

- Periodic surface strain give rise to satellite diffraction rods

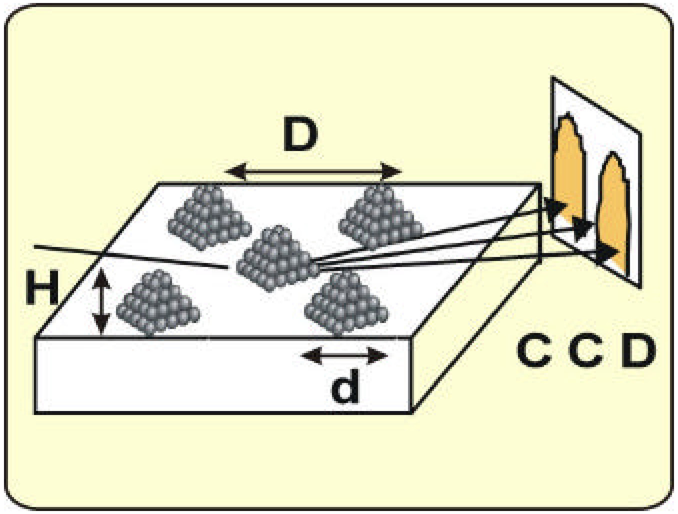
Other groups:
T. Metzger (ESRF, Grenoble): Quantum dots stackings
J. Eymery (CEA Grenoble): wafer bonding

GISAXS: Grazing Incidence Small Angle X-ray Scattering

Small Angle → **Objects >> atoms**

Grazing Incidence → **Surface sensitive**

PRINCIPLE



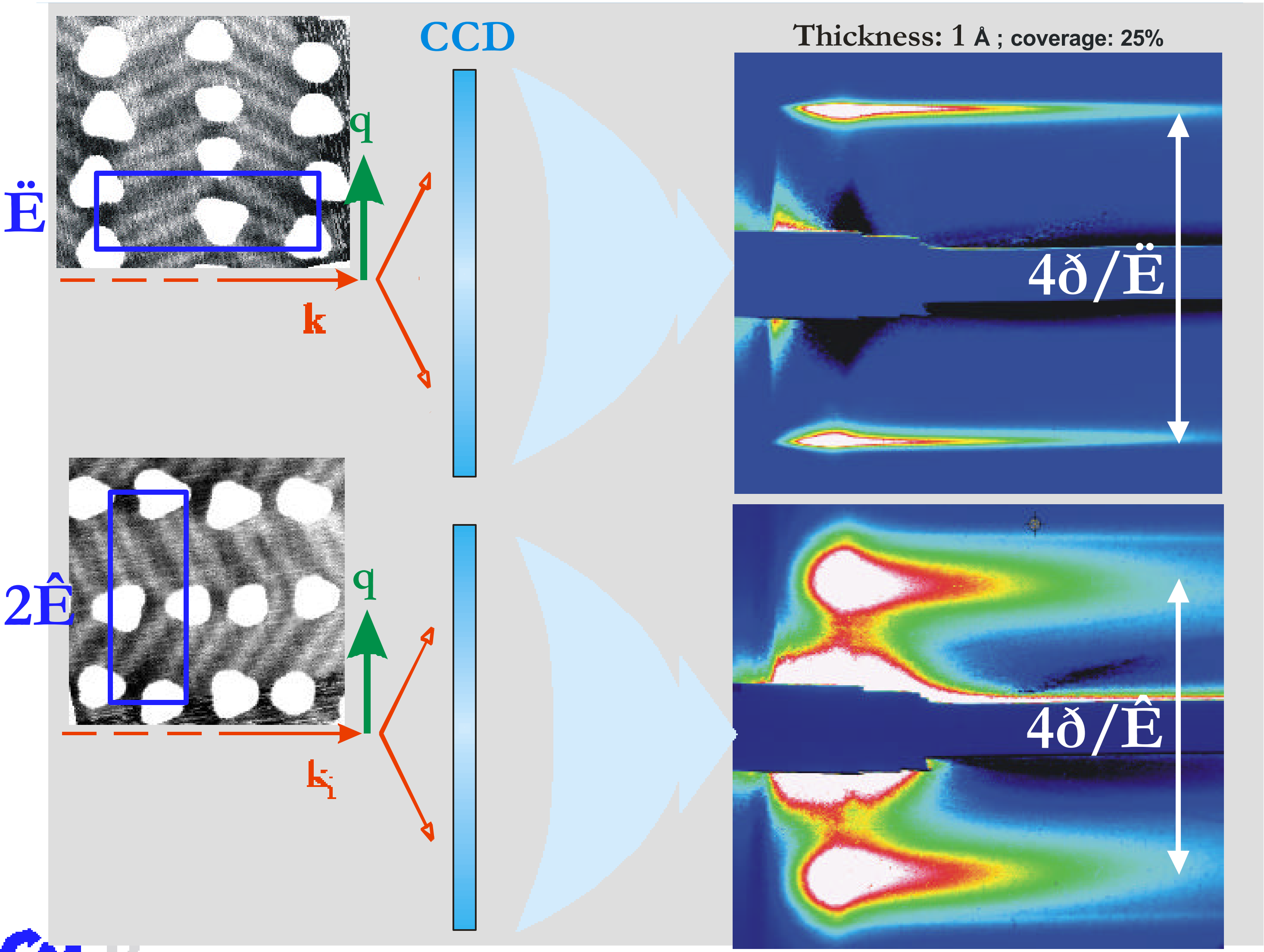
- In-plane / out-of-plane diffusion
- Probes size (H,d), shape, correlations

TECHNICAL ASPECTS

- ID32 beamline at ESRF
- In-situ under UHV:
  - real time
  - background substraction
- No window before sample : low background

G. Renaud et al., Science 300, 1416 (2003)

O. Fruchart et al., Europhys. Lett. 63, 275 (2003)

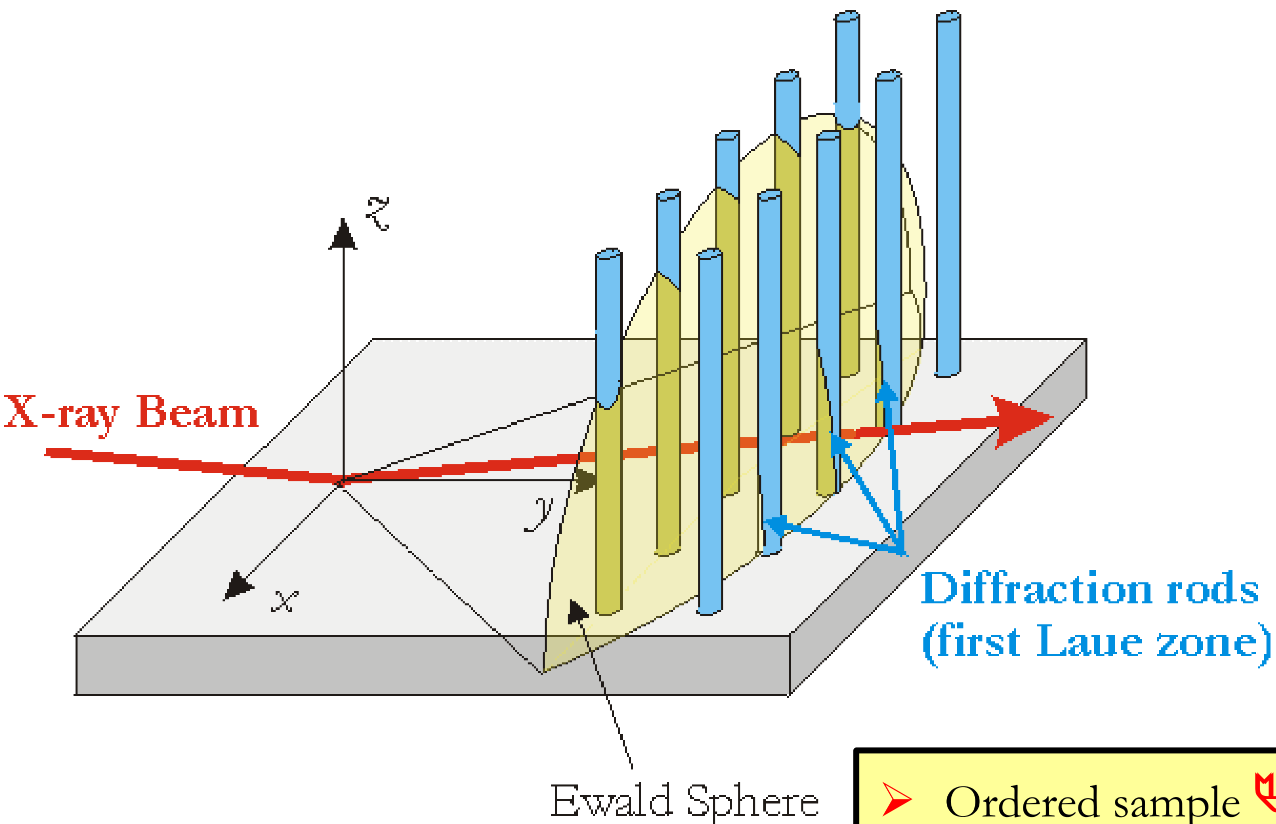


INTRA-ROW ORDER: SUPER-CRYSTAL

DQ/Q=3%

INTER-ROW ORDER: LIQUIDE-TYPE

K=8.5nm
s=2.1nm

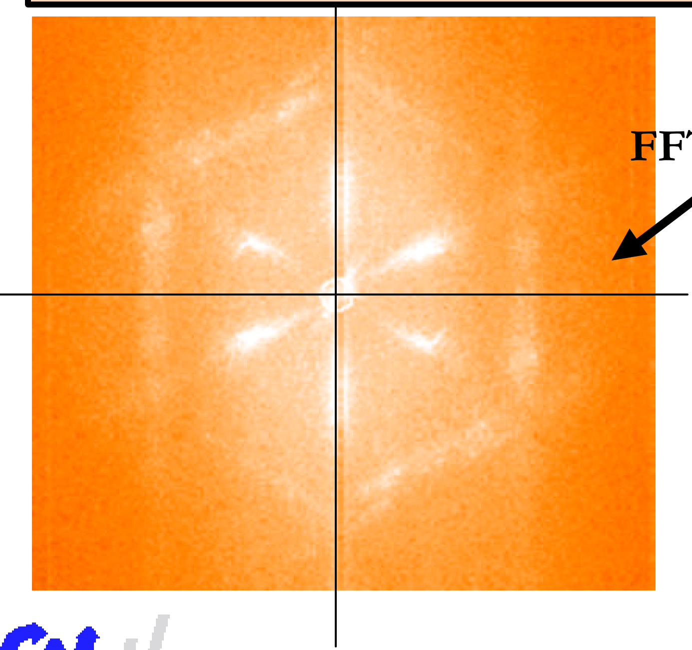


- Ordered sample ↳ 'super' reciprocal space ?
- Grazing incidence and 2D detector
  ↳ similarity with RHEED

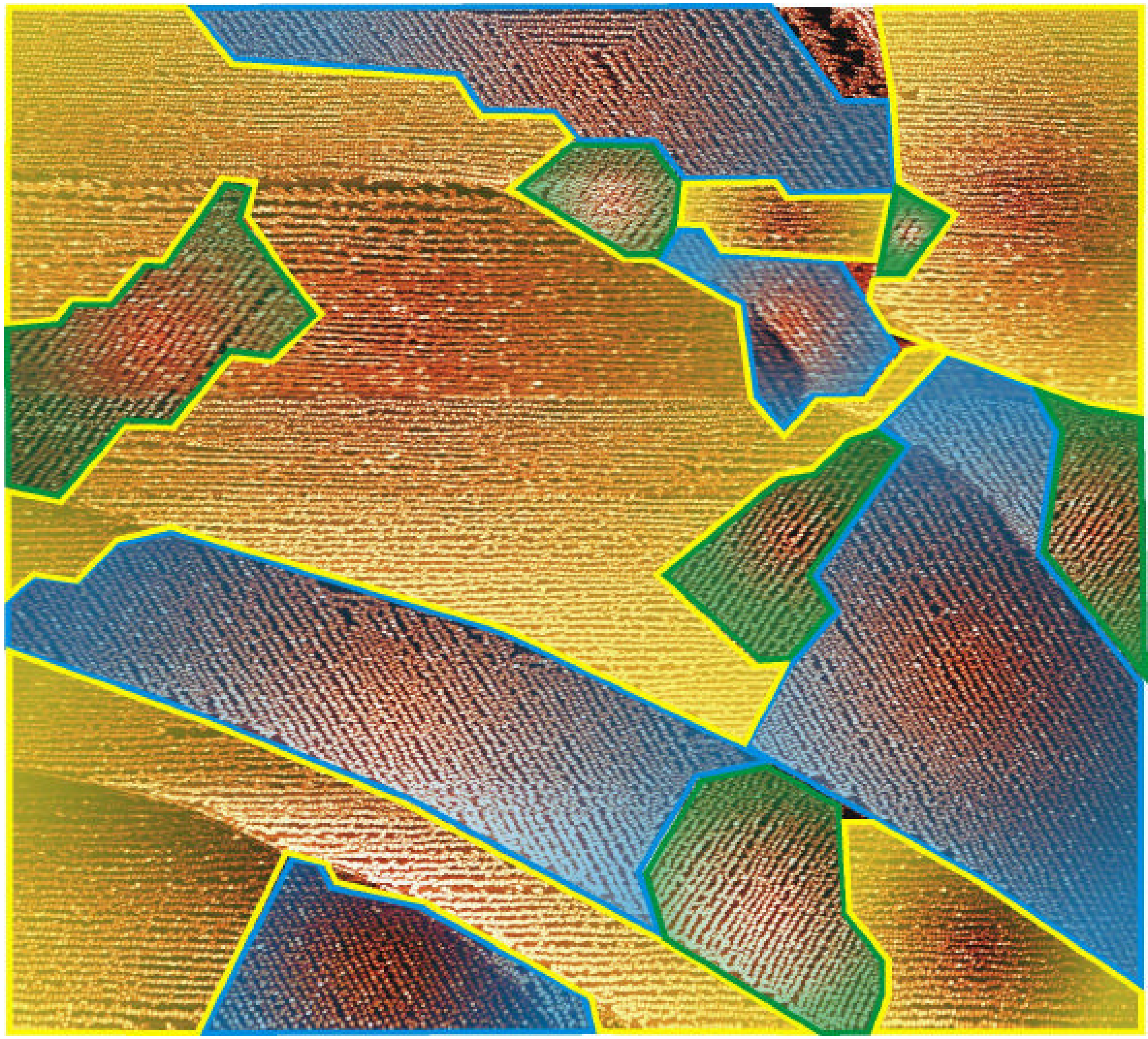
1.5mm x 1.5mm STM image

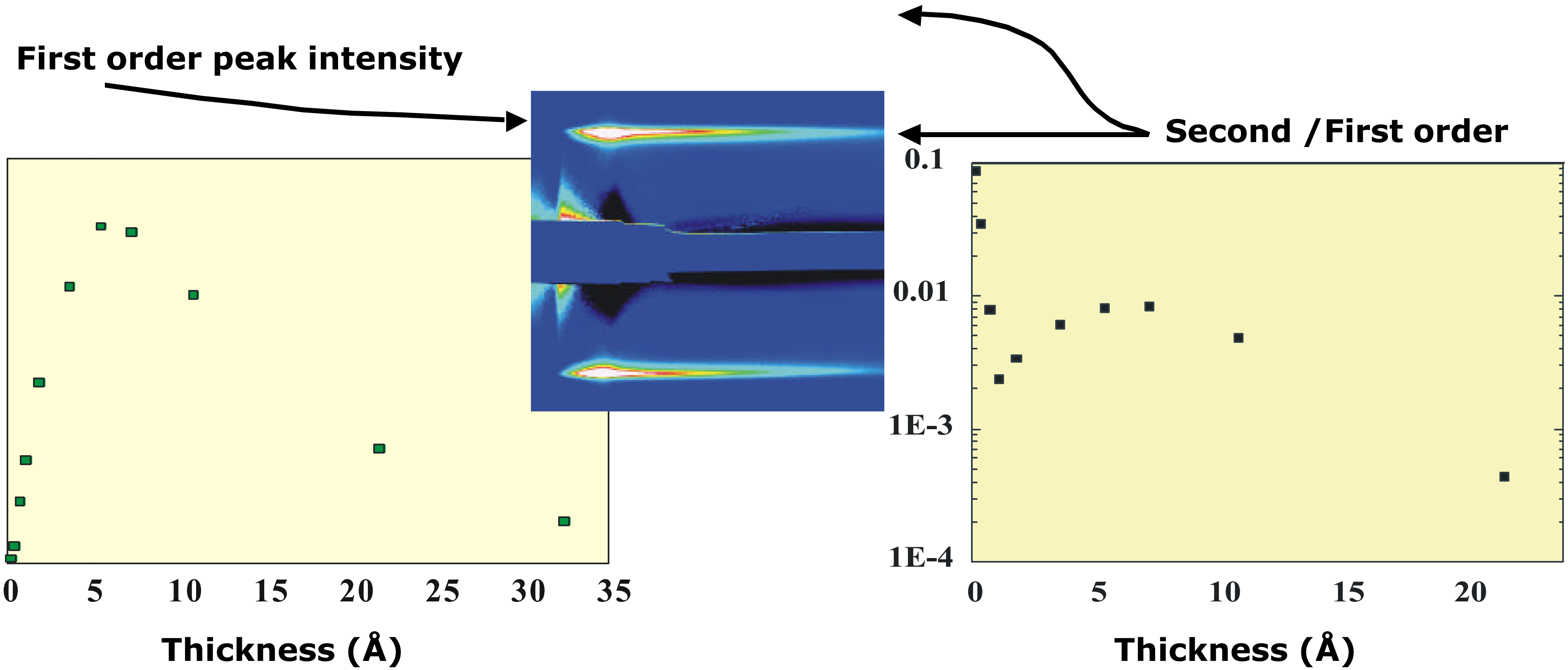
3-fold symmetry of Au(111) crystal

➢ 3 'equivalent domains'



FFT



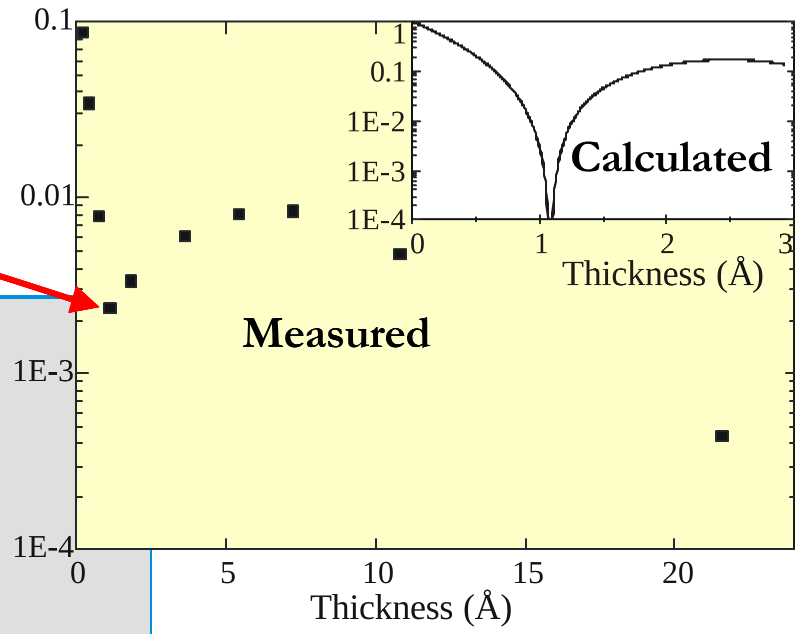


Features to explain

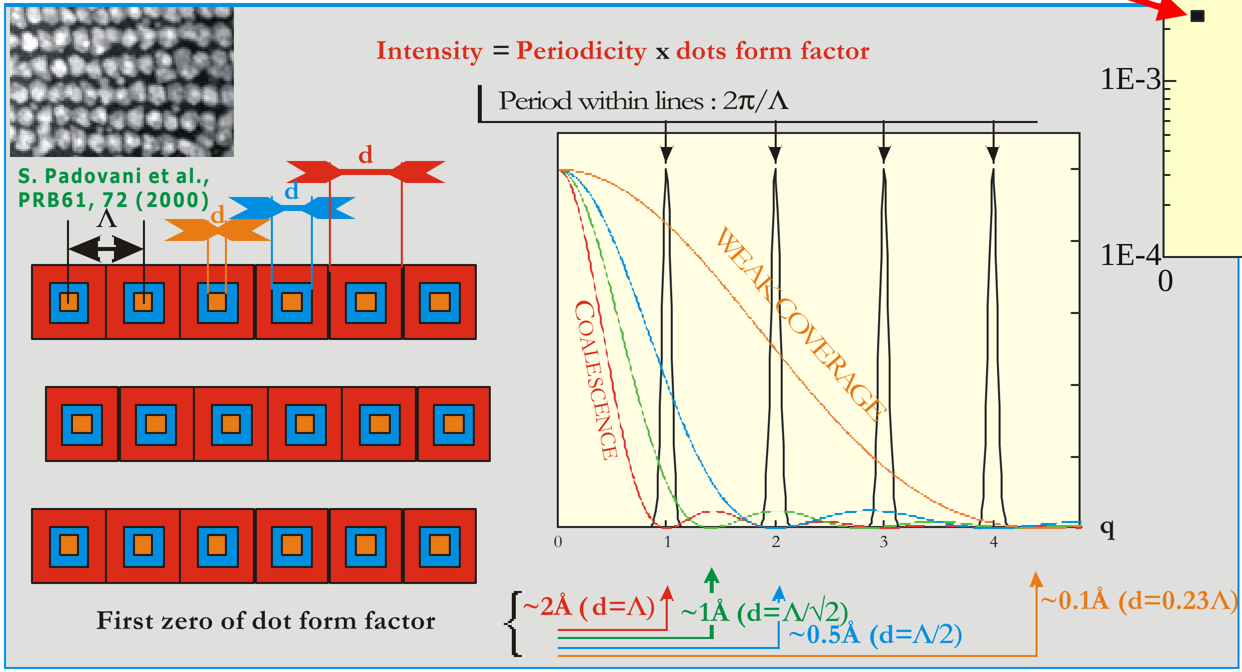
- Maximum at 6Å = 3 atomic layers ?
- Significant intensity for continuous film ?
- Weak intensity ?
- Intermediate minimum ?

RATIO: Second /First order peak intensity

➢ Deposition rate calibration

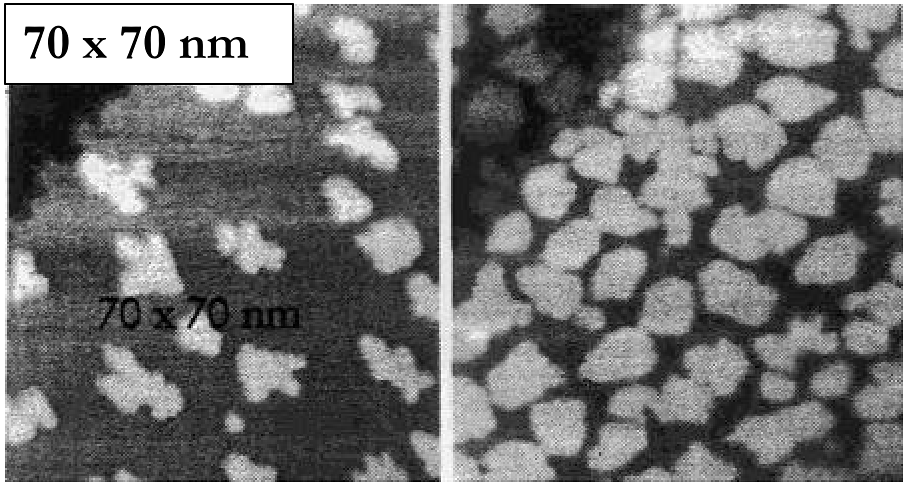


Simple model of 1D coalescence



Any use for magnetism?

'Ferromagnetic' transition with macrospins



Fe / W(110)

H.J.Elmers *et al.*, Phys.Rev.Lett.73, 898(94)

Example:

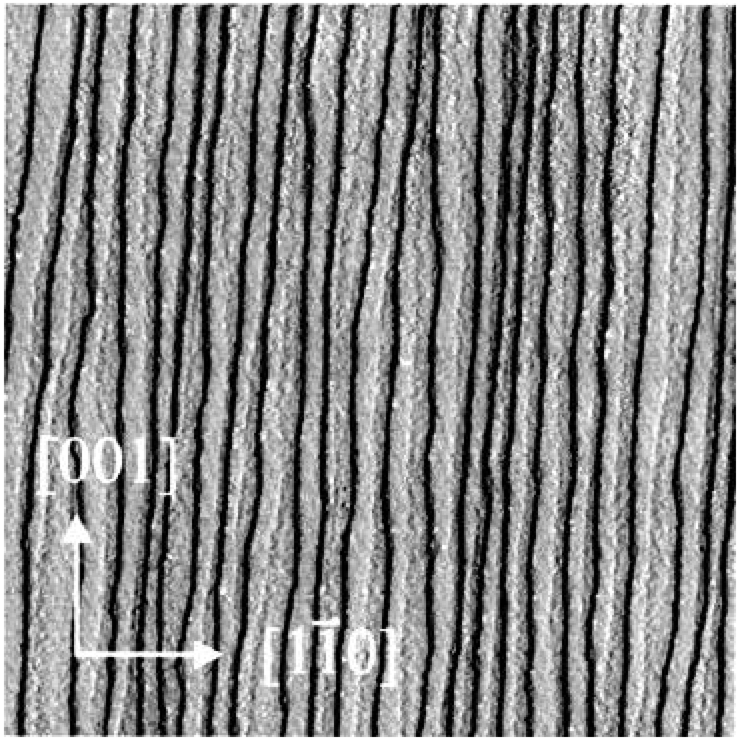
« Test of scaling theory at a two-dimensional Ising-like transition »

Ch. Würsch et al., J. Magn. Magn. Mater 177-181, 617 (1998).

Magnetic order in 1D

(stabilized by dipolar interactions)

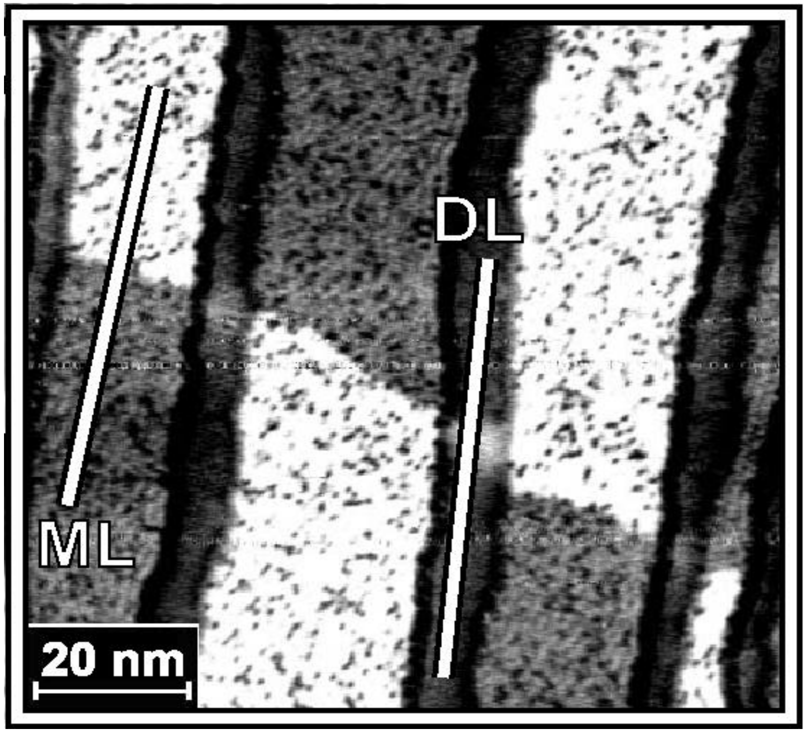
Vicinal Fe(110)/W(110)



250 x 250 nm

Tc=179K

J.Hauschild *et al.*, Phys.Rev.B57, R677(1998)

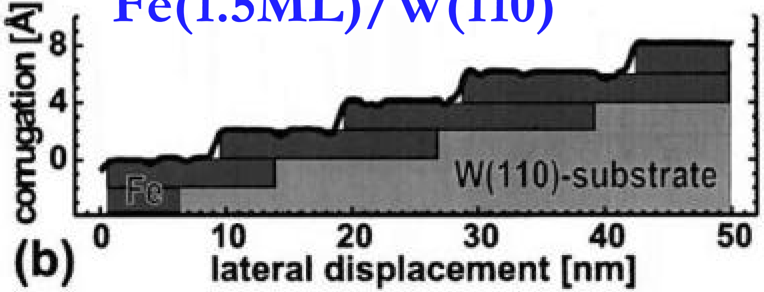


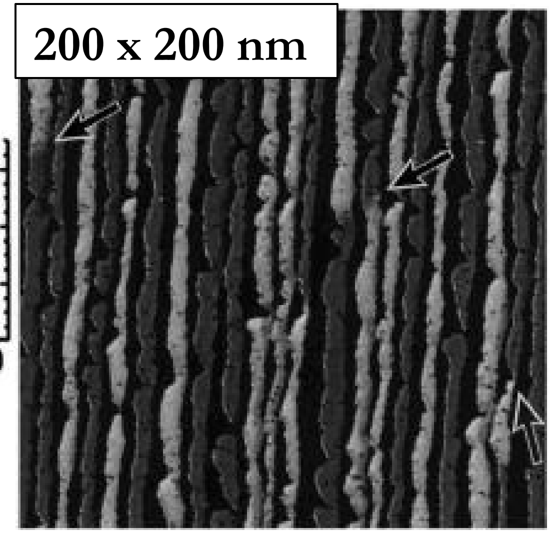
M. Pratzer *et al.*, PRL87, 127201 (2001)

Domain walls in constriction

Spin-Polarized Scanning Tunneling Spectroscopy

Fe(1.5ML)/W(110)

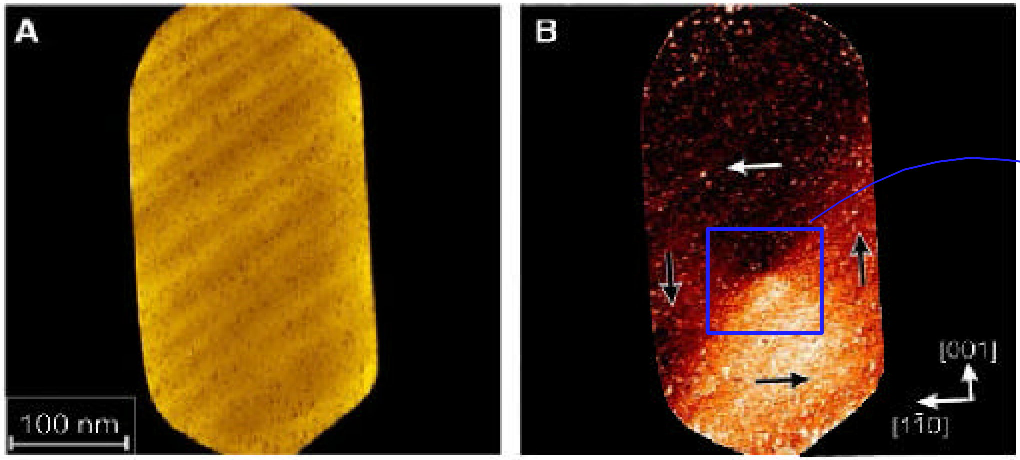


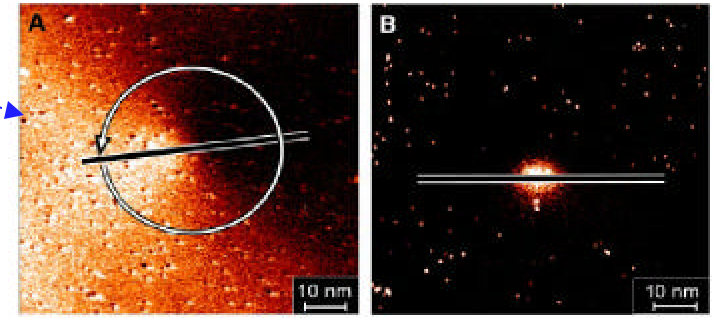


M. Bode et al, J. Electr. Spectr. Rel. Phenom. 114– 116, 1055 (2001)

Theorical prediction: P. Bruno, Phys. Rev. Lett. 83, 2425 (1999)

Magnetic vortex core

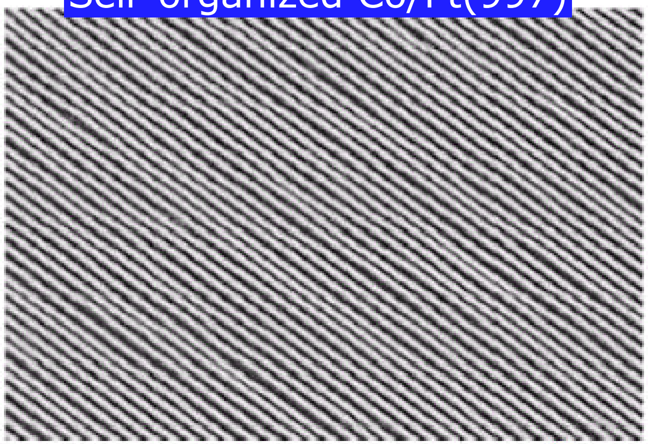


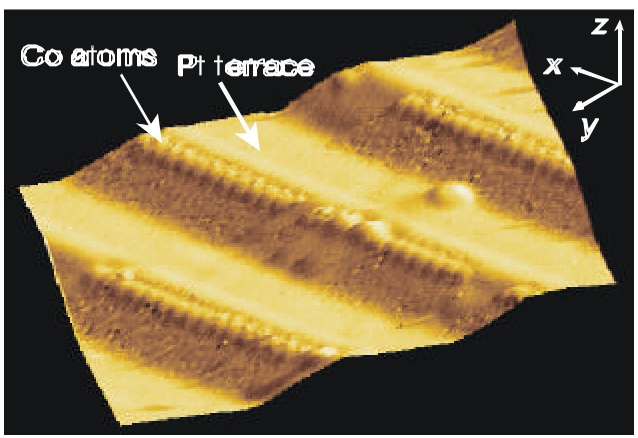


A. Wachowiak, Science 298, 577 (2002)

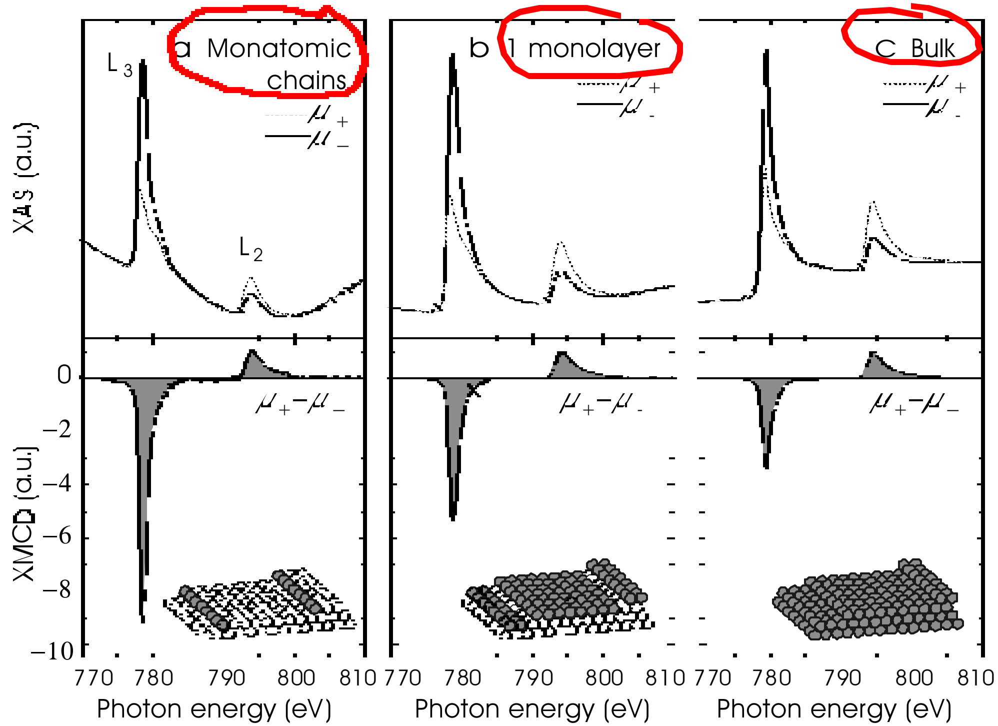
From surface to wires (1D)

Self-organized Co/Pt(997)





Magnetic circular dichroïsm



$$m_L \approx \int L_3 + \int L_2$$

$$m_S^{\mathrm{eff}} \approx -\int 2L_3 + 4\int L_2$$

Conclusion:

- Increase of orbital moment (necessary condition for anisotropy)

P. Gambardella et al., Nature 416, 301 (2002)

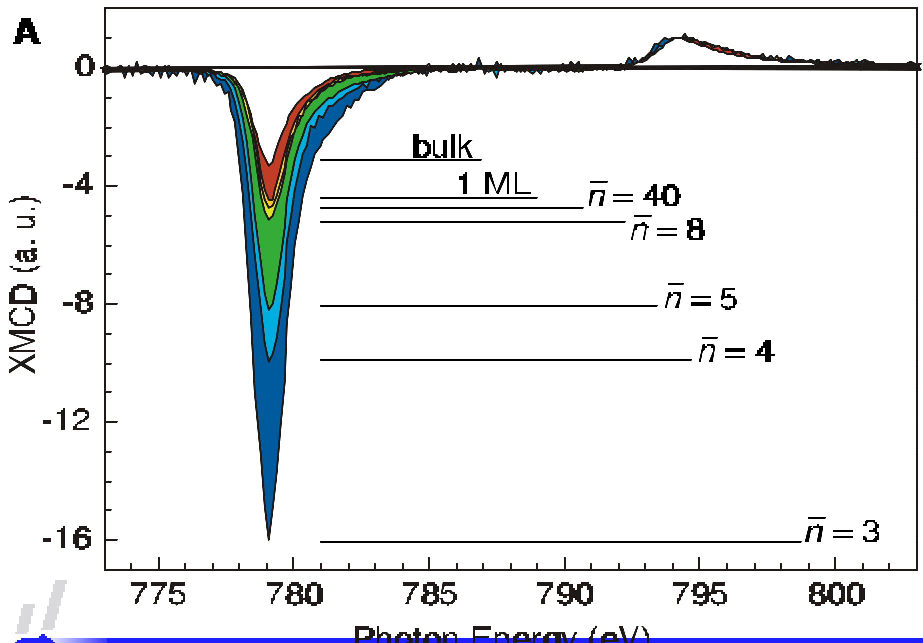
From surface to atoms (0D)

Co/Pt(111)

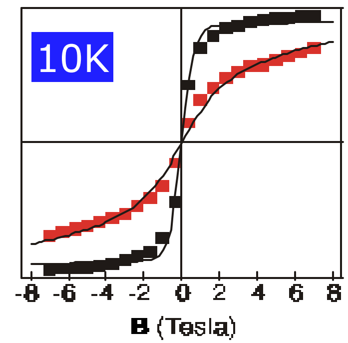
Giant Magnetic Anisotropy of Single Cobalt Atoms and Nanoparticles

P. Gambardella,[1,2*] S. Rusponi,[1,2] M. Veronese,[3] S. S. Dhesi,[4†] C. Grazioli,[3] A. Dallmeyer,[5] I. Cabria,[5] R. Zeller,[5] P. H. Dederichs,[5] K. Kern,[1,2] C. Carbone,[3,5] H. Brune[1]

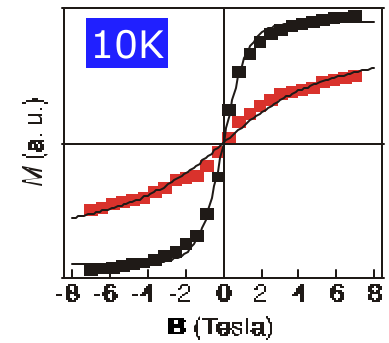
P. Gambardella et al., Science 300, 1130 (2003)



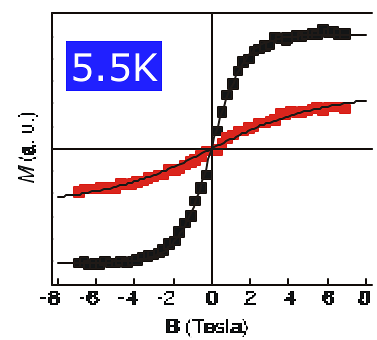
8 atoms



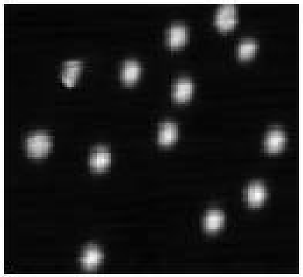
4 atoms



1 atom



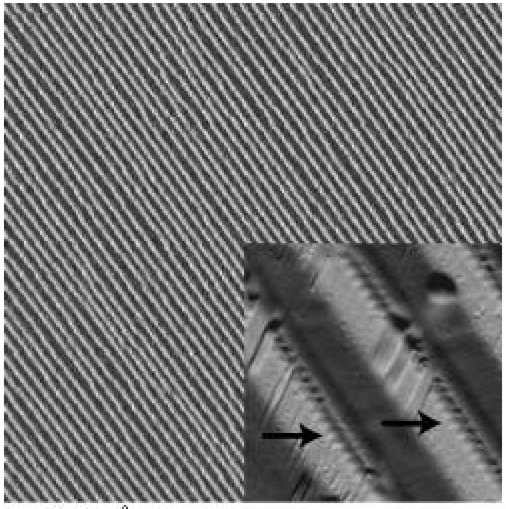
STM, 8.5nm, 5.5K

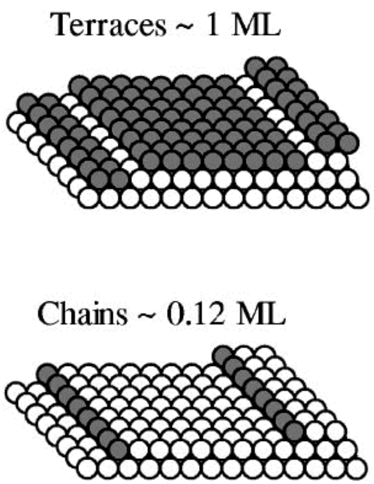


Qualitatively:

- Easy axis of magnetization perpendicular to Pt(111)

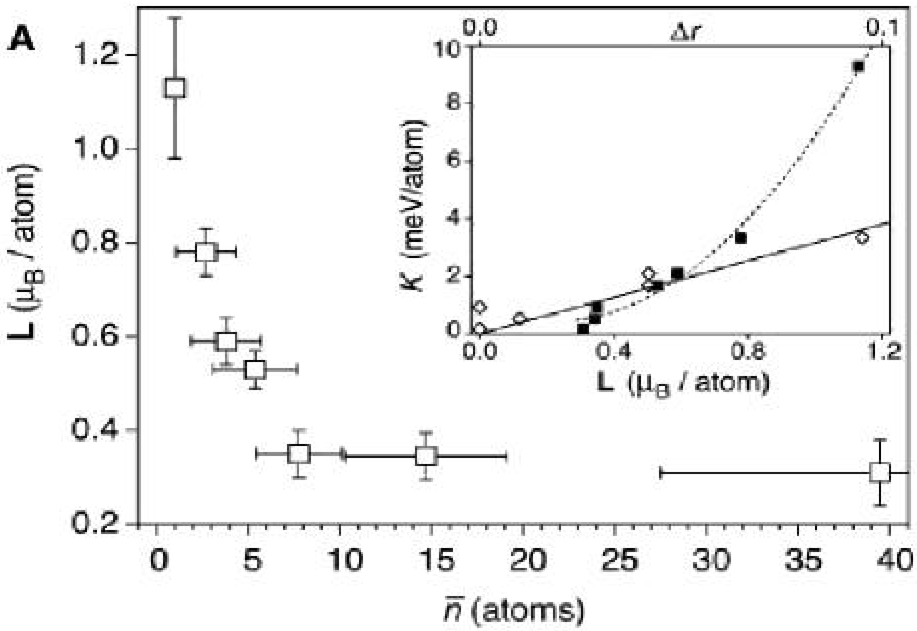
Co/Pt(997)





A. Dallmeyer *et al.*, Phys.Rev.B 61(8), R5153 (2000)

Co/Pt(111)



P. Gambardella et al., Science 300, 1130 (2003)

Conclusions

- Bulk: m_L=0.14μ_B/at.
- Surface: m_L=0.31μ_B/at.
- Bi-atomic wire: m_L=0.37μ_B/at.
- Mono-atomic wire: m_L=0.68μ_B/at.
- bi-atom: m_L=0.78μ_B/at.
- atom: m_L=1.13μ_B/at.

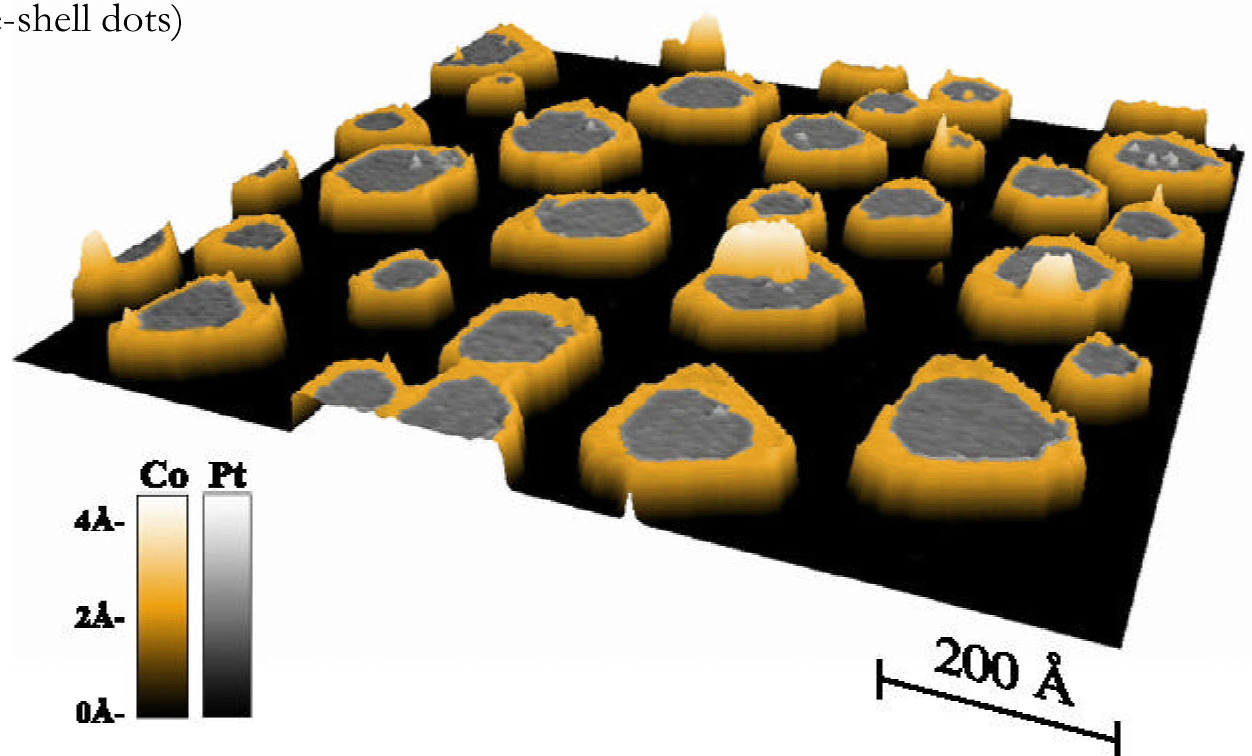
Conclusions

- From bulk to atoms: considerable **increase of orbital moment**
- **2 atoms closer to wire than 1 atom**
- **bi-atomic wire closer to surface than wire**

P. Gambardella et al., Nature 416, 301 (2002)

Manipulation of edge anisotropy

(core-shell dots)



S. Rusponi et al., Nature Mater. (2003)

- **Self-organization : concepts**
- **Self-assembly : towards materials?**

- (Grenoble)
- I. Overview of self-organization processes
- II. Self-organization for magnetism (litterature)
- III. Our contribution for magnetism

Use of self-organization for magnetism

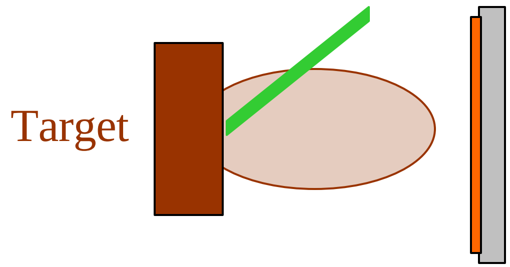
- Model systems for studying intrisic phenomena
- Direct use of self-organized systems as materials?

Outline

- **Fe/cc(110) dots – Micromagnetism**
- **Co/Au(111) pillars – Overcome low-dimensionality**
- **Fe/cc(110) stripes – Overcome low-dimensionality**
- **Extend versatility of self-assembly**

PULSED LASER DEPOSITION, U

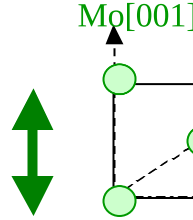
Nd:YAG
Pulsed Laser

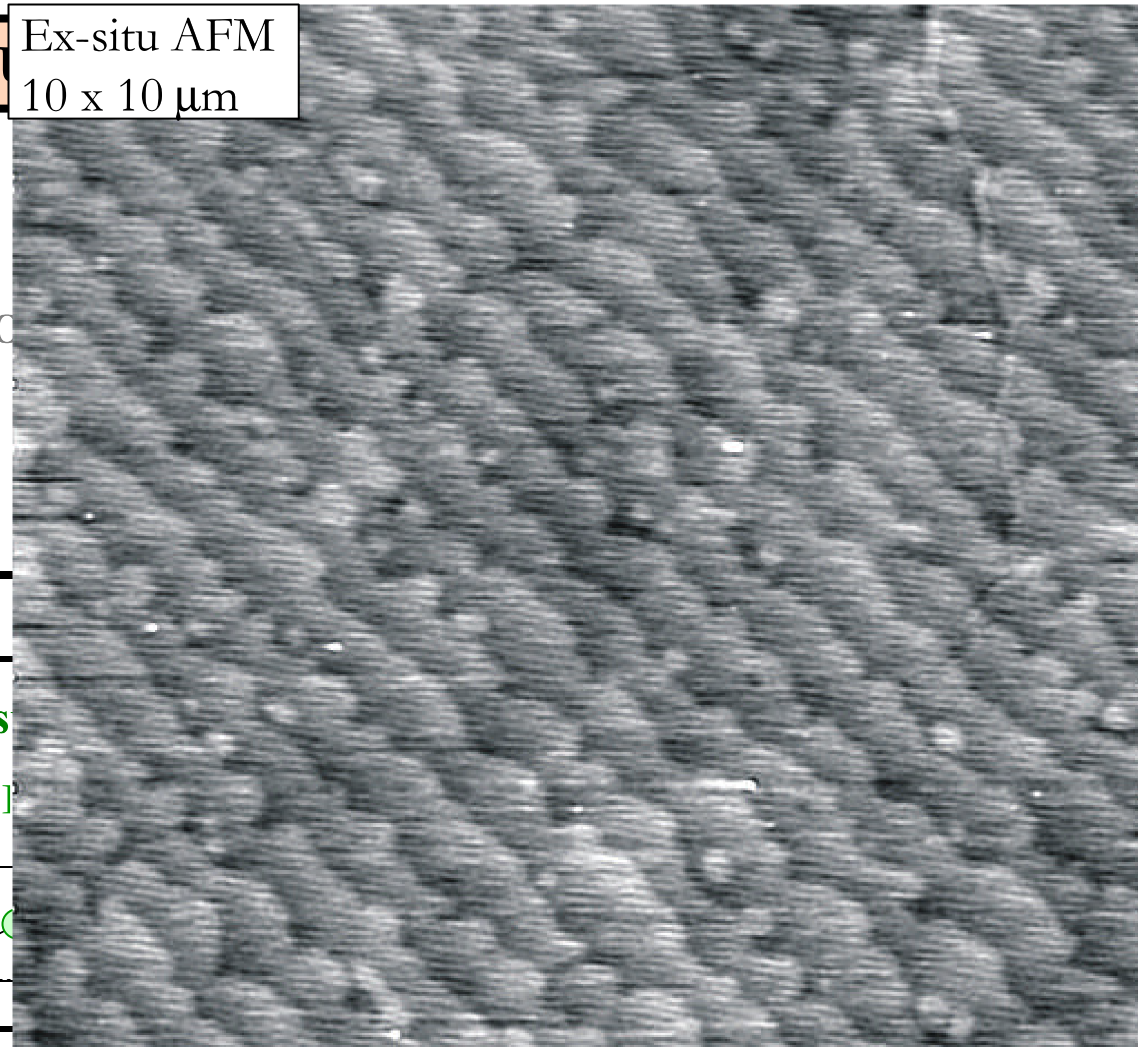


cc(110)/Al_2O

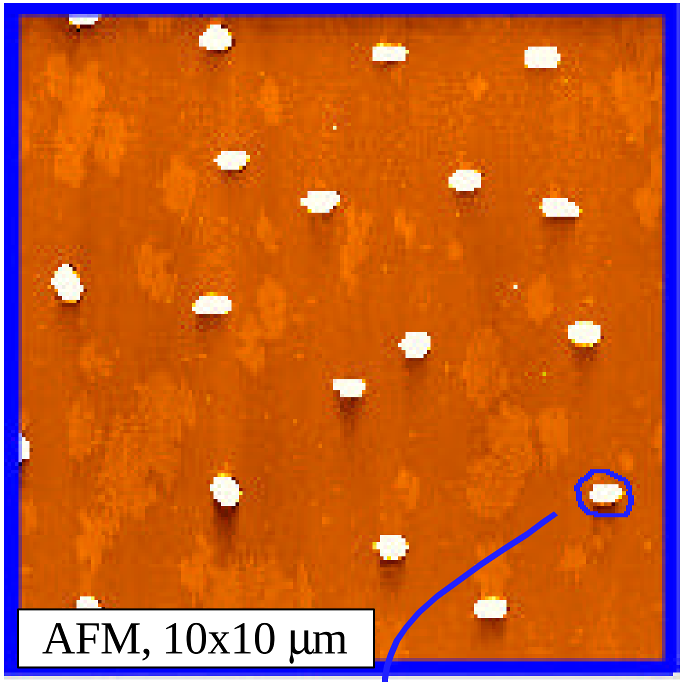
cc=Mo, W,

cc(110) s

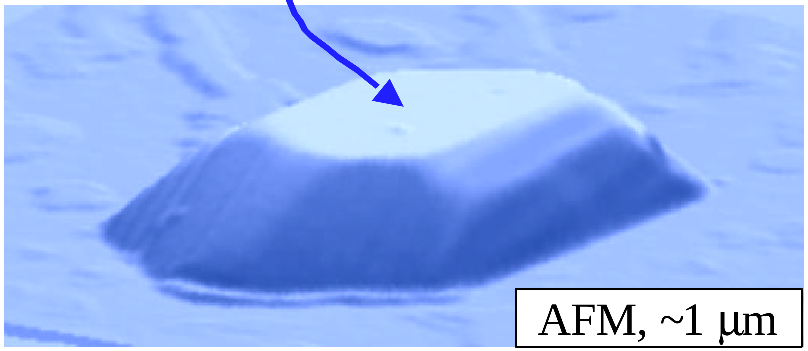




Buffer layer growth : O. Fruchart, S. Jaren, J. Rothman, Appl. Surf. Sci. 135, 218 (1998)



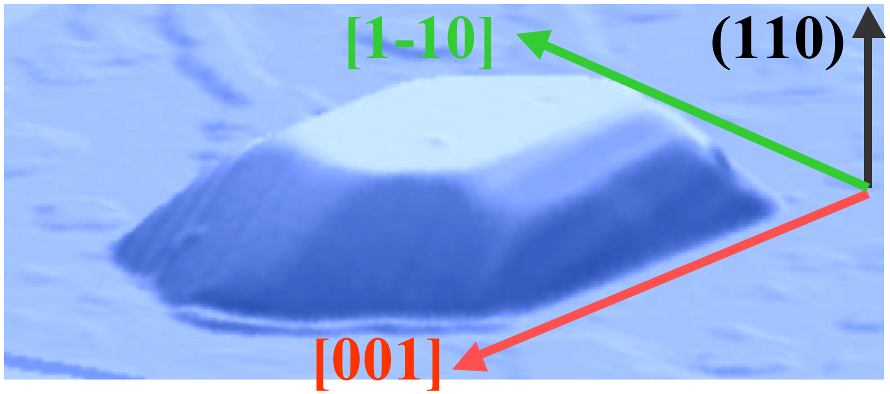
- Fe/Mo(110) ingots-shaped dots fabricated at 450°C (P.-O. Jubert, PhD, now in IBM)

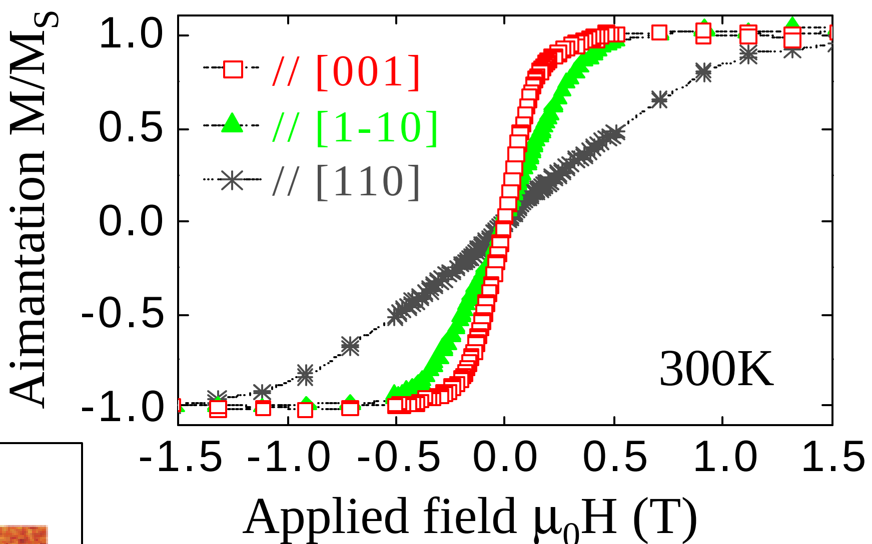


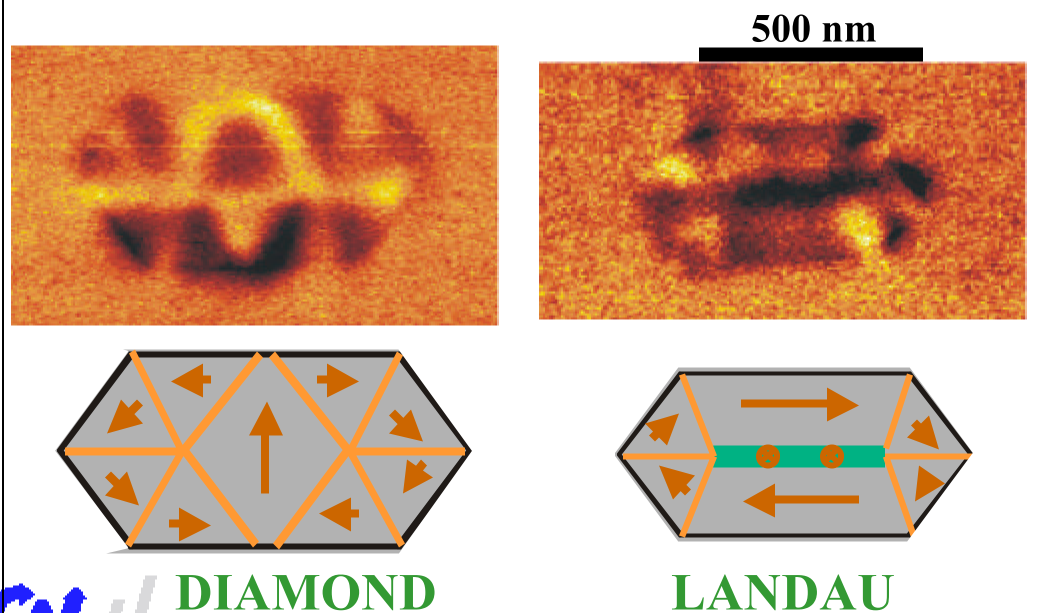
Use these dots as 'micro-laboratories'

P.-O.Jubert *et al.*, JMMM 226, 1842 (2002)
P.-O.Jubert *et al.*, PRB64, 115419 (2002)
P.-O.Jubert *et al.*, Europhys. Lett. 63, 135 (2003)

Agrees with Wulff's construction







MFM: Y. Samson, DRFMC (Grenoble)

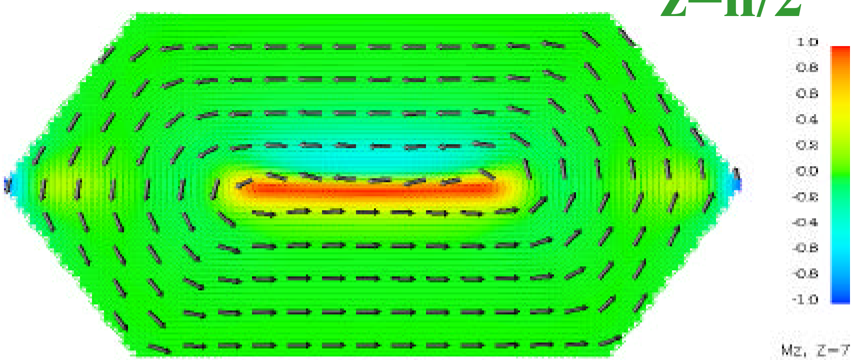
H_{sat} // [001]

➢ Why two magnetic configurations ?

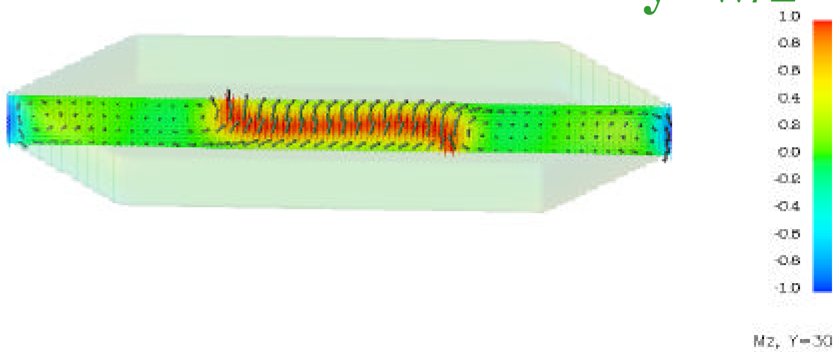
$\mu_0 H_{app} = 0.00T$

LANDAU

z=h/2

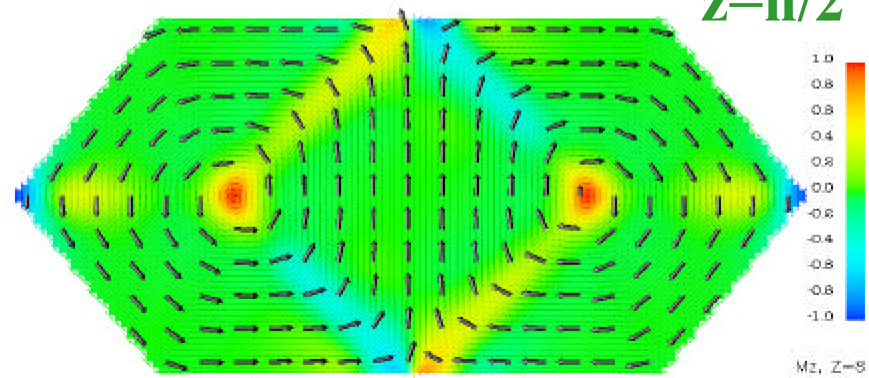


y=w/2

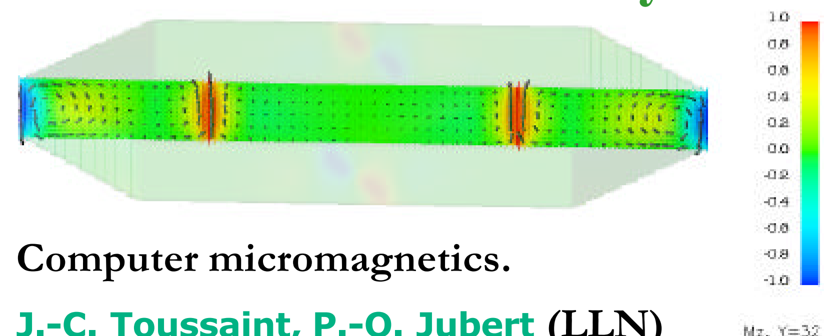


DIAMOND

z=h/2



y=w/2

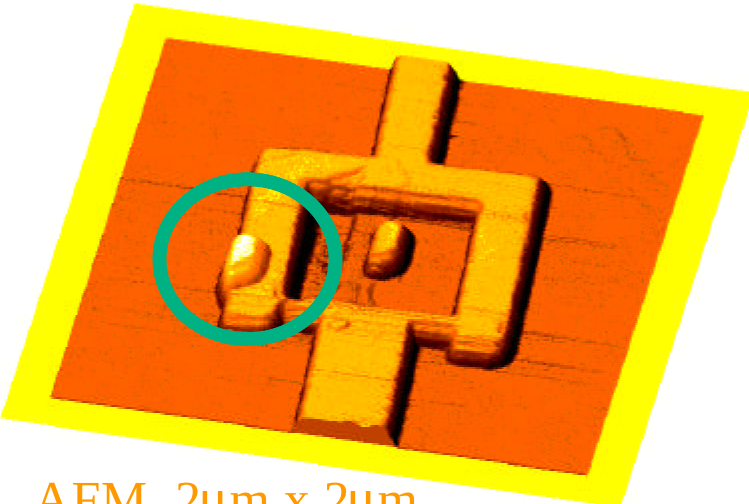


Computer micromagnetics.

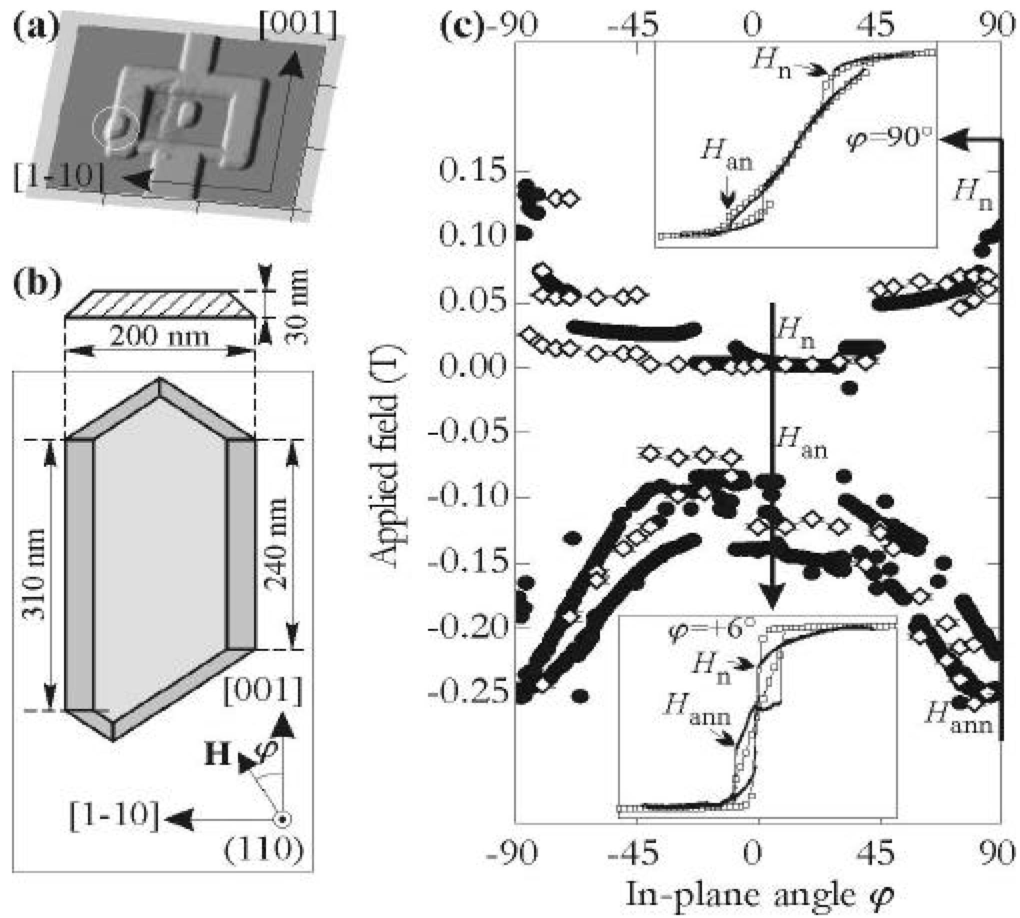
J.-C. Toussaint, P.-O. Jubert (LLN)

- Macroscopic and mesoscopic features
- Landau configuration costs less energy : why diamond is observed ?

Measurement of single dots



AFM, 2µm x 2µm

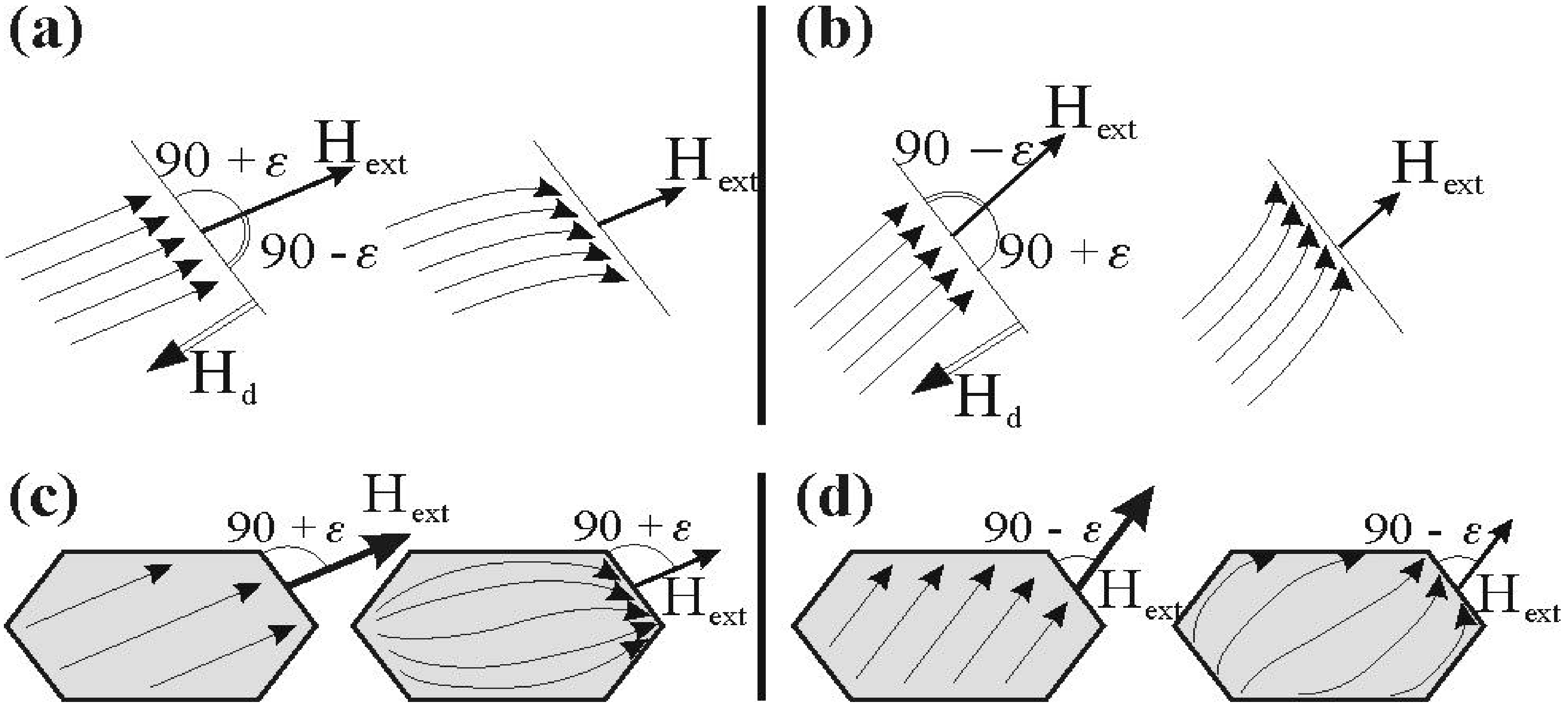


W. Wernsdorfer, LLN

µ-SQUID fabrication directly on dot:

- UHV Nb/Mo/Fe/Mo(110)
- e-beam lithography (D. Mailly, L2M)

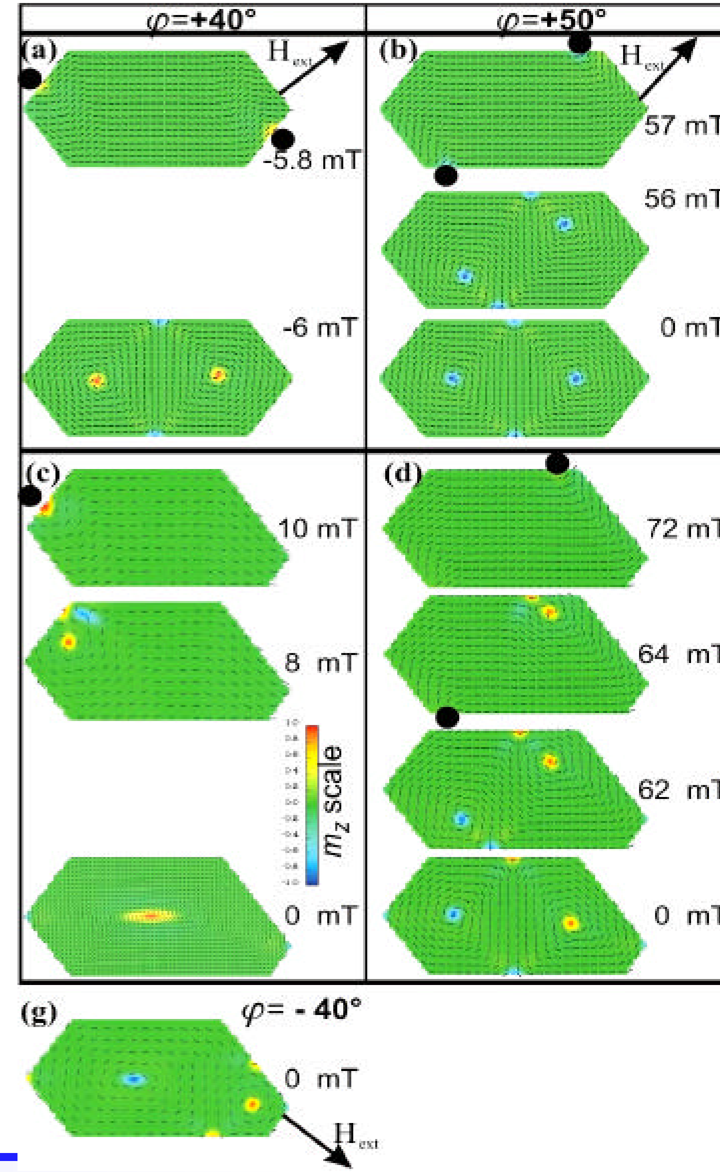
Non-uniform states imply bifurcations



Microscopic view of bifurcations

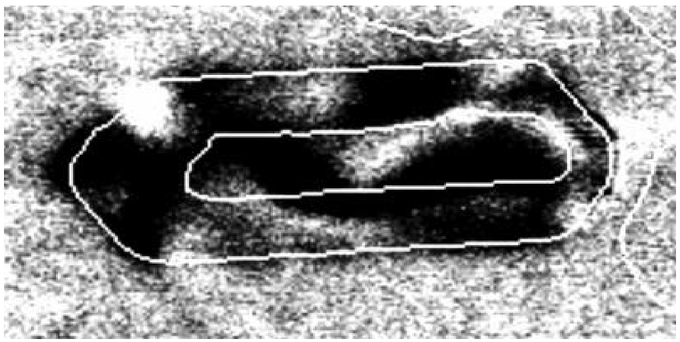
Non-uniform state explains bifurcation

Breaking of point-reversal symmetry explains the two zero-field states



O. Fruchart *et al.*, submitted

Unclear MFM patterns



Bloch points predicted by simulations

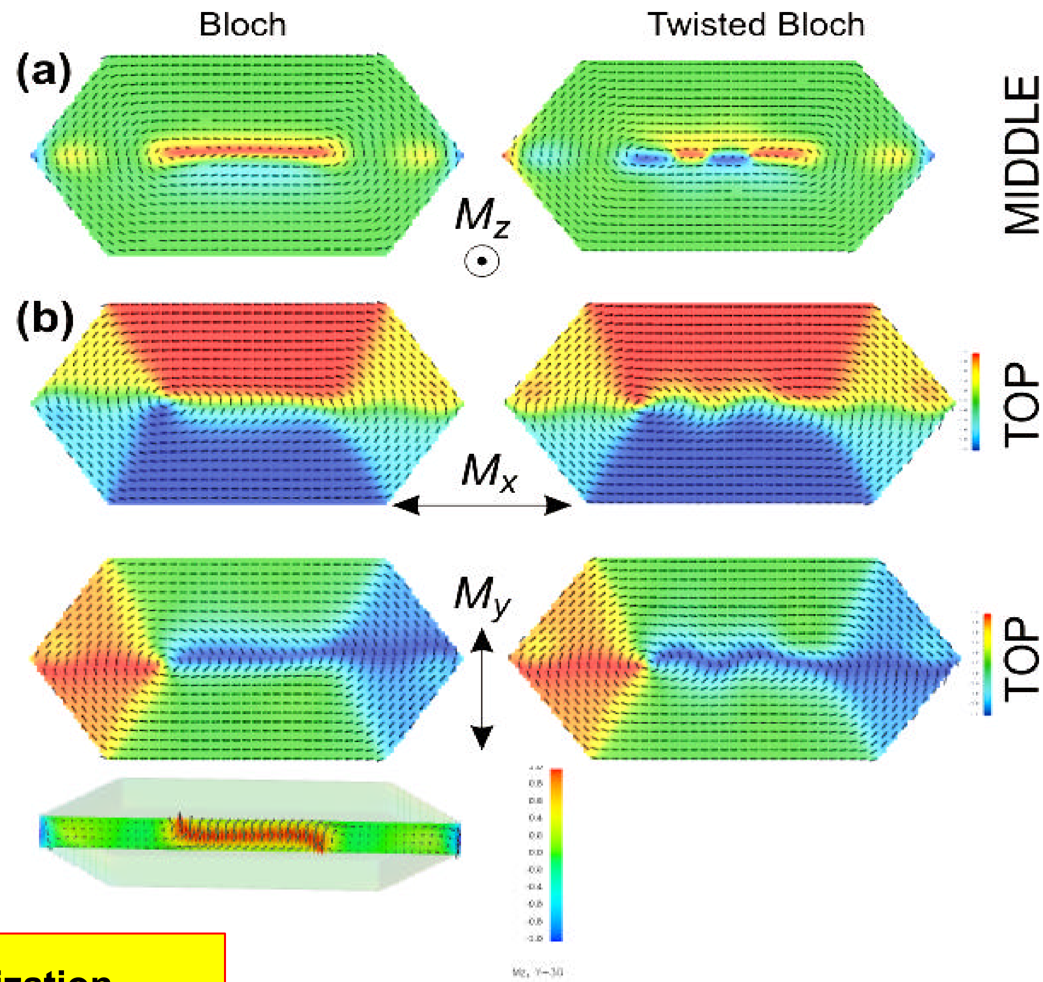
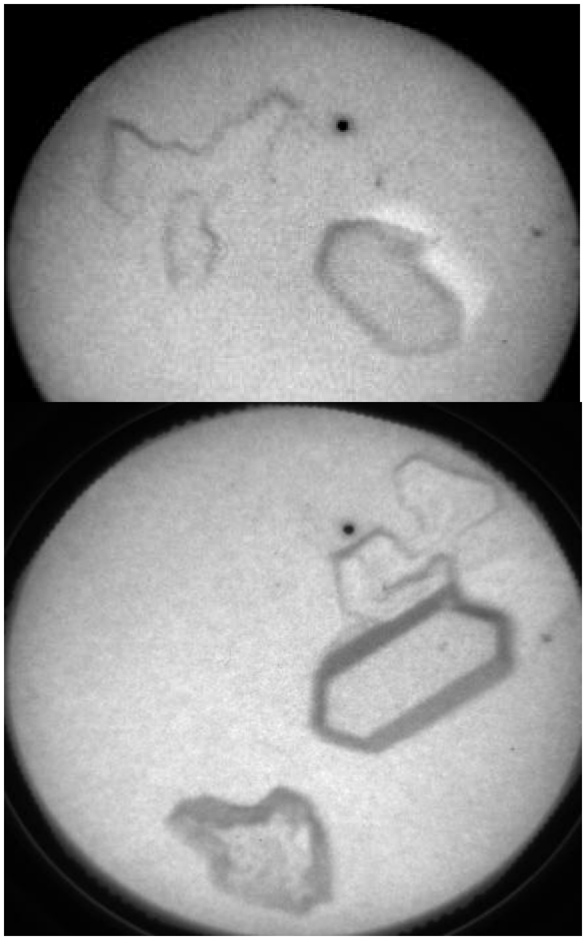


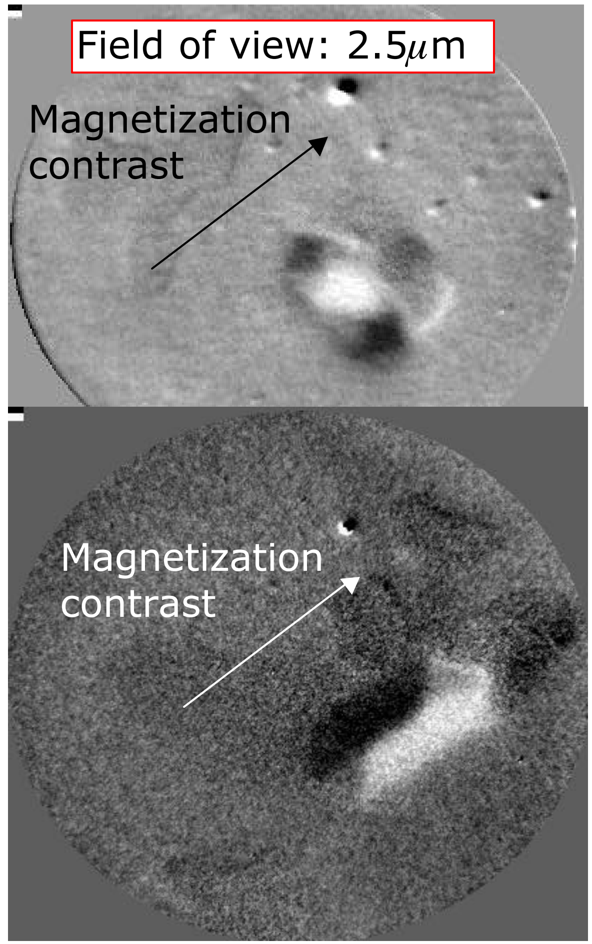
Image surface magnetization for better insight ?

PEEM = Photo-Emission Electron Microscope

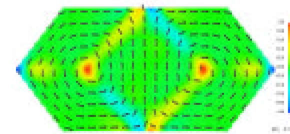
LEEM image

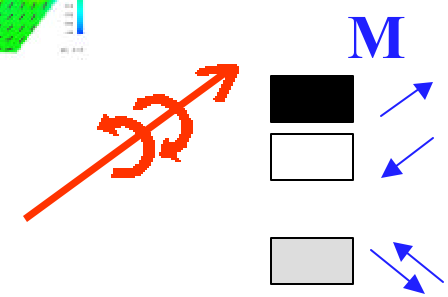


X-PEEM image

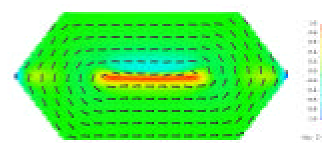


Landau state
(thin dots)





Polarized R-xays



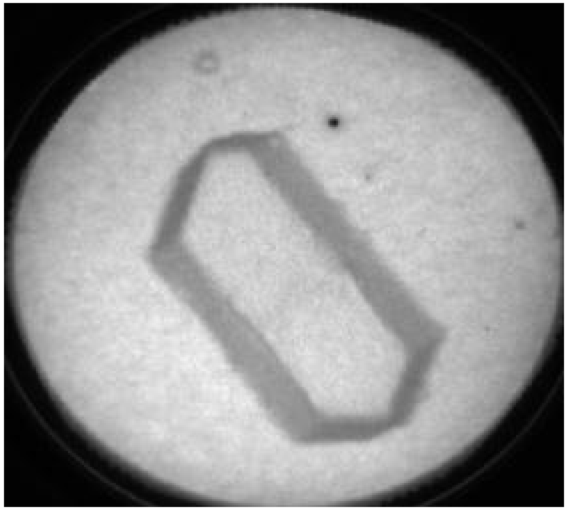
Diamond state

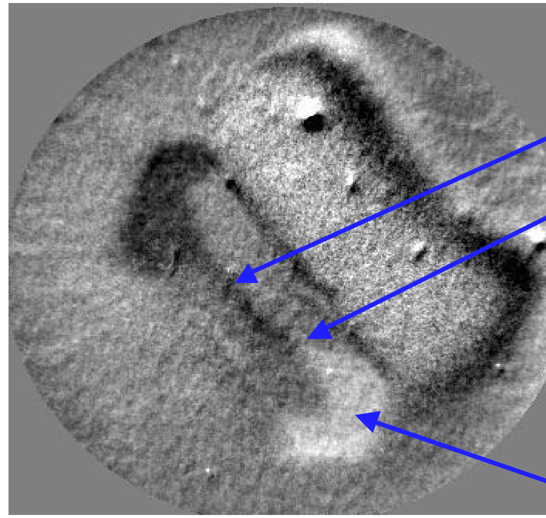
(thicker dots)

ELETTRA Syncrotron, Trieste

S. Cherifi (LLN), A. Ballestrazzi, S. Heun (ELETTRA)
Laboratoire Louis Néel, Grenoble, France.

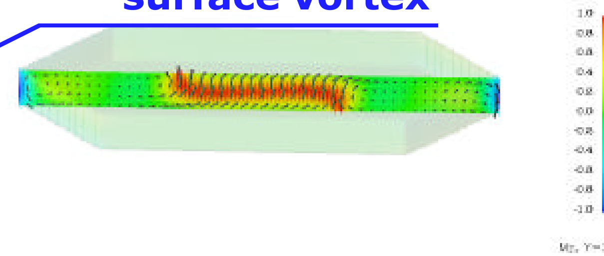
Thin versus thick dots:
From 2D nanostructures towards bulk materials



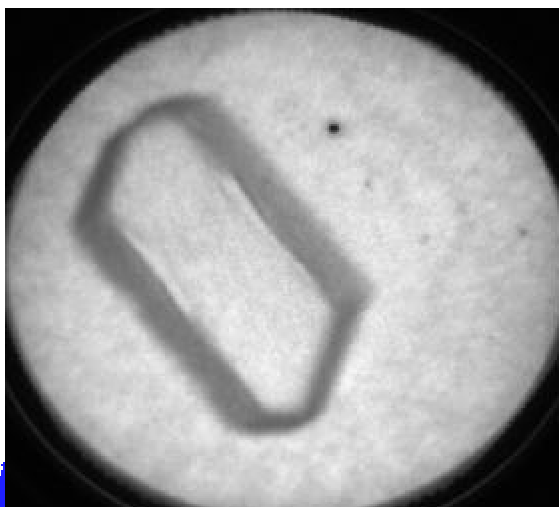


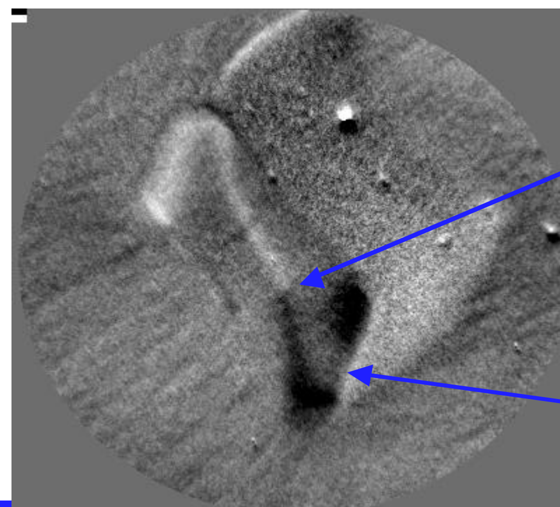
Néel cap

Asymmetric surface vortex



Asymmetric end domains





Néel cap switch

Magnetization not parallel to edges (3D effect)

III. Our contribution for magnetism

Outline

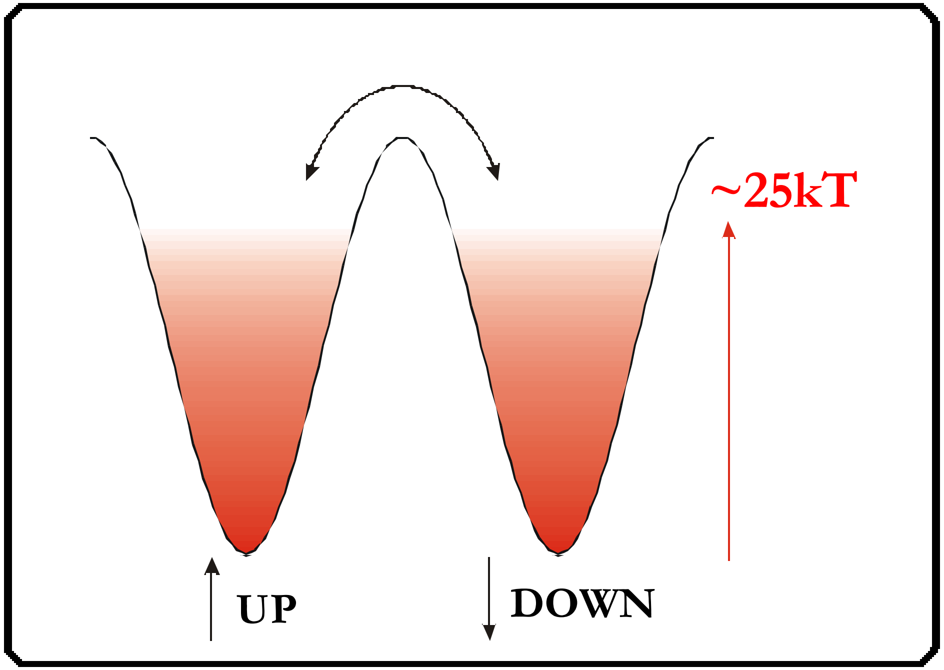
Fe/cc(110) dots – Micromagnetism

Co/Au(111) pillars – Overcome low-dimensionality

Fe/cc(110) stripes – Overcome low-dimensionality

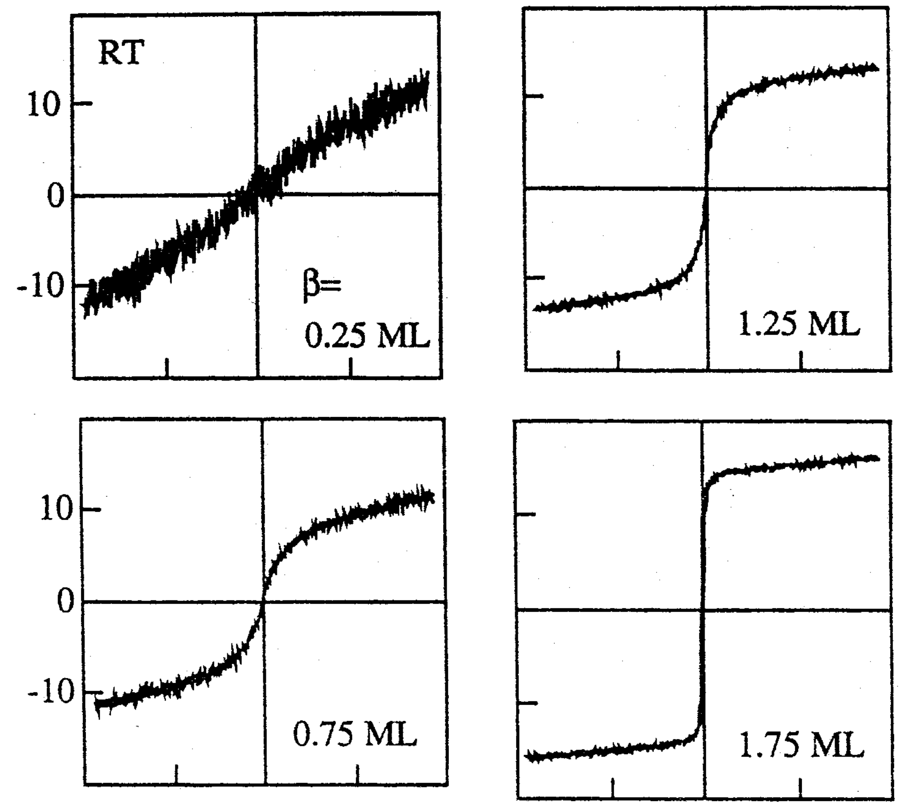
Extend versatility of self-assembly

Anisotropy barrier ~KV



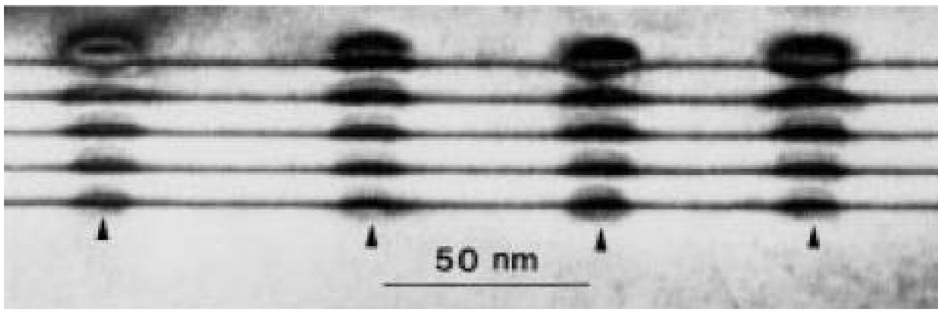
Blocking temperature Tb ~ 20K
H.Dürr et al., PRB**59**, R701 (1999)

Example: Co/Au

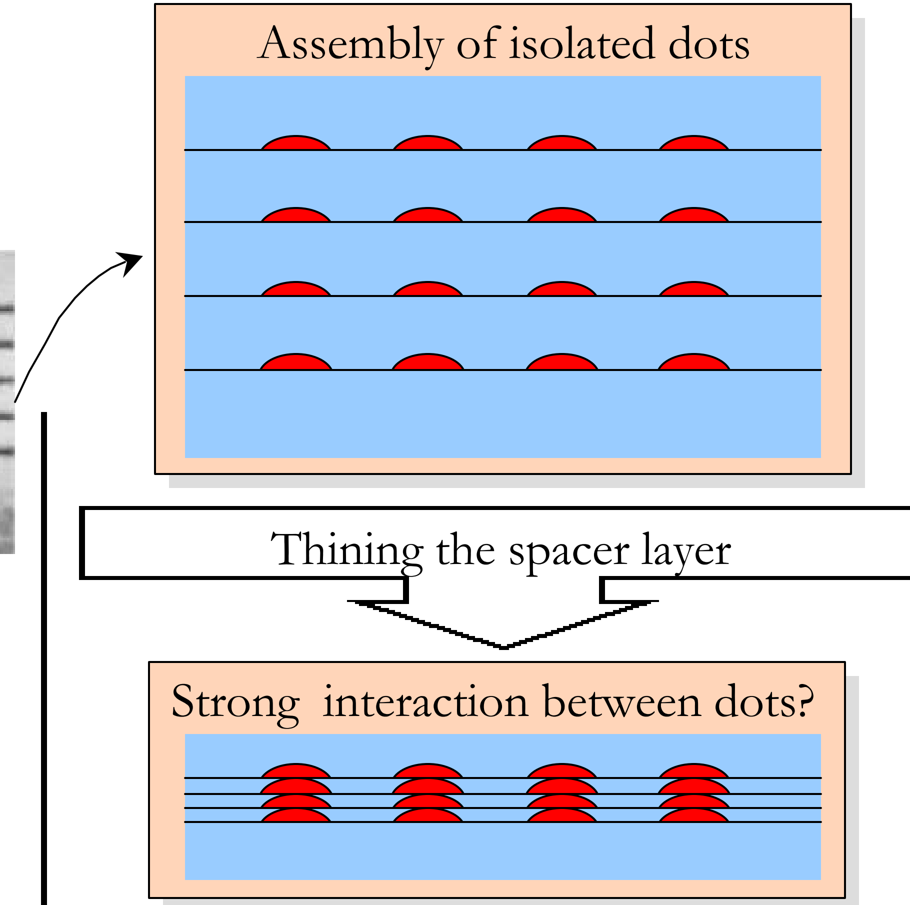


H.Takeshita et al., JMMM**165**, 38 (1997)

- Vertical 3D self-organization of **$In_xGa_{1-x}As/GaAs$** :



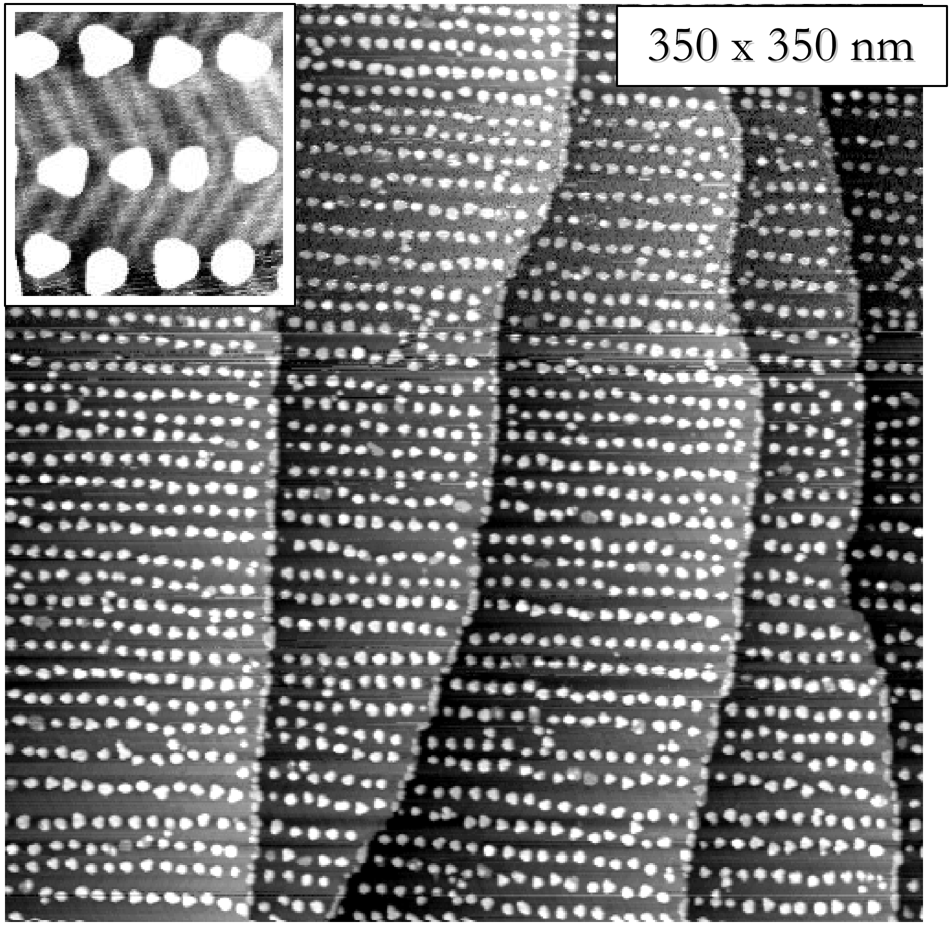
Q.Xie et al., Phys.Rev.Lett.75(13), 2542 (1995)

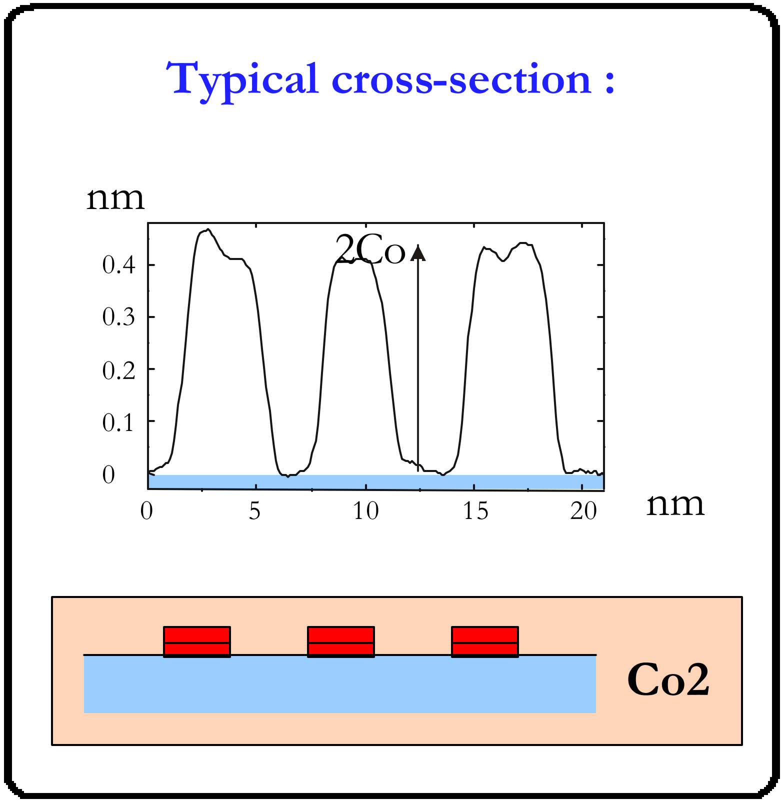


↪ superparamagnetism overcome ?

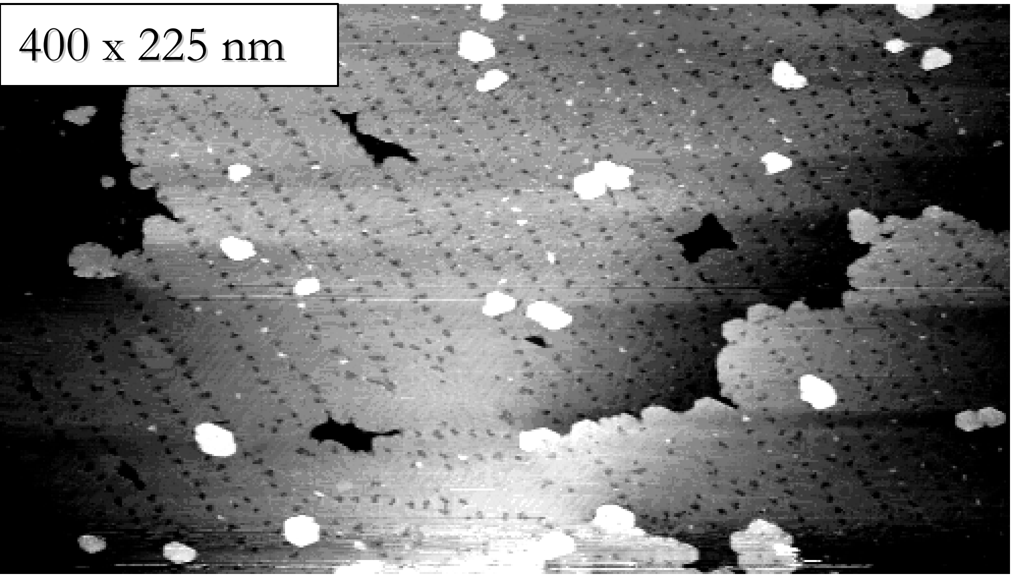
↪ Enhanced magnetic signal

➢ **Step 1** : 0.2ML Co @300K





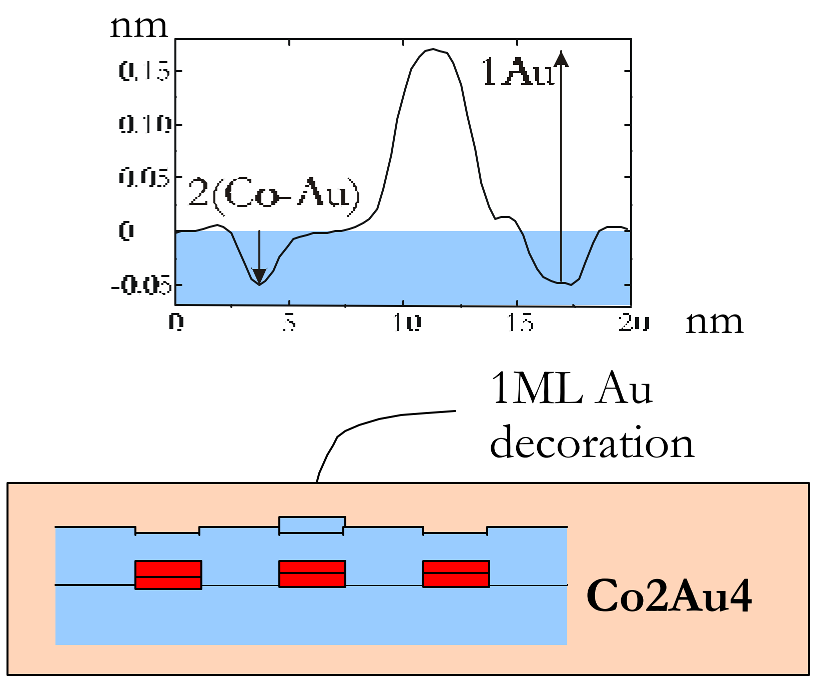
- **Step 2** : 3.8ML Au @375↗410K



See also : Wollschläger *et al.*, Surf.Sci.**277**, 1 (1992)

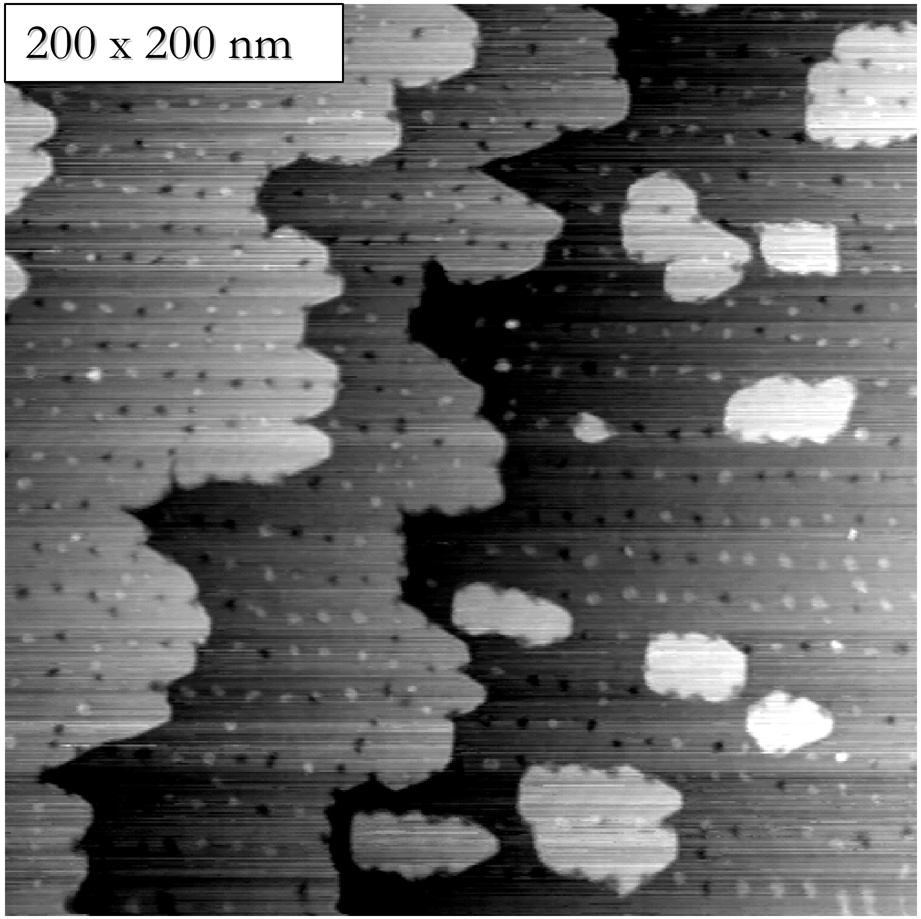
1ML Co hcp ≈ 0.205nm
1ML Au fcc ≈ 0.235nm
} Array of hollows

Typical cross-section :

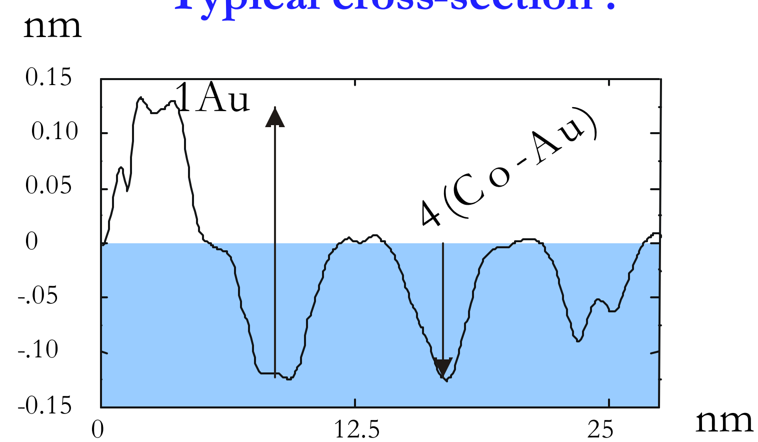


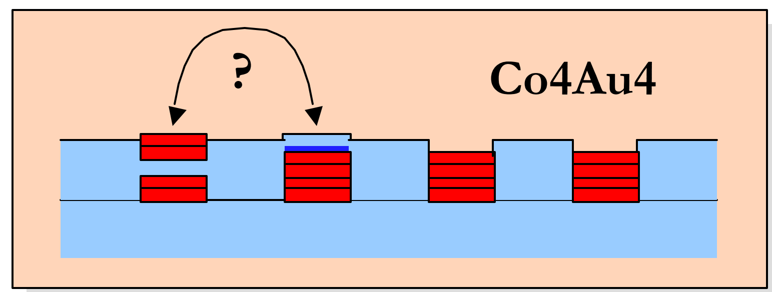
- Surface smoothing
- Unaffected Co dots

- **Step 3** : 0.2ML Co @425K

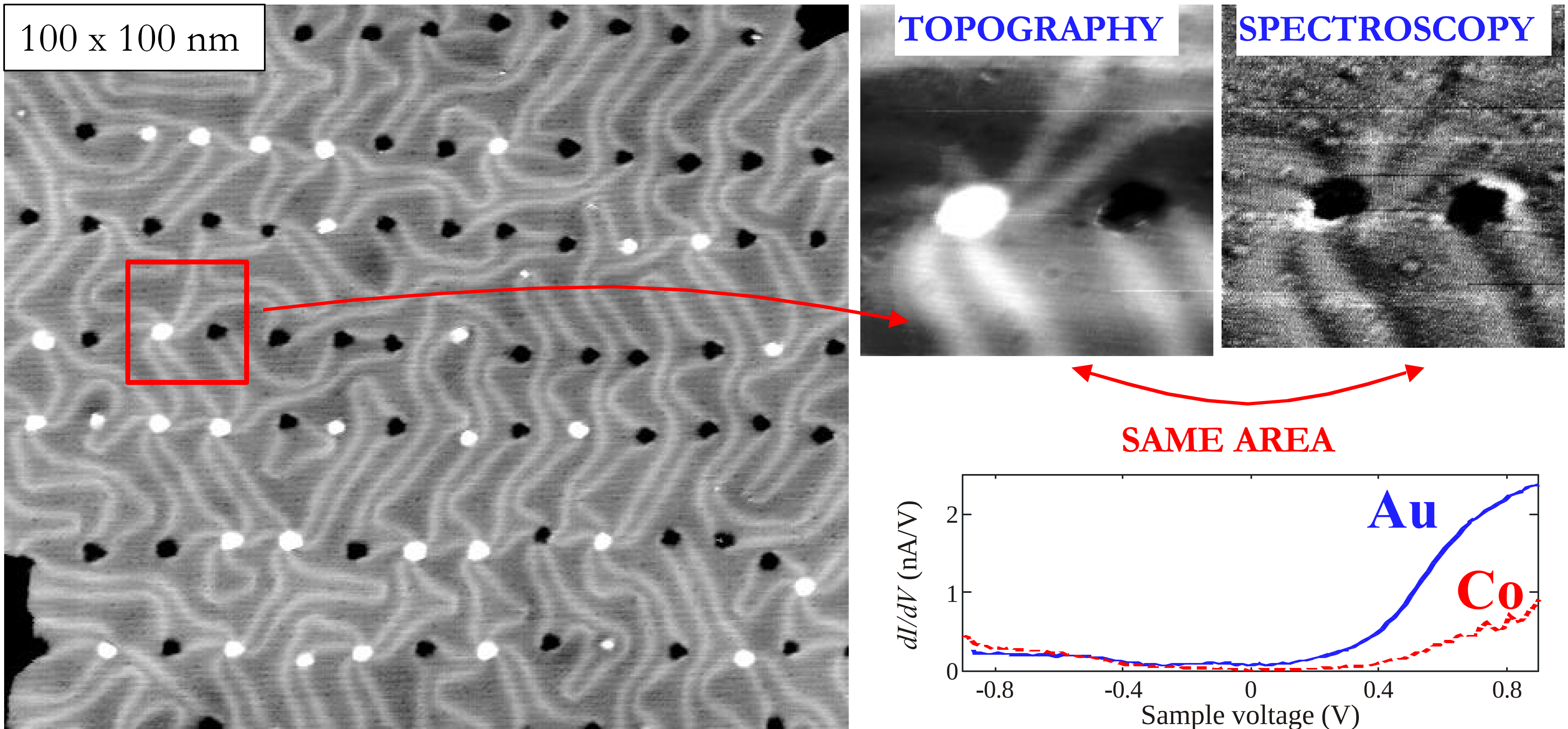


Typical cross-section :



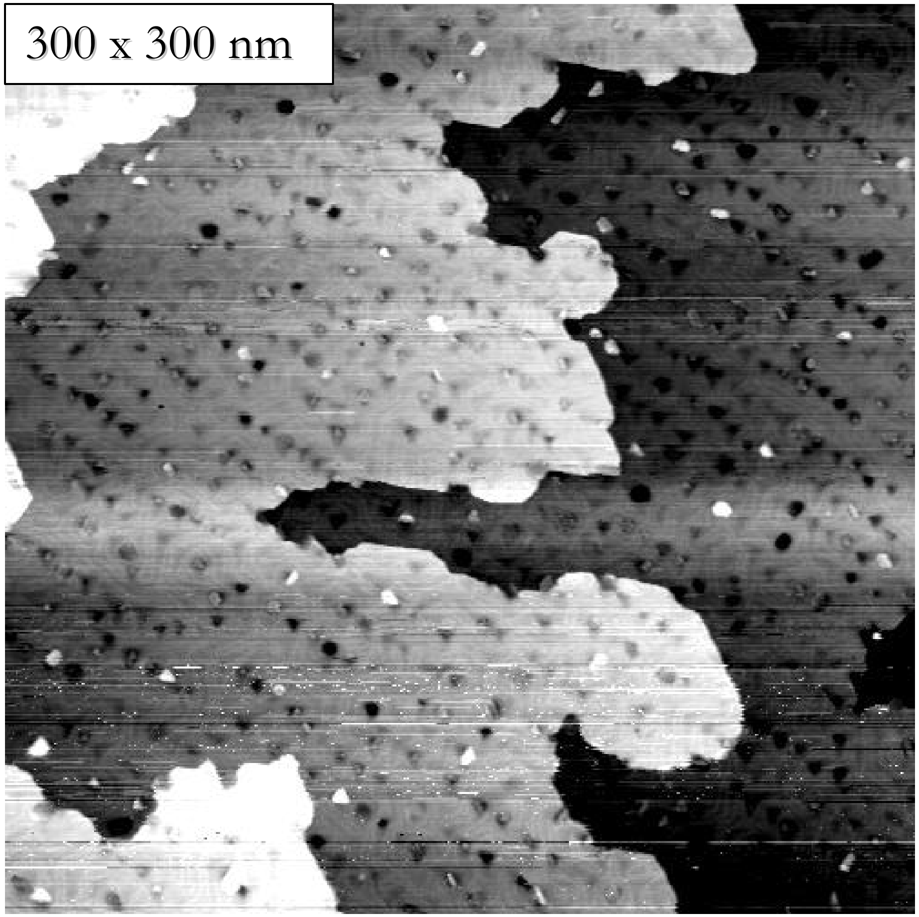


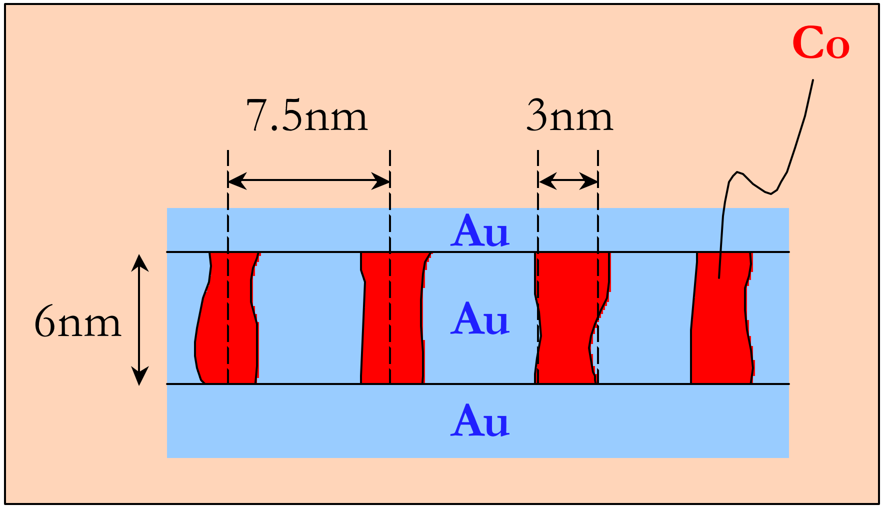
- Co/Au exchange mechanism
- The dots are now **4ML high**



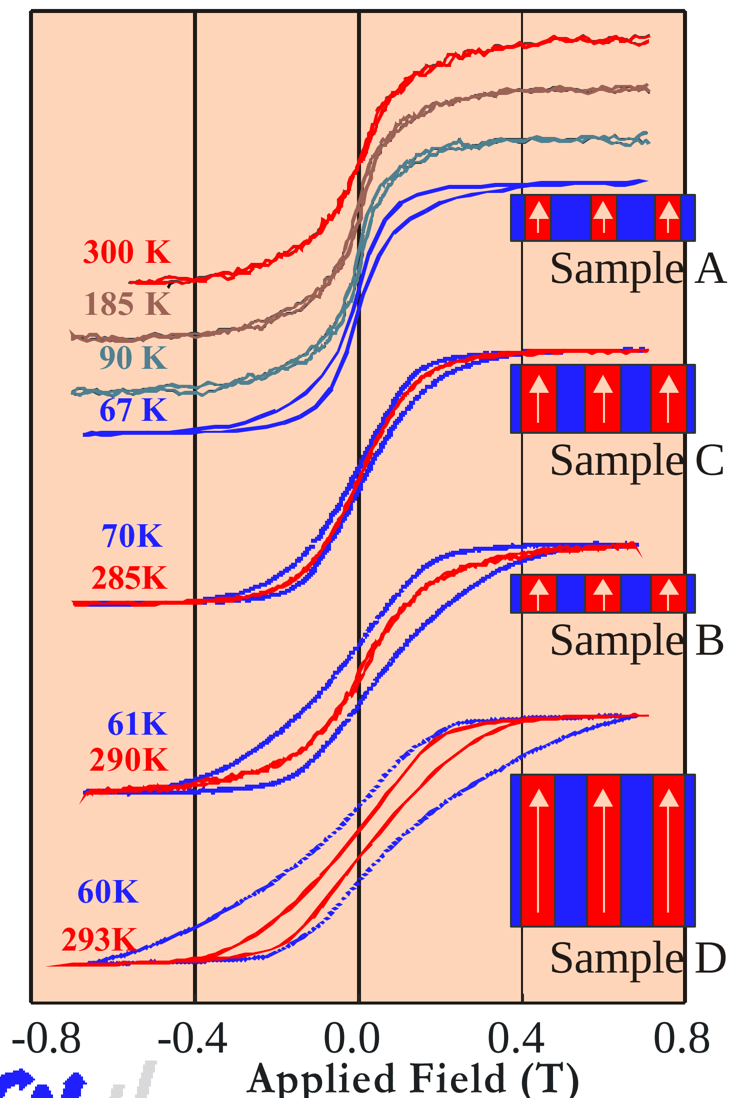
Co atoms grow only on existing dots

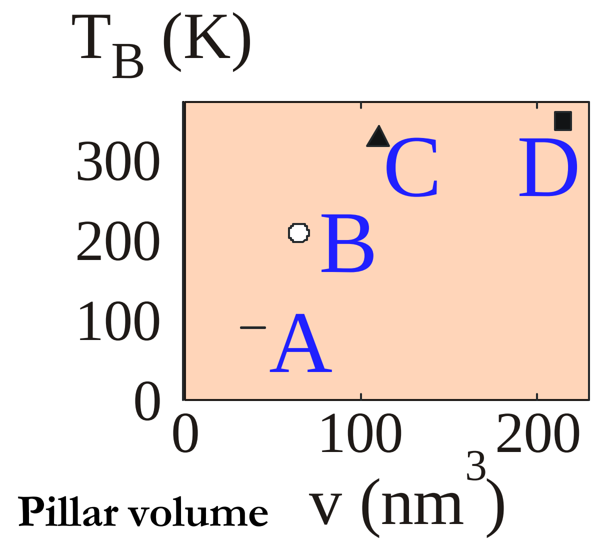
↳ VERTICAL SELF-ORGANIZATION





- Self-organization nearly undisturbed
- Pillars with 2:1 vertical aspect ratio





- **Blocking temperature > 300K**
  (~ 30K for flat Co/Au dots)

III. Our contribution for magnetism

Outline

Fe/cc(110) dots – Micromagnetism

Co/Au(111) pillars – Overcome low-dimensionality

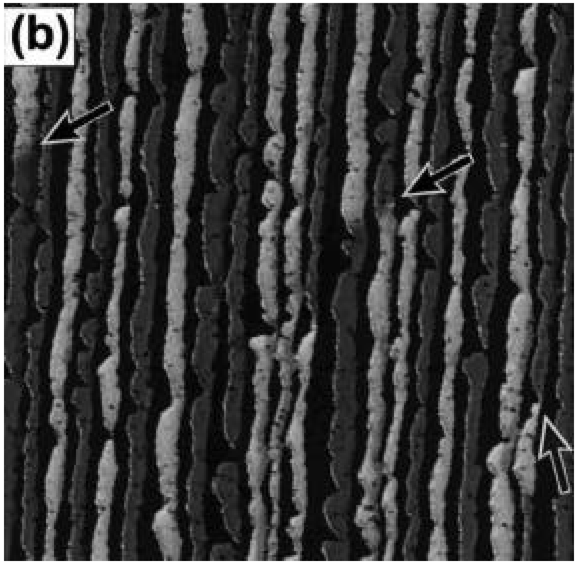
Fe/cc(110) stripes – Overcome low-dimensionality

Extend versatility of self-assembly

ATOMIC LAYER RANGE : WETTING

↳ nanometer-world / surface physics

low temperature



1.5AL on vicinal Fe/W(110)

M. Bode et al, J. Electr. Spectr. Rel. Phenom. 114– 116, 1055 (2001)

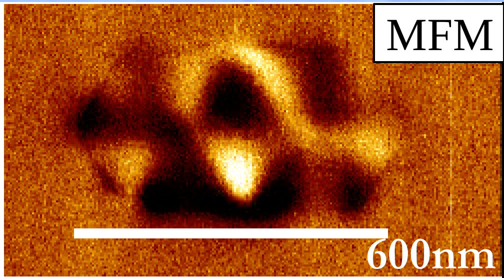
THICK DEPOSITS : NO WETTING

↳ micrometer-world / materials physics

room temperature

Fe/Mo(110) (Pulsed Laser Deposition)

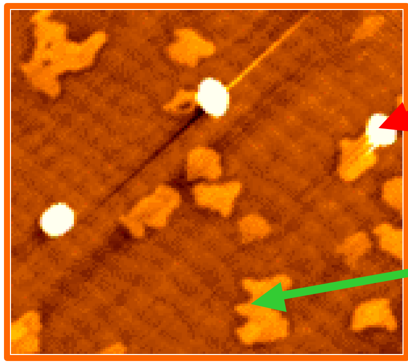
MFM:
Y. Samson
(CEA/France)



P.-O. Jubert *et al.*, JMMM 226, 1842 (2002)
P.-O. Jubert *et al.*, PRB64, 115419 (2002)
P.-O. Jubert *et al.*, Europhys. Lett. 63, 135 (2003)

↳ Is there an intermediate world ?

e_{nom} = 0.7 nm ~ 3.5ML

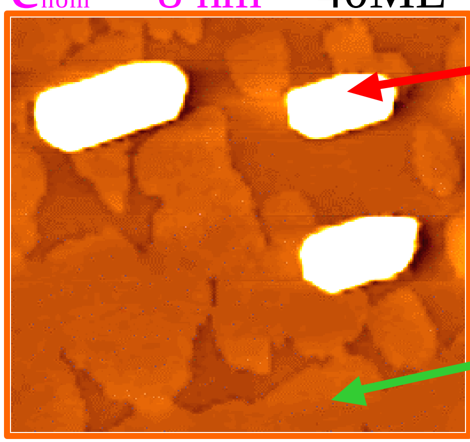


50% Vol. **3D**

h=1nm
50% Vol. **Flat**

AFM, 3μm x 2.8μm

e_{nom} = 8 nm ~ 40ML

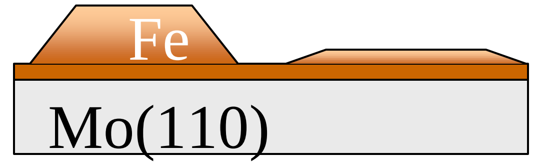


90% Vol. **3D**

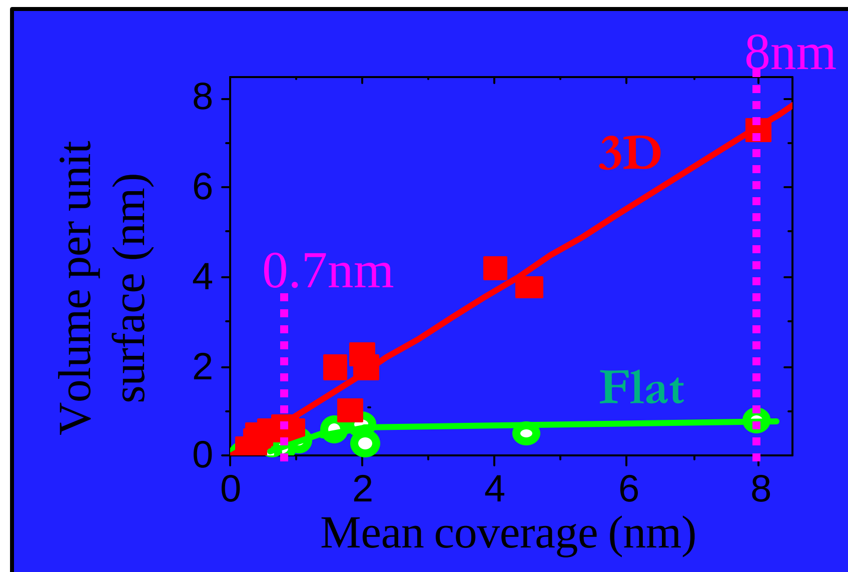
h=1nm
10% Vol. **Flat**

AFM, 3.6μm x 3.6μm

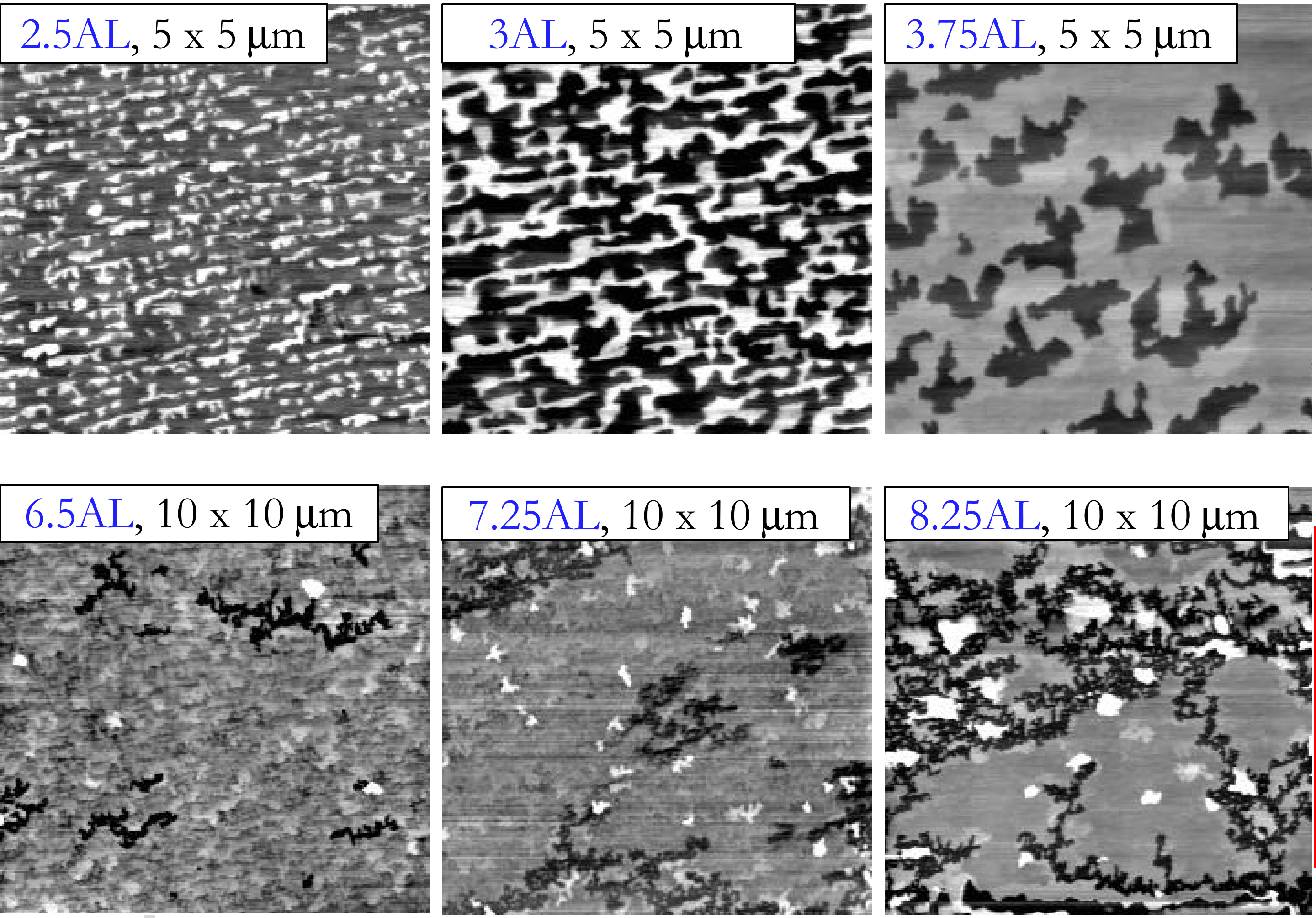
Ts = 700K



Bimodal Stranski-Krastanov growth



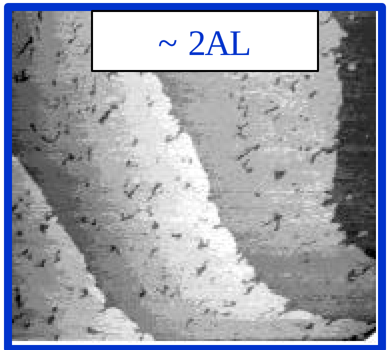
25°C growth + 450°C Annealing - Ex-situ AFM

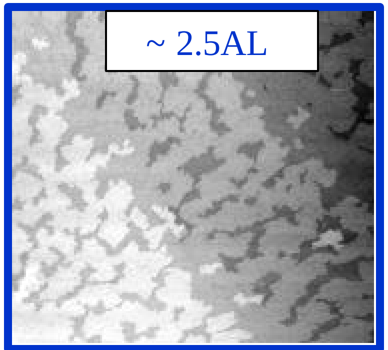


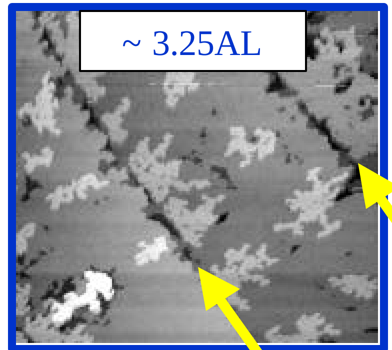
- **t<7AL**: 7AL metastable patches
- **t>7AL**: patches are 'sucked'

↳ 3D dots more stable than 7AL patches.

Step 1: layer-by-layer growth at 150°C



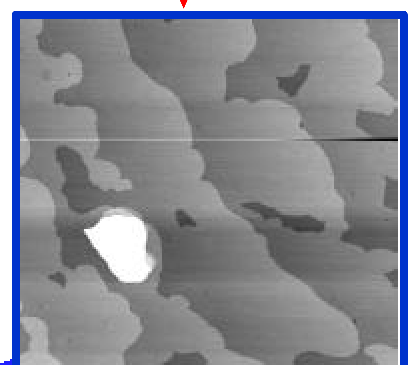


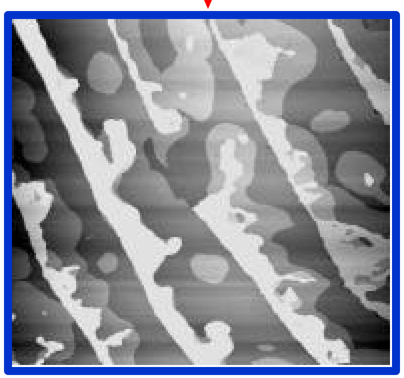


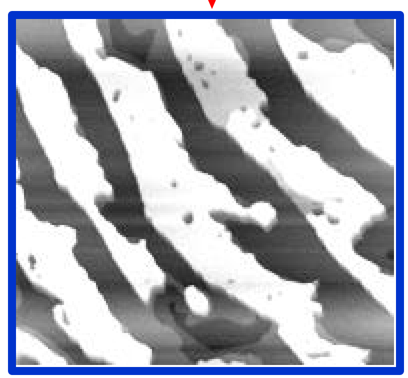
Fe films grown at 150°C

STM, 600nm x 600nm

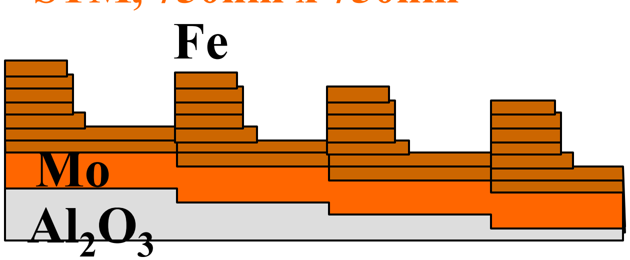
Step 2: annealing at 500°C --> stripes along steps



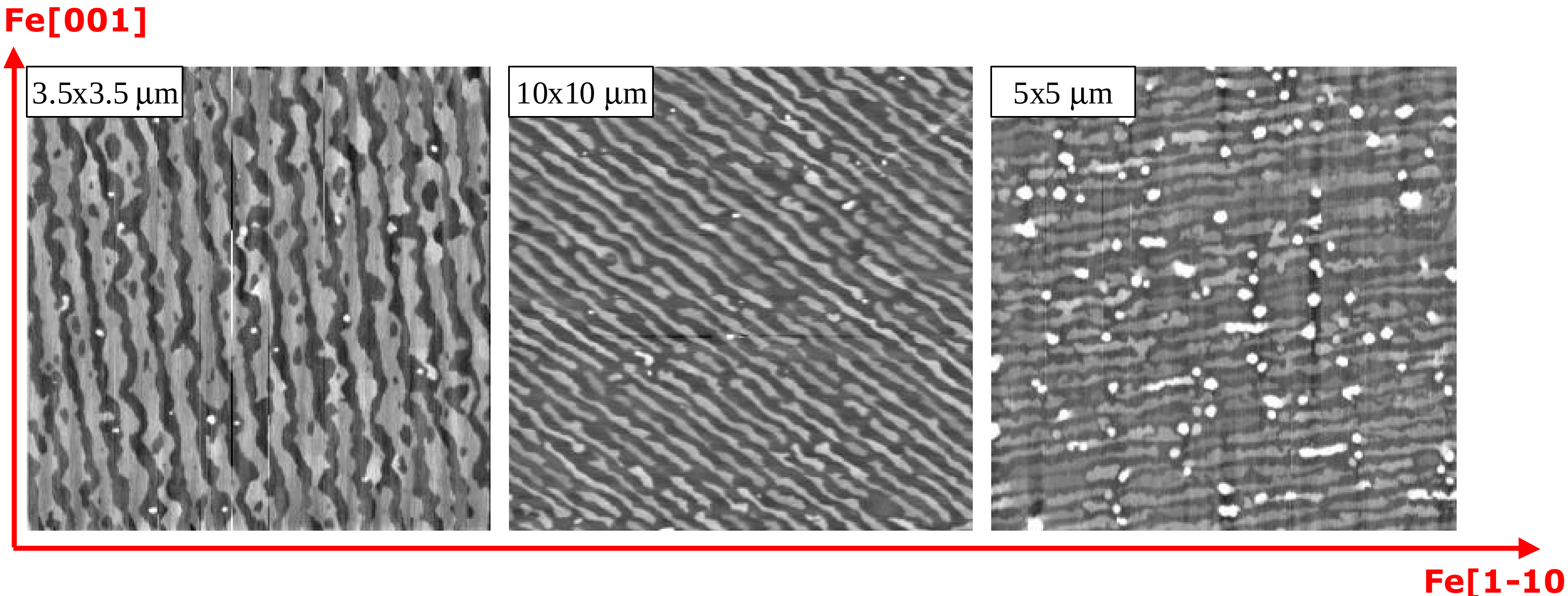




STM, 750nm x 750nm



Our contribution: Fe/Mo(110) stripes – orientation



(Slightly too high temperature for this sample...)

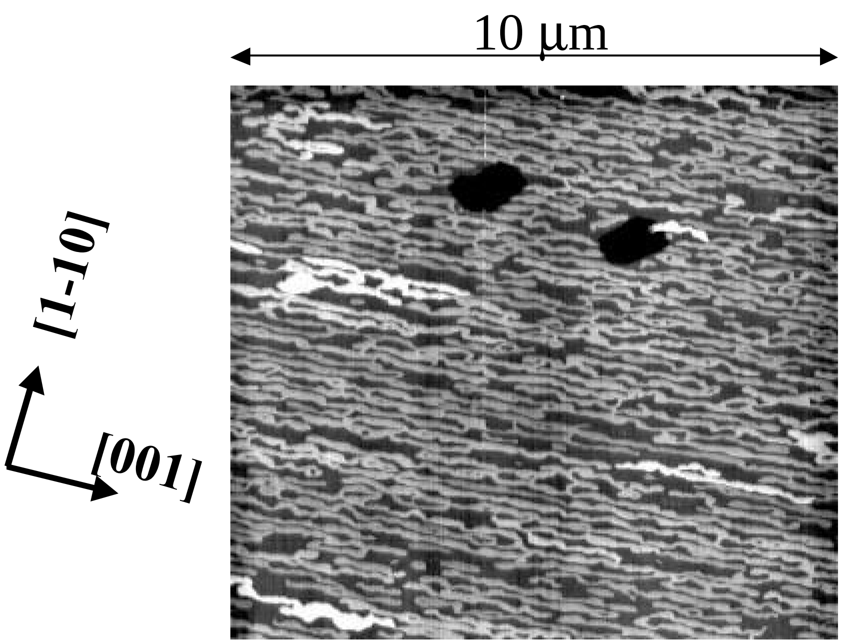
↳ **Tunable orientation**

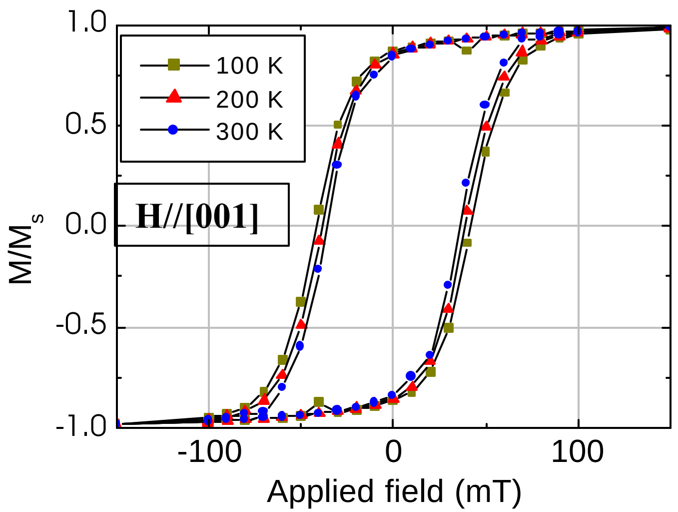
↳ Still too thin for static coercivity at 300K

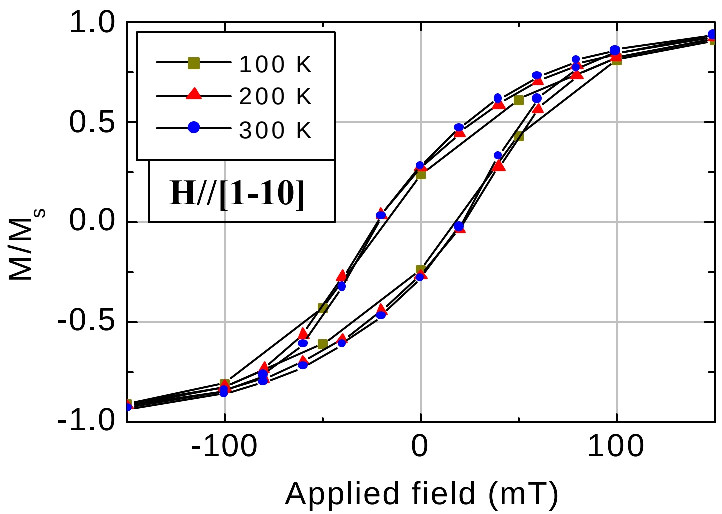
Coercivity and remanence at 300K

Sapphire \ W \ Fe(3nm) \ Mo

Stripe height = 5.5nm





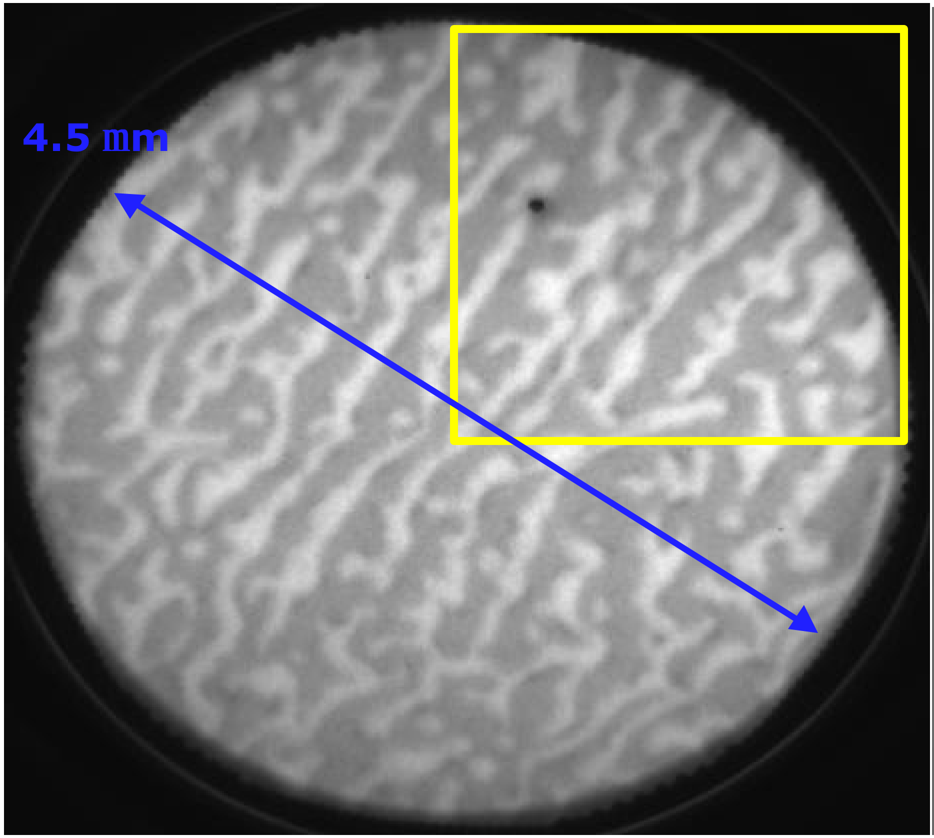


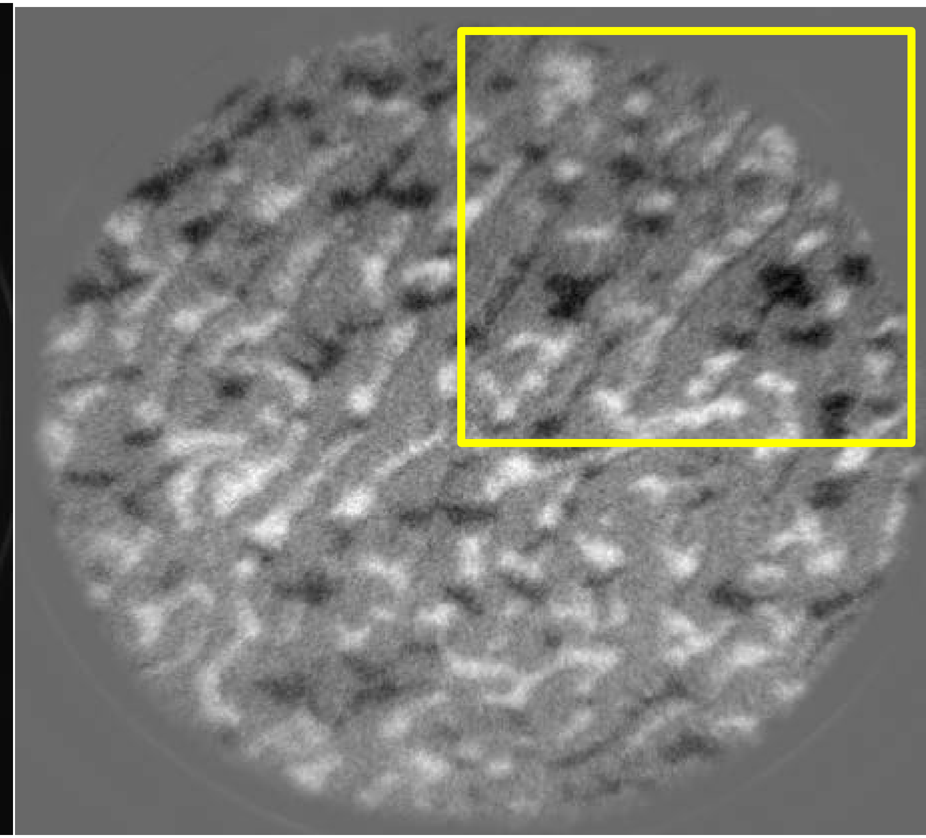
- **Coercivity and high remanence at 300K**
- **Weak temperature dependence**
  > behaves like a conventional material

O. Fruchart *et al.*, APL 84, 1335 (2004)

PEEM = Photo-Emission Electron Microscope

Demagnetized state

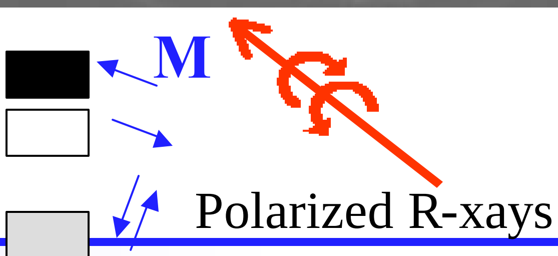


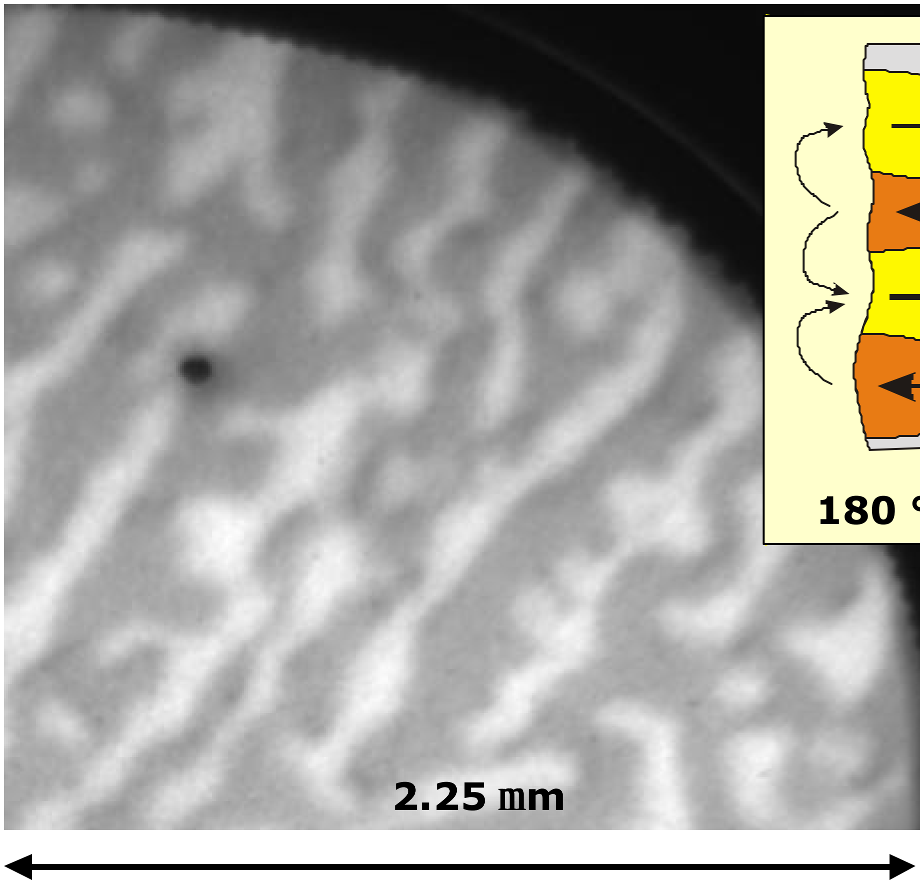


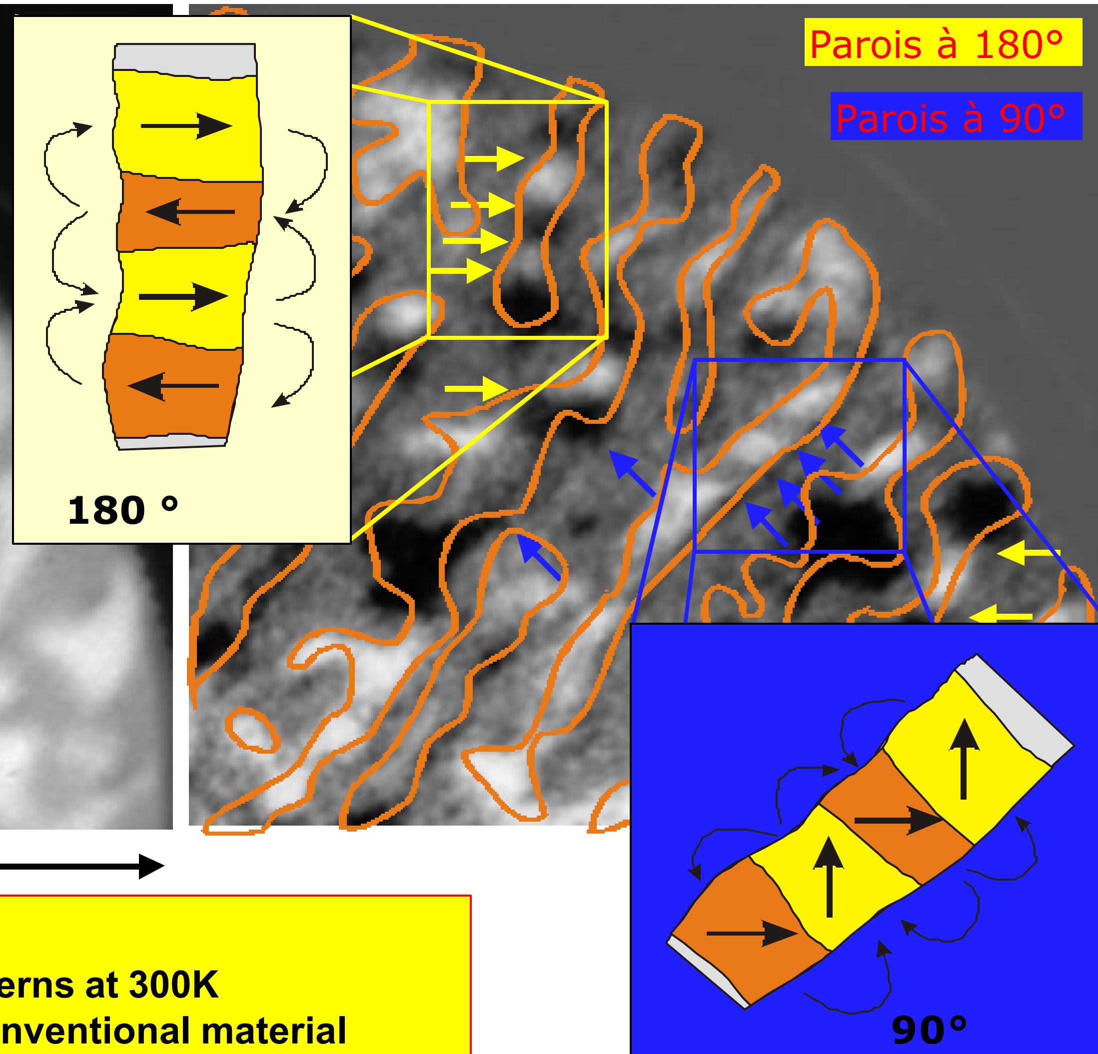
Sample:

Sapphire\W(8nm)\Fe(2.5nm)\Mo(1nm)\Al(3nm)

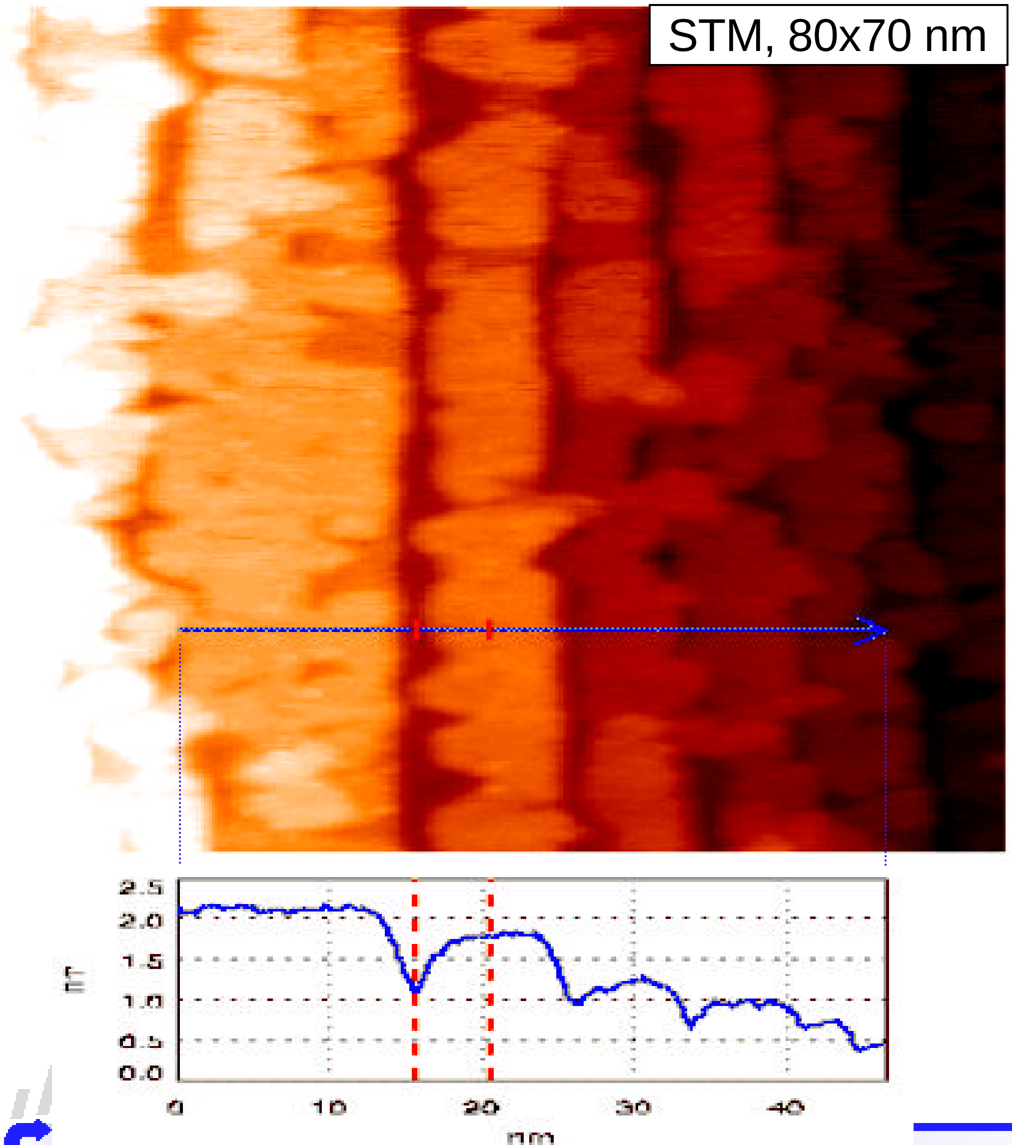
ELETTRA Syncrotron, Trieste







Stable domain patterns at 300K
> behaves like a conventional material



3 ML $Fe_{65}Ni_{35}$ / Cu(111)-vic 1.2°

- **Grooves along steps**

General phenomenon that may be exploited ?

S. Cherifi *et al.*, PRB 64 (2001) 184405

III. Our contribution for magnetism

Outline

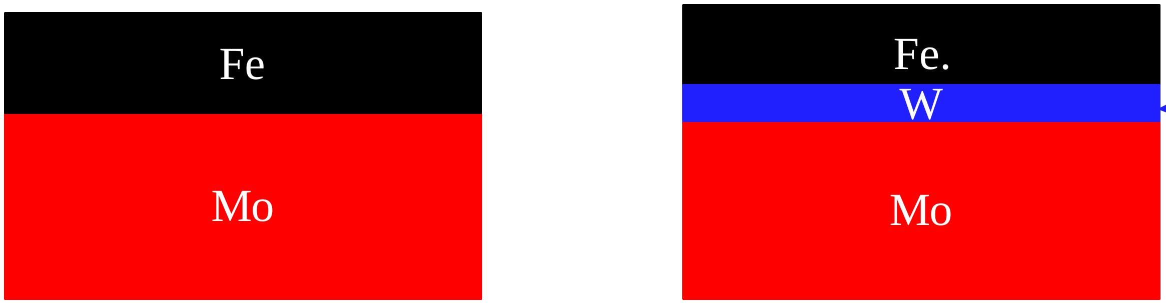
Fe/cc(110) dots – Micromagnetism

Co/Au(111) pillars – Overcome low-dimensionality

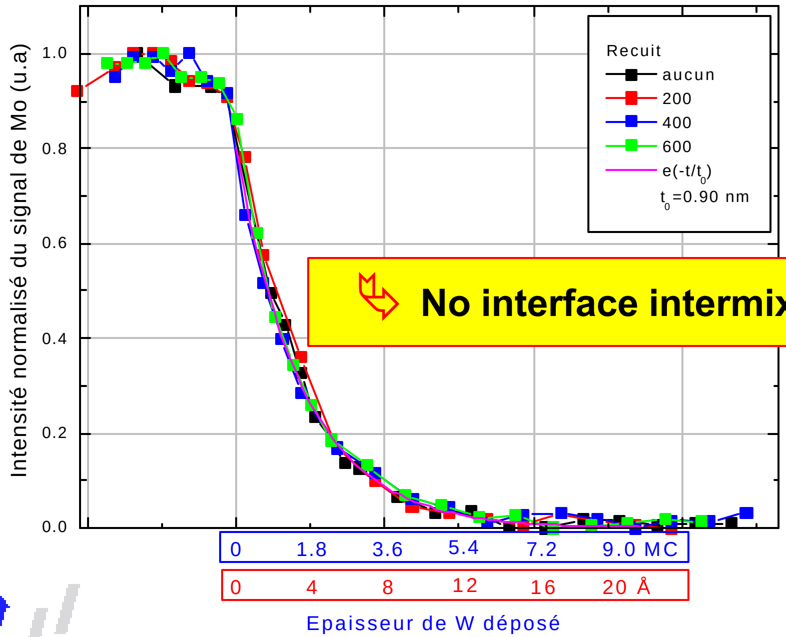
Fe/cc(110) stripes – Overcome low-dimensionality

Extend versatility of self-assembly

Control interface independently from lattice parameter

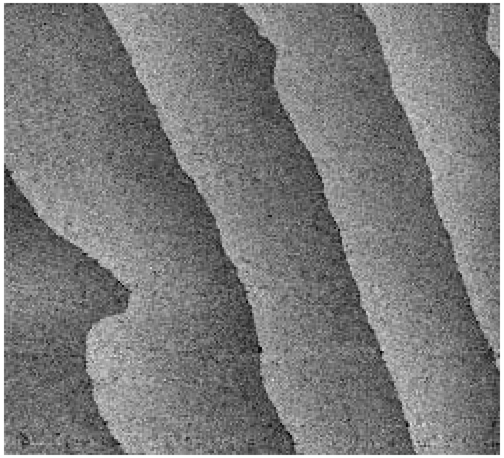


25°C growth + 800°C Annealing



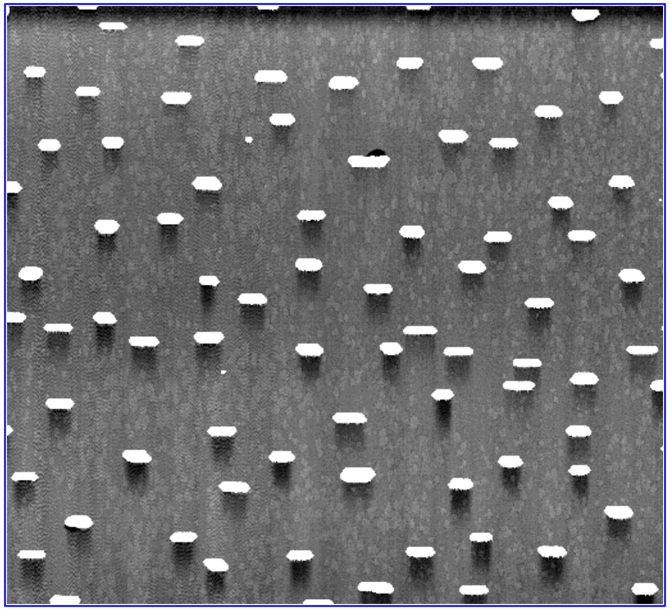
No interface intermixing

STM (800x800 nm)

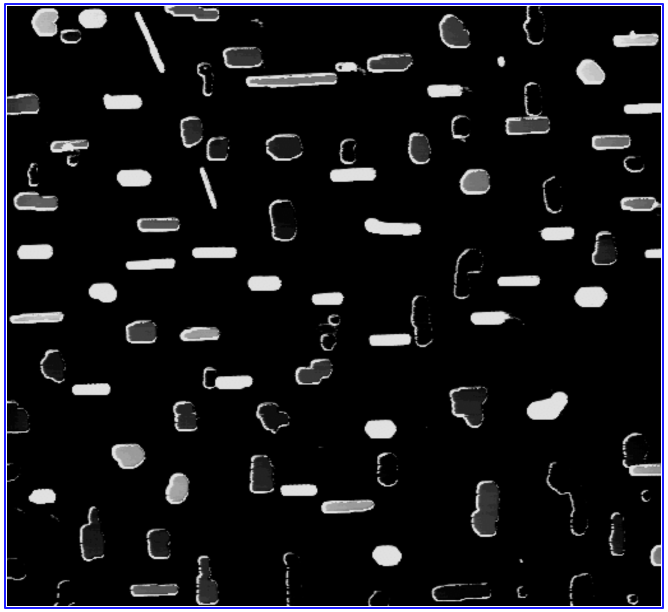


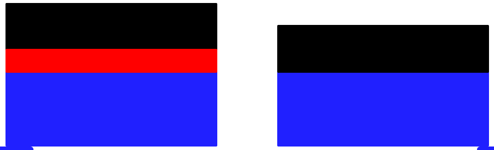
Atomically-flat surface

Effect of interface on shape of 3D dots



Fe(2.8 nm) @ 500°C





Fe / Mo(110) / W(110)

AFM (20x20 µm²)

$$r = L/W = 2.3 \pm 0.5$$
$$\eta = H/W = 0.23 \pm 0.07$$

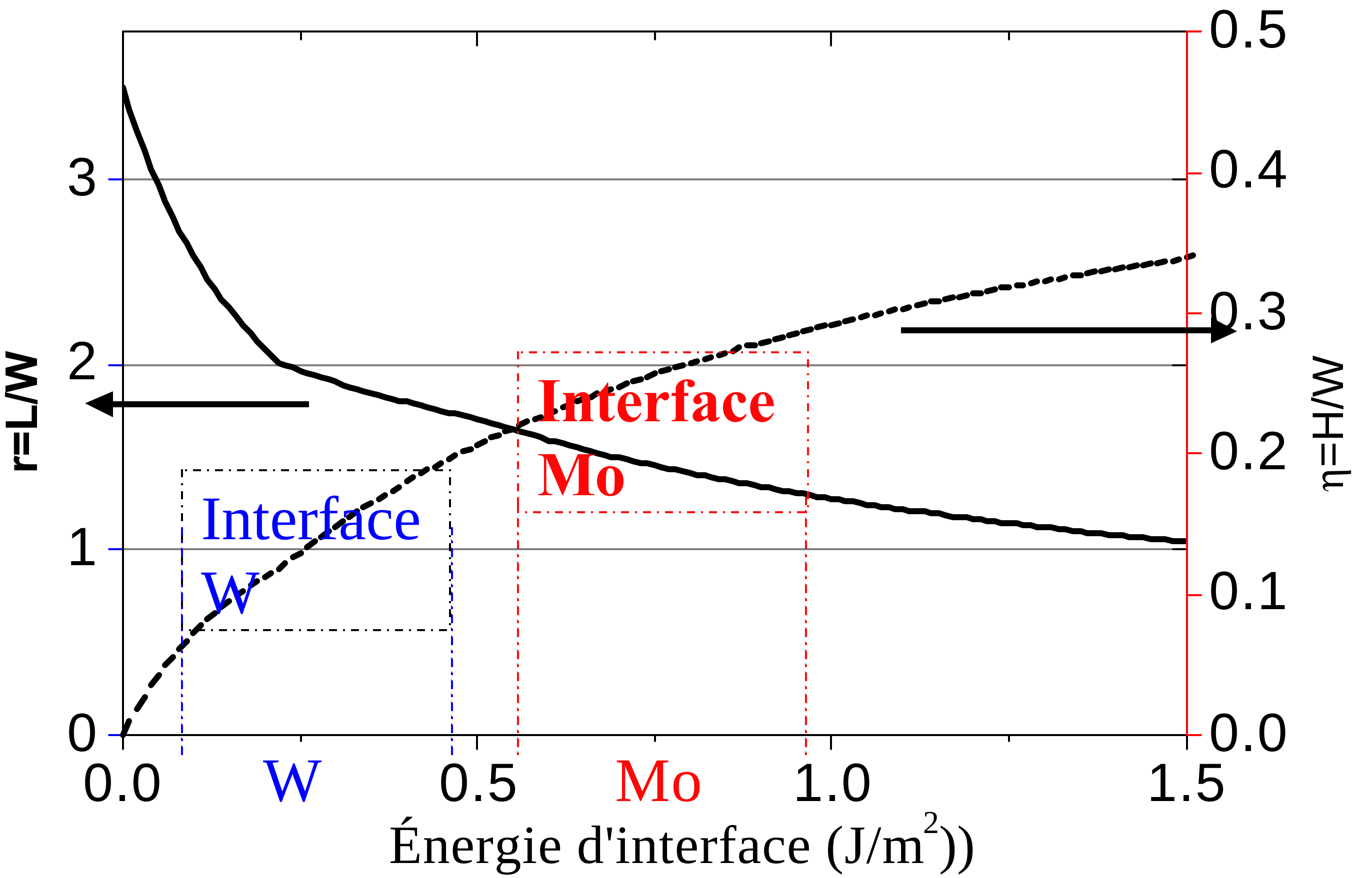
Fe / W(110)

AFM (20x20 µm²)

$$r = L/W = 2.7 \pm 0.8$$
$$\eta = H/W = 0.07 \pm 0.03$$

Interface energy deduced from measurements

Based on Wulff's construction



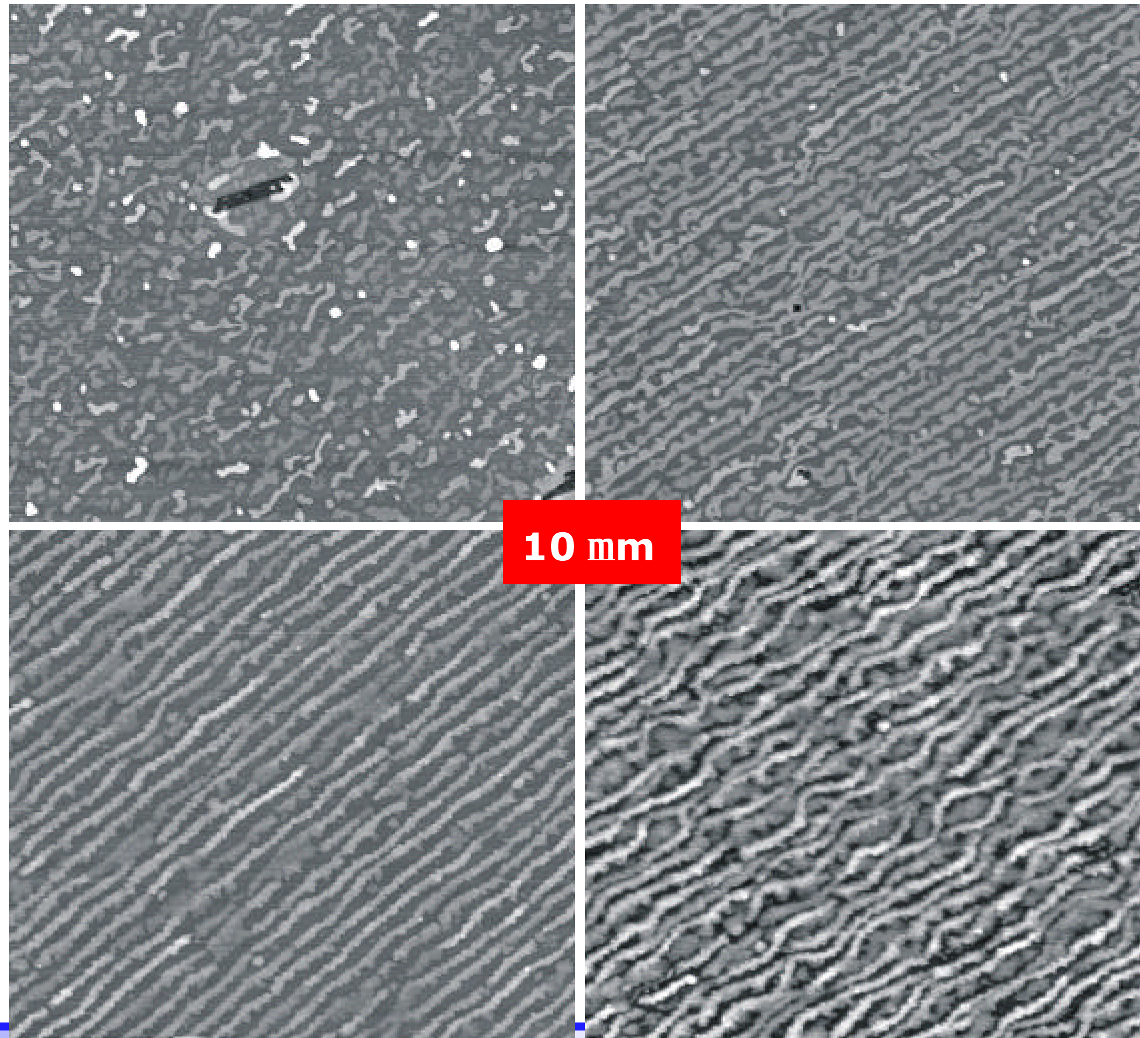
Sapphire\Mo(8nm)\interface\Fe(150°C, 450°C annealing)

1nm | 2.5nm | Average thickness

Fe /W(<1nm) /Mo

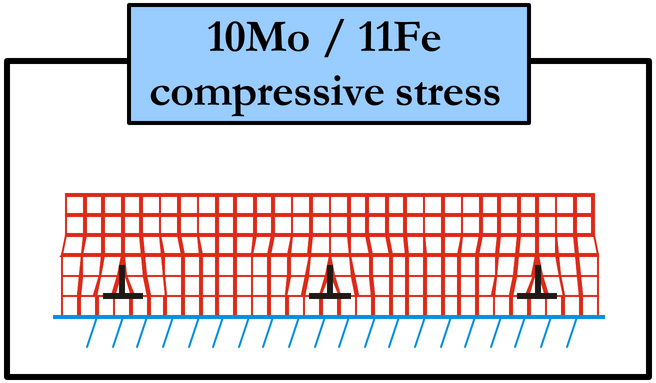
Fe /Mo

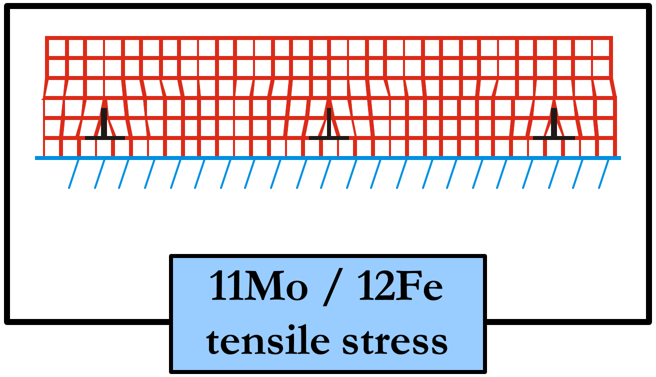
Chemical interface



Height : 4.5nm

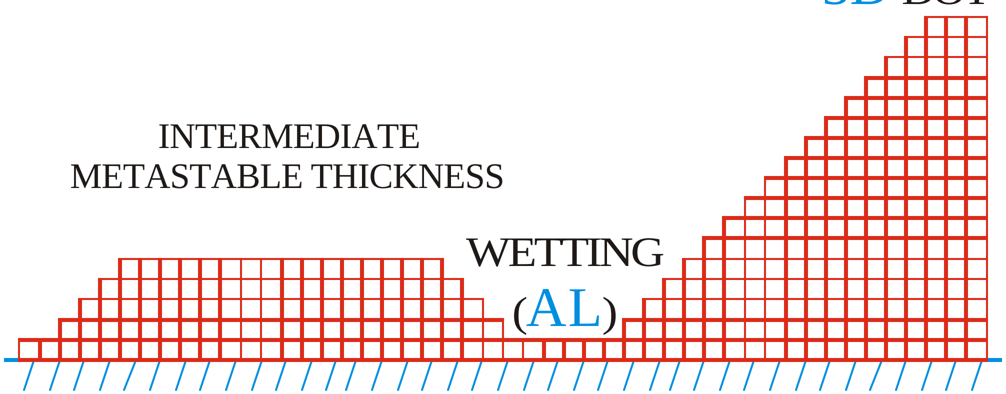
Height : bimodal 1.5/4nm





UNUSUAL BEHAVIOR.

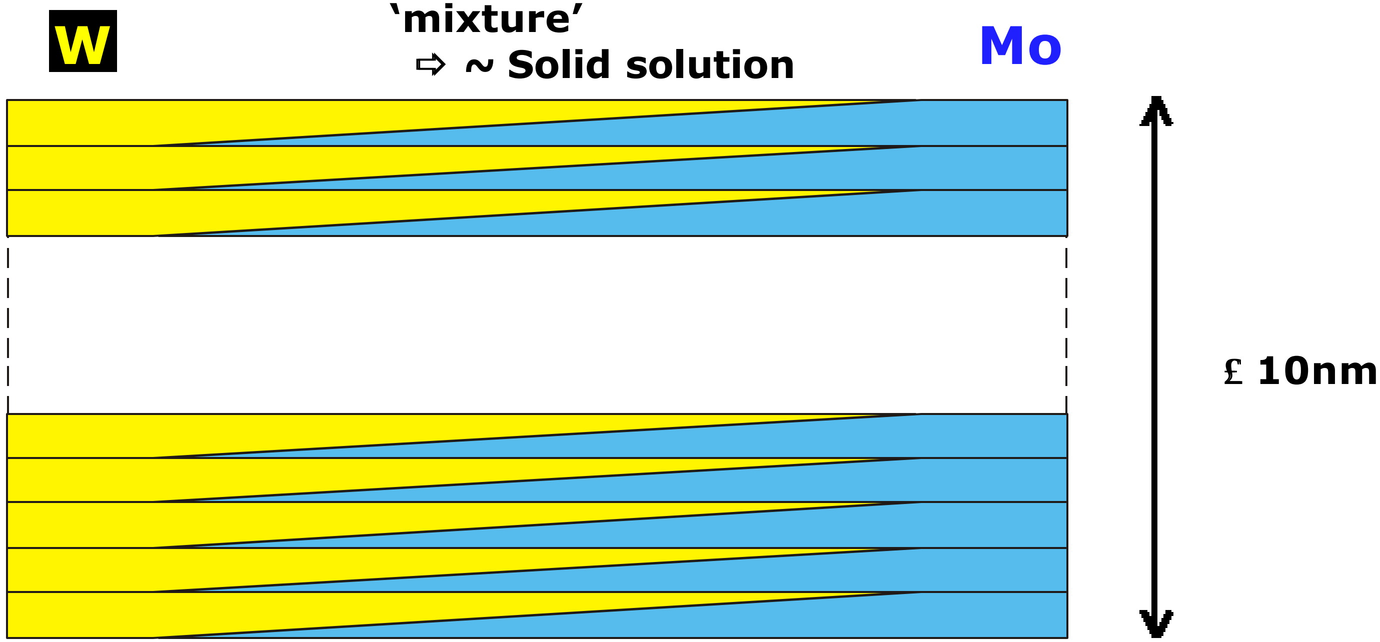
Possible explanation = elastic energy minimization
commensurate / incommensurate transition of interface dislocation array for thickness > 7AL



Continuous control of lattice parameter

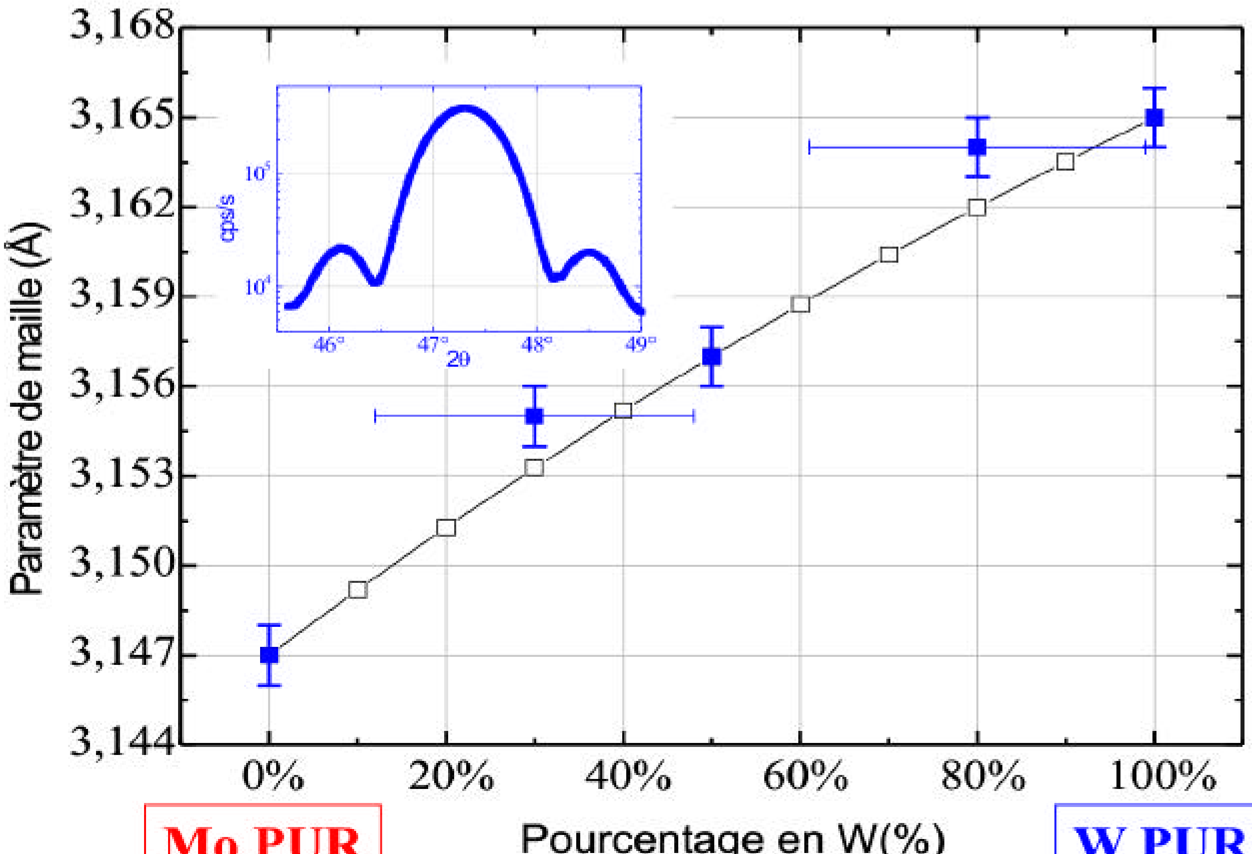
Opposite wedges

'mixture'
⇨ ~ Solid solution



- Continuously variable buffer layer lattice parameter
- Atomically flat surface; atomic steps array

Continuous control of lattice parameter

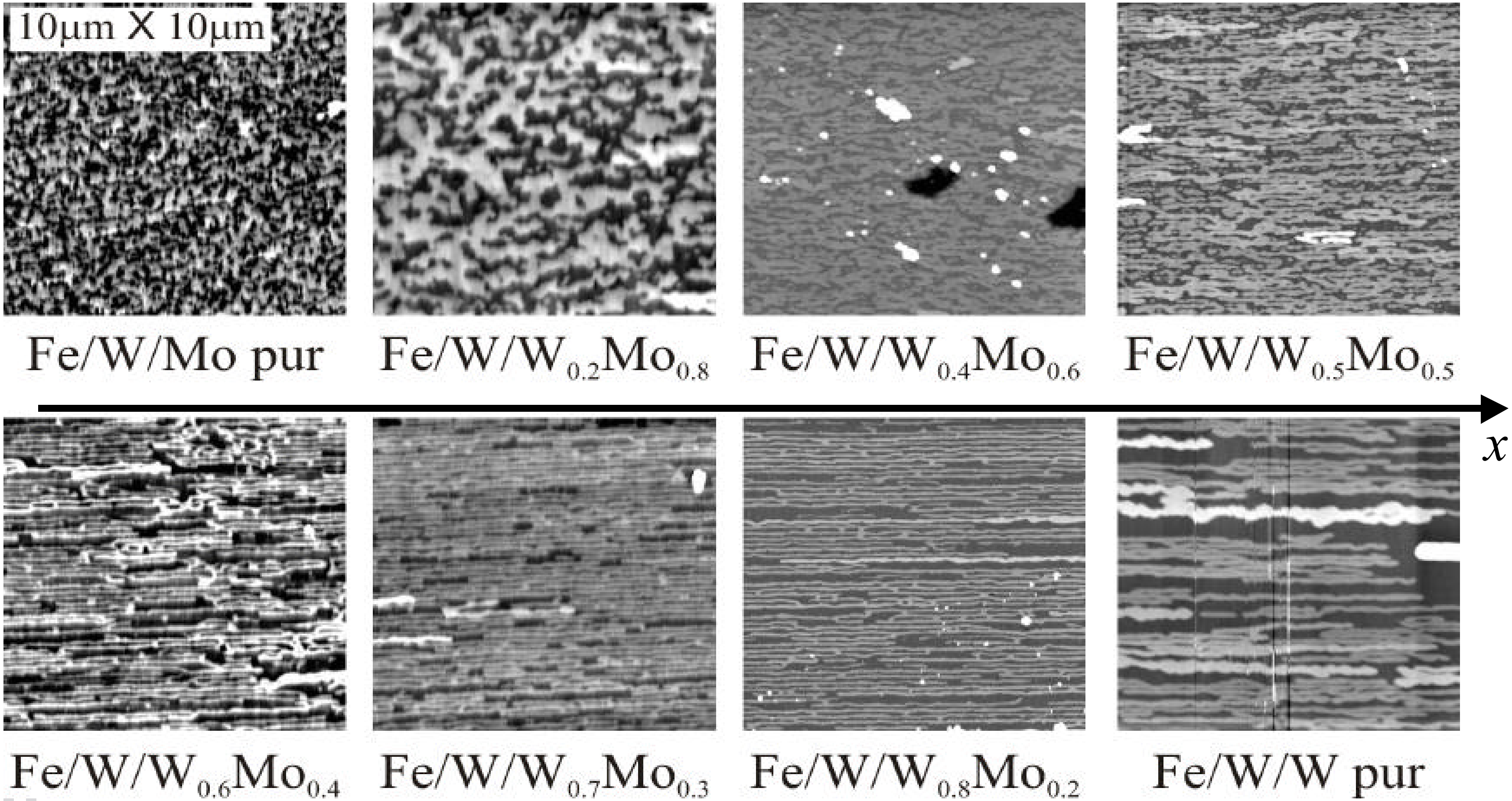


Mo PUR **W PUR**

In-plane lattice parameter from a_{Mo}= 3.147 Å to a_W = 3.165 Å

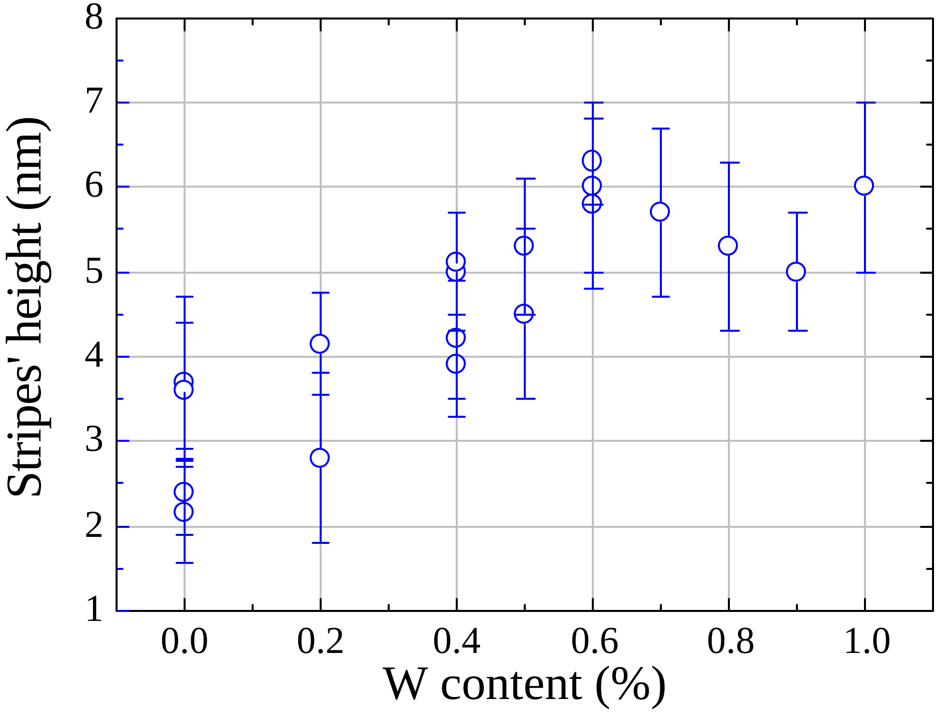
Continuous control of lattice parameter

Dramatic effect on stripe growth



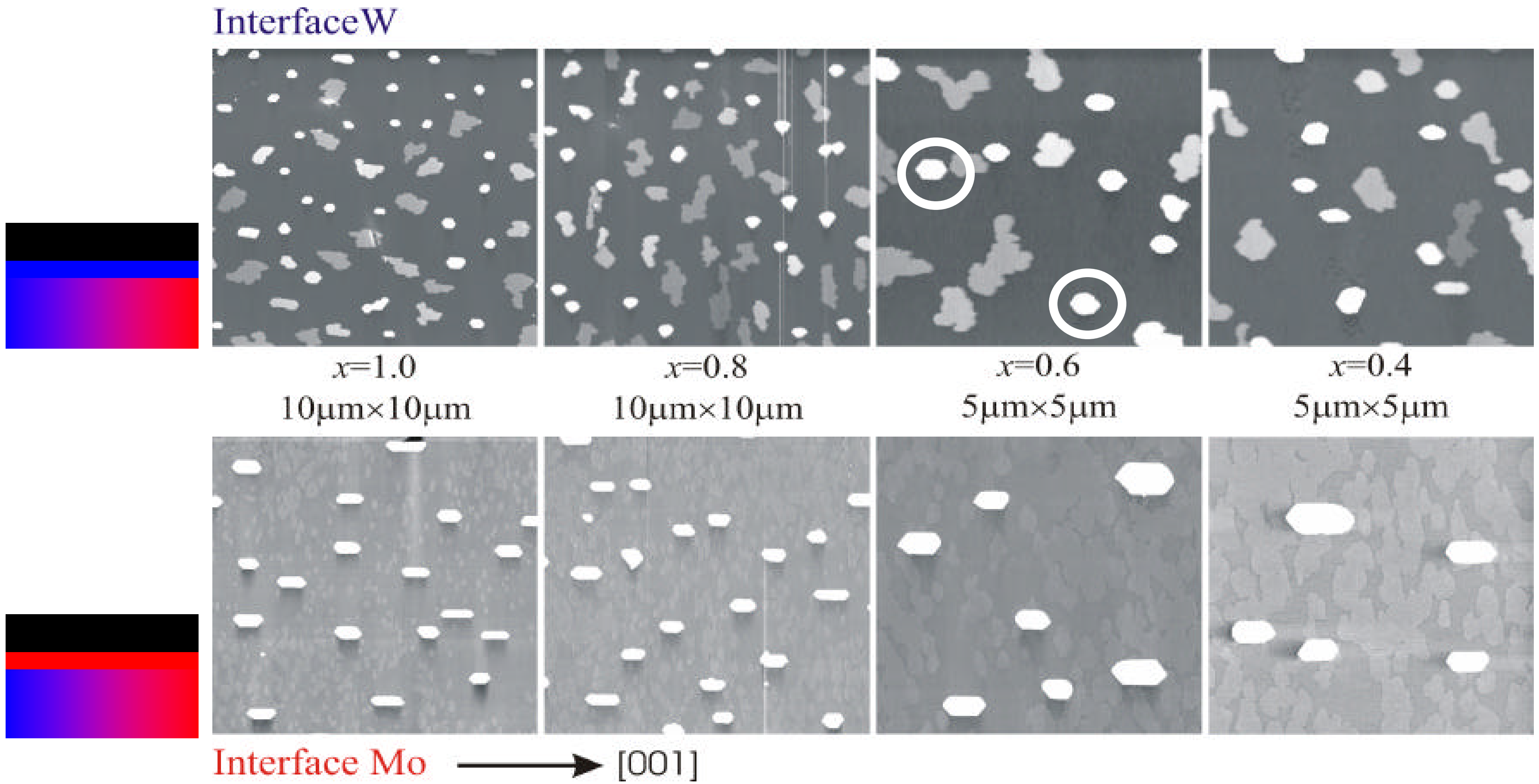
Continuous control of lattice parameter

Significant effect on stripe height



- Hypothesis of commensurate/incommensurate transition needs to be confirmed

Lattice parameter : weak effect on dots



Differences: size, shape, density, aspect ratios

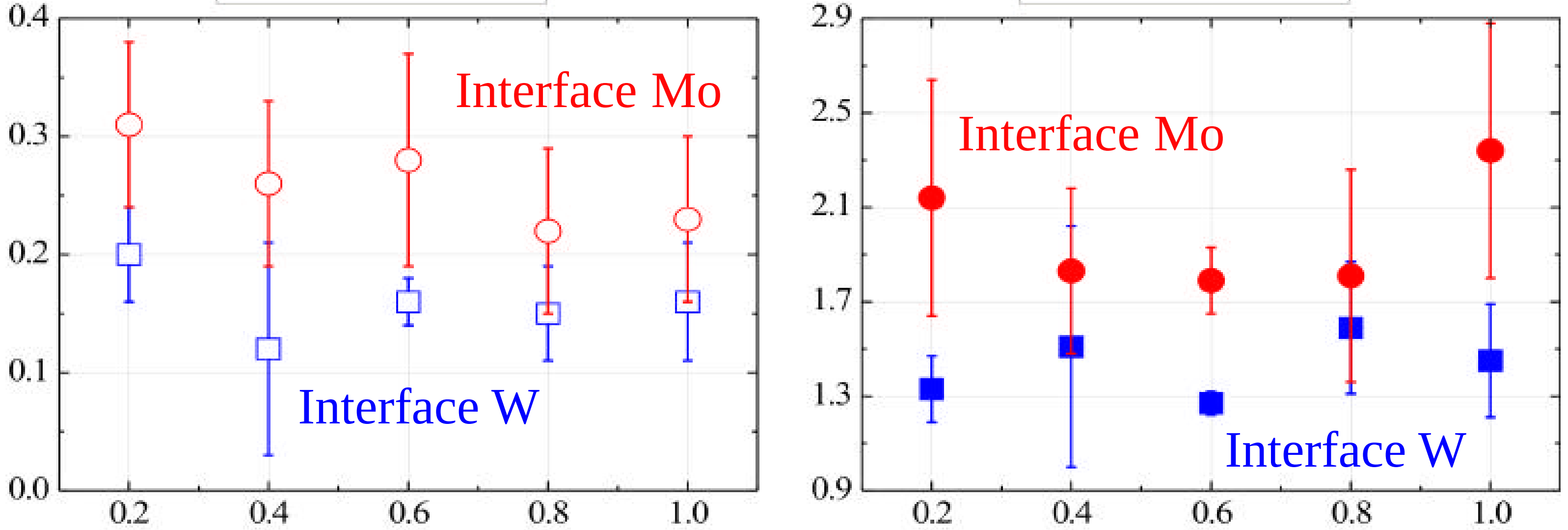
Weak lattice parameter change : no effect on dots

Vertical aspect ratio

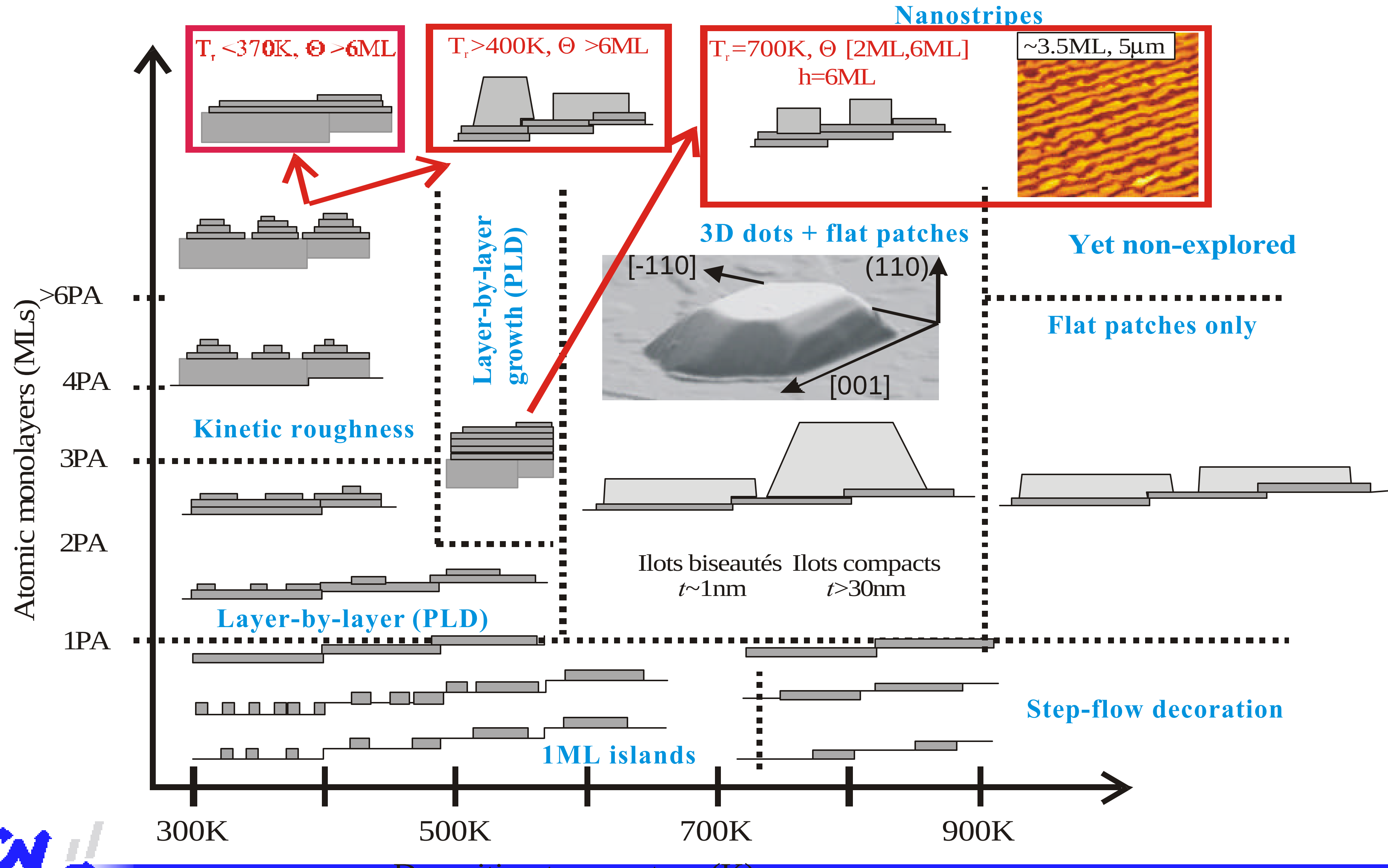
$$\eta = H/W$$

In-plane aspect ratio

$$r = L/W$$

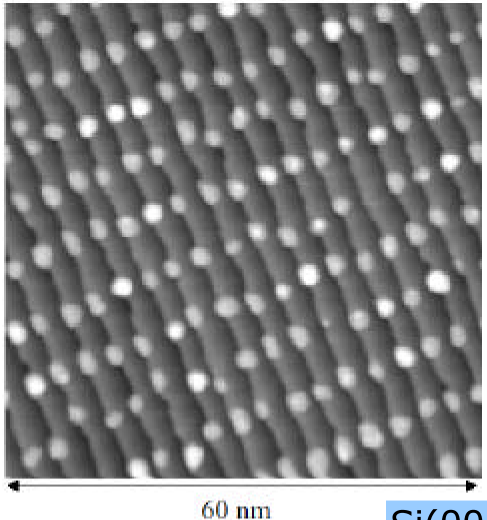


x: $W_x Mo_{1-x}$

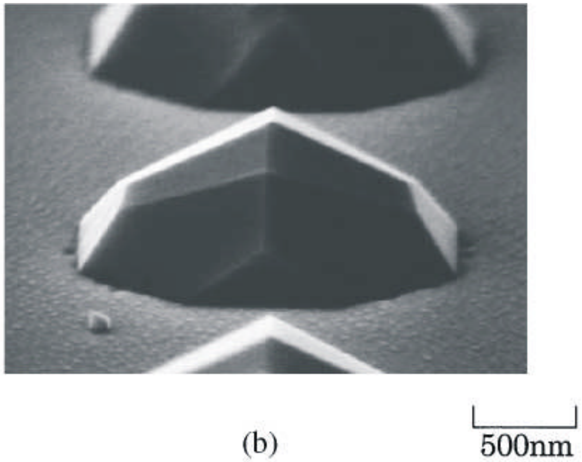

Nanostripes
T_r <370K, Θ >6ML
T_r >400K, Θ >6ML
T_r =700K, Θ [2ML,6ML]
h=6ML
~3.5ML, 5µm
Layer-by-layer growth (PLD)
3D dots + flat patches
Yet non-explored
[-110]
(110)
[001]
Flat patches only
>6PA
4PA
3PA
2PA
1PA
Atomic monolayers (MLs)
Kinetic roughness
Ilots biseautés
t~1nm
Ilots compacts
t>30nm
Layer-by-layer (PLD)
Step-flow decoration
1ML islands
300K
500K
700K
900K
Deposition temperature (K)

Fe/Mo(110) dots

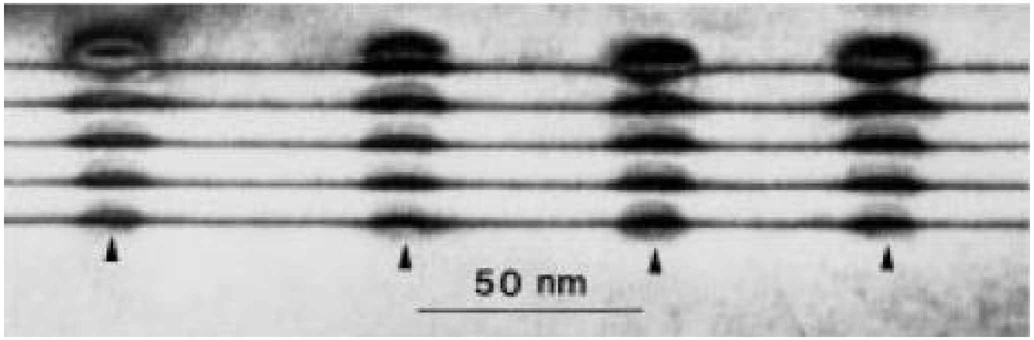
Co/Au(788) dots



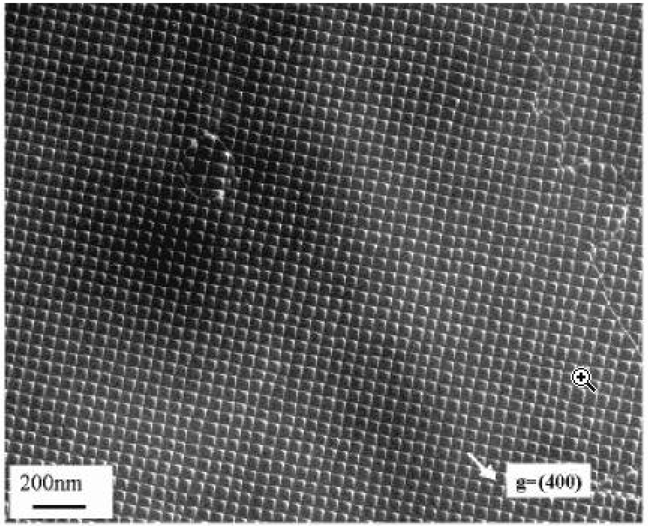
GaAs/GaAs(001) dots



InAs/GaAs(001) dots

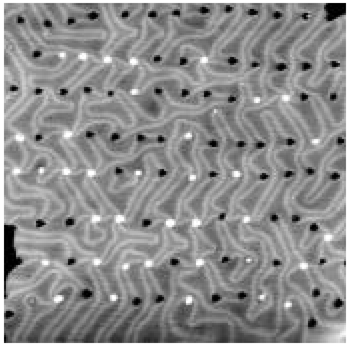


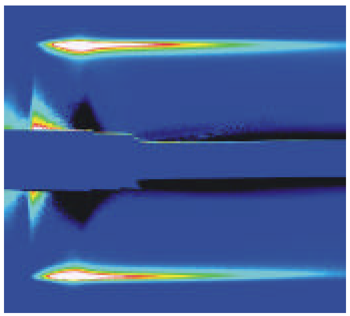
Si(001) bonding



Many tricks to be used

↳ **Just let your imagionation help nature !**

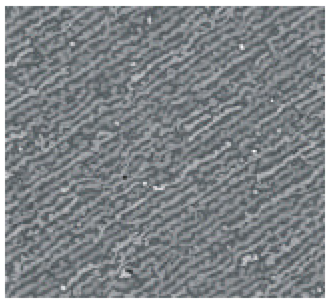


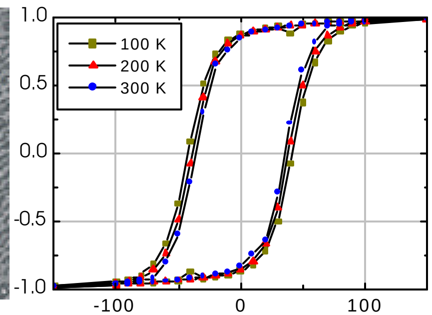


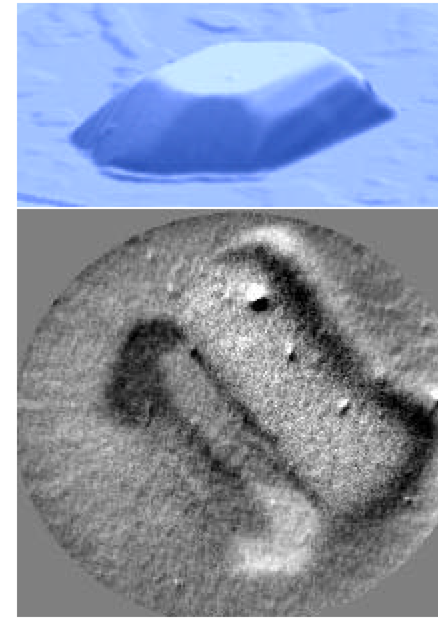
Self-assembly for magnetism

- Micron-size dots used as model systems

- Vertical pillars with alternative deposition
- Step-decoration process well above 1ML





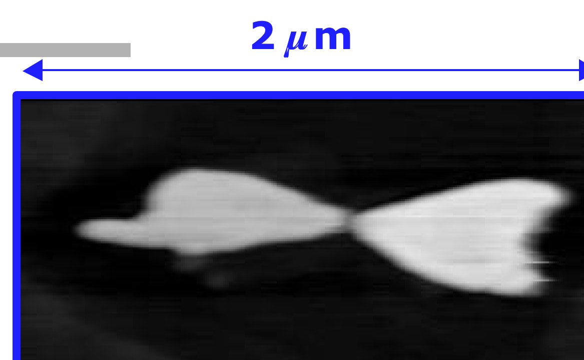


Contribution to self-assembly

- Continuous tunability of stripe height

- Confirm origin of metastable height

- New self-assembled systems
  Ex: nano-tie-knots (domain wall in constriction)



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