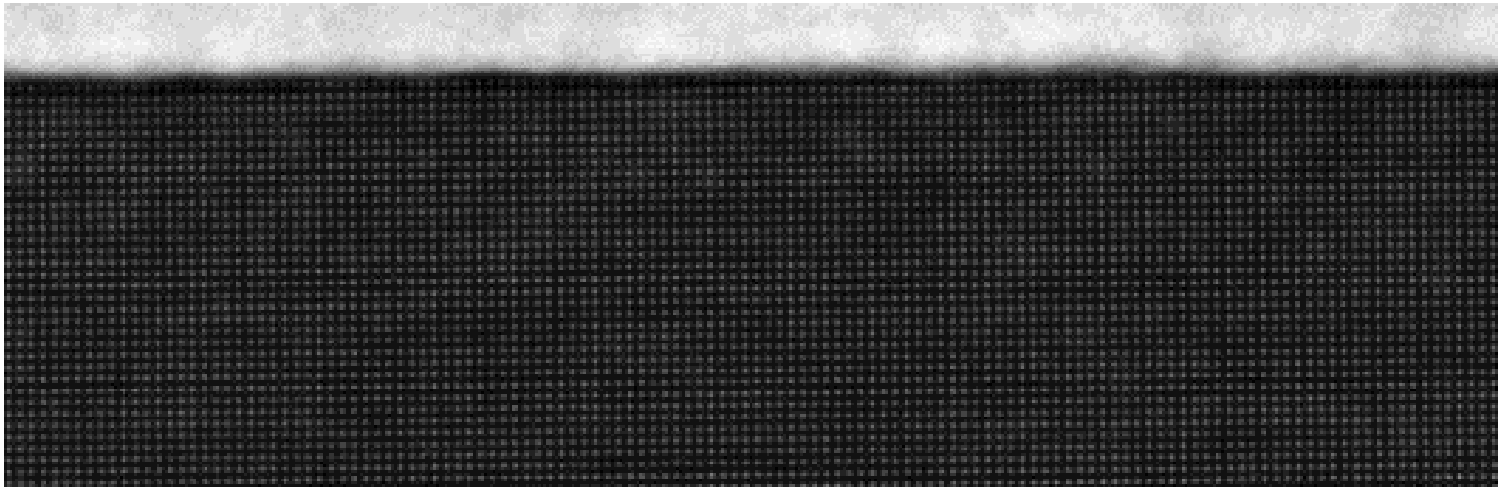
Fisica del Estado Solido

Sólidos con simetría de traslación



FABRICACION DE MATERIALES/ MUESTRAS

Métodos químicos y fisicos

nano (top-down) desde la fisica

Alto vacio

Ultra alto vacio

Micro y nanofabricacion

CARACTERIZACION

Enfoque : local / medio

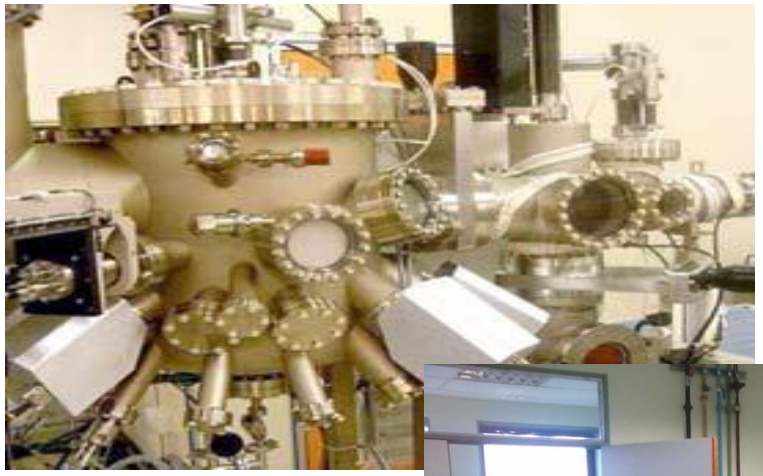
Facilidades multiusuarios luz sinchrotron

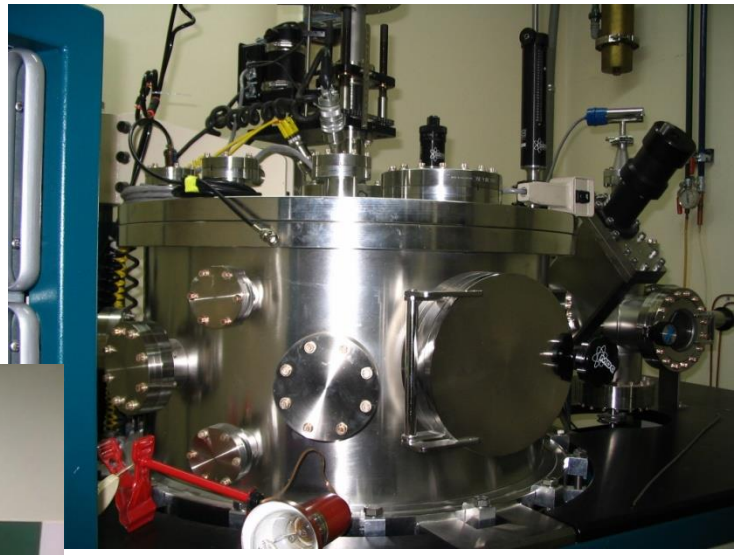
neutrones

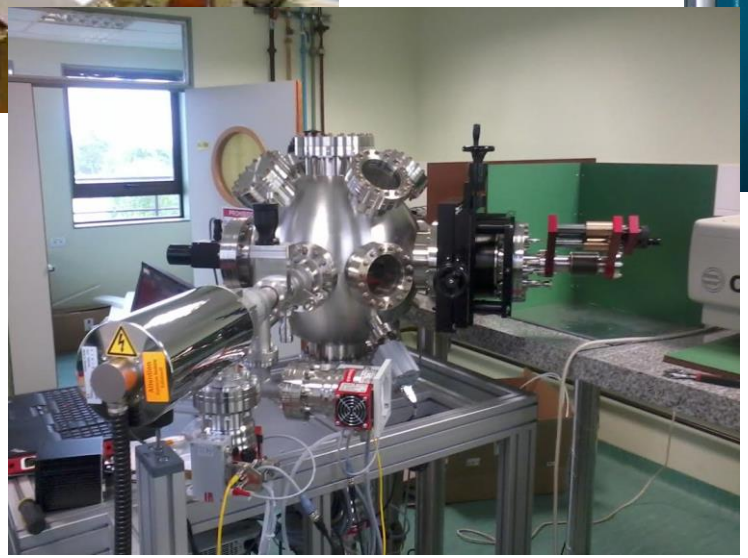
Metodos quimicos: polvos, ceramicos, particulas, alambres y tubos

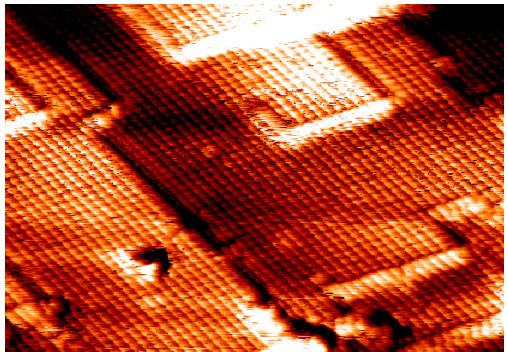
Metodos fisicos: peliculas delgadas y multicapas

HV Ablasion Laser (2-10nm/min)
Sputtering (1-10nm/min)
UHV Molecular Beam Epitaxy (MBE) (0.05 – 1nm/min)







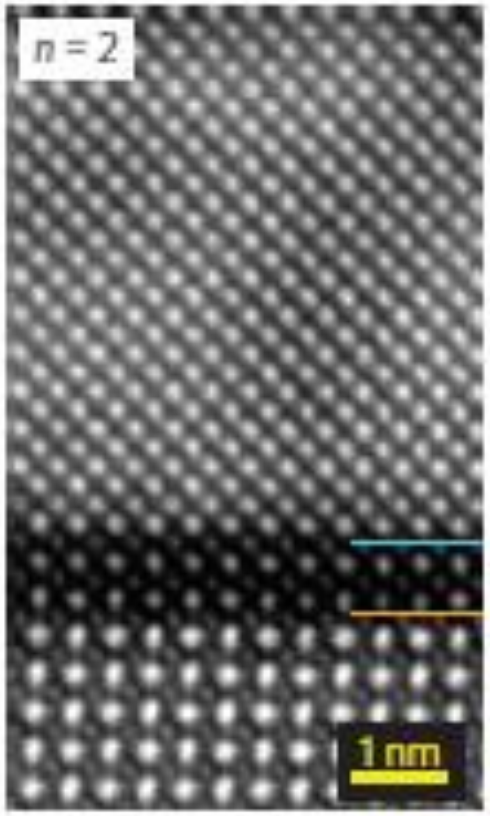


“DISEÑO DE MATERIALES A MEDIDA”

+ Apilando materiales de distintas caracteristicas

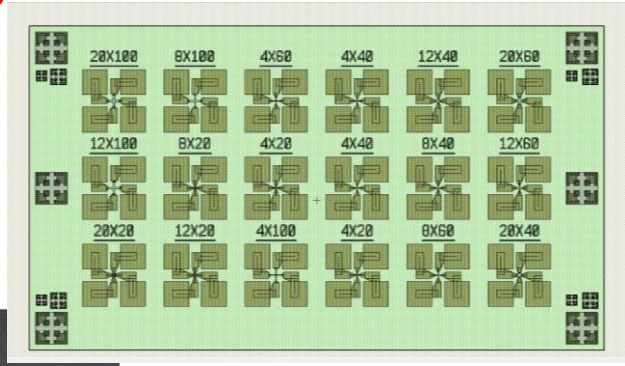
+ Acoplando interfaces terminadas de manera controlada

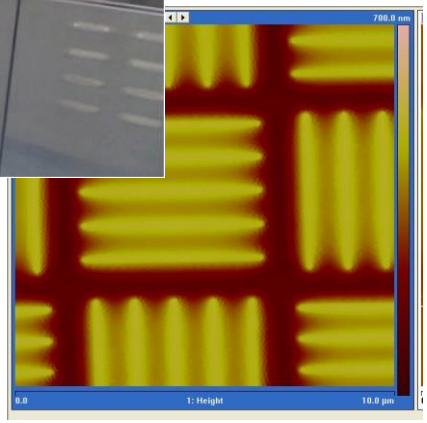
+ Modificando interfaces con sustratos/ buffers: contenido O, distorsion de red, tensiones….

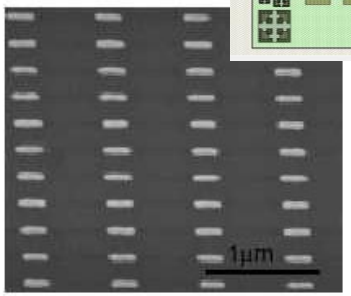


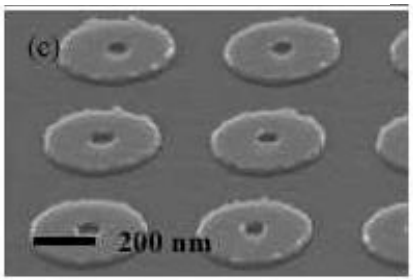
μ y nanoESTRUCTURACION de MUESTRAS Y DISPOSITIVOS

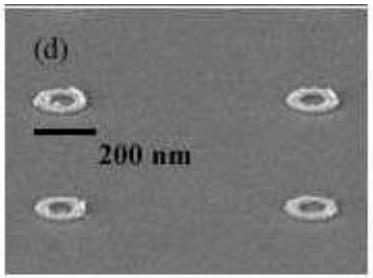
LITOGRAFIA + EROSION
FOCUSED ION BEAM (FIB), ETC





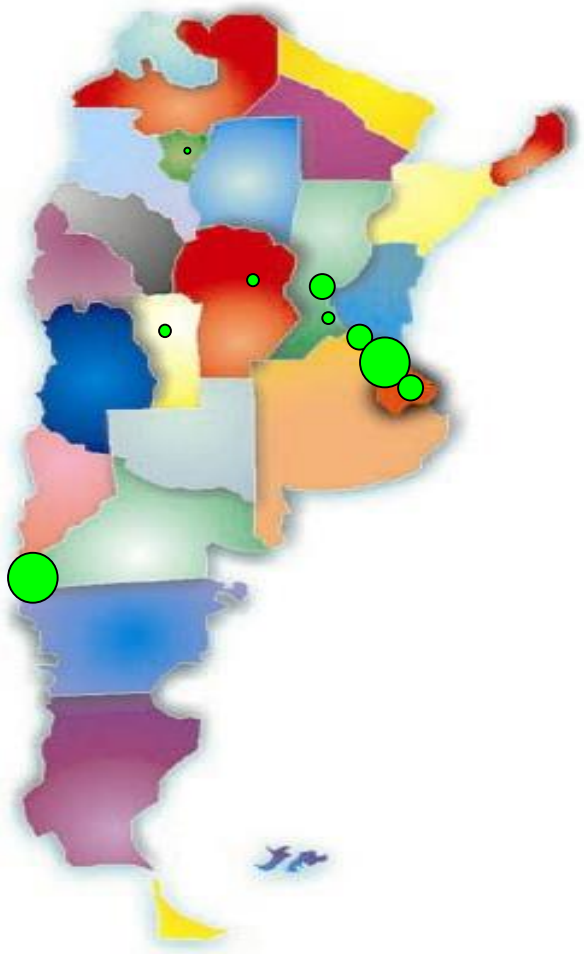






Litografia optica y electronica
Ataques quimicos, ionicos, ionicos reactivos

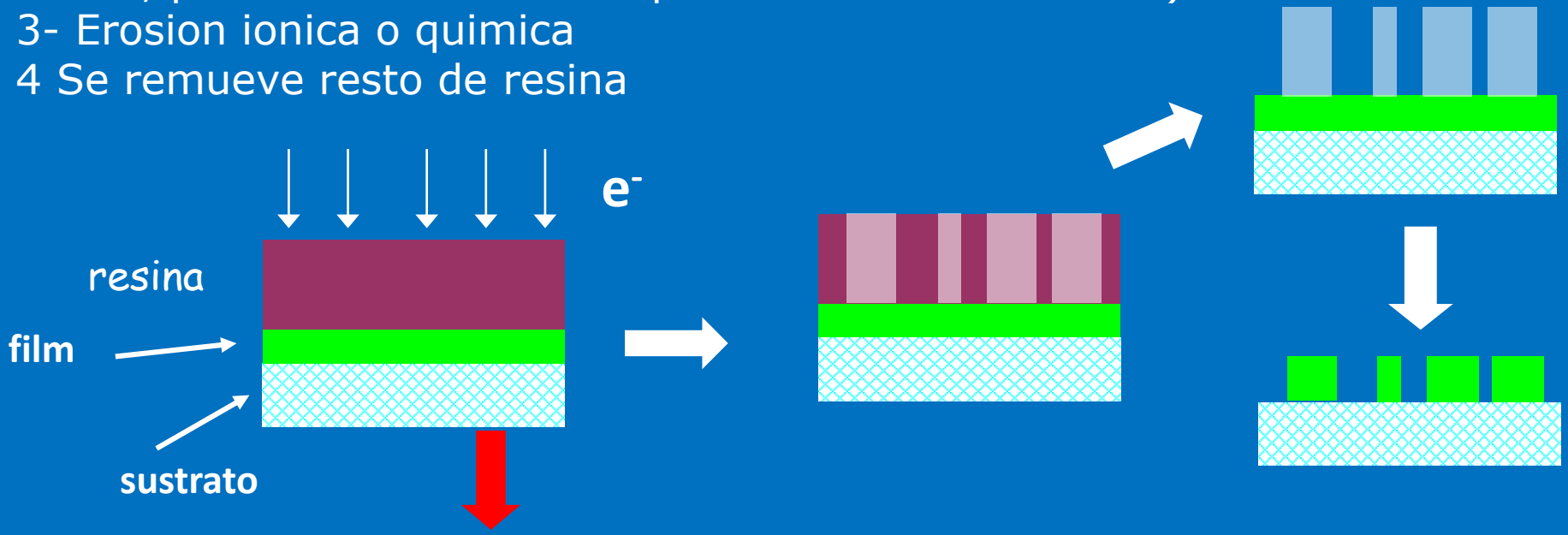
Facilidades de Nanofabricacion en Argentina



- Litografia electronica
- Litografia Optica (UV)
- Deposito de metales y dielectricos
- Comido quimico - fisico
- Nanofib
- Tratamientos termicos
- Microscopia electronica de barrido
- Caracterizacion
- Montaje Chips : bonding

Grabado de muestras por tecnicas litograficas

1- Se transfiere un patron definido, a traves de una mascara sobre una resina foto sensible (resol. micron). Caso electrones no hace falta mascara (resol. decenas nm).
2- Revela resina y se remueve resina no Iluminada (segun el tipo de resina, podria ser al reves => parte la resina iluminada)
3- Erosion ionica o quimica
4 Se remueve resto de resina



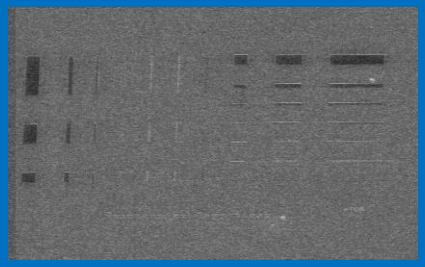
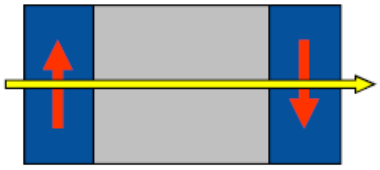
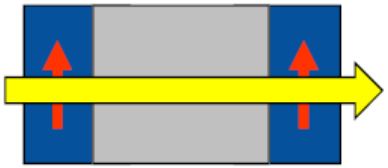
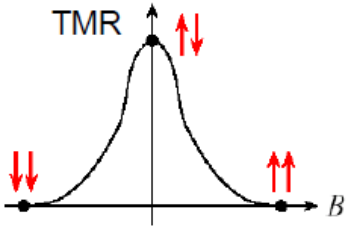


Imagen SEM de la muestra luego de ser litografiada

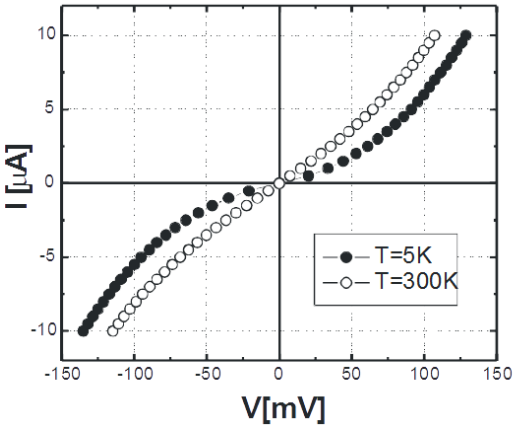
DISPOSITIVOS: EJ. JUNTURAS TÚNEL



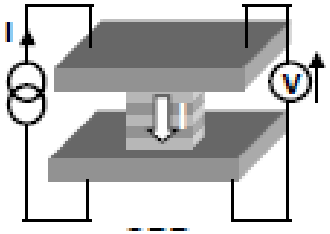


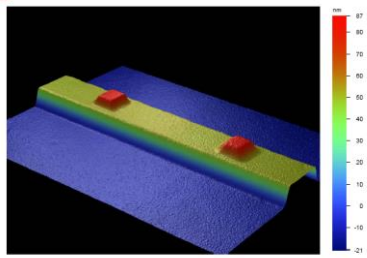


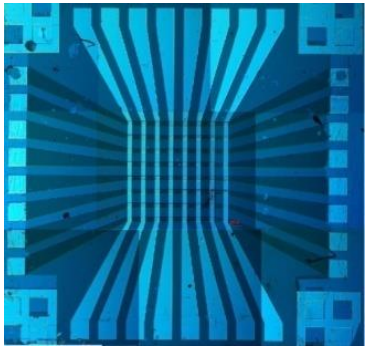
$$TMR = (g^{P} - g^{AP}) / (g^{P} + g^{AP})$$



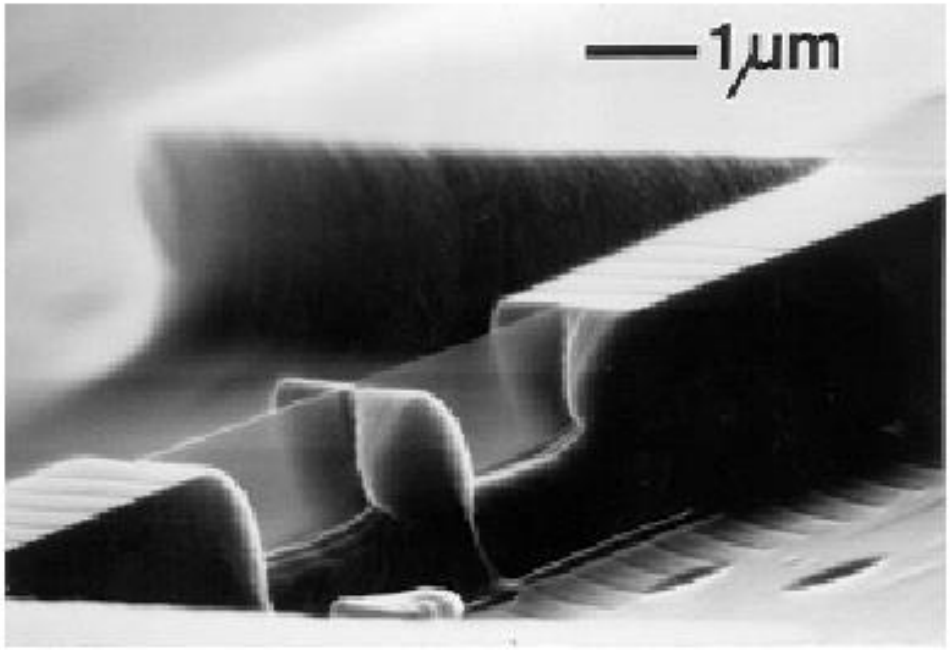
M. Julliere, Phys. Lett. **54A**, 225 (1975)
J. S. Moodera et al., Phys. Rev. Lett. **74**, 3273 (1995)



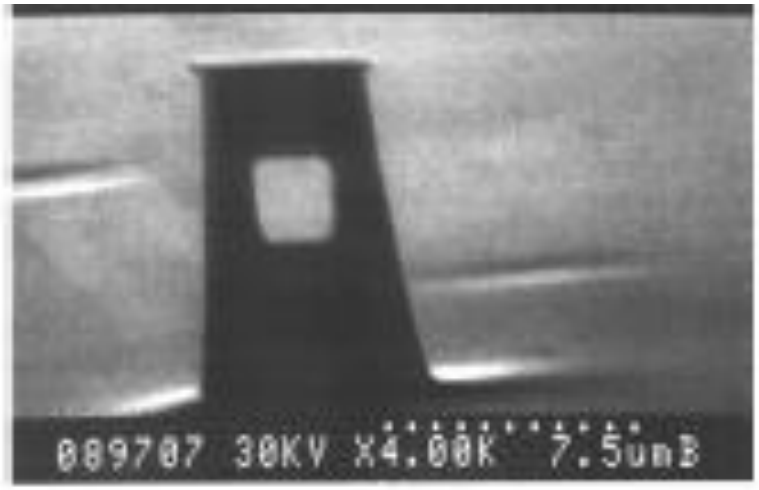




Focused Ion Beam (FIB). Aplicaciones



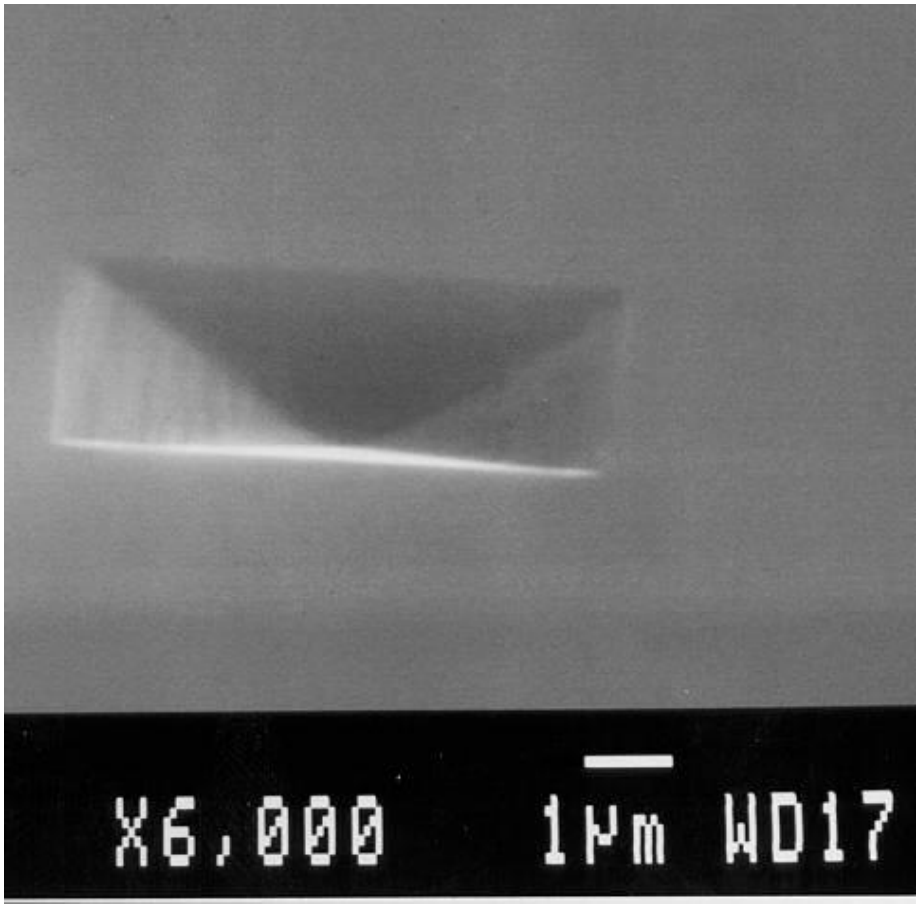
Specimen preparation for TEM microscopy



Drilling a hole in a pillar

(ex L2M): LPN

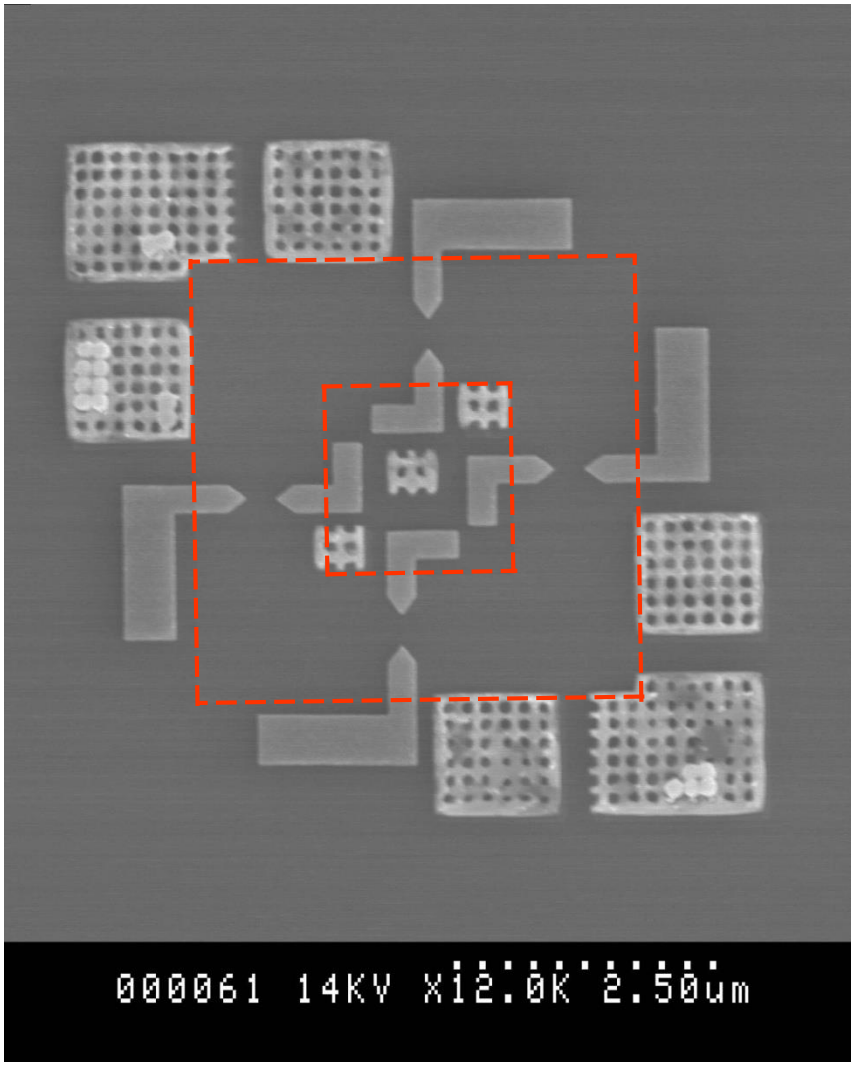
Grabado 3D

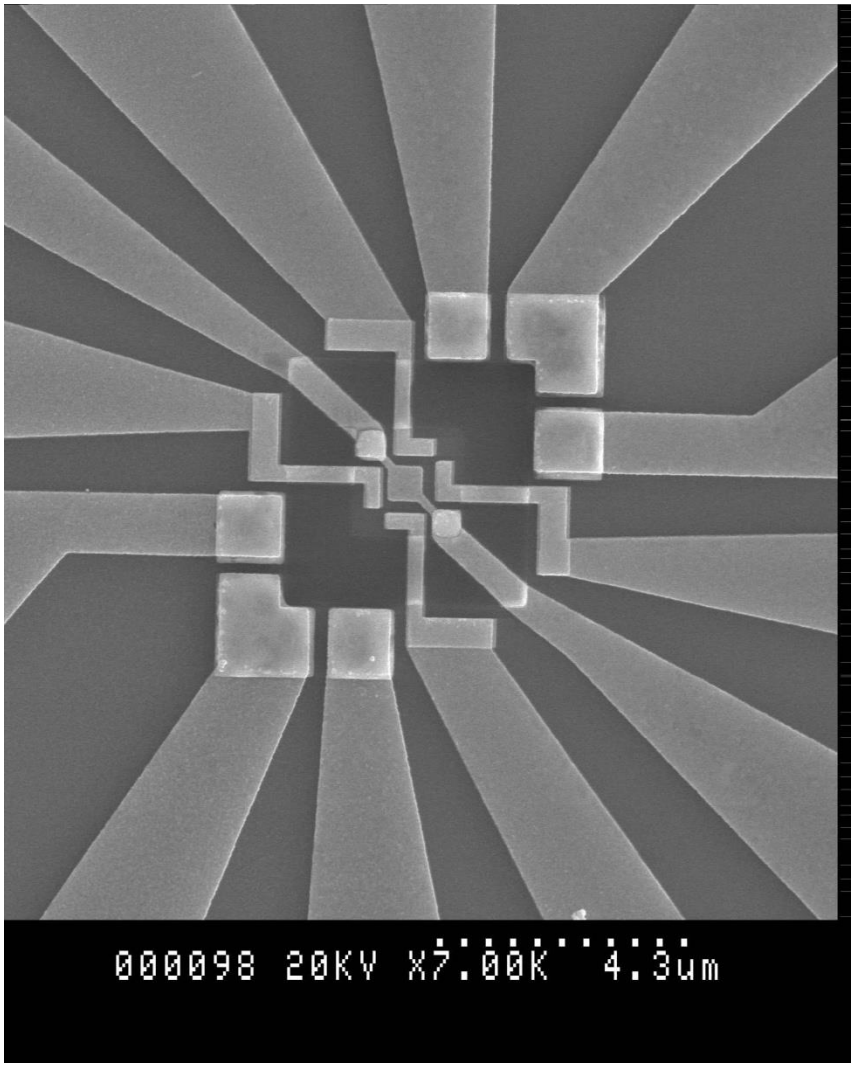


(ex L2M): LPN

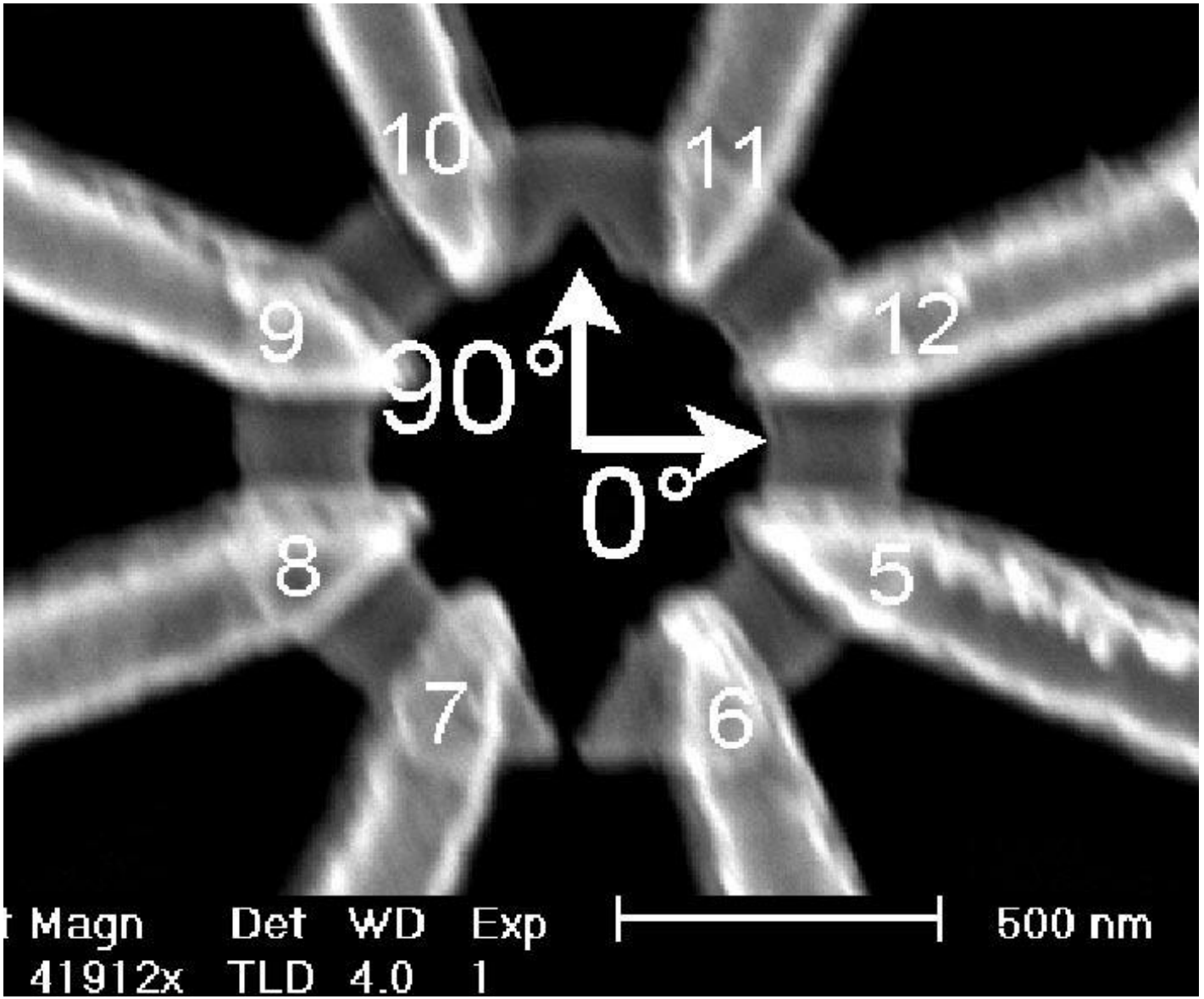
Interferometro HBT

Coherence of a quantum state



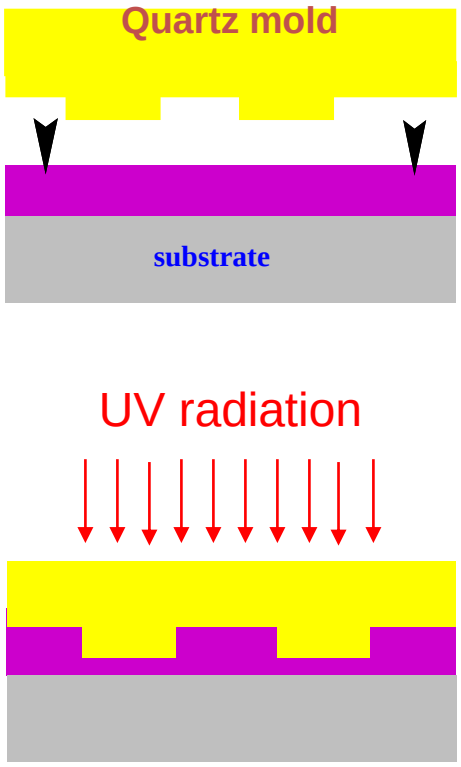


LPN, CEA Saclay



LPN
Konstanz Un.
Cambridge Un.

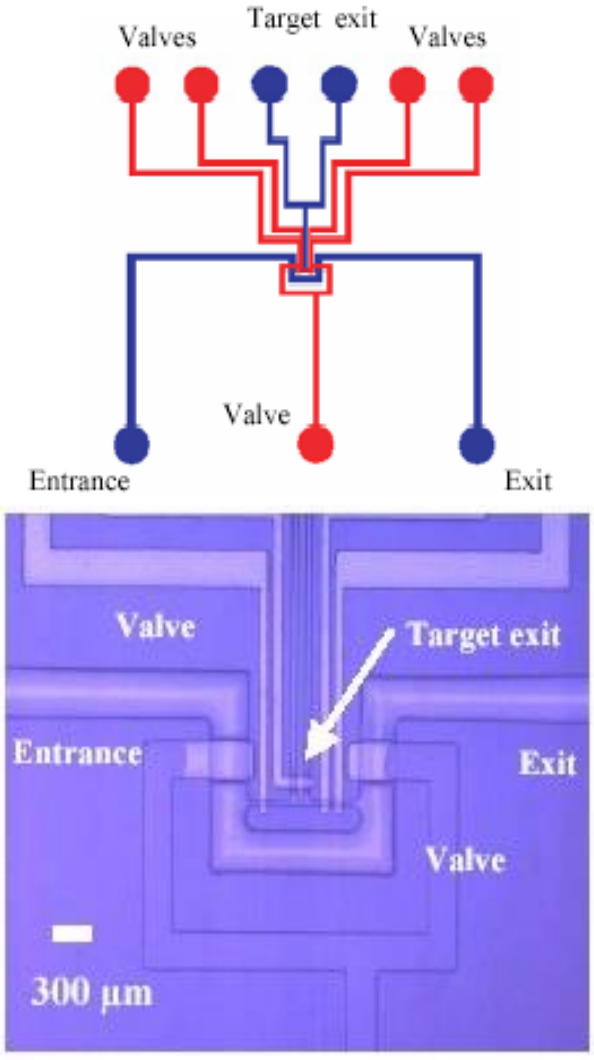
Mezcla de dos liquidos

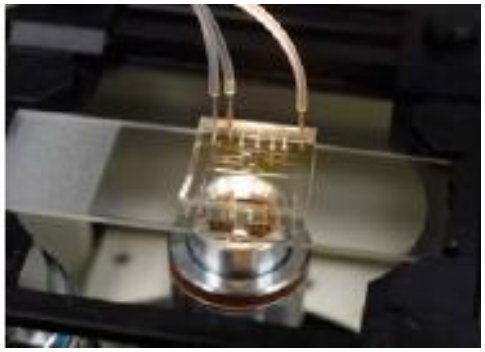


UV hardening of the resist

LPN

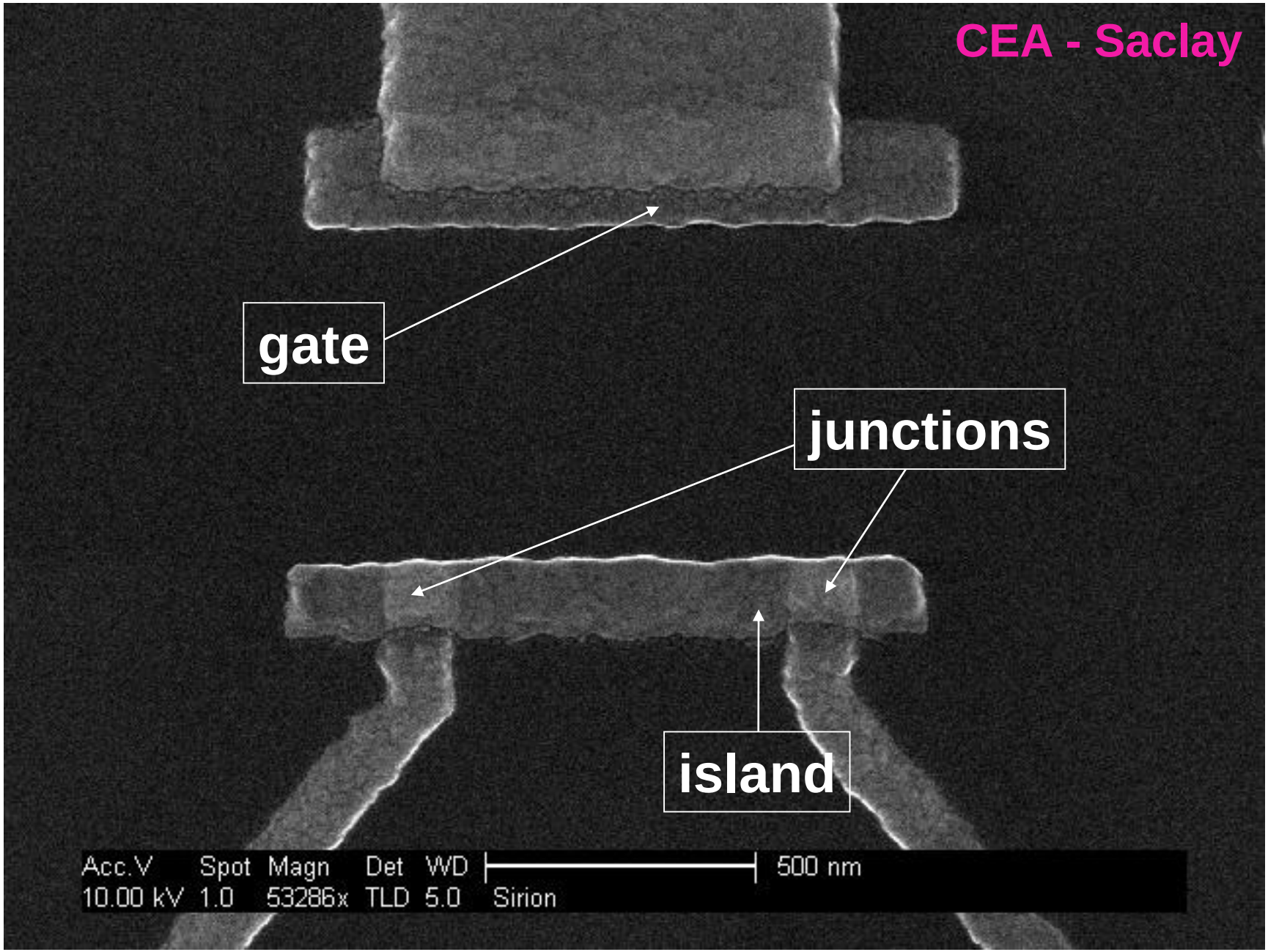
Clasificador de celulas de mamiferos

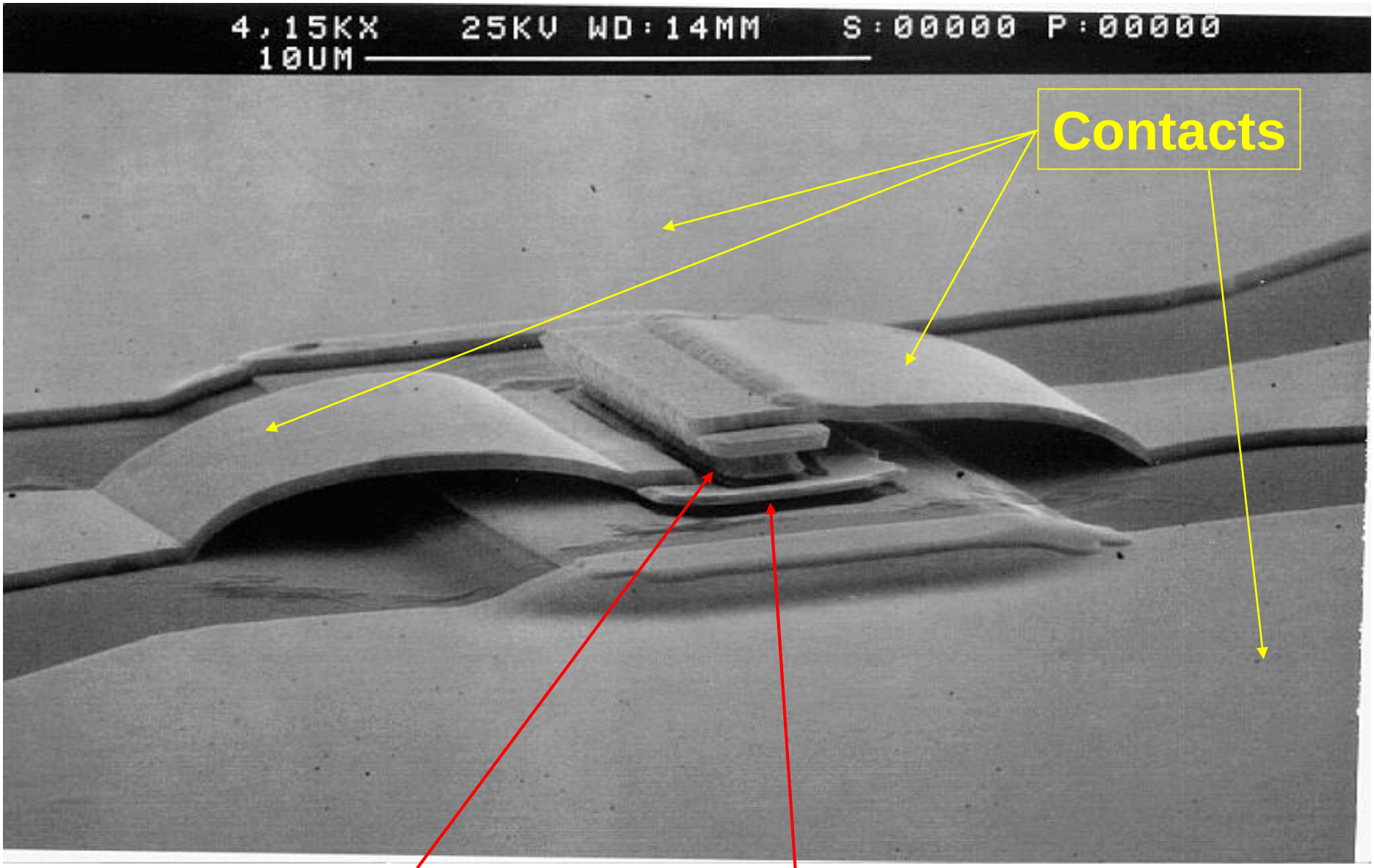




V. Studer , R. Jameson, E. Pellereau, A. Pépin et Y. Chen (MNE 2003)

LPN


CEA - Saclay
gate
junctions
island
Acc.V Spot Magn Det WD
10.00 kV 1.0 53286x TLD 5.0 Sirion
500 nm



The chemically controlled over-etch permits to avoid short-cuts between contacts

LPN

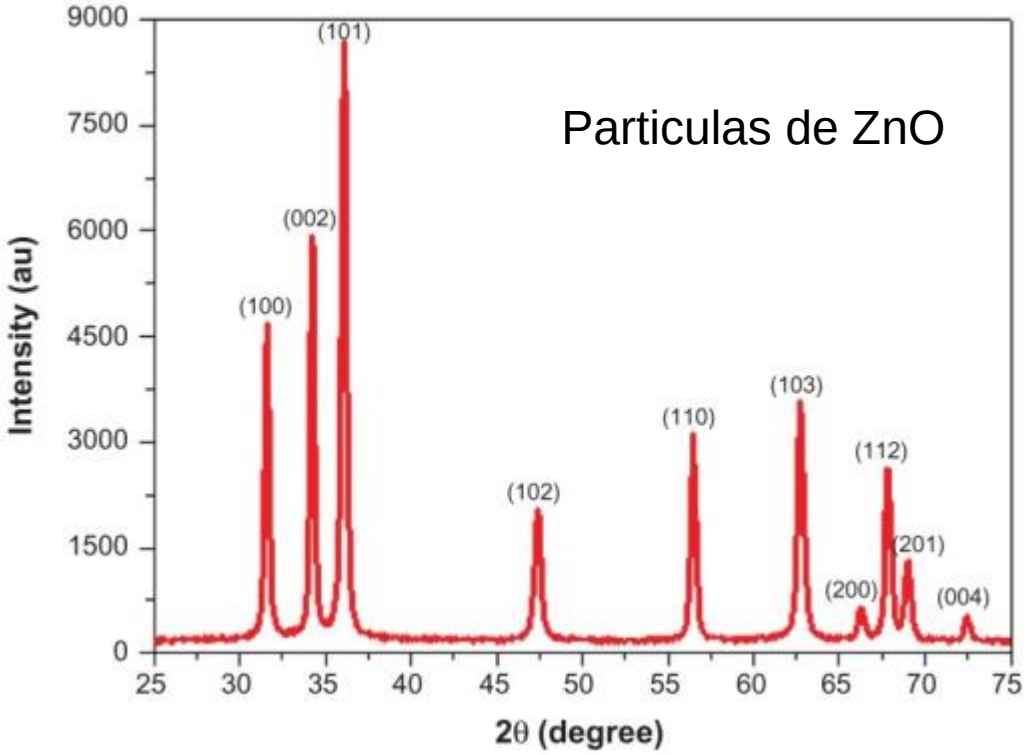
TECNICAS EXPERIMENTALES PARA EL ESTUDIO DE MATERIA CONDENSADA

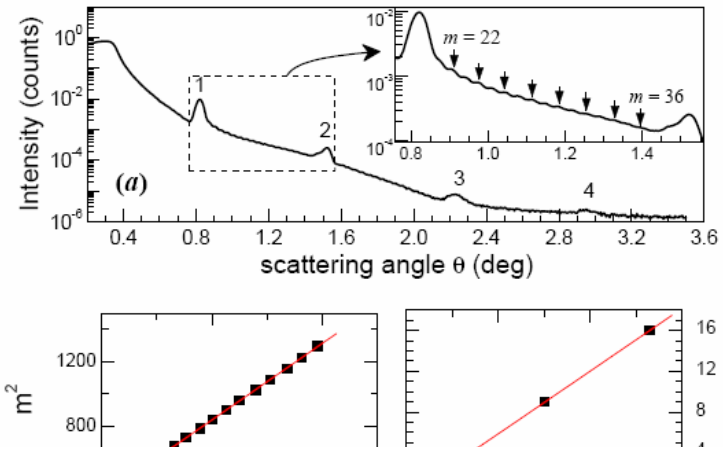
- Estructura cristalina
- Fonones
- Electrones => espectroscopia de superficies, transporte electrico
- Semiconductores
- Transporte electronico
- Magnetismo

ESTRUCTURA CRISTALINA

Difracción de rayos X

Estructura en polvos,
Textura en films
Parametros de red





Reflectividad de rayos X
$(La_{0.75}Sr_{0.25}MnO_3/ LaNiO_3)x20$

J.C. Rojas Sanchez et al, Phys. Rev. B 85 , 094427 (2012)

EXAFS Y XANES

Experimento de absorción de rayos X.

Sensibilidad elemental

Permite determinar

- **Estado de oxidacion**
  - **Numero de coordinacion**
- **Desorden respecto a los atomos vecinos**
- **Distancia a vecinos**

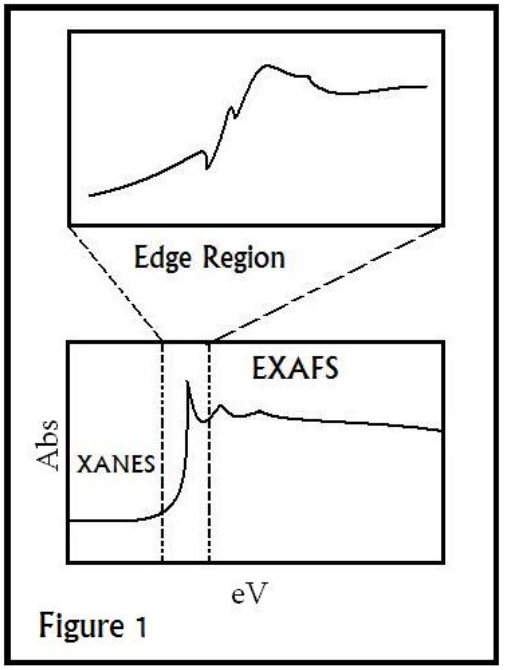
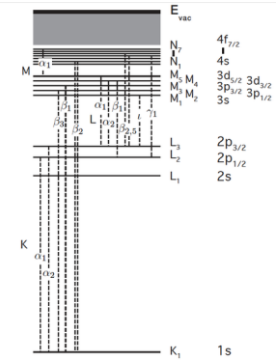


Figure 1



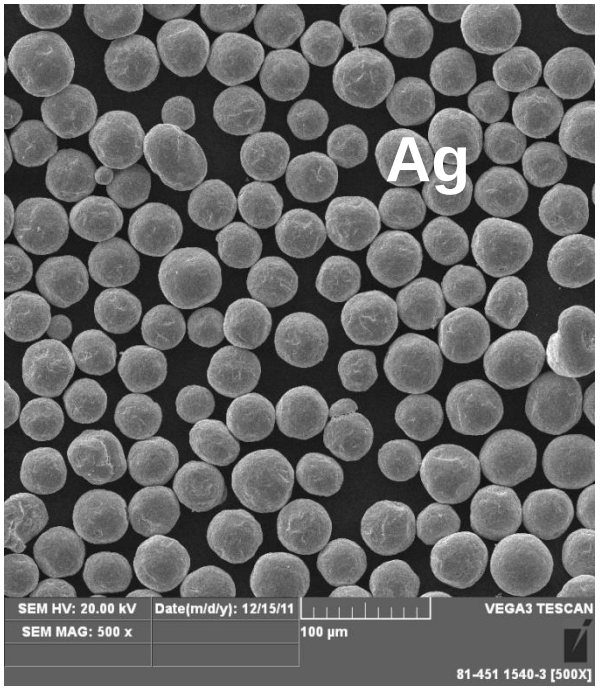
ANALIZO borde de absorción de un elemento dado

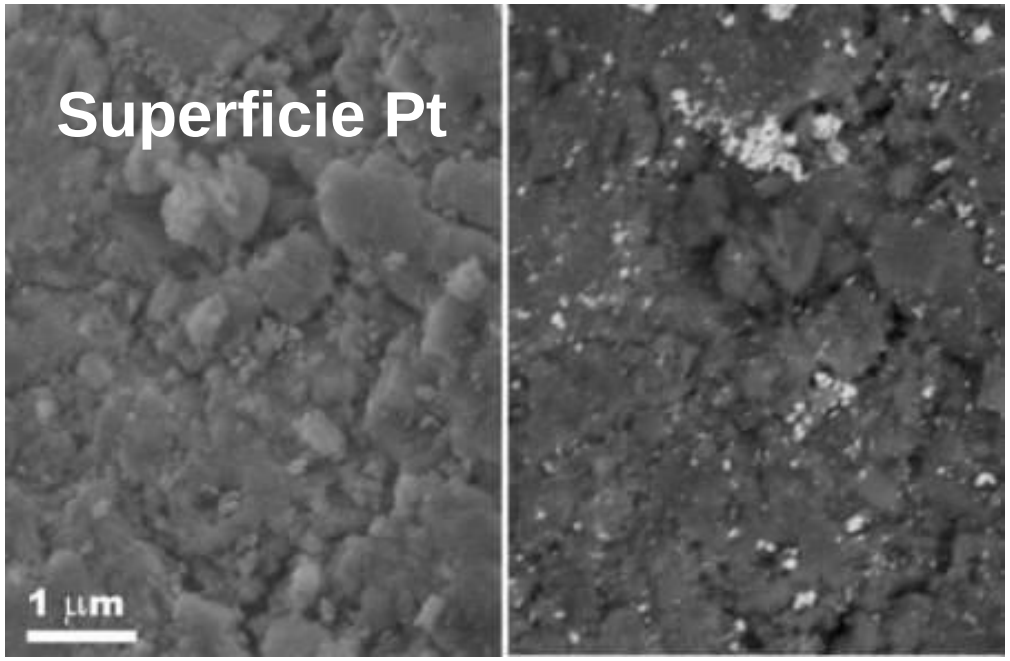
MICROSCOPIAS

- SEM
- TEM
- Sonda local (AFM, STM, MFM, PFM….)

SEM

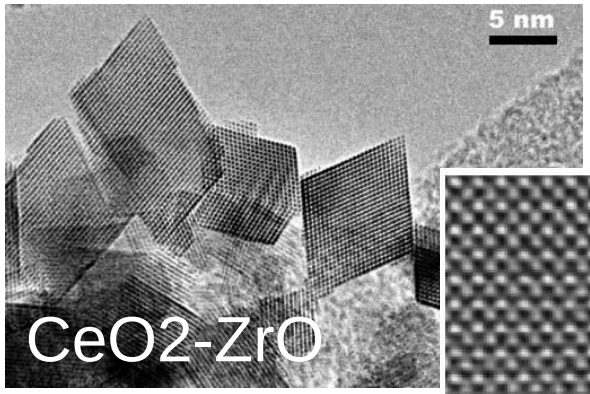

NORAN

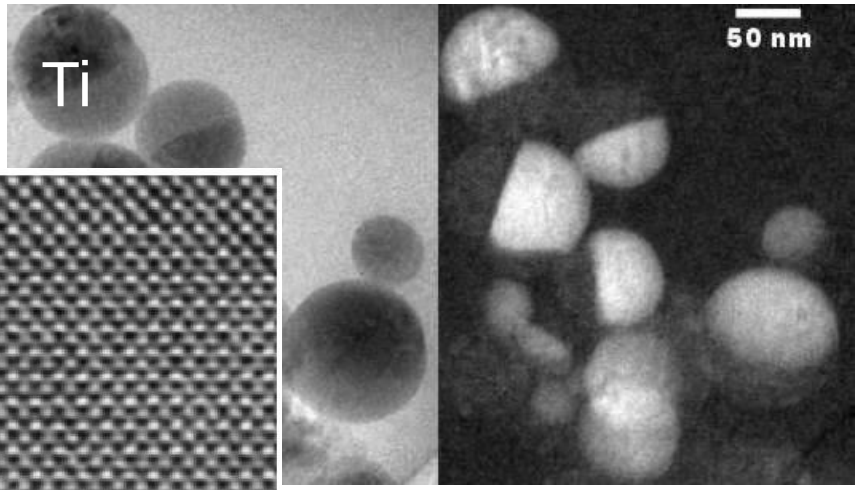

Ag
SEM HV: 20.00 kV
Date(m/d/y): 12/15/11
VEGA3 TESCAN
SEM MAG: 500 x
100 µm
81-451 1540-3 [500X]

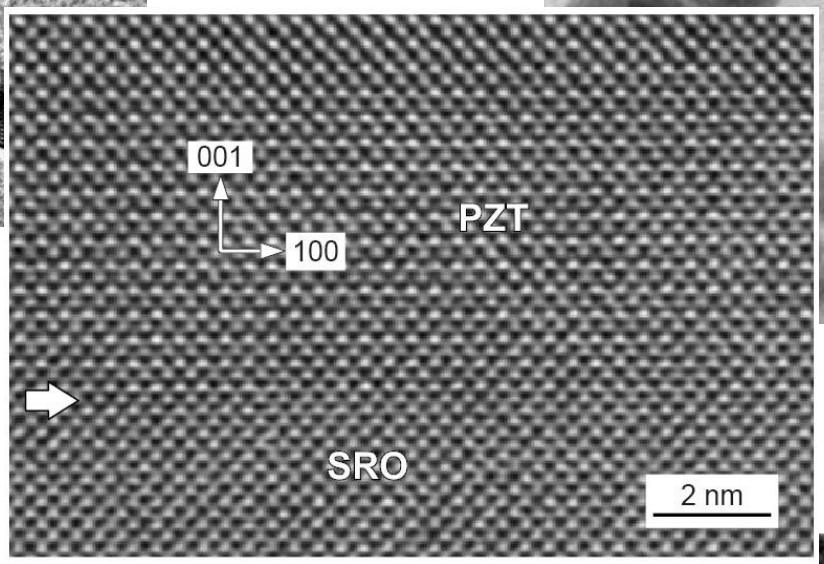

Superficie Pt
1 µm

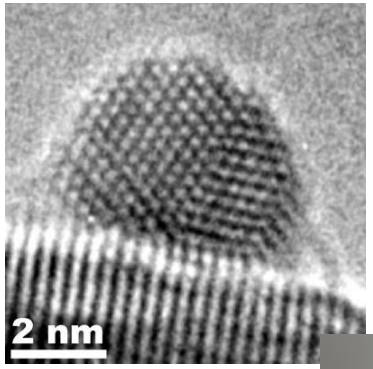

Asbesto

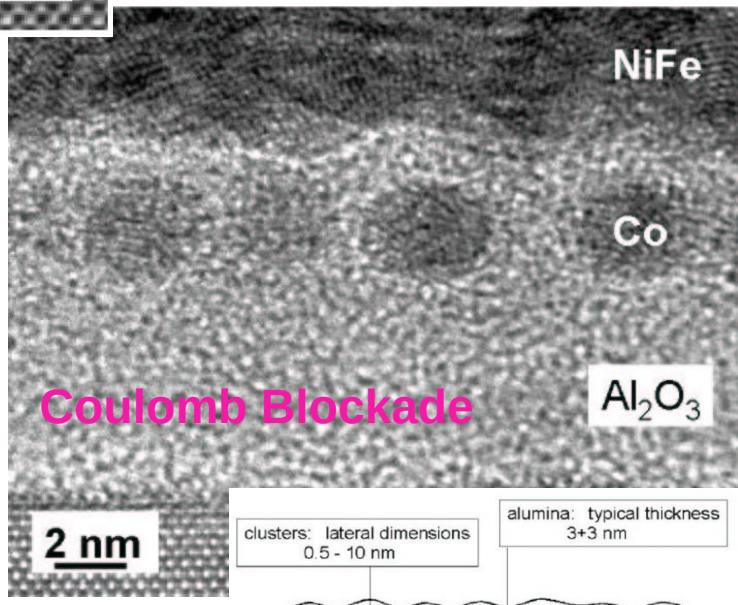
HR-TEM

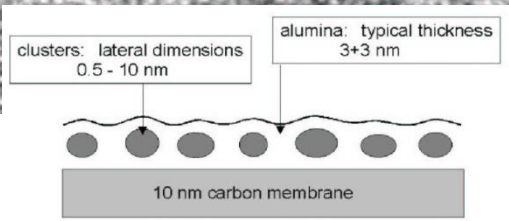

5 nm
CeO2-ZrO


Ti
50 nm

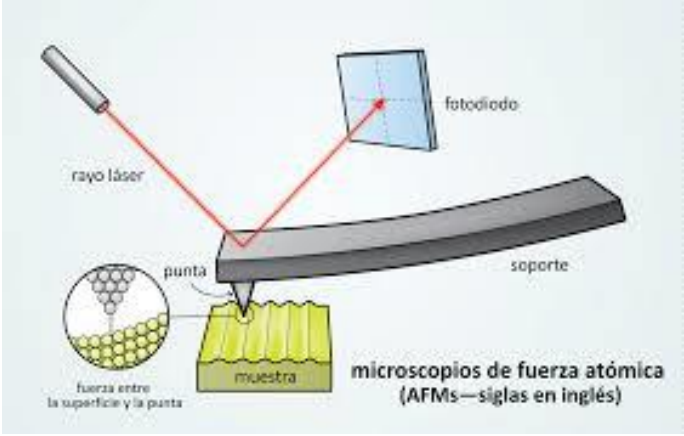

001
100
PZT
SRO
2 nm

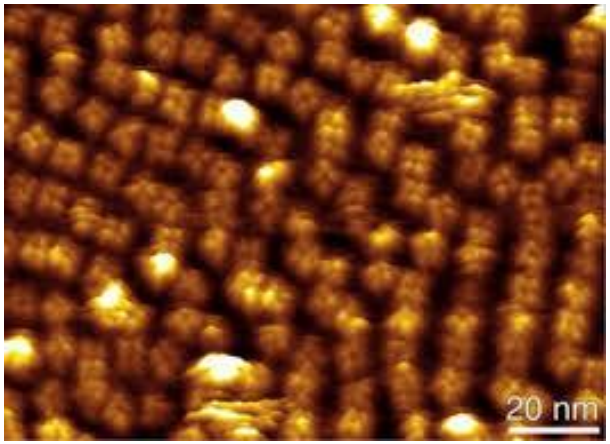

2 nm


NiFe
Co
Coulomb Blockade
Al2O3
2 nm

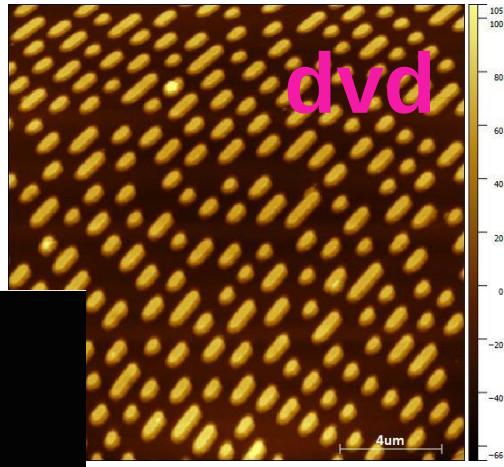

clusters: lateral dimensions
0.5 - 10 nm
alumina: typical thickness
3+3 nm
10 nm carbon membrane

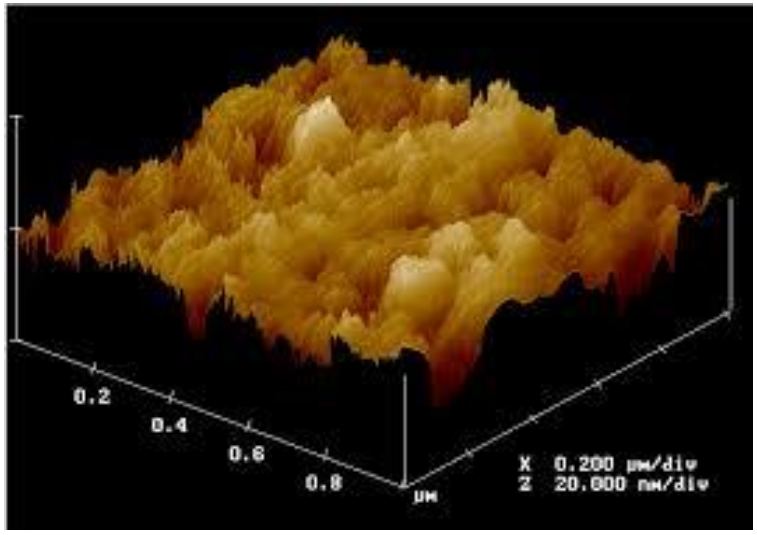
MICROSCOPIAS DE SONDA LOCAL

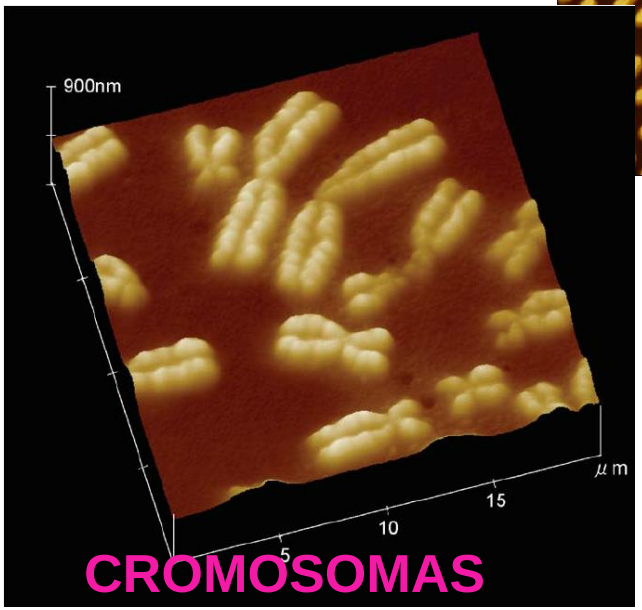




AFM

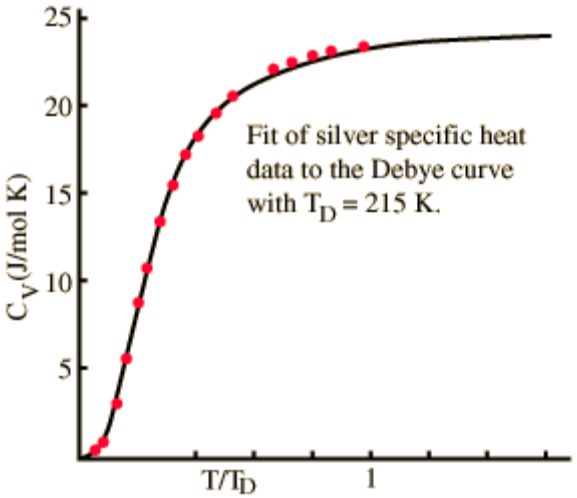


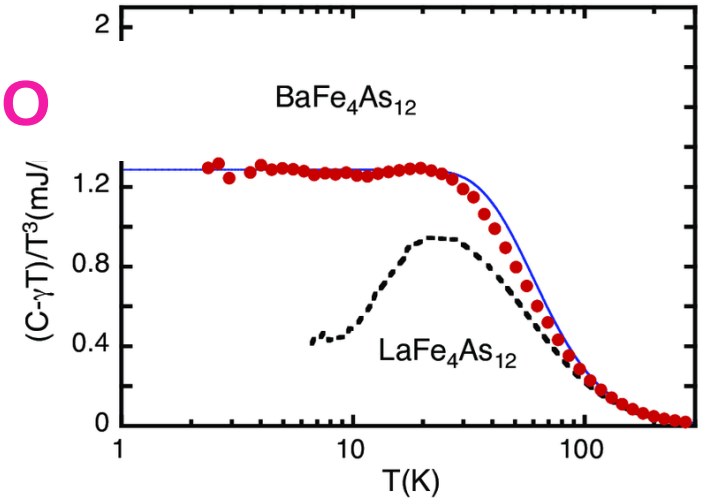




FONONES

CALOR ESPECIFICO





RELACION de DISPERSION FONONES

NEUTRONES
Inelastic X-RAY SCATTERING

Optica

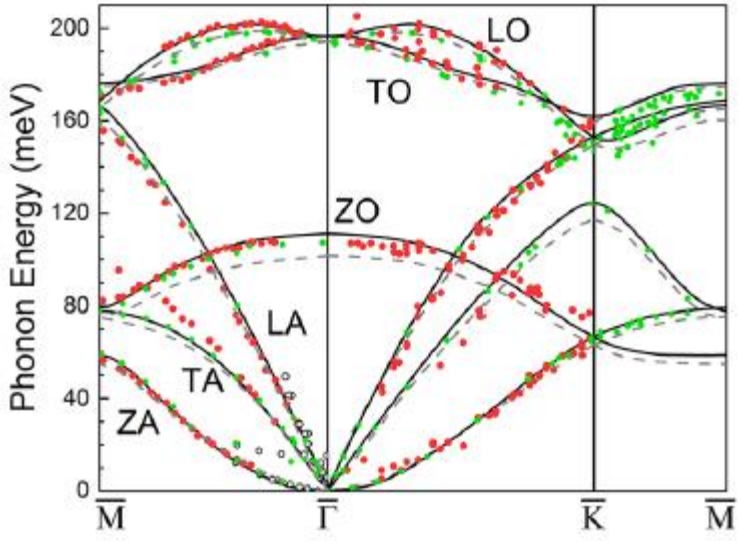


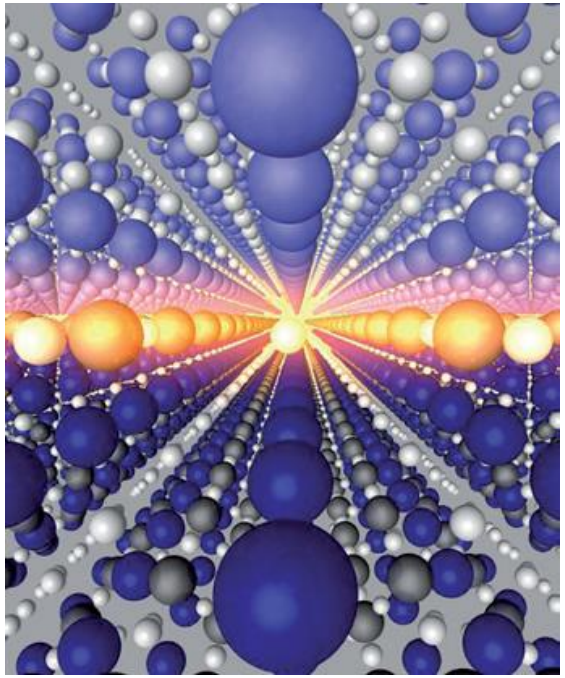
Figure 2. Phonon dispersion of graphite from HREELS (red dots, [54, 55]), inelastic x-ray scattering (green dots, [53]) and inelastic neutron scattering (open circles, [56]). DFT calculations for Gr are shown by gray-dashed lines [57] and solid lines [58].

ELECTRONES

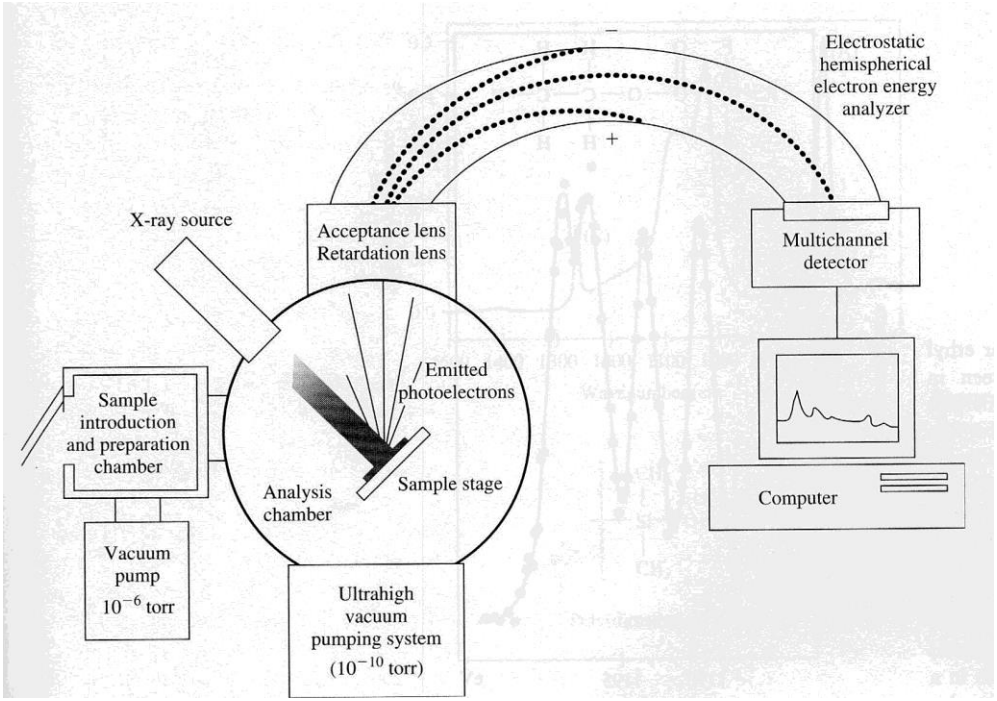
Tecnicas de caracterizacion en superficies -

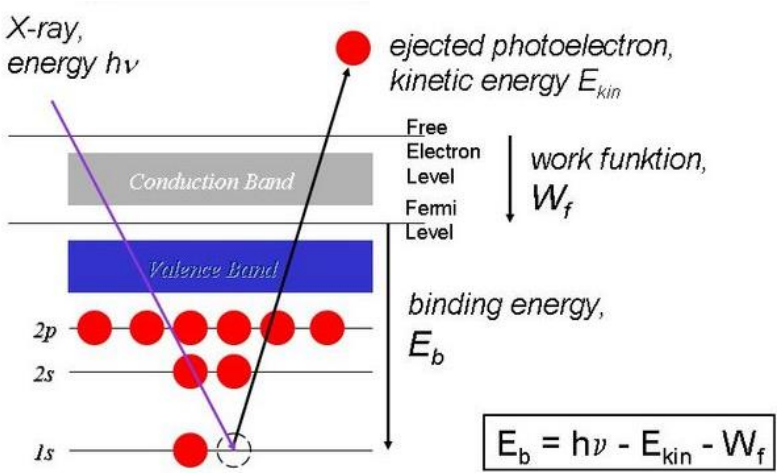
- Excitación: rayos X, UV, electrones, iones
- Detección: rayos X, electrones, iones….

- Longitud de penetración: algunos nm, dependiendo de la técnica



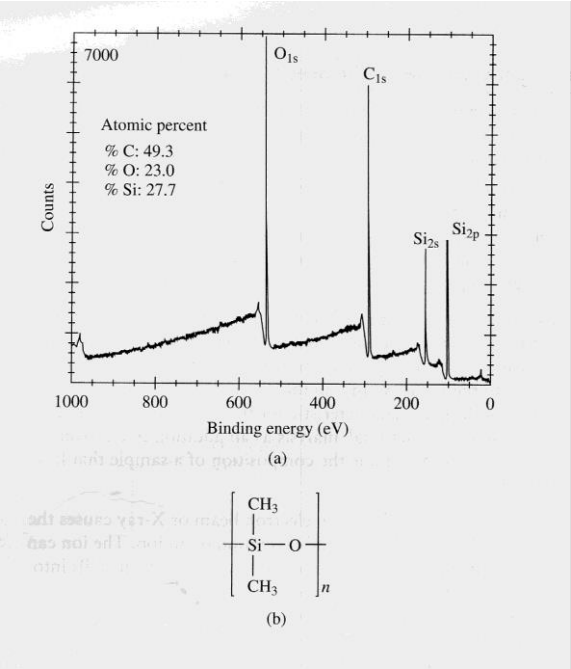
X-ray Photoelectron Spectroscopy XPS





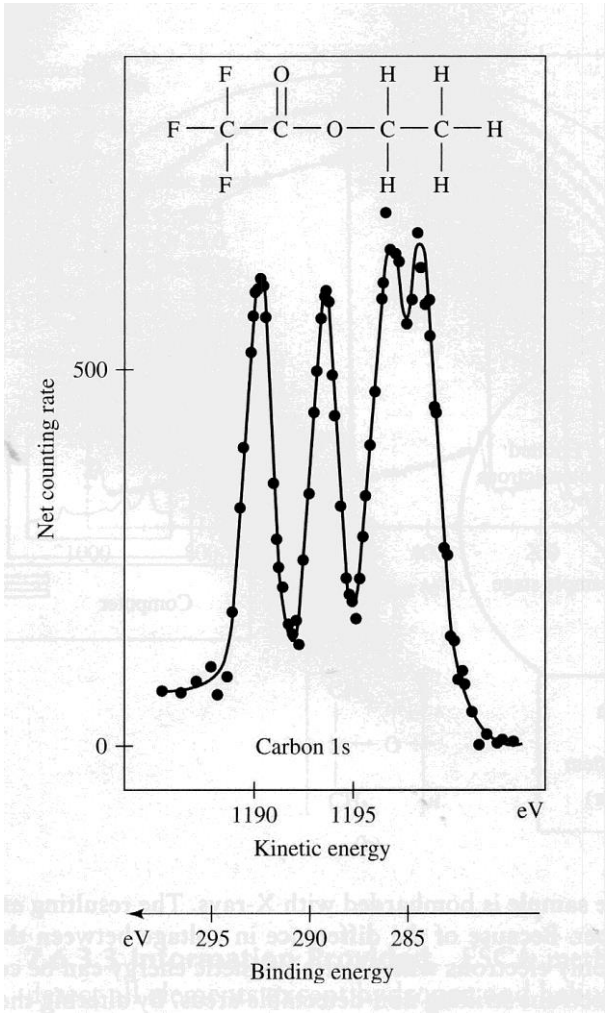
Electrons emitidos como resultado de la incidencia de los rayos X son separados de acuerdo a su energia cinetica y contados en un detector

Las energias de ligaduras varian con el elemento y tipo de ligadura



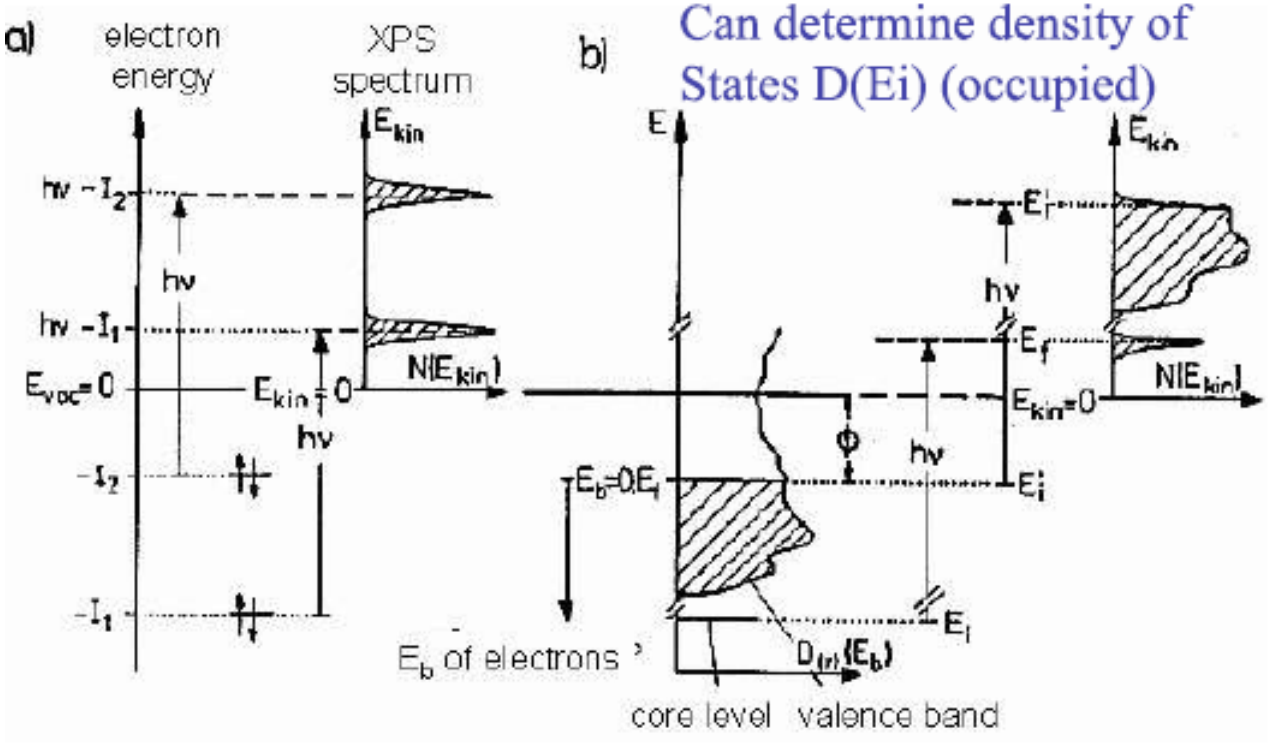
Espectro XPS
(polydimethyl siloxane)

Espectro de trifluoracetato.

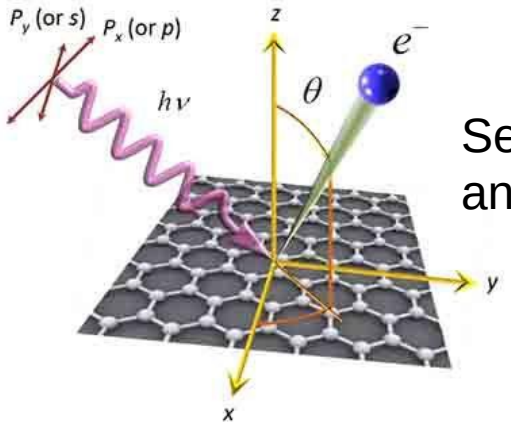


Ultraviolet Photoelectron Spectroscopy (UPS)

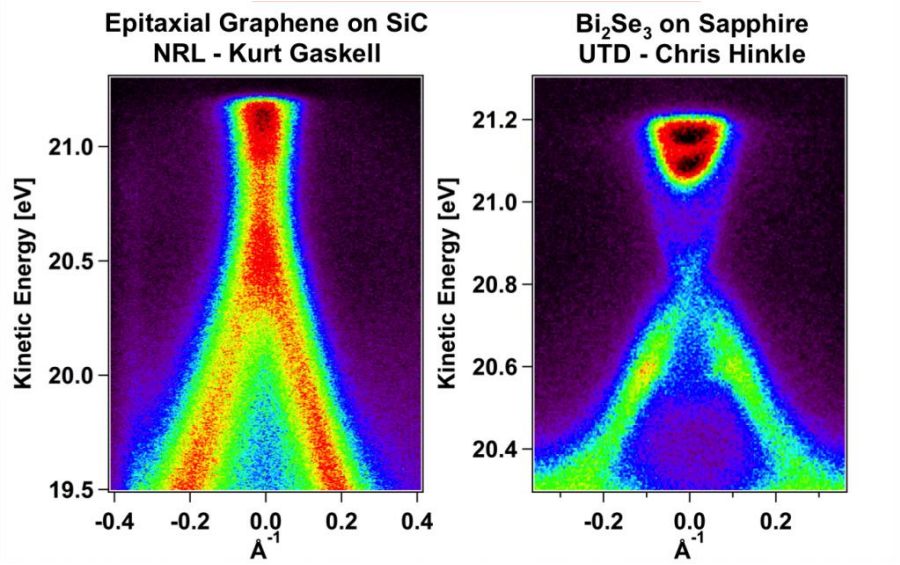
UV light (hν = **5 to 100** eV) to excite photoelectron. From an analysis of the kinetic energy and angular distribution of the photoelectrons, information on the **electronic structure** (band structure) of the material under investigation can be extracted with surface sensitivity.

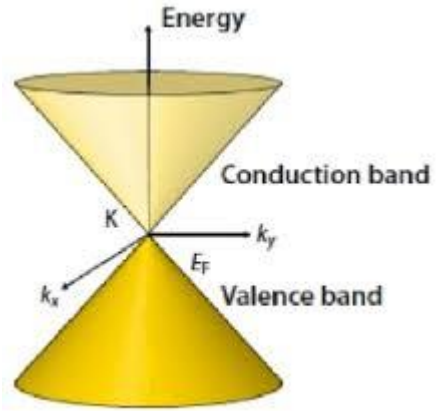


Angle Resolved Photoemission Spectroscopy ARPES

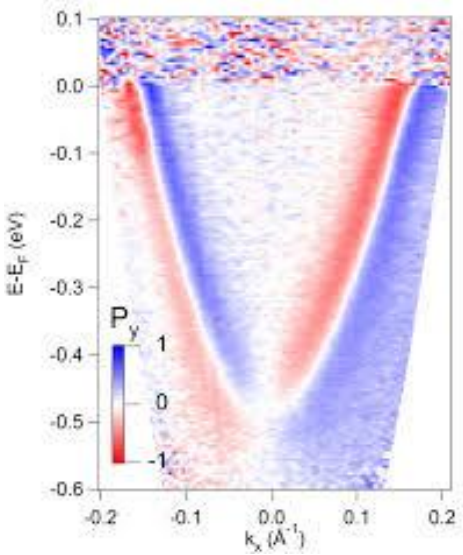


Se mide Eel + angulo θ



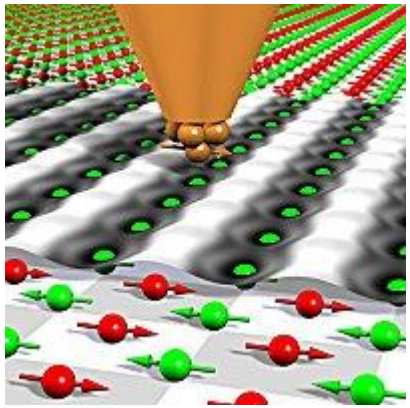


Conos de Dirac



Spin-resolved ARPES

SCANNING TUNNELING MICROSCOPE



Microscopio STM-AFM de ultra alto vacío y variable en temperatura (25 – 1000K) // CAB

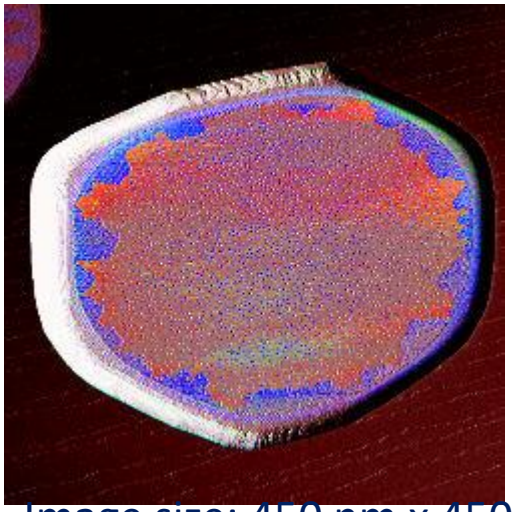
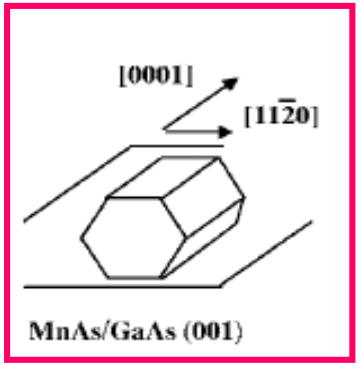


Image size: 450 nm x 450 nm

STM images



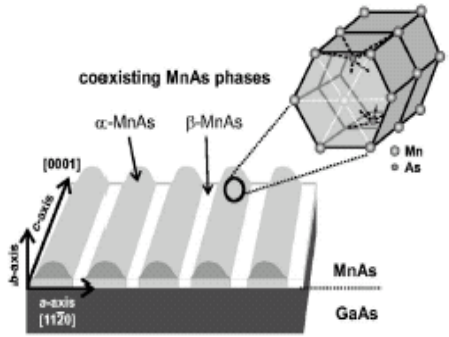
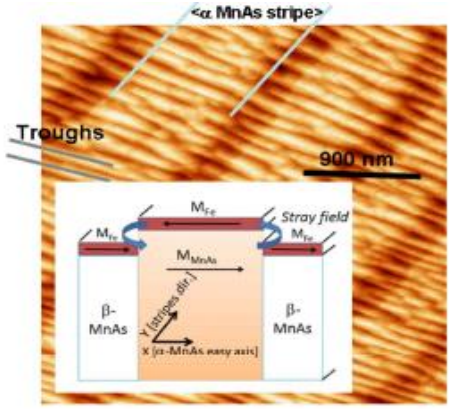
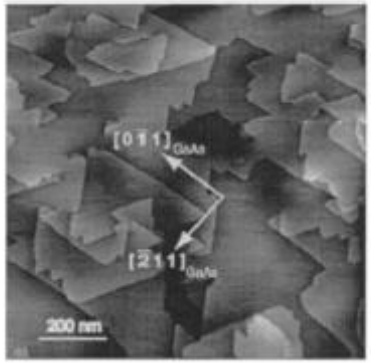
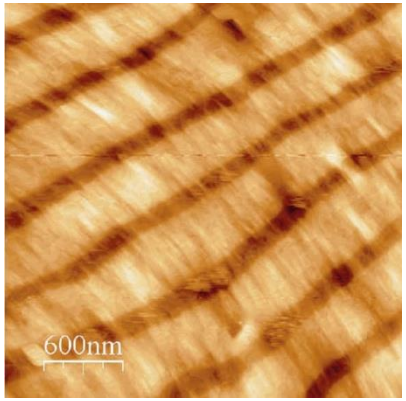


FIG. 1. Sketch of the stripe structure of the strain-stabilized coexisting α- and β-MnAs phases on GaAs(001) in the temperature range from 10 to 40 °C. The in-plane a axis is the easy axis of magnetization and the magnetic hard axis is along the in-plane c-axis direction (MnAs[0001]). On the top right, a detailed sketch of the hexagonal α-MnAs cell is shown.





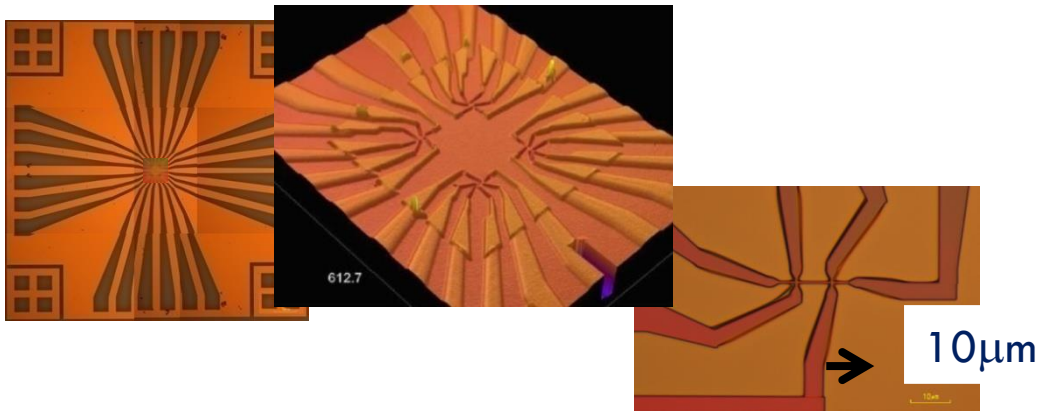


TRANSPORTE ELECTRONICO

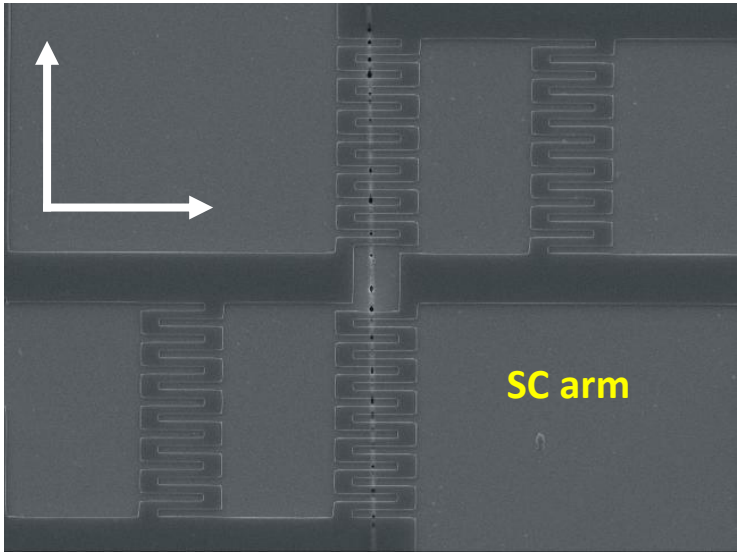
- Resistividad -> difusivo (semi-clasico), R(T) se pueden analizar mecanismos de scattering
- Hall effect Rxy (H): numero y tipo de portadores
- Haas van Alphen R(H) podiamos sondear superficie de Fermi
- Balistico Fermi, interferencia (onda): cuantica

Medidas de efecto Hall y magnetoresistencia

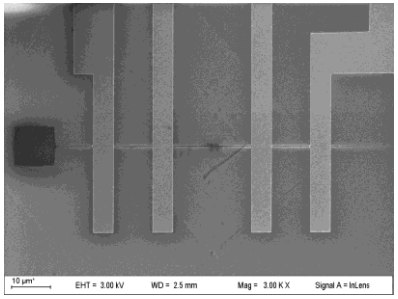
Grabado micro y nanohilos con contactos eléctricos sobre films de MnAs por litografía



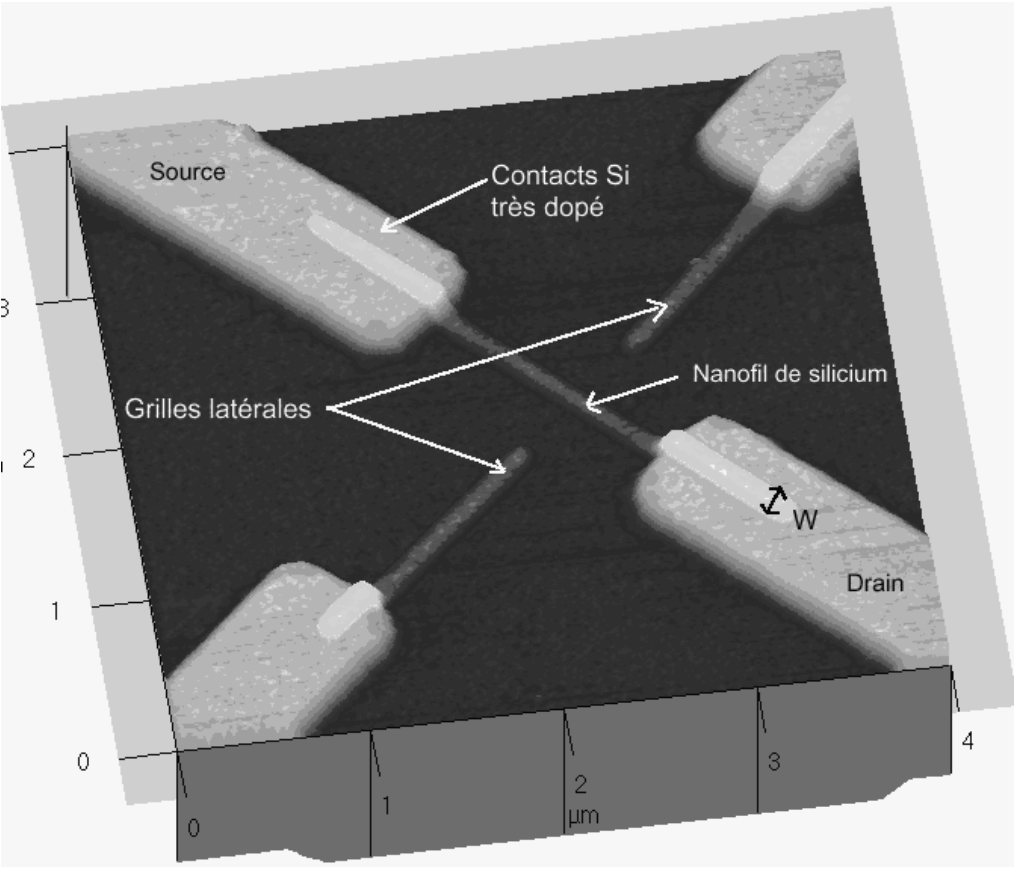
GB arm

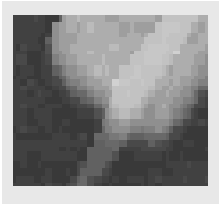


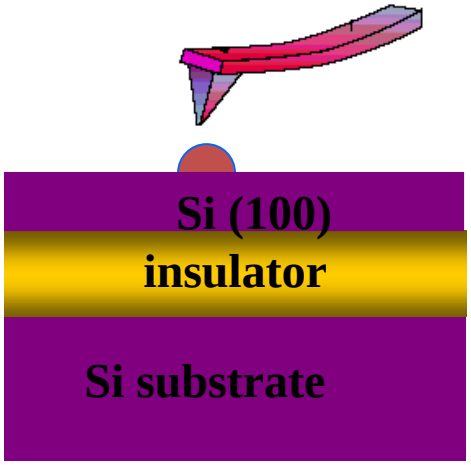
MR en nanohilos de oxidos!
Defectos de distintas geometrias y tamaños

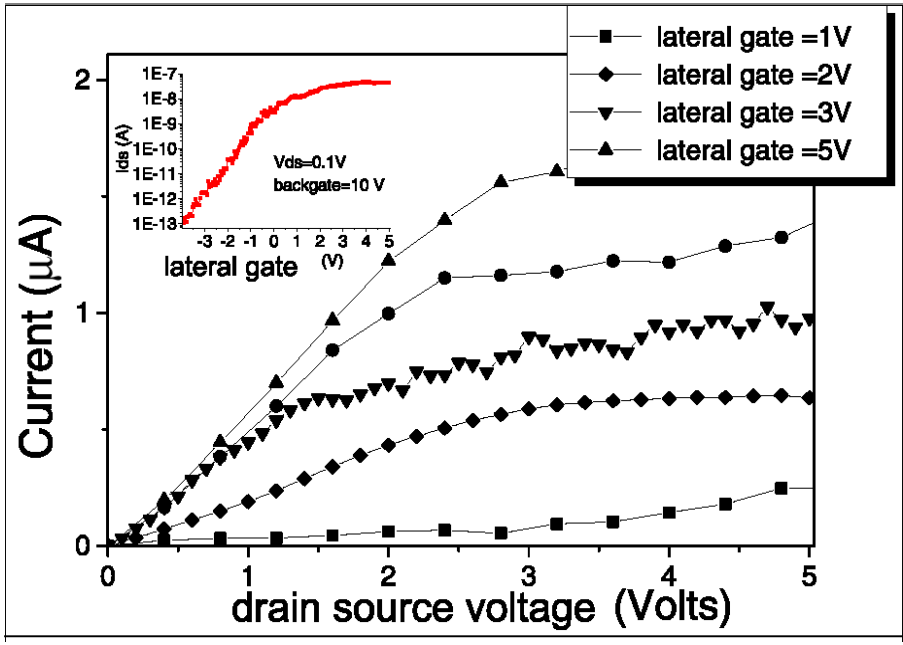


Connecting structures: nano- transistor





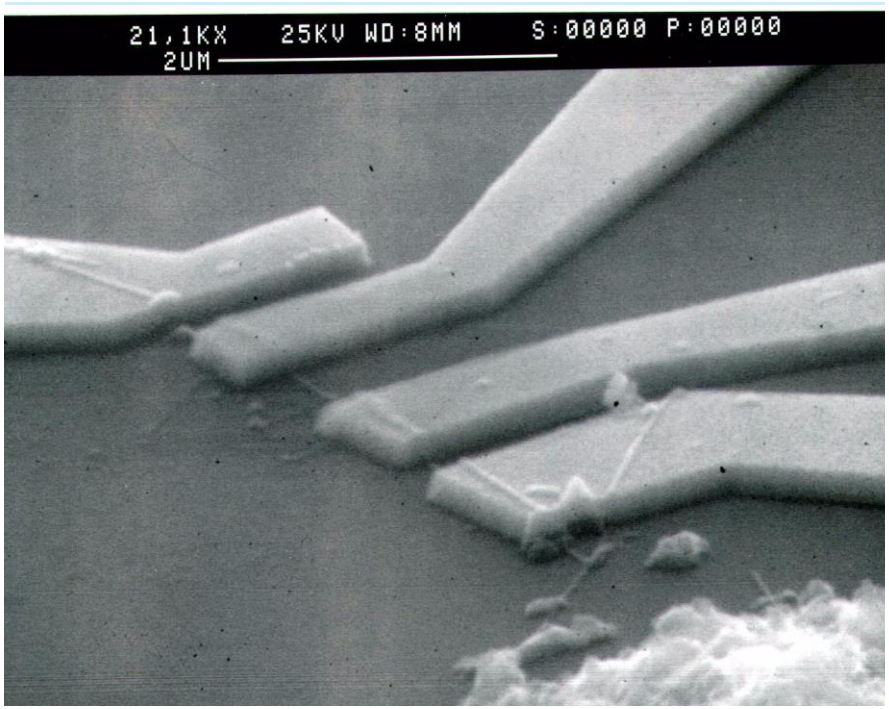


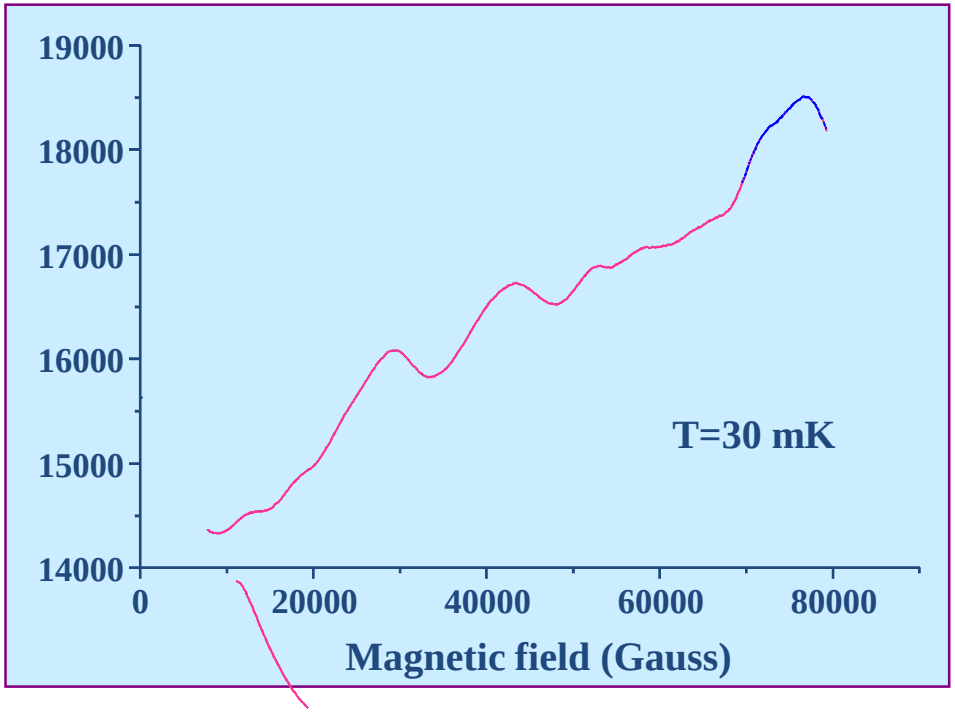


Electric test pattern on SOI substrate provided by the CEA-LETI laboratory (France-Grenoble)

IN Grenoble

Nanotubos de carbono y EBL

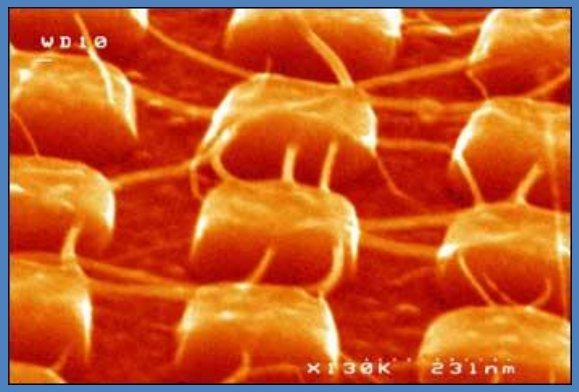


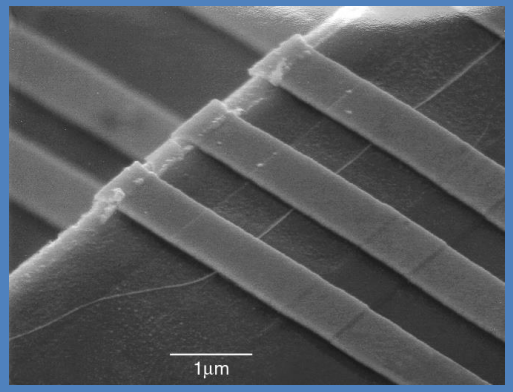


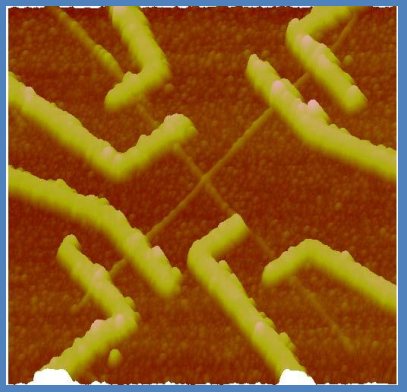
C.Naud, G.Faini, D.Mailly, H.Pascard, C.R. Acad. Sci. Paris 327, Série IIb (1999)

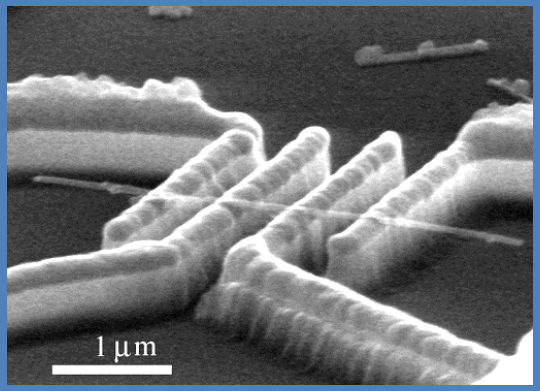
LPN

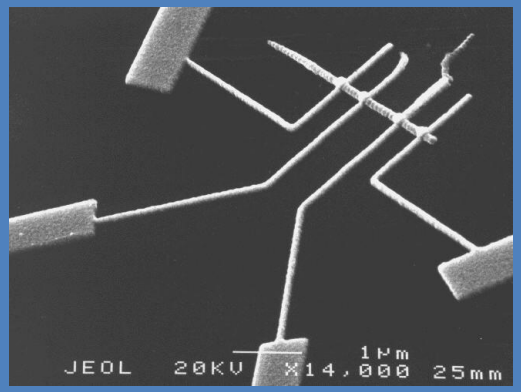
Distintas aproximaciones

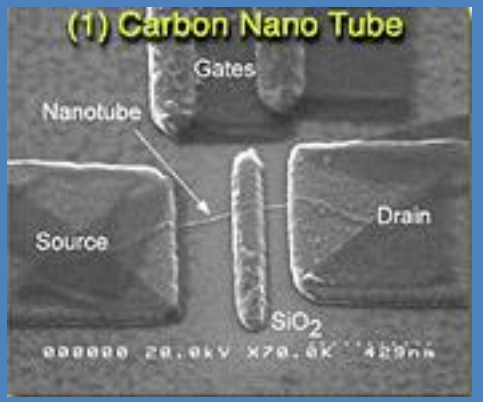








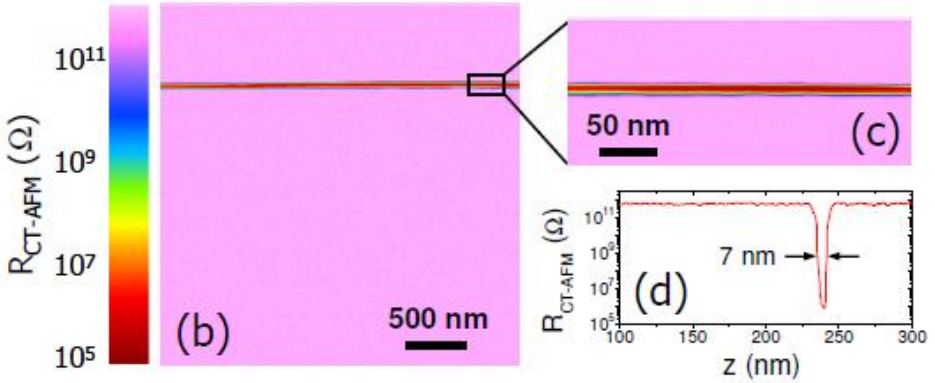




Different kind of systems:
Carbon nanotubes; semiconductor, magnetic, superconductor nanowires

Efectos de interfaces: aparecen fenomenos inesperados…

Deteccion de un gas de electrones 2D entre dos aislantes SPM



MAGNETISMO

- **TRADICIONALES**
- **Magnetometria**
- **MOKE**
- **FMR**

- **SUPERFICIES**

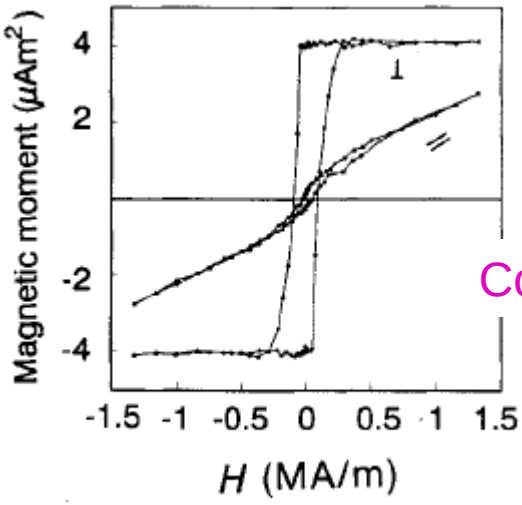
Fuentes de electrones polarizados o analizadores

- **SONDA LOCAL**

STM, MFM

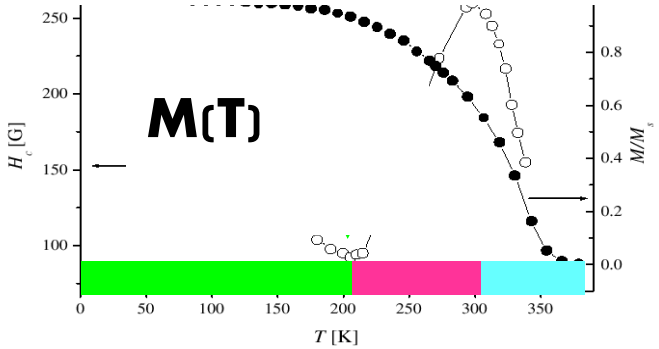
MAGNETOMETRIA

Ciclo de histeresis M(H)



Co/Ni/Co/Pt

MnAs 100nm/GaAs(111)



* **Equipos de distinta sensibilidad:** **SQUID 10-8 emu**
  VSM 10-6 emu
* **TODOS SENSAN VOLUMEN**
* **Trabajan a distintos campos magneticos y temperaturas**

Estudio de orden magnetico, anisotropias, acoplamientos entre capas

FMR espectrometro de resonancia magnetica electronica

MEDIDA DE VOLUMEN

TECNICA MUY SENSIBLE: PARTES POR MILLON

MEDIDAS DE ANISOTROPIA MAGNETICA, EXCITACIONES, ACOPLAMIENTO INTERCAPAS

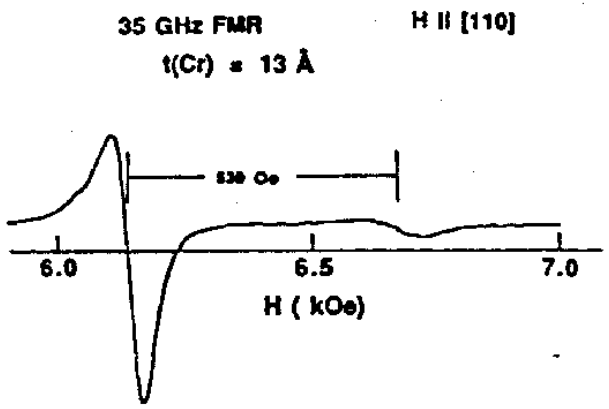
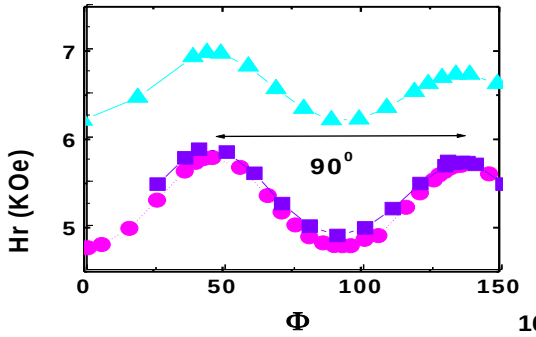
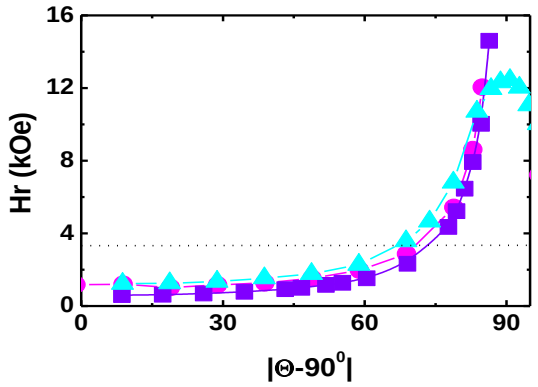


FIG. 6. Derivative FMR spectra of an Fe/Cr/Fe(001) sample at 35 GHz showing the out-of-phase antiferromagnetically coupled mode which occurs at a field $4\tilde{J}$ above the regular in-phase mode.



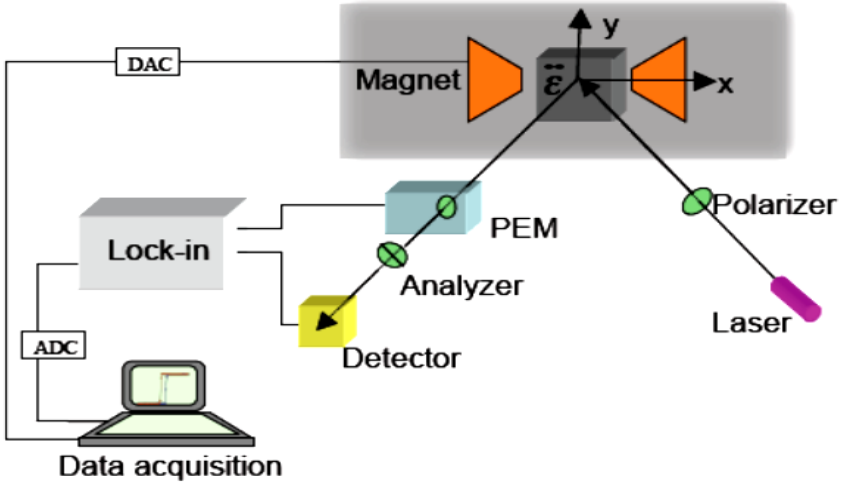


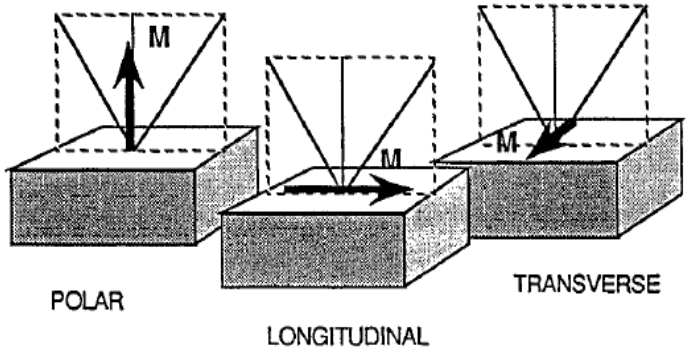
Magneto-Optical Kerr Effect (MOKE)

Interaccion de luz con la magnetizacion del material: cambio de polarizacion del haz incidente

Resolucion lateral: diametro haz : decenas de μm

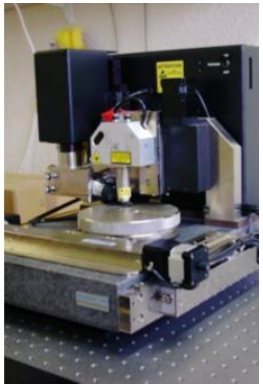
Distintas geometrias





M contenida en el plano de incidencia y reflexion de luz (polar y longitudinal) o perpendicular (transversal)

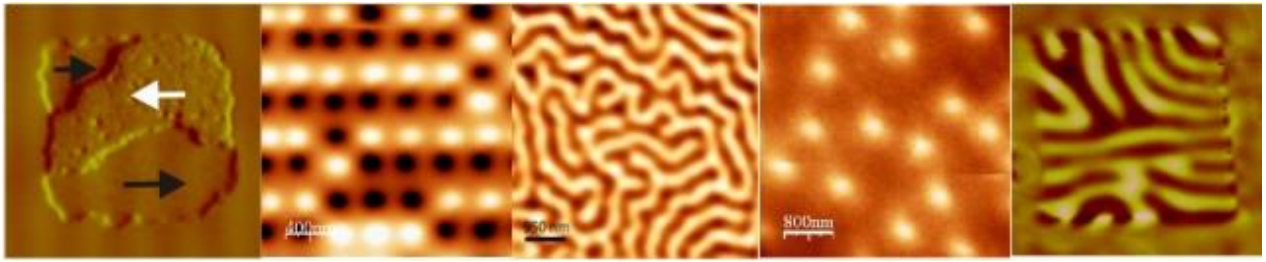
RESOLUCION LATERAL: SUBMICROMETRICA

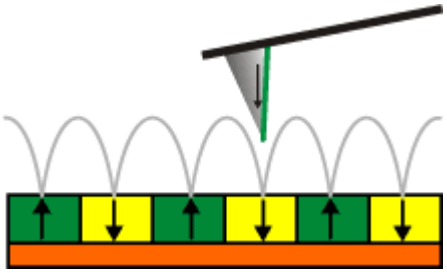


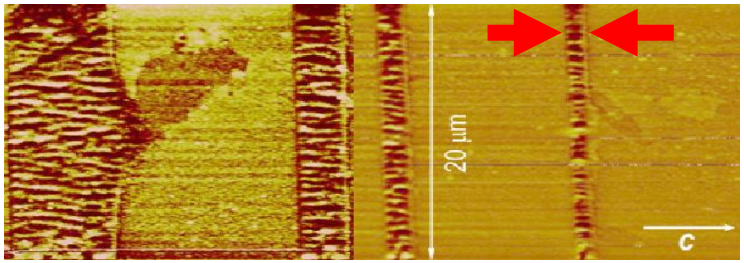
MICROSCOPIA DE FUERZA MAGNETICA

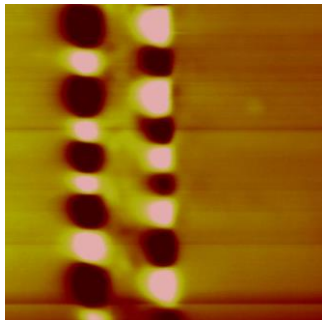
Detecta fuerza de Van der Waals y dipolar

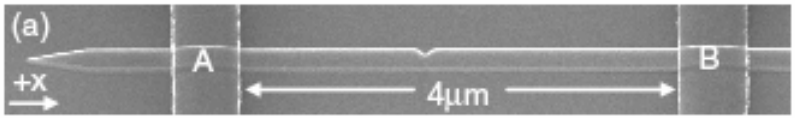
La estrategia es medir a distintas distancias de la muestra para poder diferenciar topografia de señal magnetica









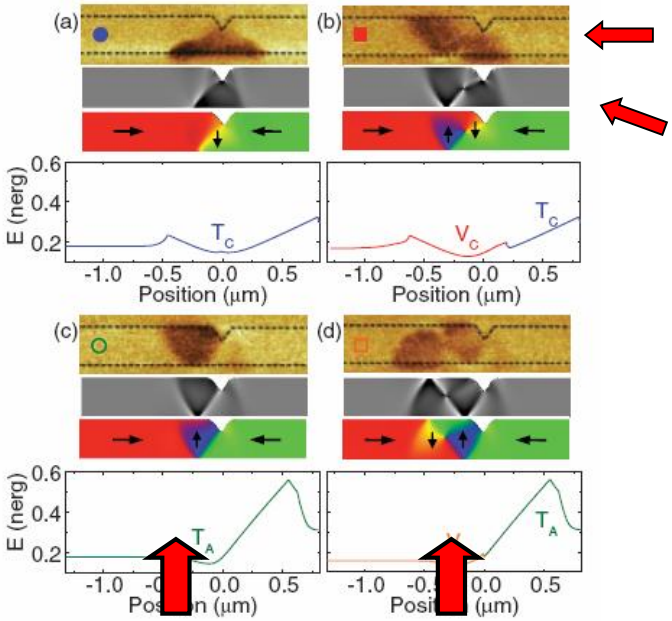


M. Hayashi *et al*,
Phys. Rev. Lett. **97**, 207205 (2006)

$Ni_{81}Fe_{19}$
WIDTH: 300 nm, THICKNESS: 10nm

Domain walls are created and moved by I injection

Charge – spin interaction

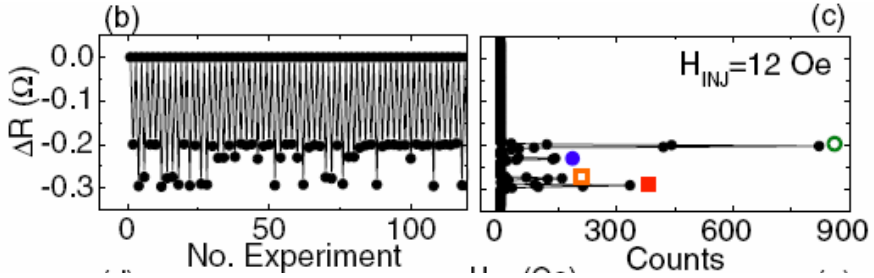


MFM images

Simulations

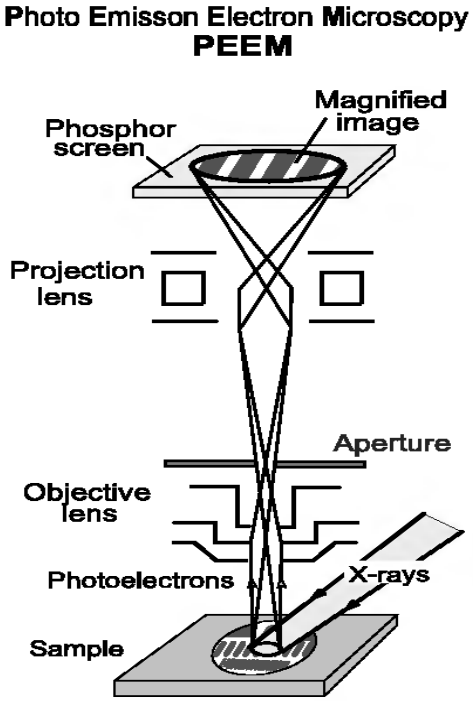
Transverse wall

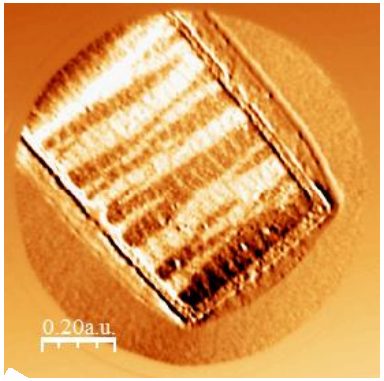
Vortex



XPEEM

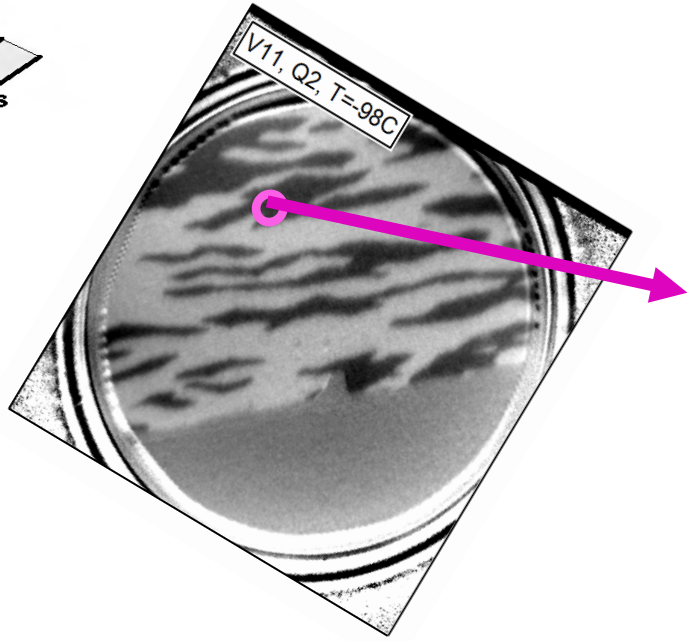
Photoemission Electron Microscopy tiene una resolucion espacial de entre 50- 100nm para resolver estructuras relevantes

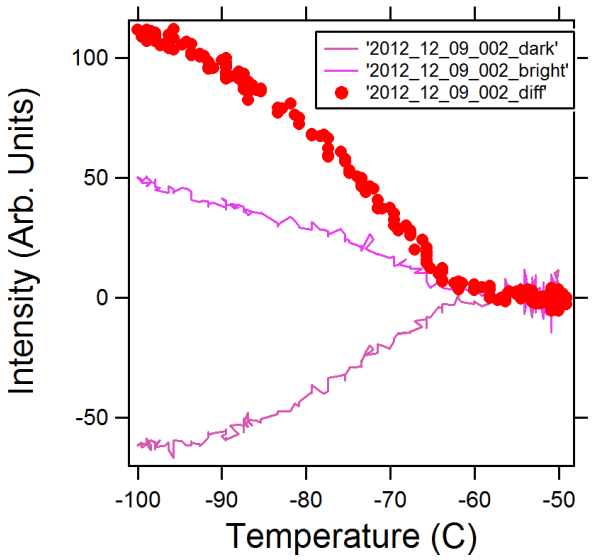




Mapeo magnetizacion mediante el analisis de electrones secundarios

*** especificidad elemental!**





TECNICAS DE ANALISIS DE SUPERFICIE POLARIZADA EN ESPIN

PERMITEN MEDIR FILMS ULTRA FINOS => NM
RESOLUCION LATERAL: TAMAÑO HAZ O RESOLUCIÓN ANALIZADOR

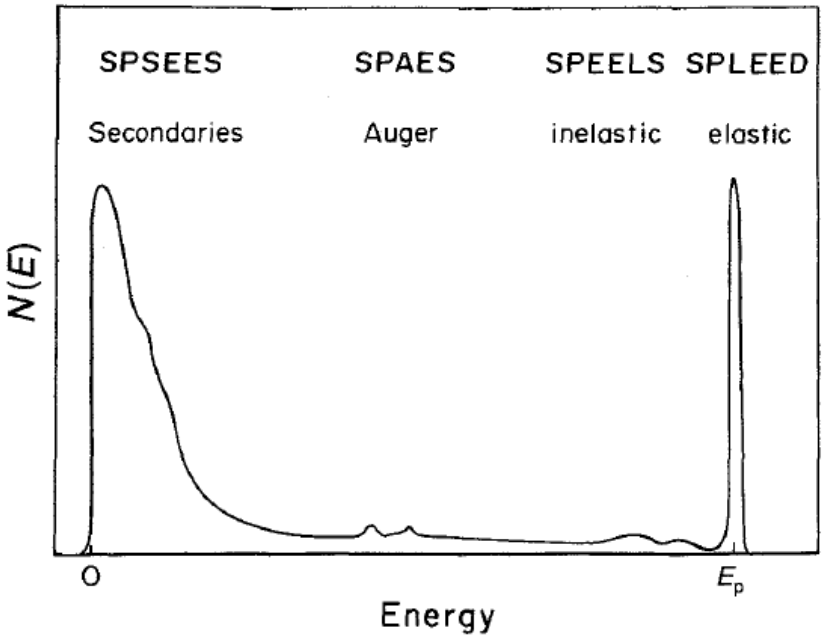
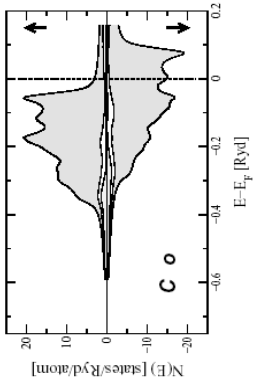


Fig. 4.1. Schematic electron energy spectrum

Espectroscopias de Superficies de electrones polarizados en espin

Fuentes polarizadas en espin o detectores de polarizacion!

MEDIDAS DE MAGNETOMETRIA CON TECNICAS DE ELECTRONES POLARIZADOS



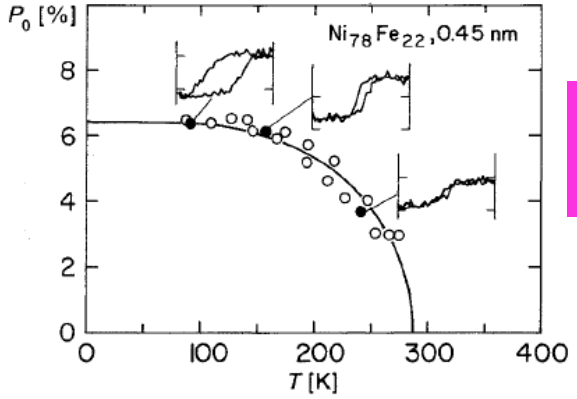


Fig. 4.22. Spin polarization $P_0(T)$ obtained by extrapolation of $P(H,T)$ to $H \to 0$ for a 0.45 nm

Medida de magnetizacion
de una monocapa de aleacion

marks on the ordinate indicates a 10% change of spin polarization and the applied field is swept from -2.0 to $+2.0$ kA/m. Data from [4.177, 165]

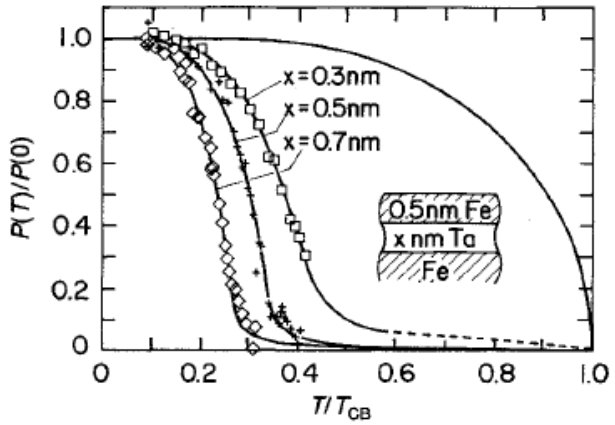
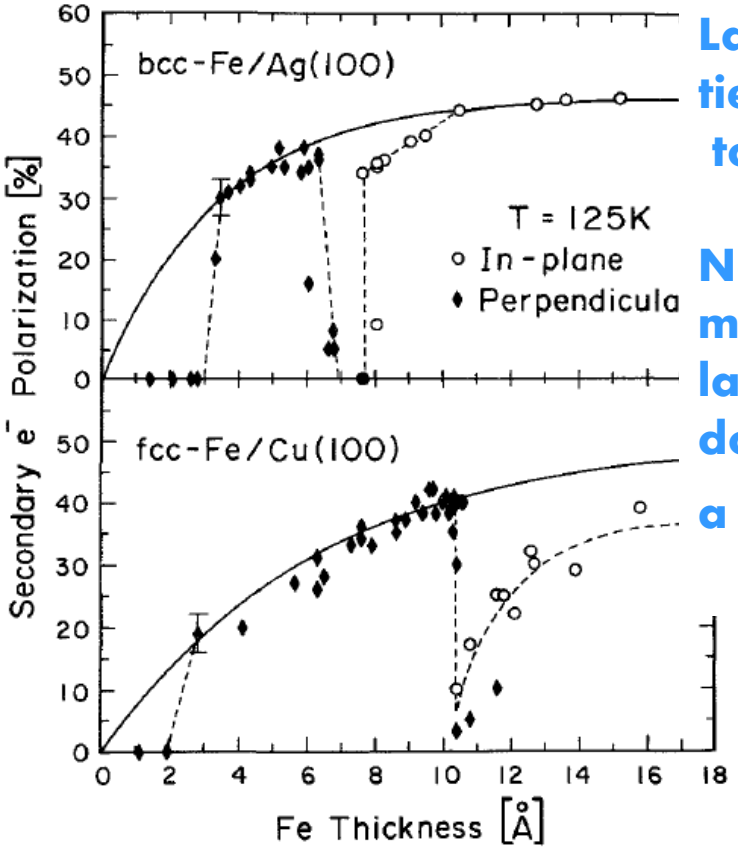


Fig. 4.25. Relative spin polarization $P(T')/P(0)$ of the low energy cascade

Medida de magnetizacion
de una monocapa de Fe
separada de un macizo de Fe
Observar cambio 2D respect a 3D

vations. The mean field curve for bulk Fe ($H_{ex} = 0$) is shown to illustrate the crossover from 2D to 3D magnetism

Medida de la polarizacion de electrones secundarios en films de Fe de distintos espesores => magnetización!



La zona donde la M del film pasa de OOP a IP tiene un ancho finito donde cae la polarización total

No se sabe si hay una perdida de magnetizacion real en esa zona o si la medida indica un split de la M en dominios (las medidas fueron hechas a H=0)

XPS polarizado en espin

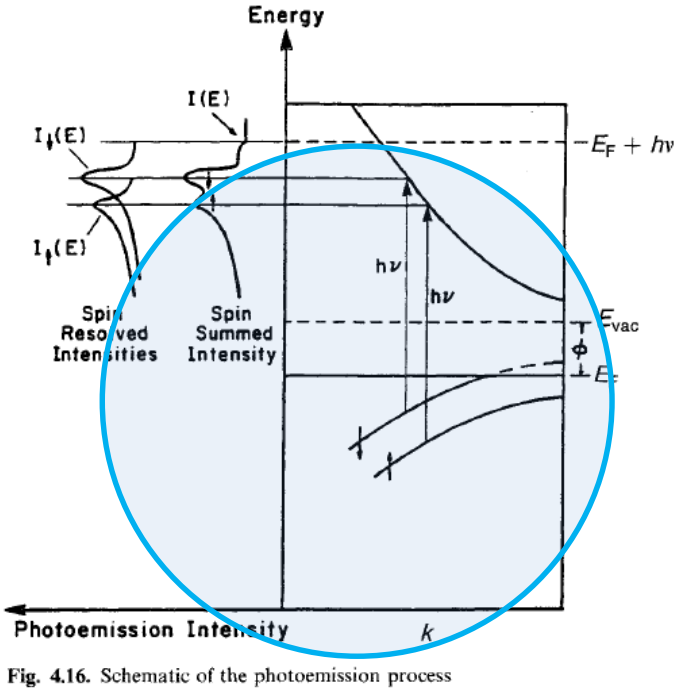
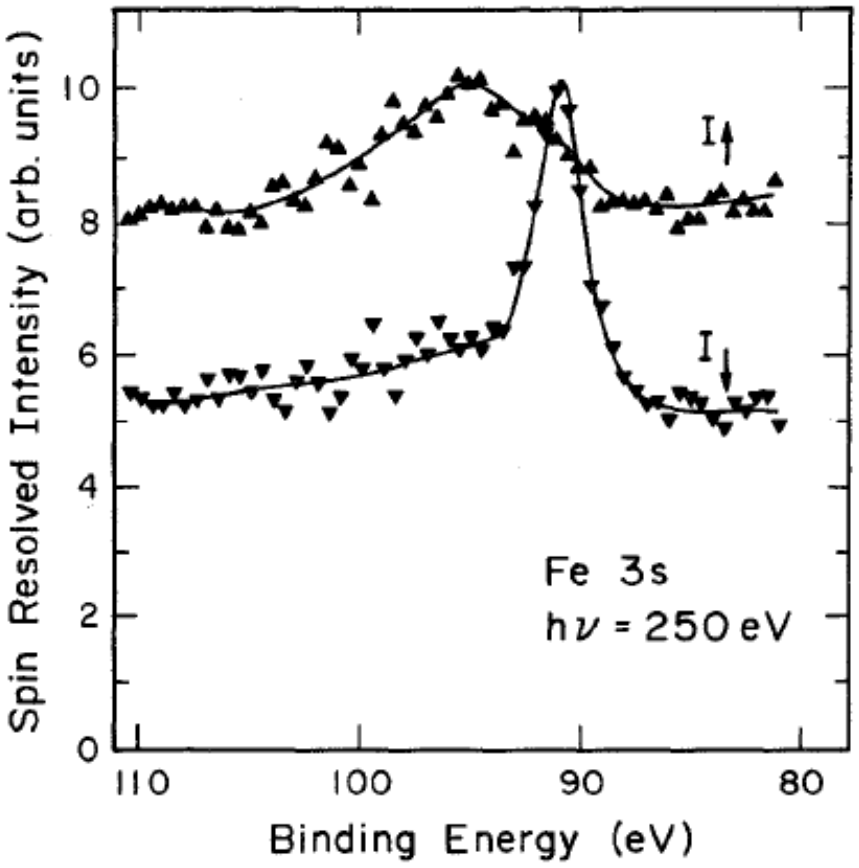


Fig. 4.16. Schematic of the photoemission process

Se puede sintonizar bandas de distinto spin



Detalle espectro lineas de niveles del Fe (3s) Intensidad dependiente de espin (XPS)

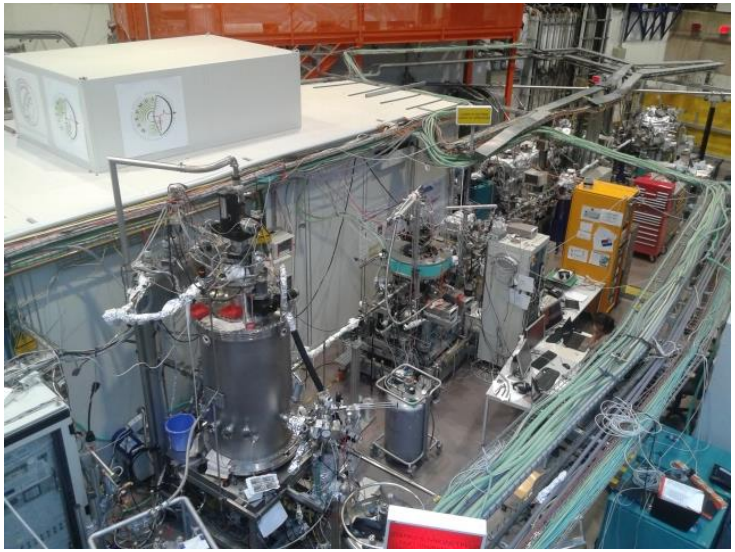
GRANDES FACILIDADES: CAMPOS MAGNETICOS INTENSOS

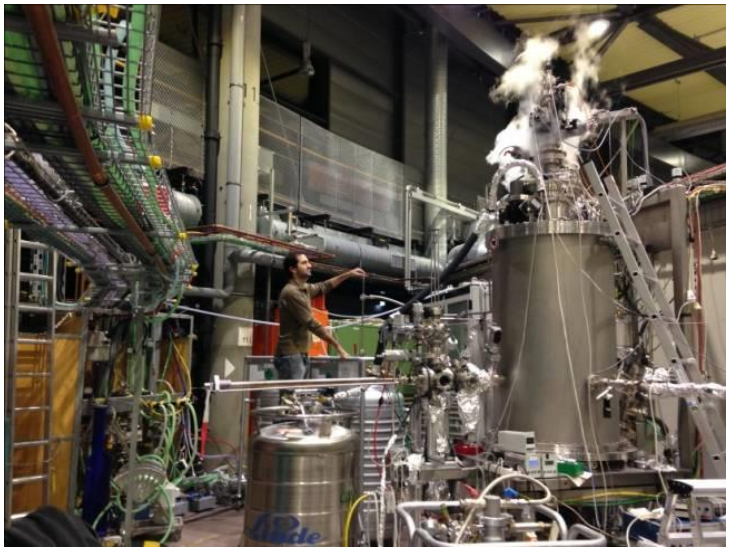
LOS ALAMOS NHMFL USA

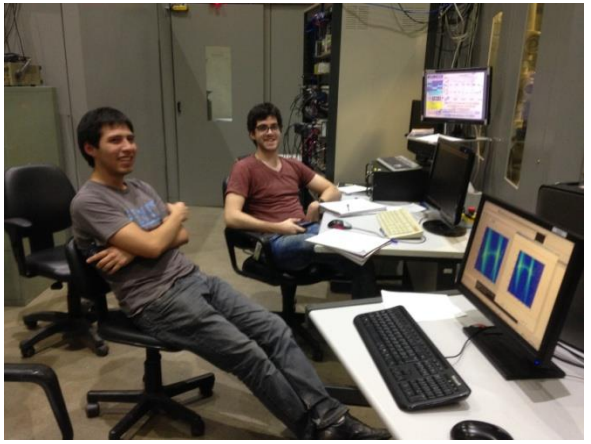
HASTA 100T
MAGNETISMO, ELECTRONICA

SINO CAMPOS PULSADOS HASTA CAMPOS MAS ALTOS

FACILIDADES DE RADIACION SYNCHROTRON







100 o mas mts de diametro