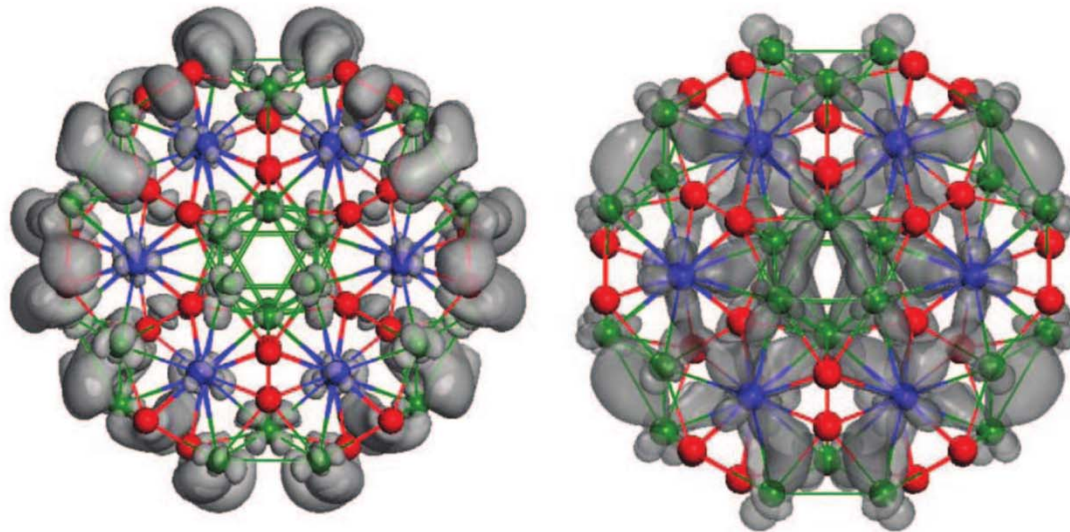




Centro de Investigación en
Materiales Avanzados

NANOTECNOLOGÍA: efectos y causas

Sion F. Olive Méndez





Contenido

- El silicio
- El efecto del tamaño:
 - ✓ Configuración electrónica
 - ✓ Área superficial
- Transistor y la demanda tecnológica
- Métodos de fabricación
- Materiales funcionales: MRAM

Definiciones

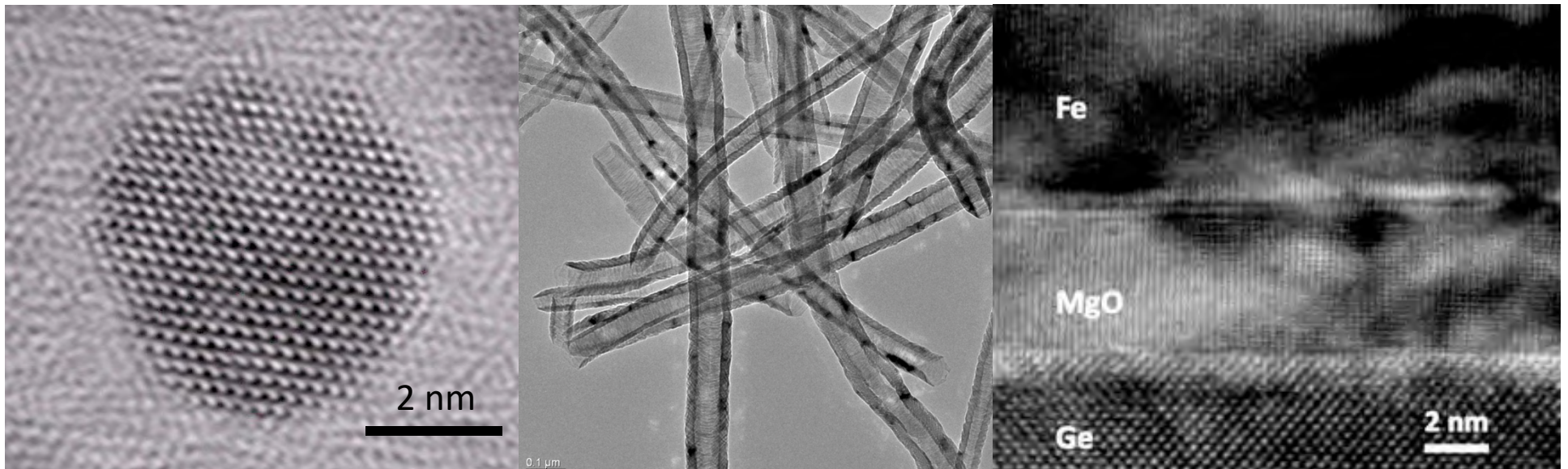
Nanotecnología → Norio Taniguchi-Universidad de Tokio → 1974 → manufactura de materiales con tolerancias de un nanómetro.

Nanociencia → estudio de fenómenos y manipulación de materiales a escalas atómica, molecular y macromolecular, para entender y explotar las propiedades inherentes al tamaño, que son diferentes de las propiedades a gran escala.

Nanociencia → Nanotecnología

$$1 \text{ nm} = 1 \times 10^{-9} \text{ m}$$

Nanotecnología: 1D, 2D, 3D < 100 nm



Dimensión del átomo



un **nanómetro** es a un **milímetro**
lo que un **milímetro** es a un **kilómetro**

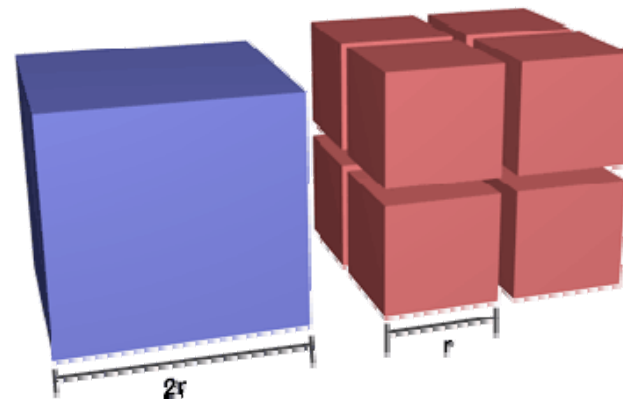
$1 \text{ nm} = 1 \times 10^{-9} \text{ m}$, en donde
caben entre 3 y 5 átomos



Espadas y escudos de guerreros tenían nanotubos de carbono

¿Qué efectos tiene en la materia la reducción del tamaño?

Nanopartículas de oro son de color rojo

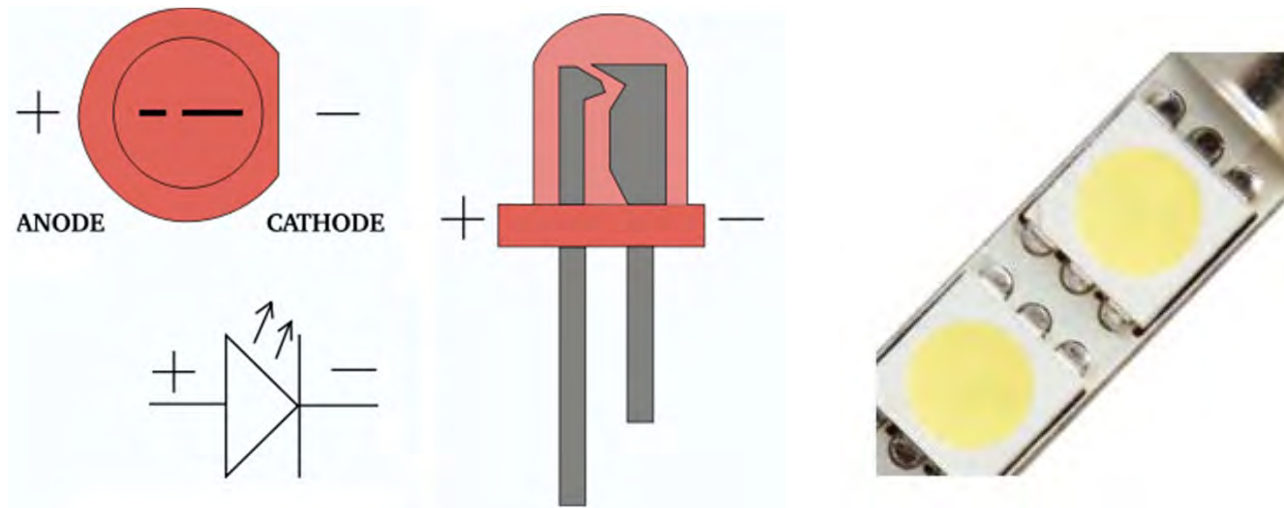


Fragmentación del material

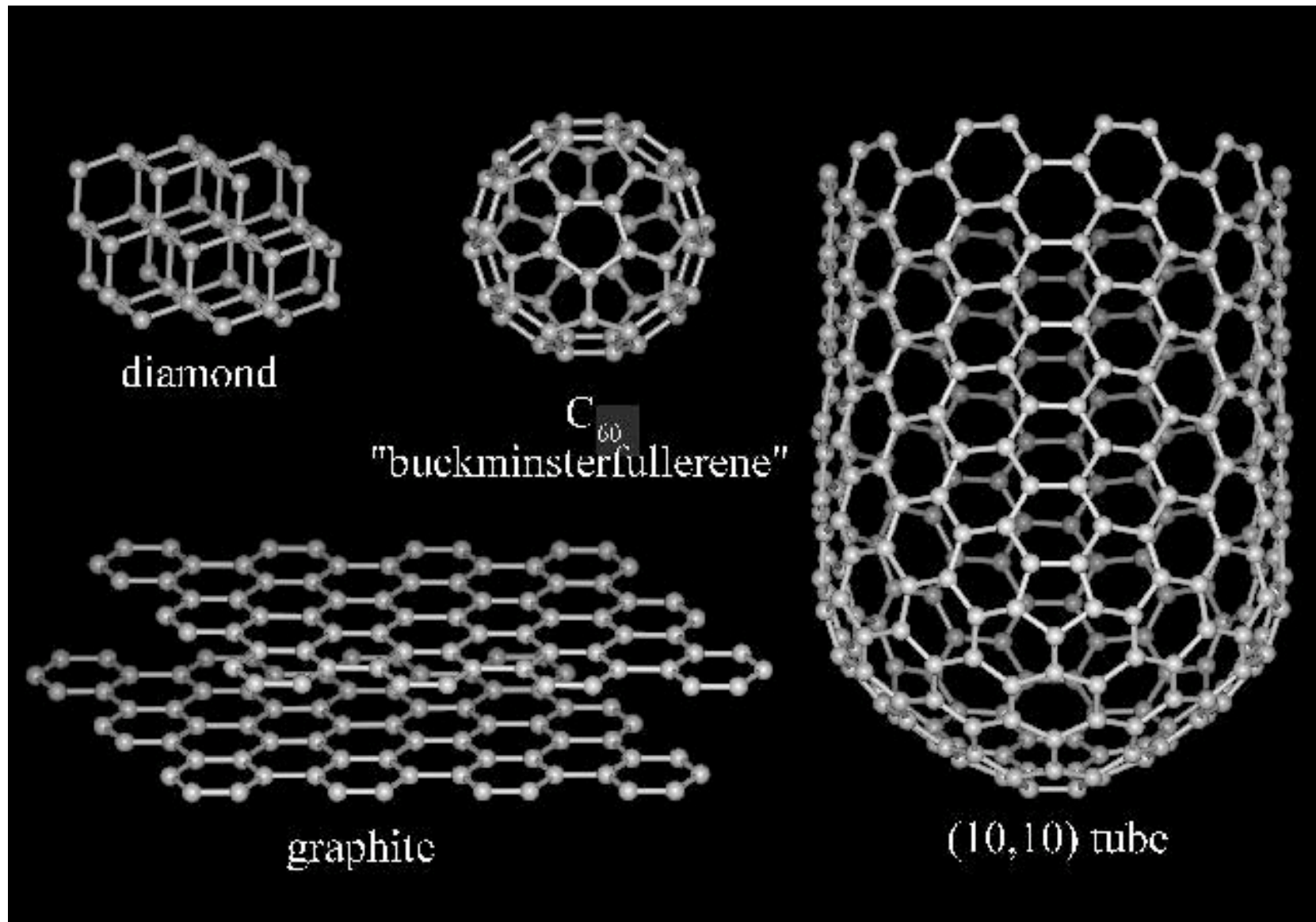
- Incremento en el área superficial
- Modificación de la estructura electrónica de los materiales → nuevas propiedades no observadas en los materiales en bulto

Light-emitting diode (LED)

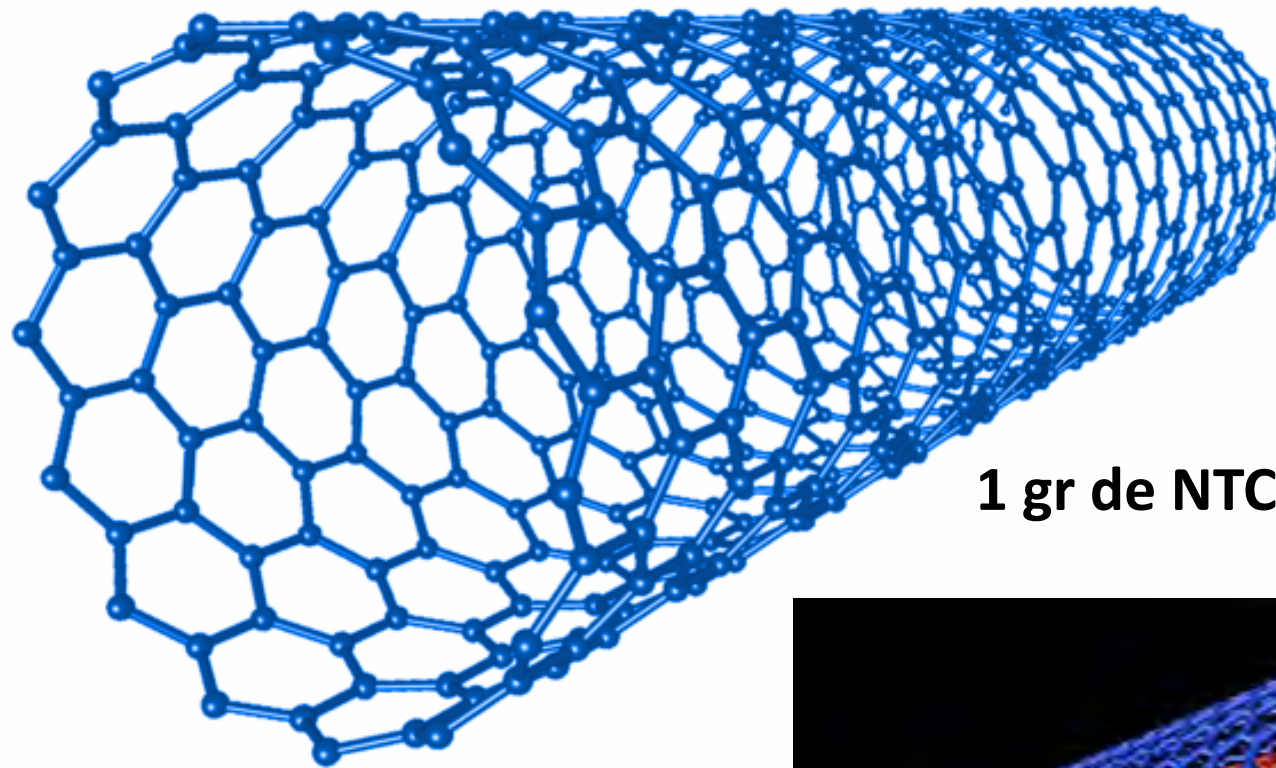
Unión de semiconductores tipo n y tipo p



Formas alotrópicas del carbono



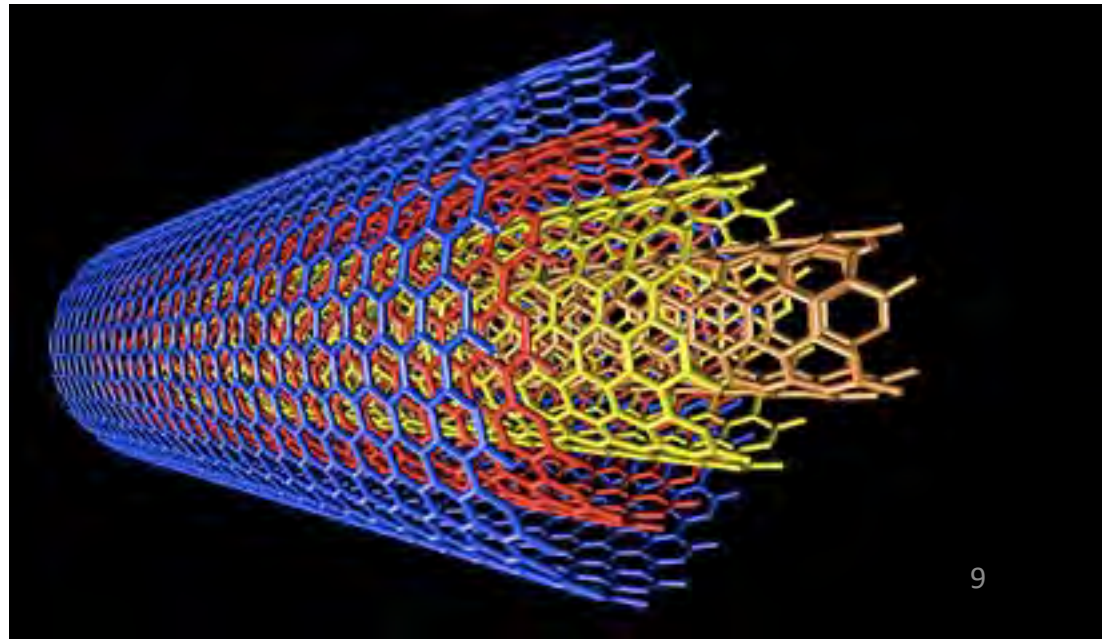
Nanotubos de carbono

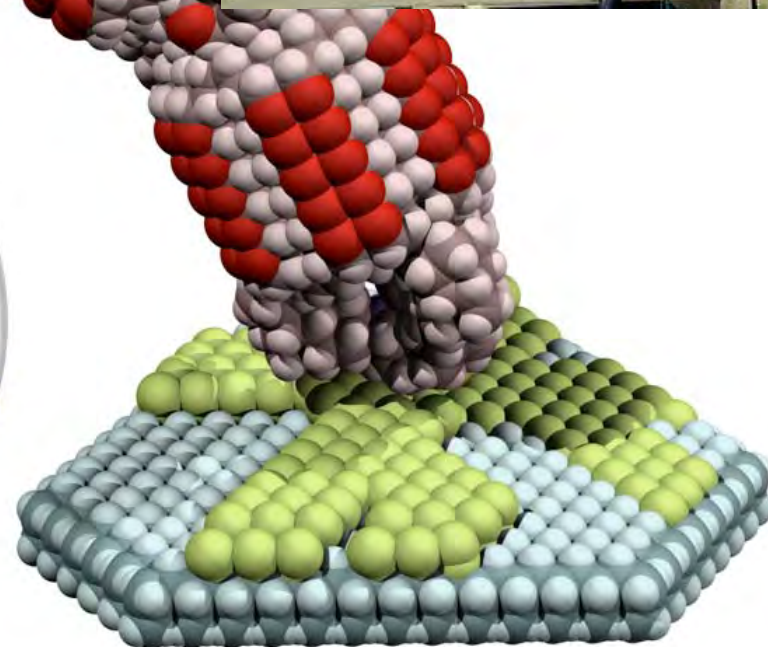
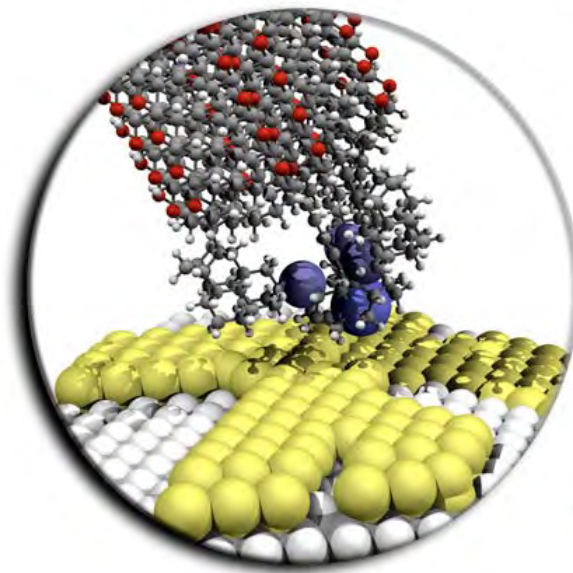
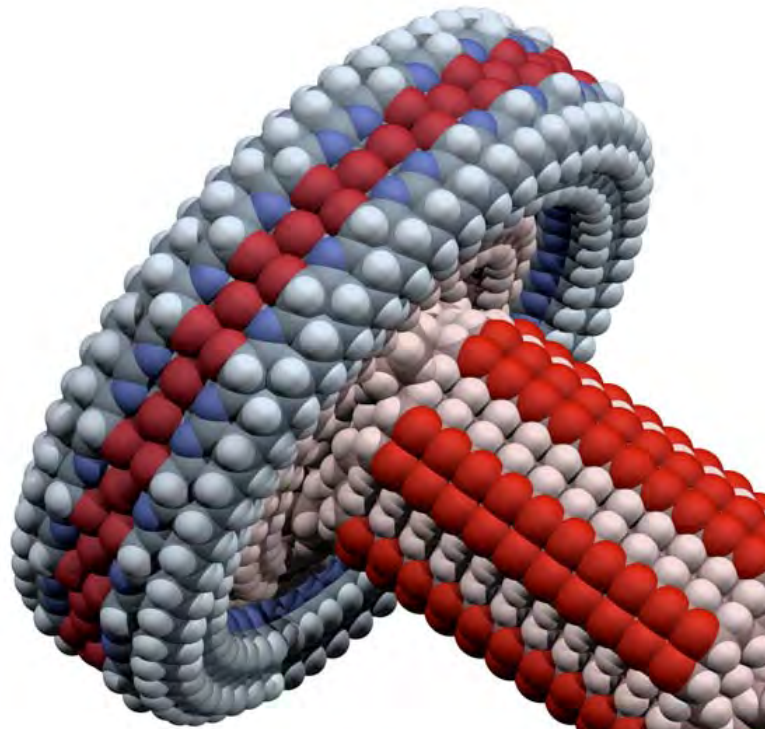


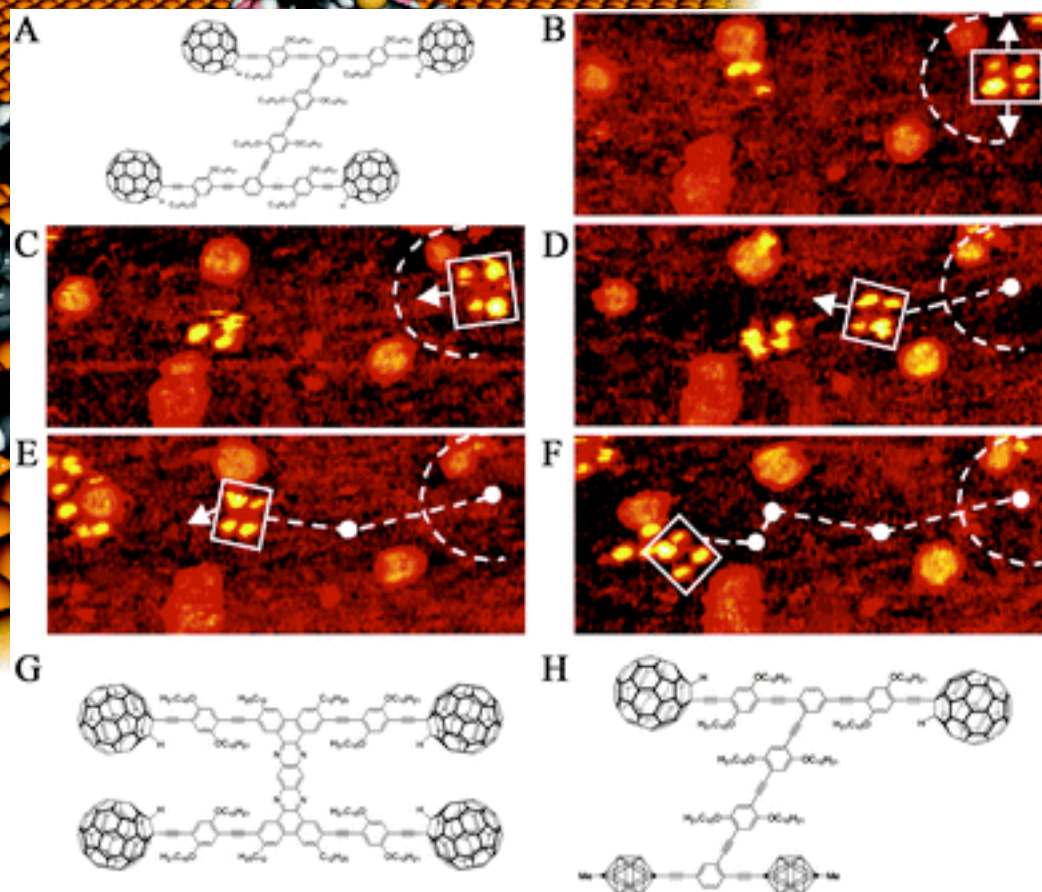
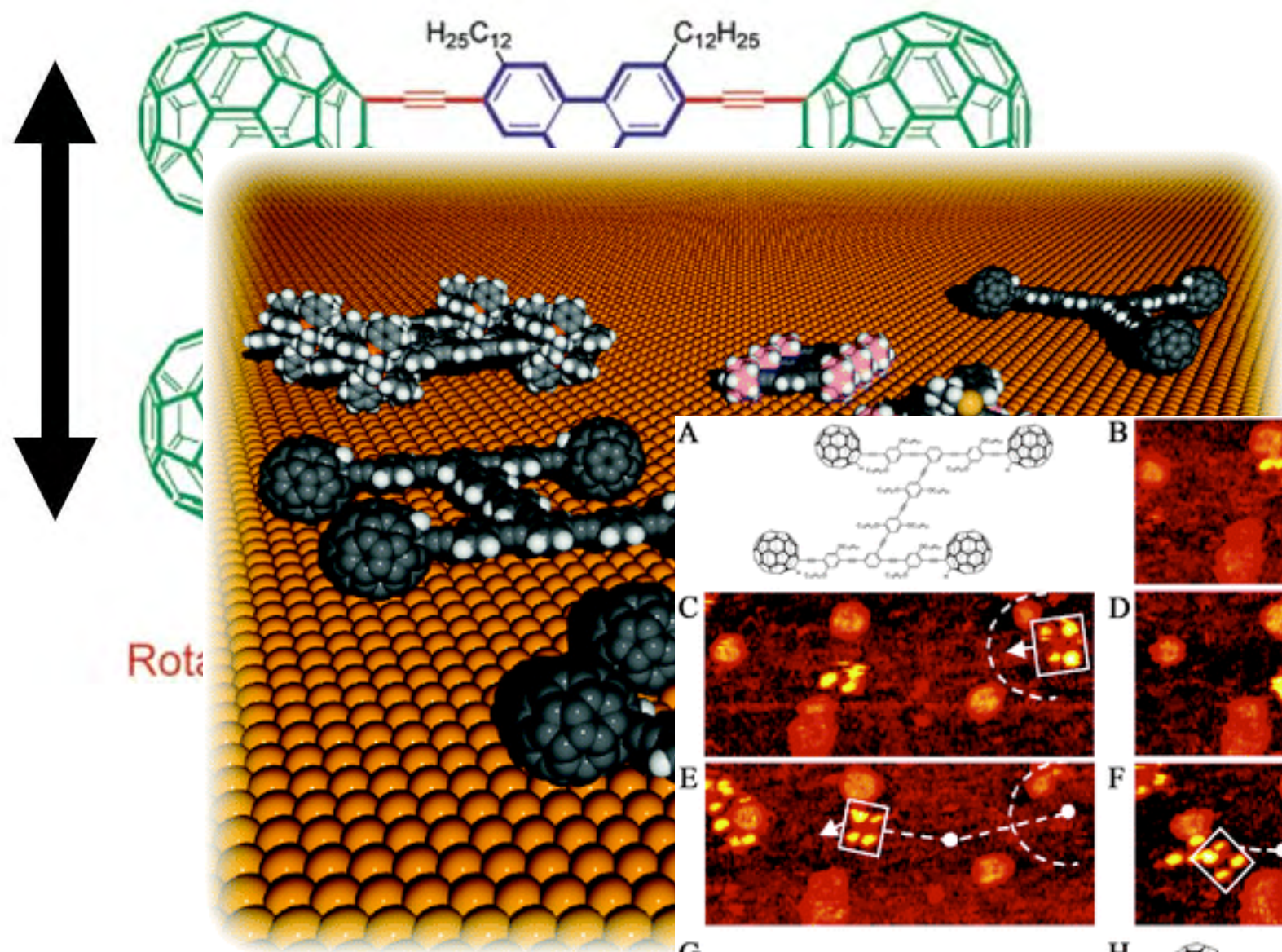
Pared simple

1 gr de NTC → 50-150 m²

Multi-pared

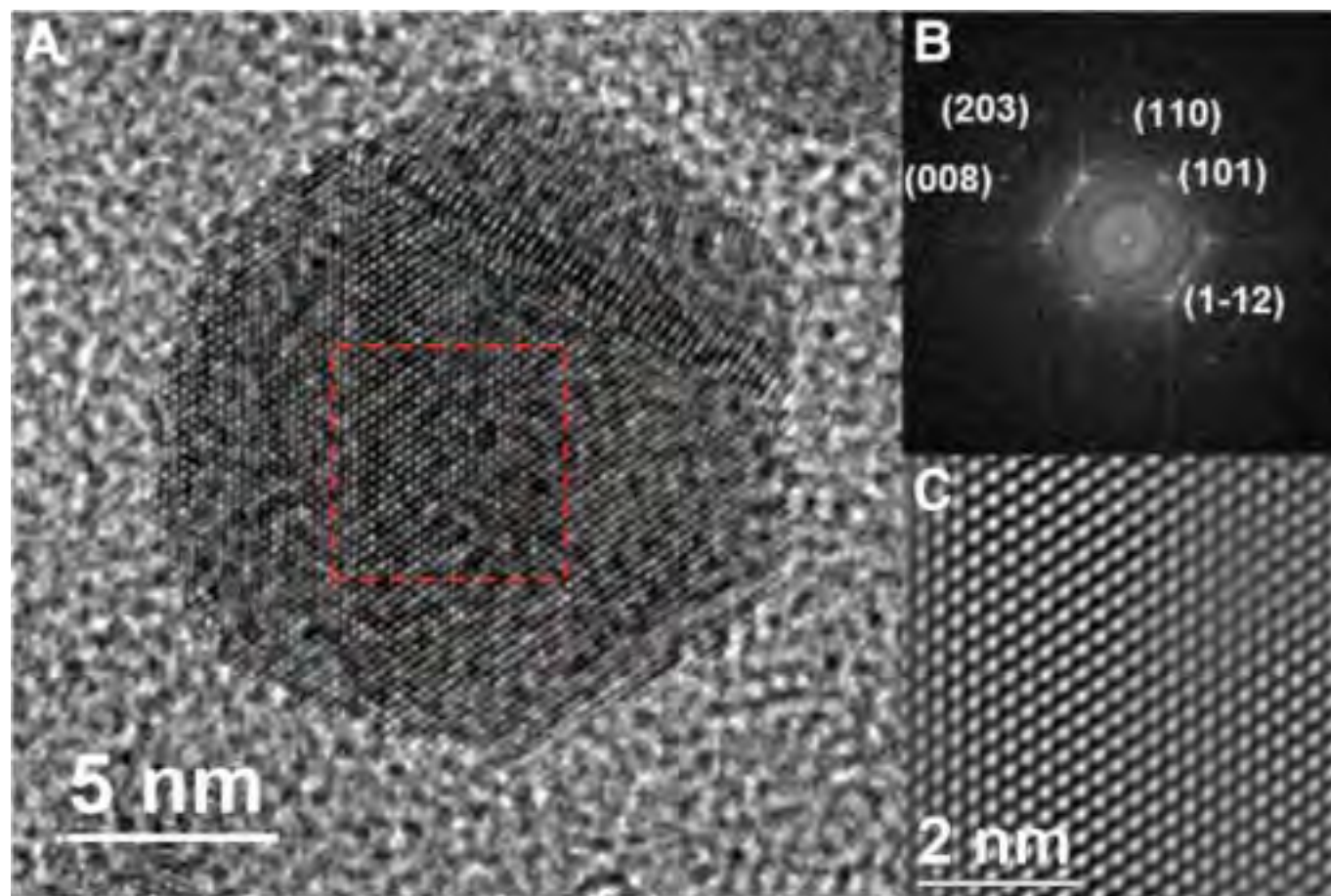






Modificación del gap en nanopartículas de CdSe

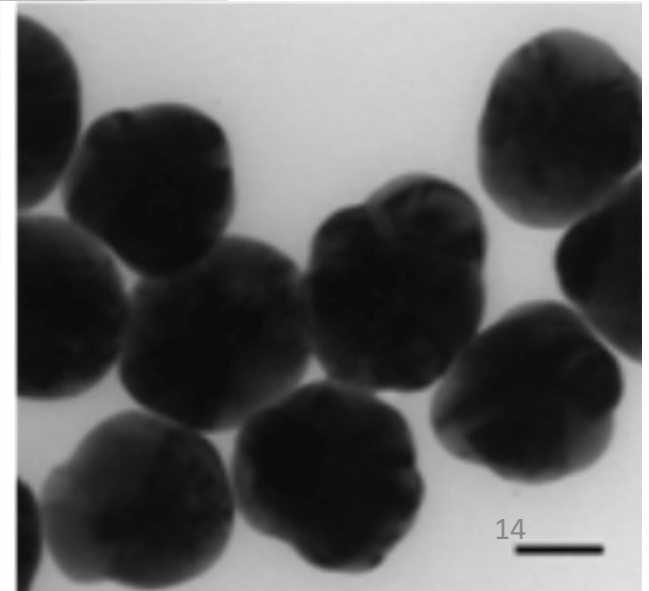
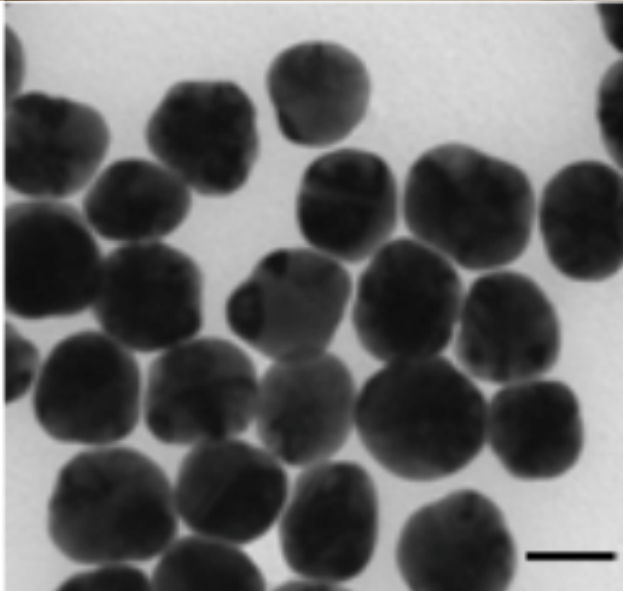
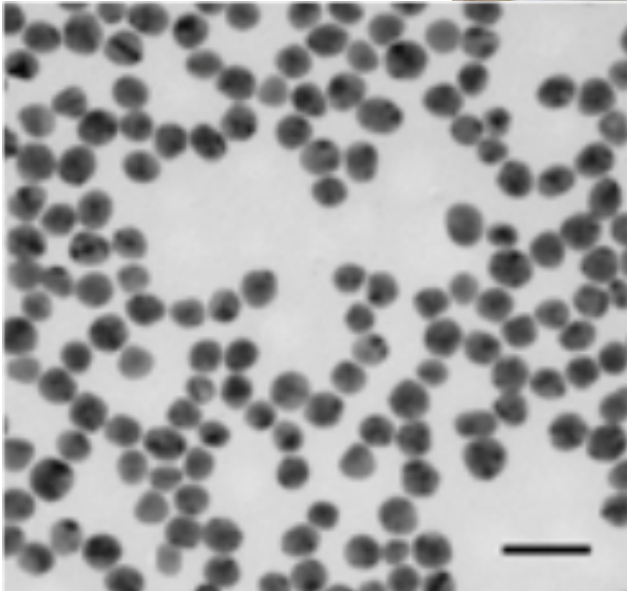


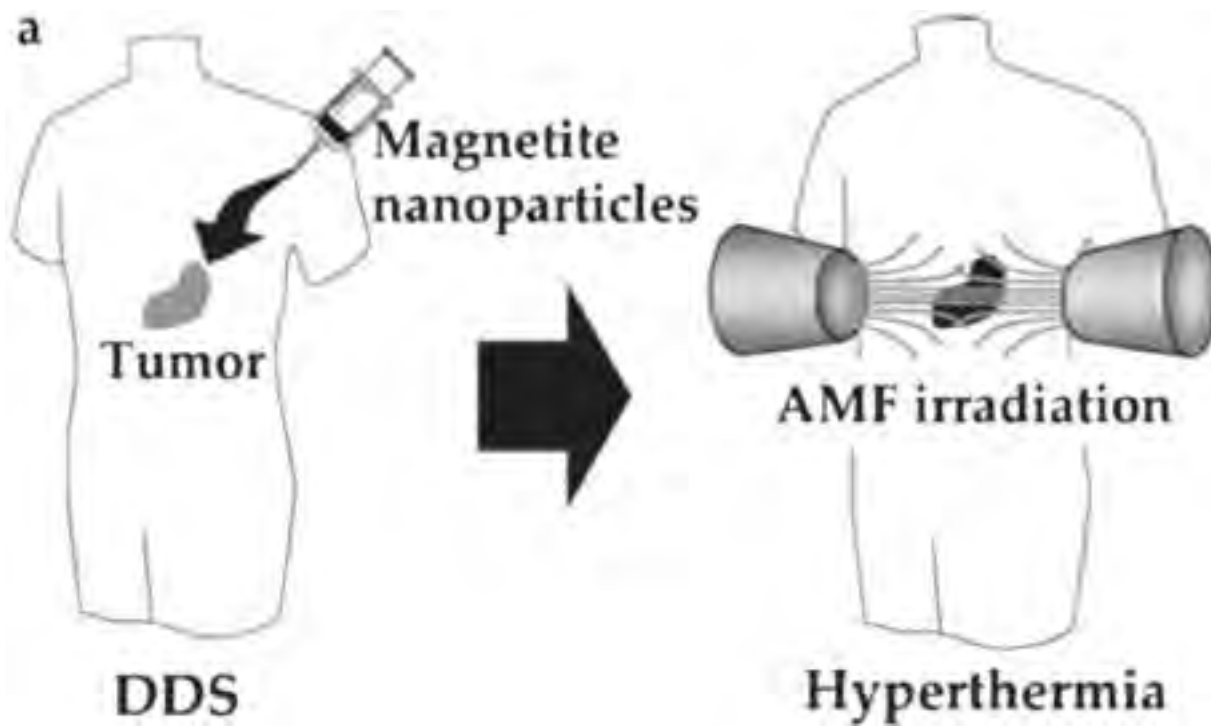


Mobiliario sanitario antibacterial

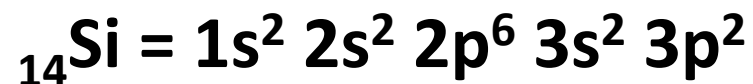


Nanopartículas
de plata







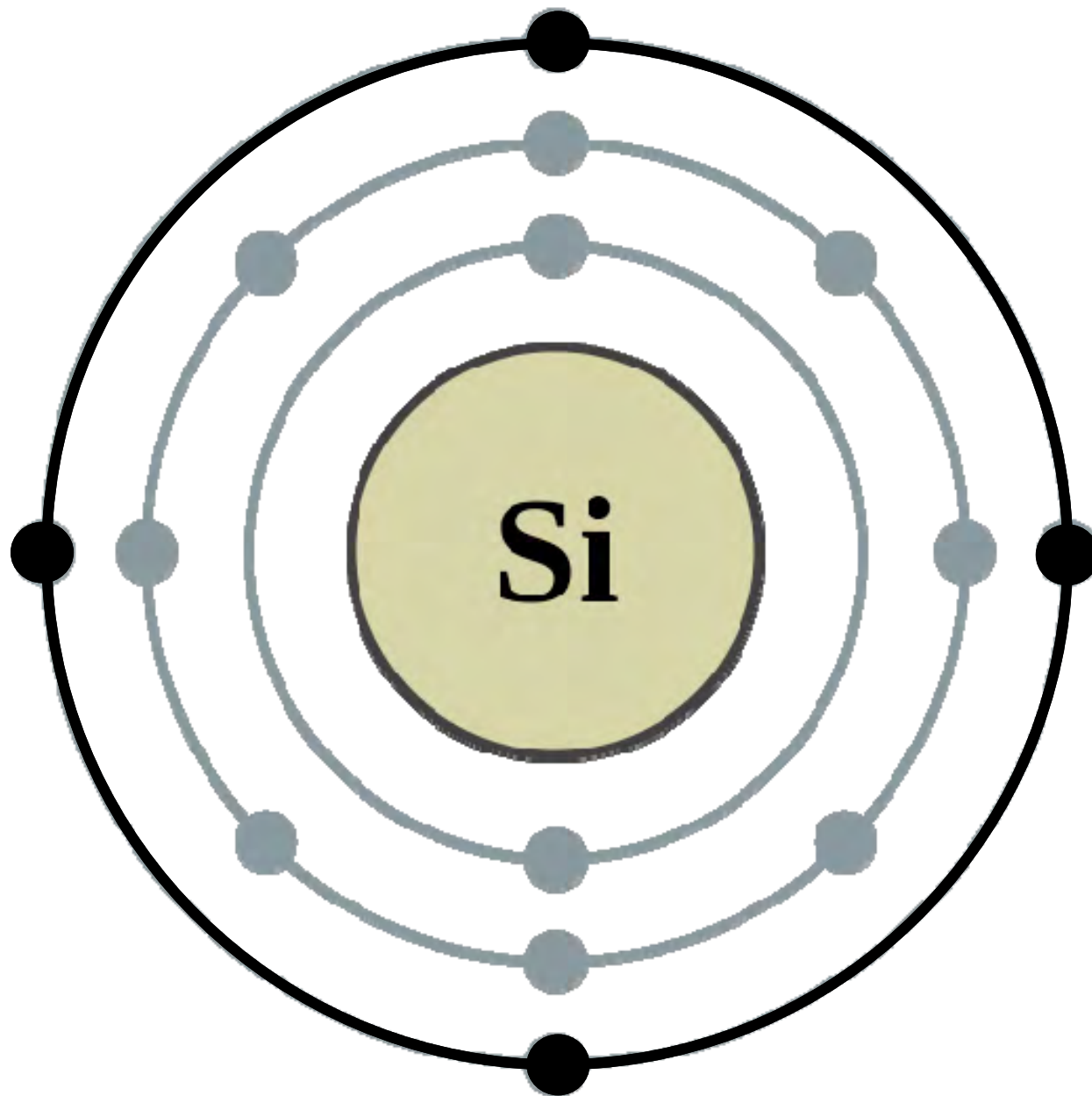


$_{14}\text{Si} = 1s^2 2s^2 2p^6 3s^2 3p^2$																							
hydrogen 1 H 1.0079																		helium 2 He 4.0026					
lithium 3 Li 6.941	beryllium 4 Be 9.0122																	boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180
sodium 11 Na 22.990	magnesium 12 Mg 24.305																	aluminium 13 Al 26.982	silicon 14 Si 28.086	phosphorus 15 P 30.974	sulfur 16 S 32.065	chlorine 17 Cl 35.453	argon 18 Ar 39.948
potassium 19 K 39.098	calcium 20 Ca 40.078	scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 29 Cu 63.546	zinc 30 Zn 65.39	gallium 31 Ga 69.723	germanium 32 Ge 72.61	arsenic 33 As 74.922	selenium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.80						
rubidium 37 Rb 85.468	strontium 38 Sr 87.62	yttrium 39 Y 88.906	zirconium 40 Zr 91.224	niobium 41 Nb 92.906	molybdenum 42 Mo 95.94	technetium 43 Tc [98]	ruthenium 44 Ru 101.07	rhodium 45 Rh 102.91	palladium 46 Pd 106.42	silver 47 Ag 107.87	cadmium 48 Cd 112.41	indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29						
caesium 55 Cs 132.91	barium 56 Ba 137.33	57-70 ★	lutetium 71 Lu 174.97	hafnium 72 Hf 178.49	tantalum 73 Ta 180.95	tungsten 74 W 183.84	rhenium 75 Re 186.21	osmium 76 Os 190.23	iridium 77 Ir 192.22	platinum 78 Pt 195.08	gold 79 Au 196.97	mercury 80 Hg 200.59	thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi 208.98	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]					
francium 87 Fr [223]	radium 88 Ra [226]	89-102 ★ ★	lawrencium 103 Lr [262]	rutherfordium 104 Rf [261]	dubnium 105 Db [262]	seaborgium 106 Sg [266]	bohrium 107 Bh [264]	hassium 108 Hs [269]	meitnerium 109 Mt [268]	ununnium 110 Uun [271]	ununium 111 Uuu [272]	unubium 112 Uub [277]		ununquadium 114 Uuq [289]									

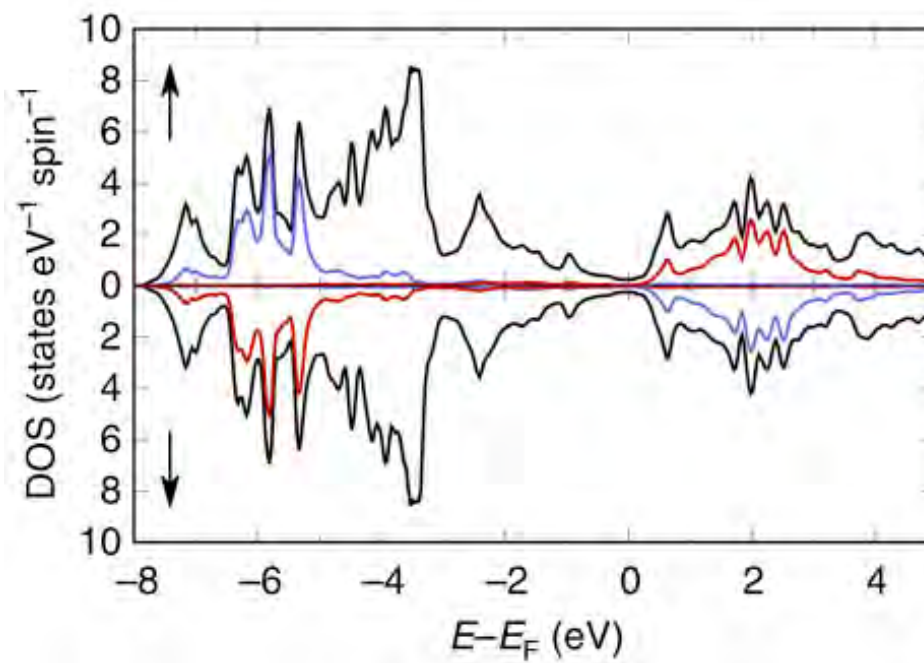
* Lanthanide series

** Actinide series

lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.04
actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mendelevium 101 Md [258]	nobelium 102 No [259]



$$i\hbar \frac{\partial}{\partial t} \Psi = \hat{H} \Psi$$



Semiconducto

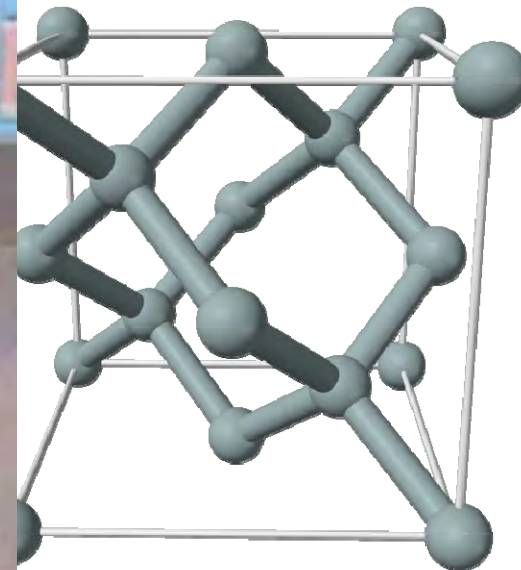


Silicio obtenido mediante procesos químicos

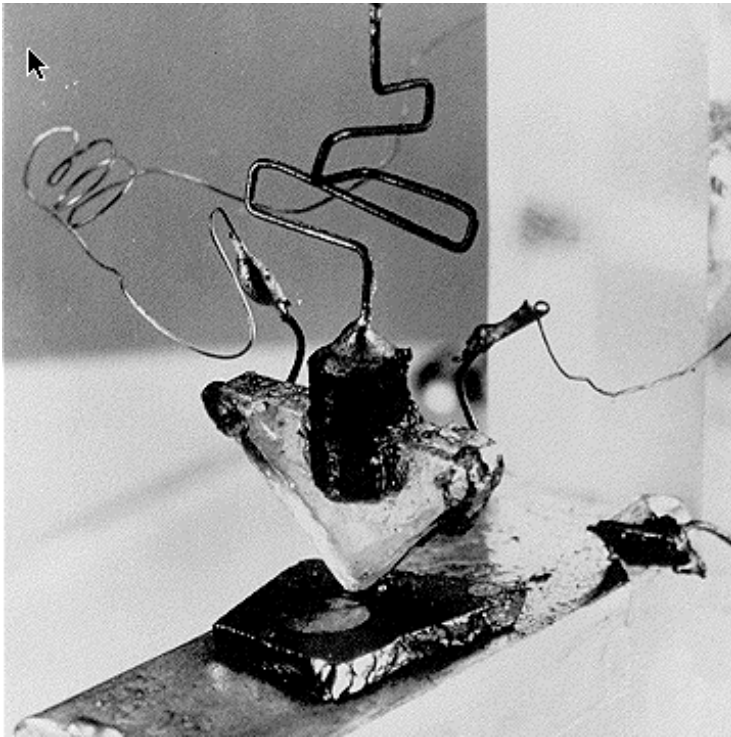
Monocrystal de Si
obtenido por el método
de Czochralski



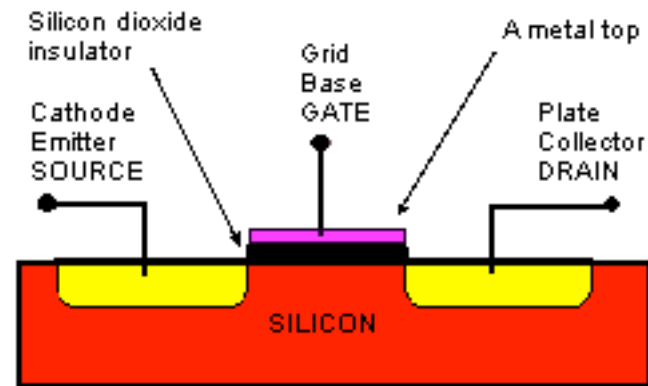
Si tiene una estructura
cúbica centrada en las
caras. Tipo diamante.



Transistor

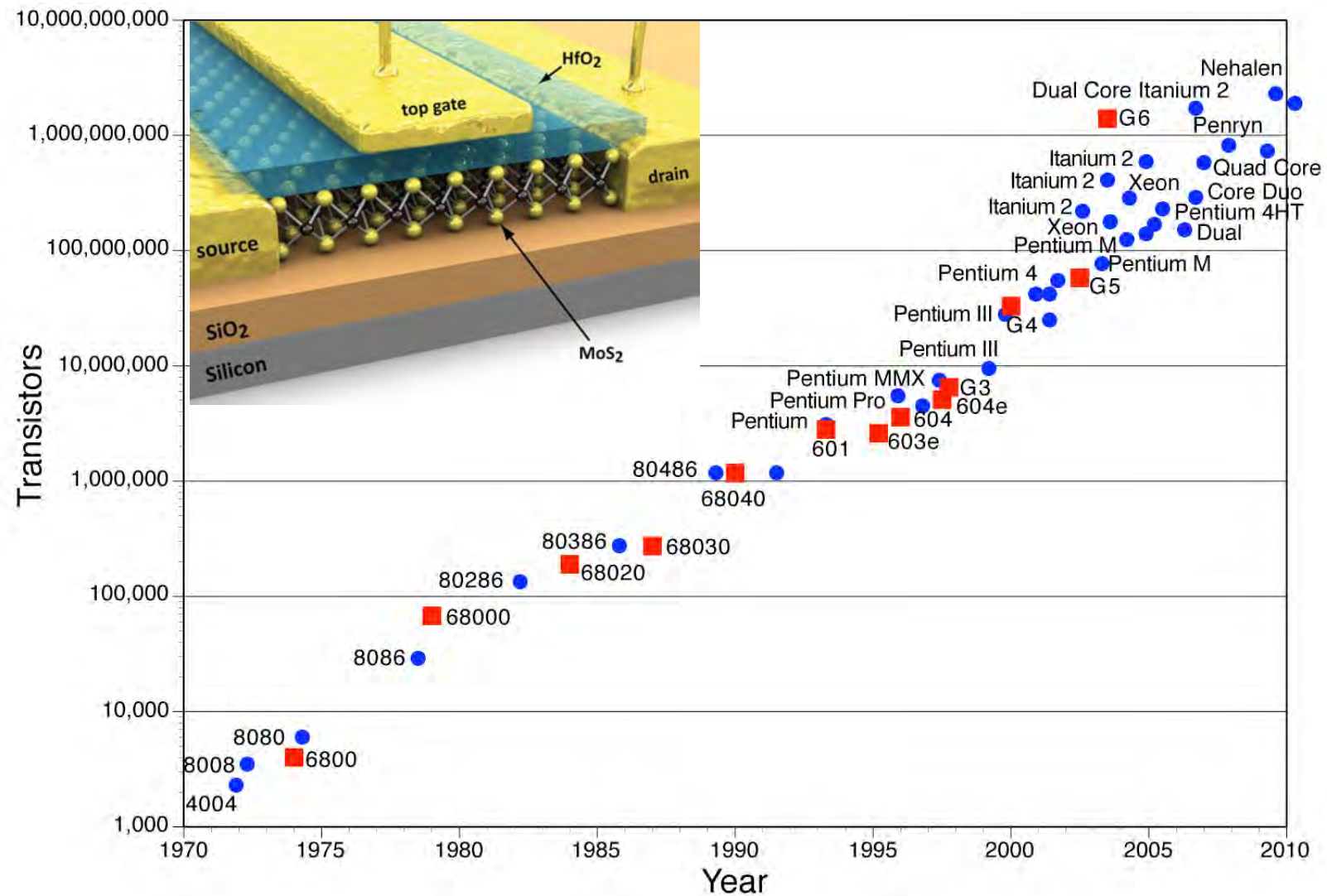


John Bardeen, 1956

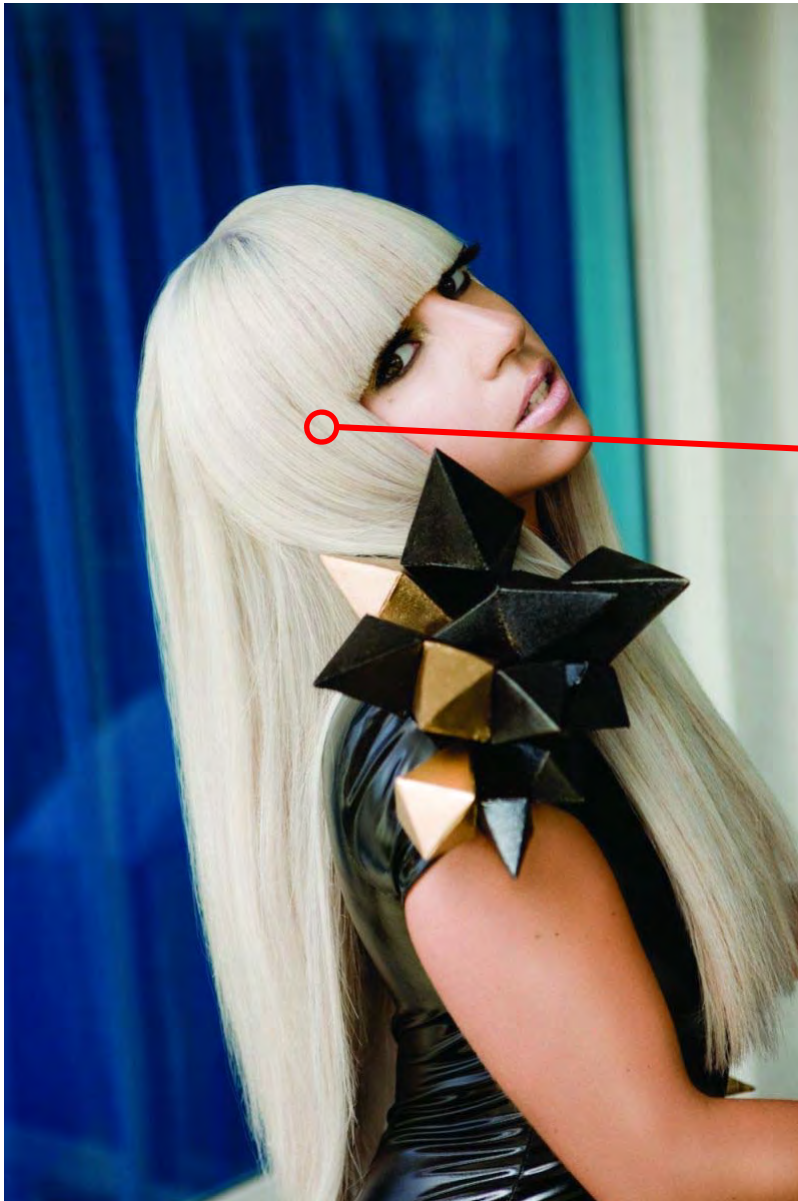


A MOSFET -- one kind of field effect transistor

Ley de Moore (Gordon)

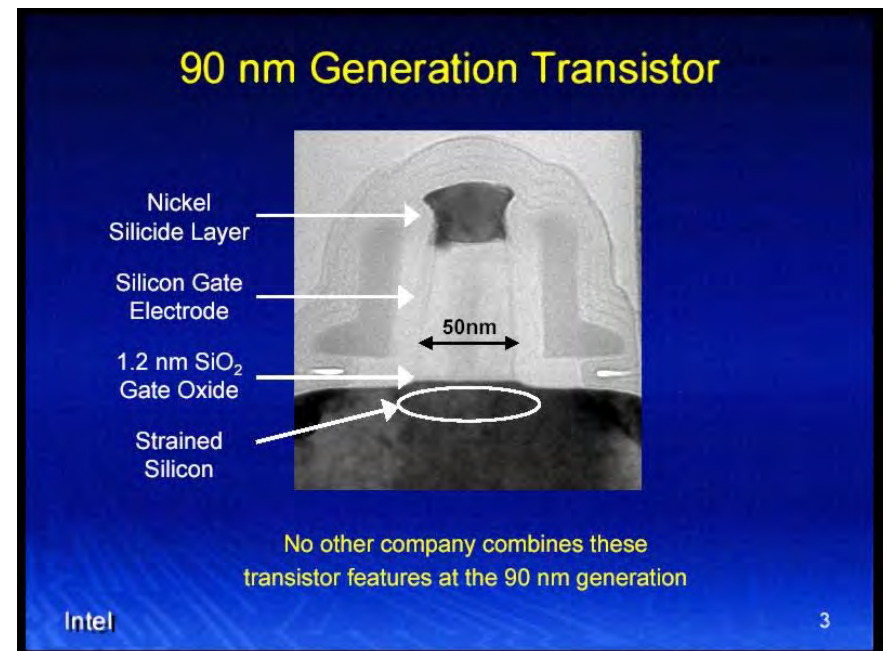


Comparación de magnitudes.....

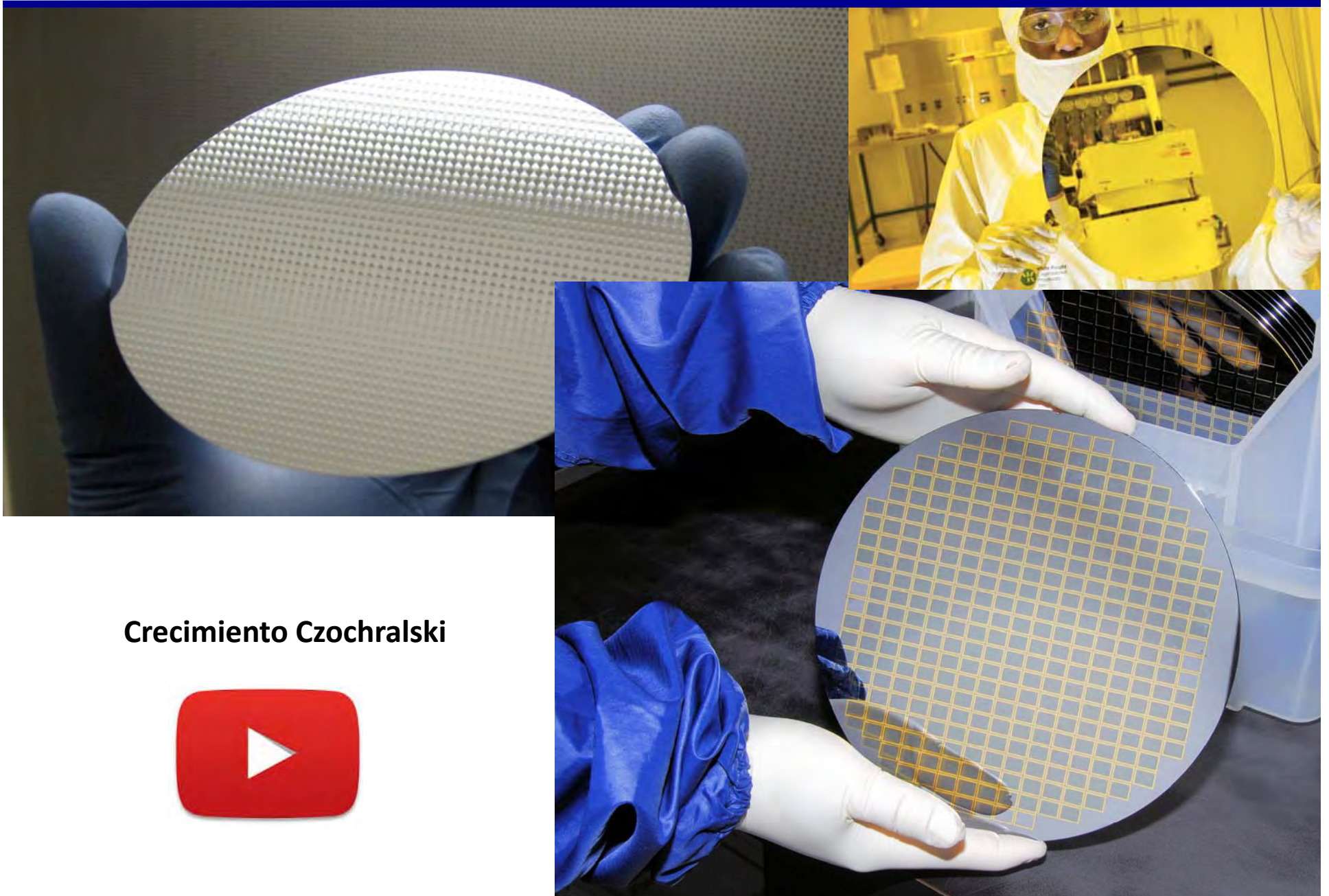


Es posible acomodar 1000 transistores e lo largo del diámetro de un cabello.....

Diametro= 70 μm

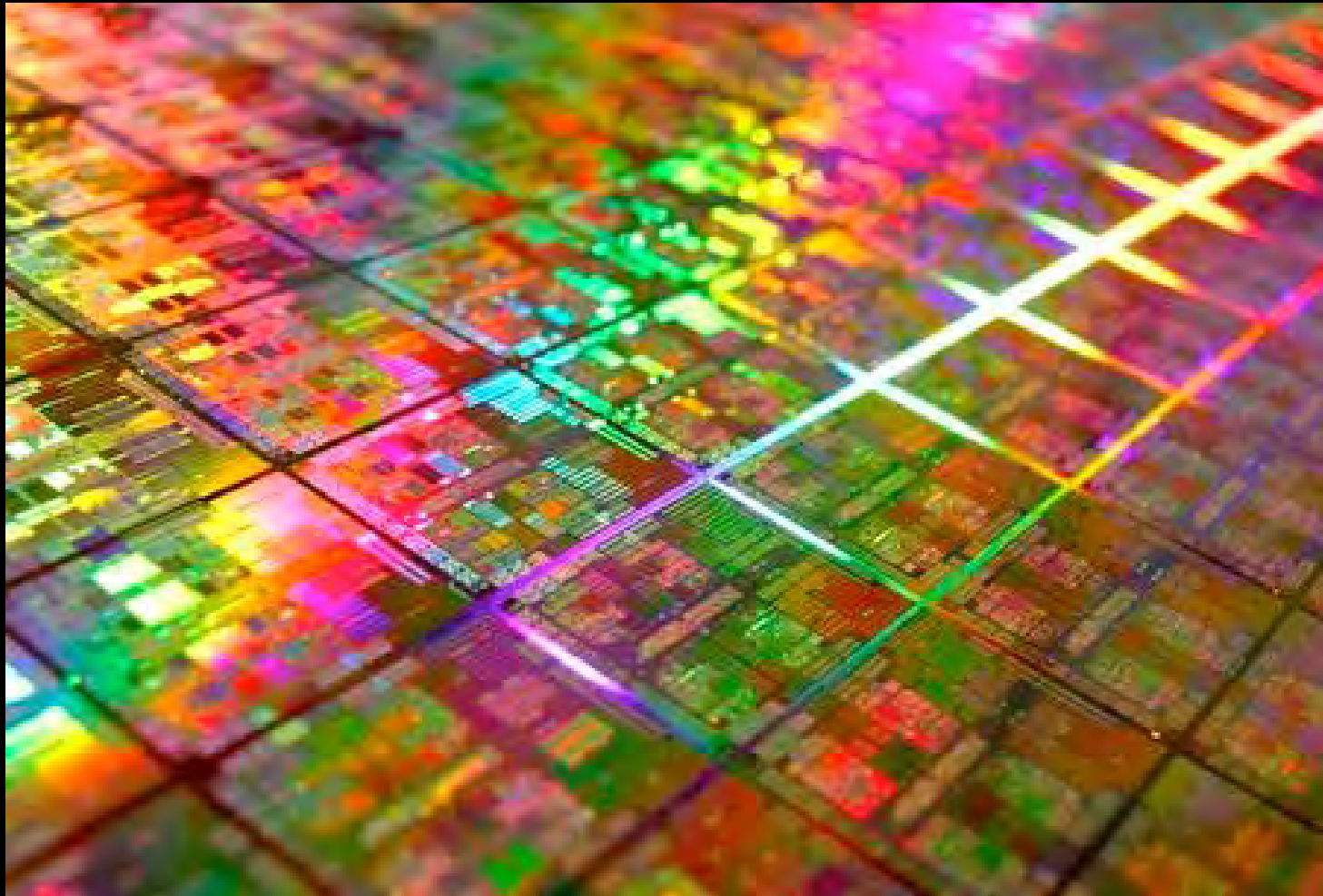


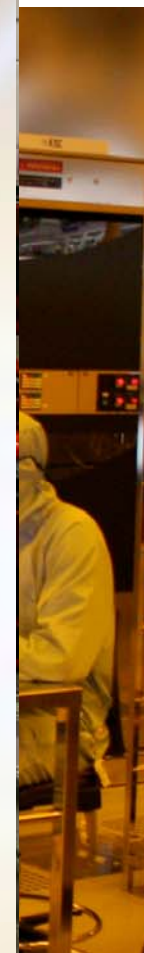
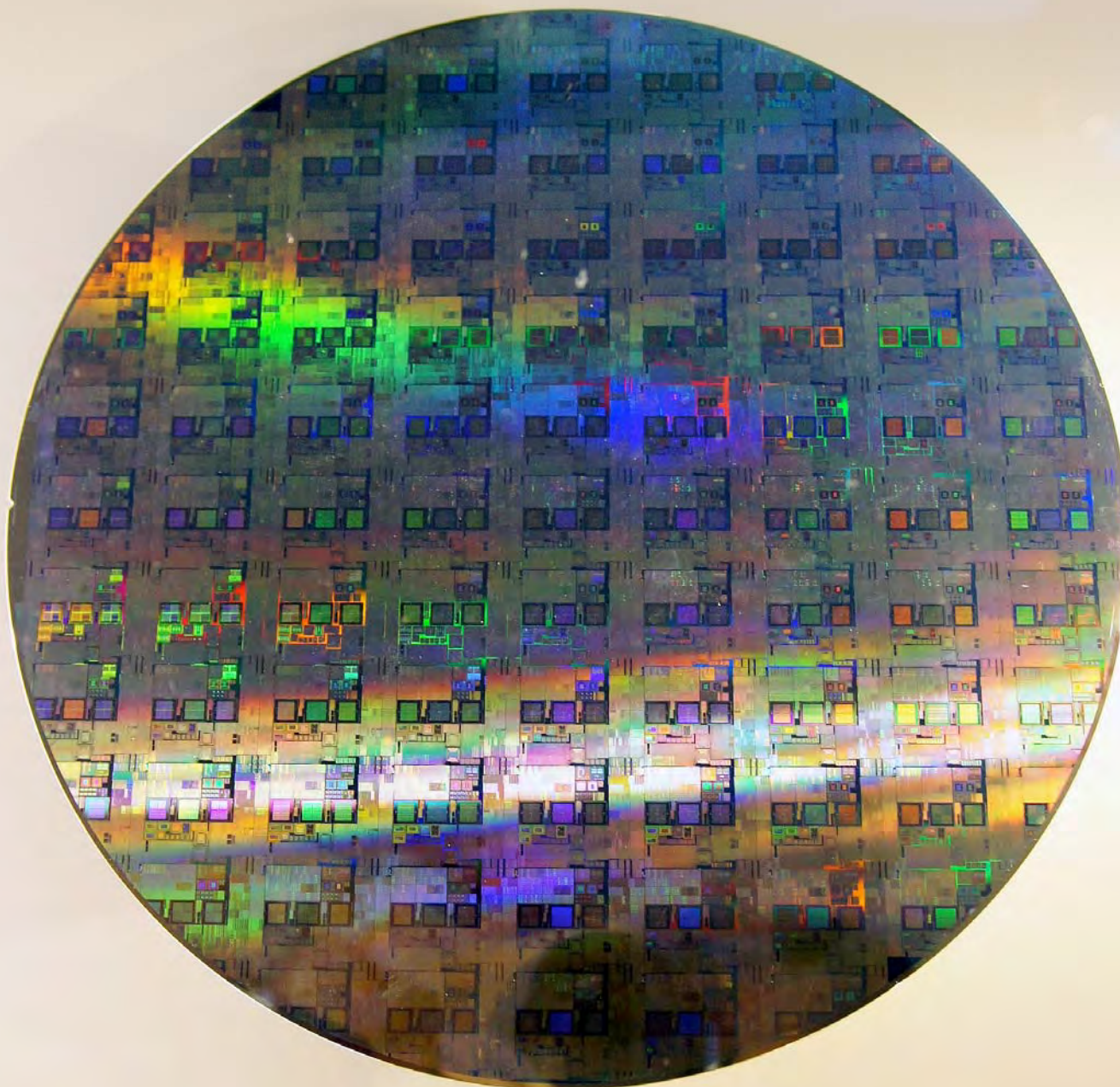
Fabricación de un sustrato de silicio



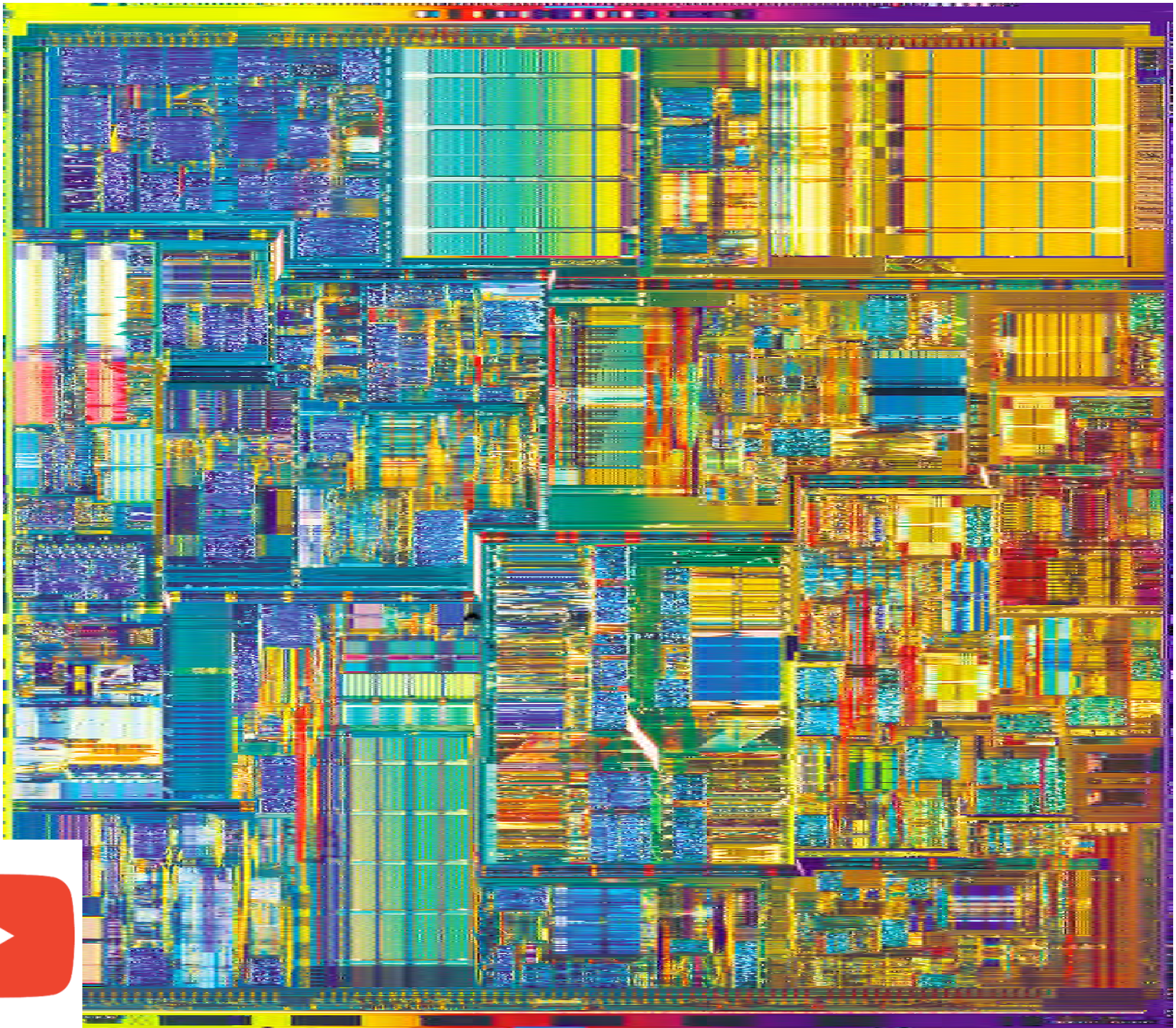
Crecimiento Czochralski

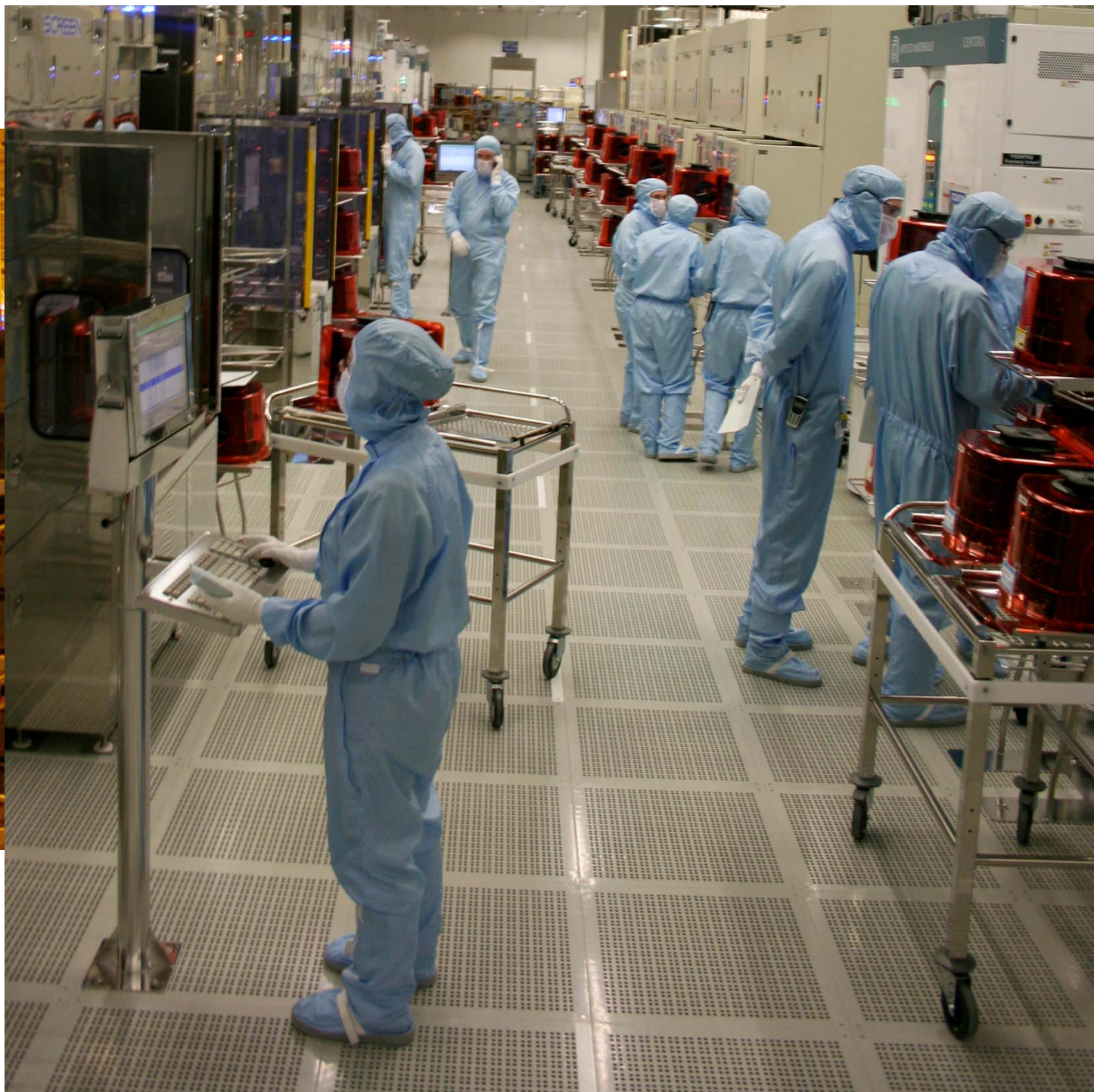




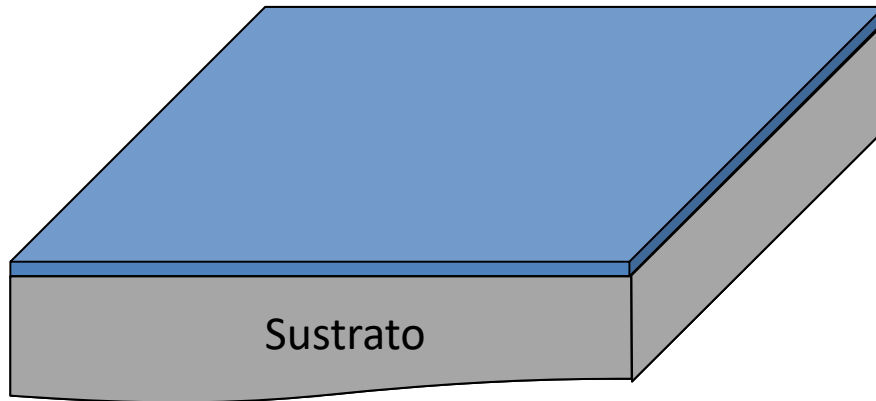


<http://crolles>



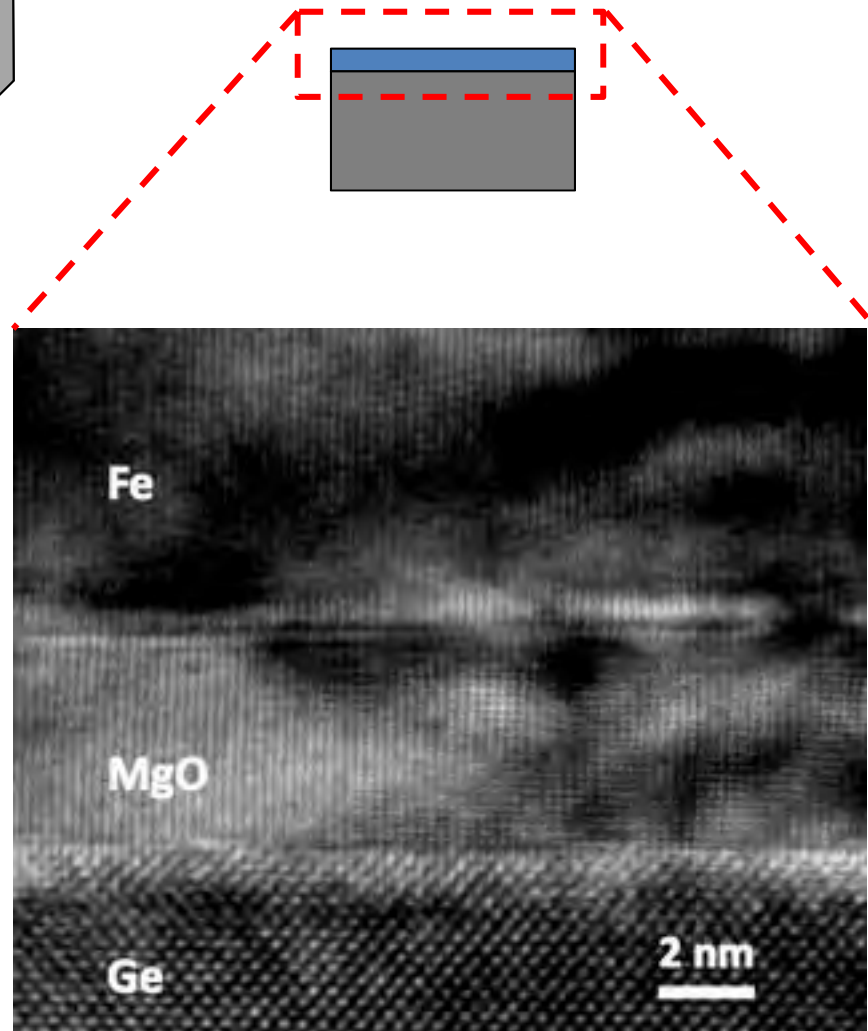


Introducción: película delgada

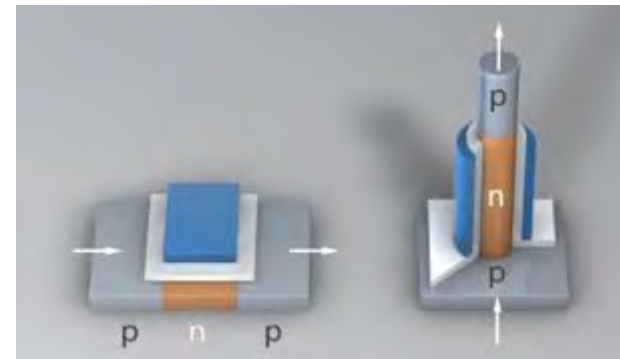
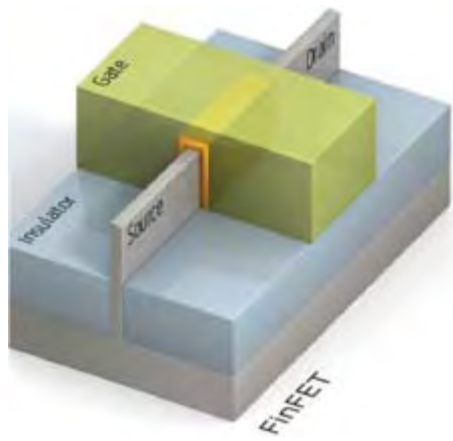
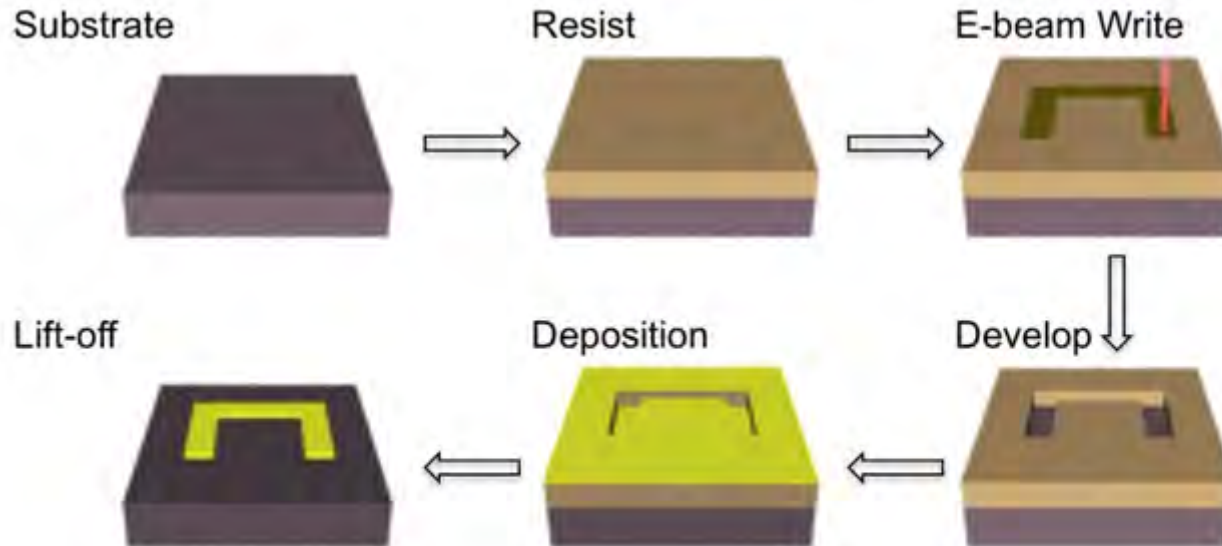


Sustratos:

- Silicio
- Germanio
- GaAs
- InAs
- Zafiro
- MgO
- Perovskitas
- etc



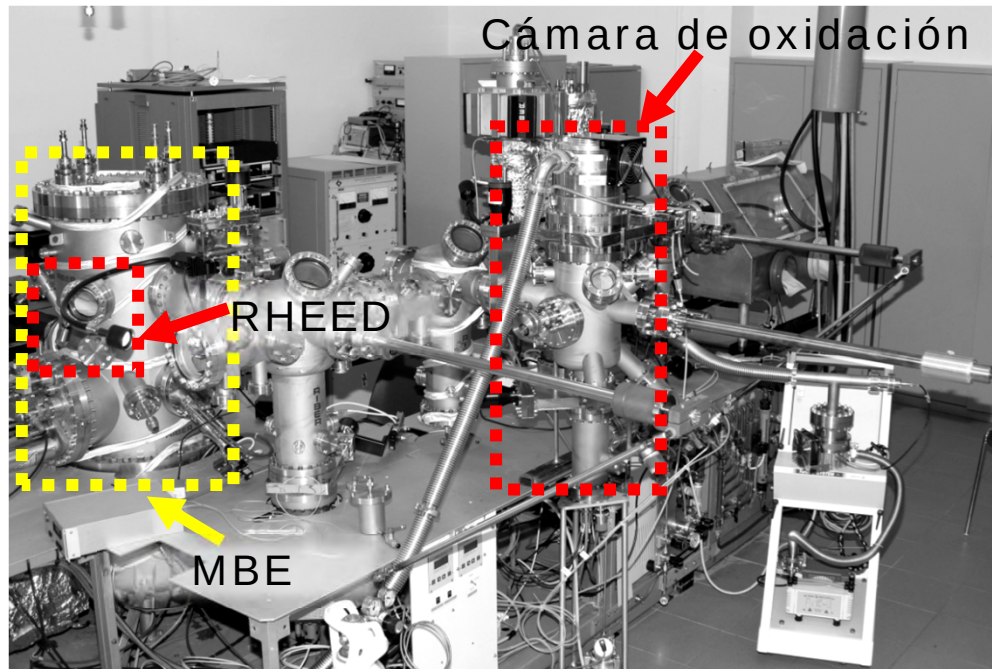
Introducción: litografía





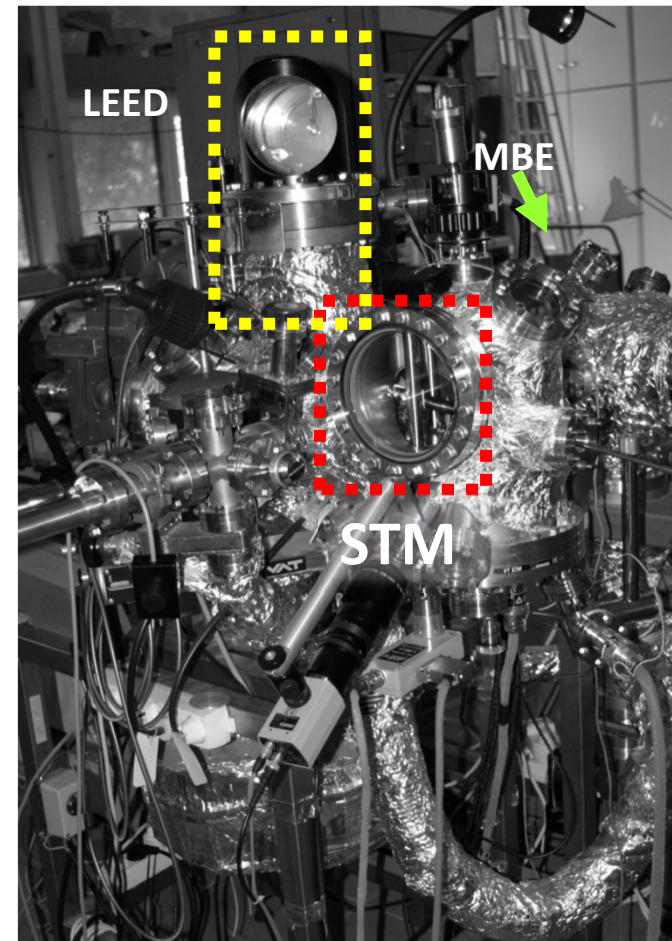
Sistemas de alto-ultra vacio (UHV)

1/ MBE + Cámara de oxidación

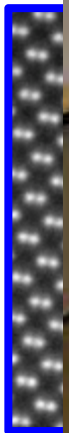


- Presión base del sistema: **$1-2 \times 10^{-10}$ Torr**
- Elaboración del material a partir de fuentes solidas: células Knudsen

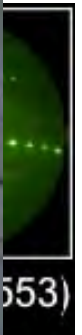
2/ STM



Pat

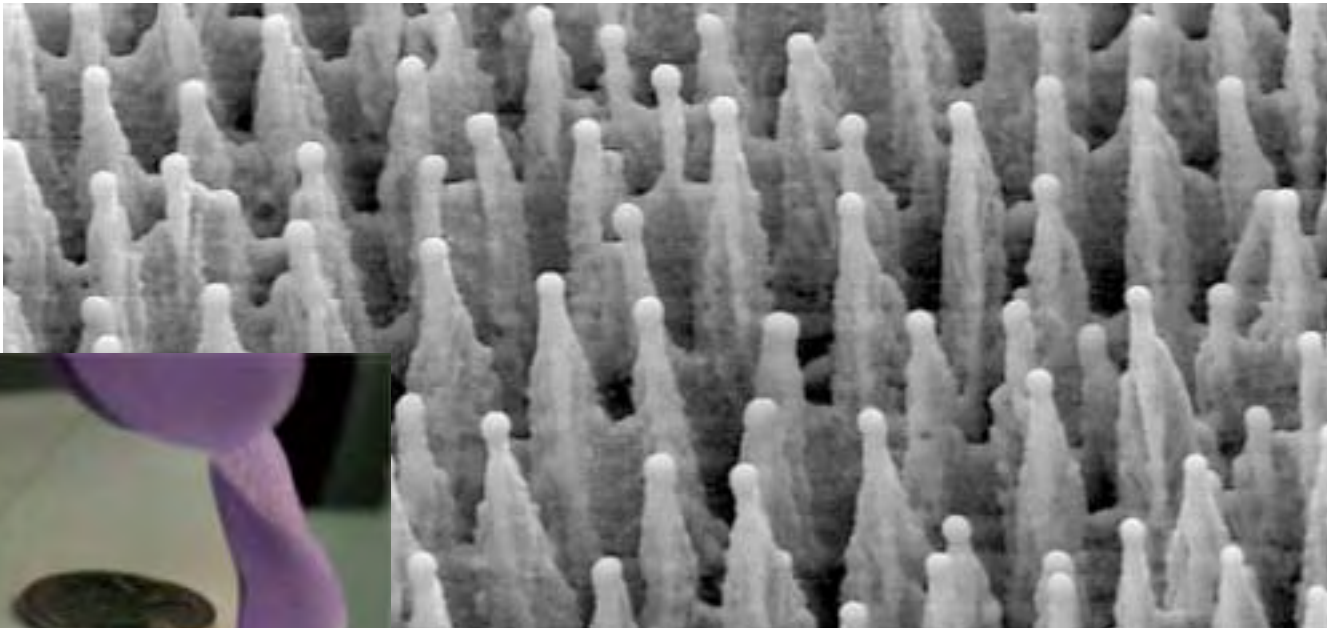


M
m
(T



Black Silicon

Presenta absorción del espectro en el rango de la luz visible



1 μm

Tendencias hacia la miniaturización

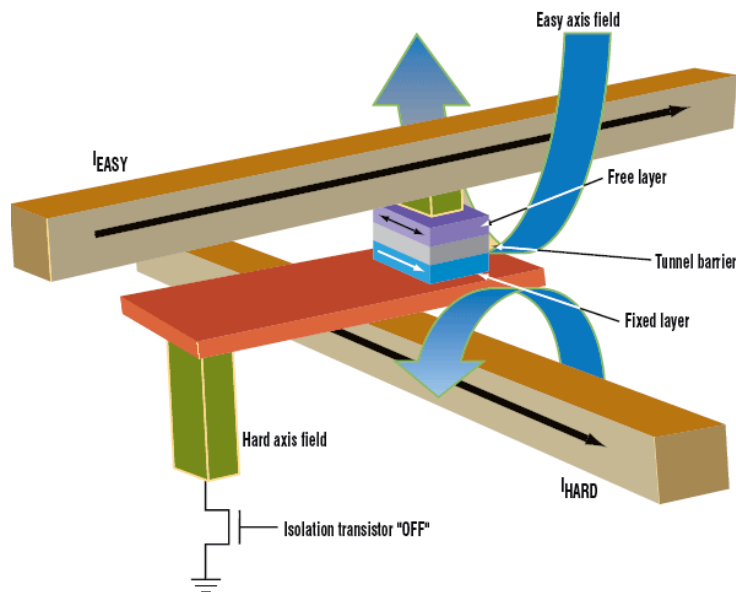
- Óxidos dieléctricos High- κ
- Moléculas semiconductoras
- Geometrías 3D
- **Spintrónica**
 - ✓ Interacciones spin-órbita
 - ✓ Torsion por transferencia de spin
 - ✓ Bombeo de spin
 - ✓ Efecto Hall de spin
 - ✓ Caloritronics

Memoria universal: MRAM (Magnetic Random Access Memory)



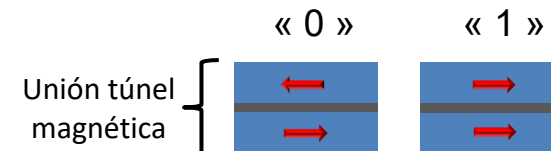
Memorias STT-MRAM

Spin Tranfert Torque - Magnetic Random Acces Memory



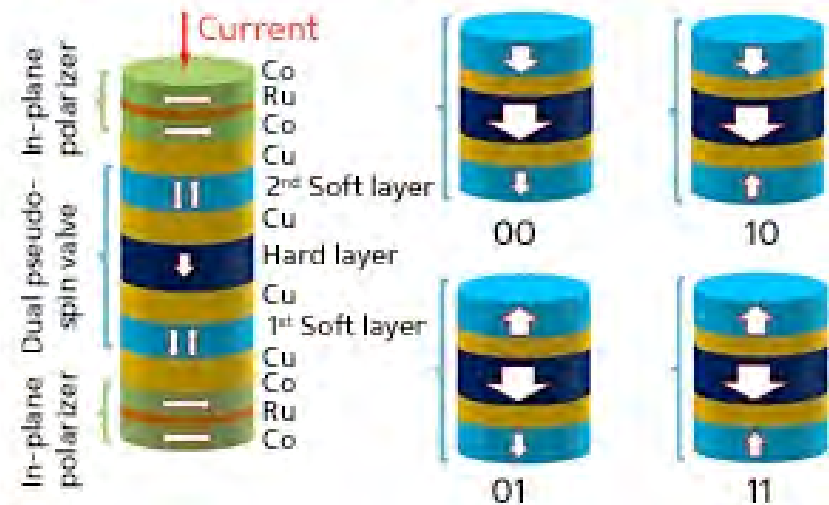
1. To write an MRAM bit, current is passed through a program line to generate a magnetic field. The sum of the magnetic field from both lines is needed to program the bit. To read an MRAM bit, current is passed through the bit and the resistance of the bit is sensed.
(courtesy of Freescale)

Estructura completa



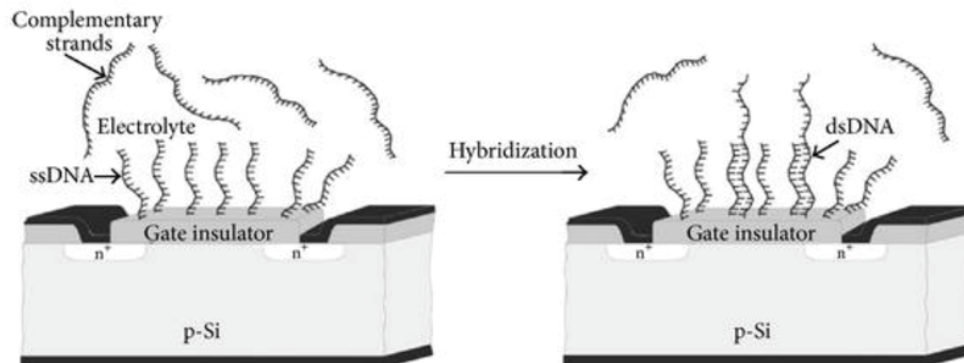
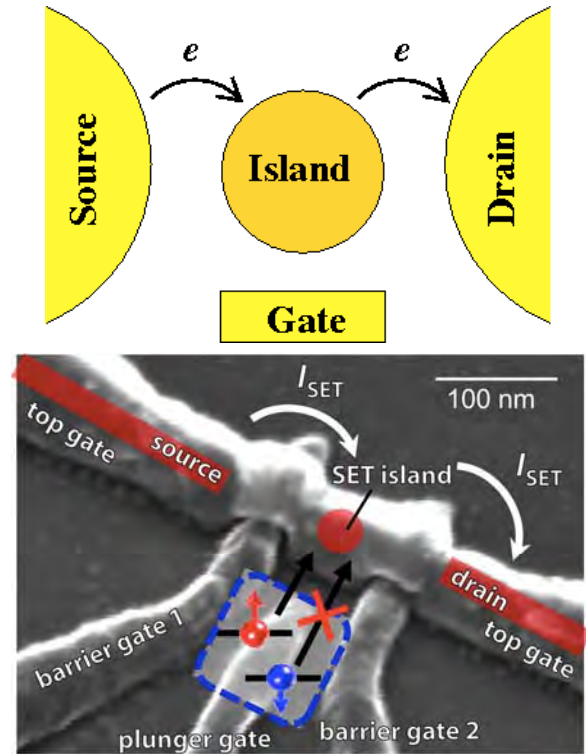
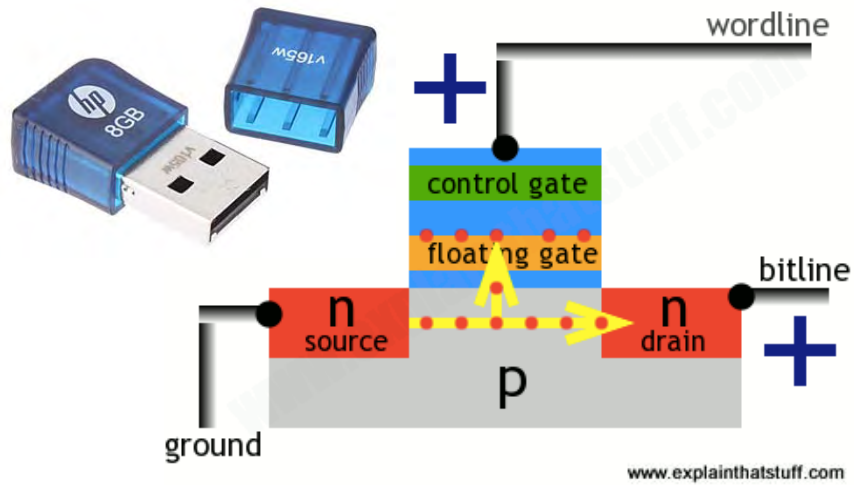
Multi-level STT-MRAM Layer Design

Magnetization states showing Multi-level

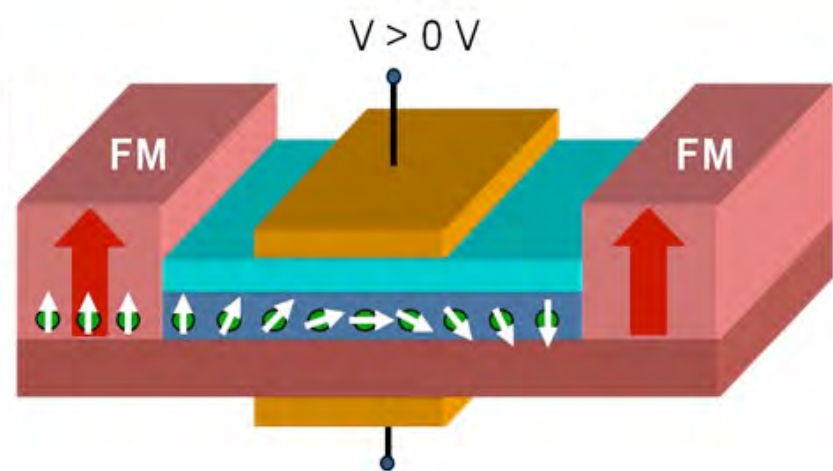
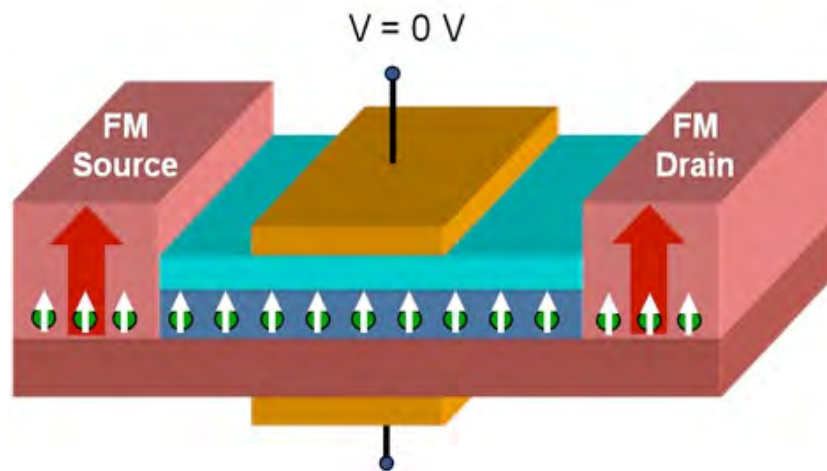
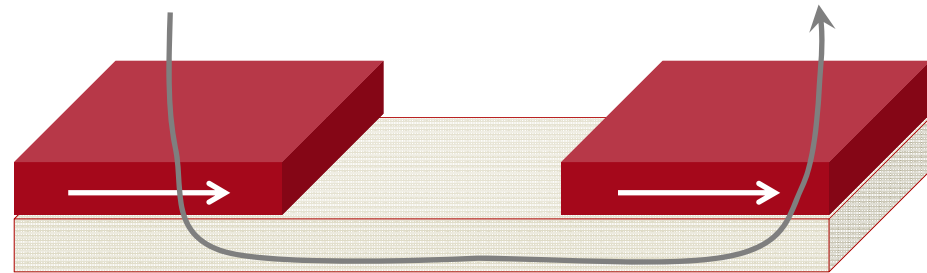
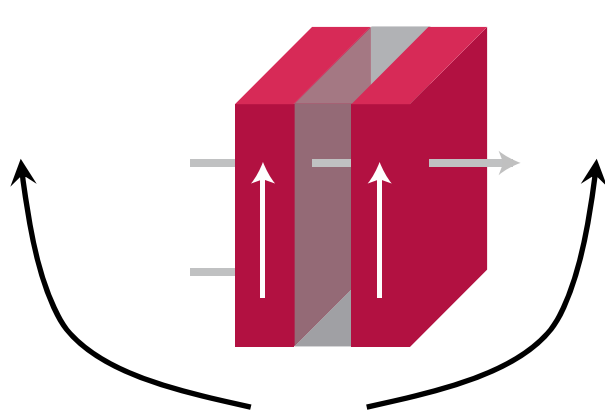


- Por STT la densidad de almacenamiento es mayor
- Se utiliza un pulso electrico para cambiar de estado 0,1, 2 → MBPC
- Mn_3Ga : ferrimagnético, baja magnetización, alta T_C , alta K_1

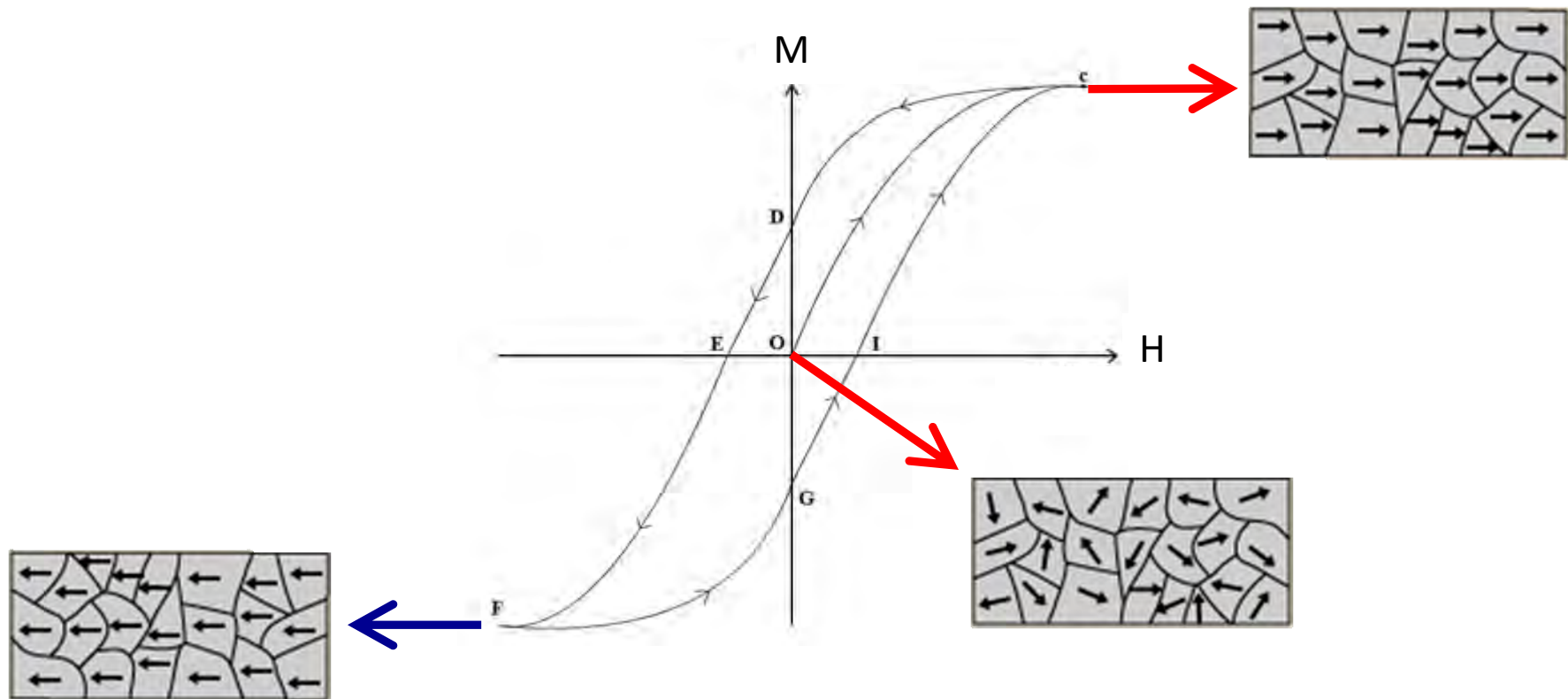
Otros transistores FET



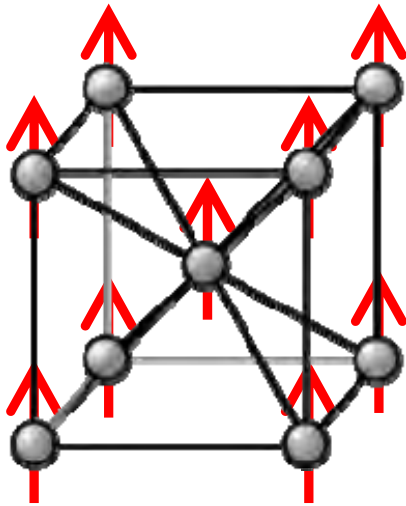
Transistor de spin



Proceso de magnetización de un material



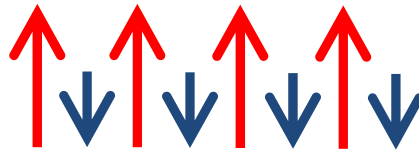
Otros comportamientos magnéticos



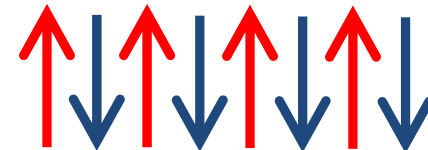
Fe, bcc



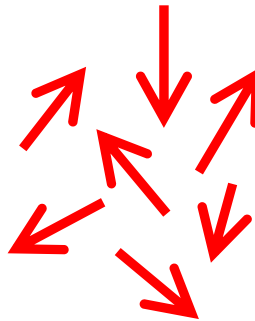
Ferromagnético



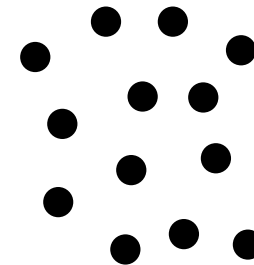
Ferrimagnético



Antiferromagnético

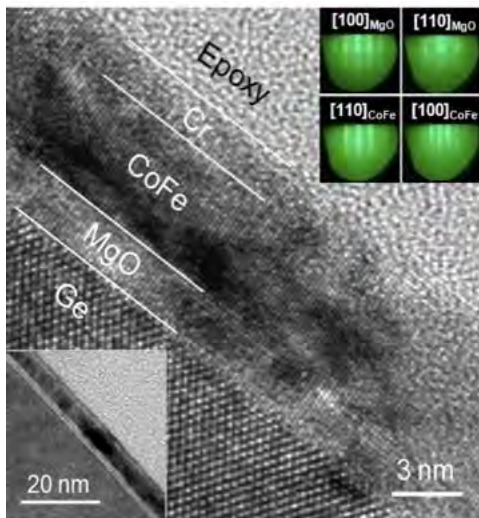


Paramagnético

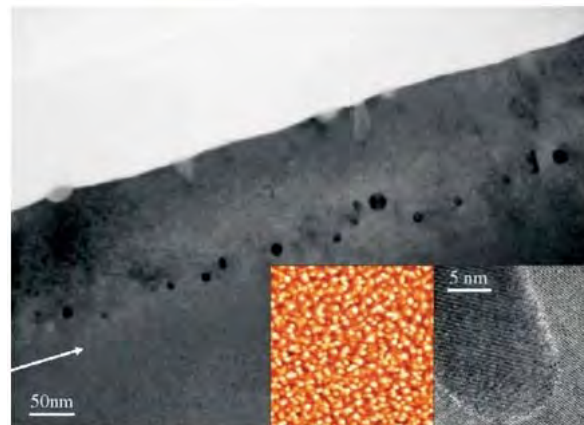
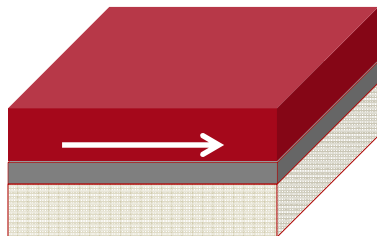


Diamagnético

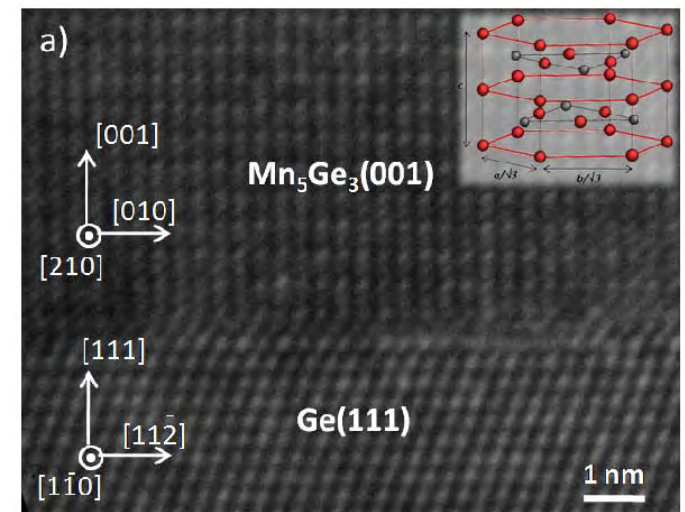
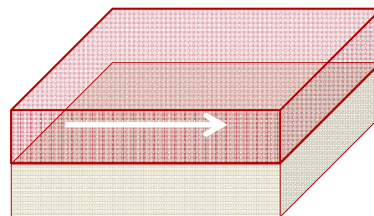
Inyección de spin



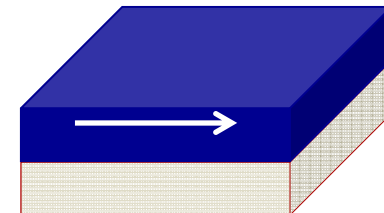
Inyección a través
una barrera túnel:
Interfaces



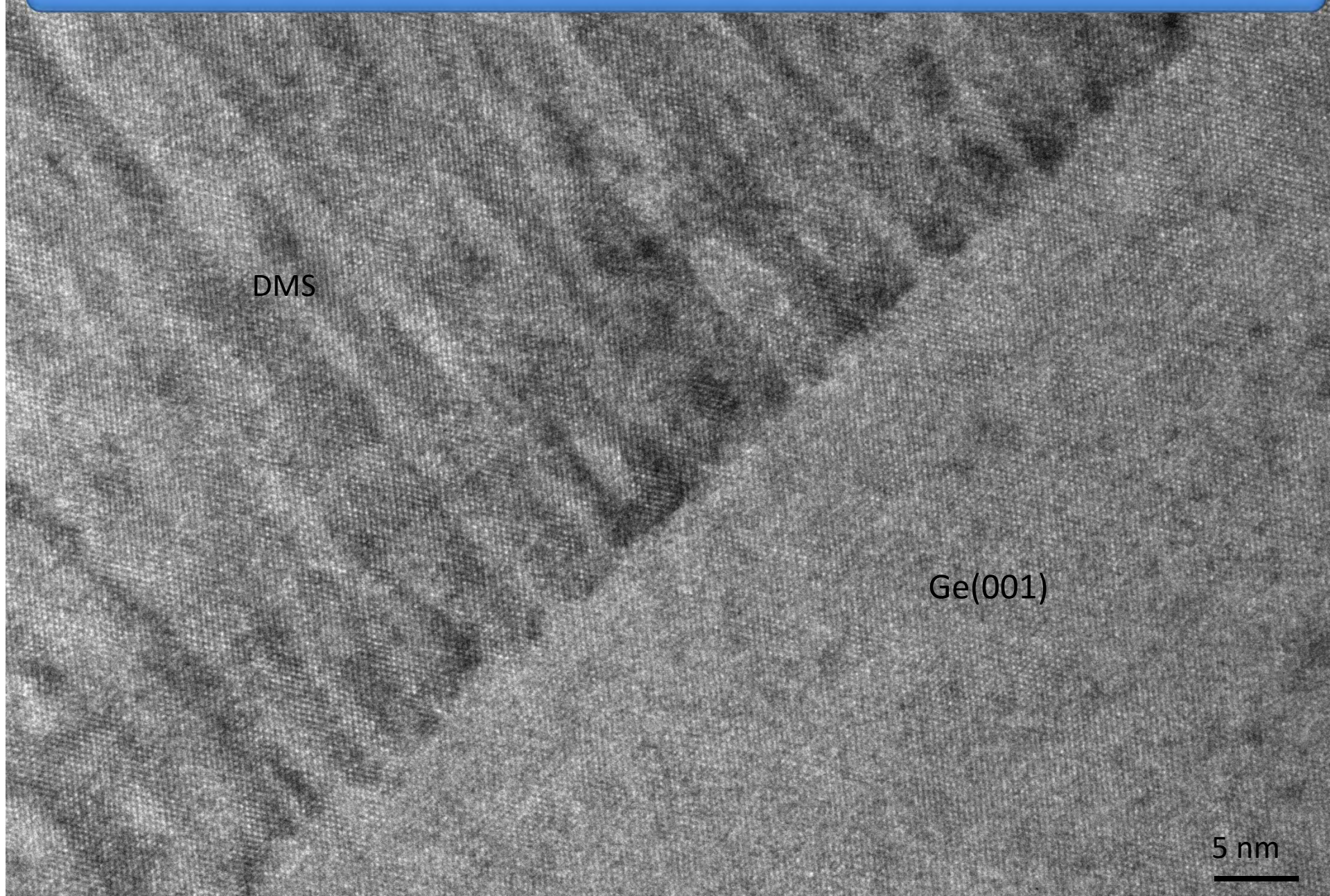
A partir de un DMS:
Baja T_C



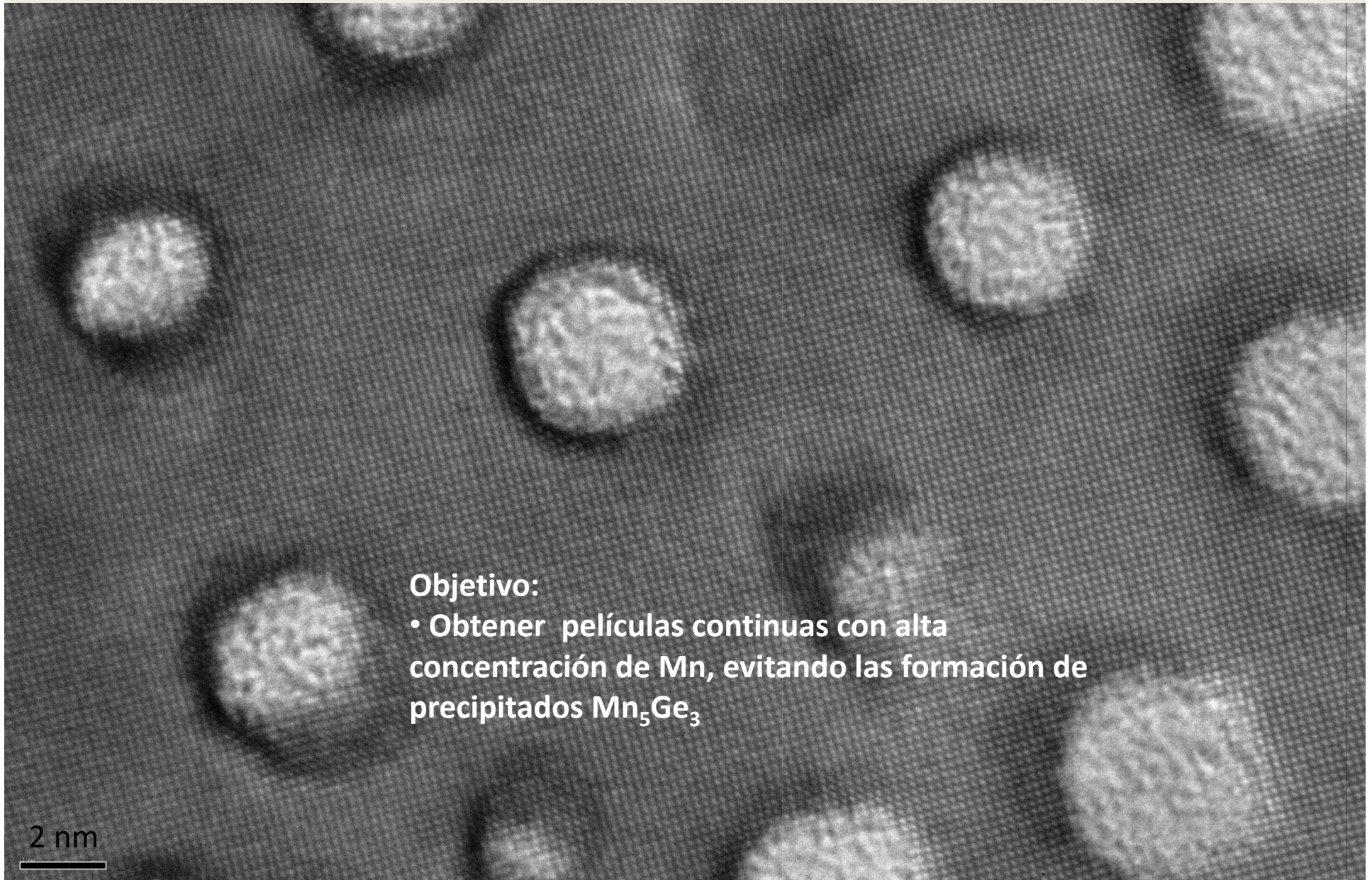
A partir de una fase
ferromagnética:
Barrera Schottky



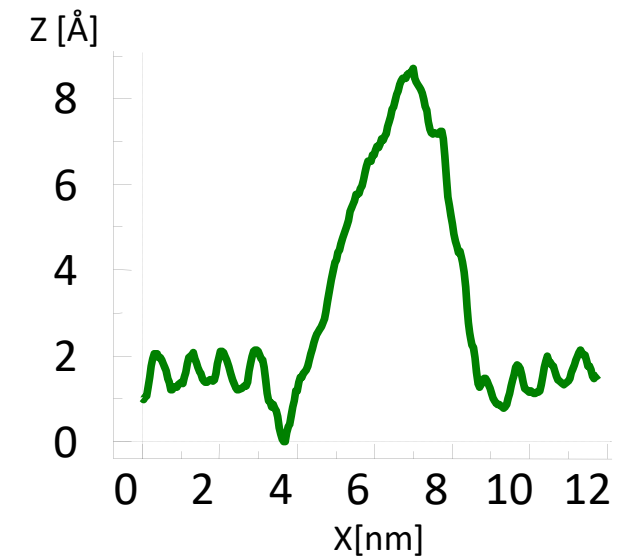
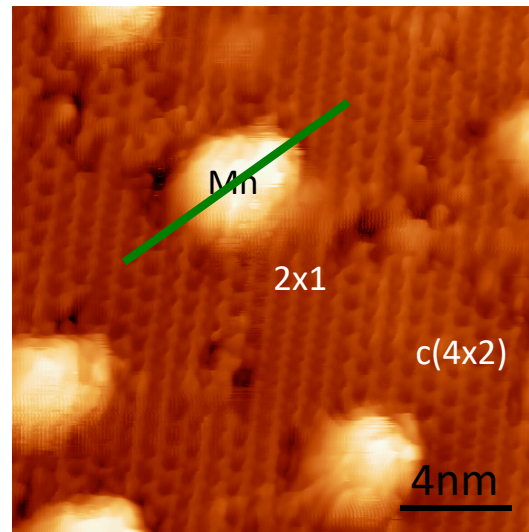
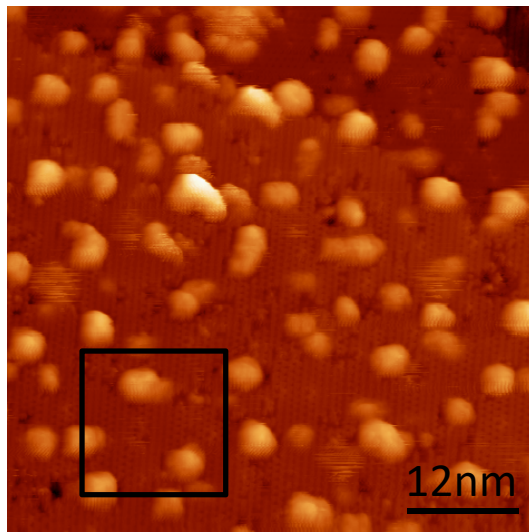
Elaboración de DMS $\text{Ge}_{1-x}\text{Mn}_x \rightarrow$ TEM: cross-section



Elaboración de DMS $\text{Ge}_{1-x}\text{Mn}_x$ → TEM: plane-view



Crecimiento 3D de Mn/Ge(001)



→ $\Theta_{\text{Mn}} = 0,44 \text{ MC}$

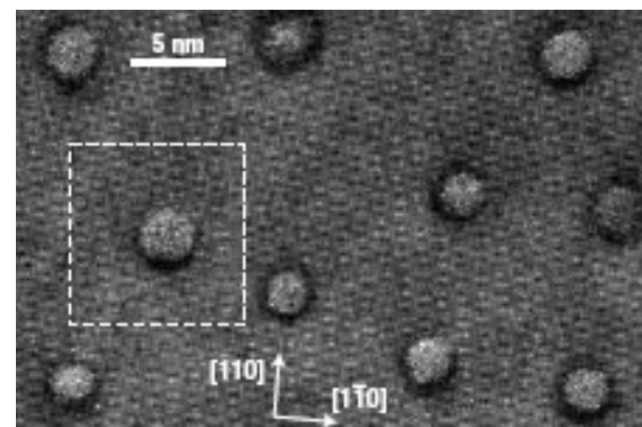
→ Formación de islotes de tamaño homogéneo

- Tamaño medio $\sim 4,5 \text{ nm}$
- Separación media $\sim 7 \text{ nm}$

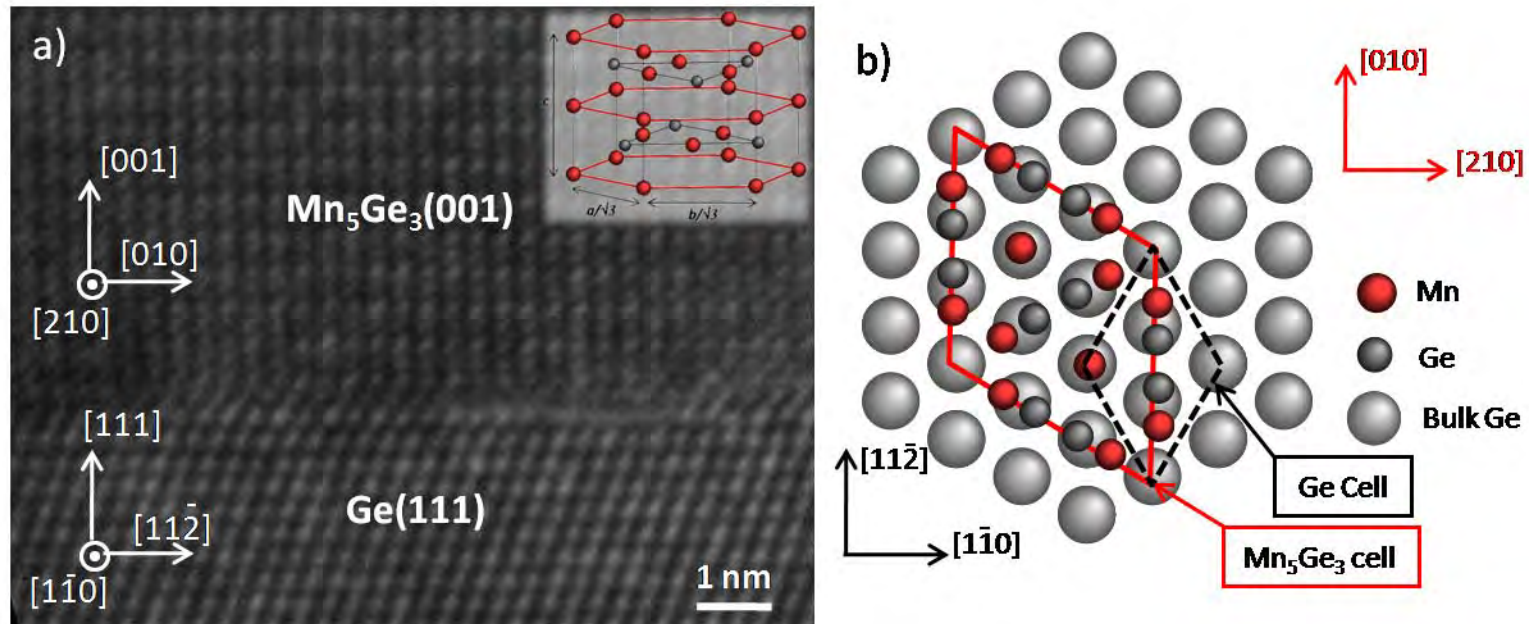
→ Entre los islotes: Ge puro

- Coexistencia de reconstrucciones 2×1 et (4×2)

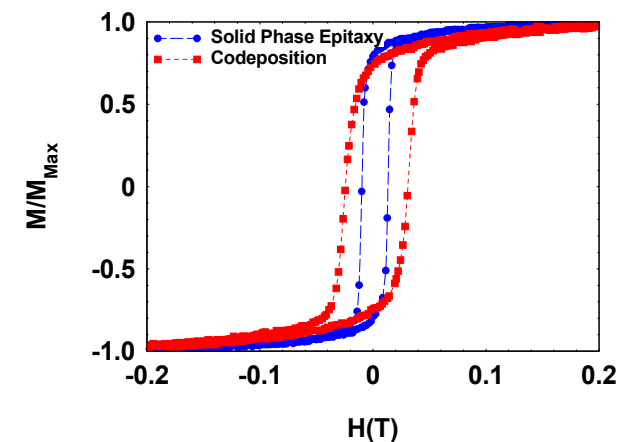
Crecimiento: modo Volmer-Weber



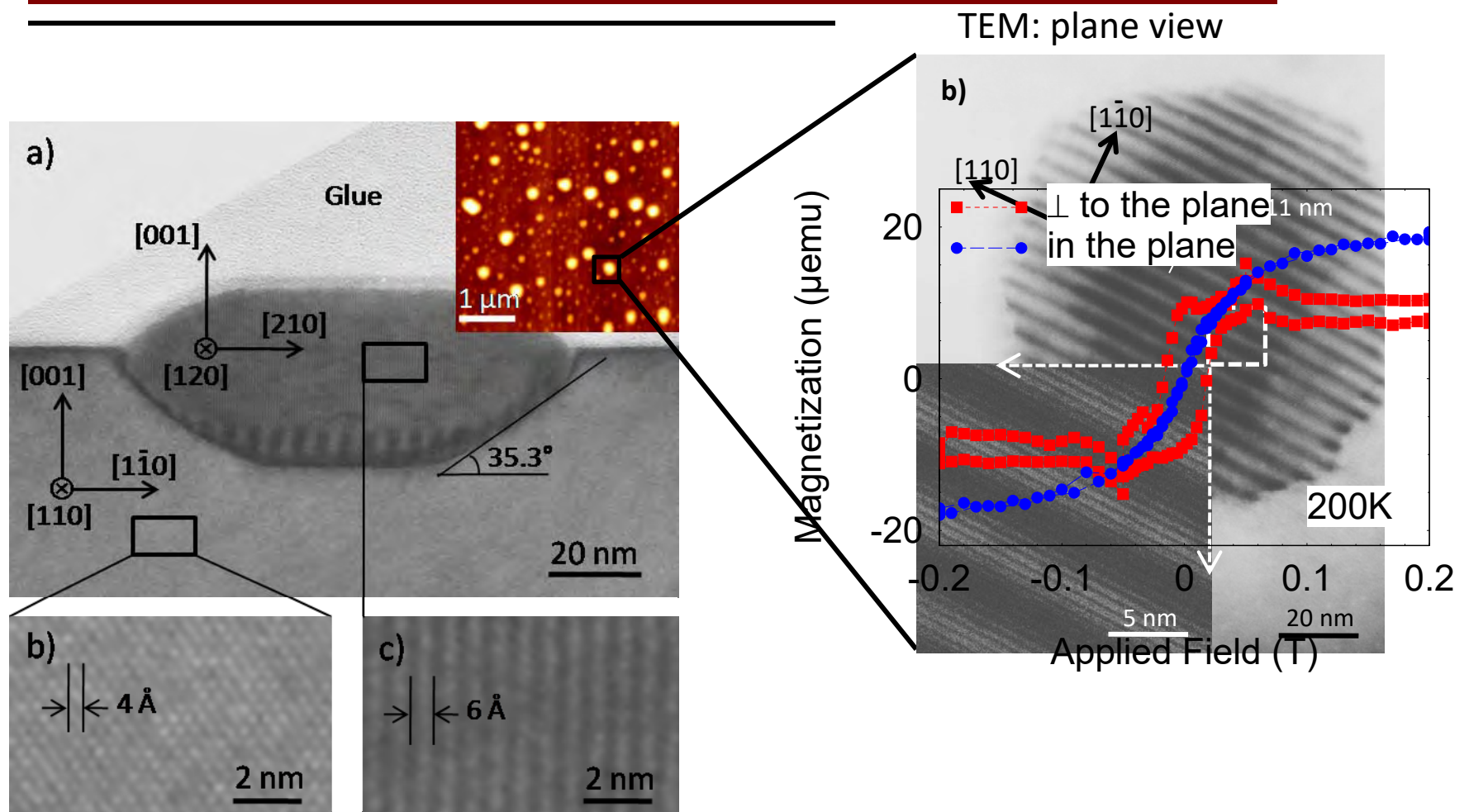
Mn₅Ge₃ : Inyector de spin



- ❑ Capa continua y térmicamente estable para $T < 700^\circ \text{C}$
- ❑ Interface Mn₅Ge₃ / Ge : Extendida a 1 MC atómica
- ❑ RHEED: relajación de Mn₅Ge₃ con $d > 1 \text{ nm}$
- ❑ Ferromagnético a temperatura ambiente
- ❑ Mn₅Ge₃:C Temp. Curie de 180°C

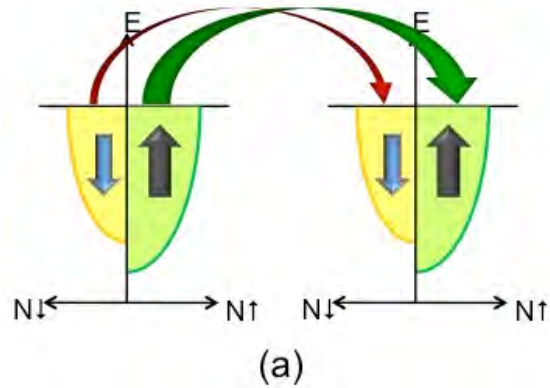


Crecimiento de $\text{Mn}_5\text{Ge}_3/\text{Ge}(001)$: SPE



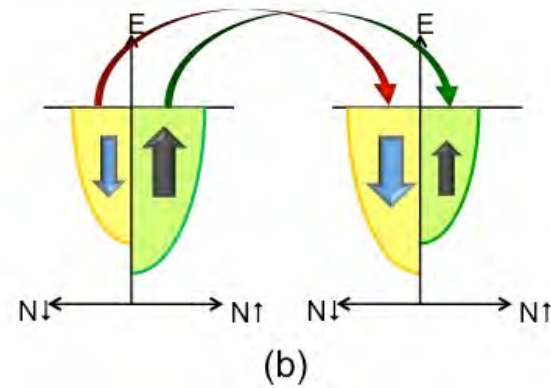
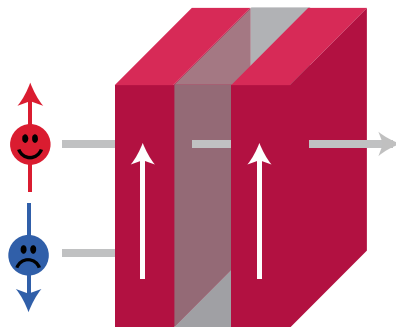
- Formación de islotes monocristalinos
- Penetración de la interface Mn/Ge en el SC

Modelo de Jullière



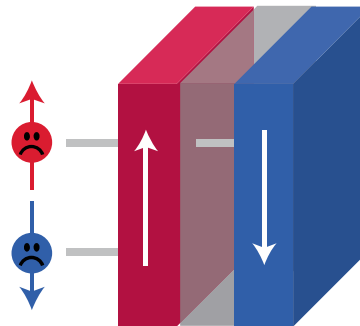
Configuración paralela

R

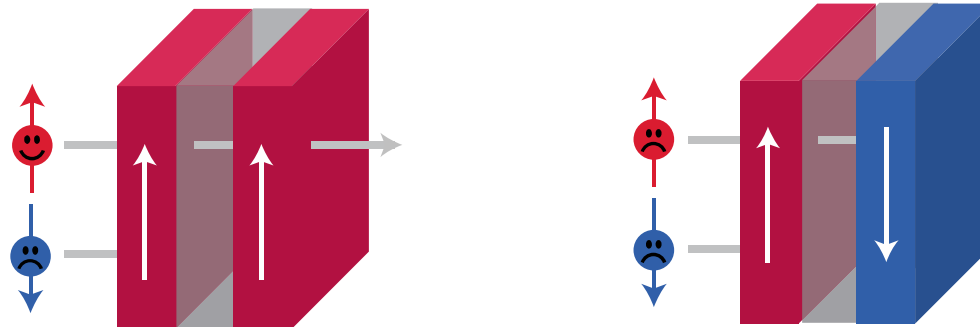
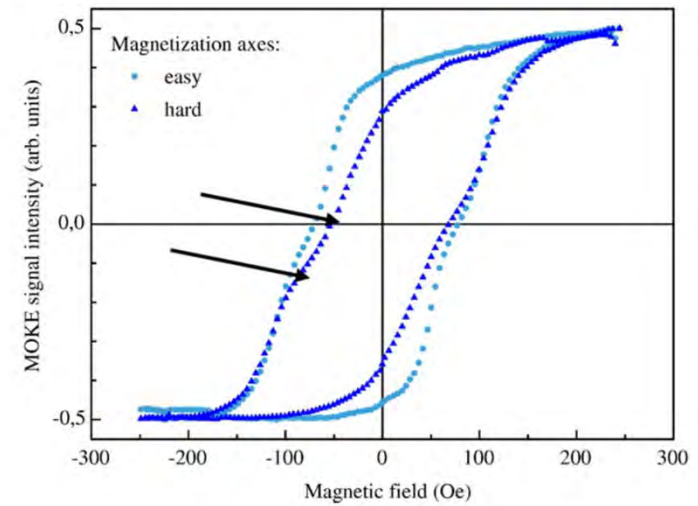
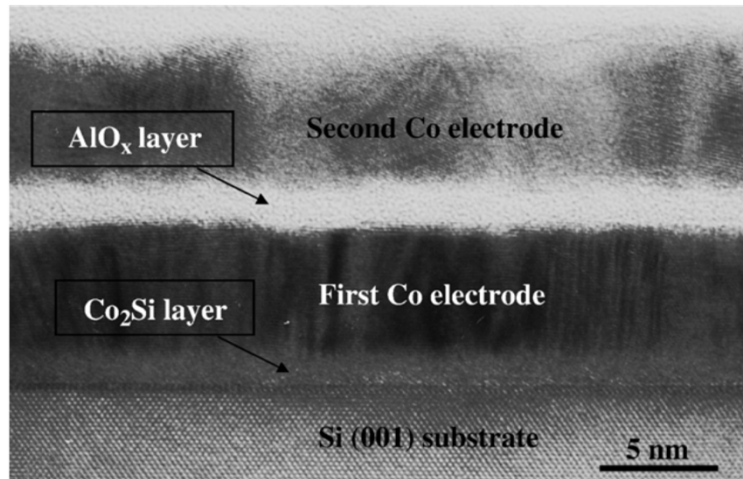


Configuración antiparalela

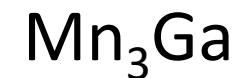
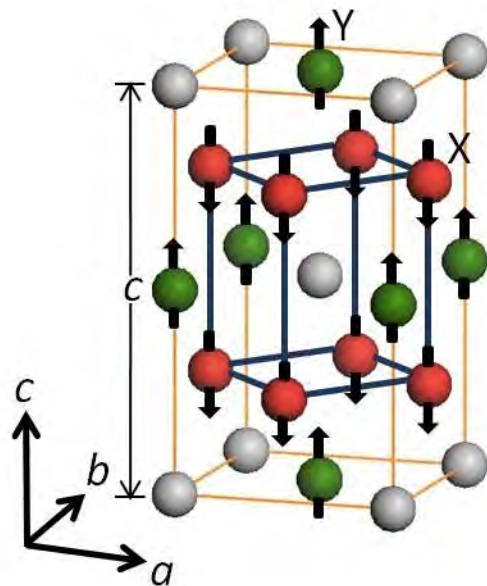
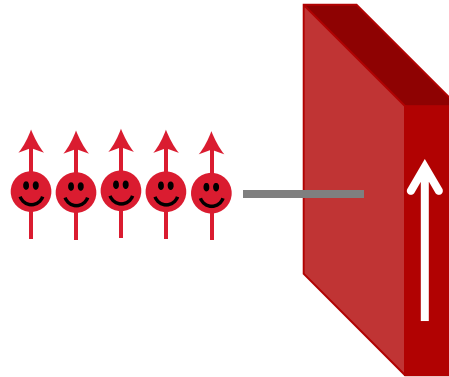
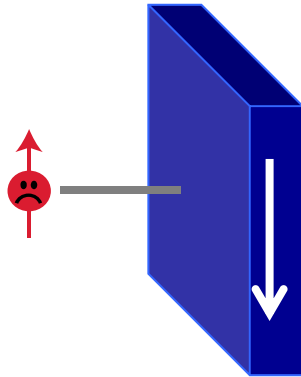
R



Unión tunel magnética Co/AlO_x/Co



Torsión por transferencia de spin



- Alta temperatura de Curie
- Alta coercitividad
- Alta anisotropía magnetocristalina

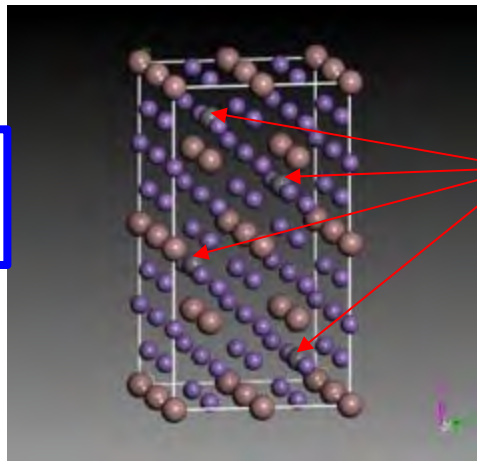
◆ X-Y = 264 pm
◆ FM > 290 pm

Dopaje con carbono: estabilidad de posiciones intersticiales

Átomos de carbono dentro de octaedros de Mn.

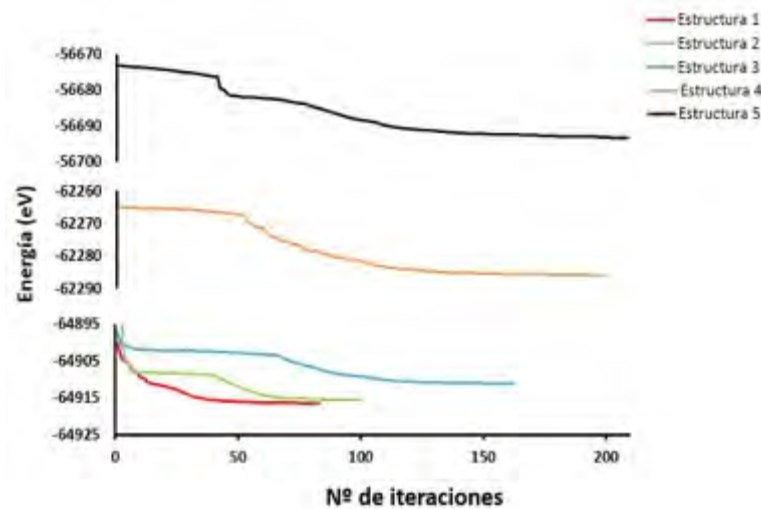
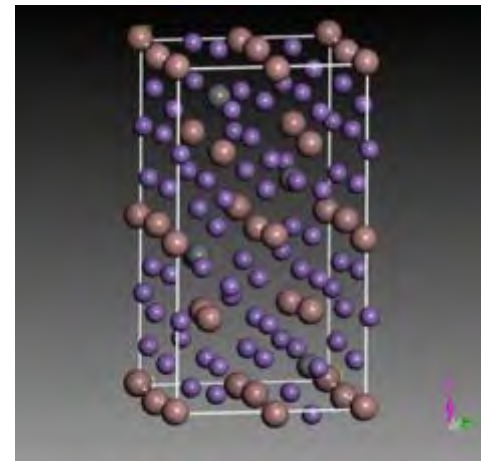
Ec. de Schrodinger:
$$i\hbar \frac{\partial}{\partial t} \psi = -\frac{\hbar^2}{2m} \nabla^2 \psi + V\psi$$

Estructura
sin optimizar

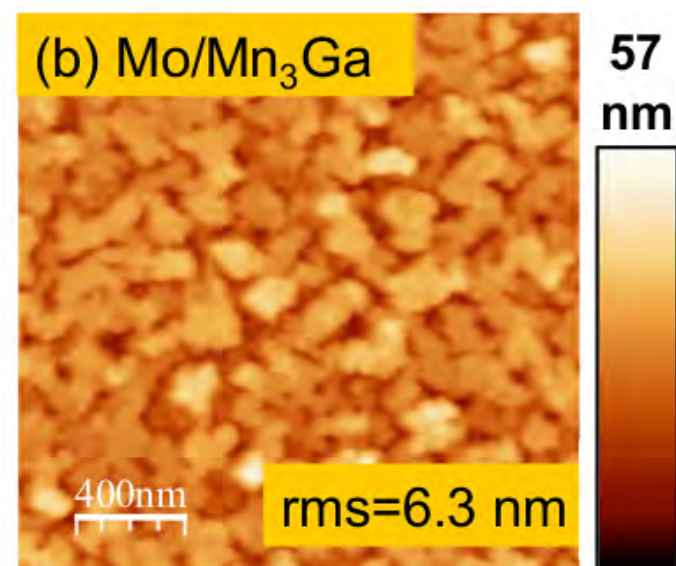
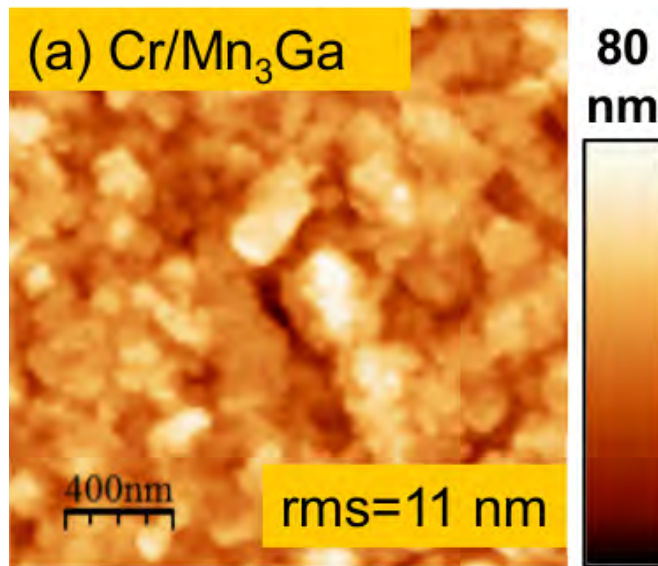
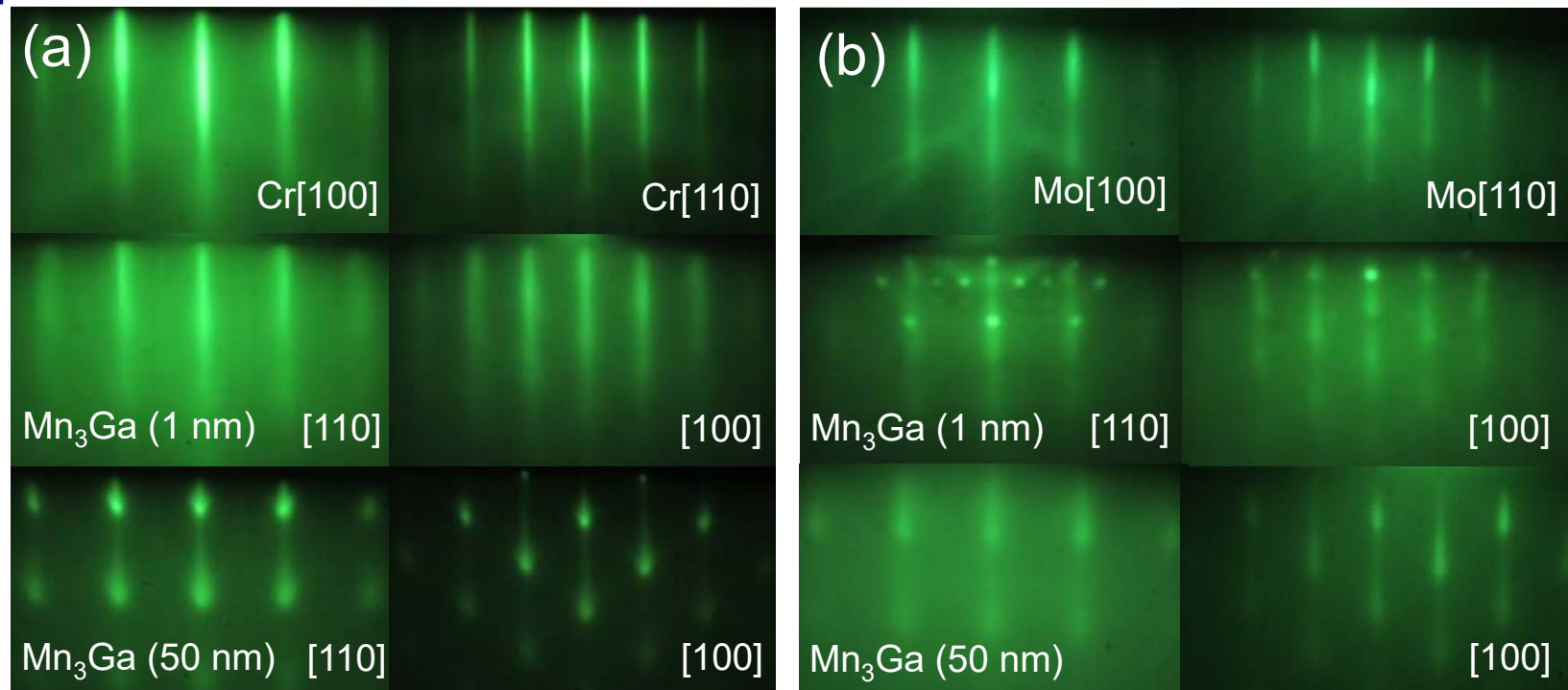


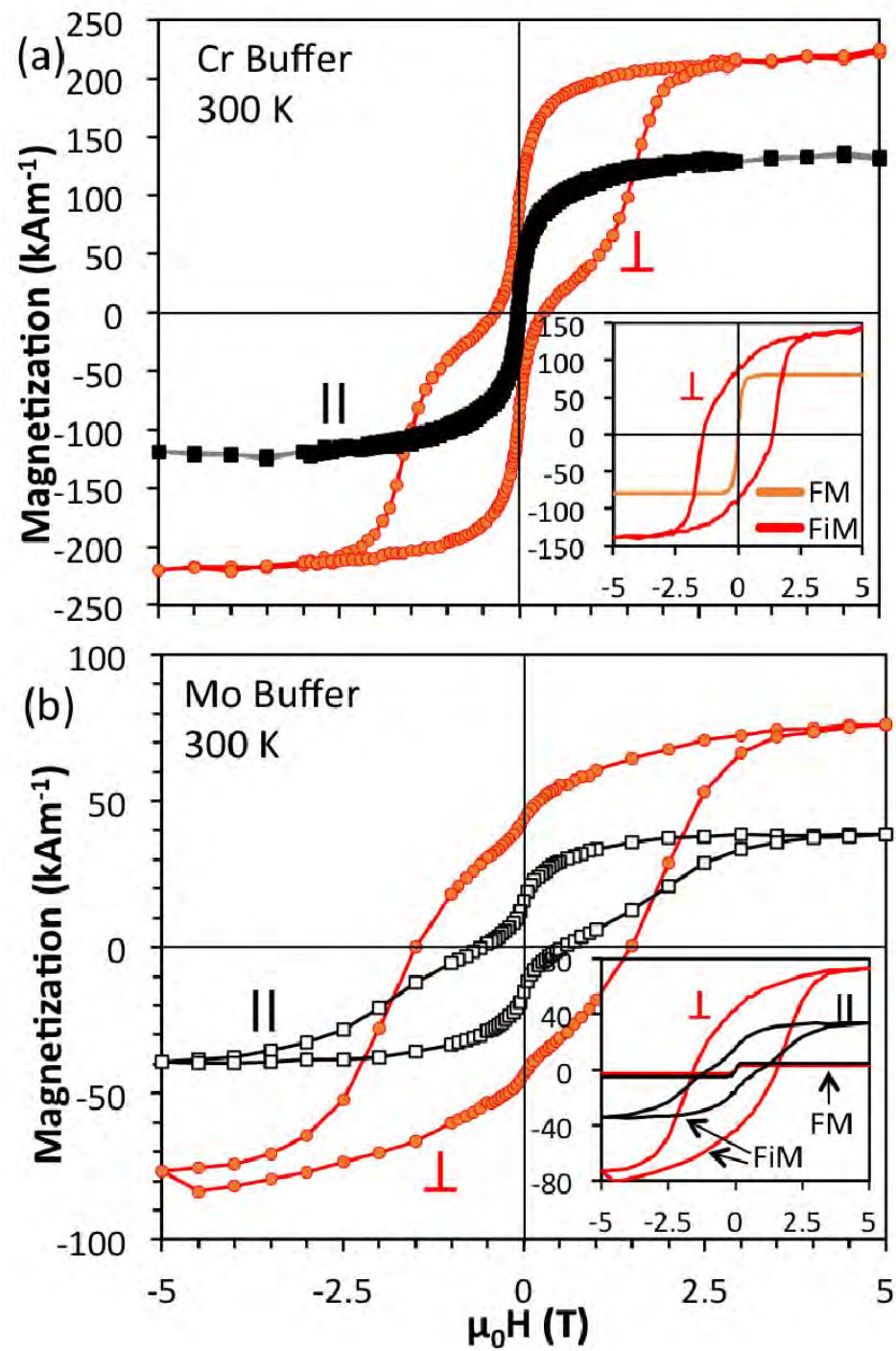
C

Estructura
optimizada

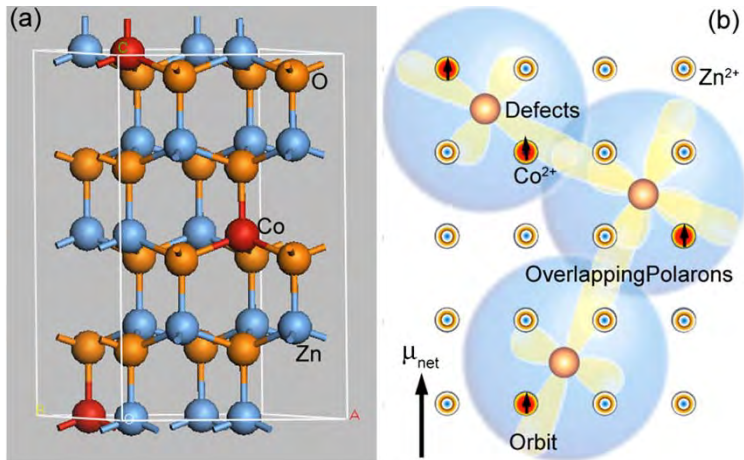


RHEED Mn_3Ga : Reflection high-energy electron diffraction





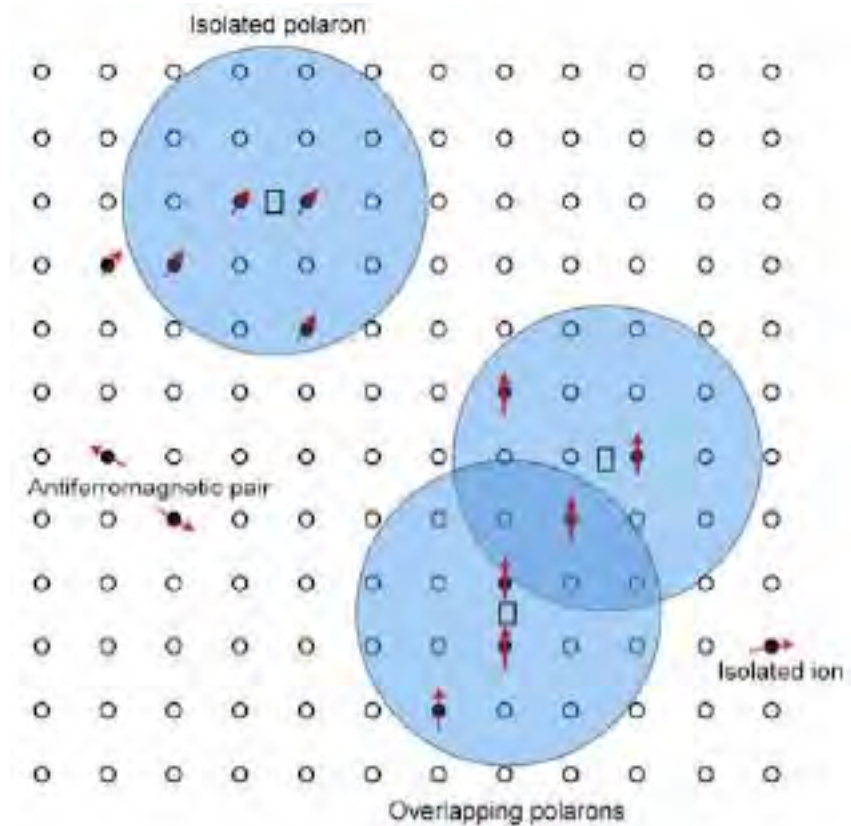
Inyección de spin: óxidos magnéticos diluidos



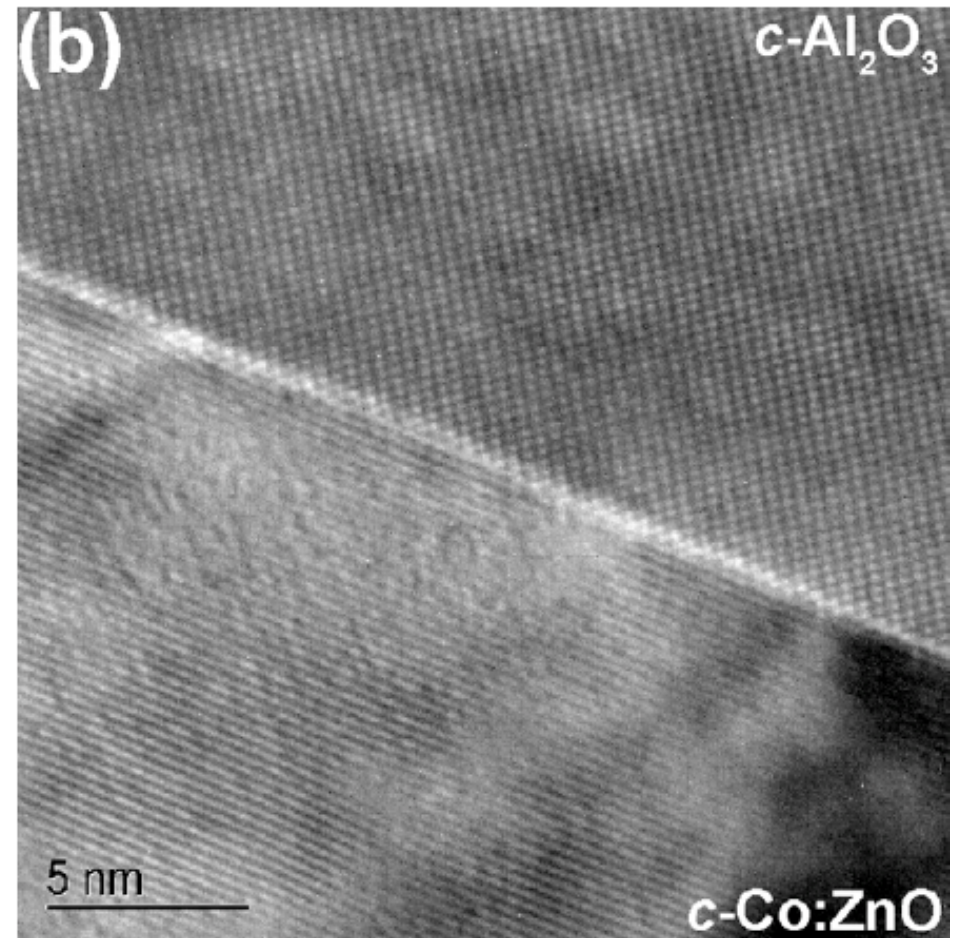
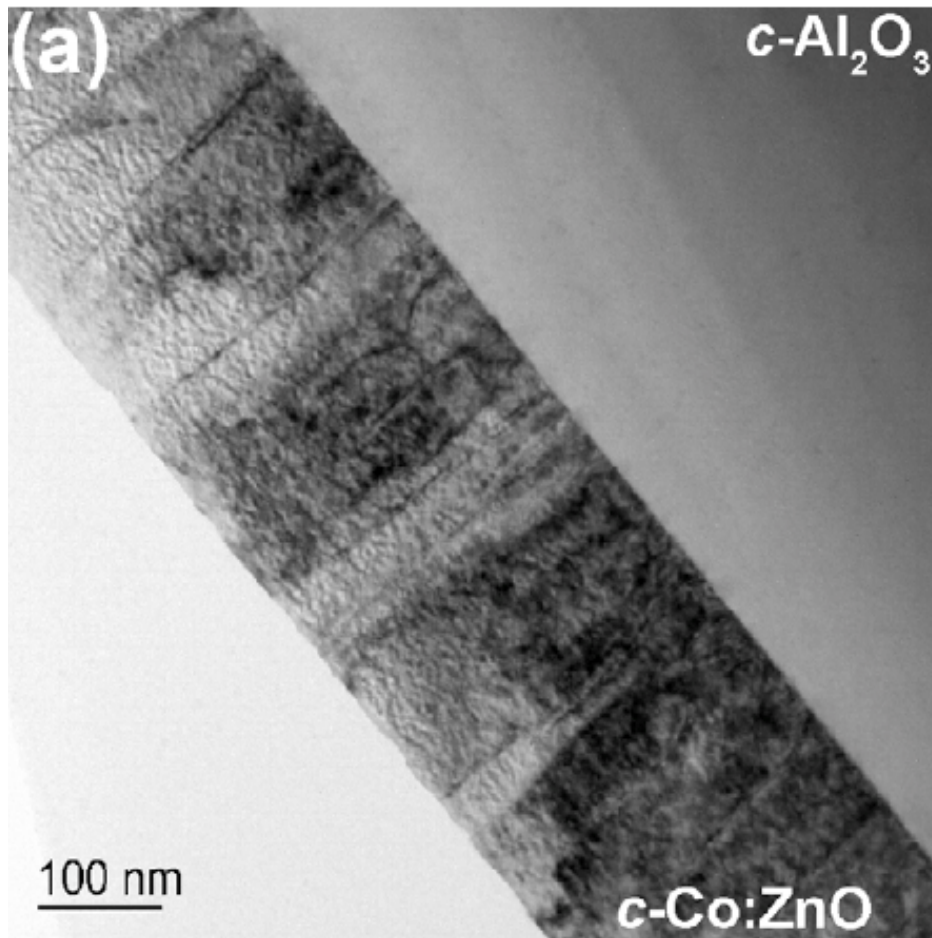
Semocinductores con alto valor de la brecha prohibida, dopados con metales 3d

Polarón magnético de enlace:

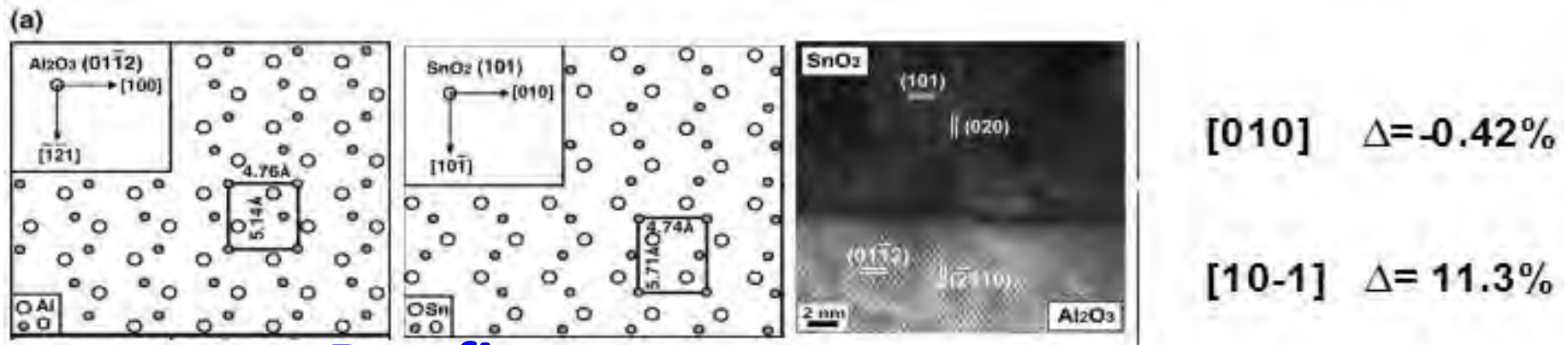
- Polarón-ión magnético



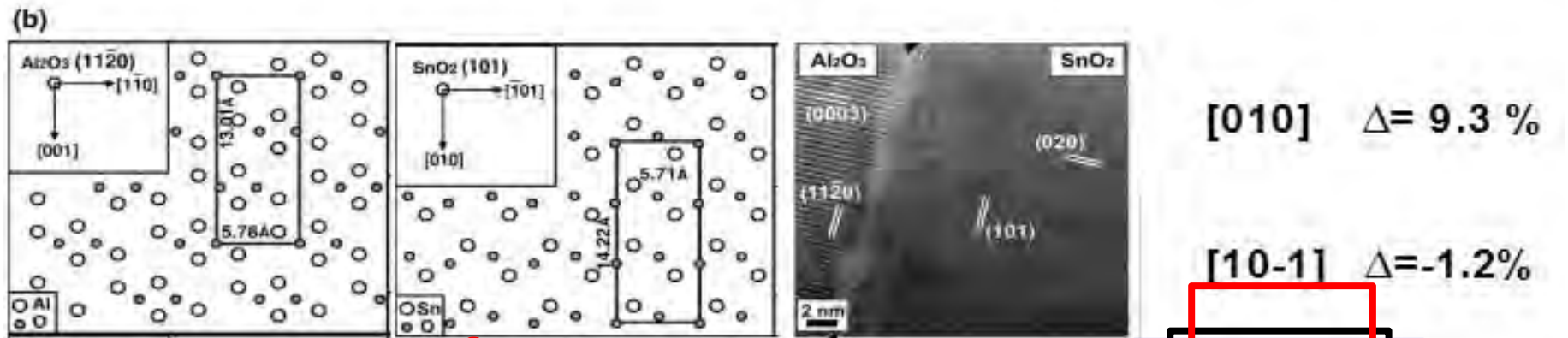
Inyección de spin: óxidos magnéticos diluidos



Inyección de spin: óxidos magnéticos diluidos

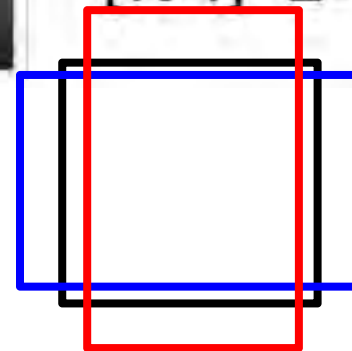


R-zafiro



A-zafiro

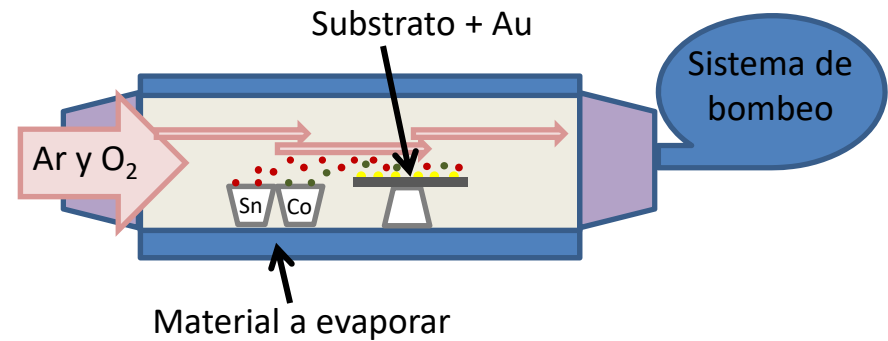
Edgar Fernando Pacheco Escalante
Javier Garnica Soria



Técnica: transporte de vapor y procedimiento VLS



Equipo adquirido con proyecto FOMIX Chihuahua



Esquema del transporte de vapor

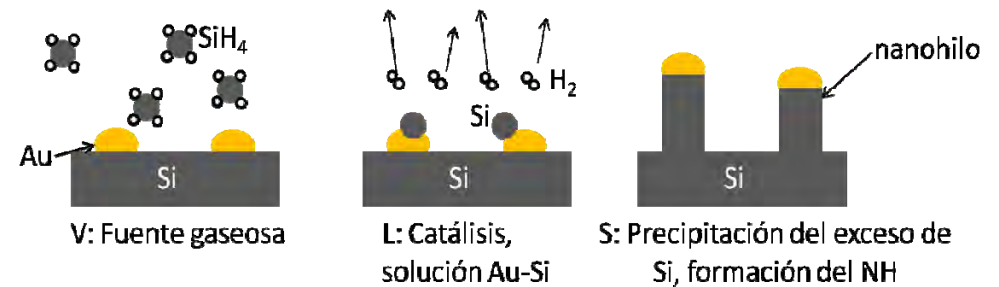
- ☐ Horno transversal para vacío, 1×10^{-2} Torr
- ☐ Capacidad de generar alto vacío, 1×10^{-6} Torr con bomba turbomolecular
- ☐ T_{max} en uso continuo 1100°C
- ☐ Opción de trat. Term. con atmósfera reductora.

Ejemplo del procedimiento VLS para el sistema Au-Si

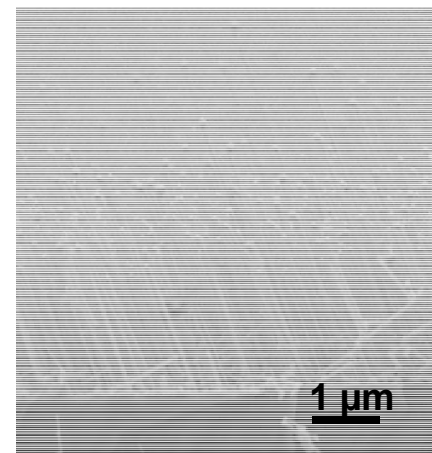
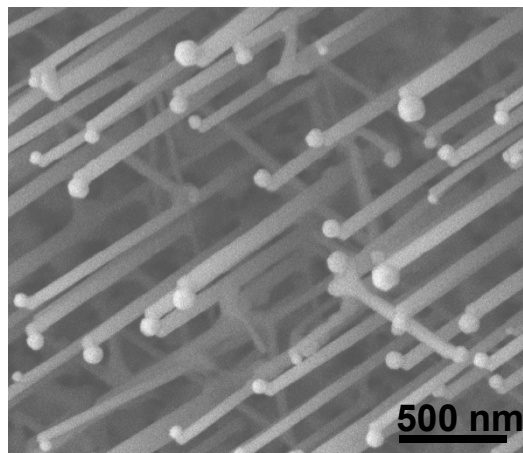
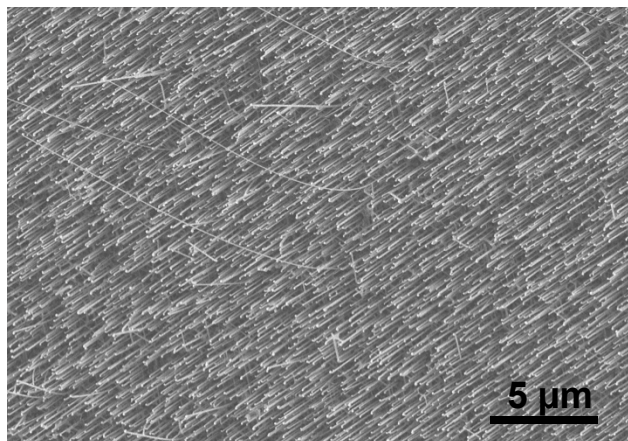
Vapor → A partir de una fuente gaseosa de material

Líquido → Solución Au-Si, a temperatura mayor que el punto eutéctico del sistema

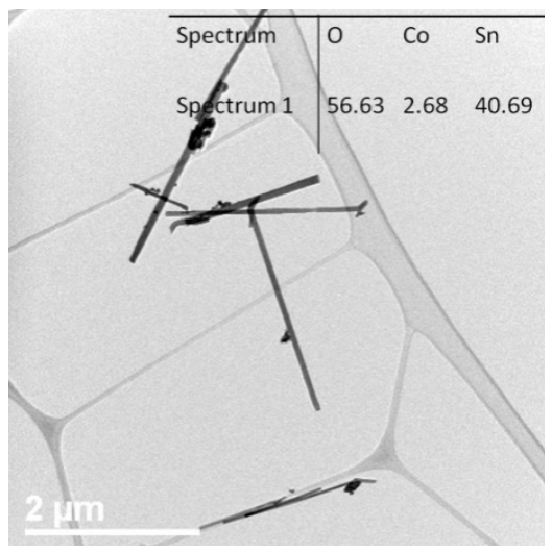
Sólido → Formación del nanohilo por la precipitación del exceso de Si en la solución líquida



Resultados: nanohilos de $\text{Sn}_{1-x}\text{Co}_x\text{O}_2$

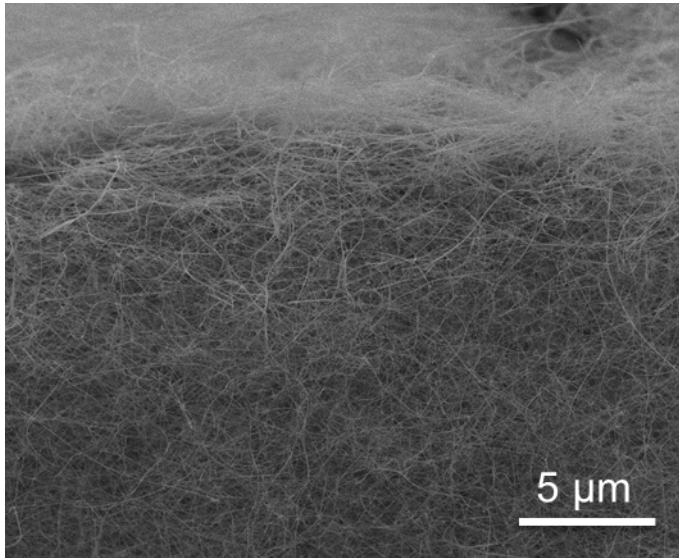


✓ Micrografías de microscopía electrónica de barrido. Crecimiento cristalino de NHs sobre toda la superficie del sustrato.

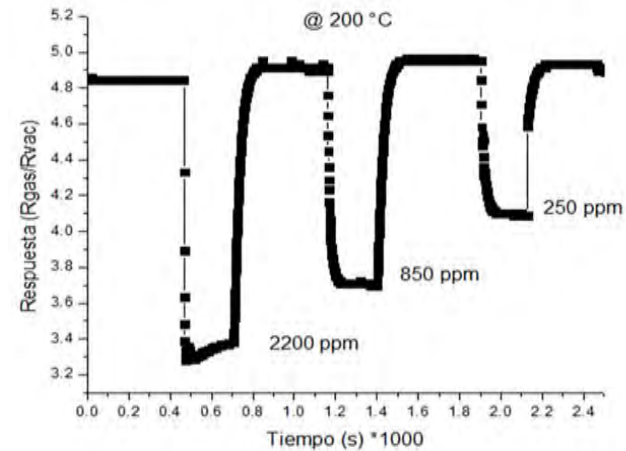


✓ Micrografías de microscopía electrónica de transmisión. Análisis hechos en una gran cantidad de nanohilos muestran la concentración atómica mostrada en el recuadro, muy cercana a la composición $\text{Sn}_{0.95}\text{Co}_{0.05}\text{O}_2$ donde se obtuvo el momento magnético gigante de $7.5 \mu_B/\text{Co}$.

Sensor basado en nanohilos de SnO_2

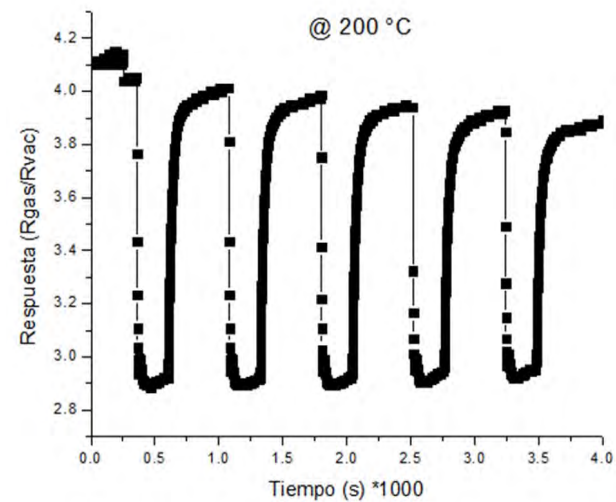


Conjunto de nanohilos de SnO_2
conectados aleatoriamente entre si

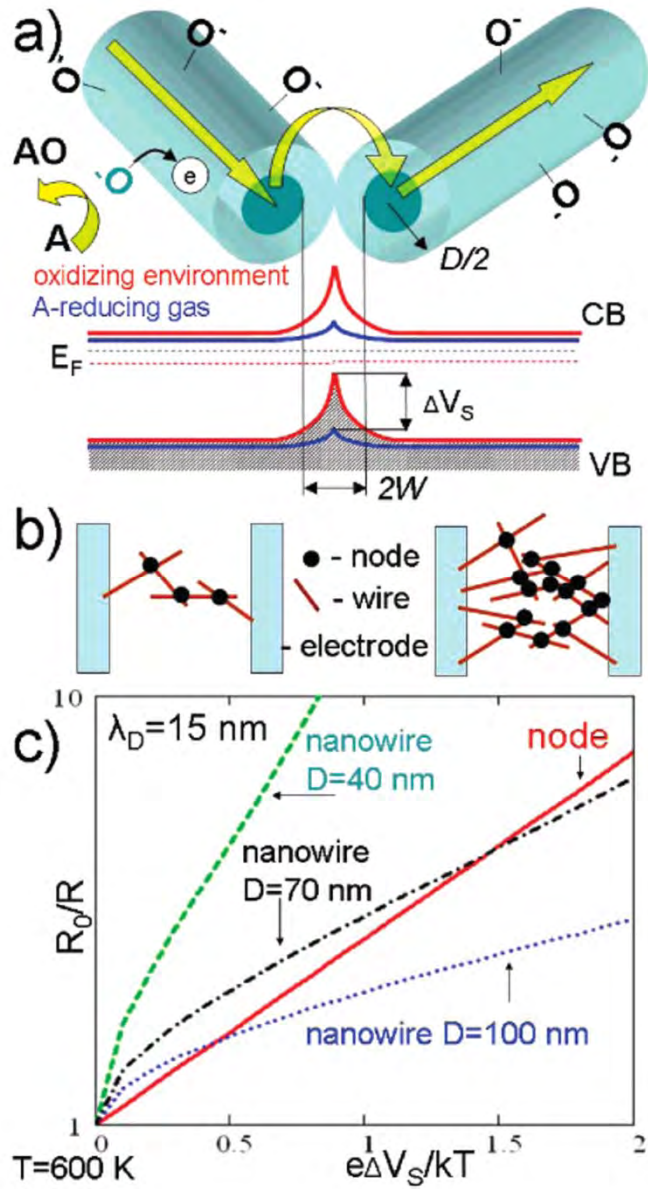


Respuesta del sensor a diferentes
concentraciones

Reproducibilidad en
las mediciones

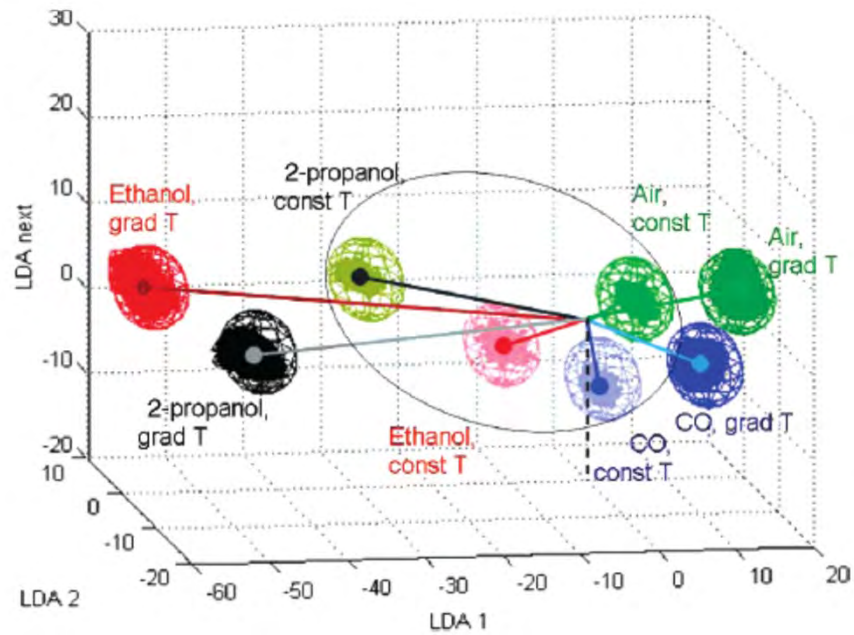


Nariz electrónica



$$\left. \frac{R_0}{R} \right|_{\text{NODE}} \approx \exp\left(\frac{e\Delta V_S}{kT}\right)$$

$$\left. \frac{R_0}{R} \right|_{\text{WIRE}} = \left(\frac{D}{D - 2\Delta W} \right)^2 = D^2 \left(D - 2\lambda_D \left(\frac{e\Delta V_S}{kT} \right)^{1/2} \right)^{-2}$$



Visión utópica

La nanotecnología permitirá diseñar y construir nanorobots ensambladores autoreplicantes, que serán capaces de producir cualquier cosa, desde sillas hasta ordenadores. Estos nanorobots, en nuestros organismos, podrán destruir virus y células cancerosas, y reparar estructuras y células dañadas.

Eric Drexler

Visión distópica

Eventualmente estos nanorobots ensambladores autoreplicantes pueden escapar a nuestro control, lo que podría conducir a nuestra propia extinción.

Bill Joy

Tipos de Nanotecnología

1. **Top-down:** Reducción de tamaño. Los mecanismos y las estructuras se miniaturizan a escala nanométrica. Este tipo de Nanotecnología ha sido el más frecuente hasta la fecha
2. **Bottom-Up:** Auto ensamblado. Se comienza con una estructura nanométrica como una molécula y mediante un proceso de montaje o auto ensamblado, se crea un mecanismo mayor que el mecanismo con el que comenzamos. Este enfoque, que algunos consideran como el único y "verdadero" enfoque nanotecnológico, ha de permitir que la materia pueda controlarse de manera extremadamente precisa.

Two Different Approaches to Nanofabrication

➤ Top ⇒ Down:

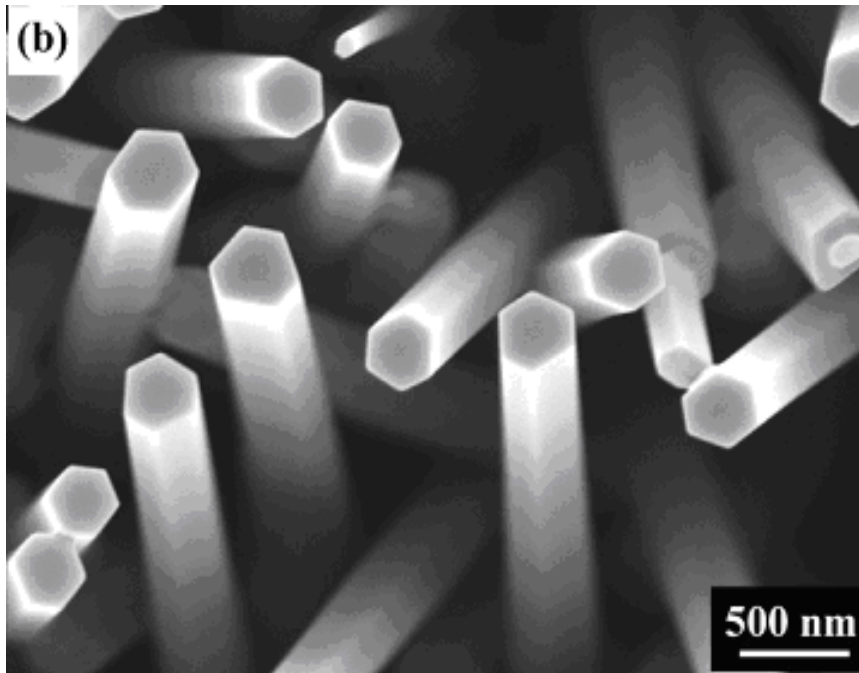
- Start with the bulk material and "cut away material" to make the what you want



➤ Bottom ⇒ Up:

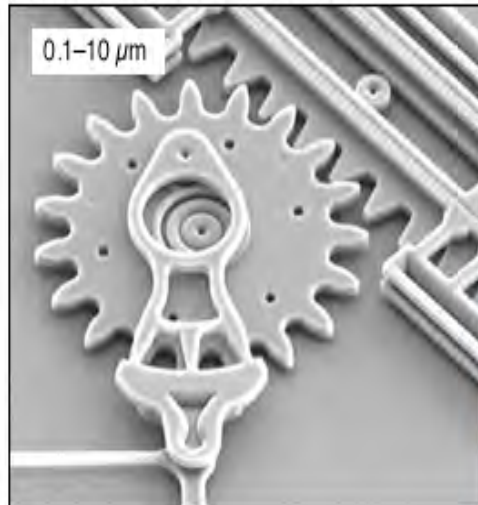
- Building what you want by assembling it from building blocks (such as atoms and molecules).
- Atom-by-atom, molecule-by-molecule, or cluster-by-cluster





Microelectronics

top-down approach, build in place



Nanotechnology

bottom-up approach, self-assembly

