Creşterea şi caracterizarea straturilor subţiri magnetice de Fe pe substraturi de Si(001) prin epitaxie din fascicul molecular

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The techniques employed are:

***MBE* chamber:**

a) *preparation facilities:* (i) sample heating up to 1200 ℃; cooling down to 7 7 K; (ii) evaporation from a 4-target e-beam evaporator; (iii) evaporation from a high temperature Knudsen cell (2000 ℃); (iv) controlled gas adsorption and desorption; (v) monitor of thicknesses using a quartz microbalance.
b) *in situ characterization:* (i) LEED (Low Energy Electron Diffraction); (ii) RHEED (Reflection High Energy Electron Spectroscopy); (iii) AES (Auger Electron Spectroscopy); (iv) Quadrupole Mass Spectroscopy (thermal induced desorption, photodesorption).

***STM* chamber:**

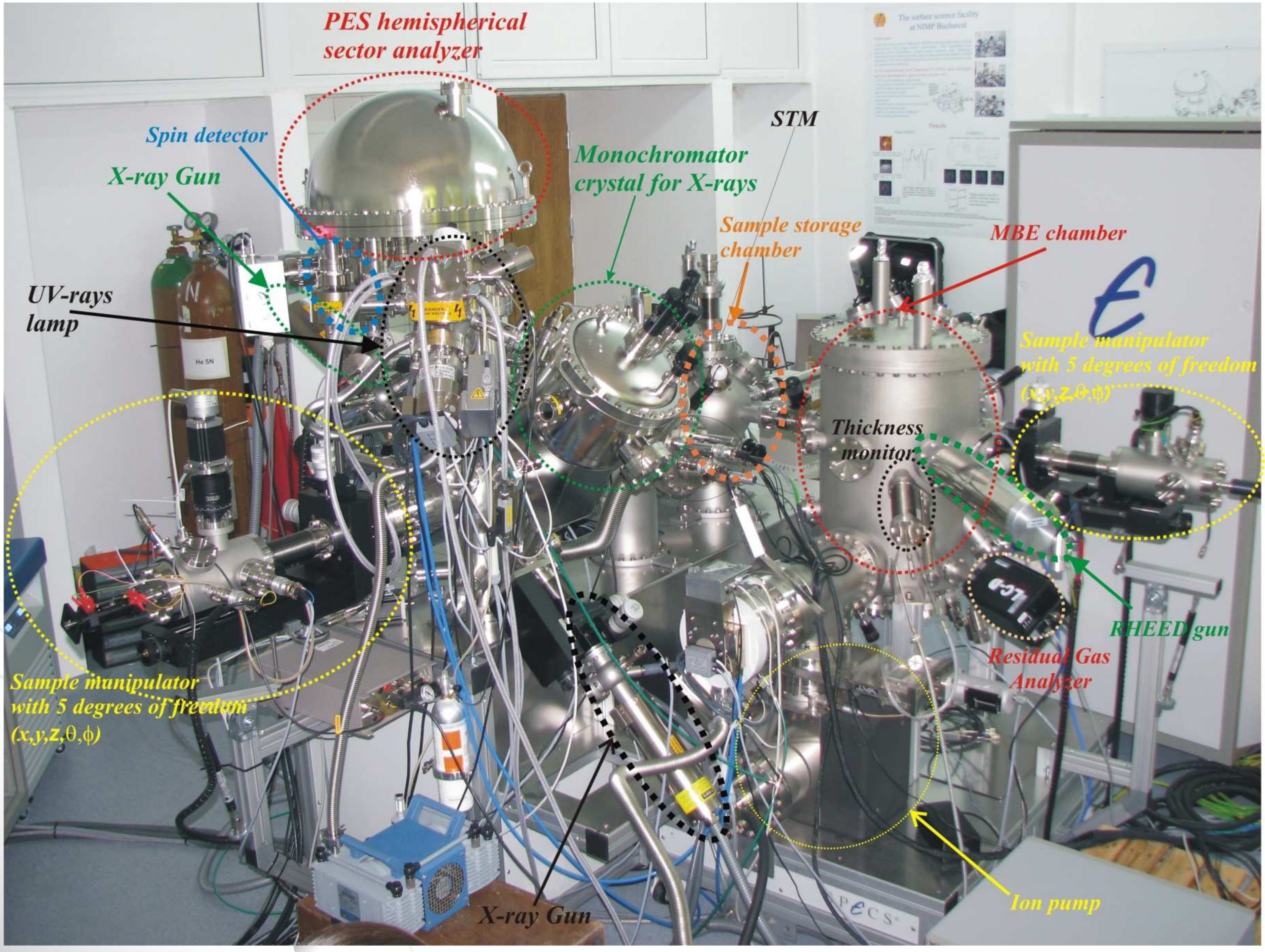
(i) sample preparation stage (heating, ion sputtering); (ii) tip preparation (ion sputtering); (iii) variable temperature (77 - 453 K) scanning tunneling microscopy; (iv) scanning tunneling spectroscopy (STS)

SARPES chamber:

(i) conventional X-ray photoelectron spectroscopy using a dual (Al/Mg K_α) anode;
(ii) high resolution XPS using a monochromatized dual (Al K_α /Ag L_α) source;
(iii) ultraviolet photoelectron spectroscopy (UPS He I, He II);
(iv) angle-resolved XPS: x-ray photoelectron diffraction (XPD);
(v) angle-resolved UPS (ARUPS): band structure, Fermi surface, etc.;
(vi) spin-resolved UPS: spin-polarized density of states;
(vii) angle- and spin-resolved UPS: spin-polarized band structure;
(viii) remote-controlled ion sputtering: depth profiling;
(ix) flood gun for sample neutralization.

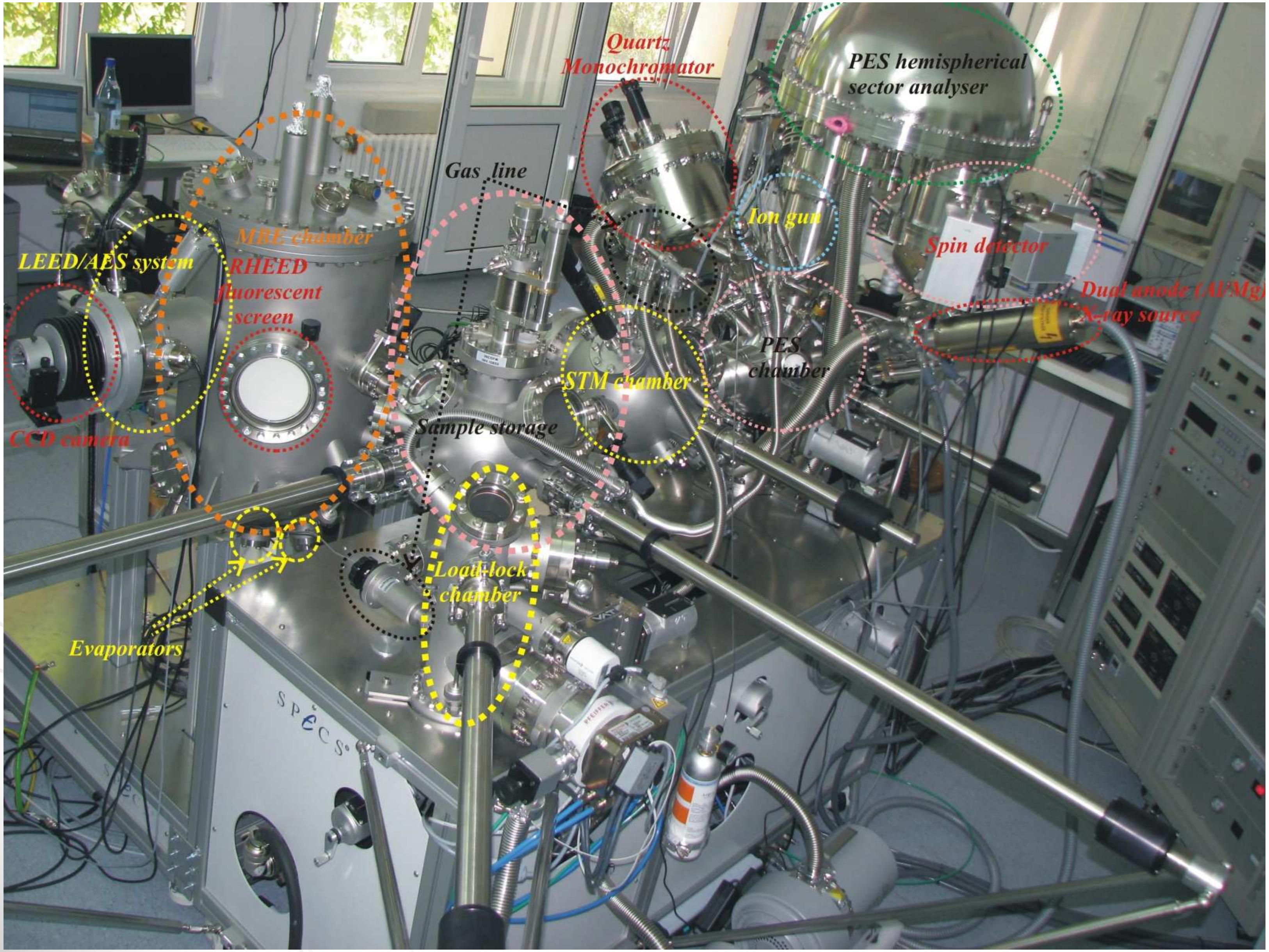
Ex situ measurements:
(i)Extended X-ray absorption fine structure (EXAFS);
(ii)X-ray absorption near-edge structure (XANES);
} Using synchrotron radiation at Hasylab, DESY, Hamburg (long-term project running)
(iii)Magneto-optical Kerr effect (MOKE);
(iv)Mössbauer spectroscopy

The setup (I)



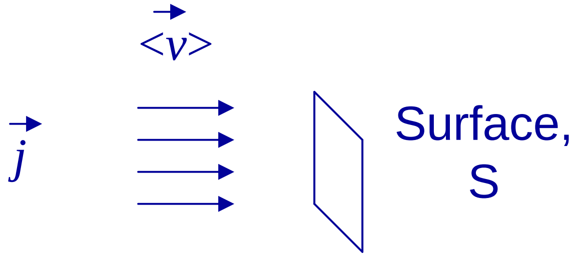
PES hemispherical sector analyzer
Spin detector
X-ray Gun
Monochromator crystal for X-rays
STM
Sample storage chamber
MBE chamber
UV-rays lamp
Sample manipulator with 5 degrees of freedom (x,y,z,θ,φ)
Thickness monitor
RHEED gun
Residual Gas Analyzer
Sample manipulator with 5 degrees of freedom (x,y,z,θ,φ)
Ion pump
X-ray Gun

The setup (II)


Quartz Monochromator
PES hemispherical sector analyser
Gas line
MBE chamber
LEED/AES system
RHEED fluorescent screen
Ion gun
Spin detector
Dual anode (Al/Mg) X-ray source
PES chamber
STM chamber
CCD camera
Sample storage
Load-lock chamber
Evaporators

Ultrahigh vacuum basics

Contamination rate of a reactive surface (metals/semiconductors)



flux of molecules
from residual gas

$$\vec{j} = n \langle \vec{v} \rangle$$

$$\langle v \rangle \approx \sqrt{\frac{3k_BT}{m}}$$ from Maxwell-Boltzmann statistics

≈ 492 m/s for N_2 (mass = 28 a.m.u.) @ 273 K

$$n = \frac{P}{k_BT}$$ from the Boltzmann equation

$\approx 2.65 \times 10^{16}$ mol./m^3 for $P = 10^{-4}$ Pa $\approx 10^{-6}$ mbar and T = 273 K

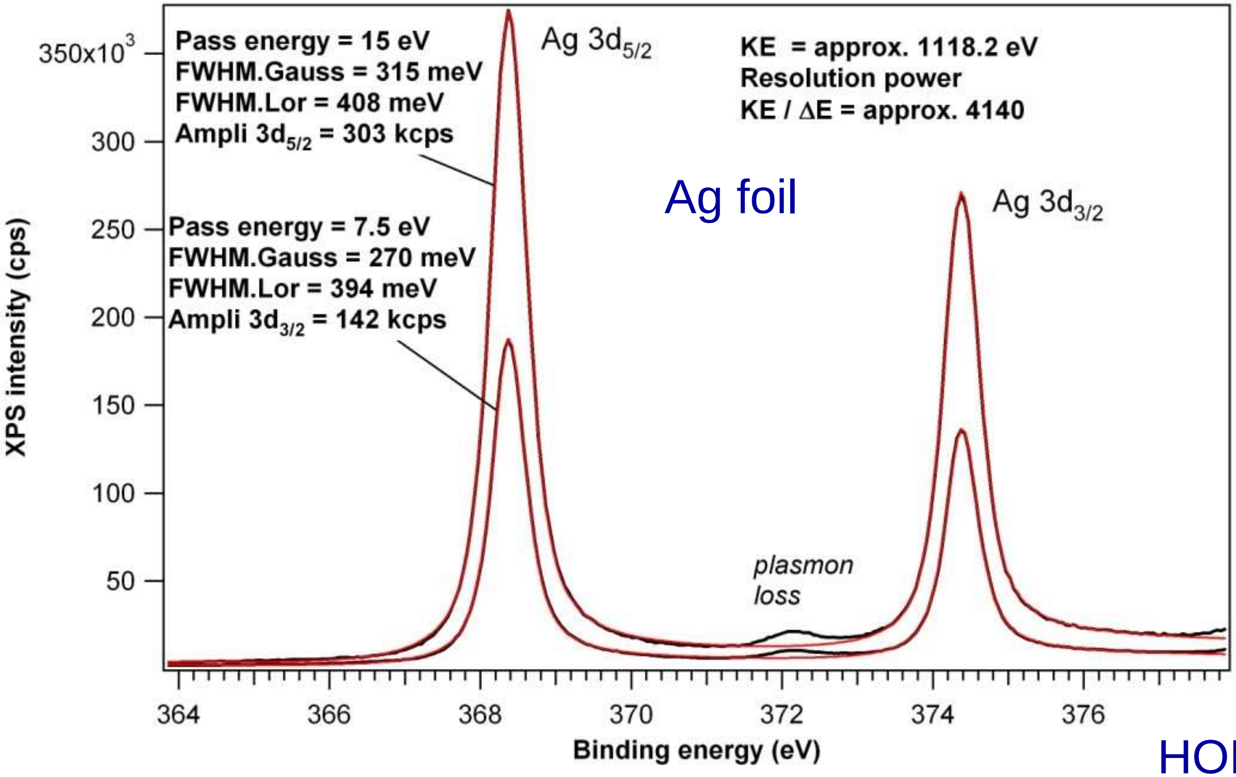
- Contamination dymanics: $$\frac{\partial N}{\partial t} = j \cdot S \approx \frac{N_r}{\tau_c} = \frac{\sigma_r S}{\tau_c} = \frac{\text{Number of reactive sites}}{\text{Contamination time}}$$

σ_r = surface density of contamination sites $\approx$ 1 site / 4 Å^2 = 2.5×10^{19} sites / m^2

$$\tau_c = \frac{\sigma_r}{j} = \frac{\sigma_r}{n \langle v \rangle} \approx \frac{2.5\times10^{19}}{2.65\times10^{16}\times492} \approx 1.9\,\text{sec.}$$

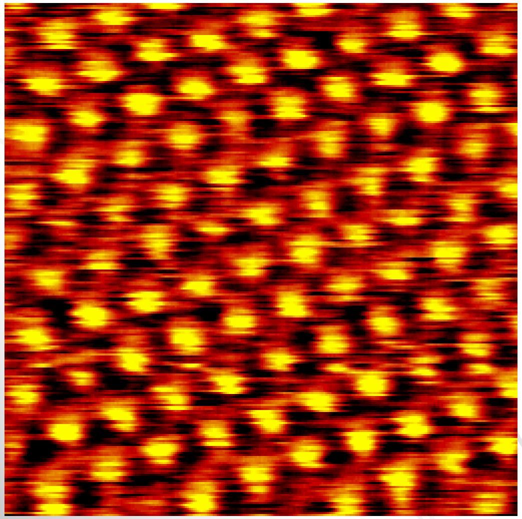
VERY FAST CONTAMINATION

Performances:

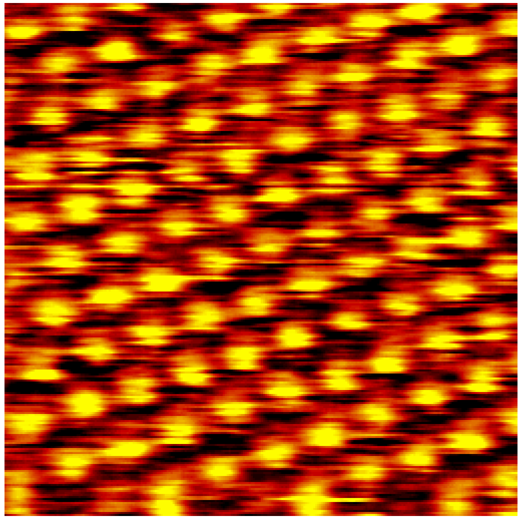


FOV=20 nm

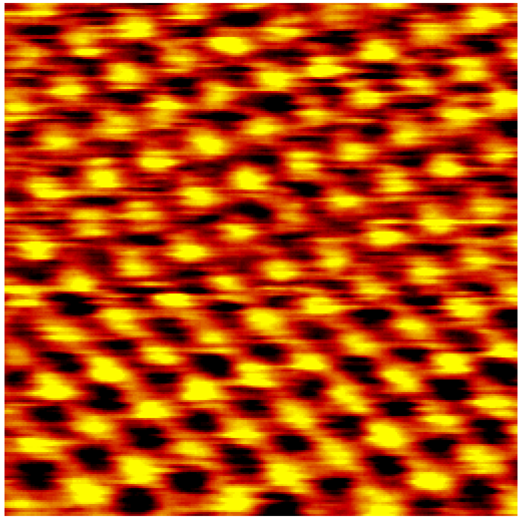
HOPG(0001)



V_t=630,5 mV



V_t=712,9 mV



V_t=883,8 mV

Why Fe/Si?

PHYSICAL REVIEW B VOLUME 55, NUMBER 12 15 MARCH 1997-II

Atomic structure of the reactive Fe/Si(111)7×7 interface

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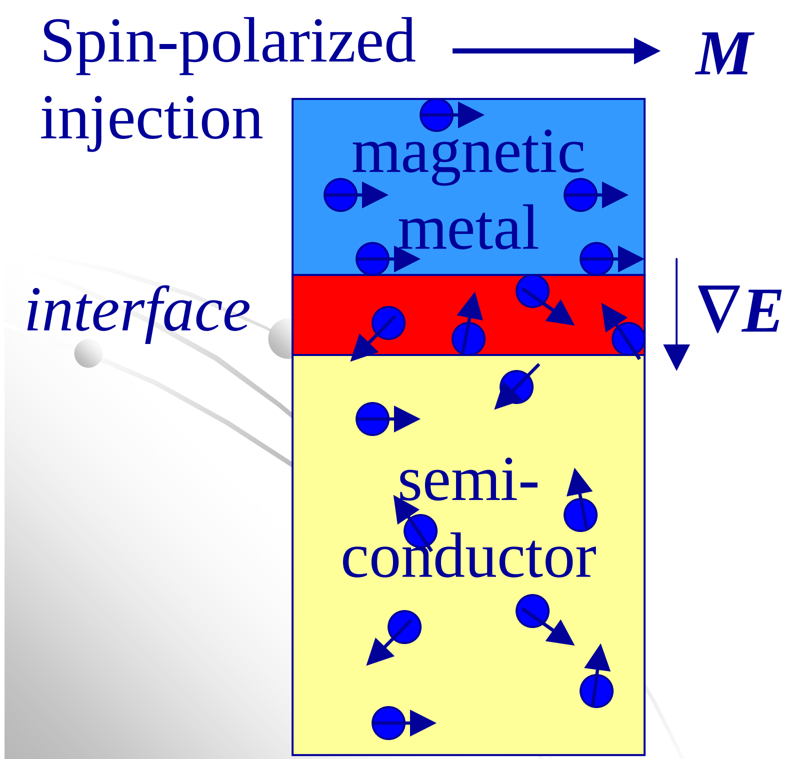
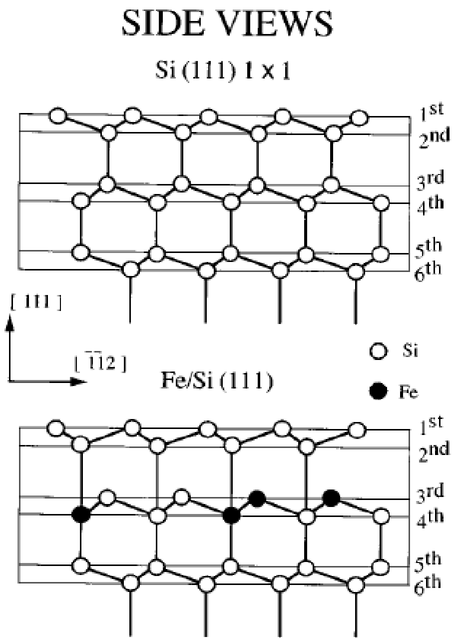
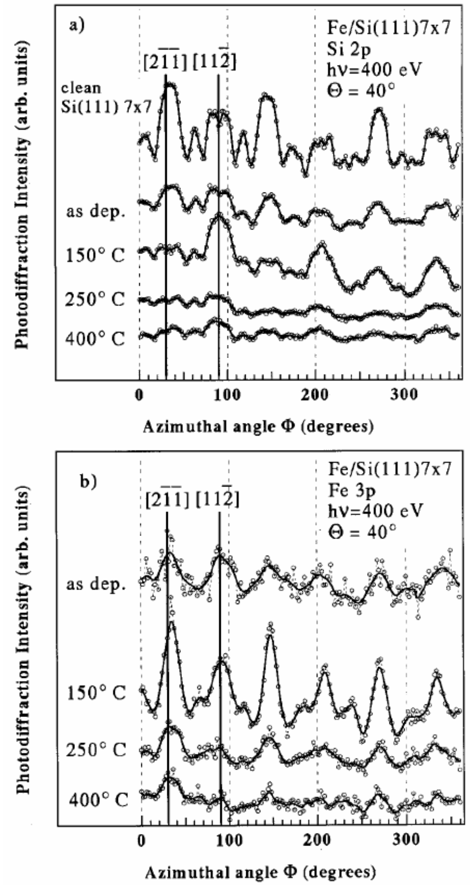
(Received 24 October 1996)

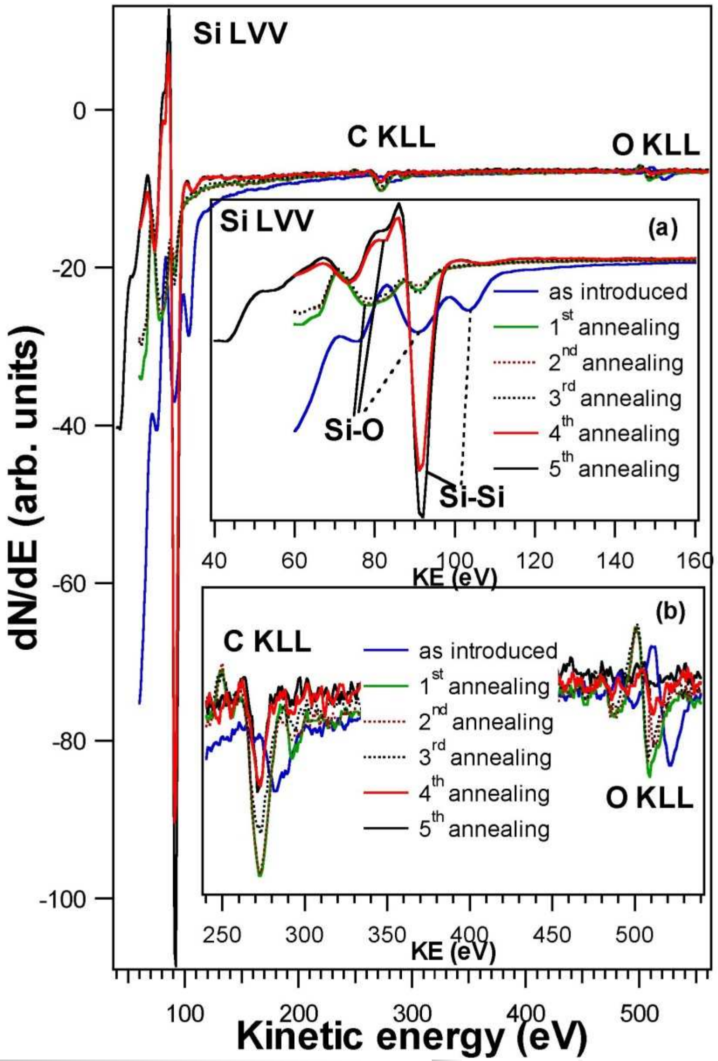






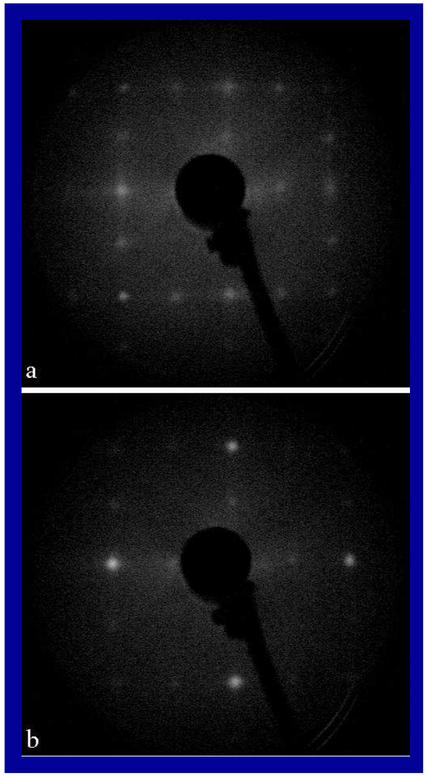
Result #1: Cleaning of Si(001) samples and study of the subsequent contamination (I)

Auger electron spectroscopy



LEED

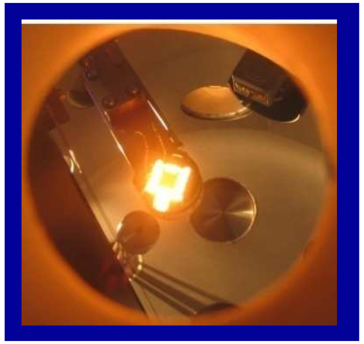
56 eV



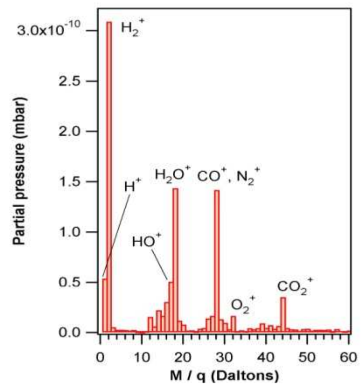
44 eV

RHEED

25 keV



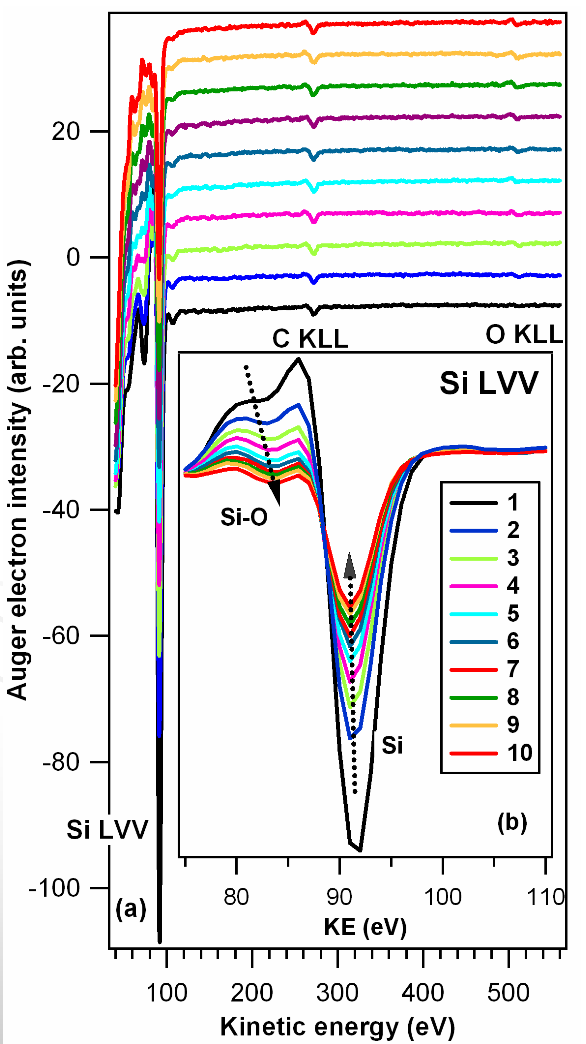
Residual gas analysis



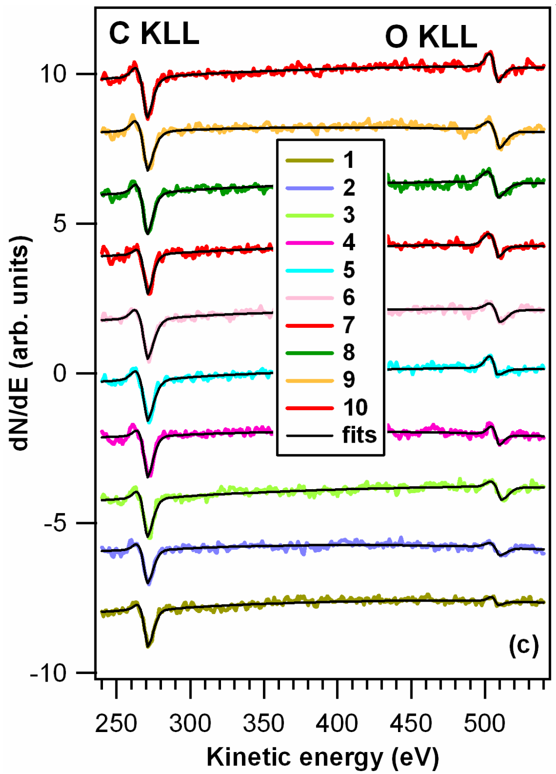
Gheorghe et al., Rom. J. Phys., submitted (2010)

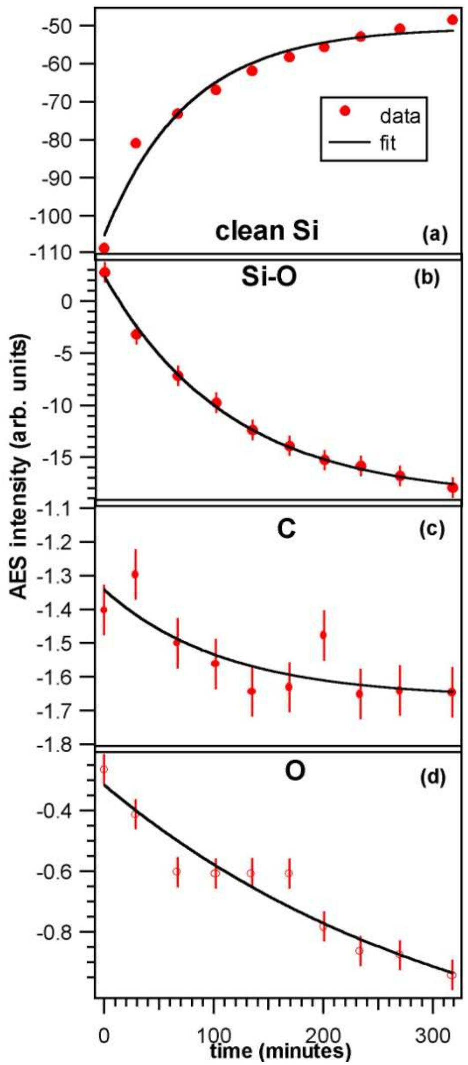
Result #1: Cleaning of Si(001) samples and study of the subsequent contamination (II)

$P_{mes.} \approx 1 \times 10^{-9}$ mbar.



Auger electron spectroscopy

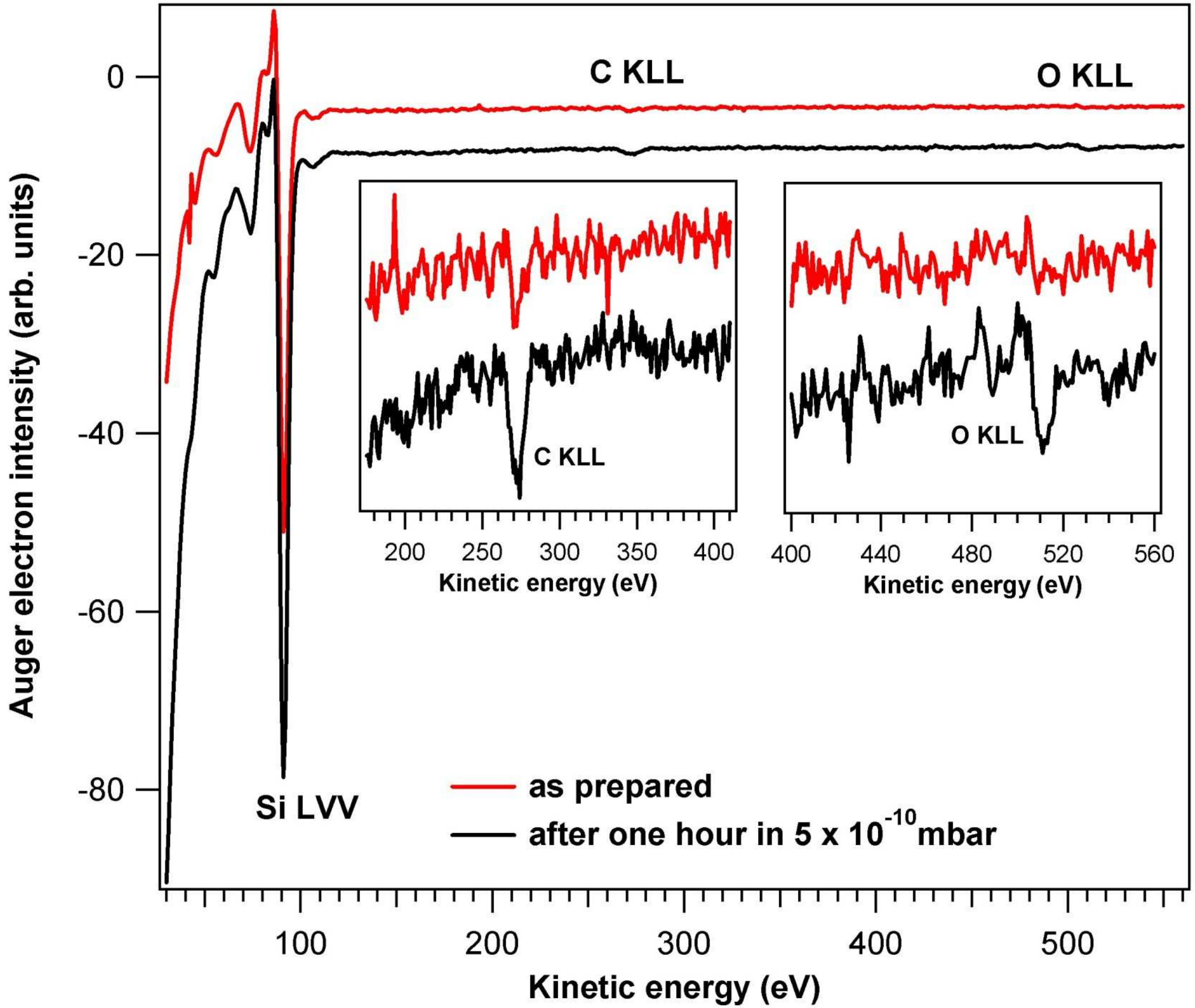




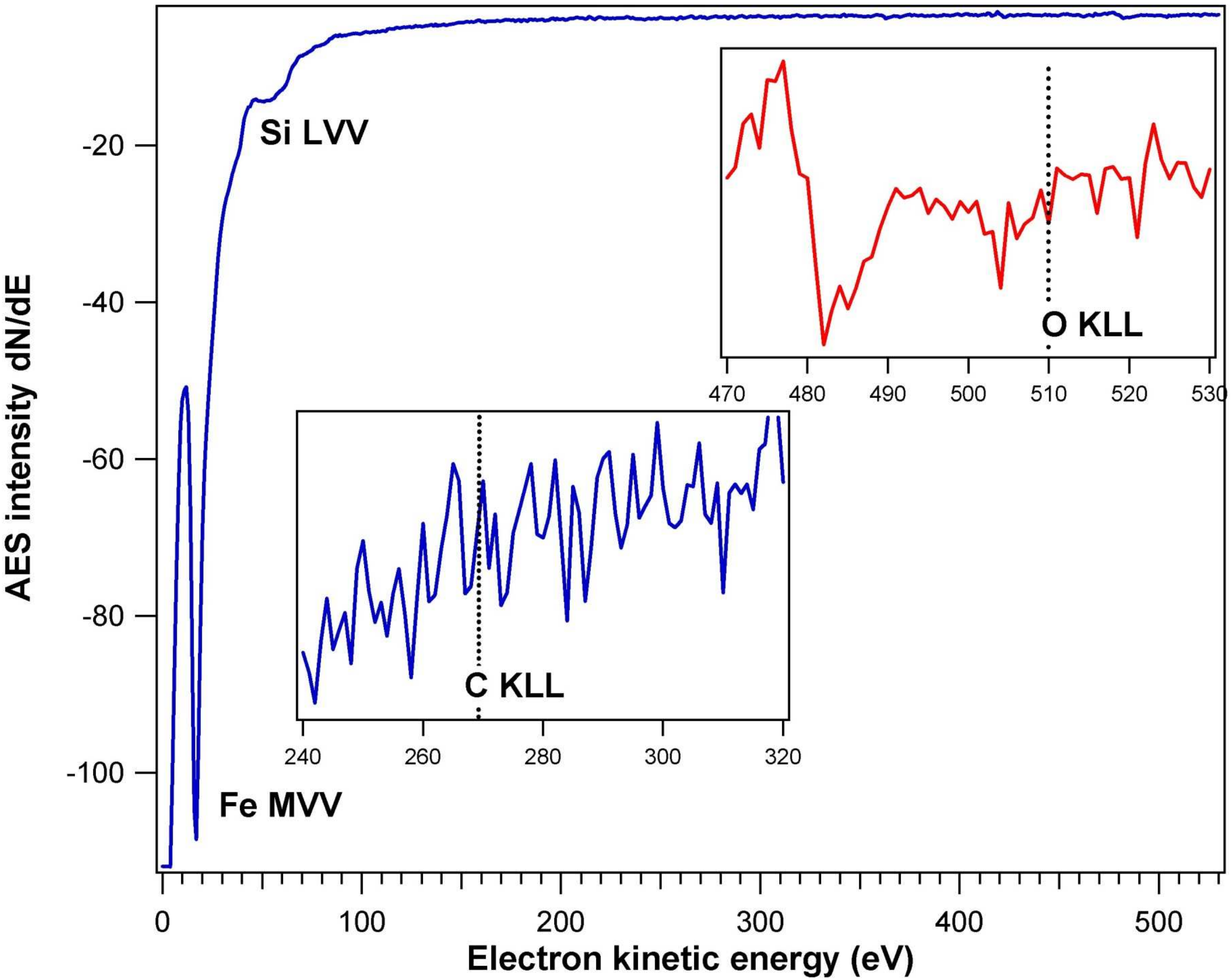
Gheorghe et al., Rom. J. Phys., submitted (2010)

Clean Si(001) - (III)

C contamination < 1.2 % of one ML!
O contamination < 0.3 % of one ML!

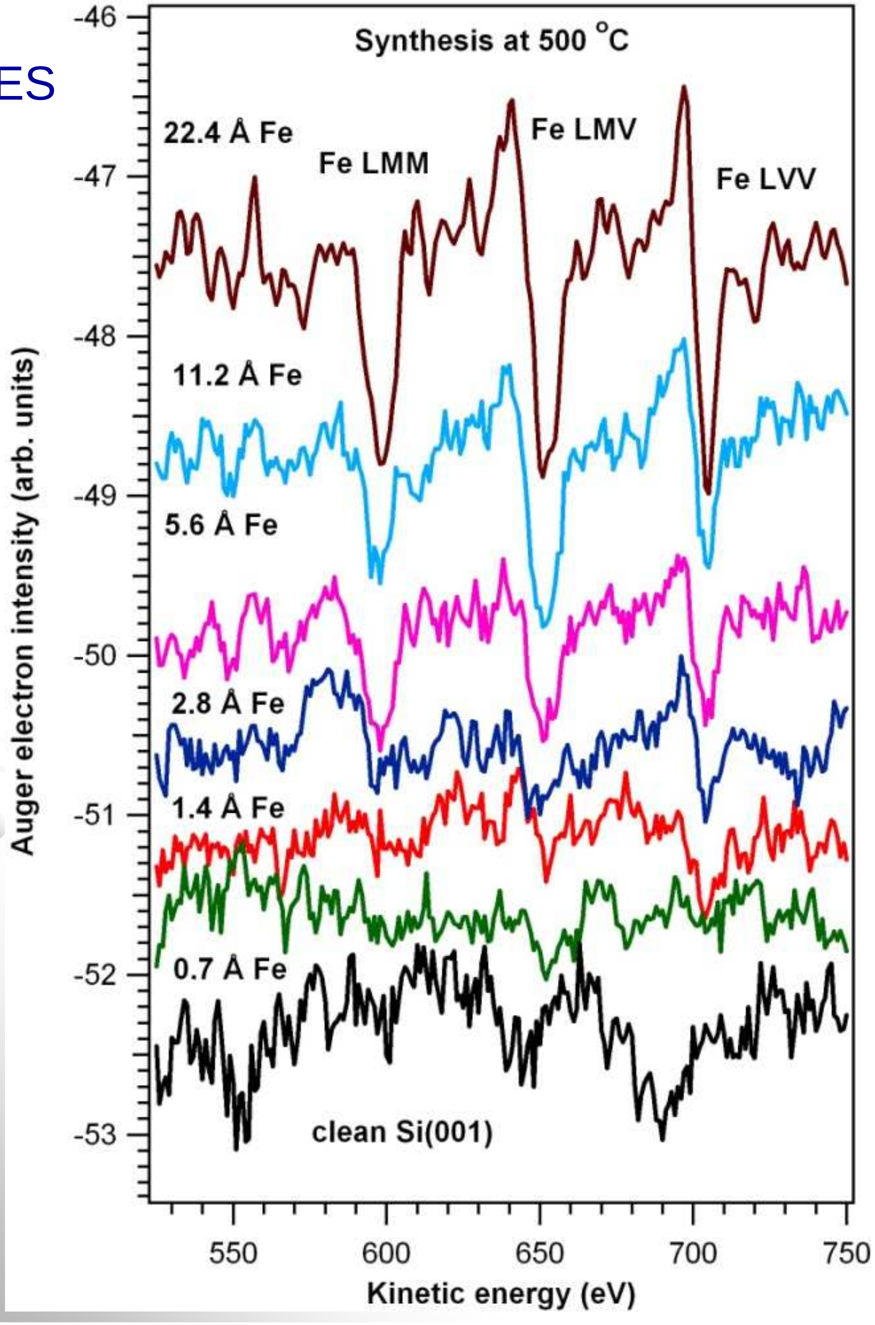


Result #2: Growth of Fe on Si(001) (I)



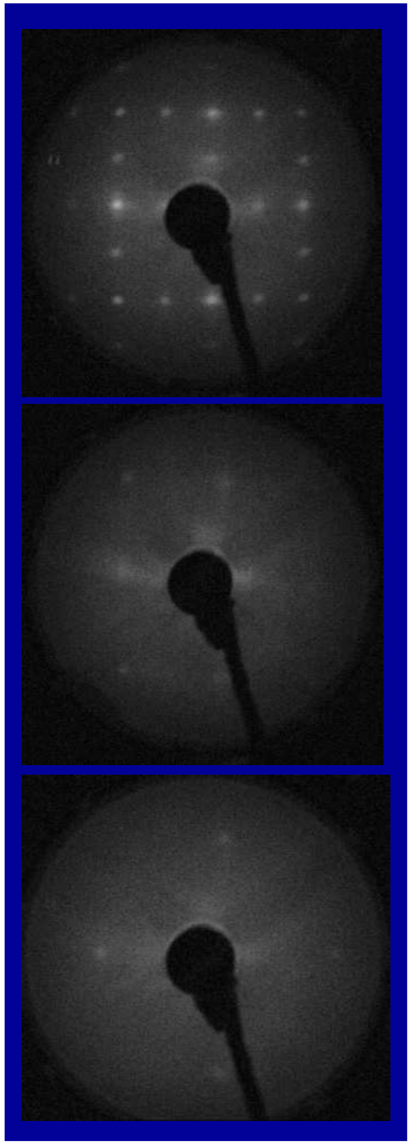
Result #2: Growth of Fe on Si(001) (II)

AES



T_s = 500 °C

LEED, 56 eV



Si(001)

0.7 Å Fe

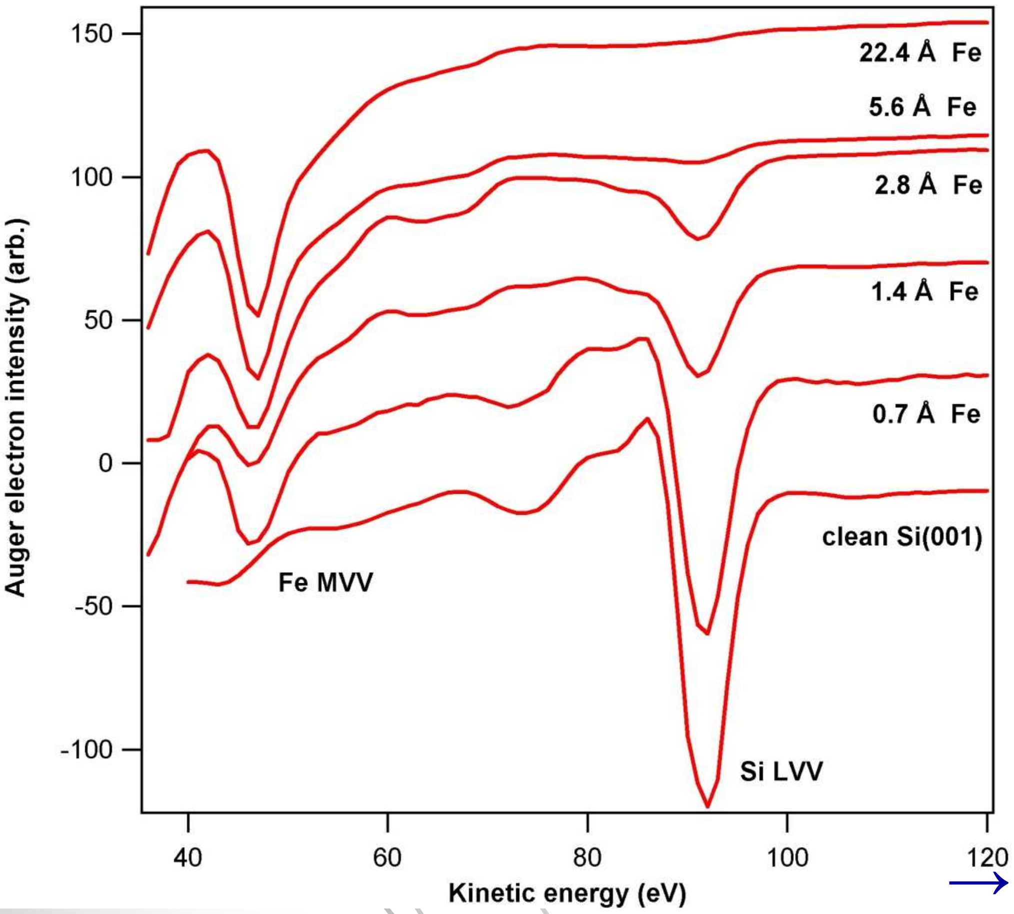
2.8 Å Fe

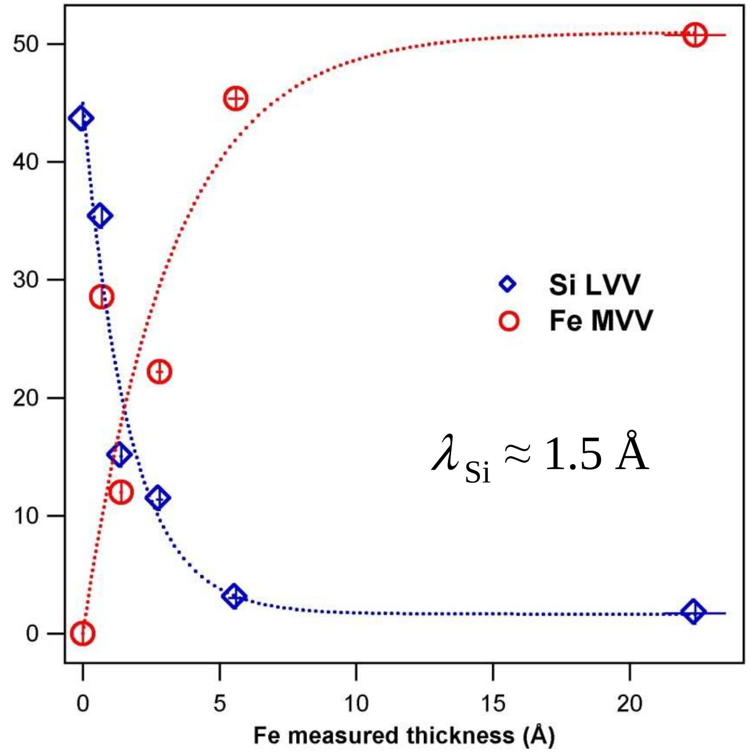
RT deposition -> no LEED

Huşanu et al., NSTI Nanotech 2010, accepted

Result #2: Growth of Fe on Si(001) (III)

Deposition at room temperature (300 K)





$$I^{(Si)} = I_0^{(Si)} \exp(-\theta/\lambda)$$

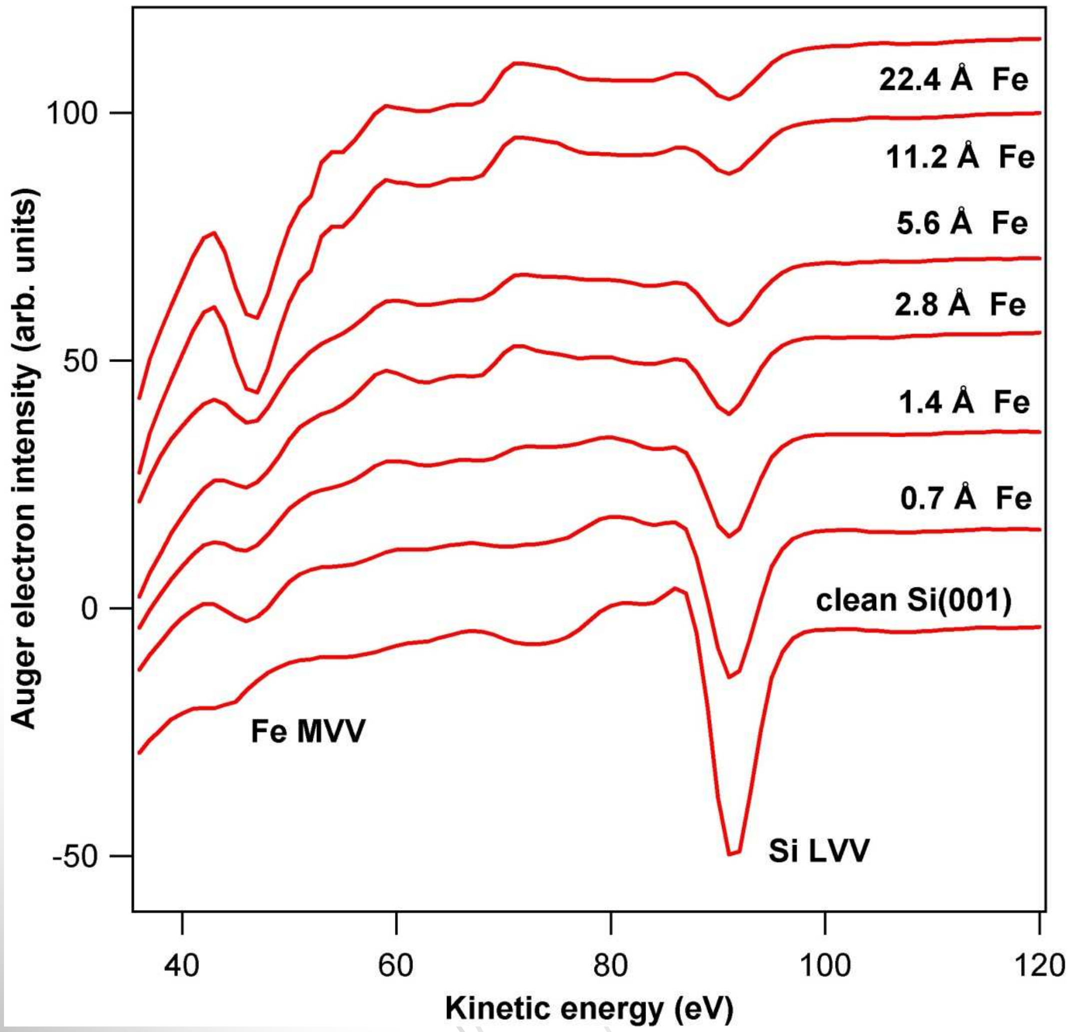
$$I^{(Fe)} = I_0^{(Fe)} [1 - \exp(-\theta/\lambda)]$$

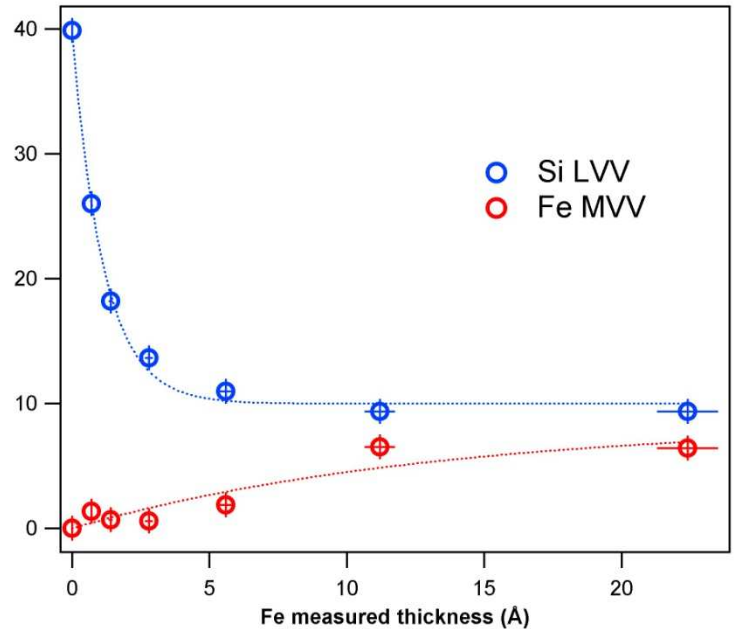
λ = electron inelastic mean free path (≈ 5-6 Å)

- → $\theta_{real} \approx 3 \times \theta_{measured}$
- → no (few) reactivity at interface
- → no diffusion of Si into Fe
- → no long range order (LEED)

Result #2: Growth of Fe on Si(001) (IV)

Deposition at 500 ℃





→ reactivity at interface

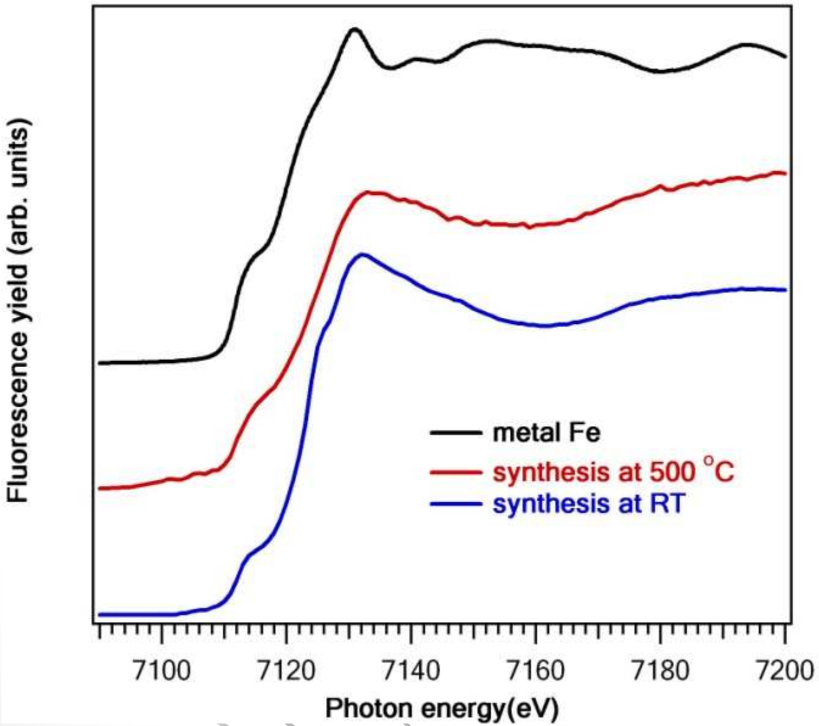
→ formation of $FeSi_{1.18}$

(mixture of FeSi and $FeSi_2$)

→ long range order (LEED)

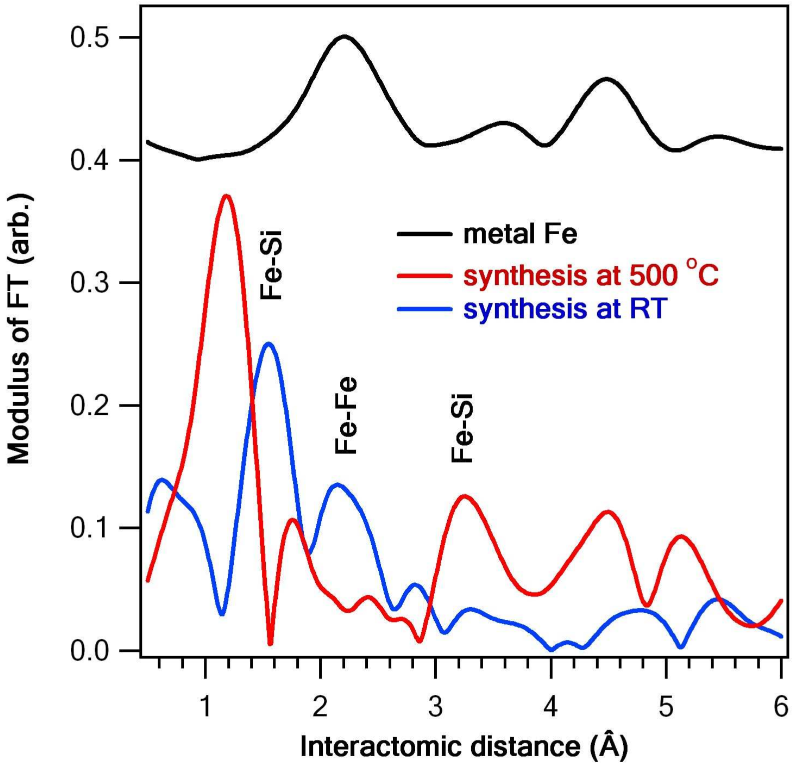
Result #2: Growth of Fe on Si(001) (V)

X-ray absorption near-edge spectroscopy (XANES)



Capped samples (with Au or Cu)

Extended X-ray absorption fine structure (EXAFS)



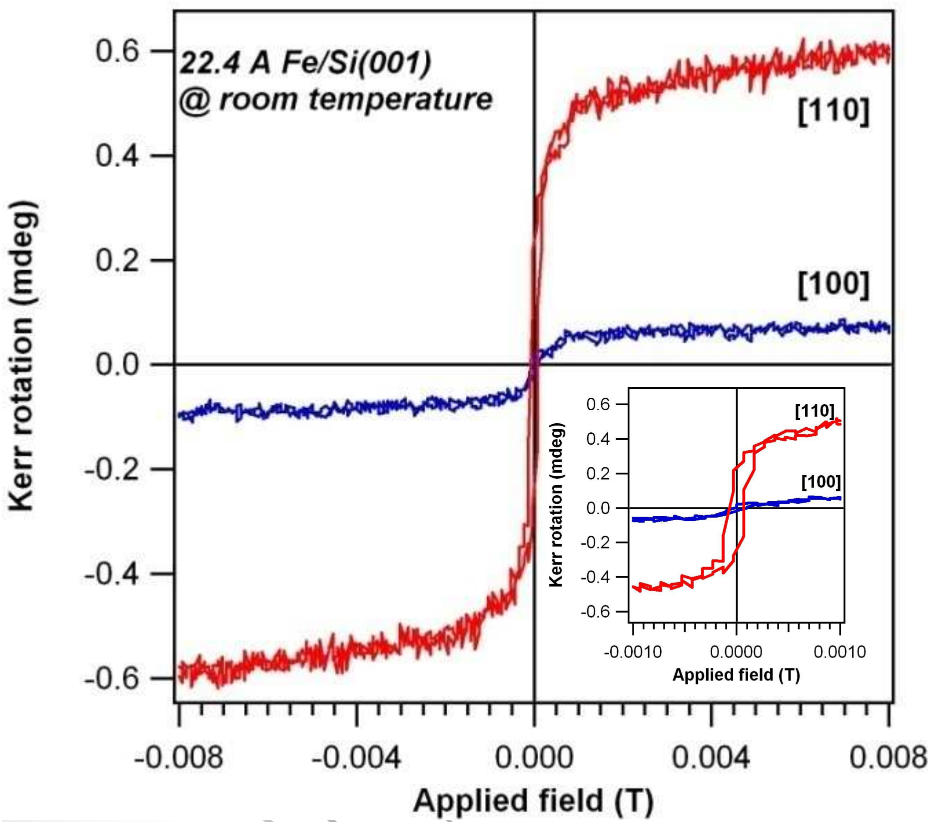
$$\chi(k) \equiv \frac{\mu(k)-\mu_0(k)}{\mu_0(k)} =$$

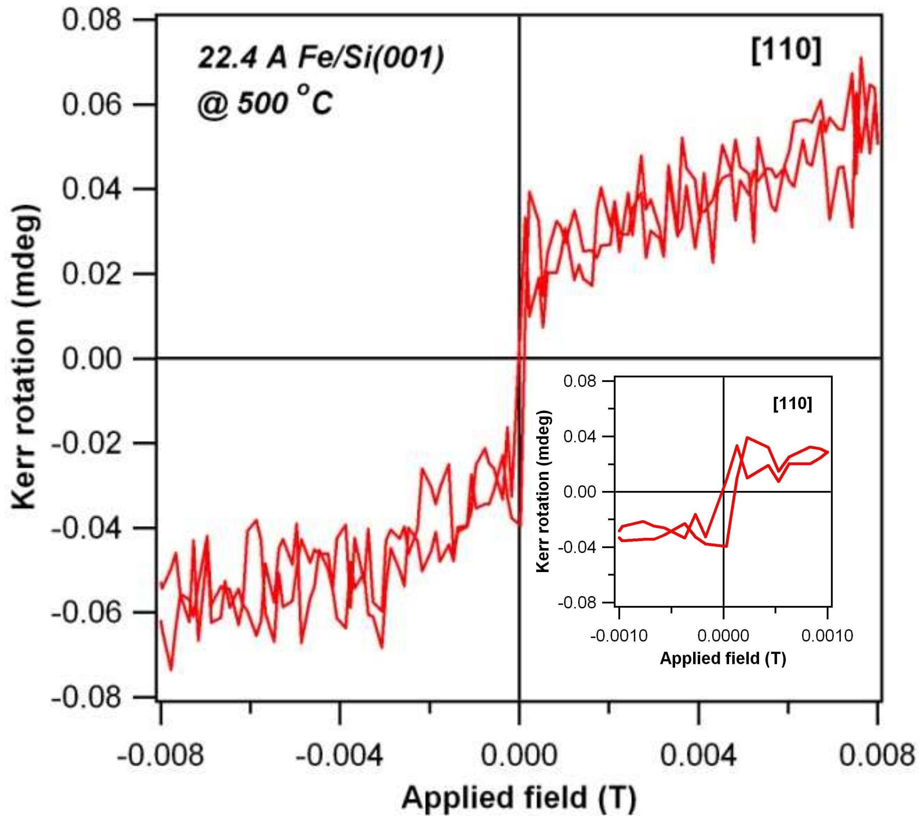
$$\sum_j \frac{N_j}{kR_j^2}\left|f_j(\pi,k)\right|^2 \exp\left(-2\sigma_j^2 k^2\right)\exp\left(-R_j/\lambda(k)\right)\times\sin\left[2kR_j+\phi_j(k)+\delta_1'(k)\right]$$

$$k=\sqrt{\frac{2m(h\nu-E_0)}{\hbar^2}}$$

Huşanu et al., NSTI Nanotech 2010, accepted

Result #2: Growth of Fe on Si(001) (VI) Magneto-optical Kerr effect (MOKE)





- formation of (ferromagnetic) iron silicide;
- disordered Fe films show enhanced magnetism;
- disordered Fe films show uniaxial anisotropy;
- magnetism ↑ when reactivity ↓.

After four months of operation of the MBE-STM-SARPES system:

Submitted/accepted papers:

1. M. Verziu, J. El Haskouri, D. Beltran, P. Amoros, D. Macovei, N.G. Gheorghe, C.M. Teodorescu, S.M. Coman, V. I. Parvulescu, *Mesoporous Tin-Triflate Based Catalysts for Transesterification of Sunflower Oil*, **Topics in Catalysis**, *accepted* (2009);
2. Ionel Stavarache, Ana-Maria Lepadatu, Nicoleta G. Gheorghe, Marius A. Husanu, George Stan, Dan Marcov, Adrian Slav, Gheorghe Iordache, Tionica F. Stoica, Vladimir Iancu, Valentin S. Teodorescu, Cristian M. Teodorescu, Magdalena Lidia Ciurea, *Structural investigations of Ge nanodots embedded in* SiO_2, **J. Nanopart. Res.**, *submitted* (2009);
3. Andrei N. Parvulescu, Davide Mores, Eli Stavitski, Cristian M. Teodorescu, Pieter C.A. Bruijnincx, Robertus J.M. Klein Gebbink and Bert M. Weckhuysen*, Chemical Imaging of Catalyst Deactivation during Biomass Conversion Processes: The Etherification of Biomass-based Alcohols with Alkenes over H-Beta Zeolites*, **J. Am. Chem. Soc.**, *submitted* (2010);
4. P. Palade, G.A. Lungu, Thermodynamic destabilization of Li-N-H system by Si addition, **J. Alloys Compds.**, *almost accepted* (2010);
5. N.G. Gheorghe, G.A. Lungu, M.A. Husanu, *Successful cleaning and study of contamination of Si(001) in ultrahigh vacuum*, **Rom. Rep. Phys.**, *submitted* (2010).

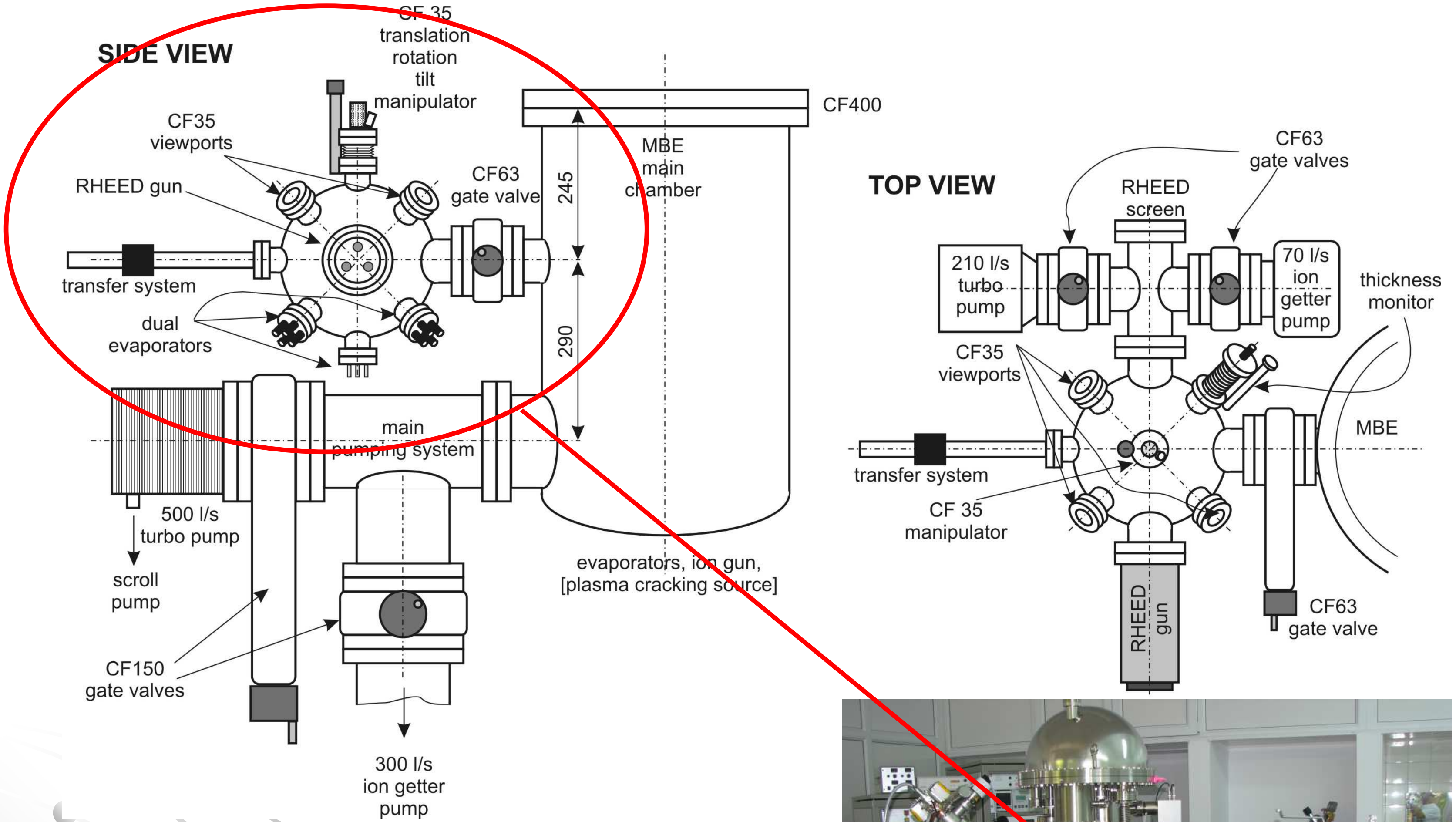
+ Other 5 papers in work: own results on Fe/Si(001) plus four in collaboration with V.I. Pârvulescu, G. Filoti, A.C. Gâlcă, G. Stan

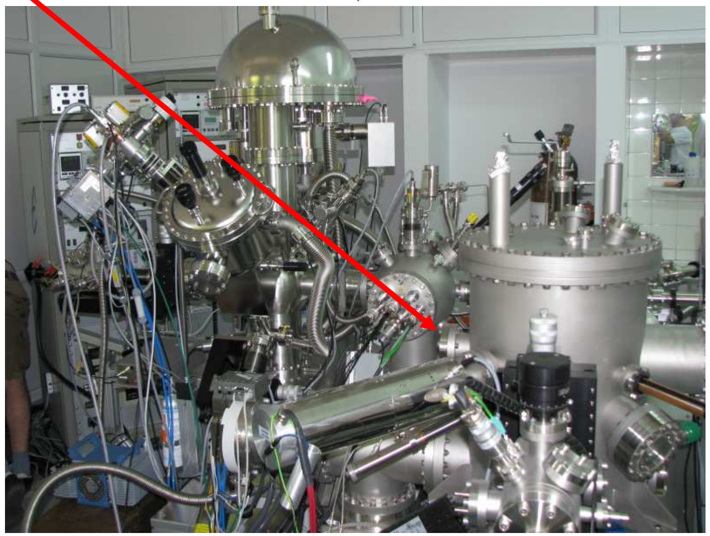
Team composition:

Dan Macovei, S.R. I
Cristian-Mihail Teodorescu, S.R. I
Marius-Adrian Husanu, Researcher
George-Adrian Lungu, A.R.
Nicoleta Gheorghe, A.R.
Eugenia Holdean, T I
Doina Vântur, T II
Adi Segal, student, T II part time
+ Ruxandra Costescu , will be hired as S.R. III from March 2010

→ setup of a reintegration grant (RP)

1. Setup of an MBE annex for III-V semiconductors.
2. Theoretical studies of (a) indirect exchange mediated by a 2DEG;
(b) transport coefficient and Wiedemann-Franz law in two dimensions.
3. Synthesis of III-V systems.
4. Synthesis of metals/III-V systems.
5. Synthesis of 2DEG heterostructures doped with magnetic ions.
6. Synthesis of "rolled-up nanotubes".
7. Thermal conduction properties by time-domain thermoreflectance measurements.
10 papers intended





Total price of the setup: Eur 50,000

- 5 evaporators (Ga, In, As, Al, 3d metals);
- thickness monitor;
- heating evaporator;
- possibly a RHEED.

Other research foreseen in 2010:

(1) Completing the work on Fe/Si(001):

- spin-resolved photoemission: high impact research;
- high resolution XPS;
- photoelectron diffraction on Fe/Si(001) (Fe and Si core levels).

→ direct comparison between EXAFS and photoelectron diffraction (never done).

(2) Mn/Si(001) and (3) Mn/Ge(001):

- Auger electron spectroscopy, LEED, RHEED, MOKE, EXAFS, XANES;
- spin-resolved PES;
- high-resolution XPS. Etc.

7-9 papers intended

Vă mulțumesc!