

Aplicaciones de la Microscopia Raman Confocal a la Caracterización de Materiales



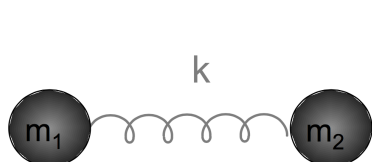
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Punteo

- ▣ Modos Vibracionales
- ▣ Reglas de Selección: IR vs Raman
- ▣ Microscopia Óptica y Confocal
- ▣ Microscopia Raman Confocal
- ▣ Aplicaciones de MicroRaman
- ▣ Microscopia de Fuerza Atómica
- ▣ Aplicaciones de MicroRamanAFM

1. Modos Vibracionales



$$V = \frac{1}{2} kx^2$$

$$\nu = \frac{1}{2\pi} \sqrt{\frac{k}{\mu}}; \quad \frac{1}{\mu} = \frac{1}{m_1} + \frac{1}{m_2}$$

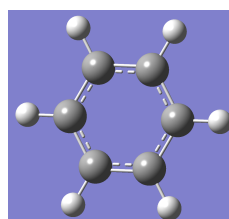
Bond	Bond Energy [kcal (kJ)]	Stretching Frequency (cm ⁻¹)
<i>Frequency dependence on bond energies</i>		
C—C	83 (350)	1200
C=C	146 (611)	1660
C≡C	200 (840)	2200
	↓ stronger bond	↓ $\bar{\nu}$ increases
Bond	Bond Energy [kcal (kJ)]	Stretching Frequency (cm ⁻¹)
<i>Frequency dependence on atomic masses</i>		
C—H	100 (420)	3000
C—D	100 (420)	2100
C—C	83 (350)	1200
	↓ heavier atoms	↓ $\bar{\nu}$ decreases

1. Modos Vibracionales

▣ Número de modos depende de los grados de libertad

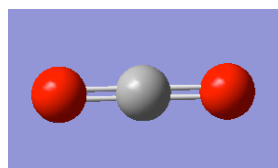
■ Moléculas no Lineales

- ▣ N° modos = 3N - 6
- ▣ Ejemplo: Benceno
 - 30 modos



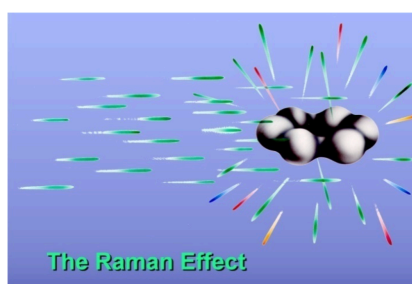
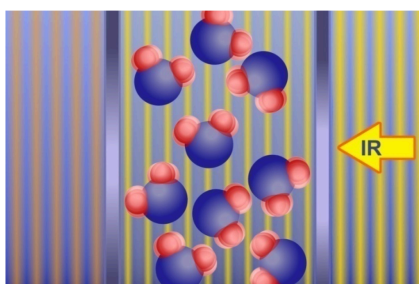
■ Moléculas Lineales

- ▣ N° modos = 3N - 5
- ▣ Ejemplo: CO₂
 - 4 modos

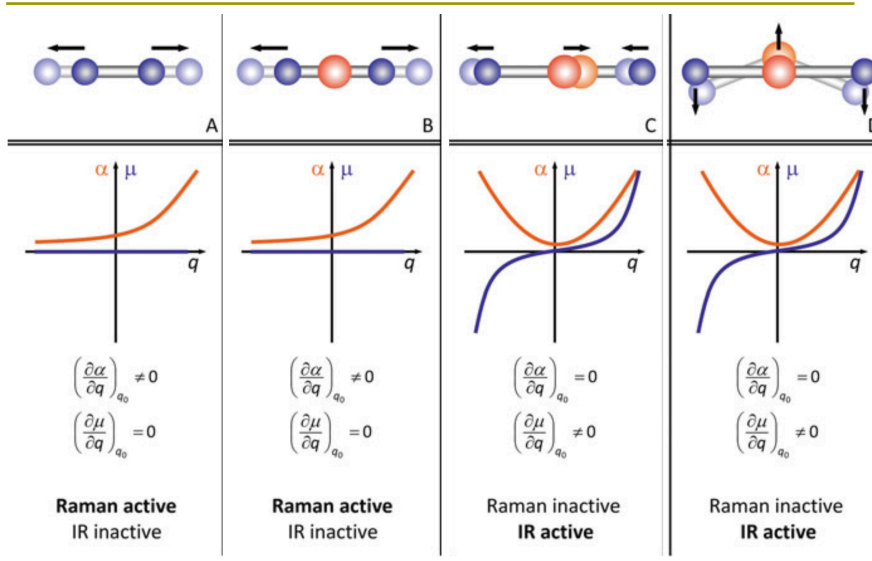


2. Reglas de Selección

- IR: Absorción de fotón por dipolo (μ) del modo normal de vibración.
- Raman: Dispersión inelástica mediada por momento dipolar inducido (polarizabilidad α) generado por la OEM.

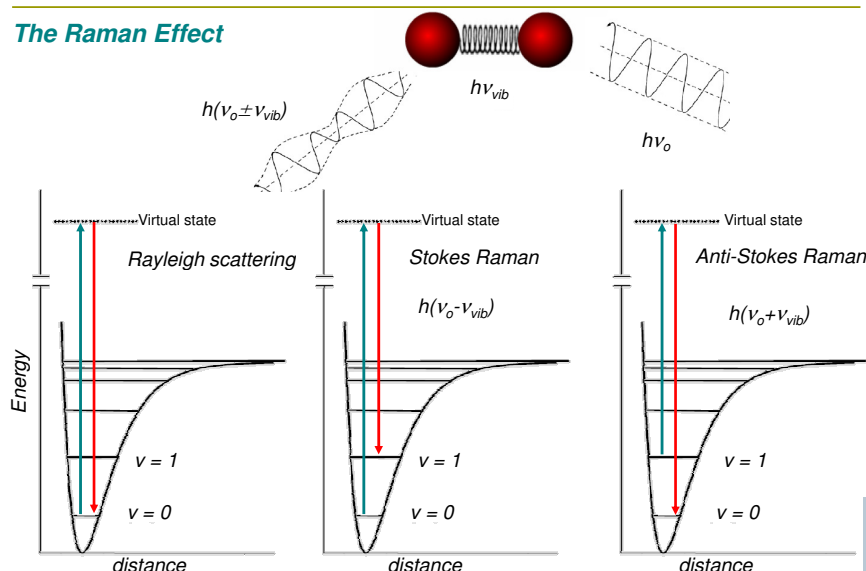


2. Reglas de Selección: IR vs Raman



2. El efecto Raman

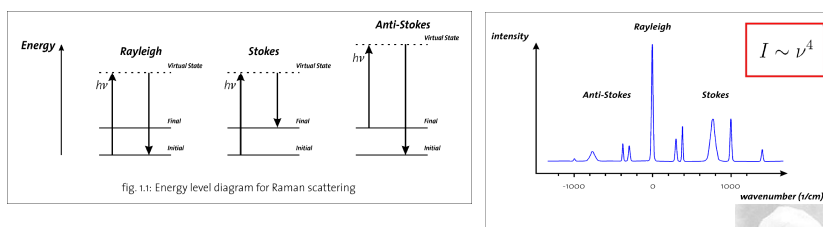
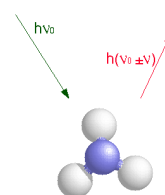
The Raman Effect



2. El efecto Raman

The Raman Effect

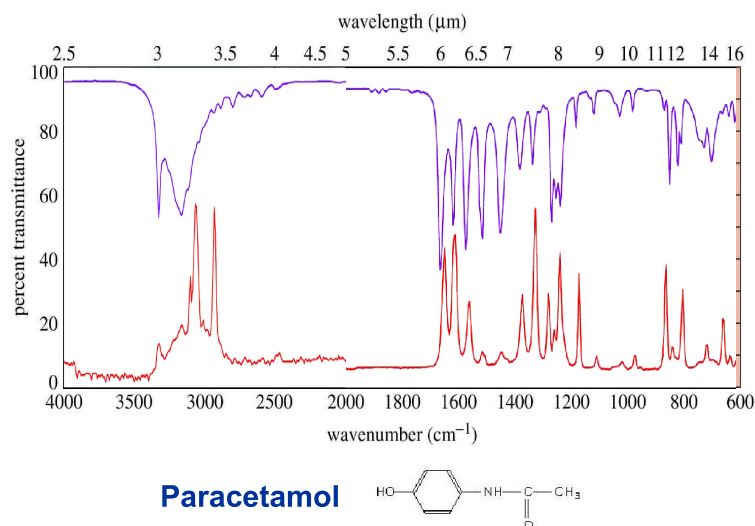
- non-resonant excitation (Stokes) or annihilation (Anti-Stokes) of a vibrational quantum
- energy shift between the exciting and scattered photon is characteristic for the molecules involved in the scattering process



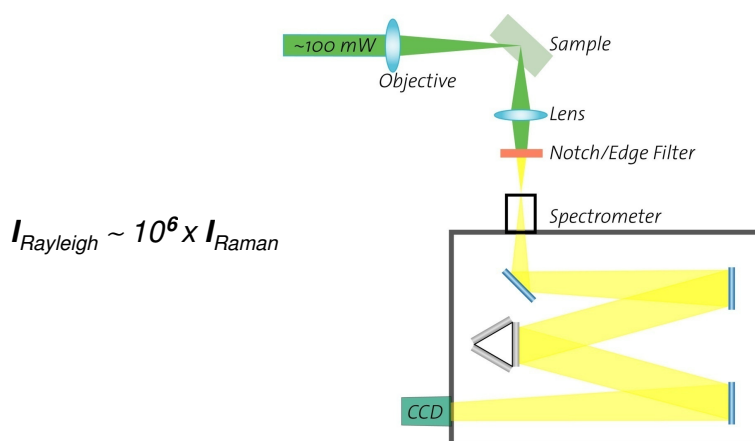
- theoretical prediction 1923 by A. Smekal
- experimentally discovered 1928 by Sir Chandrasekhara Raman, Nobel Prize 1930



2. Infrarrojo vs. Raman

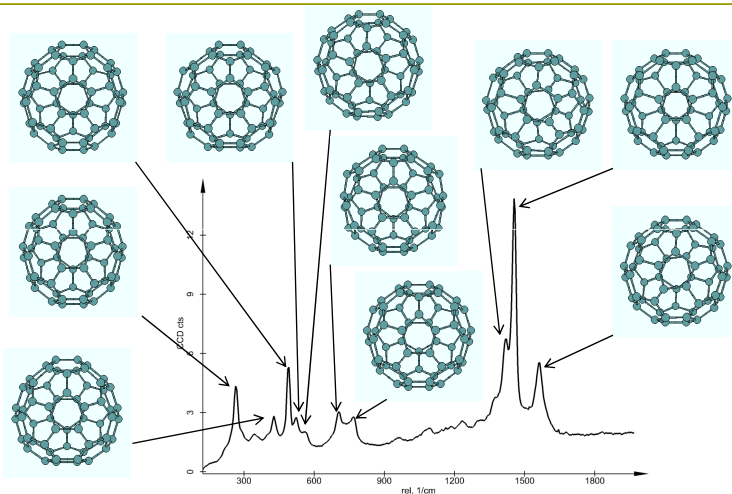


2. Esquema Típico de Experimento



- typical integration times: seconds - several minutes

2. Espectroscopia Raman



chemical, but NO spatial resolution

2. Identificación de Bandas

Functional Group/ Vibration	Region	Raman	InfraRed
Lattice vibrations in crystals, LA modes	10 - 200 cm^{-1}	strong	strong
$\delta(\text{CC})$ aliphatic chains	250 - 400 cm^{-1}	strong	weak
$\nu(\text{Se-Se})$	290 - 330 cm^{-1}	strong	weak
$\nu(\text{S-S})$	430 - 550 cm^{-1}	strong	weak
$\nu(\text{Si-O-Si})$	450 - 550 cm^{-1}	strong	weak
$\nu(\text{Xmetal-O})$	150-450 cm^{-1}	strong	med-weak
$\nu(\text{C-I})$	480 - 660 cm^{-1}	strong	strong
$\nu(\text{C-Br})$	500 - 700 cm^{-1}	strong	strong
$\nu(\text{C-Cl})$	550 - 800 cm^{-1}	strong	strong
$\nu(\text{C-S})$ aliphatic	630 - 790 cm^{-1}	strong	medium
$\nu(\text{C-S})$ aromatic	1080 - 1100 cm^{-1}	strong	medium
$\nu(\text{O-O})$	845 - 900 cm^{-1}	strong	weak
$\nu(\text{C-O-C})$	800 - 970 cm^{-1}	medium	weak
$\nu(\text{C-O-C})$ asym	1060 - 1150 cm^{-1}	weak	strong

$\nu(\text{CC})$ alicyclic, aliphatic chain vibrations	600 - 1300 cm^{-1}	medium	Medium
$\nu(\text{C}=\text{S})$	1000 - 1250 cm^{-1}	strong	weak
$\nu(\text{CC})$ aromatic ring chain vibrations	*1580, 1600 cm^{-1}	strong	medium
	*1450, 1500 cm^{-1}	medium	medium
	*1000 cm^{-1}	strong/medium	weak
$\delta(\text{CH}_3)$	1380 cm^{-1}	medium	strong
$\delta(\text{CH}_2)$ $\delta(\text{CH}_3)$ asym	1400 - 1470 cm^{-1}	medium	medium
$\delta(\text{CH}_2)$ $\delta(\text{CH}_3)$ asym	1400 - 1470 cm^{-1}	medium	medium
$\nu(\text{C}-(\text{NO}_2))$	1340 - 1380 cm^{-1}	strong	medium
$\nu(\text{C}-(\text{NO}_2))$ asym	1530 - 1590 cm^{-1}	medium	strong
$\nu(\text{N}=\text{N})$ aromatic	1410 - 1440 cm^{-1}	medium	-
$\nu(\text{N}=\text{N})$ aliphatic	1550 - 1580 cm^{-1}	medium	-
$\delta(\text{H}_2\text{O})$	~1640 cm^{-1}	weak broad	strong
$\nu(\text{C}=\text{N})$	1610 - 1680 cm^{-1}	strong	medium
$\nu(\text{C}=\text{C})$	1500 - 1900 cm^{-1}	strong	weak
$\nu(\text{C}=\text{O})$	1680 - 1820 cm^{-1}	medium	strong
$\nu(\text{C}\equiv\text{C})$	2100 - 2250 cm^{-1}	strong	weak
$\nu(\text{C}\equiv\text{N})$	2220 - 2255 cm^{-1}	medium	strong
$\nu(-\text{S}-\text{H})$	2550 - 2600 cm^{-1}	strong	weak
$\nu(\text{C}-\text{H})$	2800 - 3000 cm^{-1}	strong	strong
$\nu(=\text{C}-\text{H})$	3000 - 3100 cm^{-1}	strong	medium
$\nu(\equiv\text{C}-\text{H})$	3300 cm^{-1}	weak	strong
$\nu(\text{N}-\text{H})$	3300 - 3500 cm^{-1}	medium	medium
$\nu(\text{O}-\text{H})$	3100 - 3650 cm^{-1}	weak	strong

2. Métodos Teóricos

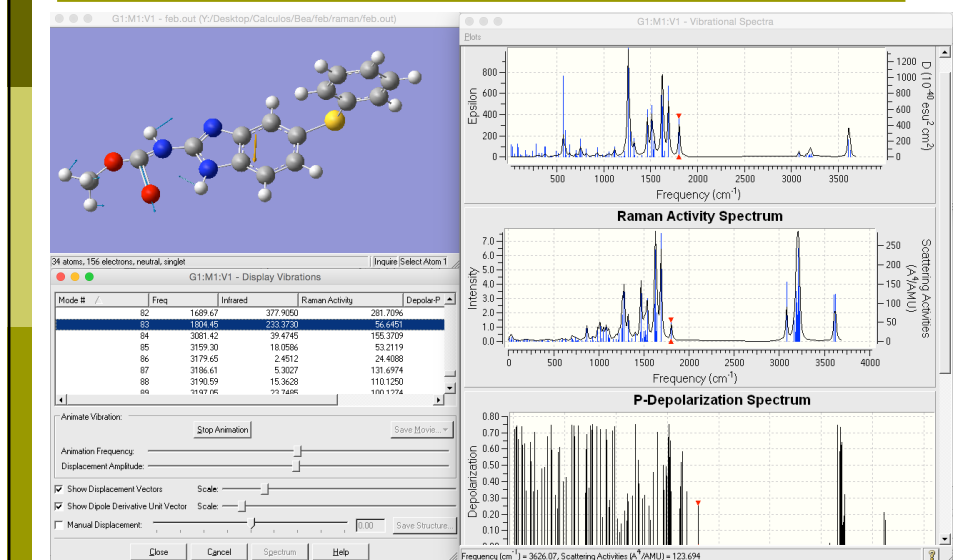
▣ Cálculos *ab initio* o *Primeros Principios*

▣ *DFT*

■ *Molecular: Gaussian*

■ *Estado Sólido: Quantum Espresso y VASP*

2. Simulación de IR y Raman

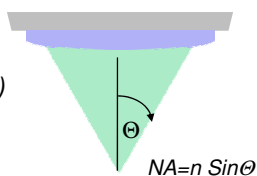


3 Microscopia Óptica Clásica

What is the resolution limit of a classical optical microscope?

Ernst Abbé (1840-1905): diffraction theory

$$\Delta x \geq 0,61 \times (\lambda / NA)$$

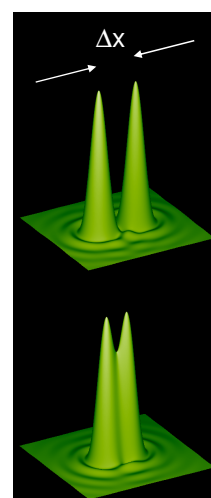


air: $NA \leq 0,95$ (340nm @ 532nm exc.)

water: $NA \leq 1,2$ (270nm @ 532nm exc.)

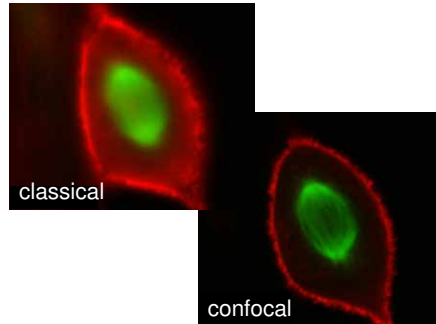
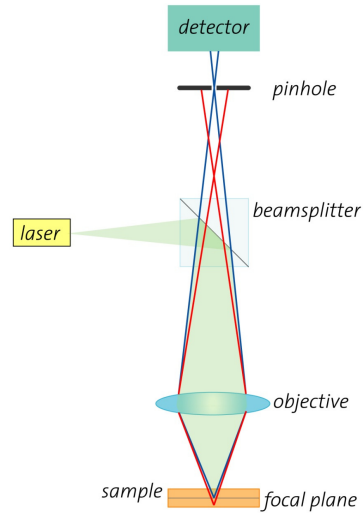
oil: $NA \leq 1,4$ (230nm @ 532nm exc.)

$$\text{resolution limit} \approx \lambda / 2$$



3. Microscopia Confocal

confocal microscopy



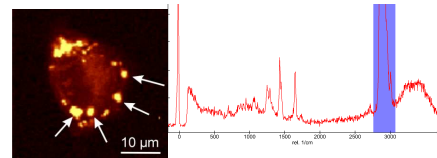
- much smaller background
- 3-D information
- slightly higher resolution possible

spatial, but NO chemical information

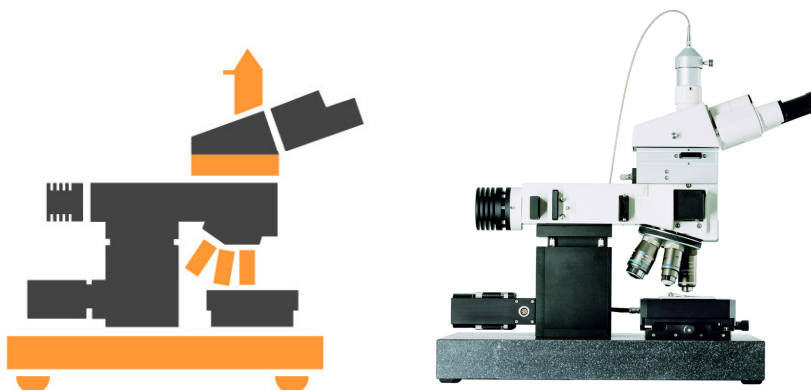
3. Microscopia Confocal + Espectroscopia Raman

3-D Imaging with chemical sensitivity

- take a complete Raman spectrum at every image pixel
- extract the relevant information (peak intensity, width, position etc.)
- display this information as image

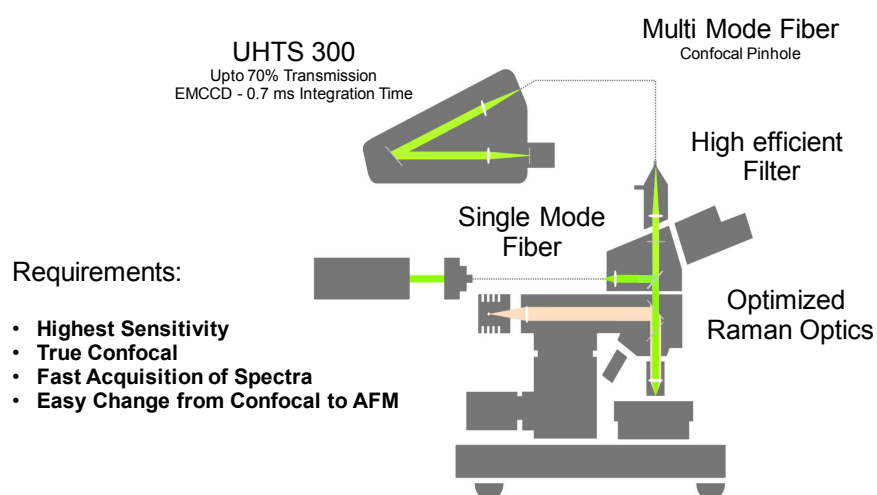


3. Microscopio Confocal + Espectrómetro Raman



Imaging with chemical sensitivity

3. Esquema



3. Características de la Técnica

- ❑ No Destructivo
- ❑ Identificación Química Directa
- ❑ Identificación de Propiedades de Materiales
- ❑ Fácil o nula preparación de muestra
- ❑ Sólidos cristalinos, sólidos amorfos y Líquidos
- ❑ Detección 3-dimensional
- ❑ Variación de Temperatura (Linkam)
- ❑ Combinación de detección química con AFM (EFM & MFM)

3. WITec Alpha 300 RA

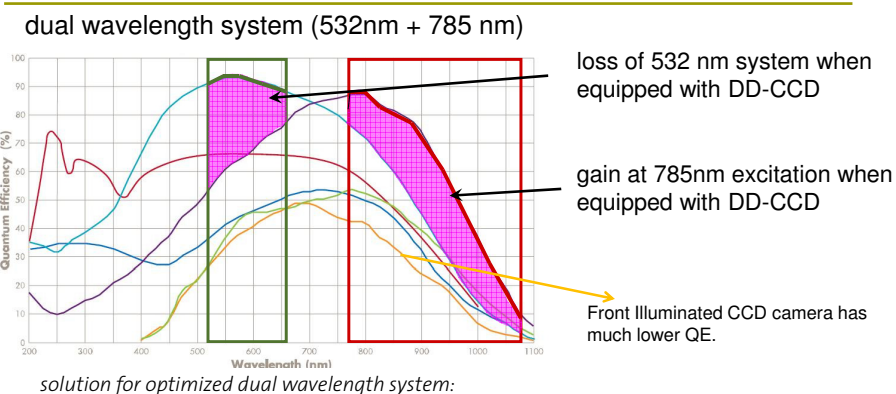
WITec Confocal Raman Microscope System Alpha300R de alta sensibilidad para longitudes de onda de excitación de 532 nm y 785 nm.

- ❑ Imagen Espectral Raman: adquisición de espectros Raman completos en cada pixel (mapping)
- ❑ Adquisición de espectros Raman en áreas seleccionadas (micro-Raman)
- ❑ Imágenes 3D Raman confocal.
- ❑ Microscopía confocal de Reflexión
- ❑ Resolución Óptica: Límite de difracción, típico 300 nm @ 532 nm de longitud de onda de excitación (objetivo NA 1.4)
- ❑ Tamaño de la muestra: máx. 120 mm x e y dirección, 25 mm de altura
- ❑ **Dos espectrómetros y detectores CCD optimizados, uno para IR cercano y otro para rango Visible.**
- ❑ Criostato para micro-confocal rango T= -196 C a 600 C (Linkam)

3. Plataforma Piezoeléctrica

- ❑ Plataforma piezoeléctrica para el barrido de muestras.
- ❑ Rango continuo de barrido de hasta 200 μm en ejes X e Y y 20 μm en eje Z.
- ❑ Dispositivo de barrido lineal con feedback de loop cerrado
- ❑ Resolución de barrido:
 - Precisión de posicionamiento:
 - $< 2 \text{ nm}$ en eje X e Y
 - $< 0.2 \text{ nm}$ ($2 \text{ \AA}$) en eje Z
- ❑ AFM, MFM y EFM
 - FSE_1_2014_1_102008 Fondo Sectorial de Energía - ANII
 - “Nanomateriales para almacenamiento de energía: nueva serie de cátodos para baterías de ion-Litio”

3. Doble CCD optimizada para cada región del espectro

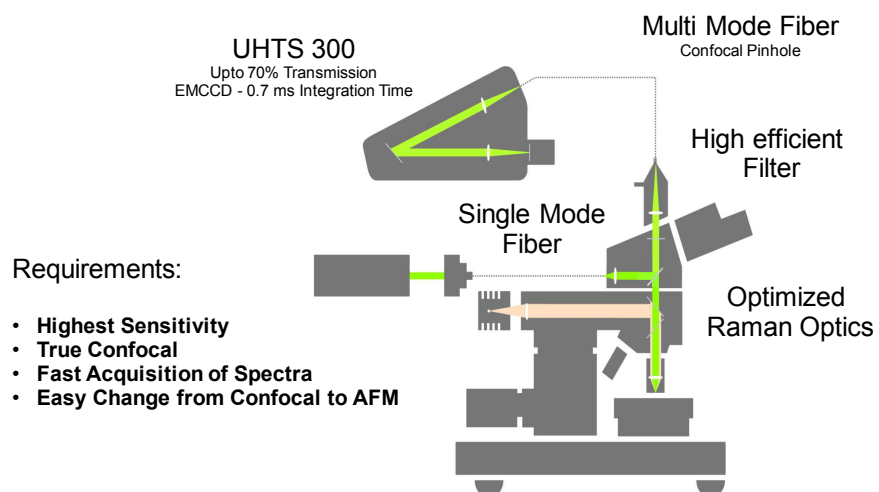


=> 2 spectrometers + 2 cameras

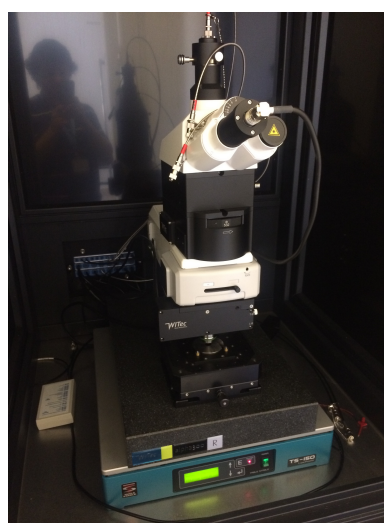
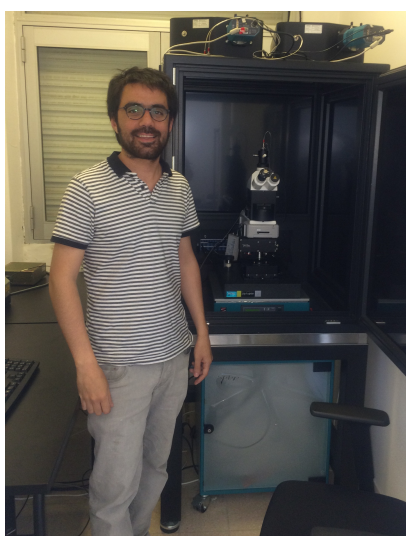
532nm excitation: 500nm blaze, standard BI-CCD

785nm excitation: 750nm blaze, DD-CCD

3. Esquema



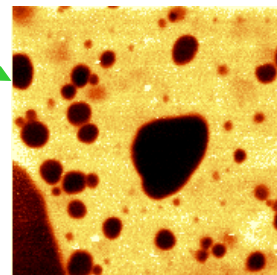
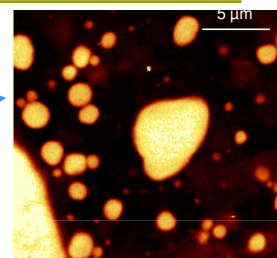
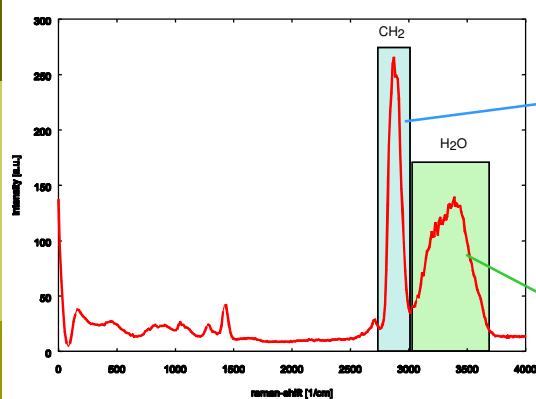
3. Disposición



4. Aplicaciones

Microscopia Raman Confocal

Imagen Raman: dispersión agua-aceite



Body lotion, imaging parameters:

2 mW excitation @ 532nm, 100x oil, NA=1,25

20 x 20 μm, 180 x 180 pixels (= 32400 spectra)

50ms/spectrum

Reconstrucción Imagen Raman 3D

Sample: Oil/Water Emulsion

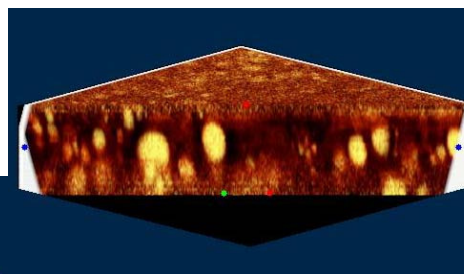
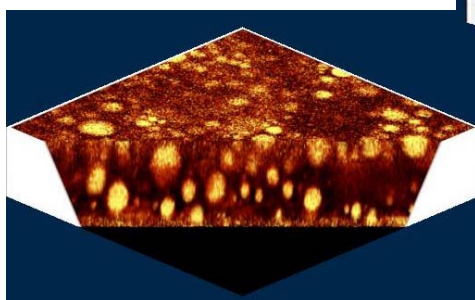
3-D Reconstruction

Evaluated Band: CH-Stretching

Excitation: 532nm

Scan Range XY: 100x100 μm

Scan Range Z: 30 μm /32 layers



Total number of Spectra: 517 500

Total Acquisition Time: 23 min

Stents para Drug Delivery



Raman cross-sectional image
of a coating of a drug plus
polymer on a stent.

Polymer (red),
amorphous drug (green),
crystalline drug (blue),
polymer + amorphous drug (yellow).
100x 10 microns scan.

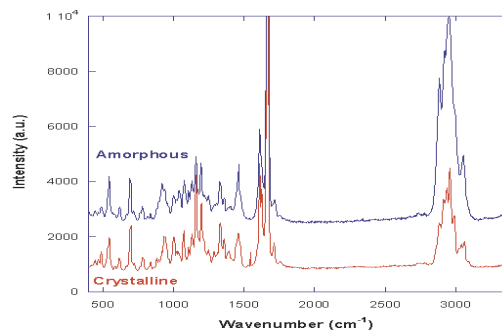
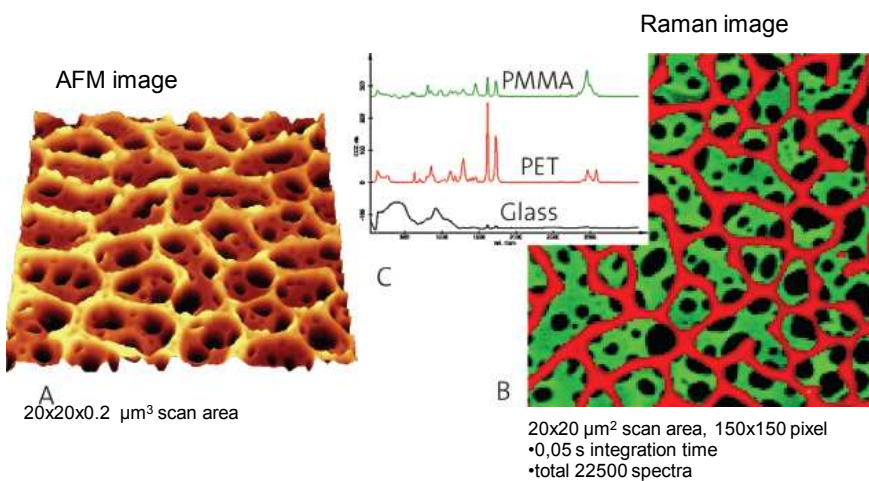


Image Courtesy:
Dr. Klaus Wormuth, SurModics (www.surmodics.com)

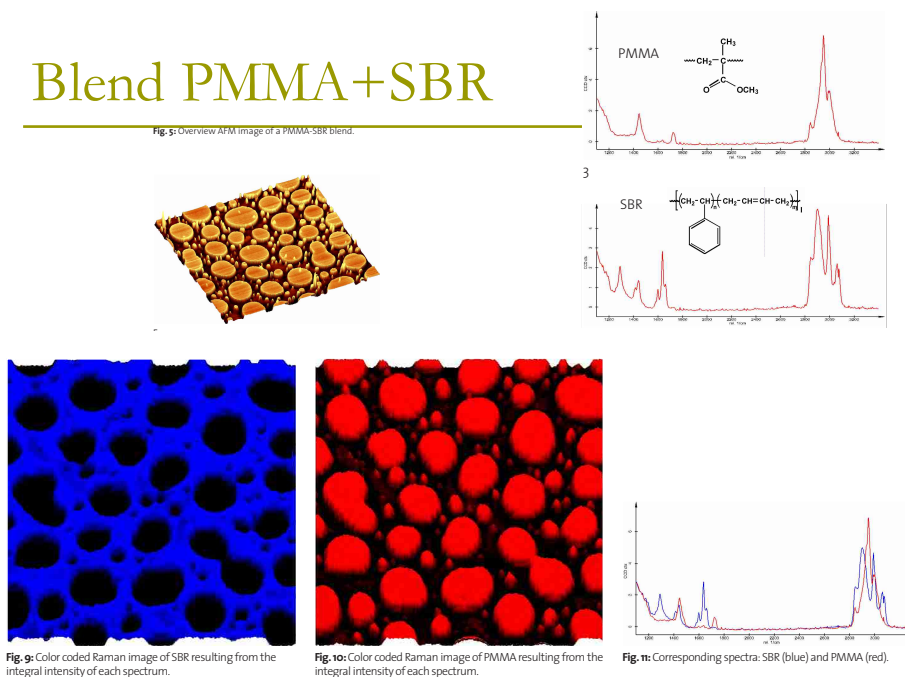
Polímeros

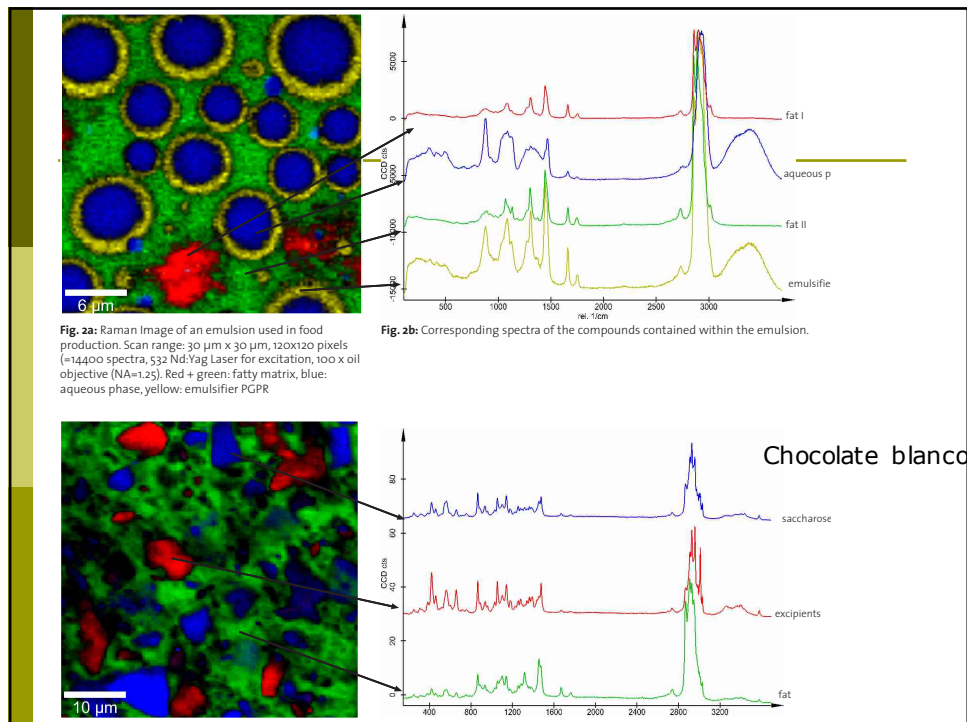
Thin Film of PMMA - PET



Blend PMMA+SBR

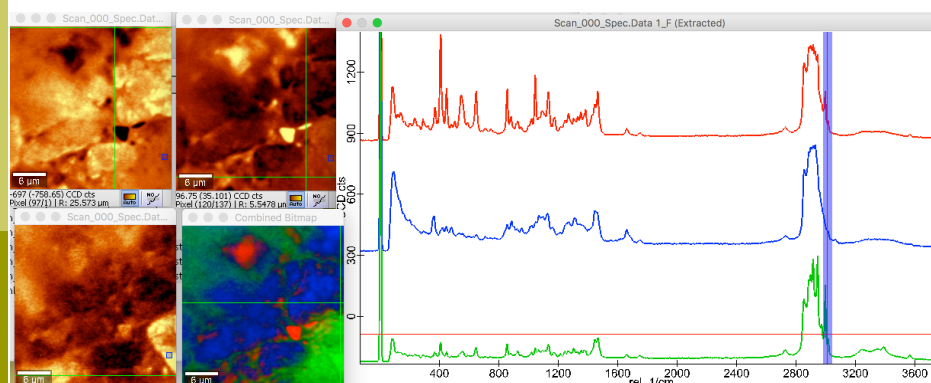
Fig. 5: Overview AFM image of a PMMA-SBR blend.





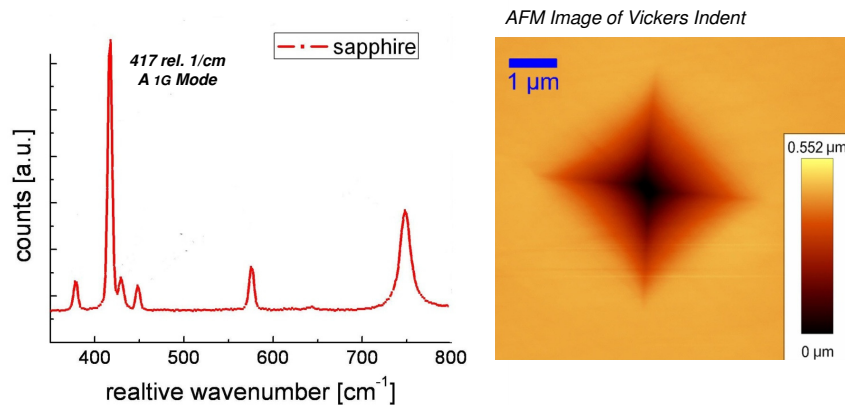
Chocolate Blanco (toblerone)

■ Sacharose, Maltose and Fats



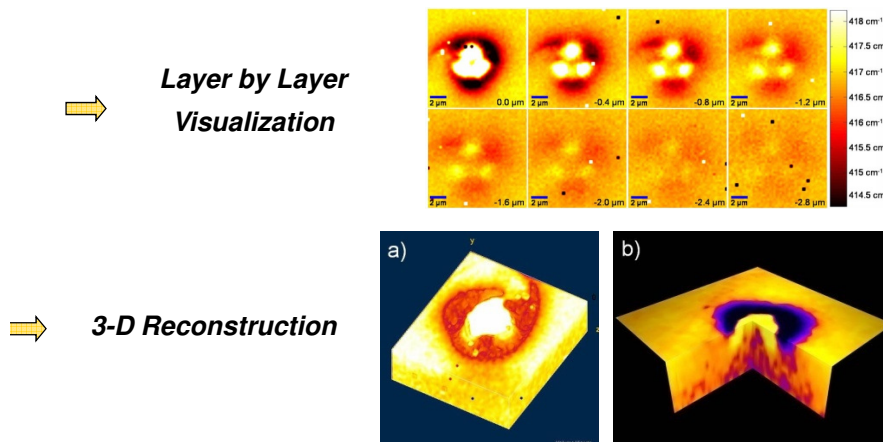
Medidas de Tensiones Residuales

Sample: Vickers Indent in Single Crystal Sapphire
Internal Stress Measurement based on Peak Shift of Raman Spectrum



Reconstrucción 3D

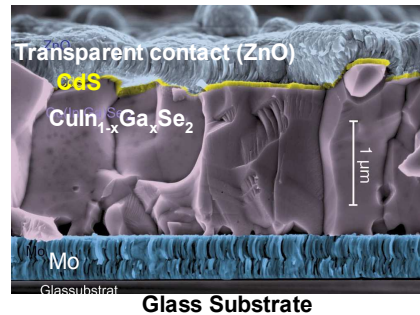
Sample: Vickers Indent in Single Crystal Sapphire
Visualization of Stress Distribution



Aplicación Celdas Solares

Composition of a CIGS ($\text{CuIn}_{1-x}\text{Ga}_x\text{Se}_2$) solar cell

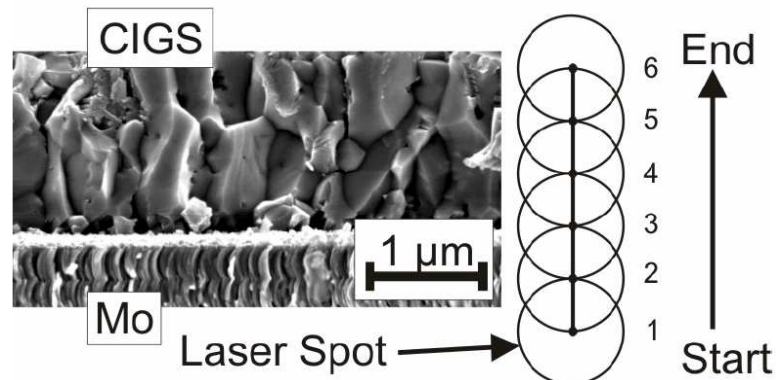
- Multilayer structure
- Ga concentration increases the bandgap energy
 - increase of efficiency of solar cells
- Interface between CIGS and Mo back contact
 - Formation of a MoSe_2 compound
⇒ ohmic type contact
- Experimental Parameter:
 - Frequency doubled NdYAG laser
- Samples:
 - Cu poor composition of CIGS
 - Ga concentration is varied from
 $x = 0$ (CIS) → $x = 1$ (CGS)



Mapping: Variación de Concentración con posición

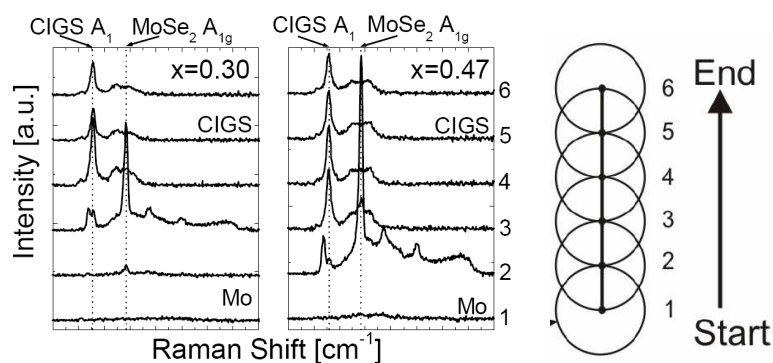
Composition of a CIGS ($\text{CuIn}_{1-x}\text{Ga}_x\text{Se}_2$) solar cell

Raman line scans on cross-sections to identify MoSe_2 interface layers

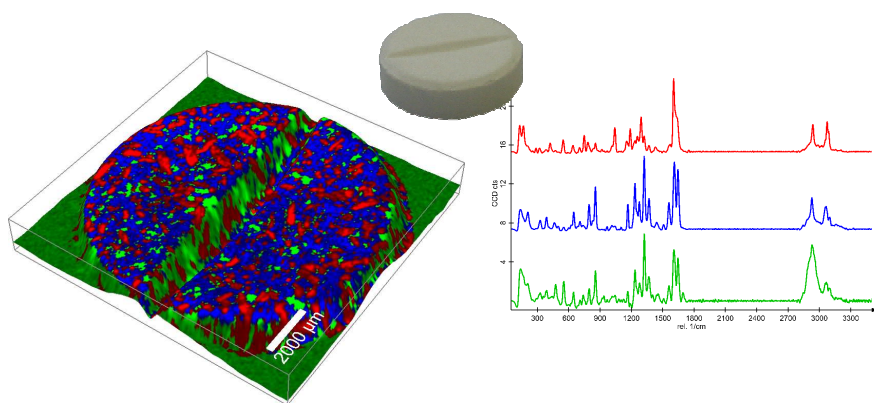


Mapping de Variación de Concentración con posición

Raman line scans on cross-sections to identify MoSe₂ interface layers



Tabletas: API y Excipientes



Stents para Drug Delivery



Raman cross-sectional image of a coating of a drug plus polymer on a stent.
 Polymer (red),
 amorphous drug (green),
 crystalline drug (blue),
 polymer + amorphous drug (yellow).
 100x 10 microns scan.

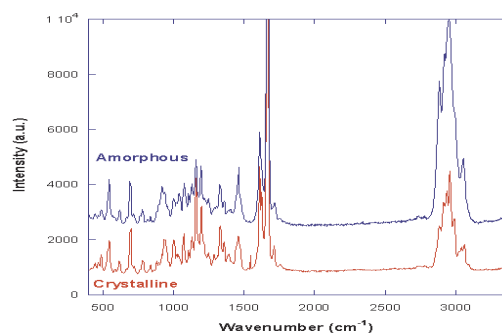
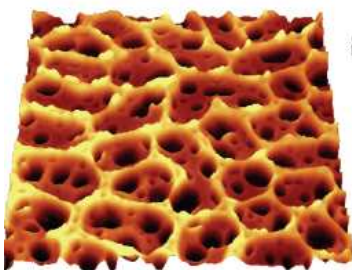


Image Courtesy:
 Dr. Klaus Wormuth, SurModics (www.surmodics.com)

Polímeros

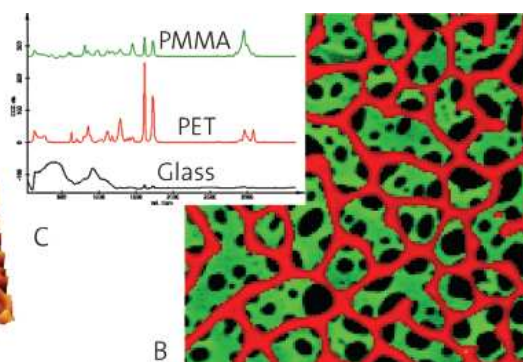
Thin Film of PMMA - PET

AFM image

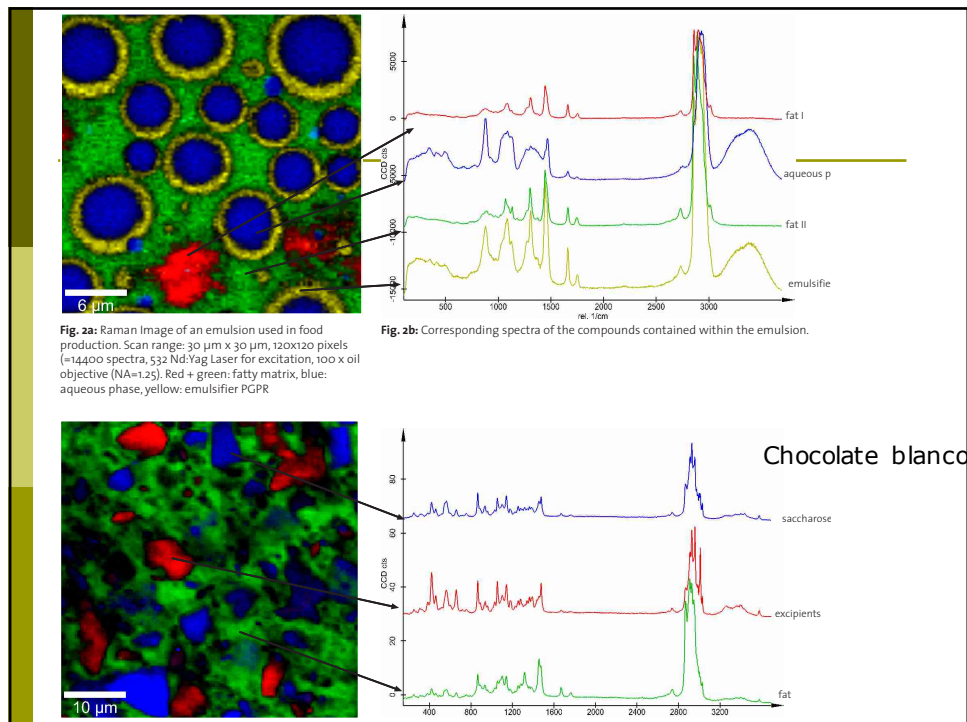


A
 20x20x0.2 μm^3 scan area

Raman image

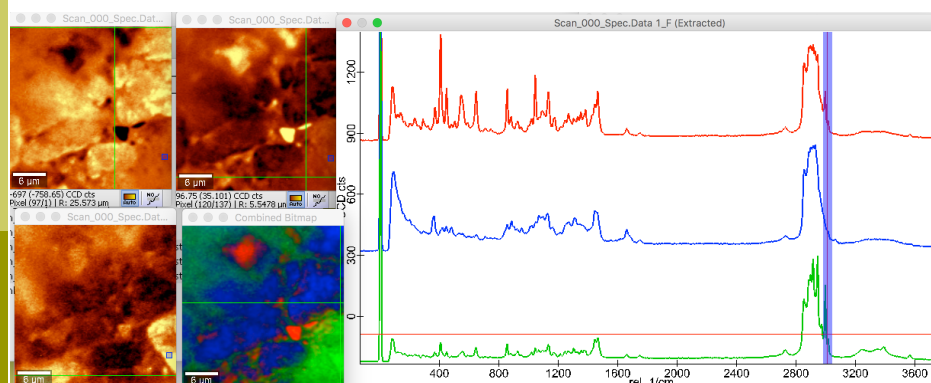


B
 20x20 μm^2 scan area, 150x150 pixel
 •0,05 s integration time
 •total 22500 spectra



Chocolate Blanco (toblerone)

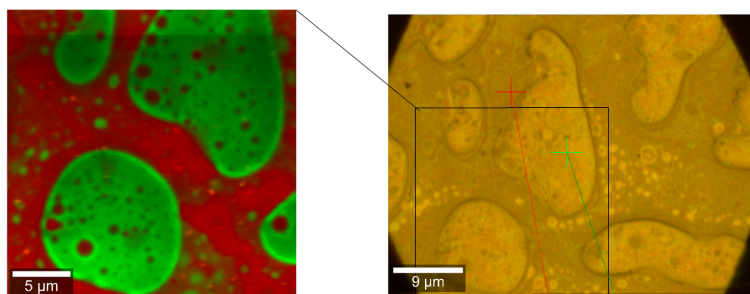
■ Sacharose, Maltose and Fats



Experiencias

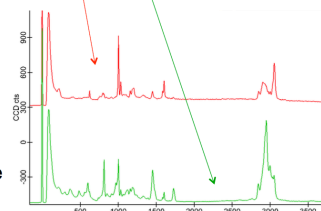
WITec alpha300RA

Ejemplo 1: Blend PMMA+PS



Mezcla de Poliestireno (PS) con polimetilmetacrilato (PMMA). Se identifican dos zonas (roja y verde), se obtiene un espectro raman en ambos lugares. El espectro indica que la zona marcada en verde es PMMA y la roja PS

Observando las diferencias en el mapping correspondiente al recuadro negro, donde se obtiene la imagen combinada de ambos componentes.



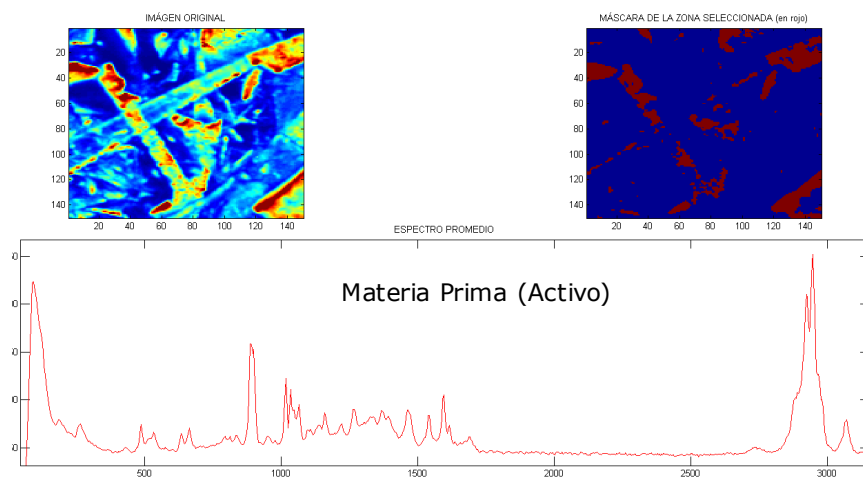
Ejemplo 2: Asesoramiento

- Ejemplo de identificación de componentes:
 - Activo
 - Excipientes
- Primero se realiza Análisis por Componente Principales (PCA)
- Luego se procede a la generación de imágenes con Project FOUR

15/6/18

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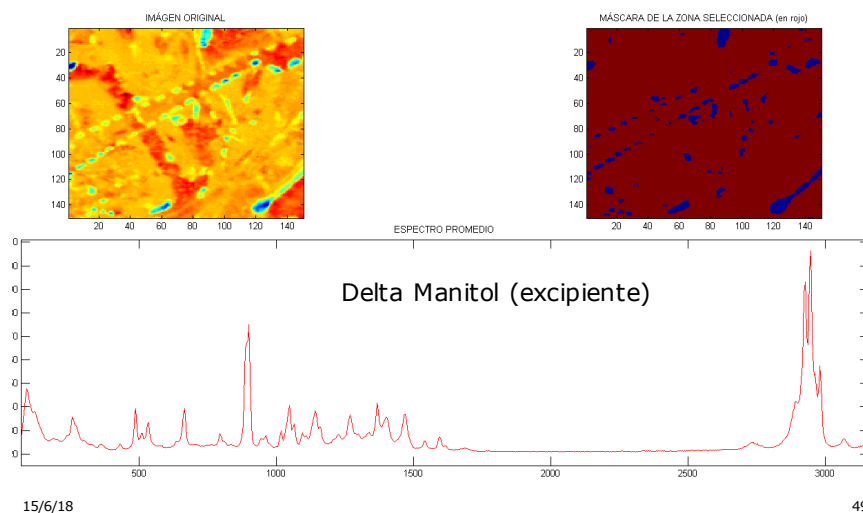
PCA: Componente 1



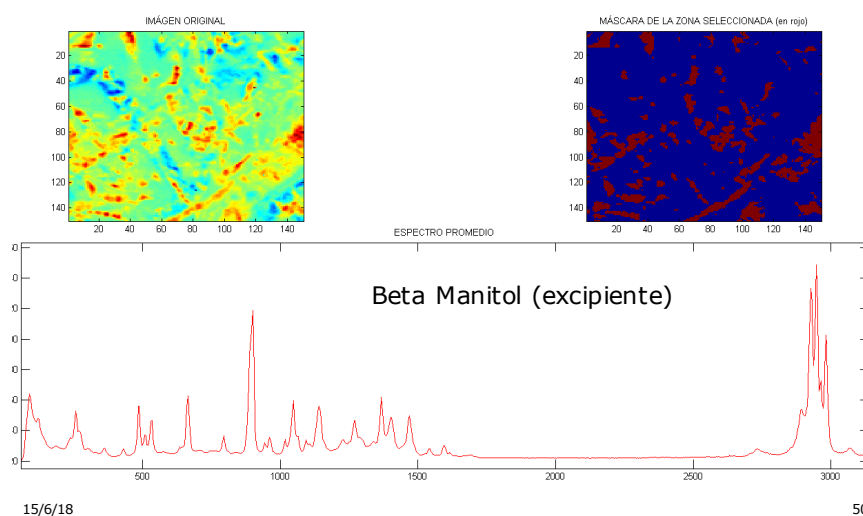
15/6/18

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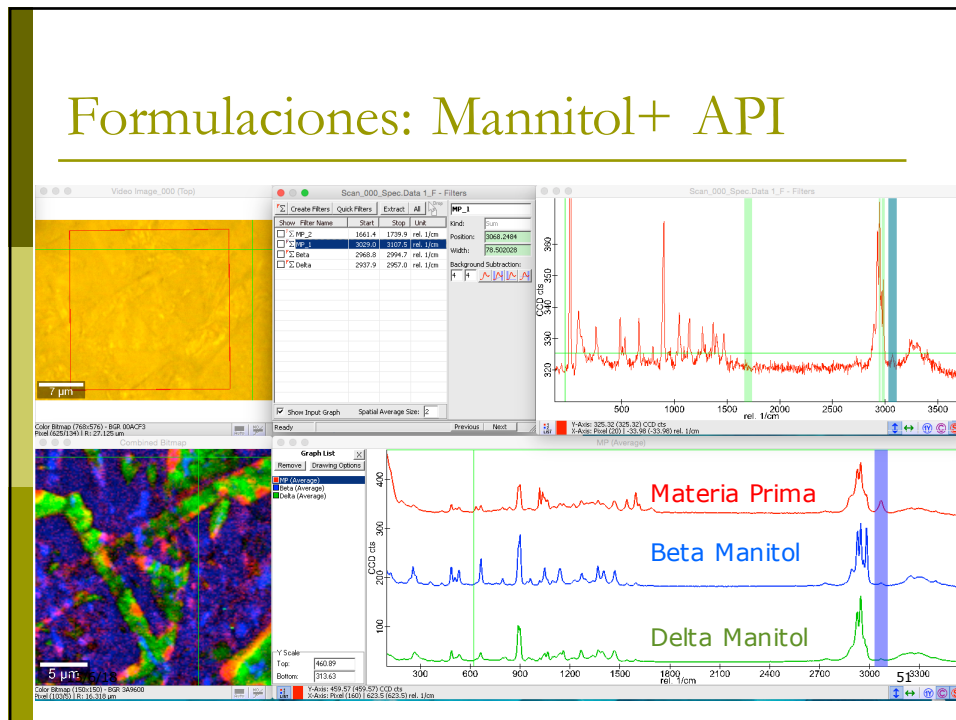
PCA: Componente 2



PCA: Componente 3



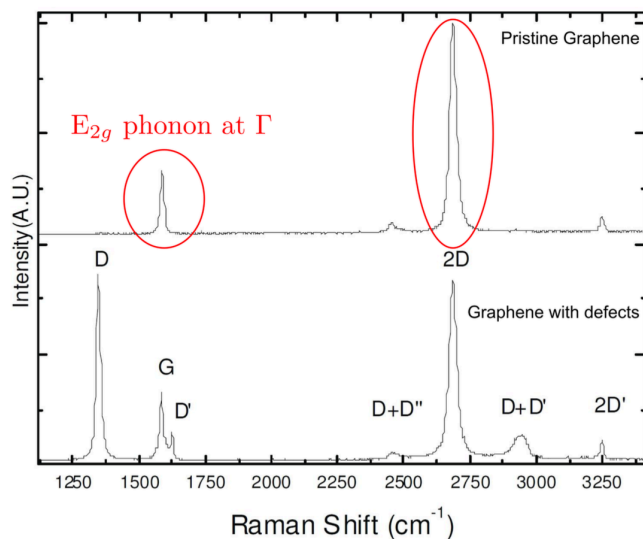
Formulaciones: Mannitol+ API



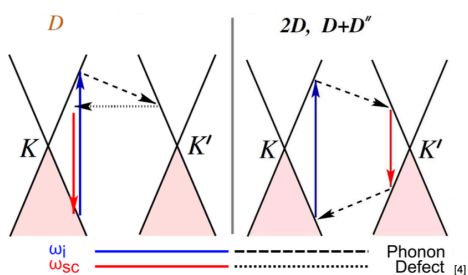
Conclusión:

- ❑ 1 solo activo
- ❑ 2 excipientes:
 - Manitol forma Beta
 - Manitol forma Delta

Ejemplo 3: Grafeno



Ejemplo 3: Grafeno



D

- Intervalley scattering with TO phonon at K-point, $\vec{q}_{ph} \neq 0$
- D peak requires defect scattering to conserve momentum

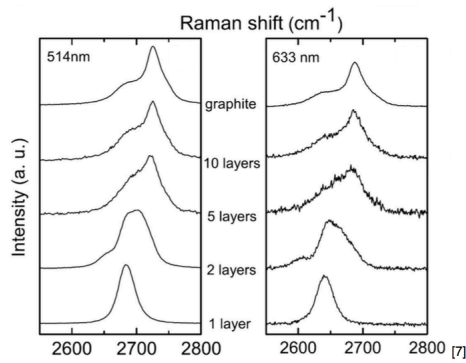
2D

- Double-resonant, intervalley scattering_[5] requires no defects
- Strong e⁻-ph coupling: 2D peak is more intense than G

T. Diening et al Confocal Raman Microscopy, Springer 2010

Ejemplo 3: Grafeno

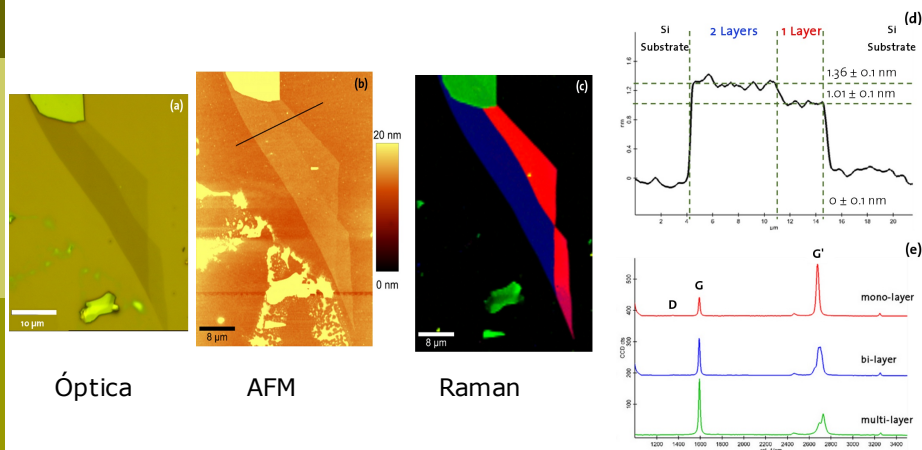
"Position and fwhm of the G and 2D peak(...)confirm presence of single-layer graphene"



- Position of 2D peak depends on number of layers
- Additional layers increase FWHM of 2D peak (more e^- states for resonant scattering)
- Occurrence of peaks at 1350 cm^{-1} (D) and 1620 cm^{-1} (D') reveal defects of graphene sample

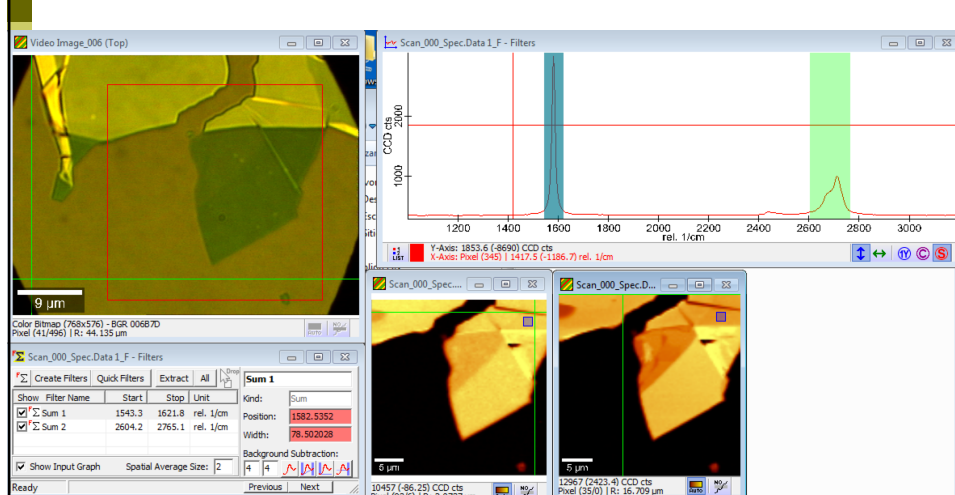
T. Diening et al Confocal Raman Microscopy, Springer 2010

Ejemplo 3: Grafeno y MLG

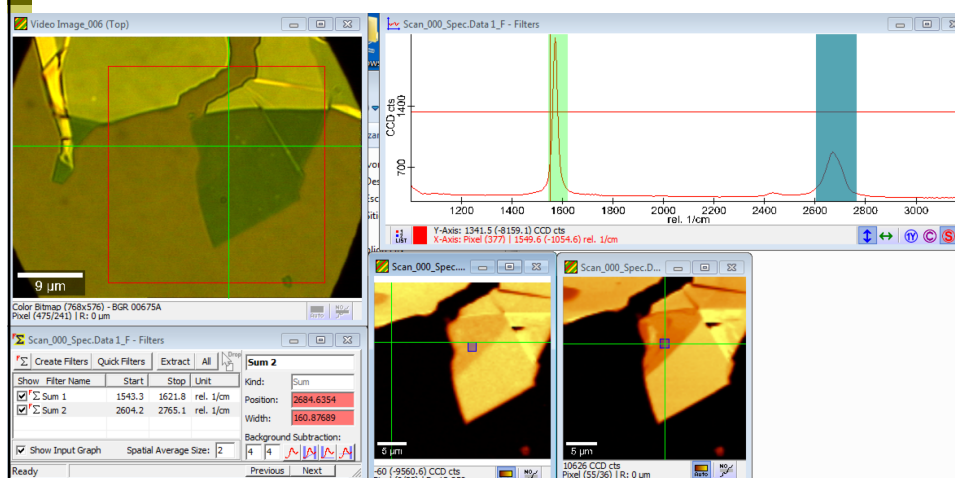


T. Diening et al Confocal Raman Microscopy, Springer 2010

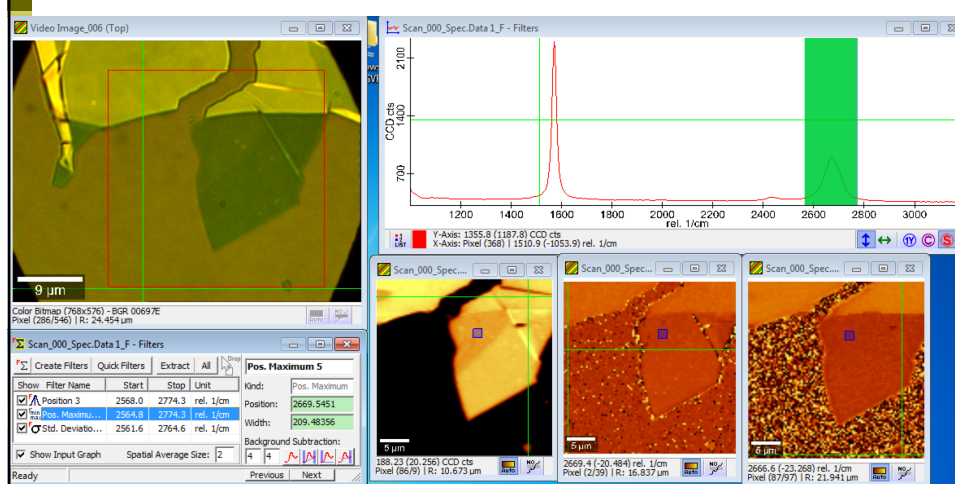
Ejemplo 3: Grafeno



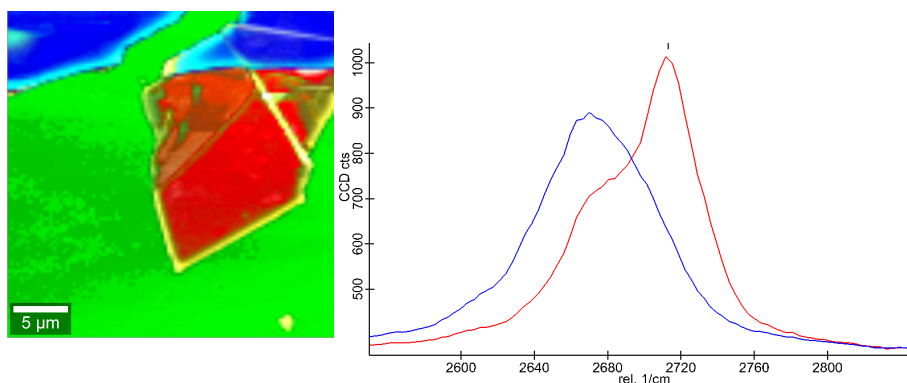
Ejemplo 3: Grafeno



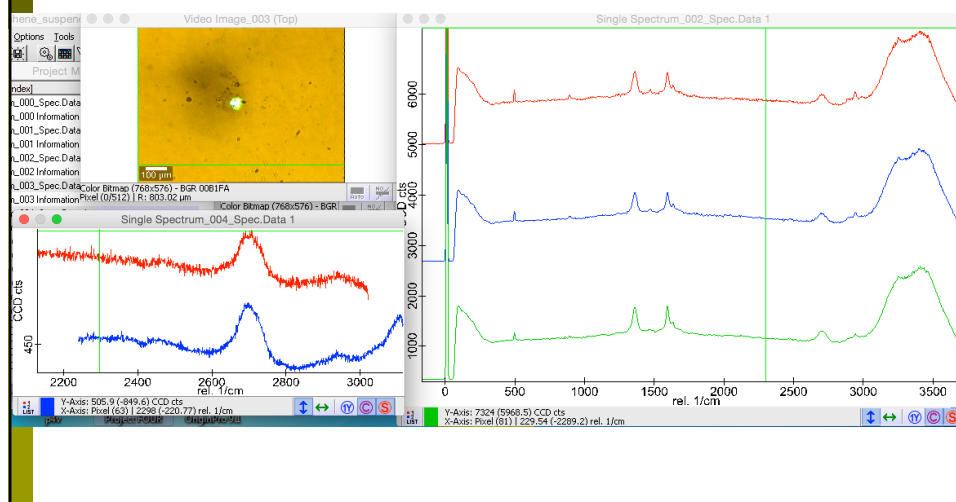
Ejemplo 3: Grafeno



Ejemplo 3: Grafeno



Ejemplo 3: Grafeno en Solución



Ejemplo 4: Nanotubos de Carbono

Fig. 5.1 Different carbon allotropes with nanometer-scale phases ranging from 0D C60 fullerenes, 1D carbon nanotubes, 2D graphene, to 3D diamond and graphite

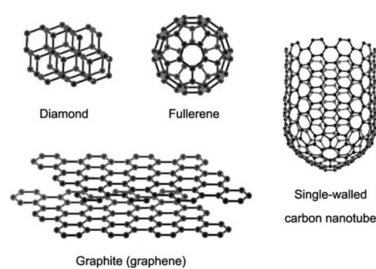
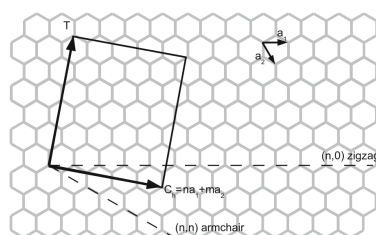


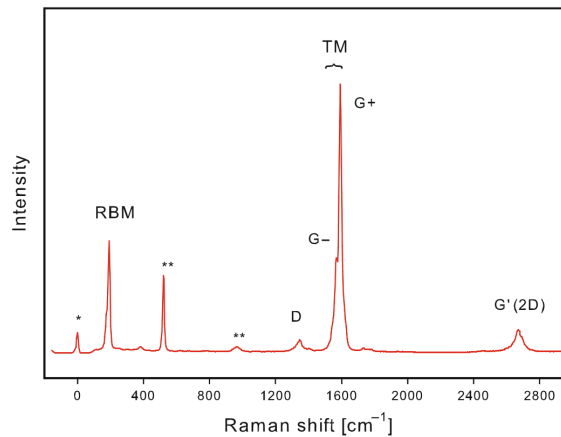
Fig. 5.2 The vector C_h describes how a sheet of graphene is rolled up to create a carbon nanotube [6]



T. Diening et al Confocal Raman Microscopy, Springer 2010

Ejemplo 4: Nanotubos de Carbono

Fig. 5.3 Typical Raman spectrum of an individual single-walled carbon nanotube recorded with a confocal micro-Raman spectroscope using a green 532 nm laser. The feature marked “*” is the attenuated elastically scattered Rayleigh line. Features marked “**” come from the Si support



T. Diening et al Confocal Raman Microscopy, Springer 2010

Ejemplo 4: Nanotubos de Carbono

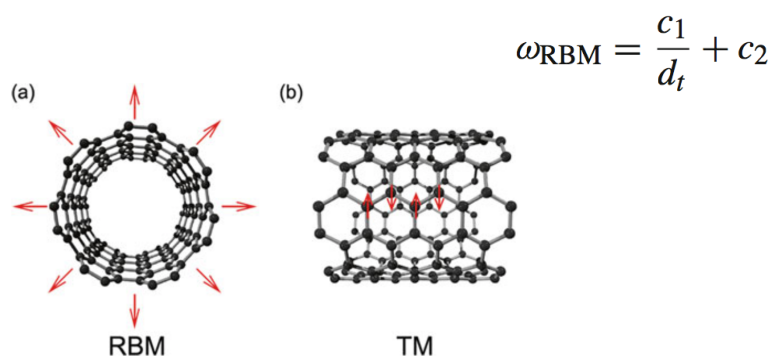
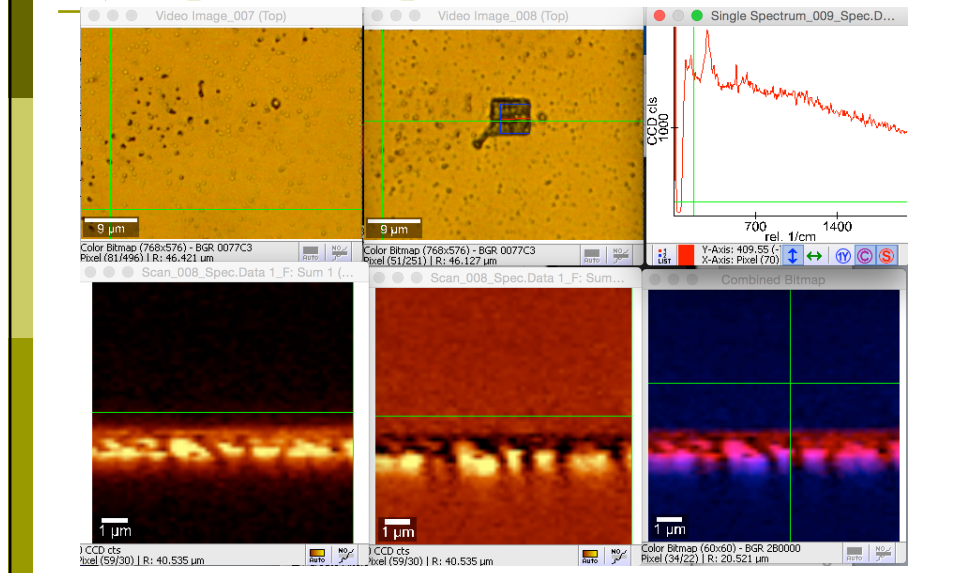


Fig. 5.4 Raman-active vibrational modes of carbon nanotubes. **(a)** The so-called radial breathing mode (RBM) is a prominent feature of the tubular nanostructure and not present in planar graphite. The Raman shift of the RBM is approximatively inversely proportional to the tube diameter. **(b)** An example of a tangential mode (TM). In analogy to graphitic Raman modes it is often also called G-mode or high-energy mode (HEM)

T. Diening et al Confocal Raman Microscopy, Springer 2010

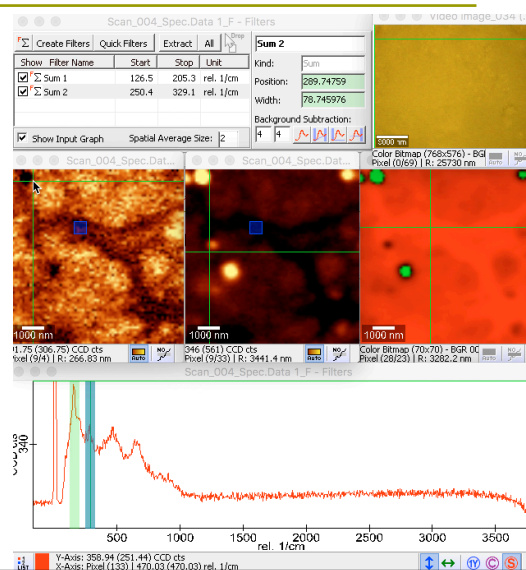
Ejemplo 6: Depth Scan Cu_2O



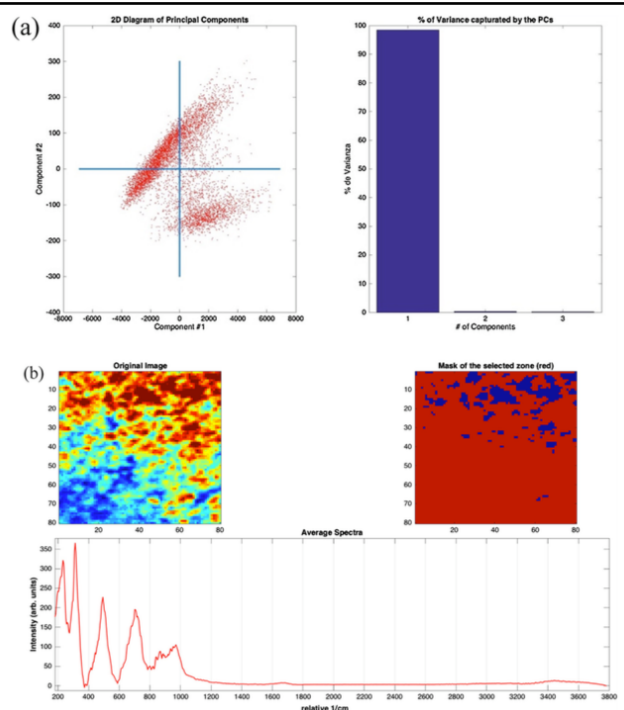
Ejemplo 7: Caracterización de NT

Ejemplo de Funcionamiento:

- Muestra de NT calentados a $T=200^\circ\text{C}$.
- Presencia de Nanopartículas de Anatasa en muestra de NT.

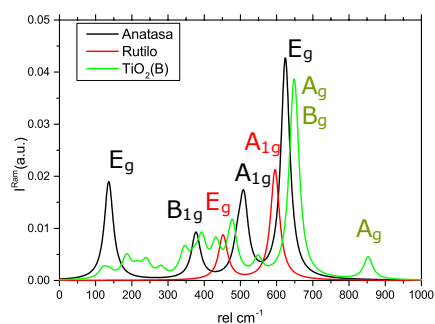


PCA para los fotoelectrodos de HTNT



Modelado: Espectros Raman de polimorfos de TiO_2

Espectros Raman Calculados

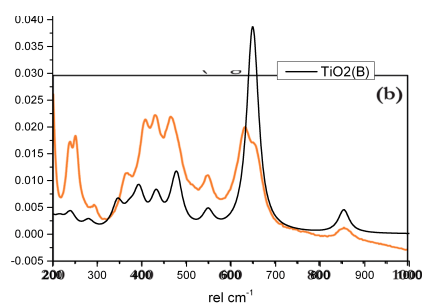


Cálculos DFT: Código VASP

Ecut=400 eV

Ondas Planas

DFPT fonones



Espectros Raman Calculados y Experimental
Dylla et al, J Phys. Chem. Lett. 2012, 3, 2015 2019

4. Ejemplo: Rutilo

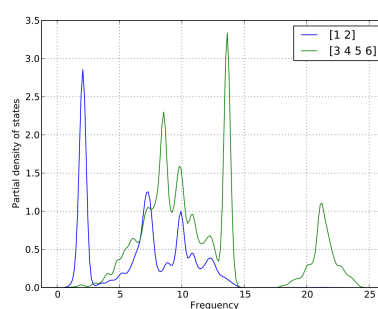
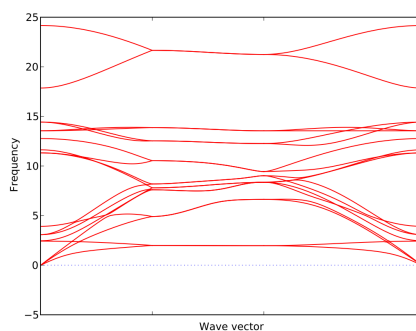
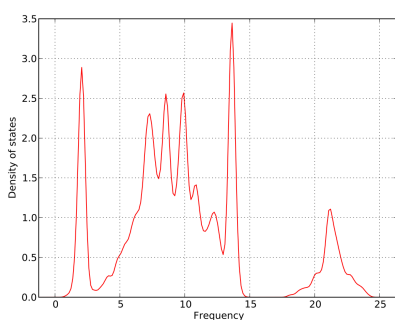
▣ Rutilo:

▣ Grupo Espacial $P 4_2/m n m$

▣ $a=b= 4.5977(4)\text{\AA}$ y $c=2.9564(2)\text{\AA}$

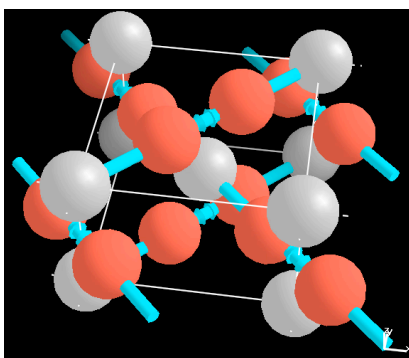
Ti^{4+} 2a 0.0 0.0 0.0

O^{2-} 4f 0.3023(3) 0.3023(3)

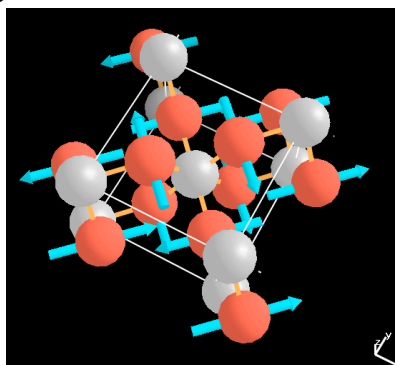


4. Ejemplo: Rutilo

▣ Modos Raman Activos



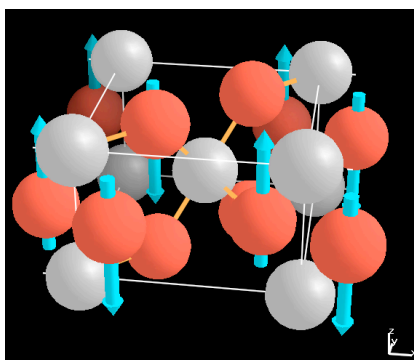
A1g



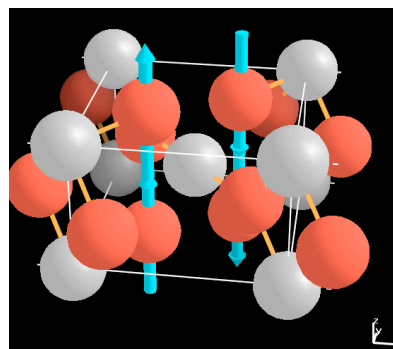
B1g

4. Ejemplo: Rutilo

▣ Modos Raman Activos



Eg



Eg

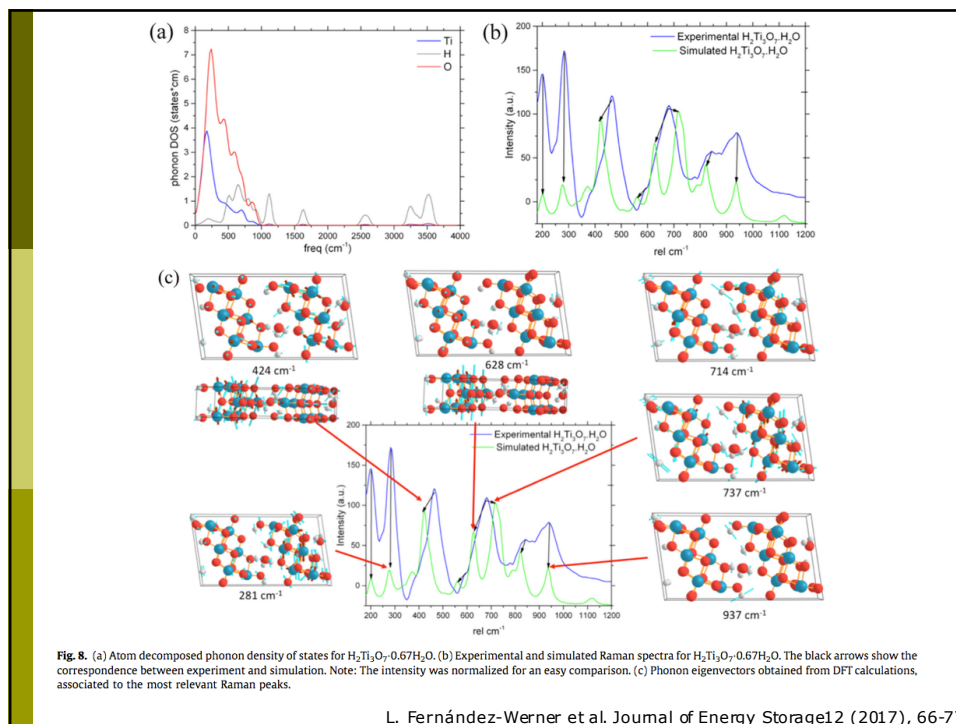
4. Ejemplo: Rutilo

▣ Actividad Raman

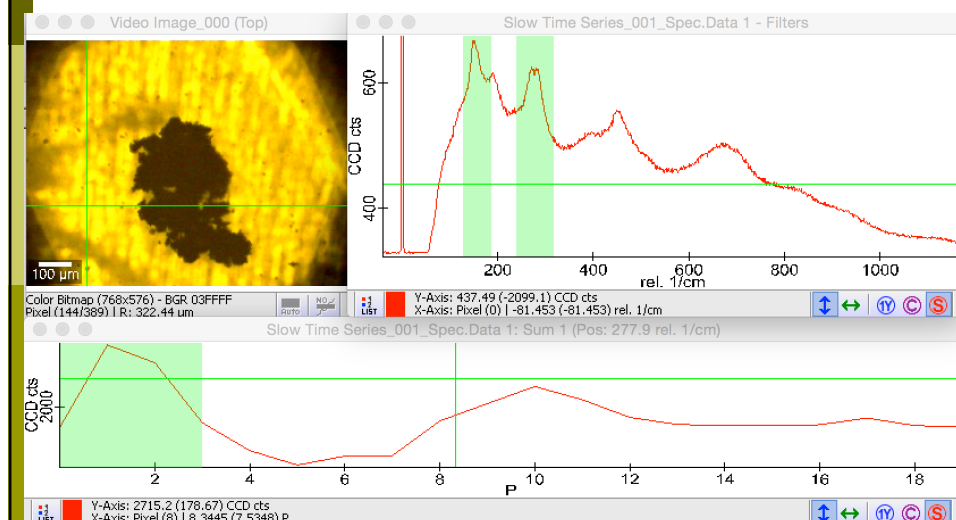
$$\frac{d\sigma_i}{d\Omega} = \left(\frac{2\pi\nu_s}{c} \right)^4 \frac{I^{Ram}}{45} \frac{h(n_i^b + 1)}{8\pi^2\nu_i}$$

$$\frac{I^{Ram}}{45} = 45 \left(\frac{d\alpha}{dQ} \right)^2 + 7 \left(\frac{d\beta}{dQ} \right)^2 = 45\alpha'^2 + 7\beta'^2$$

mode	freq(cm-1)	alpha	beta2	activity	Irrep.
001	806.01625	0.0111139	0.119	0.842	B2g
002	595.69219	3.6897265	126.828	1500.431	A1g
003	481.19473	0.0093502	0.000	0.005	Eu
004	481.19473	0.0017736	0.000	0.001	Eu
005	451.96183	-0.0246816	43.201	302.435	Eg
006	451.96183	0.0092582	43.239	302.678	Eg
007	425.86581	0.0028455	0.000	0.001	A2g
008	387.96675	0.0016885	0.000	0.000	B1u
009	377.61627	0.0072289	0.000	0.002	Eu
010	377.61627	0.0039901	0.000	0.001	Eu
011	130.66567	0.0017733	0.042	0.300	B1g
012	102.57426	0.0134835	0.000	0.008	Eu
013	102.57426	0.0080623	0.000	0.004	Eu
014	82.10969	0.0392713	0.000	0.071	A2u
015	80.61206	-0.0024535	0.000	0.000	B1u



Ejemplo 6: Temp. Scan.



Ejemplo 7. LLTO-PMMA

Microscopia Raman Confocal:

- LLTO muestra muy buena afinidad con grupos nitrato

Fig. 3 – Confocal Raman spectroscopy for LLTO (red), PMMA (blue) and LiNO_3 (black) sample references (a) and LiPMMA-LX with X=0 (b), 1 (c), 2(d) and 3(e). Raman spectra ascribed to LLTO-rich, PMMA-rich and LLTO-PMMA interface zones are represented with red, blue and black lines, respectively.

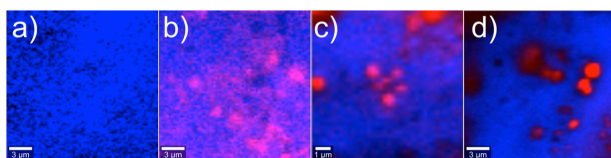
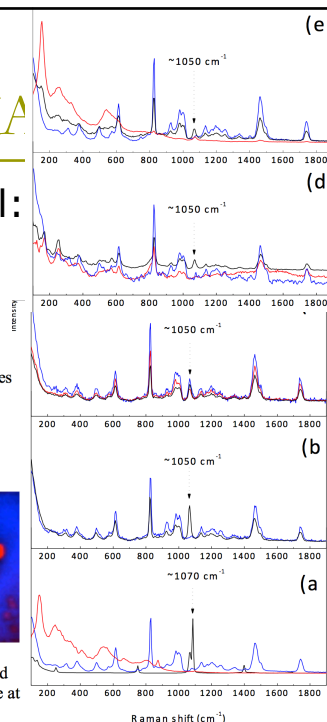


Fig. 4 – Confocal Raman microscopy for LiPMMA-LX with X=0 (a), 1(b), 2(c) and 3(d). The filtering of the LLTO A_{1g} mode at $\sim 145 \text{ cm}^{-1}$ and the PMMA $\nu(\text{C}=\text{O})$ mode at $\sim 1725 \text{ cm}^{-1}$ are shown in red and blue, respectively.



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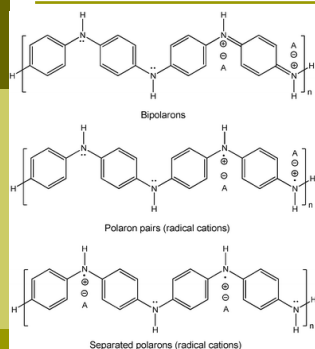
Enhancement of lithium conductivity and evidence of lithium dissociation for LLTO-PMMA nanocomposite electrolyte

Mariano Romero ^{a,b}, Ricardo Faccio ^{a,b,*}, Santiago Vázquez ^{a,b}, Álvaro W. Mombrú ^{a,b}

^a Centro NanoMat/CryssMat, DETEMA, Facultad de Química, Universidad de la República, Uruguay

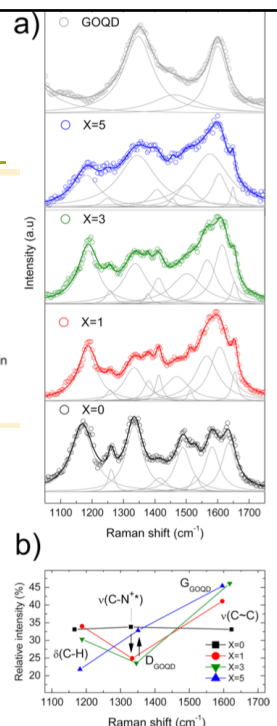
^b Centro Interdisciplinario de Nanotecnología, Química y Física de Materiales, Espacio Interdisciplinario, Universidad de la República, Uruguay

Ejemplo 8: PANI-GQD



PANI: modelo polarón

D. Mombrú et al. Tuning Electrical Transport Mechanism of Polyaniline-Graphene Oxide Quantum Dots Nanocomposites for Potential Electronic Device Applications. J. Phys. Chem. C 2016, 120, 25117–25123

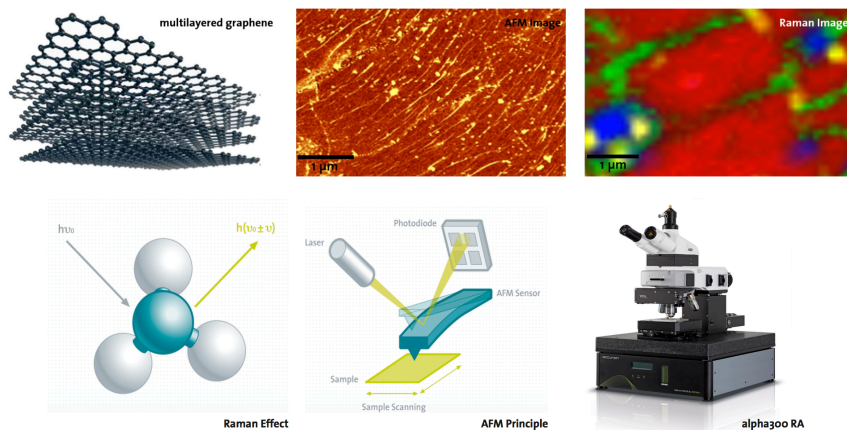


Resumen: Micro Raman Confocal

- No Destructivo
- Identificación Química Directa
- Identificación de Propiedades de Materiales
- Preparación sencilla de muestra
- Sólidos y Líquidos
- Detección 3-dimensional
- Combinación de detección química con AFM
- Variación de Temperatura (Linkam)

Micro Raman AFM Dual

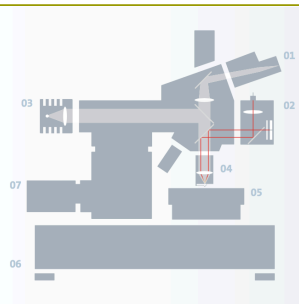
- ▣ Alpha 300R → Alpha 300RA
- FSE_1_2014_1_102008 - ANII



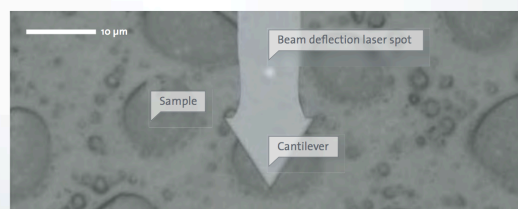
AFM y Raman

BEAM PATH

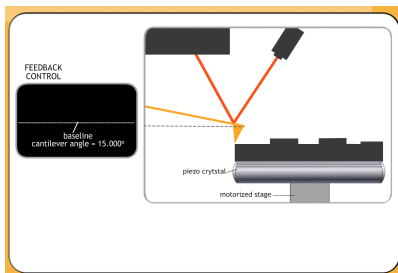
- 01 Video camera system
- 02 Beam deflection unit
- 03 LED white light illumination
- 04 AFM objective with cantilever
- 05 Scan-stage
- 06 Active vibration-isolation table
- 07 Z-stage for focusing



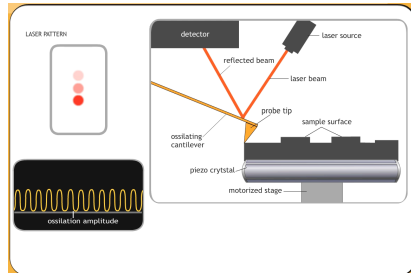
SIMULTANEOUS CANTILEVER AND SAMPLE VIEW



Métodos de Medida

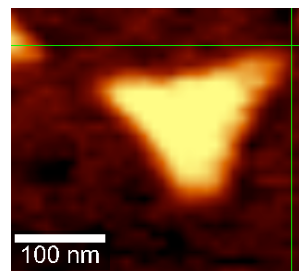
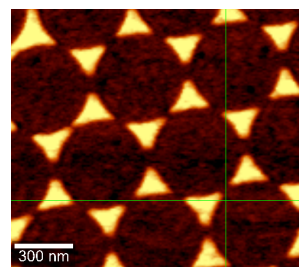
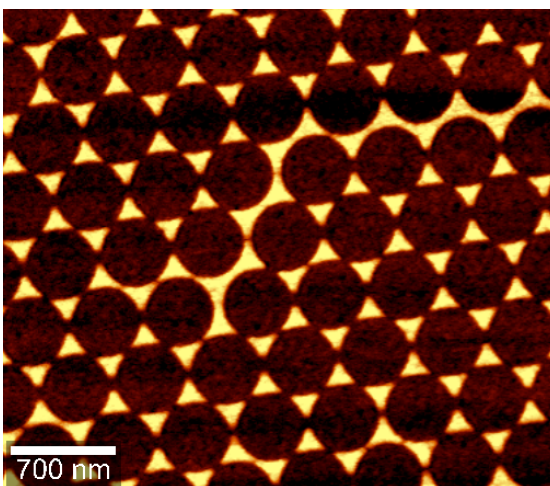


Contacto

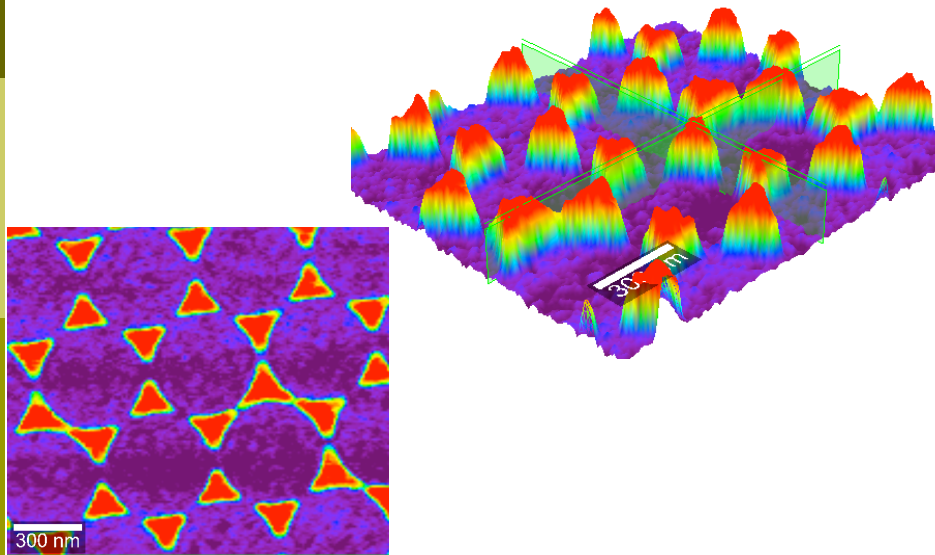


AC Mode

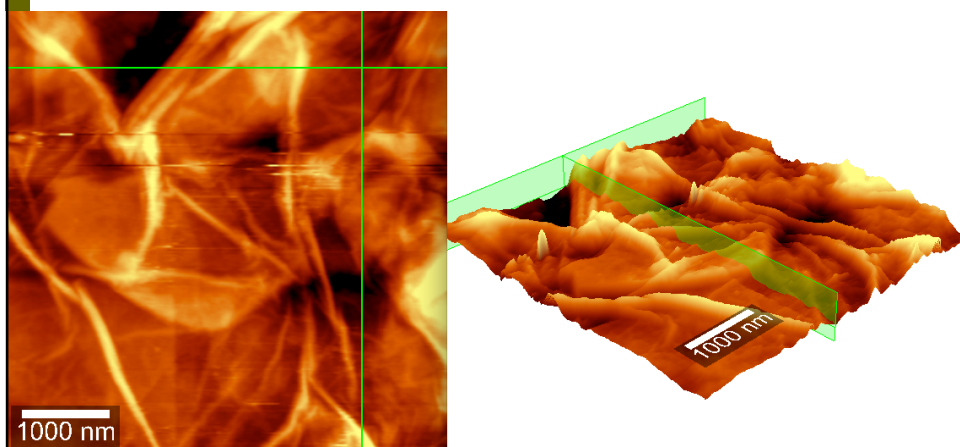
Contact mode: Triángulos de Al



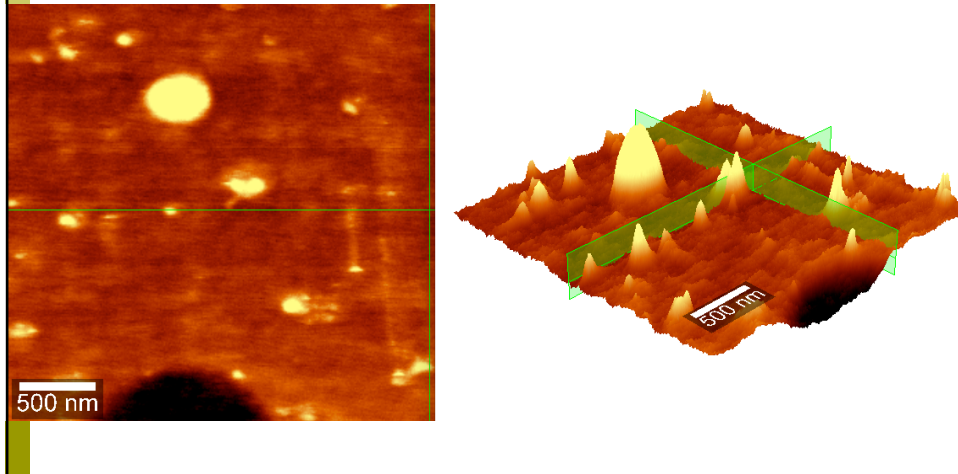
Contact mode: Triángulos de Al



Grafeno: Microscopia de Fuerza Atómica

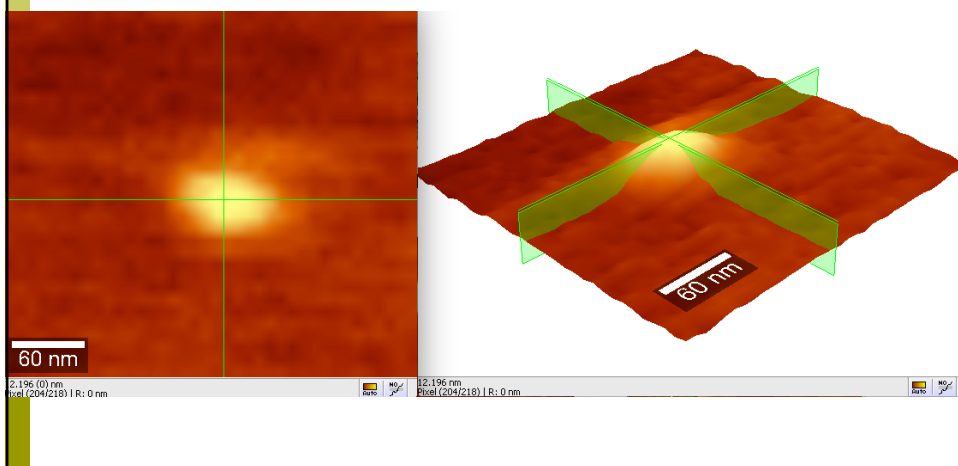


Grafeno: Puntos Cuánticos

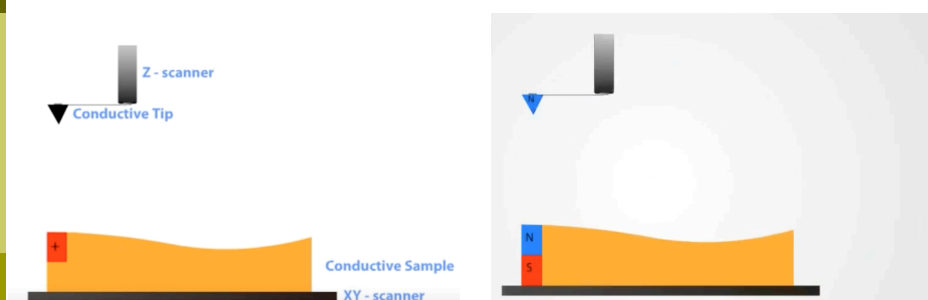


Grafeno: Puntos Cuánticos

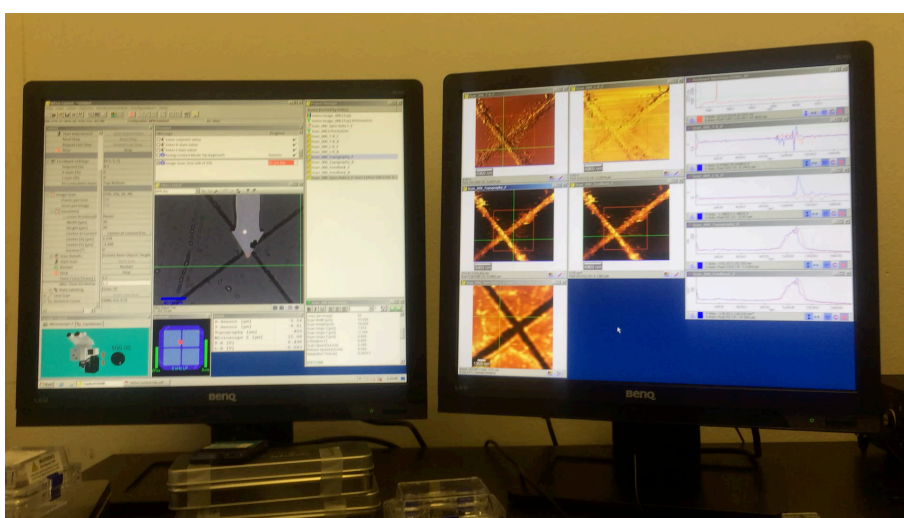
▣ 60 nm de diámetro y 13 nm de alto

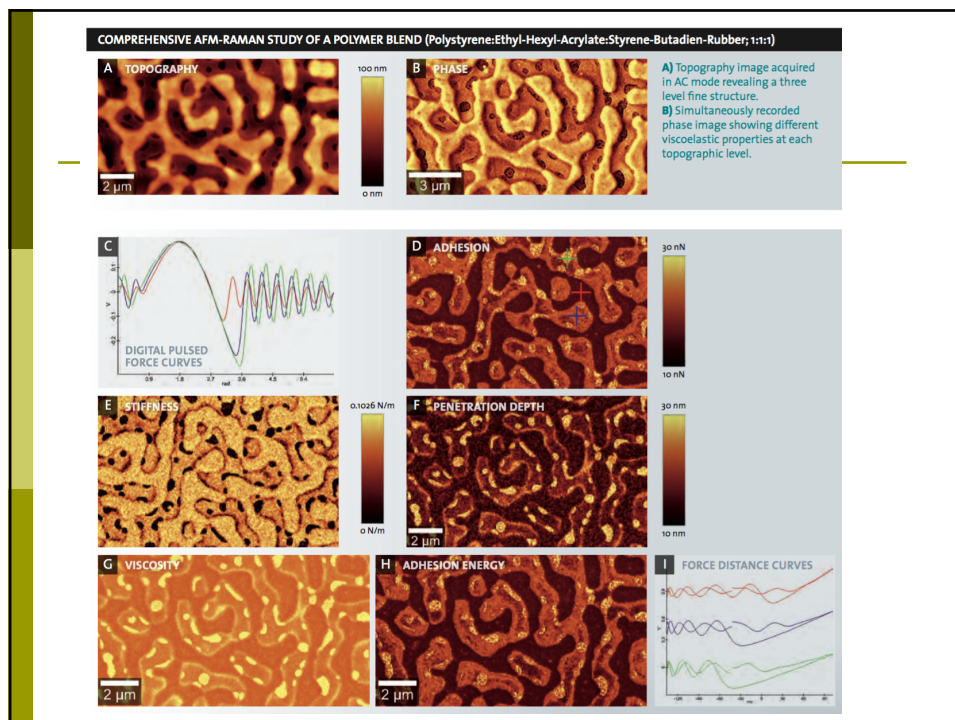


EFM & MFM

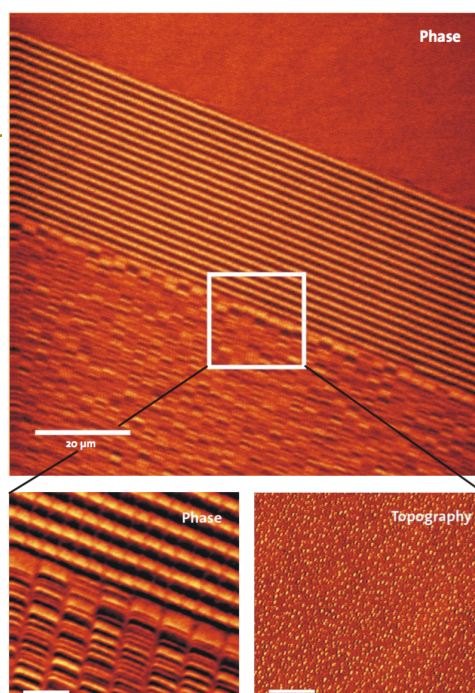


Raman & AFM Dual





□ MFM



Resumen: AFM/EFM/MFM

- Diferentes Modos de Medida:
 - *Contacto*
 - *No Contacto*
 - *Liftmode*
- AFM/EFM/MFM
- Topología y Propiedades Físicas:
 - *Dureza*
 - *Viscosidad*
 - *Adhesión*
- Posibilidad de medir en Líquidos

Agradecimientos



AGENCIA NACIONAL
DE INVESTIGACIÓN
E INNOVACIÓN

- Parque Científico y Tecnológico de Pando (PCTP) / Instituto Polo Tecnológico de Pando
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 - Microbiología-Biotecnología, DEPBIO – FQ.
 - Instituto Nacional de Donación y Trasplante - INDT
 - Grupo Física del Estado Sólido– IF-FING
 - Cátedra de Química Inorgánica –FQ
 - Cátedra de Análisis Instrumental – FQ
 - Cátedra de Fisicoquímica -FQ
 - Laboratorio de Biomateriales – FCIEN



