Topography and magnetic properties of epitaxial Fe/Cu/Si(111) nanostructures

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Magnetic films and multilayers:

- giant magnetoresistence
- magnetic memories
- microwave devices

Systems characterized by the change of

- value of magnetic moment
- magnetization axis
  - vs thickness
  - choosing appropriate combination of materials

WHY

magnetic systems on Si substrate ?

- Silicon is cheaper and easier to prepare than any metallic single crystal substrate

- In view of their potential integration with Si technology

BUT

Si does not provide a close lattice match to any of the elemental magnetic metals

↓

It is not easy to achieve epitaxial growth

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Serious limitations of the device performances

Buffer layer !

Methodology and experimental techniques

- Growth in UHV system: p~1x10^{-10} torr
- Cu and Fe deposited on the sample kept at RT

LEED :

- to check the quality of the Si substrate reconstruction
- to monitor morphology and structural changes after the buffer layer formation and each Fe deposition

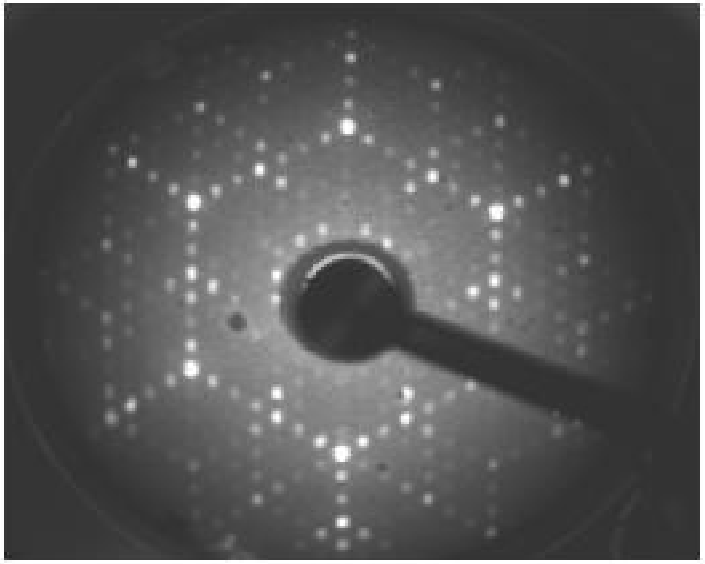
Auger spectroscopy:

- to check the atomic purity of substrates & overlayers

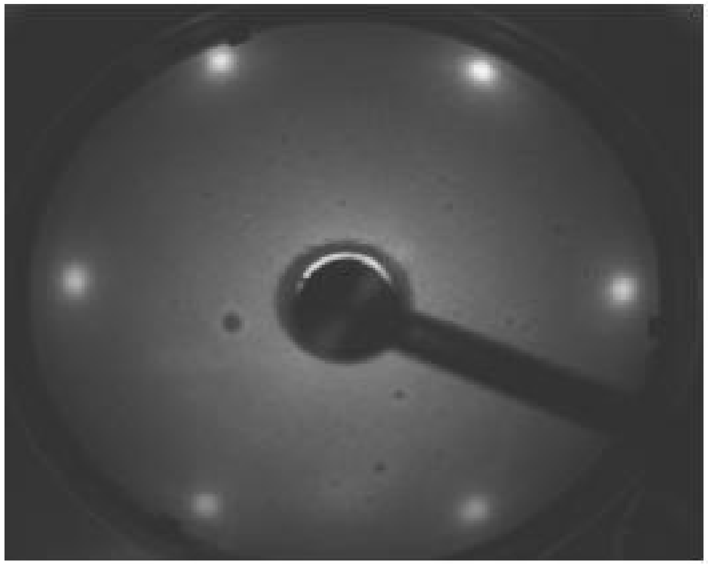
- **STM and MFM**
- **SMOKE & Resonant magnetic scatterng**
- **Auger electron diffraction**

3 nm Cu RT deposited on Si(111)7x7 surface

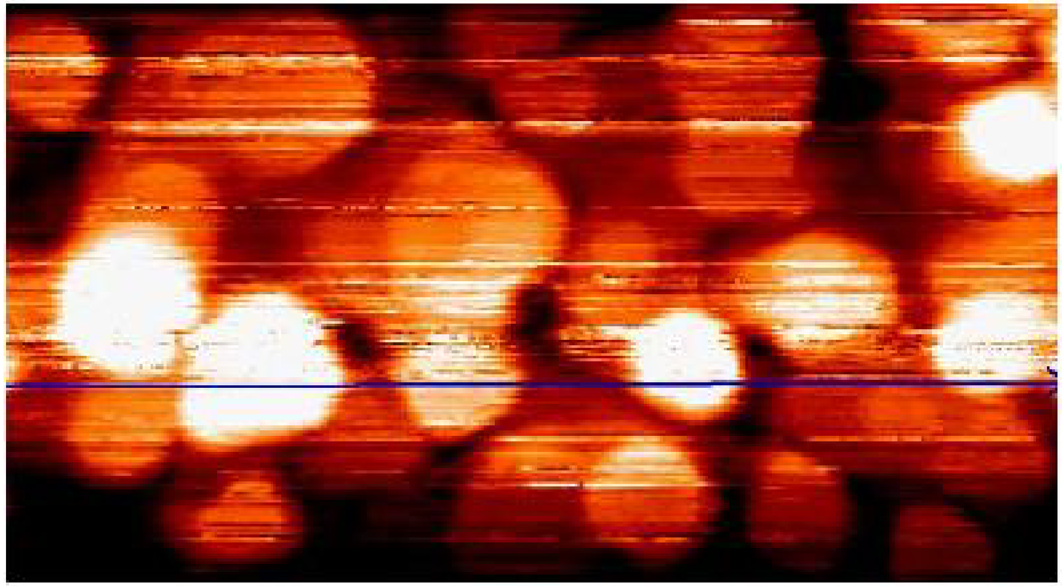
Si(111)7x7

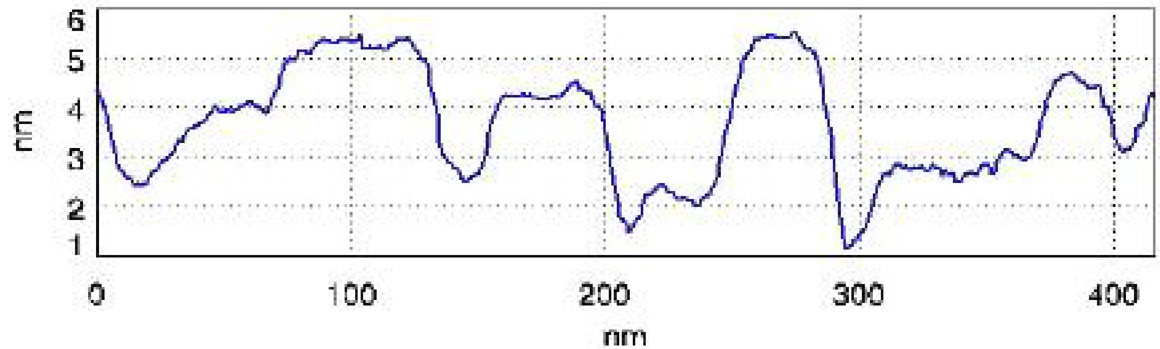


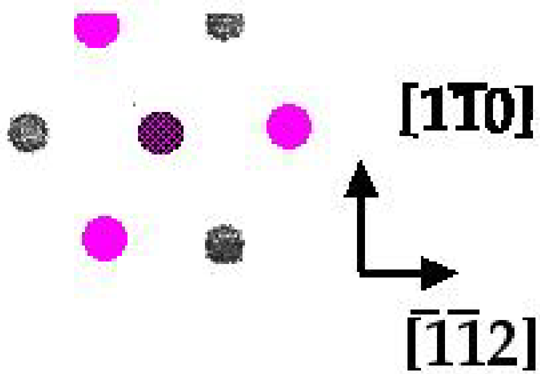
Cu/Si(111)7x7



LEED images for E_p = 70 eV



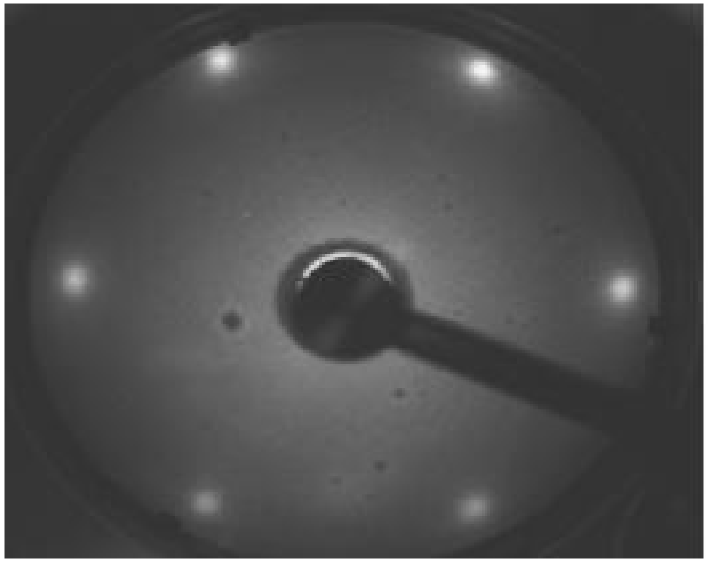




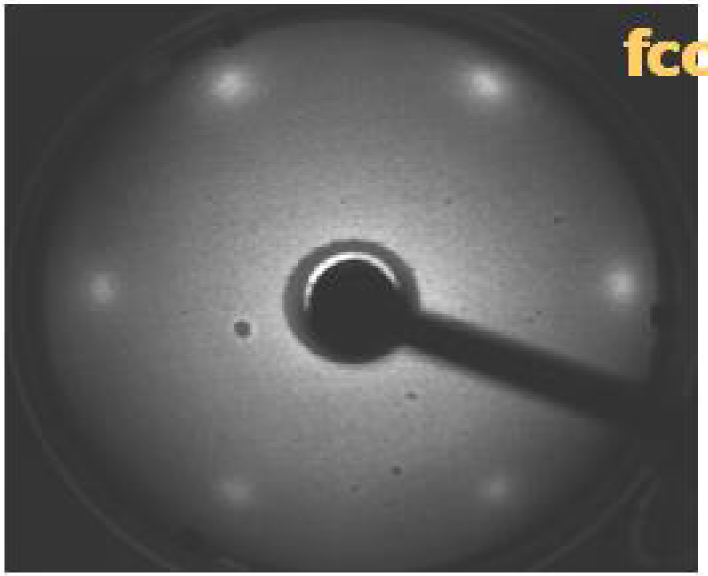
30-40 nm

0.4 nm Fe RT deposited on Cu/Si(111)

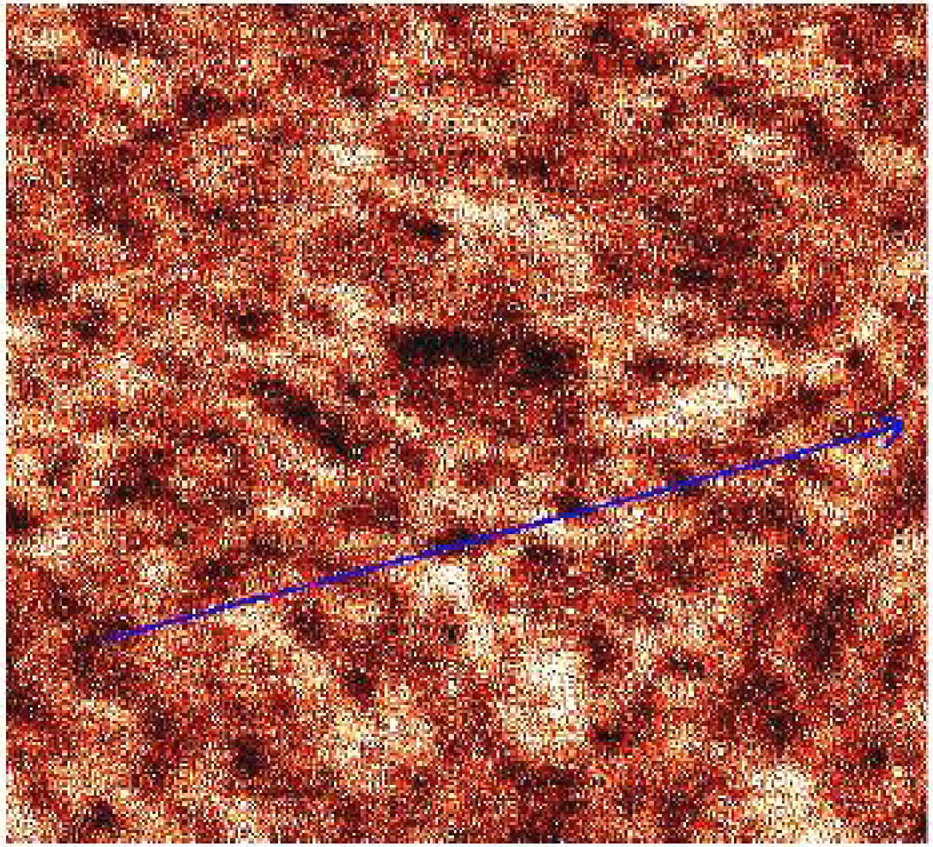
Cu/Si(111)7x7



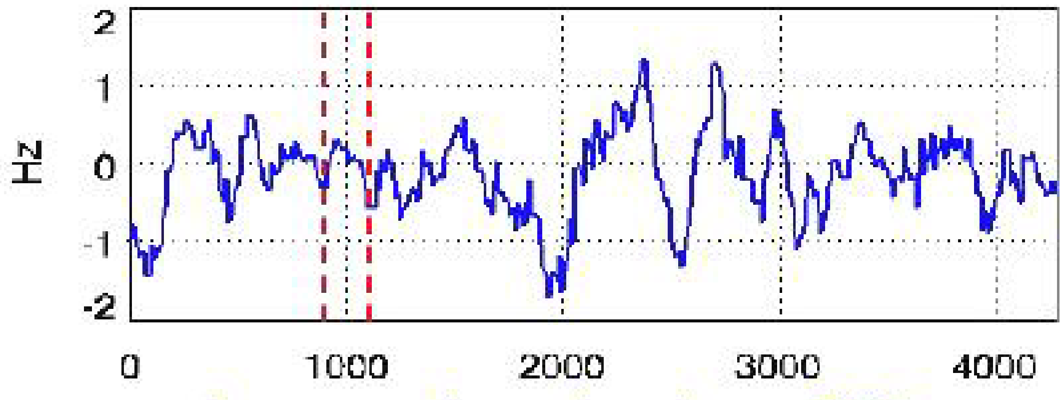
Fe/Cu/Si(111)7x7



LEED images for E_p = 70 eV



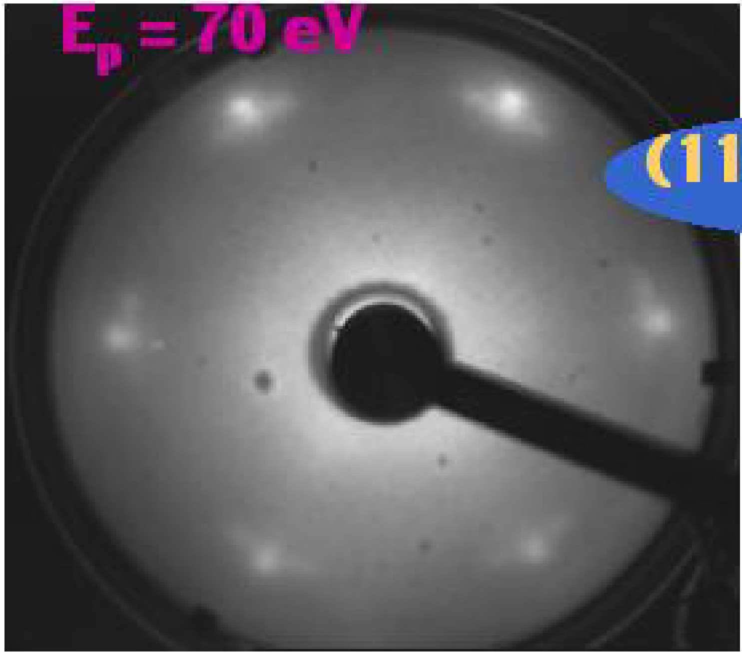
Out of plane magnetization



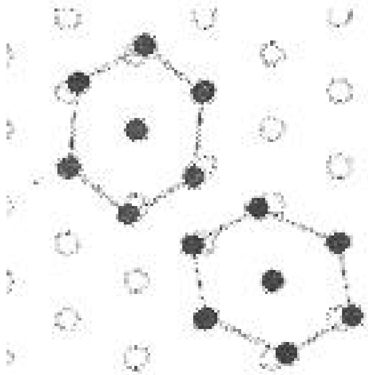
Average domain size ≈ 250 nm

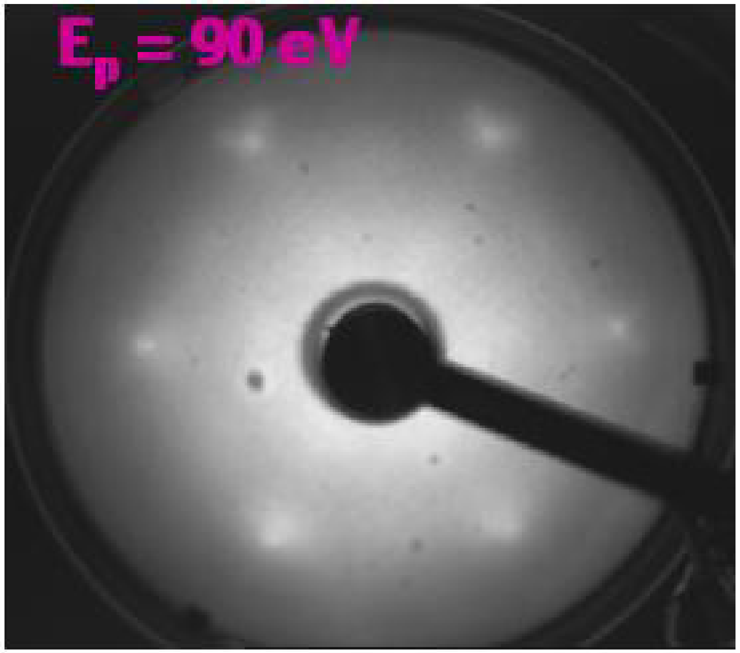
0.8 nm Fe RT deposited on Cu/Si(111)

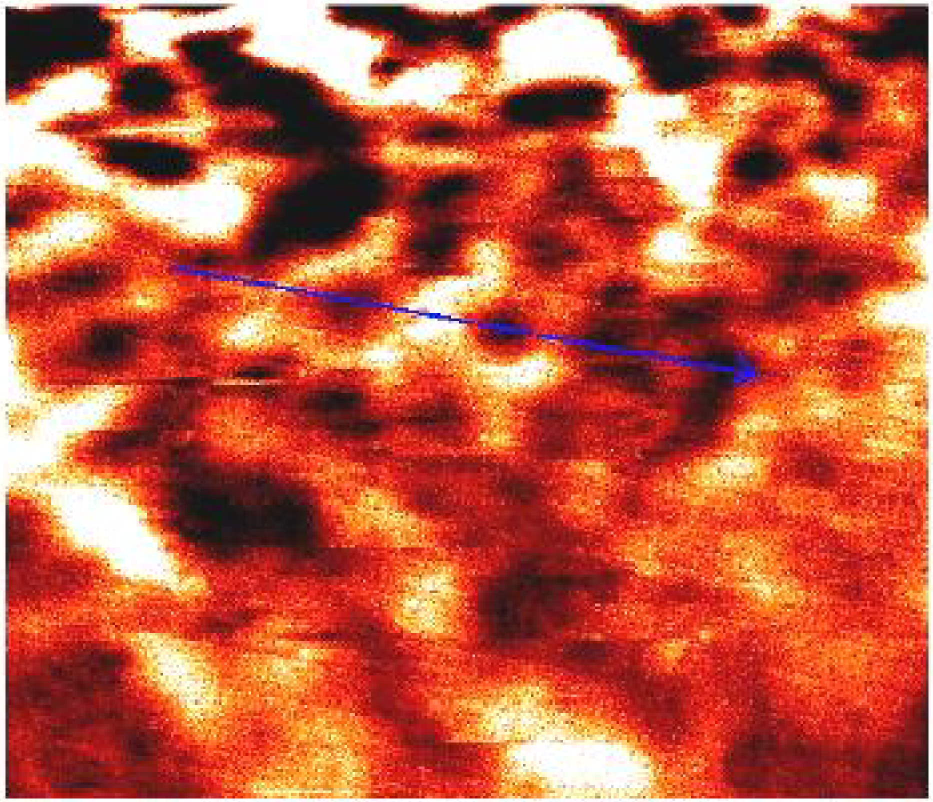
LEED images



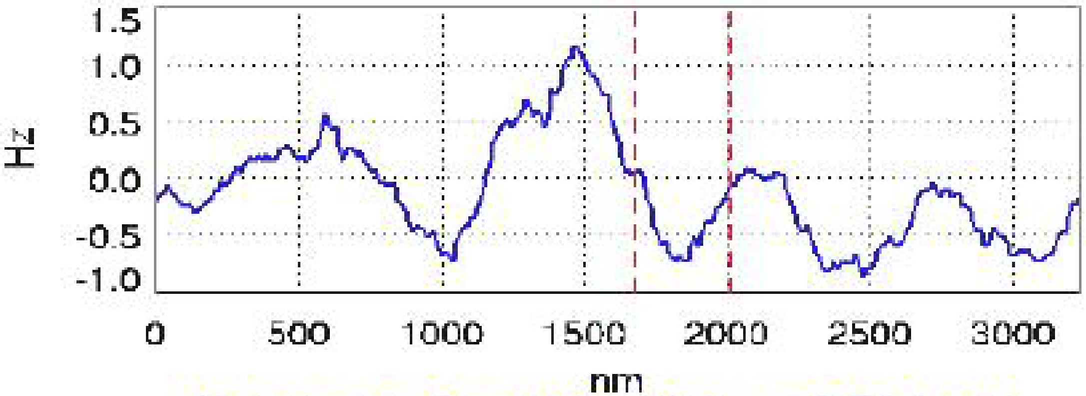
(110) bcc in KS





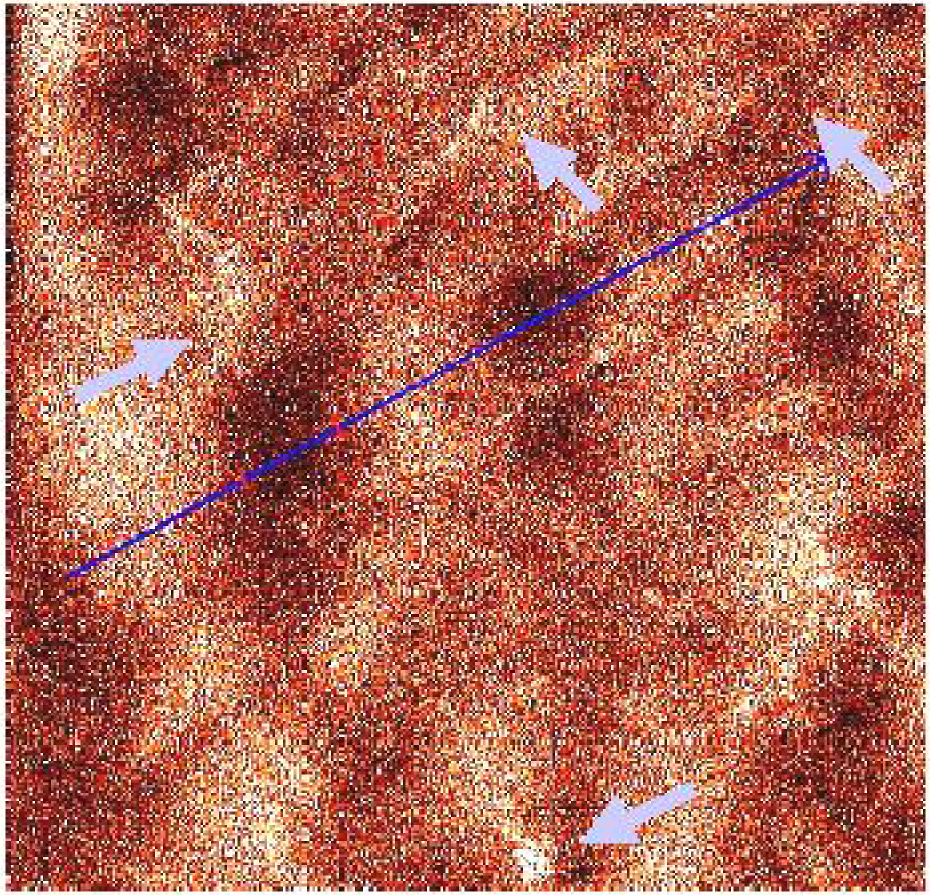


Out of plane magnetization



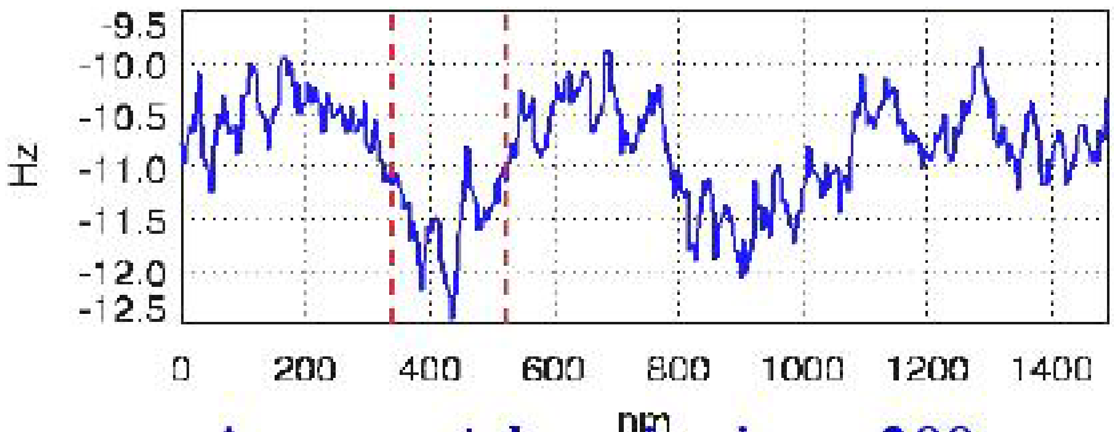
Average domain size ≈ 350 nm

1.2 nm Fe RT deposited on Cu/Si(111)



LEED images still suggest
the presence of
bcc (110) structures in the
Kurdjomov-Sachs orientation

in-plane and out-of-plane magnetization



Average ⊥domain size ≈ 200 nm

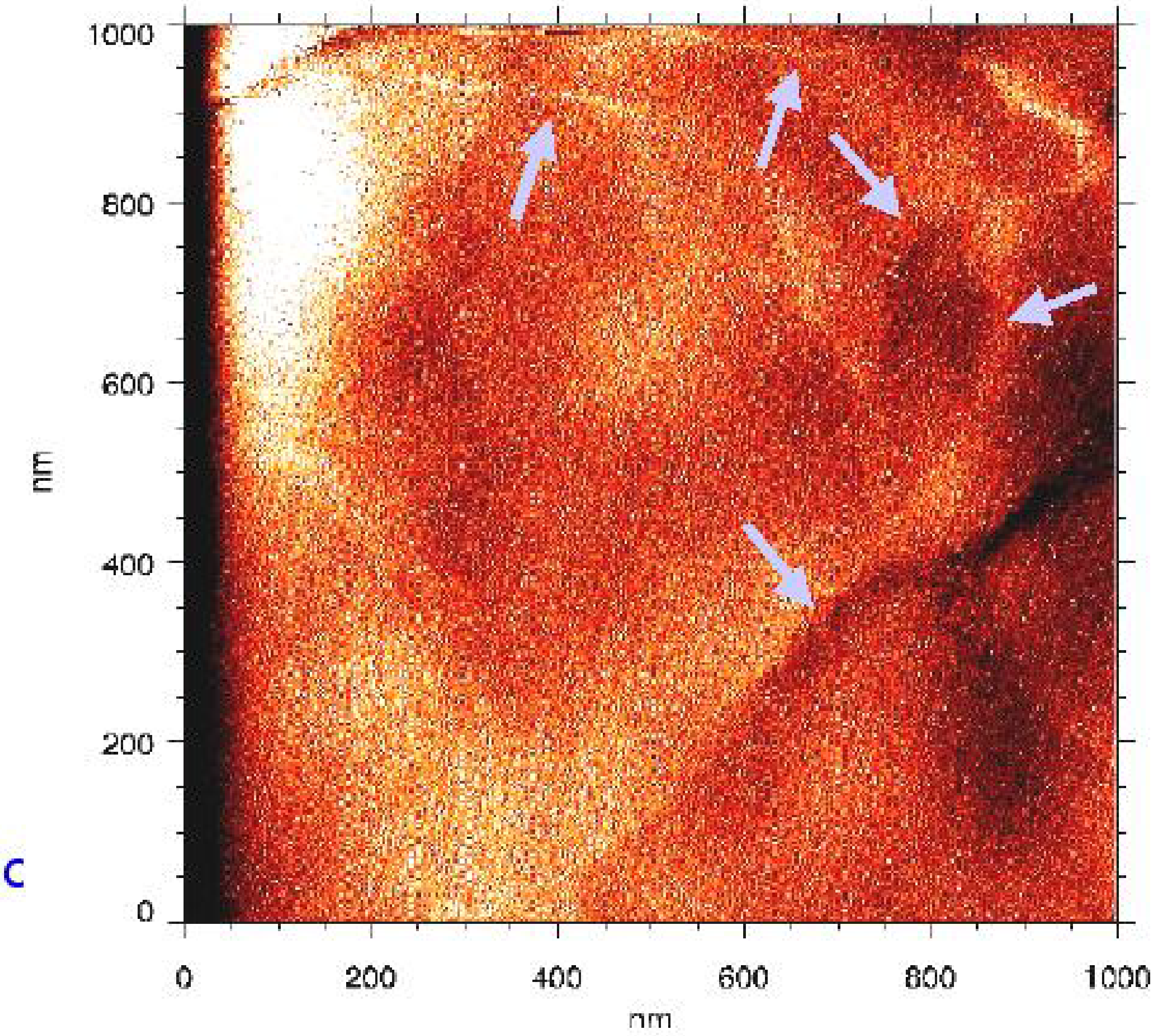
3.0 nm Fe RT deposited on Cu/Si(111)

In the LEED image the satellite spots, typical of the KS orientation, are still present

BUT

appreaciably broadened

Increasing of rotationally relatec disorder

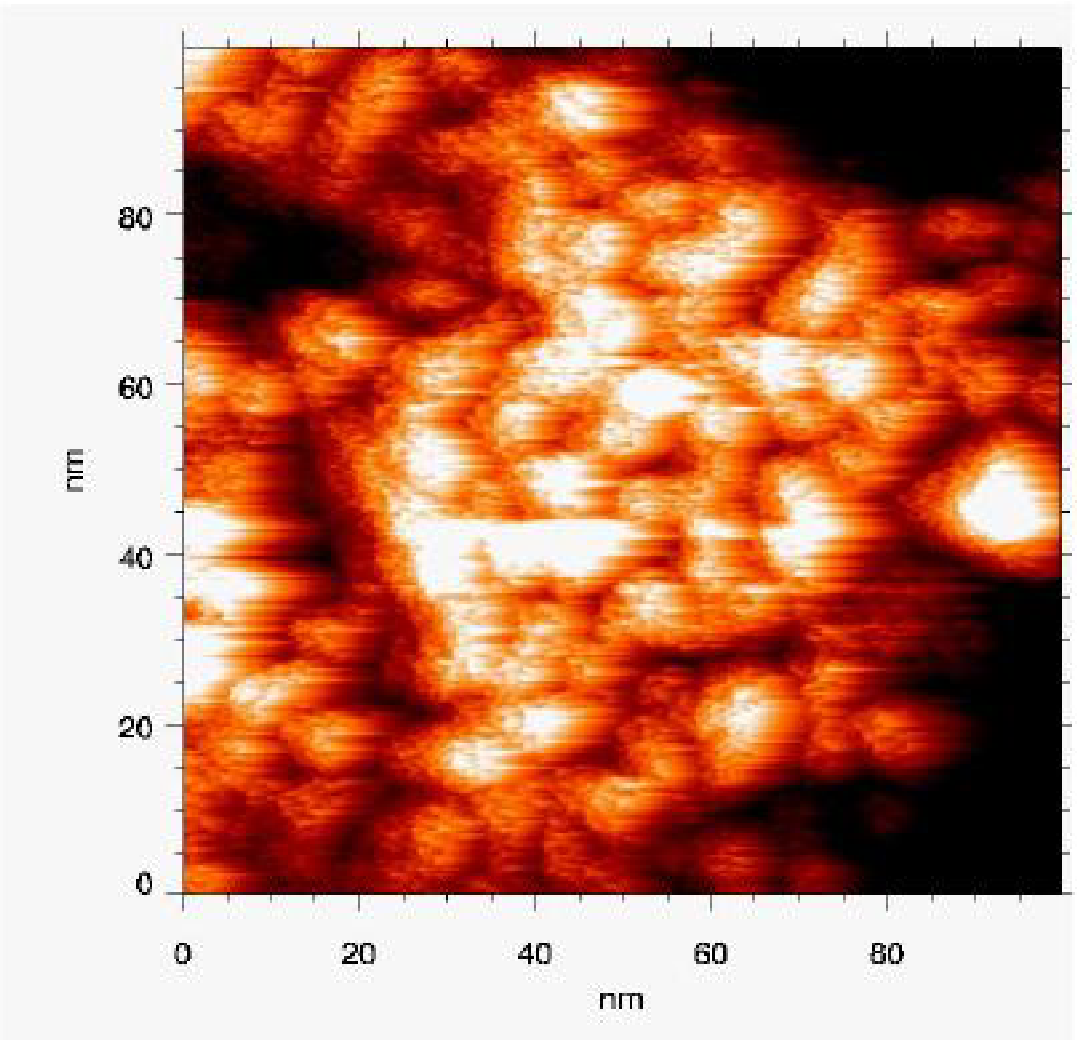


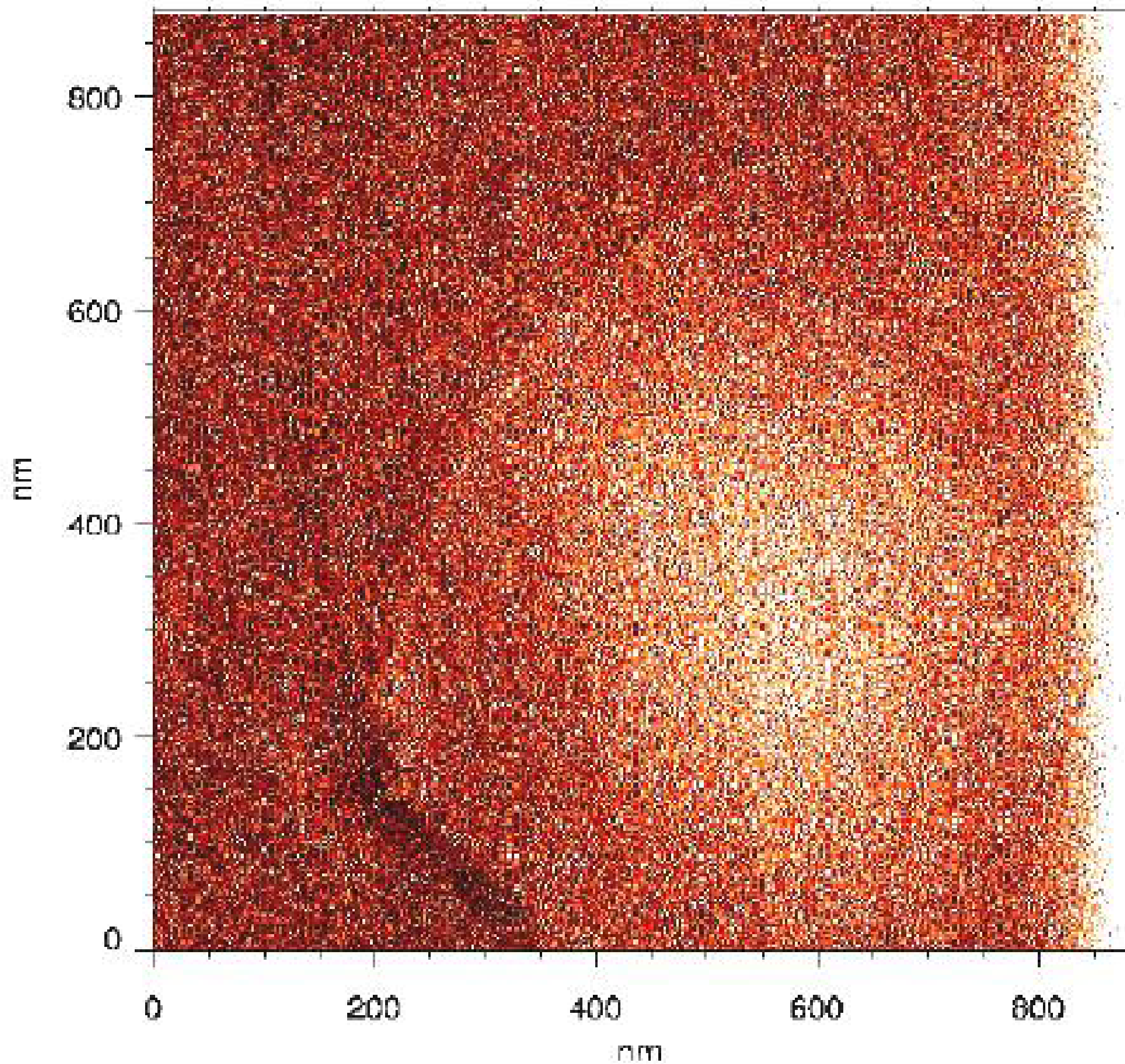
In–plane magnetization

8.0 nm Fe RT deposited on Cu/Si(111)

STM image :

Nanostructures average size : 5-6 nm

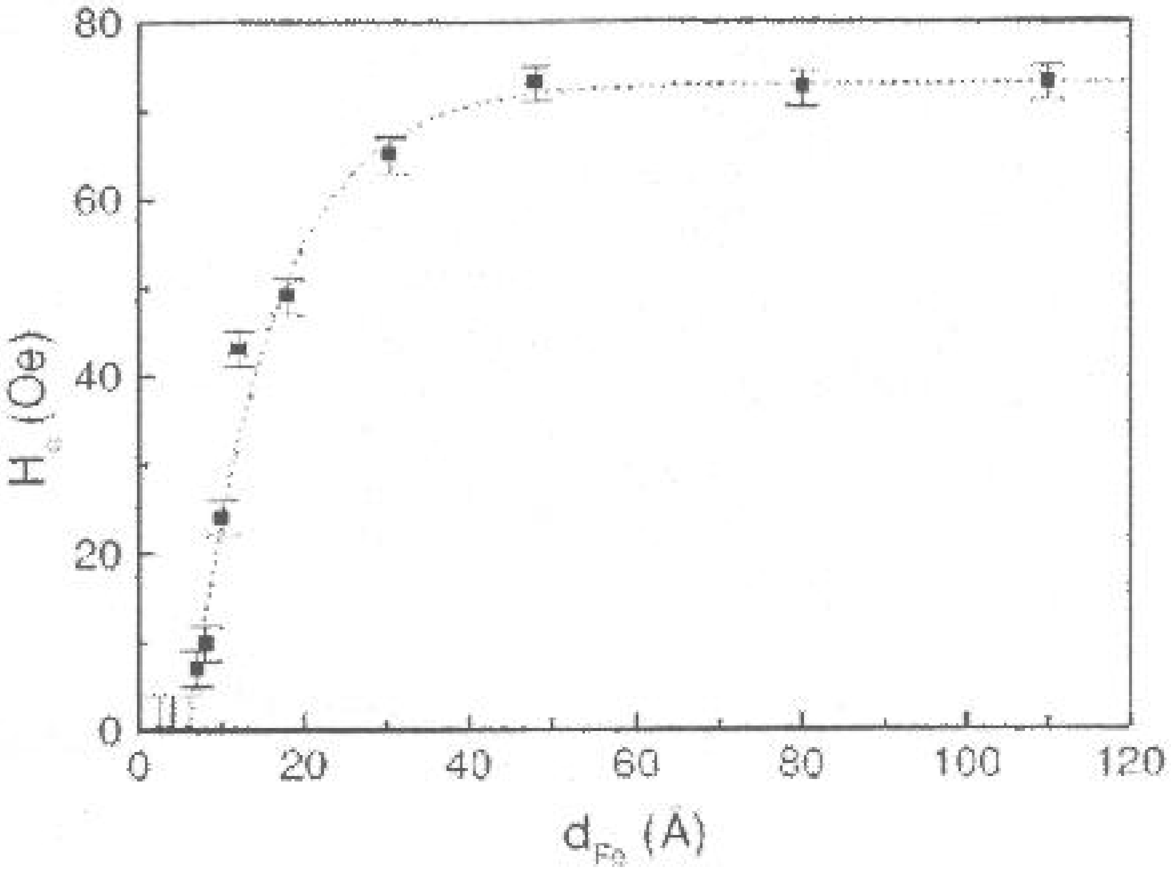




In–plane magnetization

RT SMOKE measurements:

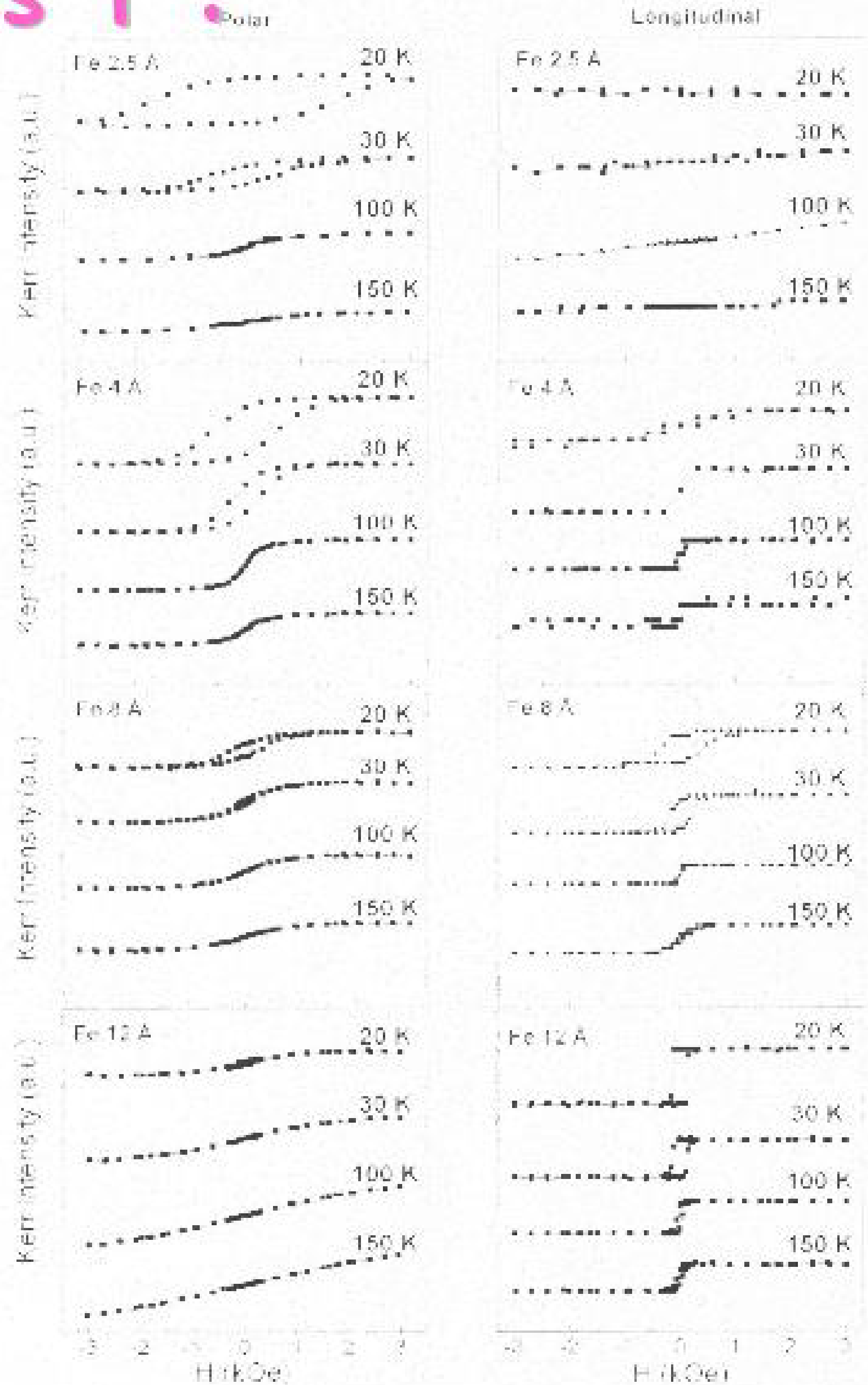
- Longitudinal loops for d_{Fe} > 0.8 nm
- No polar loops



The coercive field increases with d_{Fe}

SMOKE measurements vs T :

- Longitudinal SMOKE loops recorded at any temperature up to RT, for $d_{Fe} > 0.8$ nm
- Polar loops recorded only for $T \leq 50$ K and for $d_{Fe} \leq 0.8$ nm



Iron high coverage range

MFM: the average size of the in-plane domains grows with d_{Fe} → decreasing of H_c

While

SMOKE: - longitudinal magnetization
- H_c increases with d_{Fe}

BUT

LEED : increasing of the structural disorder

↓

The domains walls can remain intrapped, due to the structural disorder, during their expansion when a magnetic field is applied

Out-of-plane → in-plane M transition occurs for d_{Fe} *slightly above the fcc → bcc* (LEED)

Nevertheless

- Polar SMOKE loops only for T ≤ 50K

- Longitudinal SMOKE loops at any T

↓

Completely separate behaviours of magnetization :

Superposition of two different structural systems?

Iron very low coverage range ($d_{Fe} \leq 0.6$ nm)

MFM: - out-of- plane magnetic domains

- their average size grows with d_{Fe}

⇒ decreasing of the H_c value

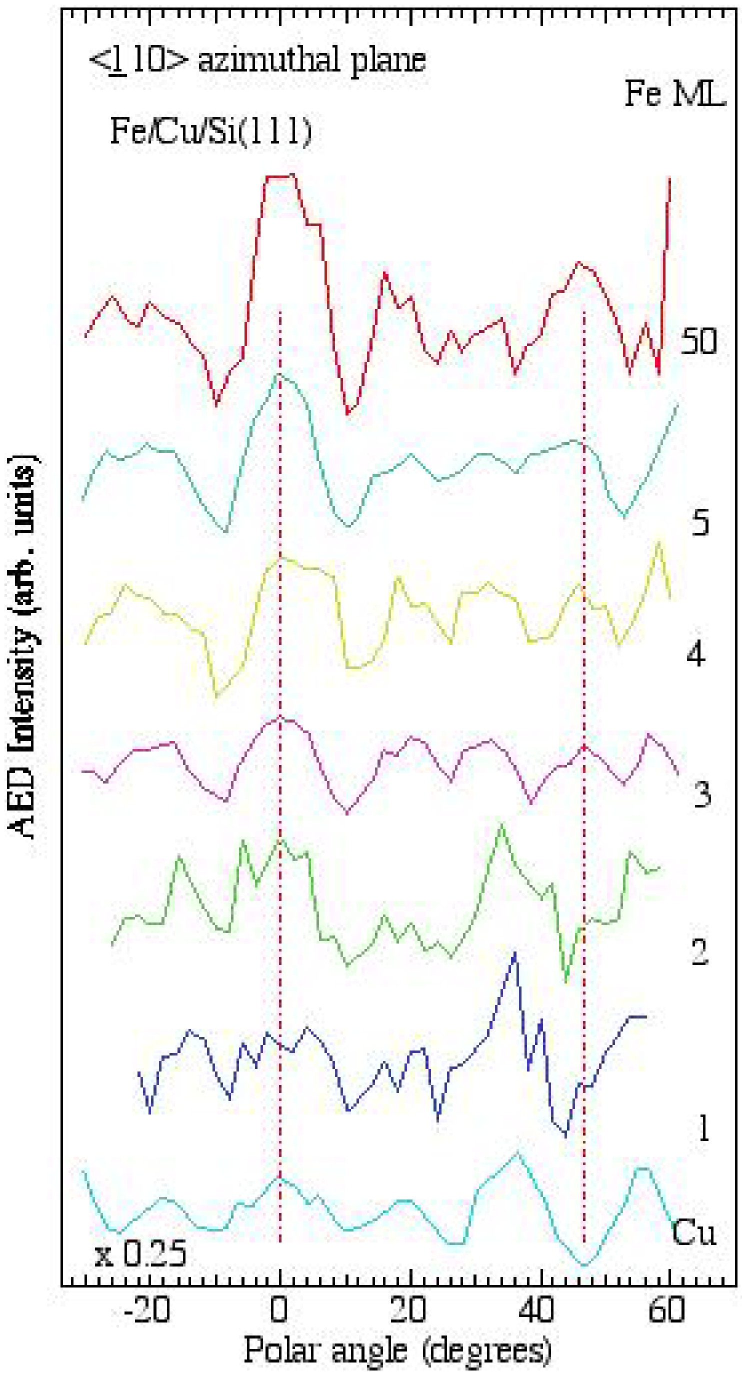
SMOKE: - H_c decreases with d_{Fe}

- polar magnetization remanence at $T \leq 50K$
- polar magnetization saturation up to $T \approx 200K$

} **Superparamagnetism ?**

LEED : fcc iron structural phase

AED polar patterns :



- presence of bcc structural phase even for 1 ML Fe equivalent coverage
- bi-tri layers fcc arranged platelets and/or intermixing processes cannot be completely excluded
- assessment at 2.5-3 ML the nominal thickness at which most of Fe prefer to arrange in a bcc structural phase

Resonant magnetic scattering of polarized x-rays at Fe $L_{2,3}$ edges

RT in-plane local magnetic moment even for 1ML iron

↓

NOT observed both by SMOKE and MFM

- SMOKE lack of sensitivity
- MFM lack of resolution to probe such in-plane domains walls

Low iron coverage ($0.8nm \le d_{Fe} \le 1.2$ nm)

Independently from the fcc → bcc structural transition detected by LEED

MFM: - for d_{Fe}=1.2nm in-plane & out-of-plane magnetic domains

- the average size of the out-of-plane domains is now decreased → in-plane M

SMOKE: -for d_{Fe}=0.8nm polar (at LT) & longitudinal (up to RT) magnetizations

Conclusions:

- Both the fcc and bcc arranged nanostructures have been probed even at 1 ML iron coverage

- The fcc → bcc transition detected by LEED can be related to the size and number of the bcc nanostructures with respect to the fcc ones

- The bcc nanostructures are in-plane magnetized and characterized by a T_c well above RT

- The fcc nanostructures present an out-of-plane magnetization and there are hints to suggest superparamagnetic behaviour