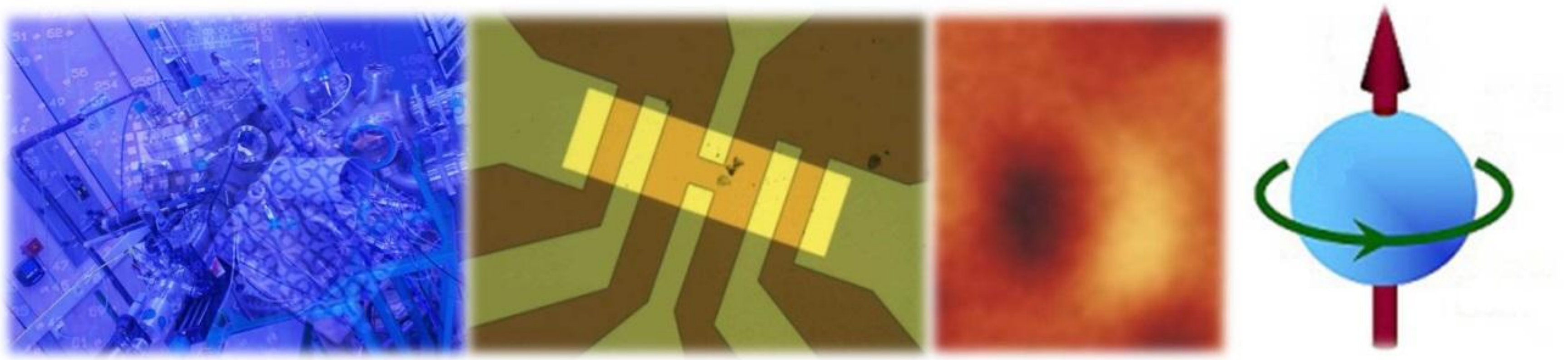
UNIVERSITATEA
TEHNICĂ
DIN CLUJ-NAPOCA

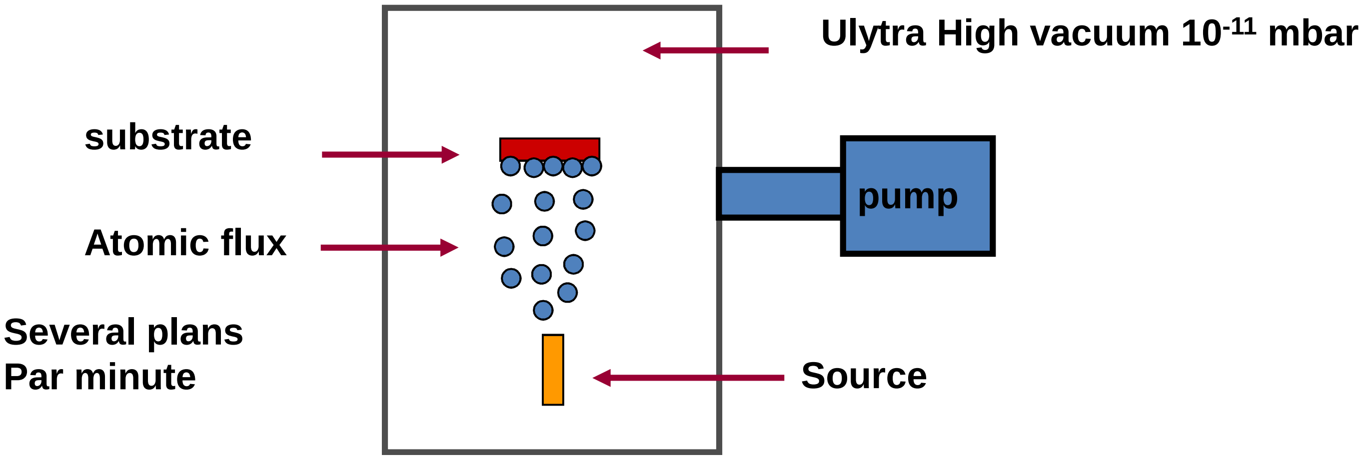


Nanomagnetism and spintronics at TUCN

Tailoring the magnetism by dimensionality for spintronics applications

http://www.c4s.utcluj.ro

Growth of thin films : e = several nm



Ulytra High vacuum 10^{-11} mbar

substrate

Atomic flux

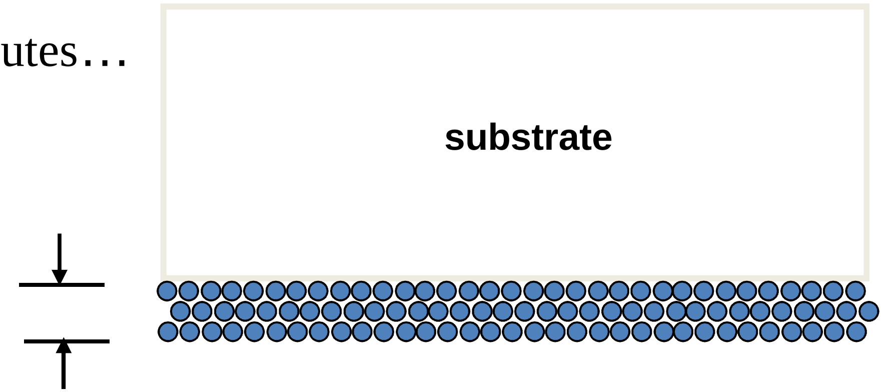
pump

Several plans
Par minute

Source

Techniques: MBE, sputtering, laser ablation, CVD, etc….

After several minutes…



substrate

3 plans = 1 nm

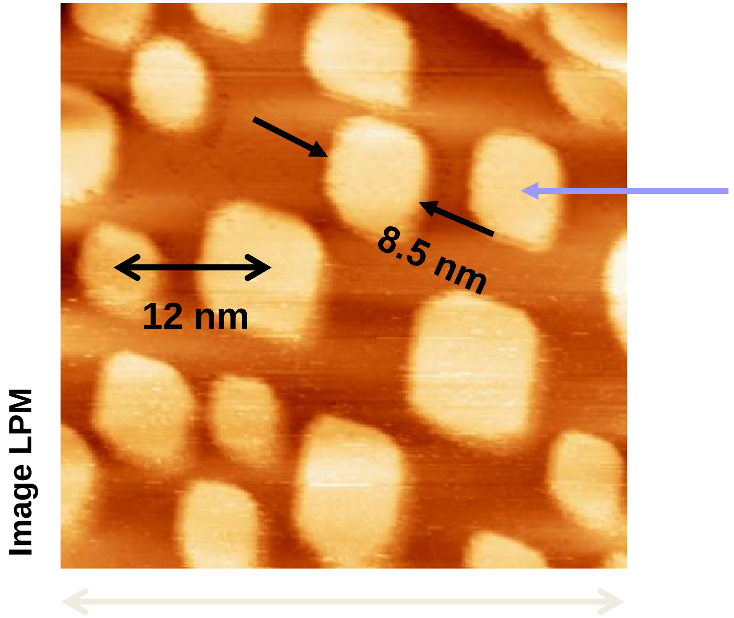
First stages of growth

1/2 plan of Cu on a Cu surface

STM image – top view

$T_{surface} = 300$ K

Grossissement : x 10 millions



50 nm (0.05 mm)

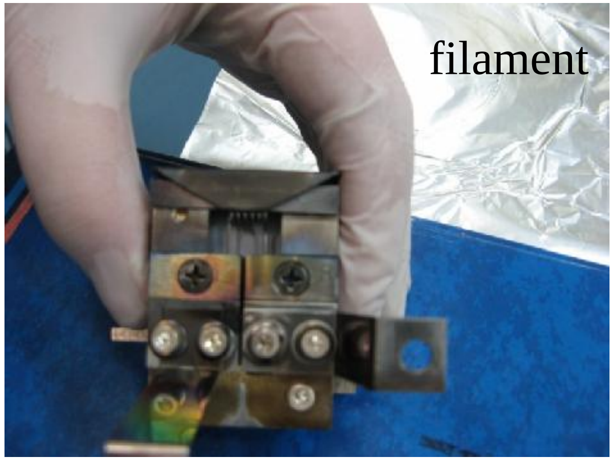
Cu island

Nano plot

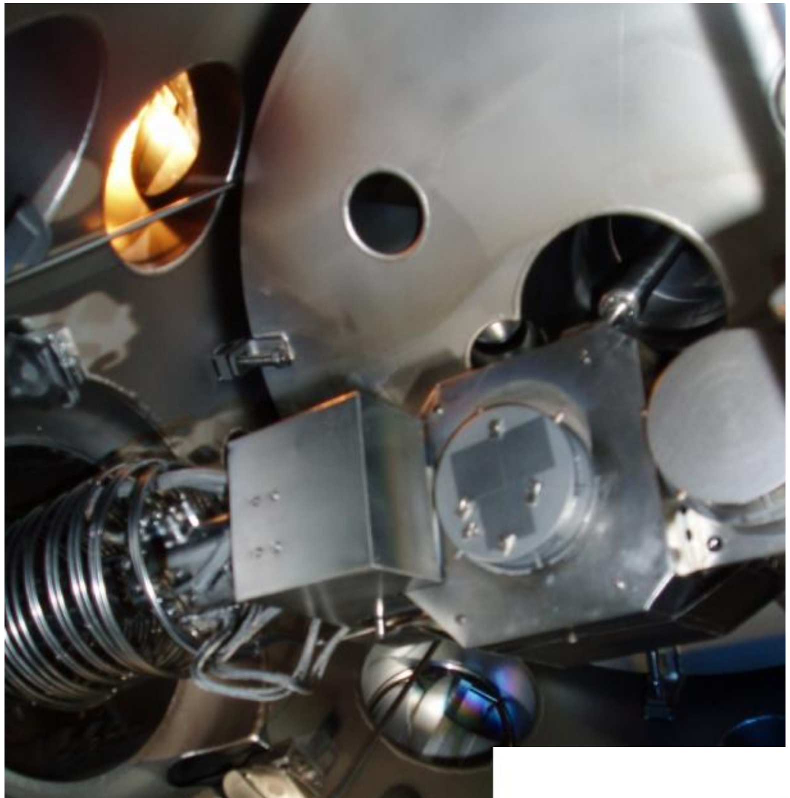
Size 10 nm

height 0.18 nm

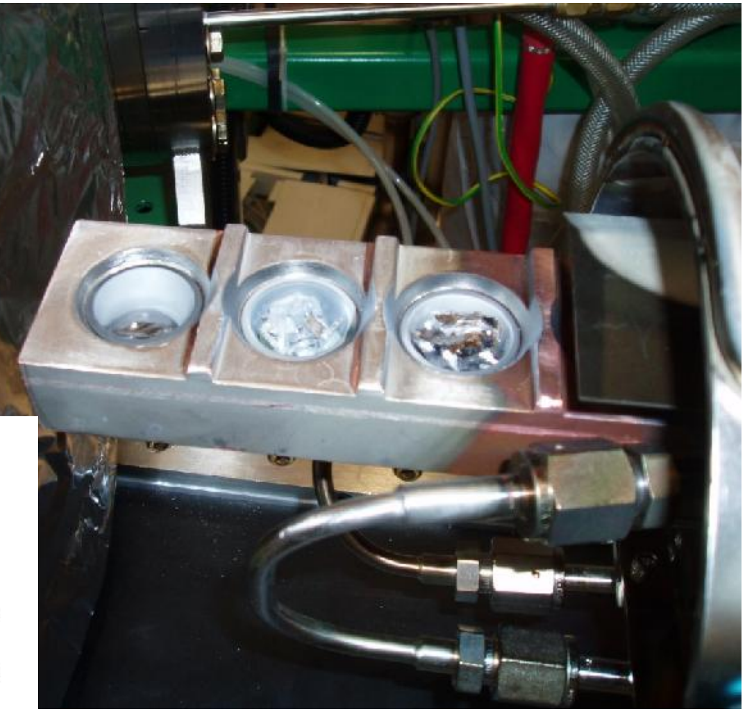
MBE: electron gun evaporation

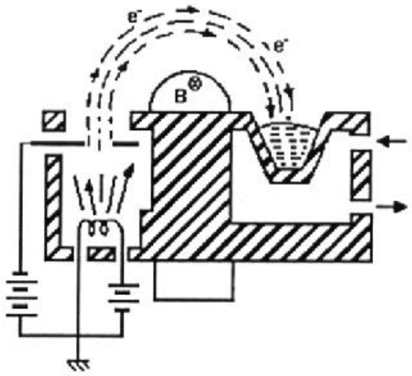

filament

Sample holder

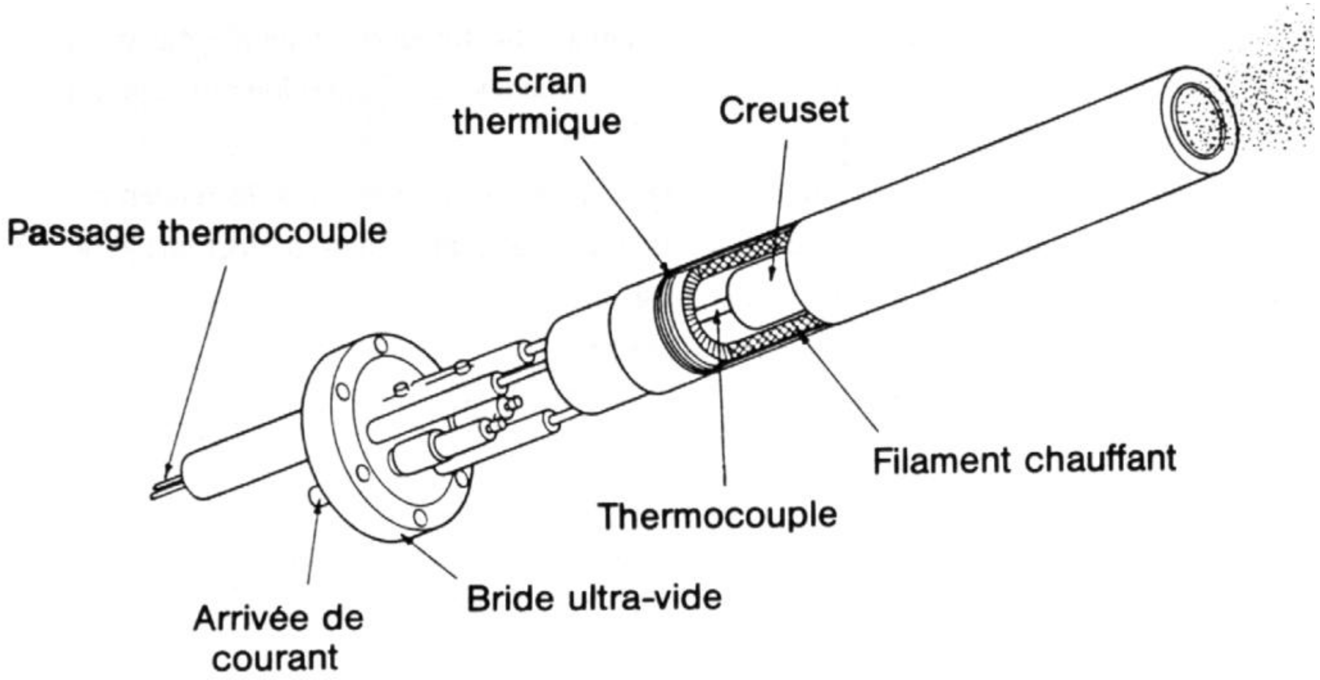


Crucible with targets

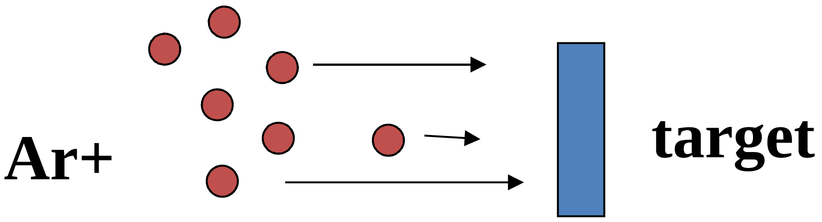




Knudsen cell

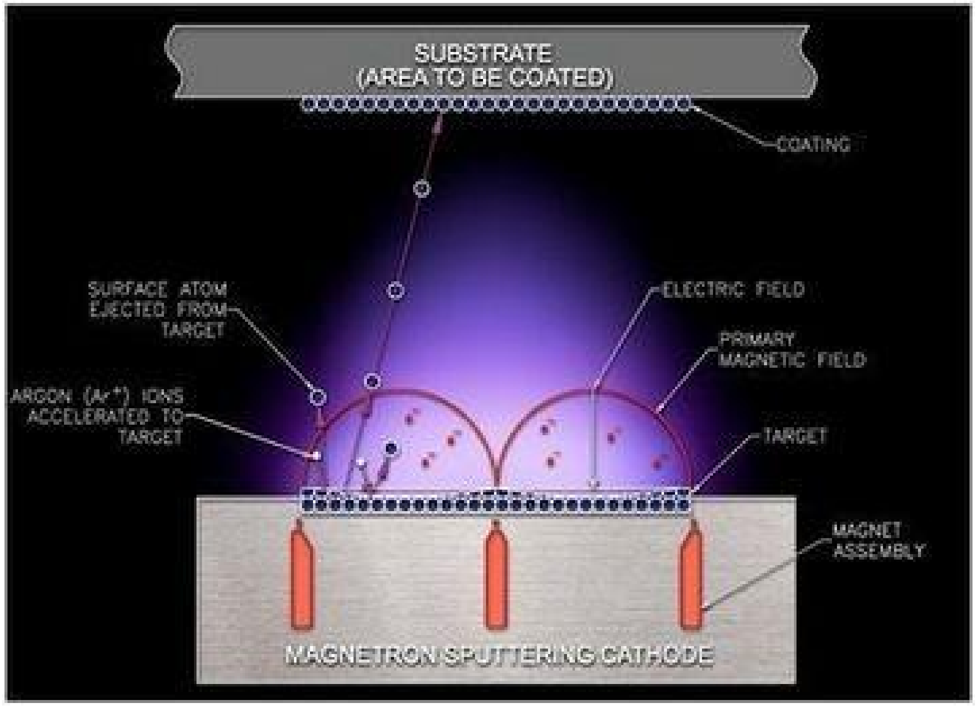


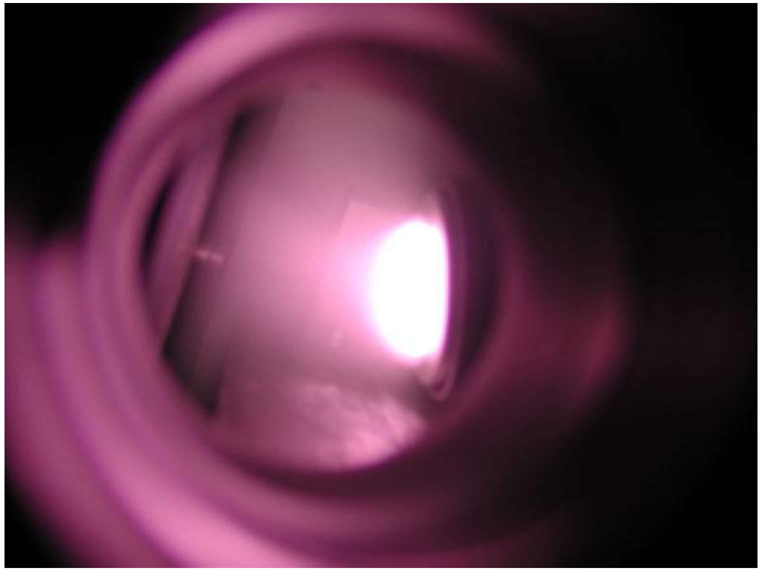
Sputtering



Ar+

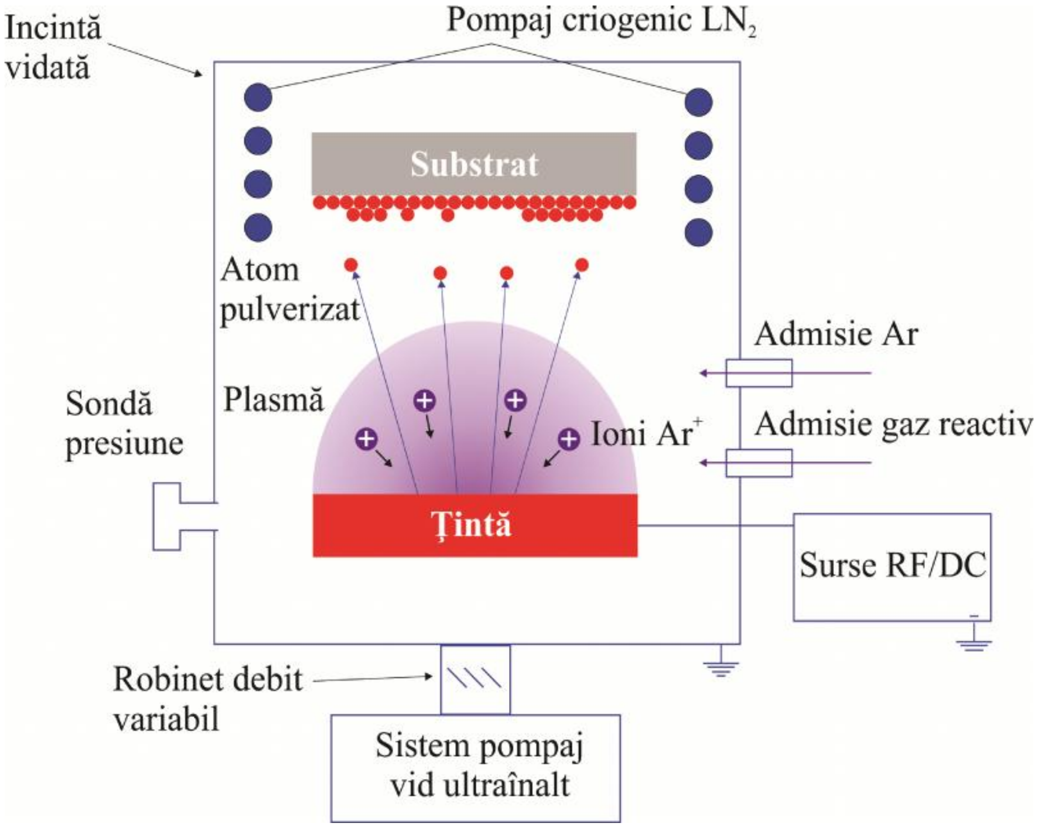
target





Bibliography

1) “MICRO ȘI NANOTEHNOLOGII. INDRUMĂTOR DE LABORATOR”.
Tehnici de fabricare și caracterizare a filmelor subțiri cu aplicații în microelectronică”
C. Tiușan, T. Petrisor Jr., M. Gabor Editura UTPRES 2013, 193 pagini, ISBN 978-973-662-824-5.

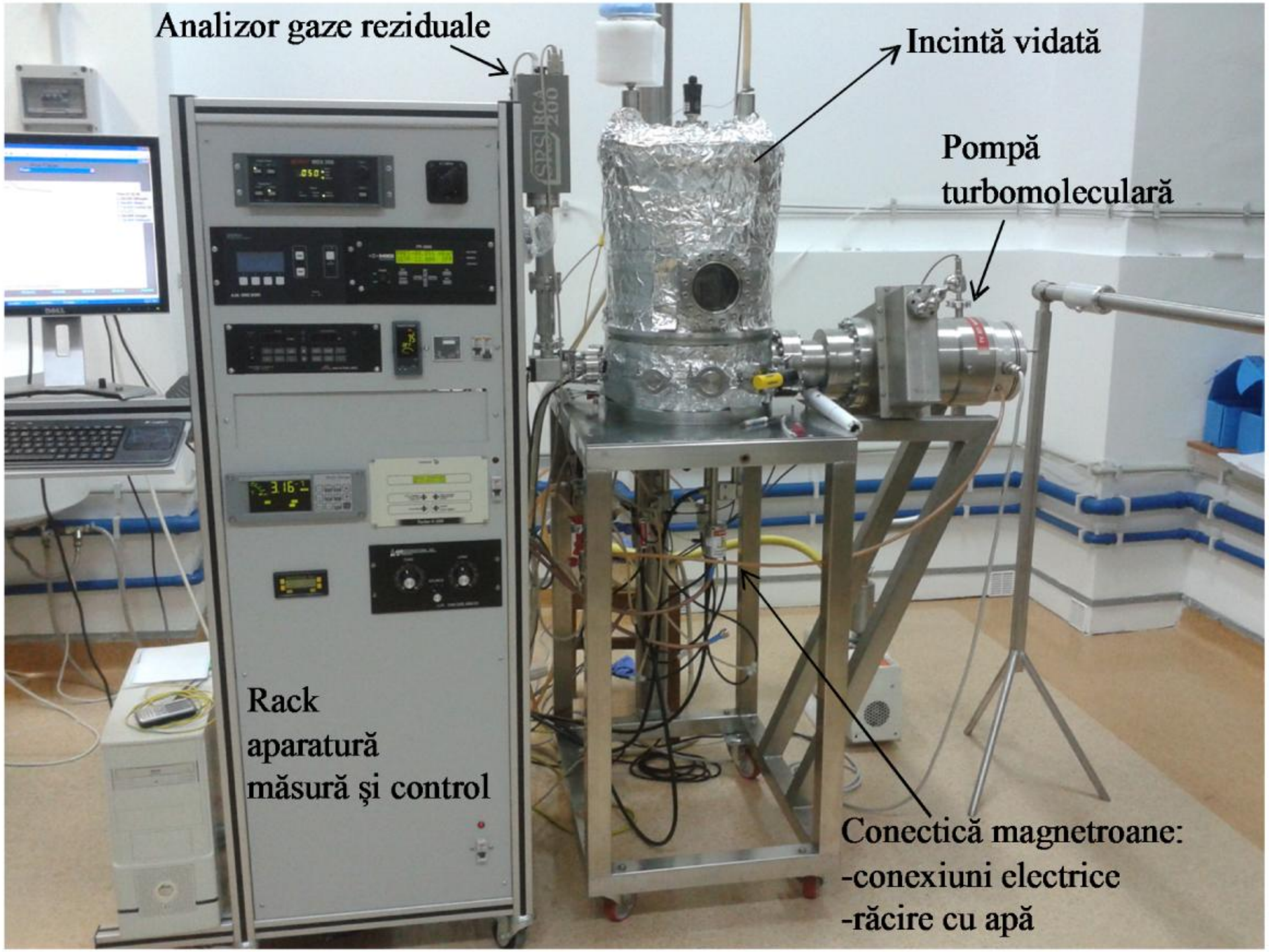


www.ajaint.com

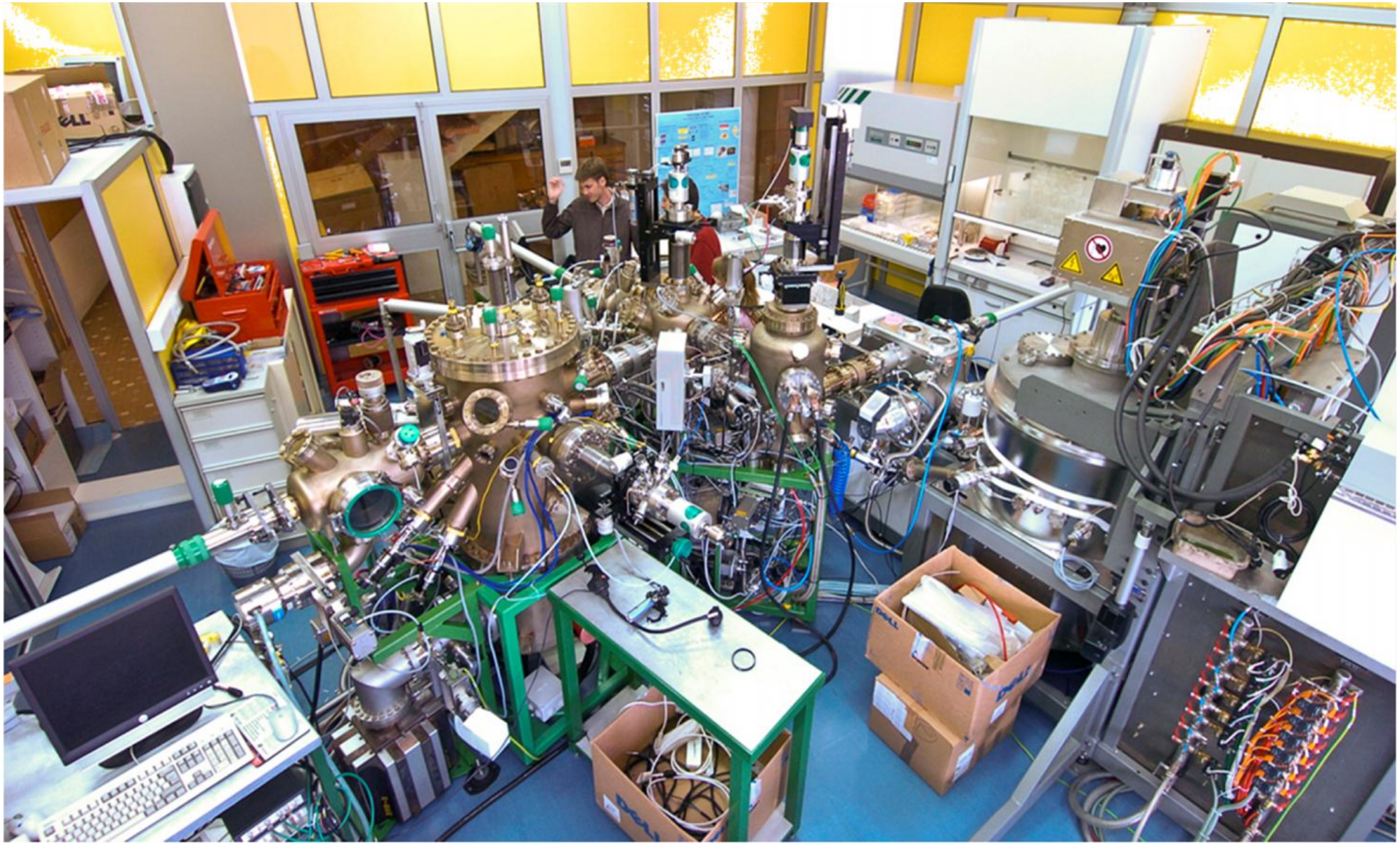
Confocal magnetron geometry

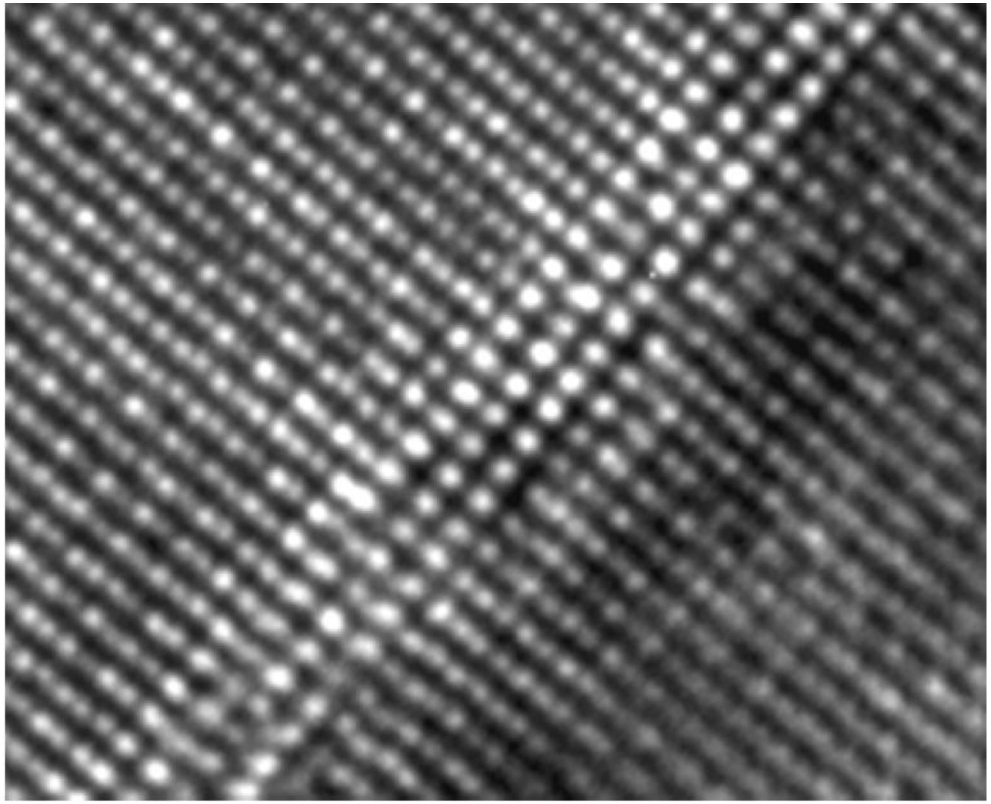
Simplified design - sputtering plant

C4S TUCN

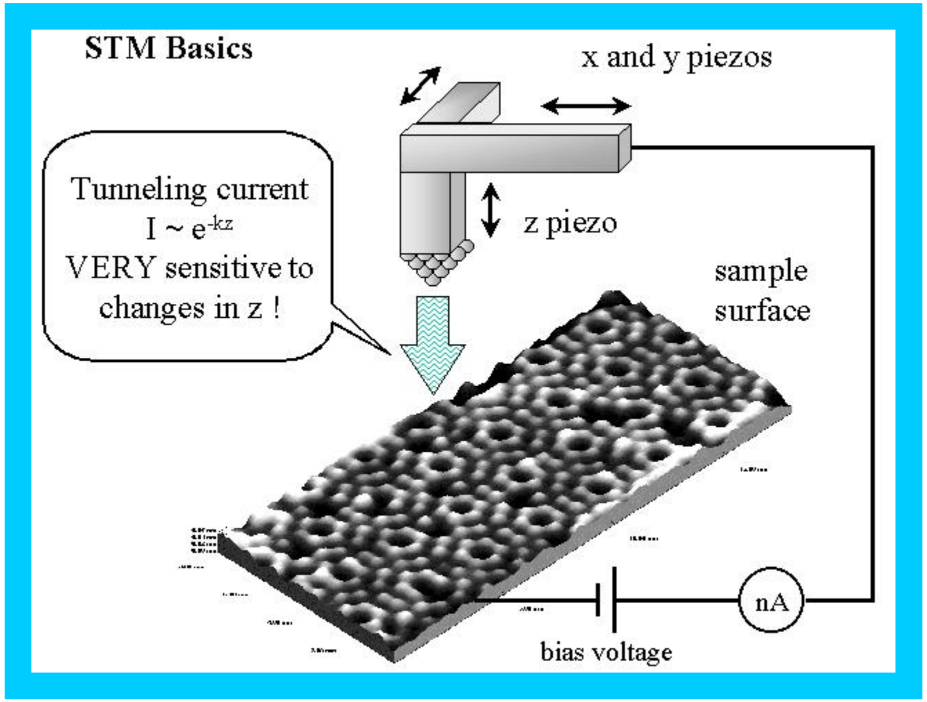

Analizor gaze reziduale
Incintă vidată
Pompă turbomoleculară
Rack aparatură măsură şi control
Conectică magnetroane:
-conexiuni electrice
-răcire cu apă

M-P-G-A Complex Nancy





Scanning tunneling microscope



1981: Gerld Binnig, Heinrich Röhrer

Nobel Prize 1986

IBM - Zurich

STM:

Looking to atoms…

atomic resolution

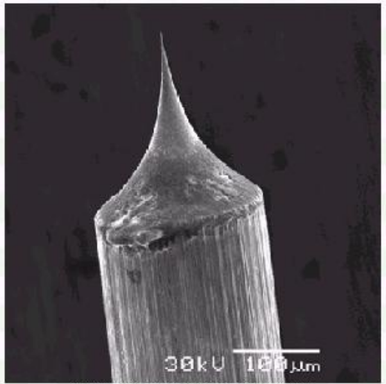
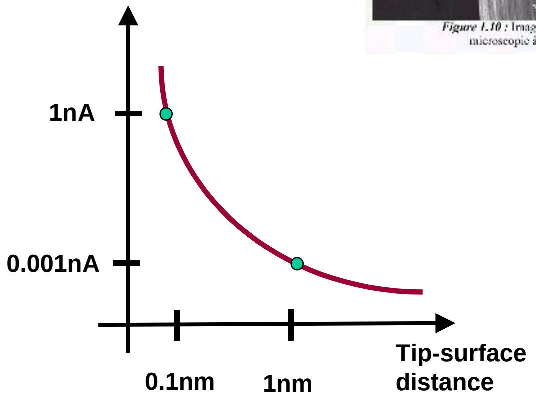
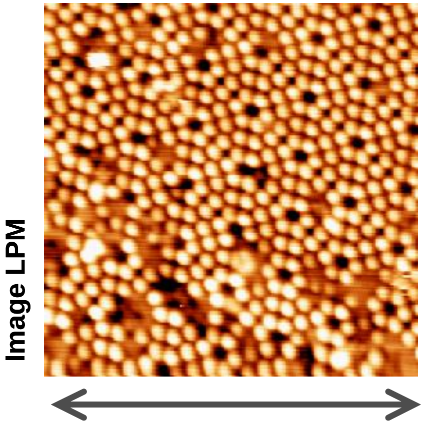


Figure 1.10 : Image de pointe STM obtenue par microscopie à balayage électronique.

STM tip



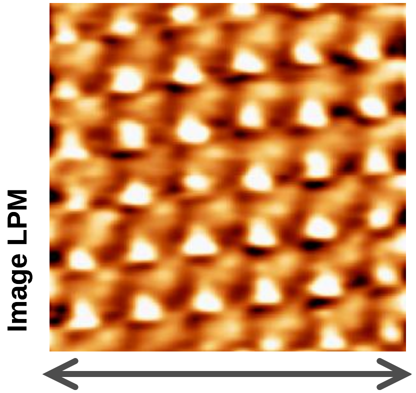
Si surface



15 nm

X 10 millions

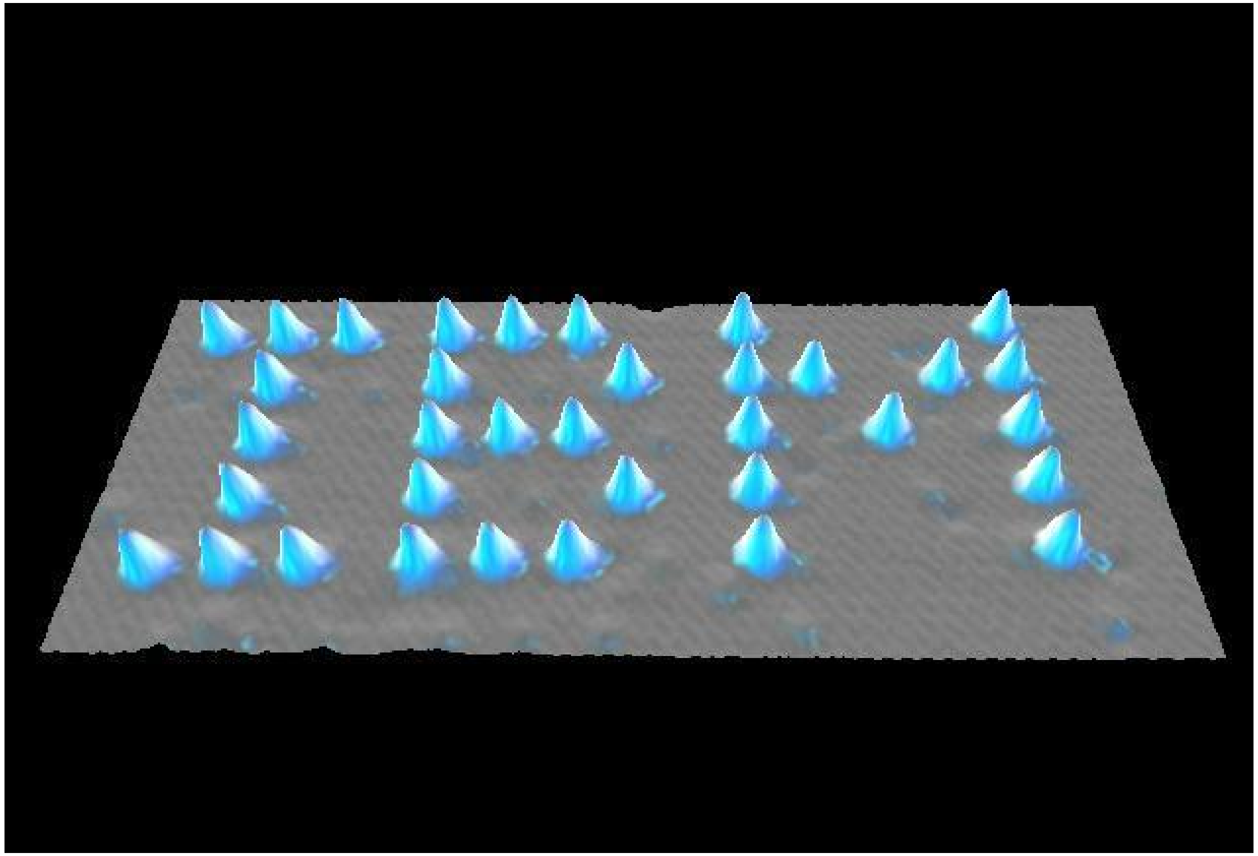
Cu surface



1.5 nm

X 100 millions

Moving atoms one by one by STM



Title : *The Beginning*

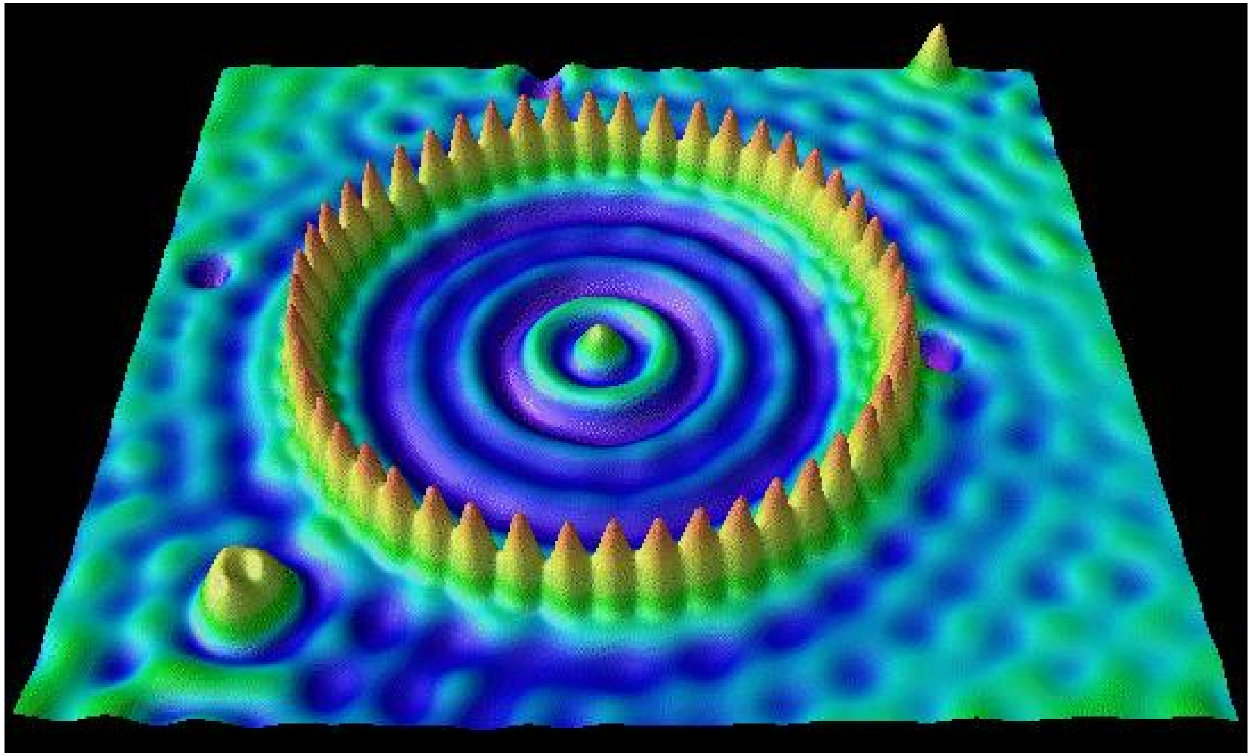
1988 Donald Eigler IBM *Xenon on Nickel (110)*

Artists have almost always needed the support of patrons (scientists too!). Here, the artist, shortly after discovering how to move atoms with the STM, found a way to give something back to the corporation which gave him a job when he needed one and provided him with the tools he needed in order to be successful.

2D finite potential well =» **QUANTUM CORAL**

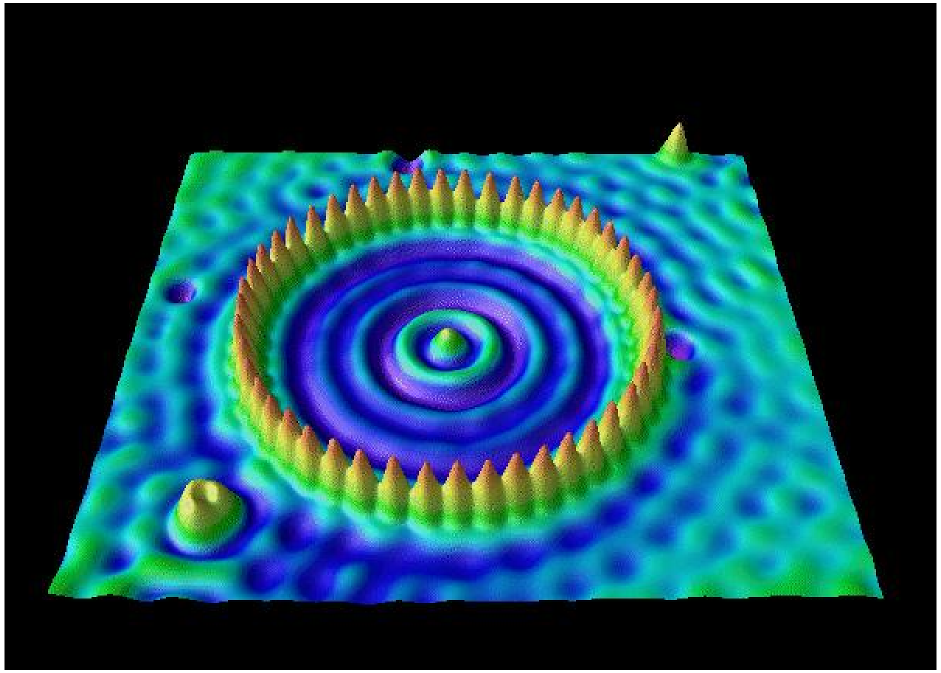
To make this image, 48 iron atoms (shown as yellow peaks) were placed in a circle on a copper surface.
The "elevation" at each point inside the circle indicates the electron density within the circle.
The standing-wave pattern is very similar to the probability distribution function for a particle
in a one-dimensional finite potential well:

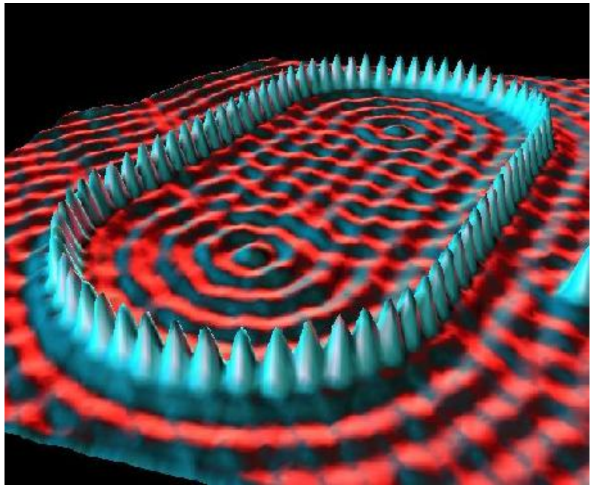
$$e\left|\Psi(x,y)\right|^2$$

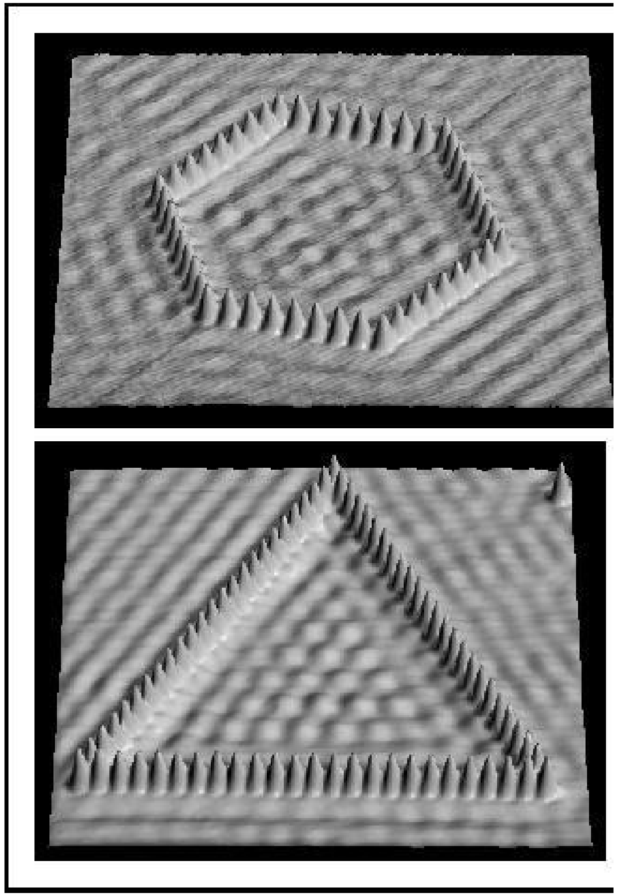


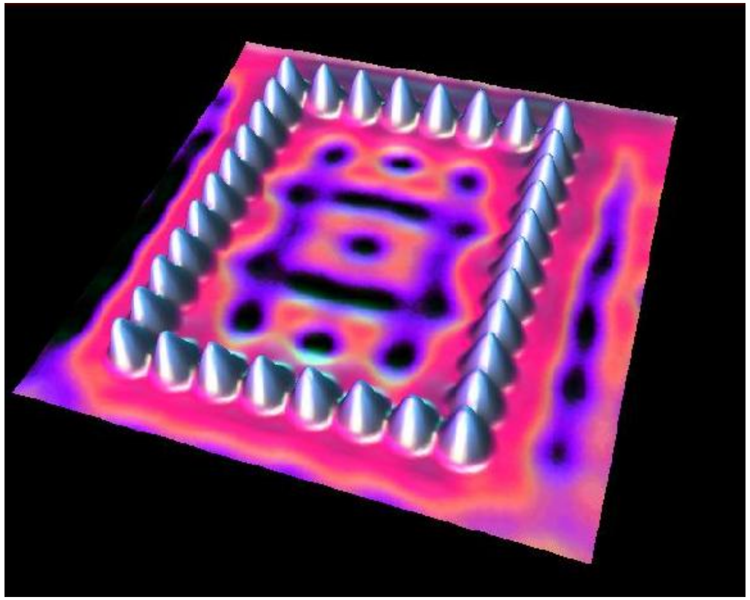
IBM- *M.F. Crommie, C.P. Lutz, D.M. Eigler, Science 262, 218-220 (1993).*

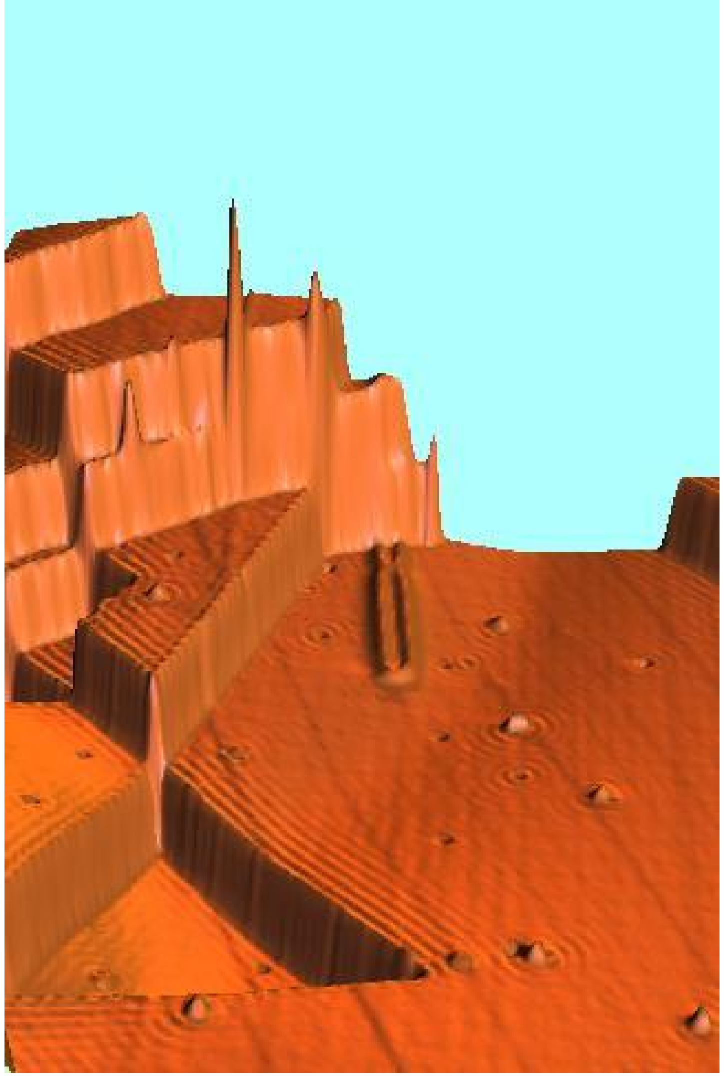
Quantum corrals









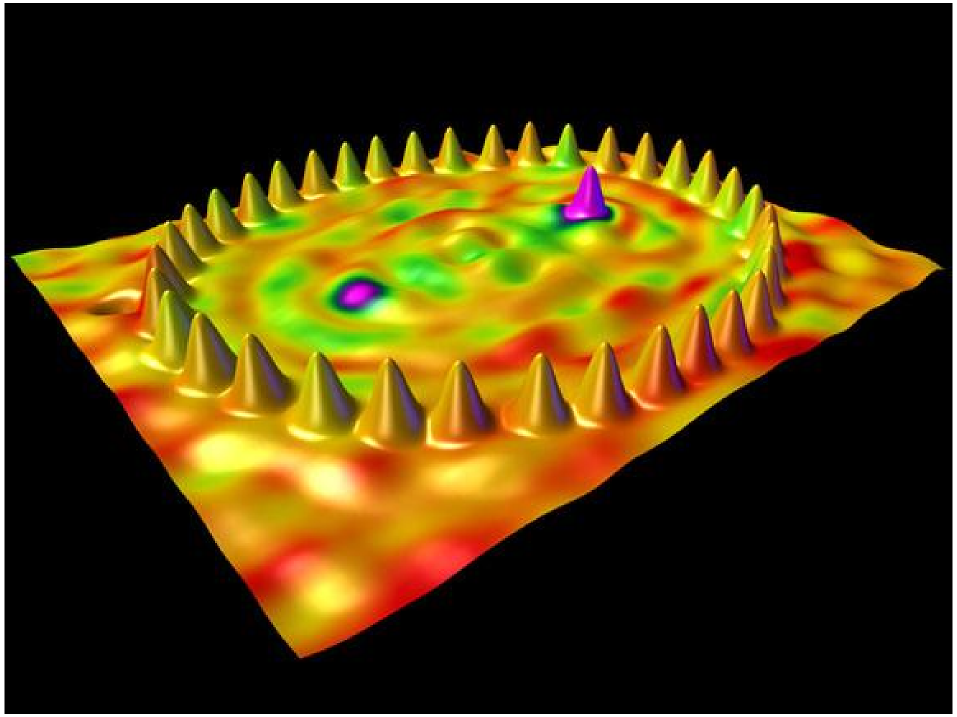


Reminiscent of formal Japanese rock gardens, here we see ripples surrounding features on the copper (111) surface.

The artists' fortunes took a major turn upward when they determined that the ripples were due to "surface state electrons."
These electrons are free to roam about the surface but not to penetrate into the solid. When one of these electrons encounters an obstacle like a step edge, it is partially reflected.

The ripples extending away from the step edges and the various defects in the crystal surface are just the standing waves that are created whenever a wave scatters off of something. The standing waves are about 15 Angstroms (roughly 10 atomic diameters) from crest to crest. The amplitude is largest adjacent to the step edge where it is about 0.04 Angstroms from crest to trough.

Quantum mirage

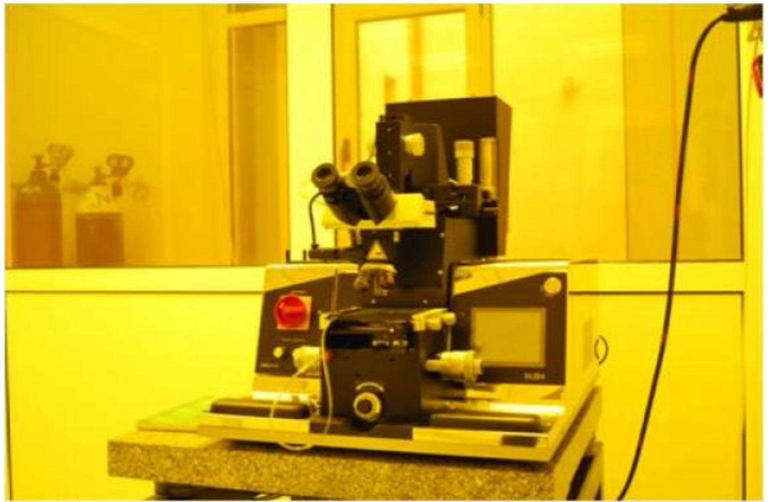


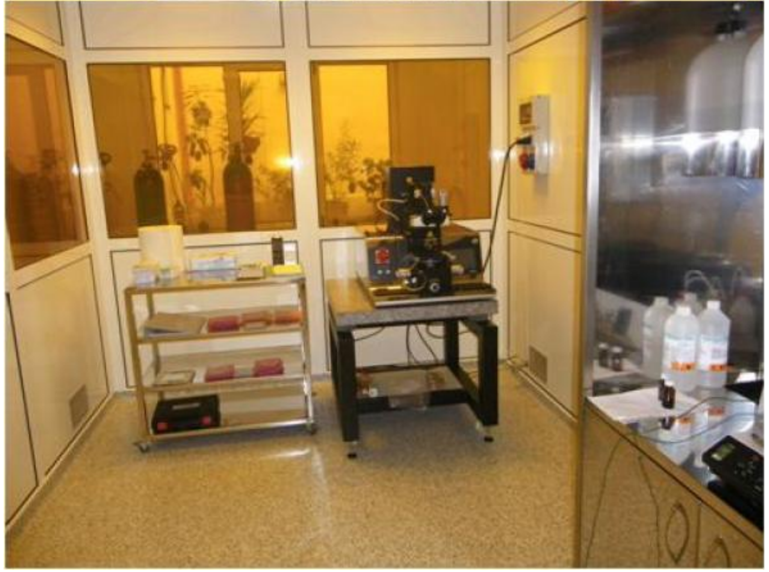
36 cobalt atoms in an elliptical structure known as a "quantum corral."
Electron waves moving in the copper substrate interact both with a magnetic cobalt atom carefully positioned at one of the foci of the ellipse and apparently with a "mirage" of another cobalt atom (that isn't really there) at the other focus.

Donald Eigler IBM Almaden

Clean room facilities (class 100):

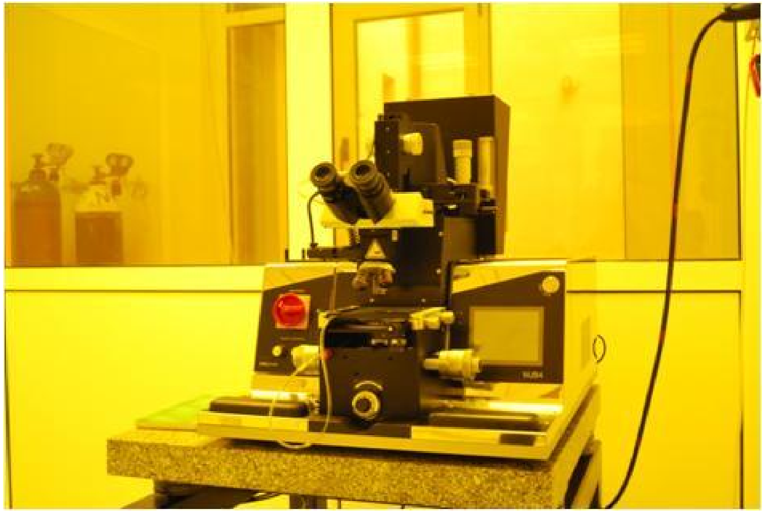
- -Optical lithography (MBJ4 SUSS mask aligner);
- -Ion Beam etching assisted by Auger Spectroscopy
- -Chemistry laboratory facilities for nanolithography

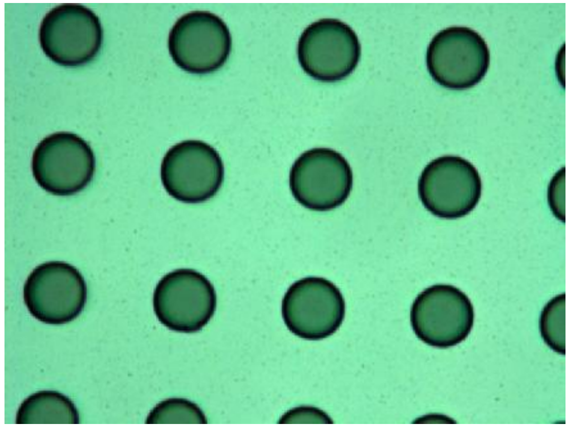


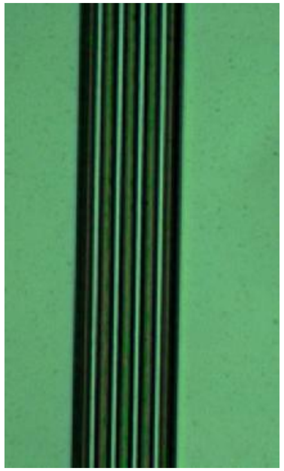


Optical lithography (UTCN)

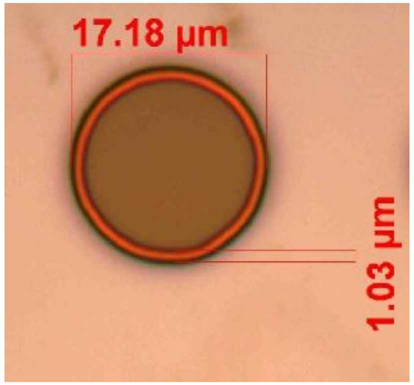
Suss MicroTech MJB4







Positive S1813

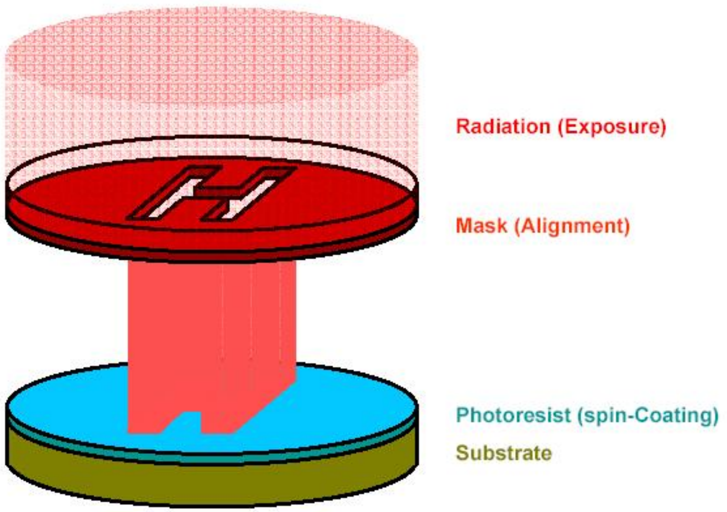


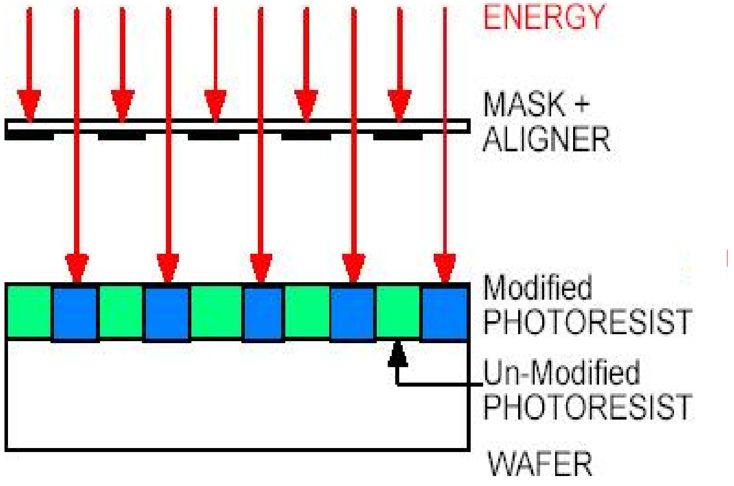
Undercut Neg ma-420

Patterning of:

-Micrometric size magnetic objects
-Current in plane electric devices
(Hall, GMR, superconducting lines)
-Current perpendicular to plane devices
magnetic tunnel junctions,
superconducting spin valves

Optical lithography / ion etching





Energy

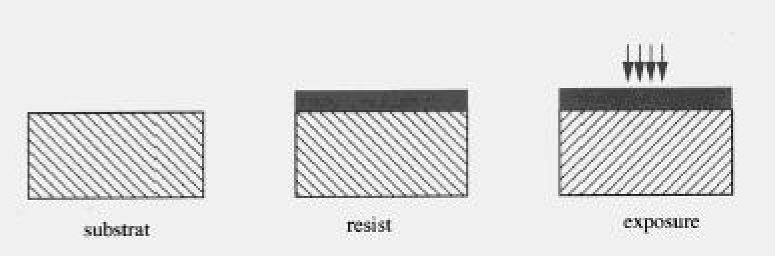
Cause chemical reactions that modify resist dissolution rate

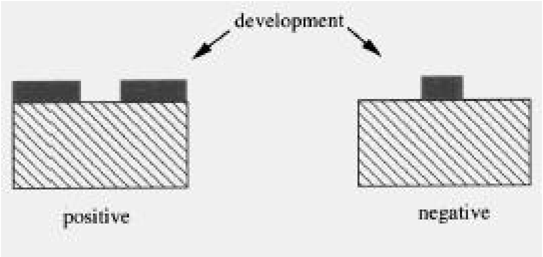
Mask

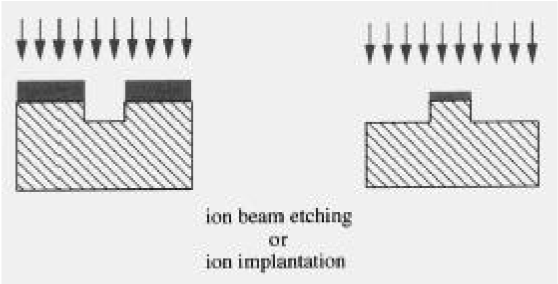
Absorber (Dark Area) & window (Open area)

Resist

Transfer image from mask to wafer







- **Positive Photoresist**
  - the polymer is weakened and more soluble in developing solution
- **Negative Photoresist**
  - the polymer is hardened and less soluble

Resists

<u>Resists</u>: (1) Positive → exposure degrades resist (dark field mask)
(2) Negative → exposure hardens resist (light field mask)

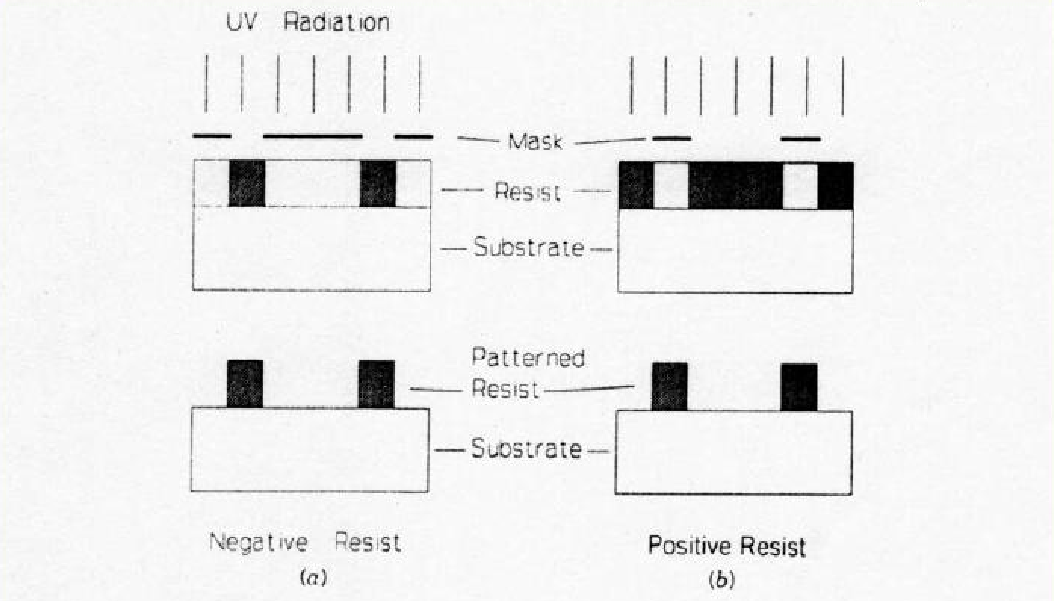
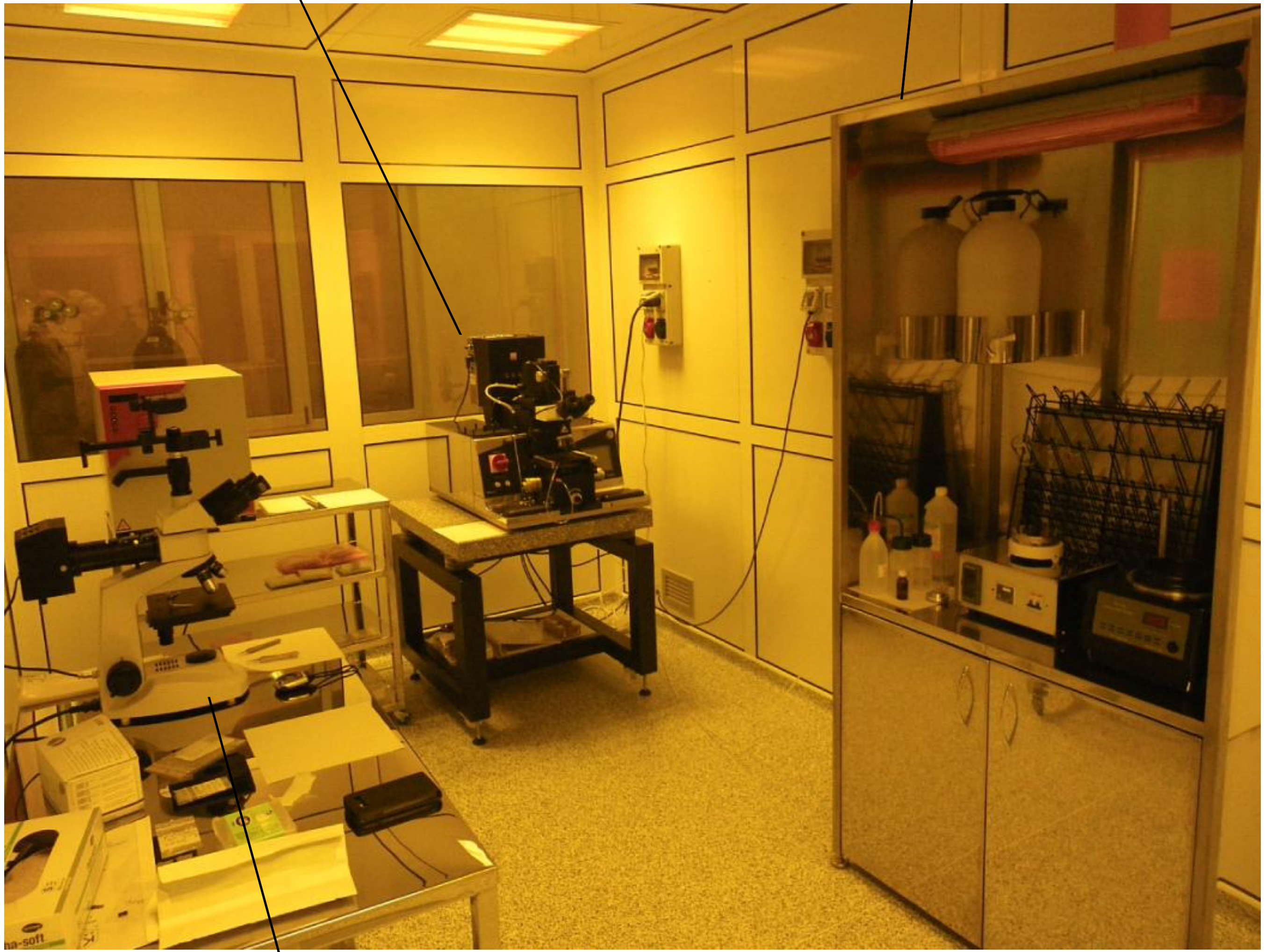


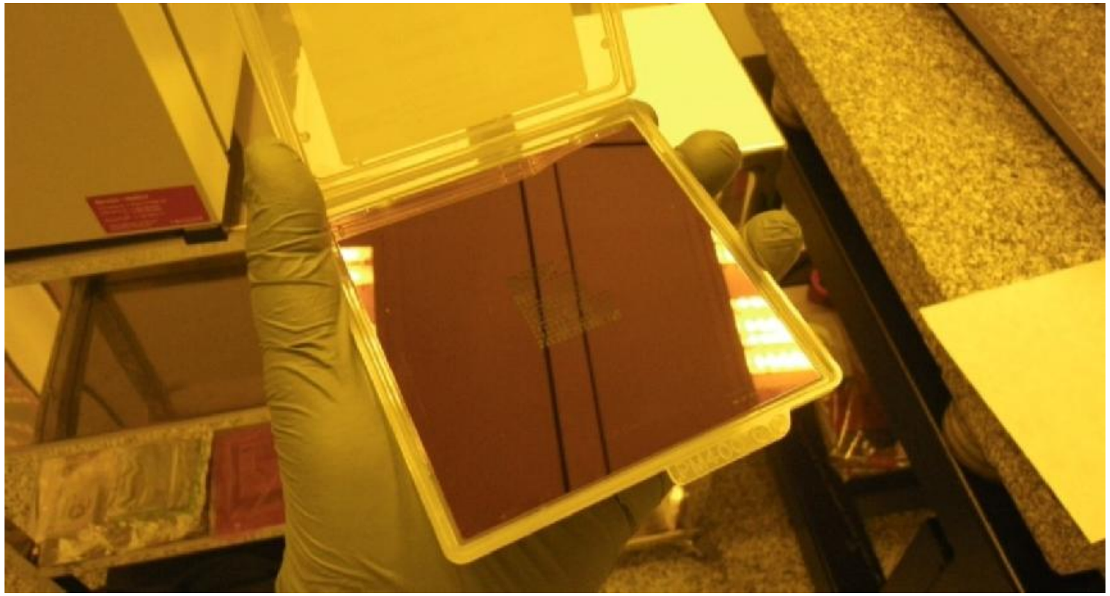
Fig. 10.2 Schematic of pattern transfer: (*a*) Negative resist and (*b*) positive resist.

Clean room facilities (class 100):

- -Optical lithography (MBJ4 SUSS mask aligner);
- -Ion Beam etching assisted by Auger Spectroscopy
- -Chemistry laboratory facilities for nanolithography

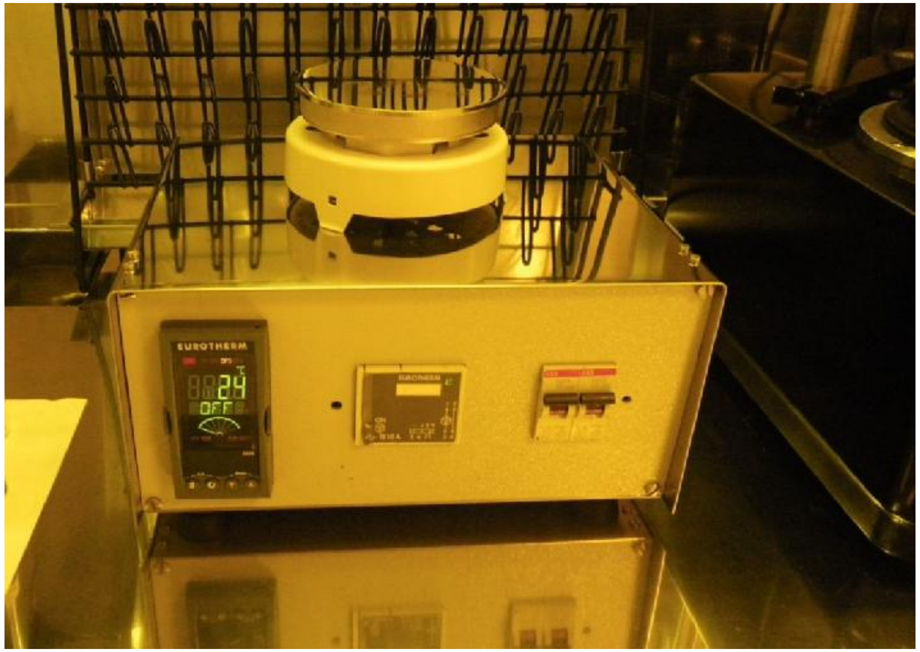


Clean room utilities



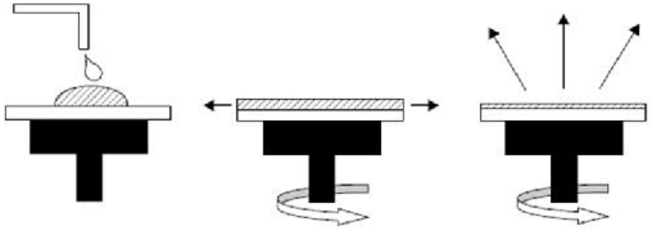
Mask

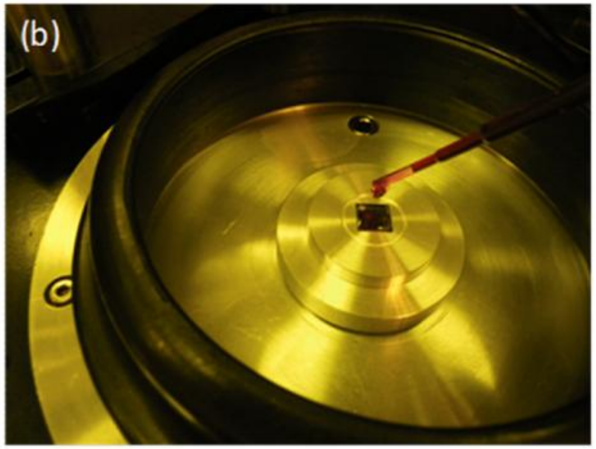
Spin coater of photorezist

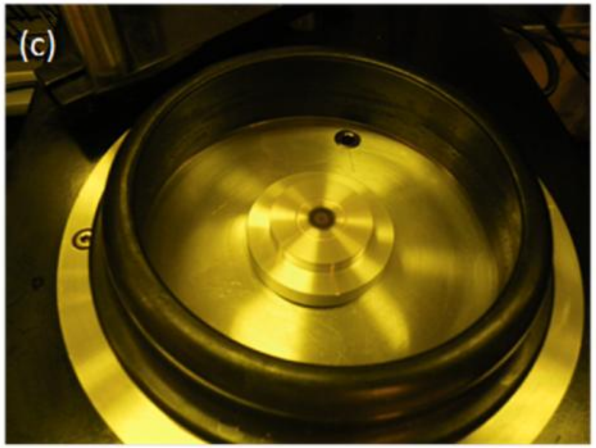


Hot plate (photorezist soft baking)

Spining the photoresist



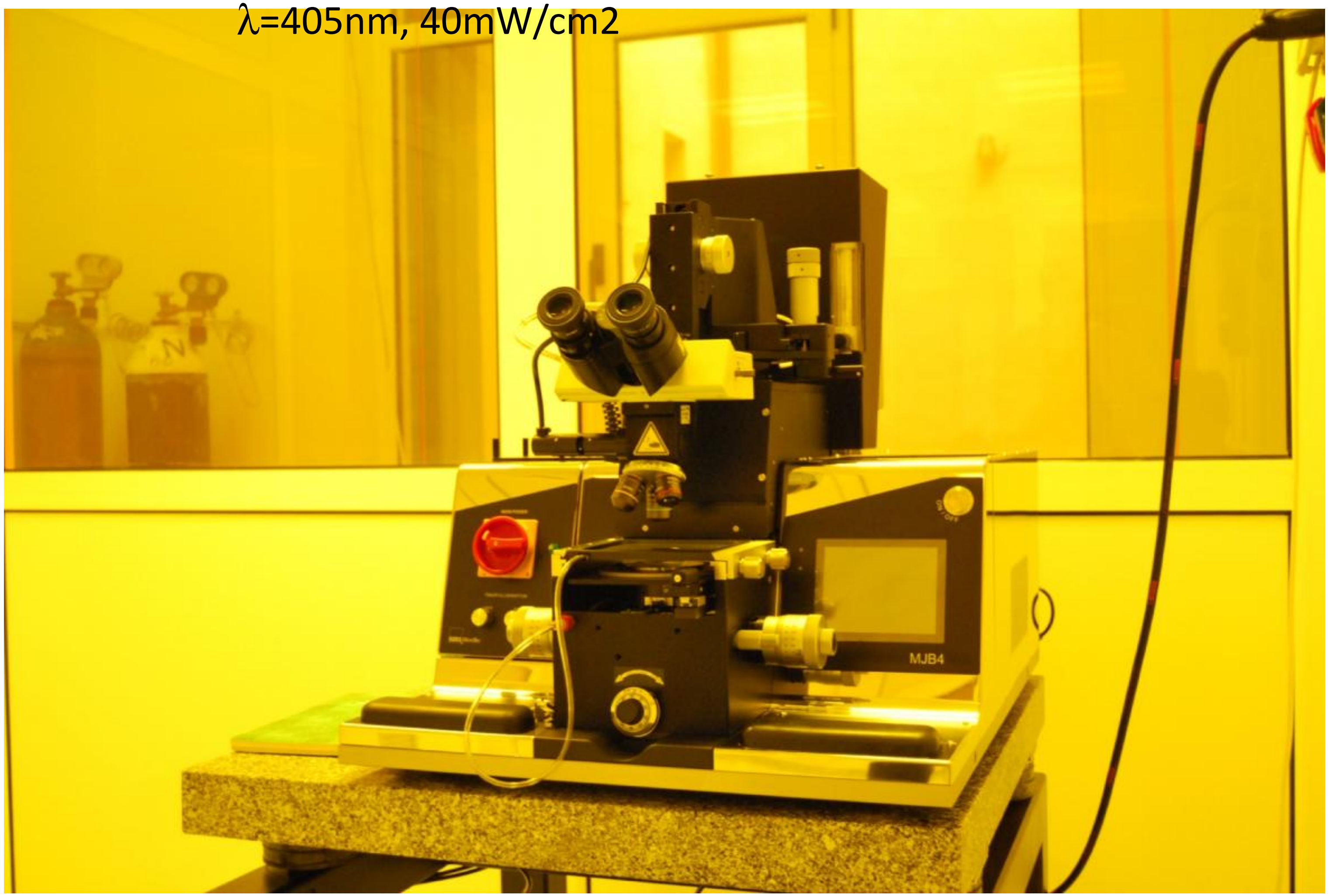




Clean room utilities

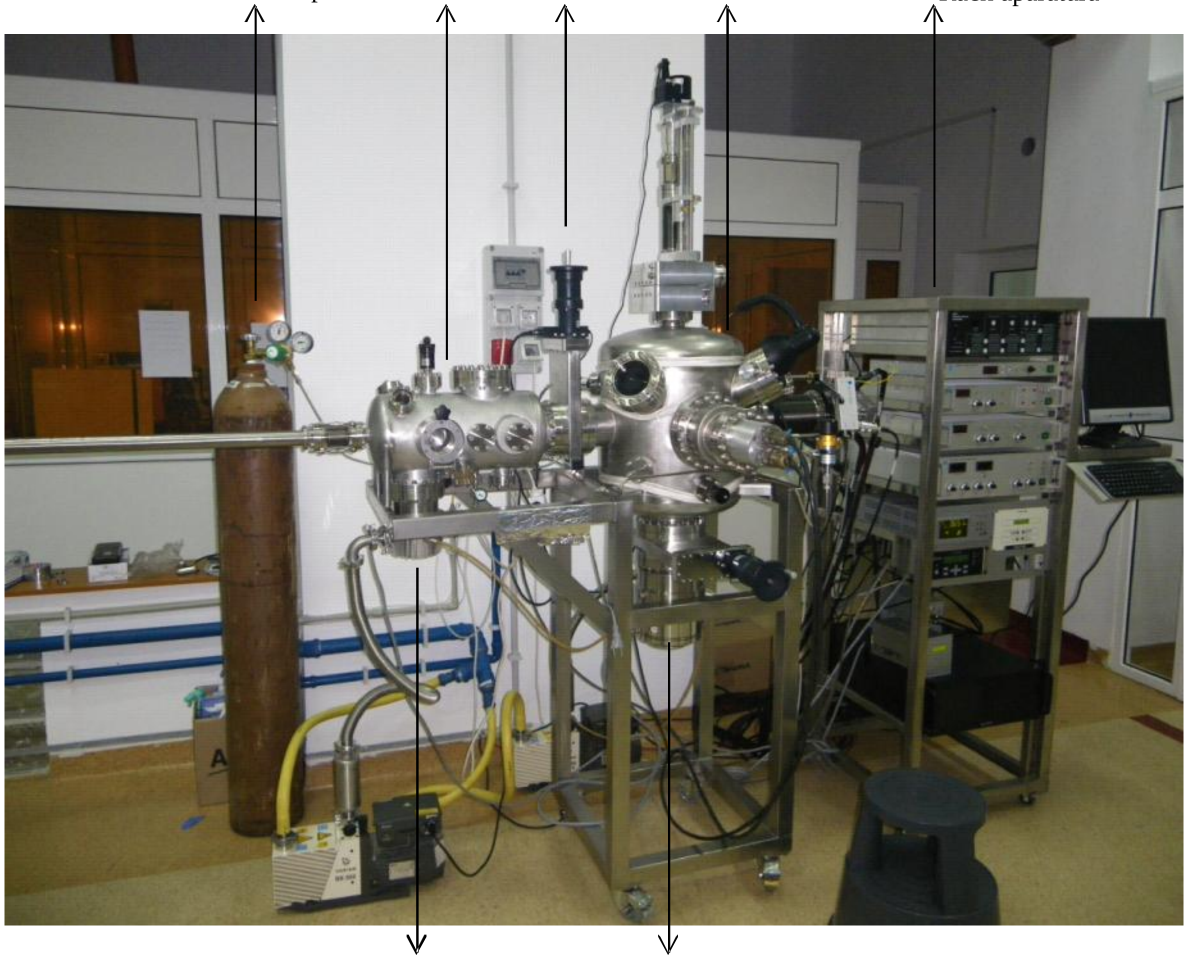
Mask aligner

λ=405nm, 40mW/cm2



C4S-UTCN

The ion beam etching plant (C4S/TUCN)



Tub argon
sursă ioni

Sas
introducere
probă

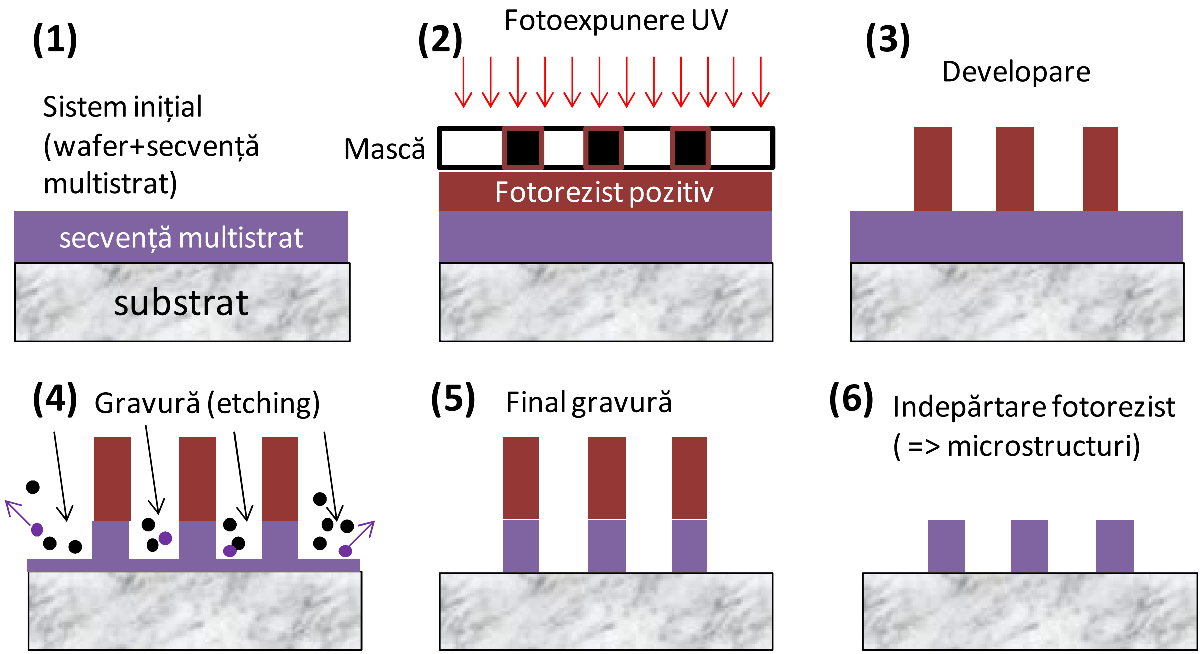
Robinet sertar
decuplare

Instalație IBE

Rack aparatură

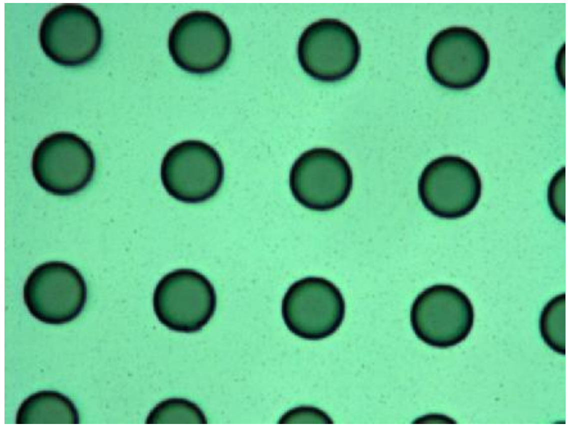
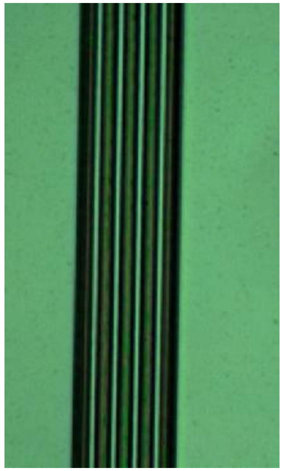
Pompaj sas

Pompaj IBE



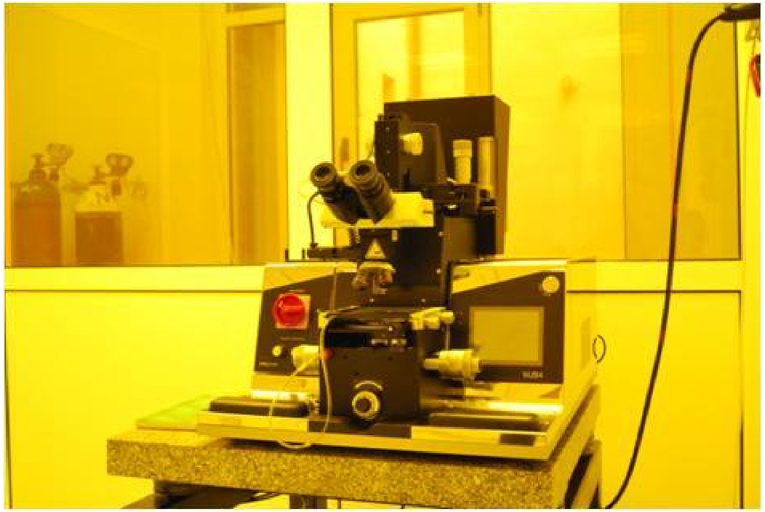
Reprezentare schematică a procesului de transfer de pe mască pe wafer corespunzător foto-litografiei cu fotorezist pozitiv

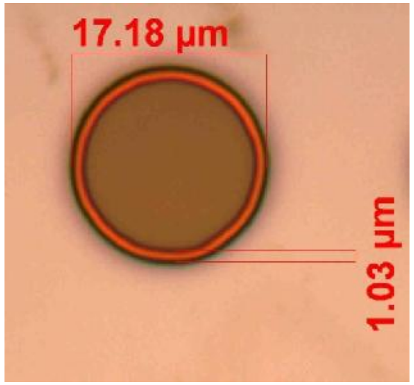
Optical lithography (UTCN)

Positive S1813

Suss MicroTech MJB4



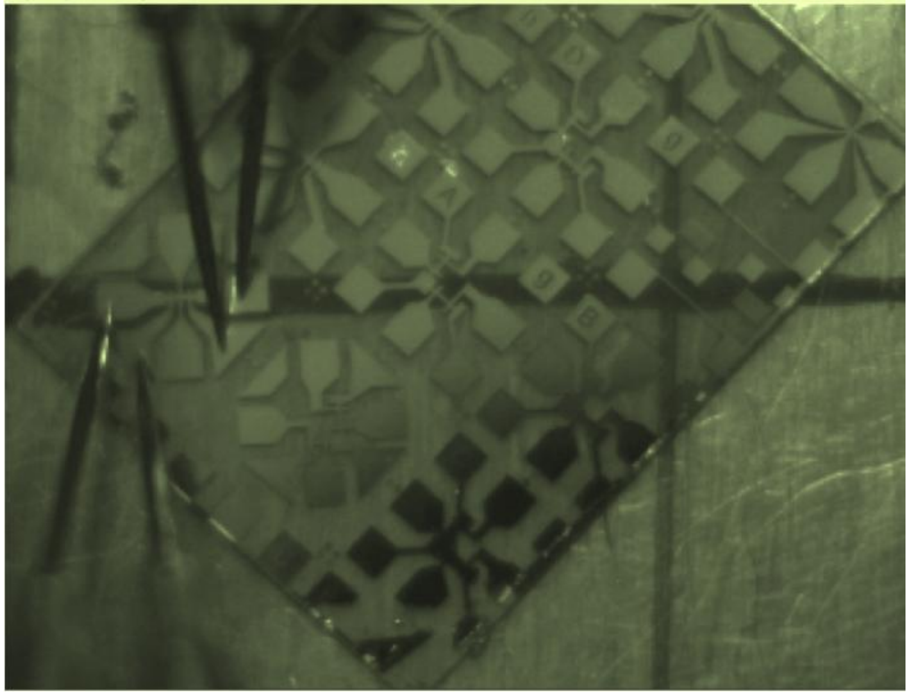


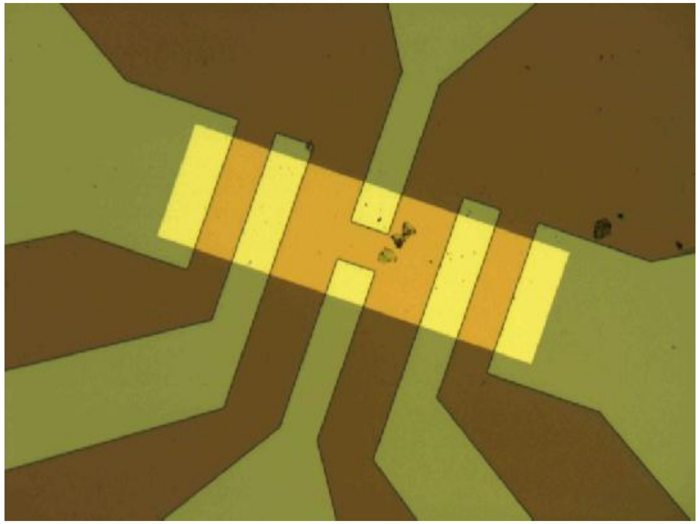
Undercut Neg ma-420

Patterning of:

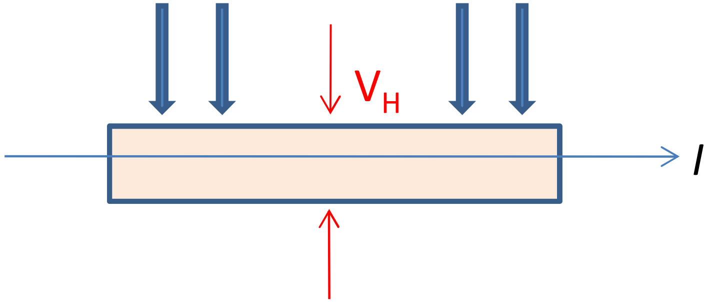
-Micrometric size magnetic objects
-Current in plane electric devices
(Hall, GMR, superconducting lines)
-Current perpendicular to plane devices
magnetic tunnel junctions,
superconducting spin valves

CIP transport (GMR, AMR, Hall ....)





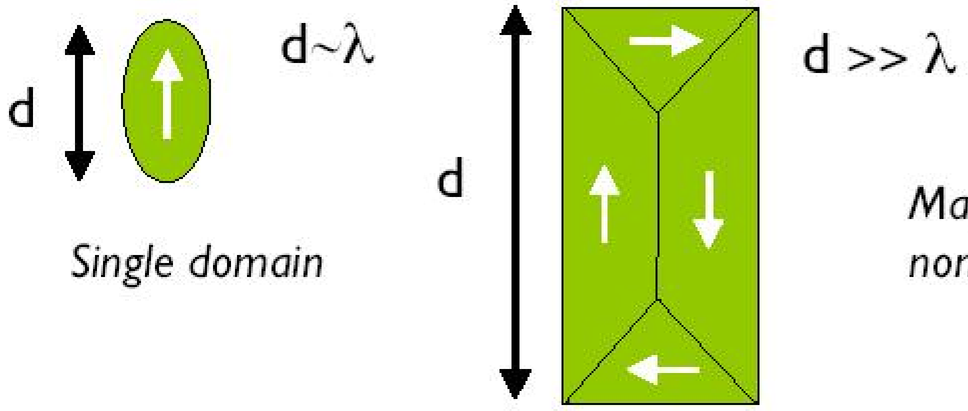
4 points mesurements



Exchange length: scale length of magnetism

How small is small?

- What determines whether a magnetic structure is made of up a single domain or many domains?



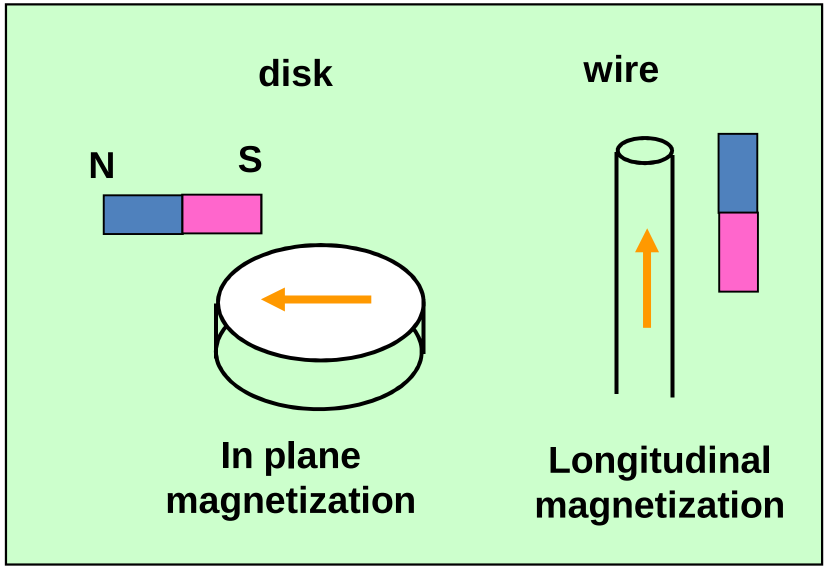
Single domain

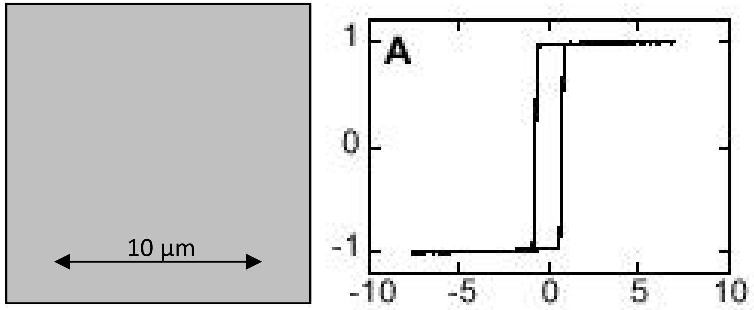
Multi-domain

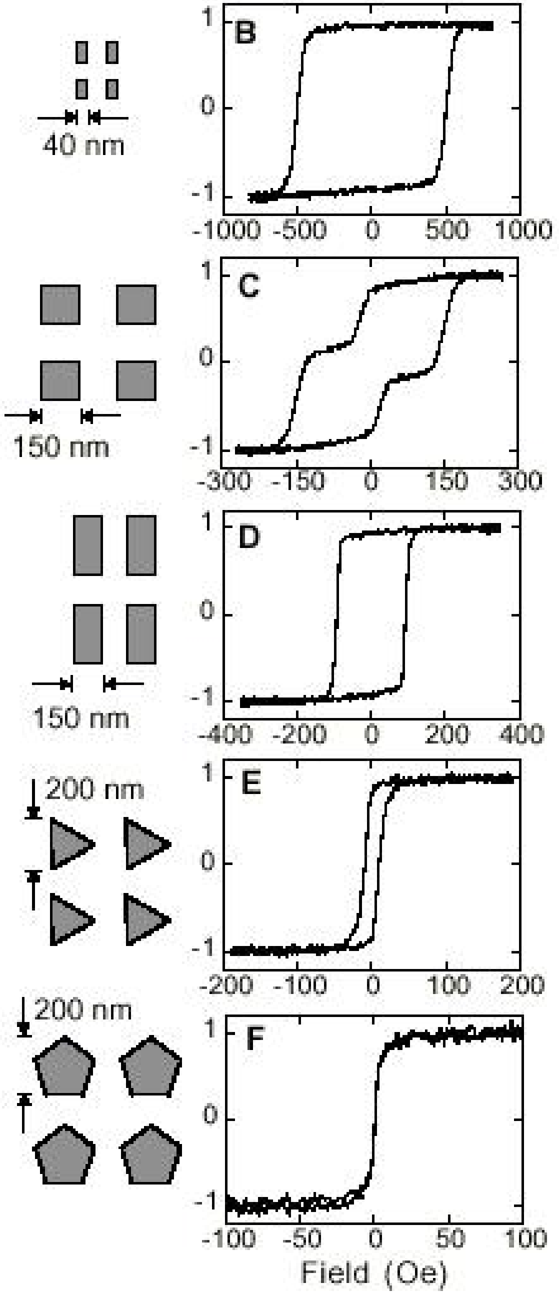
Magnetization could also be non-uniform within a domain

- Characteristic length scales
  - *Exchange length*- over which magnetic moments are parallel
    $\lambda = \sqrt{A} / M_s$ where A= exchange constant, M_s= saturation magnetization
  - *Domain wall width*-
    $\delta = \pi \sqrt{(A/K)}$ where K= anisotropy constant

Example: Modulation of magnetism via the shape of objects





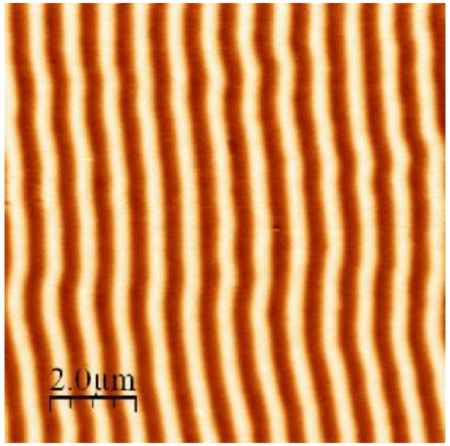


Mezomagnetim

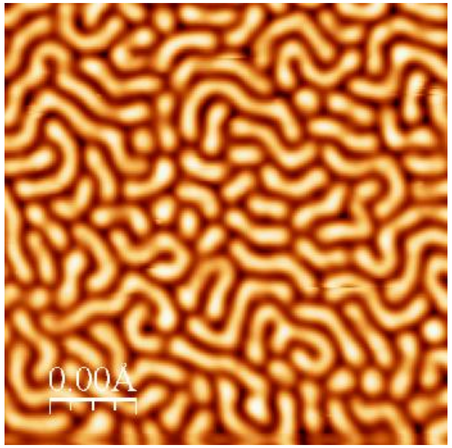
Magnetism modulation in reduced dimension objects useful for spintronics

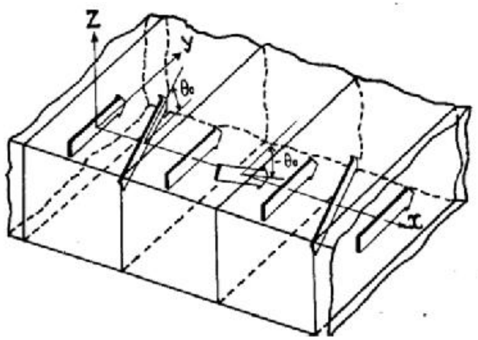
Nanometric-thick thin films

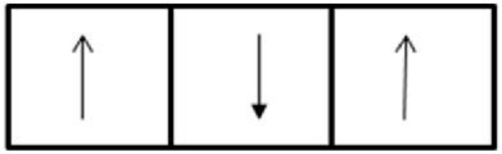
Ni80Fe20 weak stripe domain wall structure



Co stripe domain wall structure
Perpendicular to film magnetization





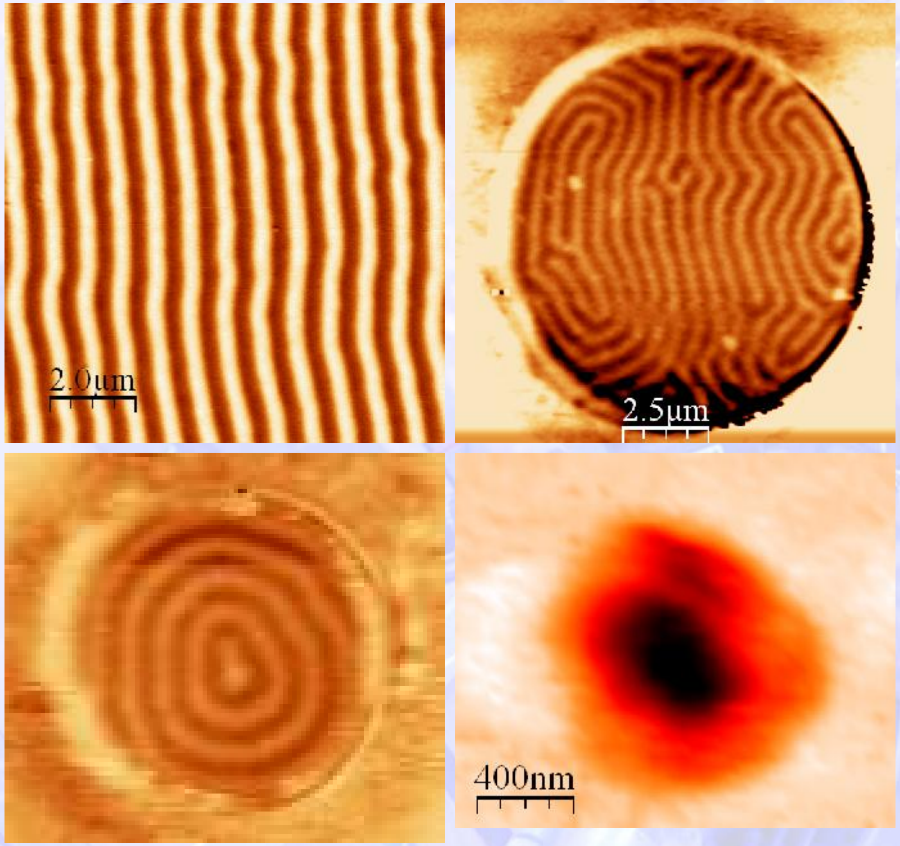


Then Patterned films

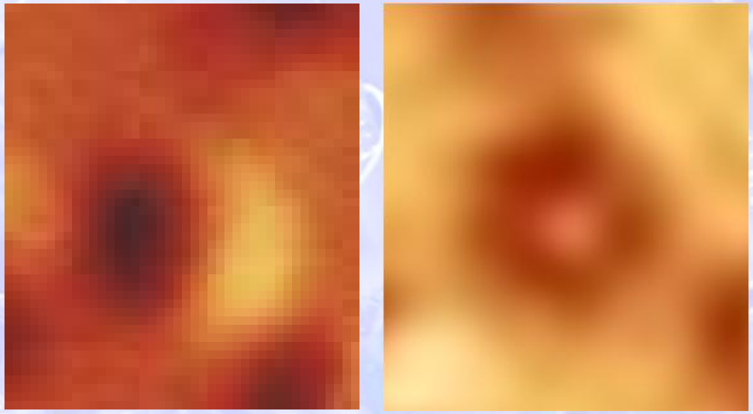
Mezoscopic magnetism at C4S/TUC-N

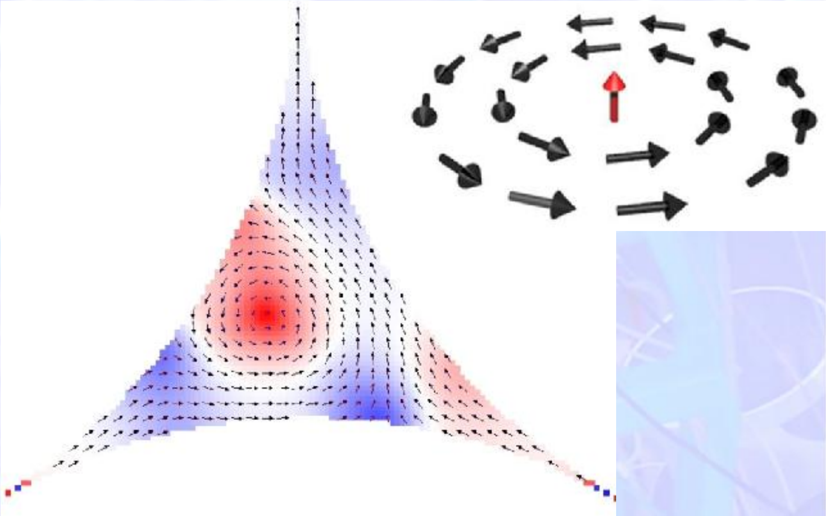
http://www.c4s.utcluj.ro/Spintronics.html

Magnetic film / dot with modulated perpendicular magnetic configuration



Monodomain/vortex in nanometric Co dot





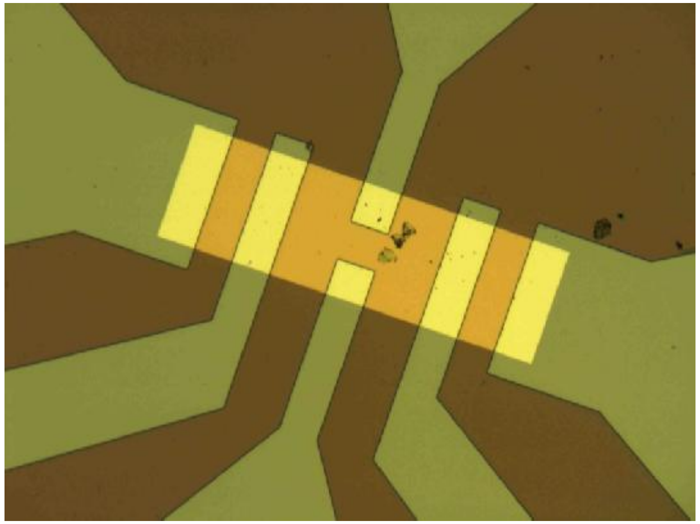
Object Oriented MicroMagnetic Framework (OOMMF)

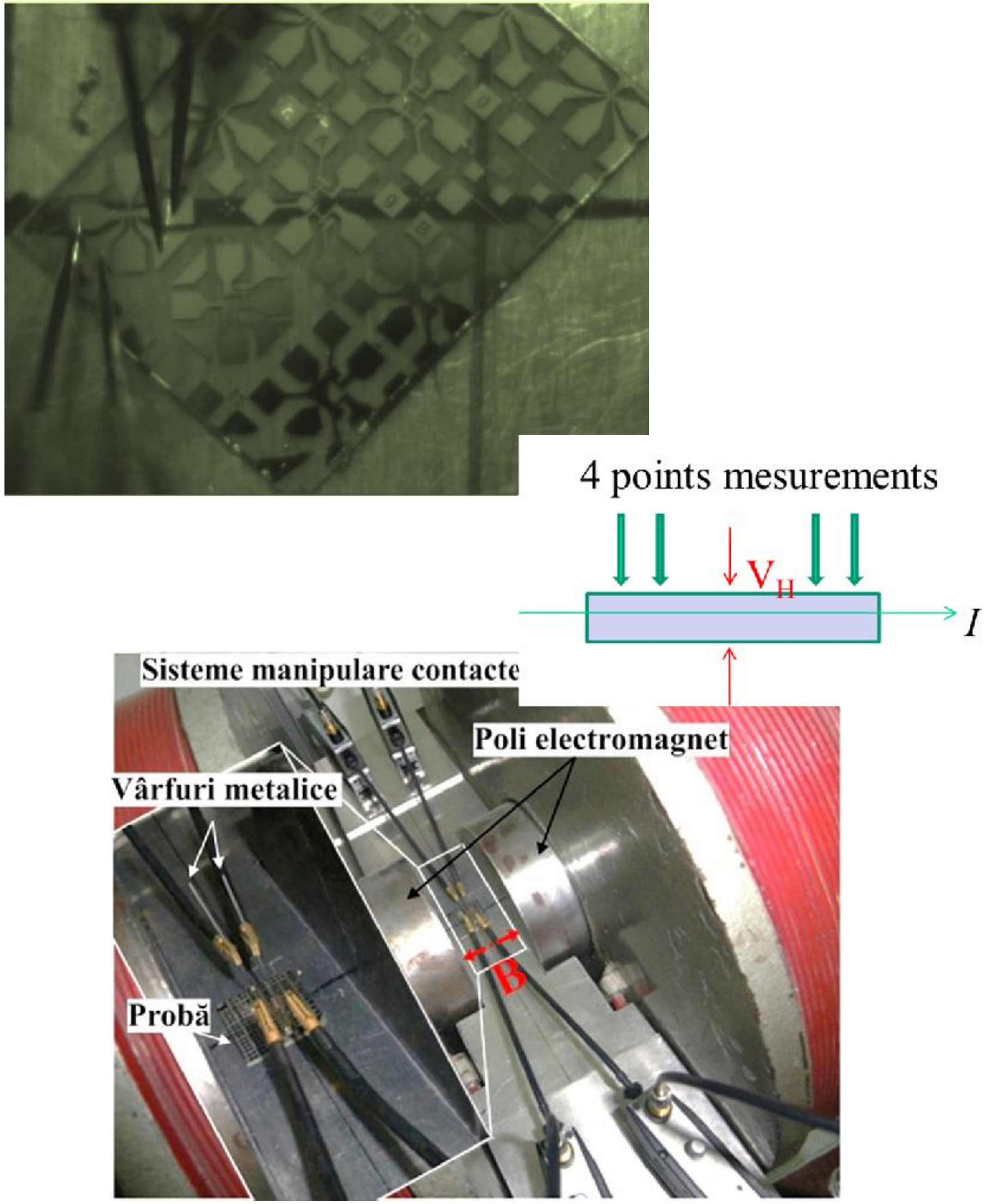
POS CCE Project 554 2010-2013

Coordinator: *Dr. Ing. Coriolan Tiusan:* coriolan.tiusan@phys.utcluj.ro

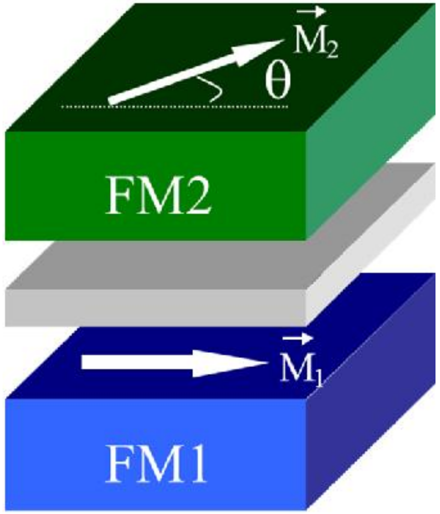
CNRS France/ TUCN Cluj-Napoca

SPINTRONIC DEVICES: Current-in-plane transport CIP (GMR, AMR, Hall ….)

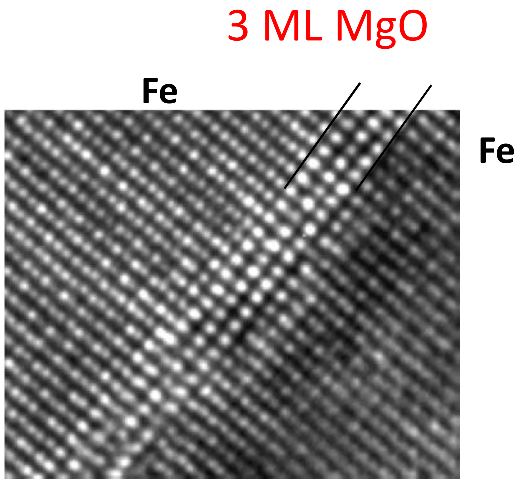


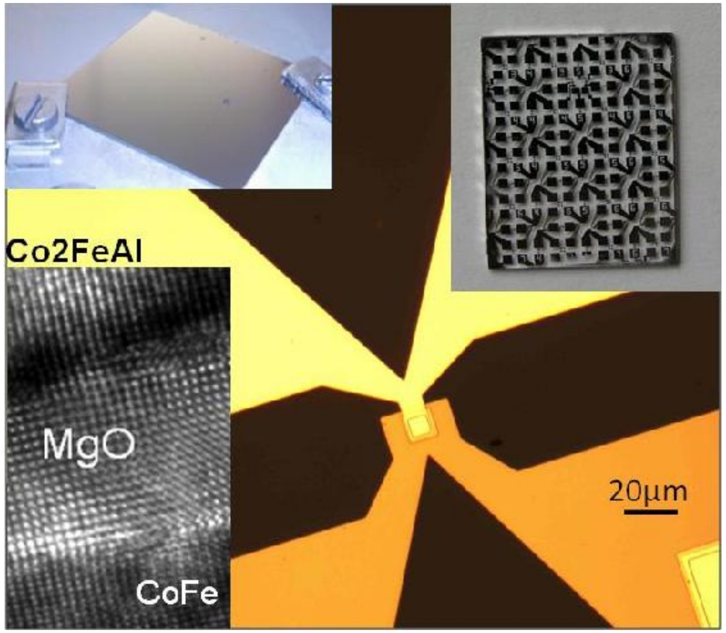


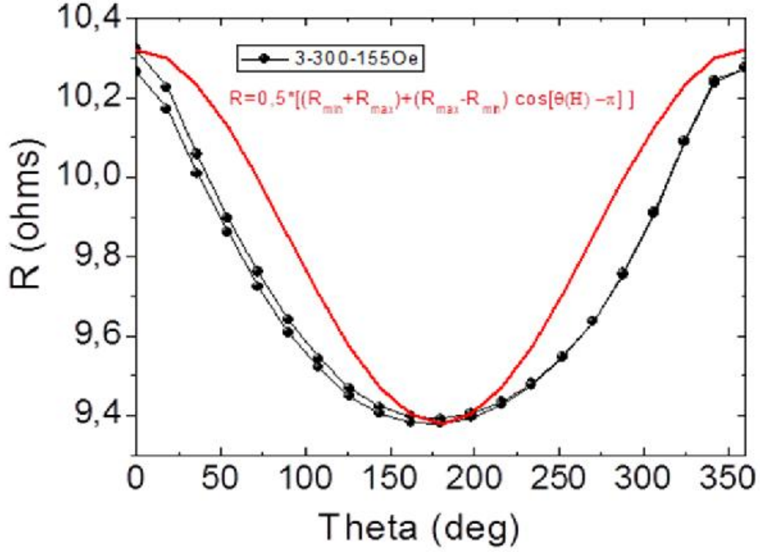
Magnetic tunnel junctions/ Data storage and sensors

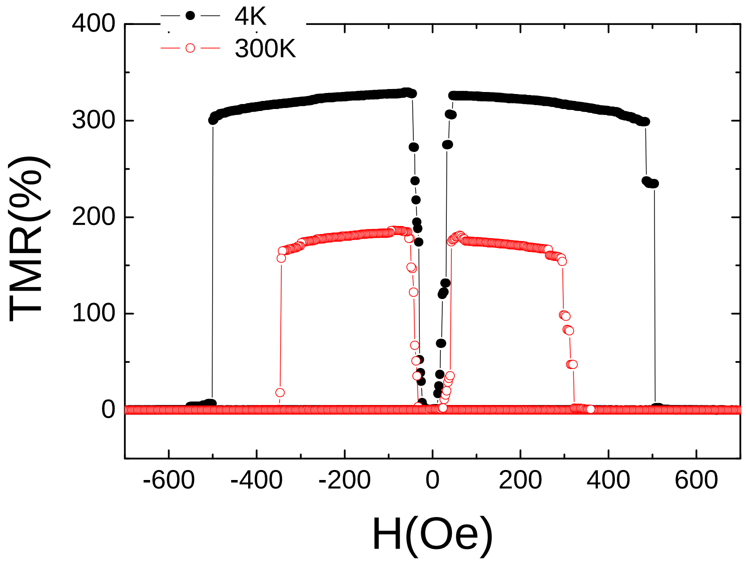


$$R = \frac{R_p + R_{ap}}{2} + \frac{R_p - R_{ap}}{2}\cos(\theta),$$
$$\theta = (\vec{M}_1, \vec{M}_2)$$





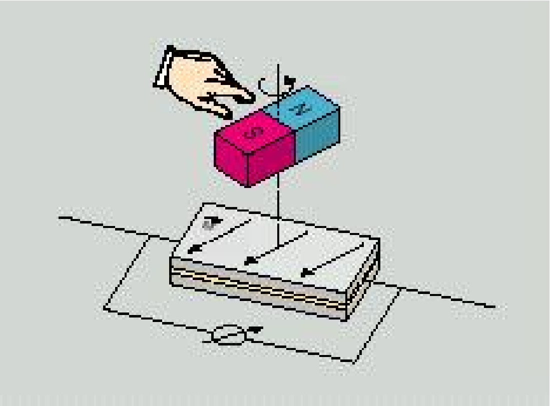


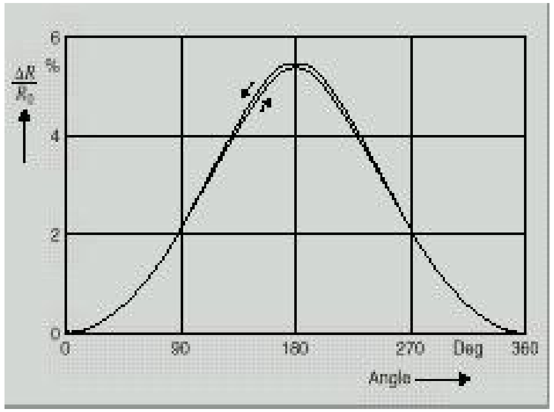


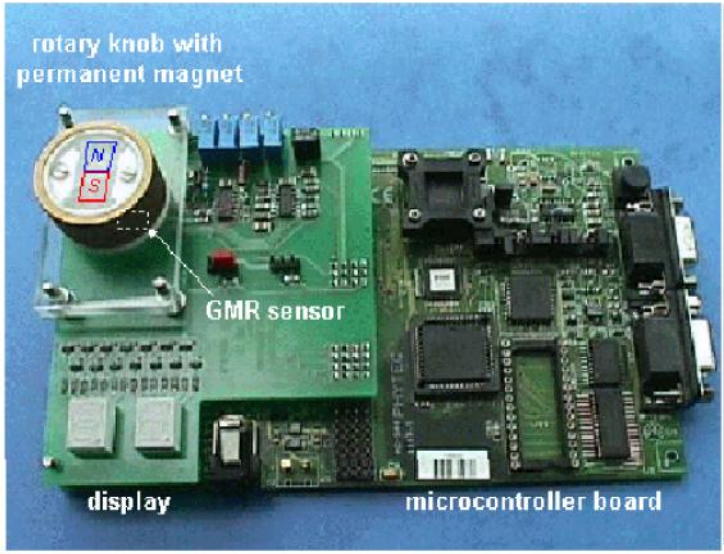
Application of spin-valves: GMR angular sensor

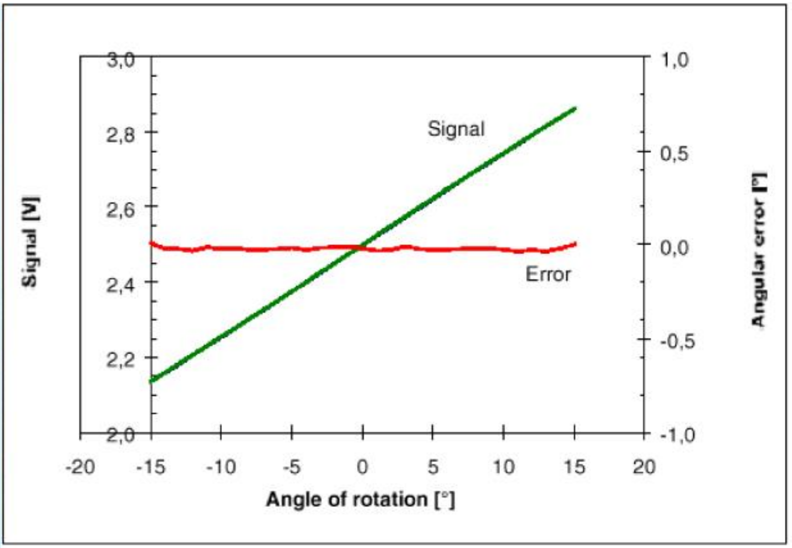
GMR angle detector: (spin valve)

H.A.M. van den Berg et al JMMM 165, 524, (1997)



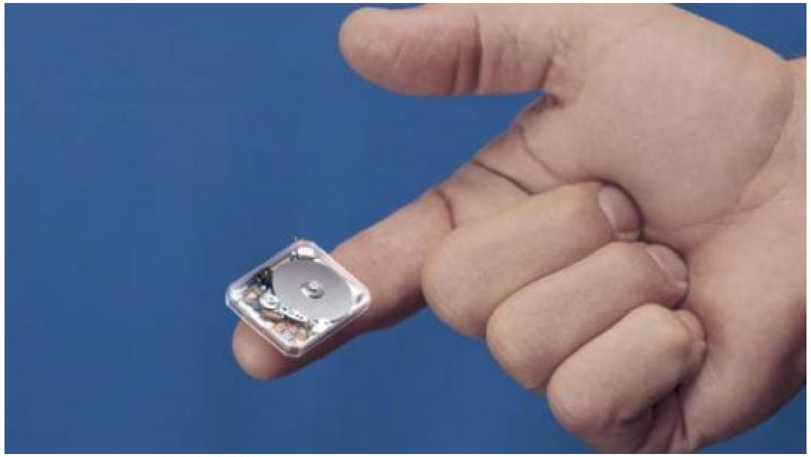




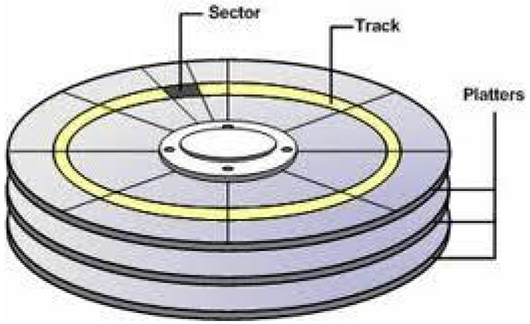


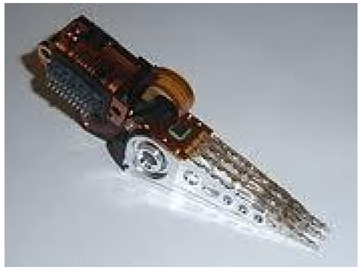
Siemens Aktiengesellschaft

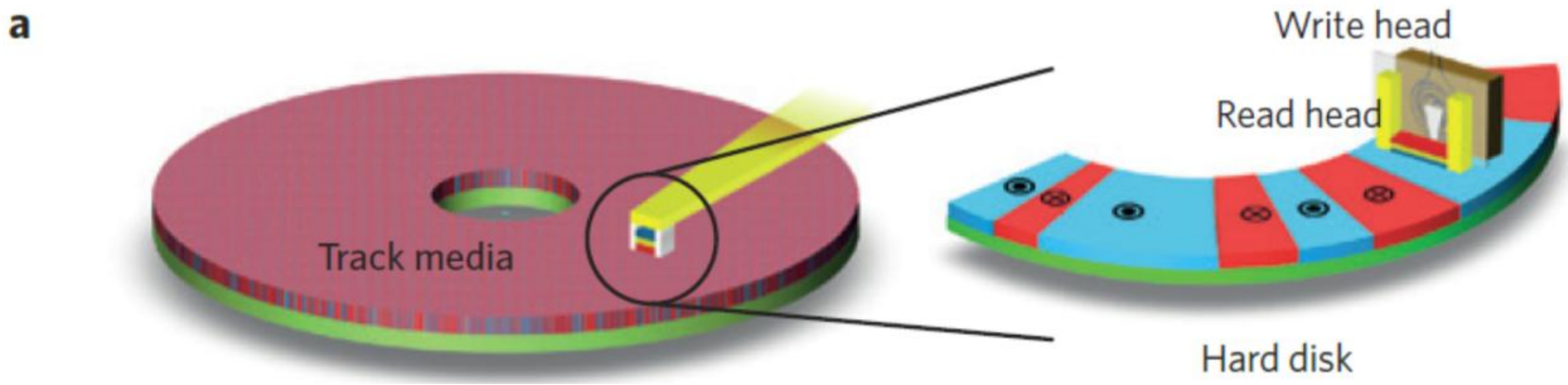
MTJS represent the read-head sensor in the high-density hard disk drives



4.0GB from Toshiba's
0.85-Inch Hard Disk Drive

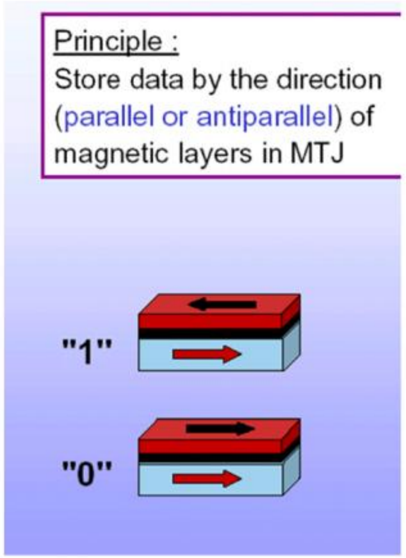




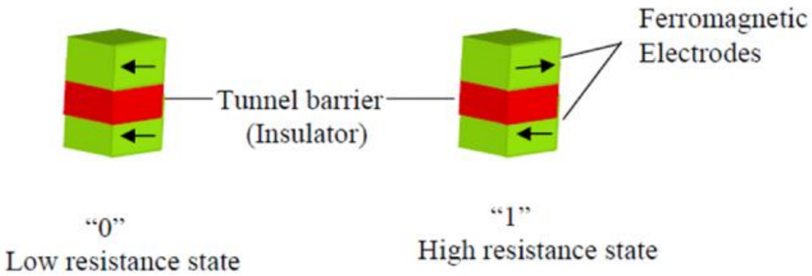


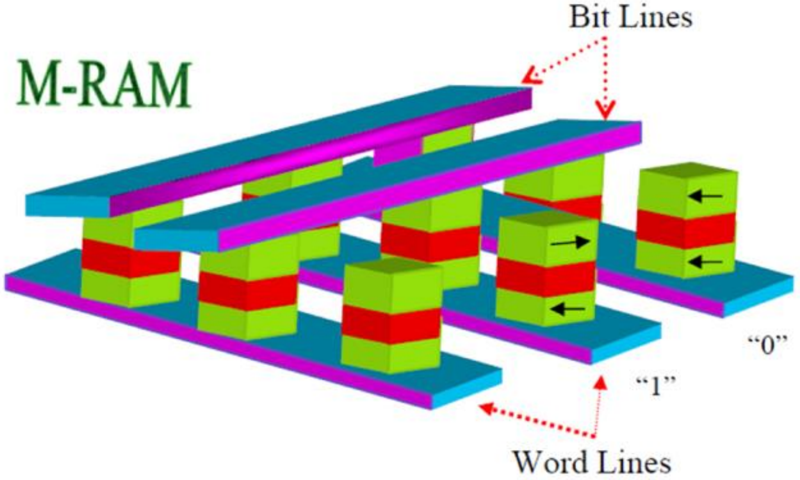
From S.S. Parkin, S-H. Yang, *Nature Nanotechnology,* **10**,195–198, (2015)

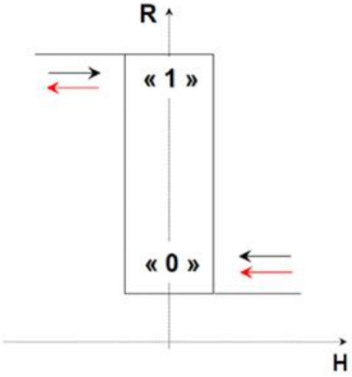
Magnetic **Random Access Memories (MRAM)**



Principle :
Store data by the direction (parallel or antiparallel) of magnetic layers in MTJ







The advantages of MRAMs:

non volatile
low power consumtion (no mechanical pieces), compared to hard-disk
stable against radiation
high speed (competitive with SRAM) and large density (competitive with DRAM)

Or 3D next generation of memories (RACE-TRACKS)…

From S.S. Parkin, S-H. Yang, *Nature Nanotechnology,* **10**,195–198, (2015)