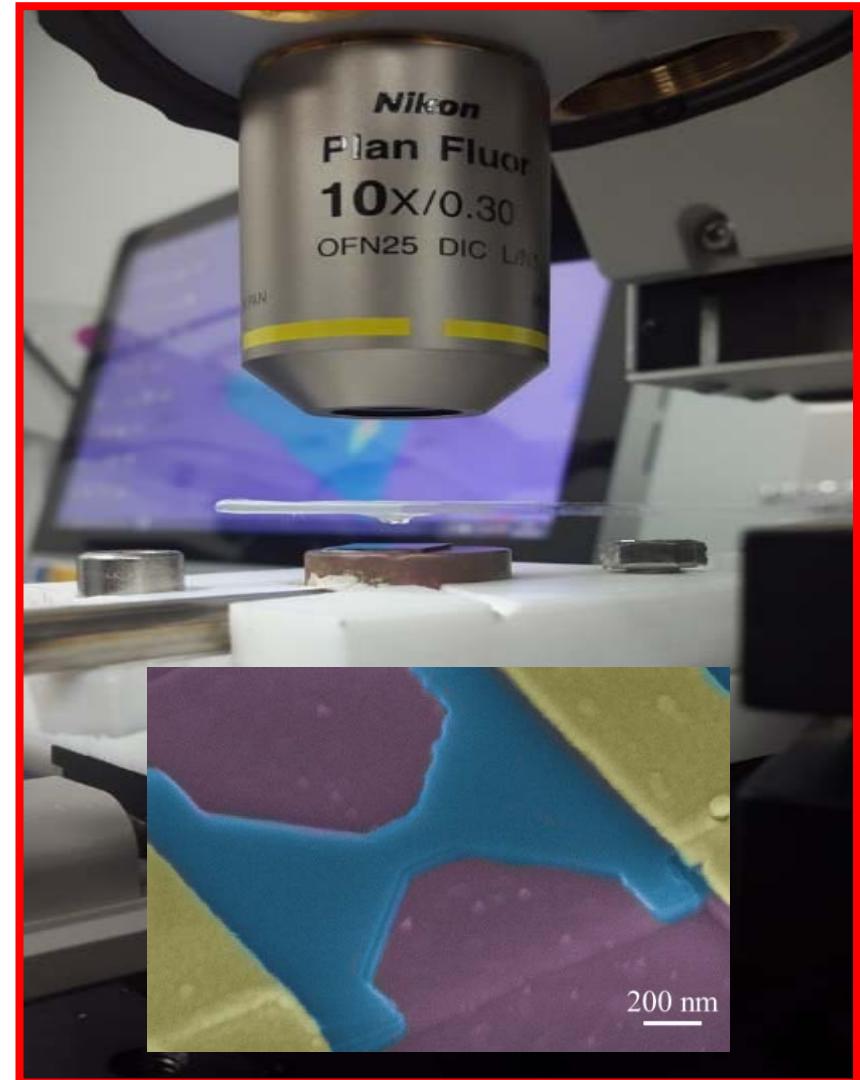


Grupo de Nanotecnología – Nanotech

Materiales cuánticos

Enrique Diez



Grupo de Nanotecnología



<http://nanotech.usal.es/>



1 Materiales cuánticos: 2D & Aislantes topológicos
Dpto. Física Fundamental
Mario Amado, Jorge Quereda, Pilar García, E.D.

2 Emisión y detección de Terahercios
Dpto. Física Aplicada
Yahya Meziani

3 Materiales Coloidales
Dpto. Química Física
Mercedes Velázquez

NanoTECH: grupo de investigación interdepartamental tras la unión de tres grupos de investigación independientes que ya colaboraban entre sí desde 2008.



COMPOSICIÓN 2020

- 11 Profesores permanentes
- 3 Postdoc
- 3 Estudiantes de doctorado
- 2 Técnicos



Grupo de Nanotecnología – Nanotech



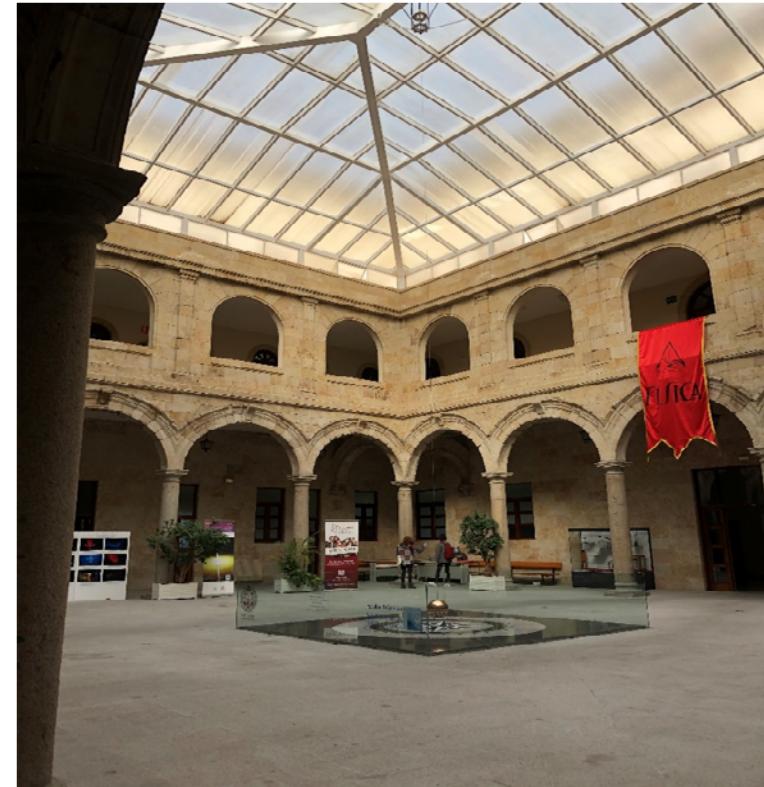
<http://nanotech.usal.es/>



Edificio Multiusos I+D+i

C/ Espejo, 2 – 37007 Salamanca

Reunión de Nanolito - 13 de noviembre de 2020

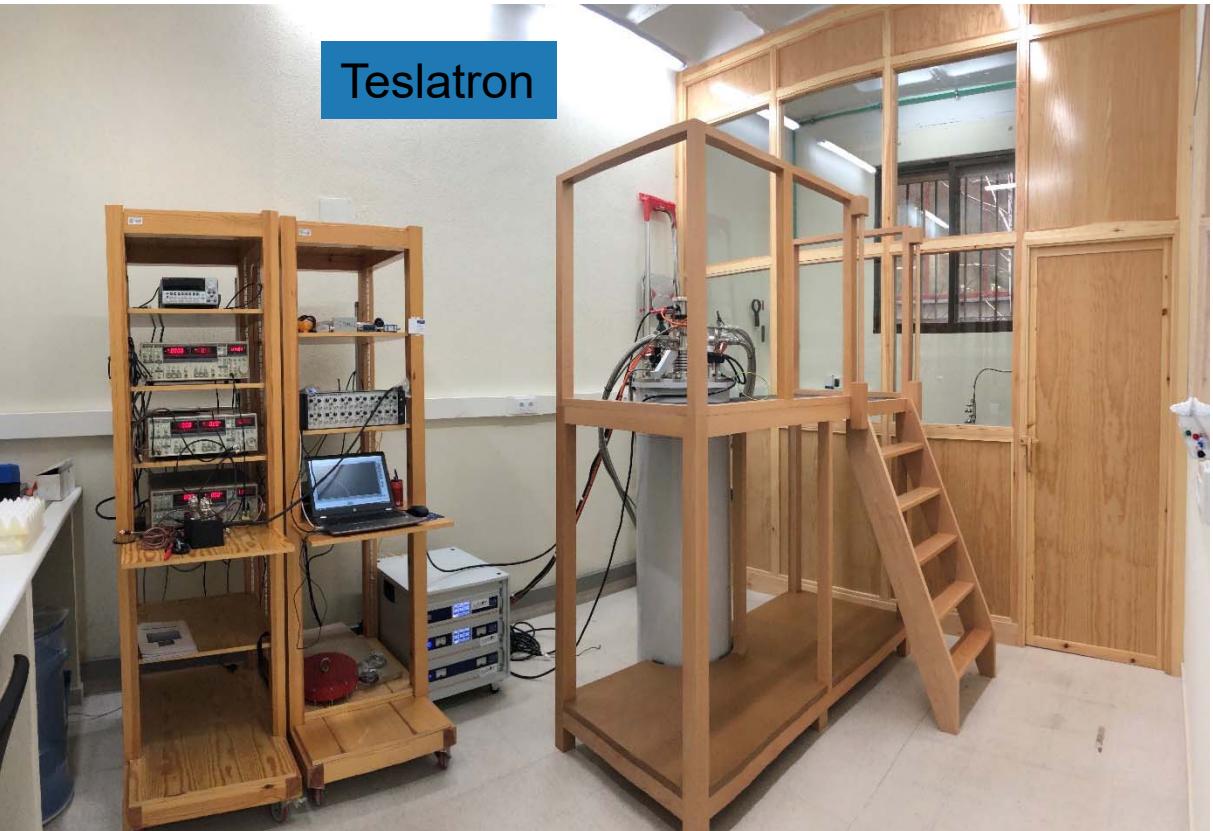
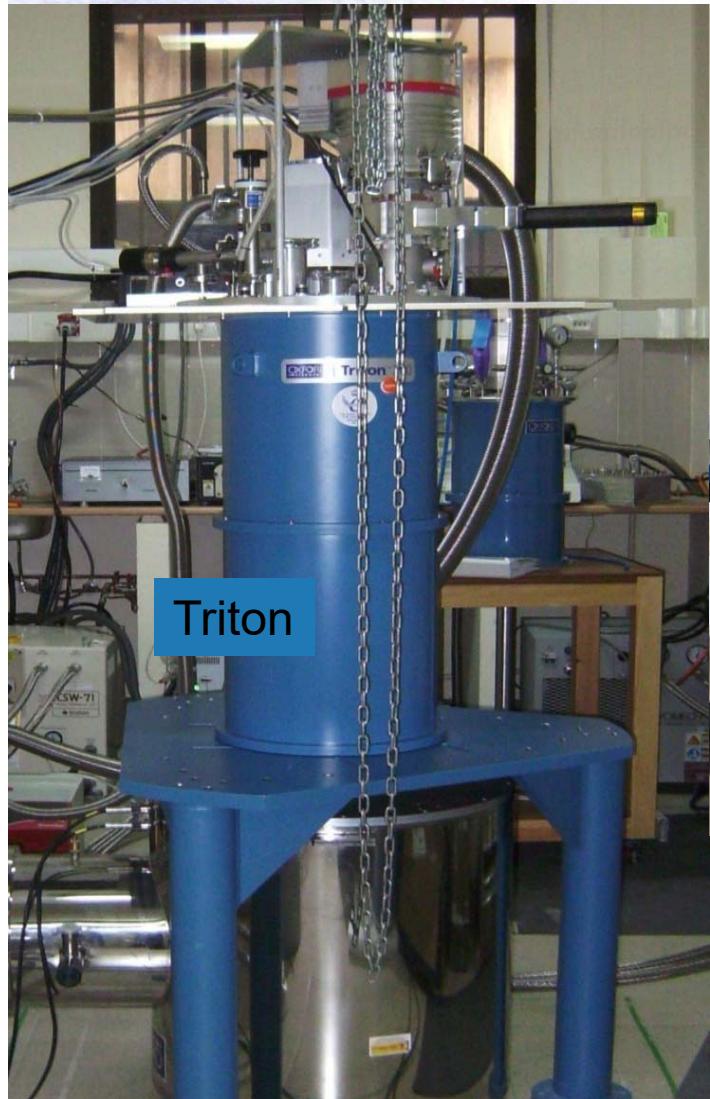


Edificio Trilingüe

Facultad de Ciencias
Plaza de la Merced, 2 - 37008 Salamanca

Laboratorio de Bajas Temperaturas

(Sin líquidos criogénicos)



Dilución $^3\text{He}/^4\text{He}$
 $< 10 \text{ mK}$

12 Teslas



Mario Amado



Laboratorio de Bajas Temperaturas (Sin líquidos criogénicos)



<http://nanotech.usal.es/>

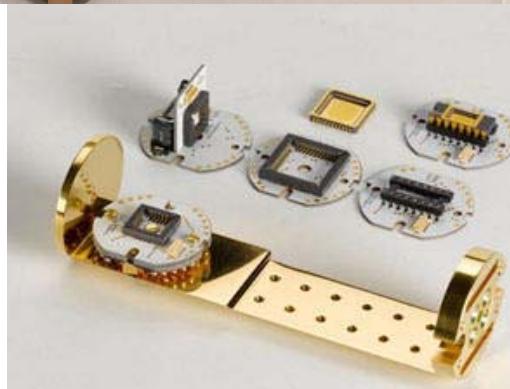


Mario Amado

Teslatron-PT



- Rotación de la muestra
- LCC44, LC20, DIL16
- VTI – 1,5K – 12 Teslas
- ^3He – 290 mK- 12 Teslas

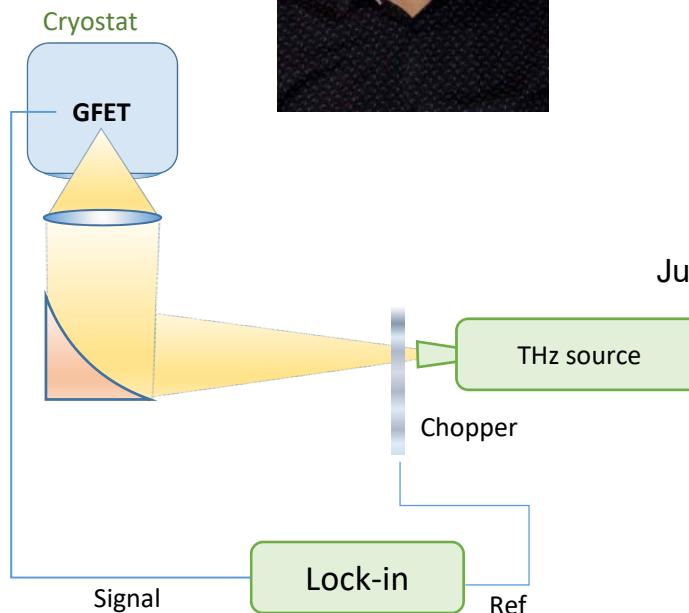
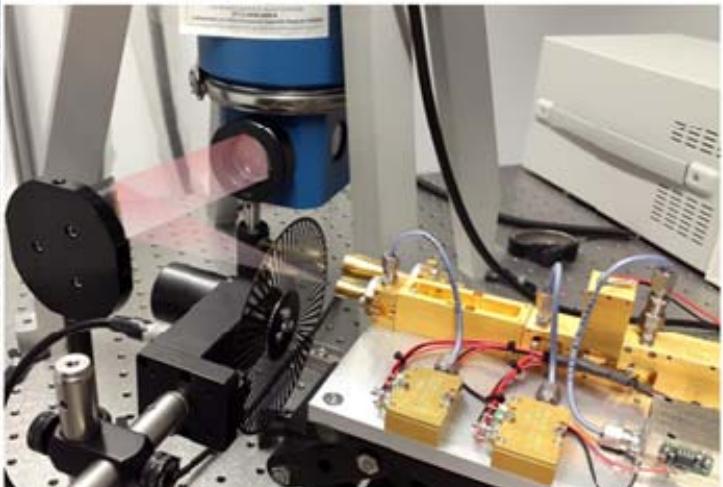


5

Laboratorio de Terahercios



<http://nanotech.usal.es/>

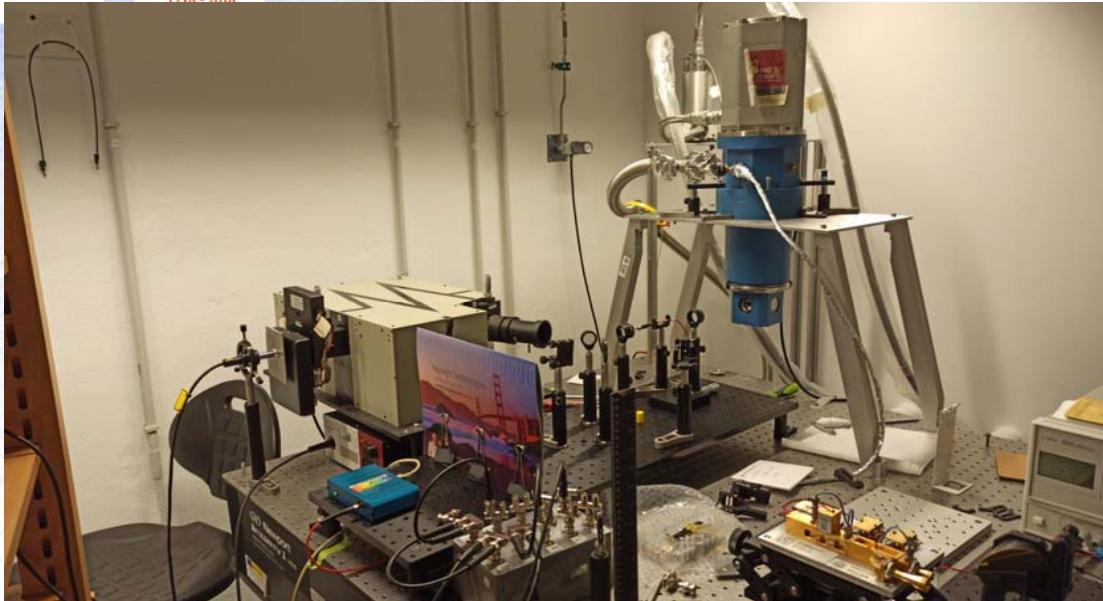


Yahya M. Meziani



Juanan Delgado-Notario

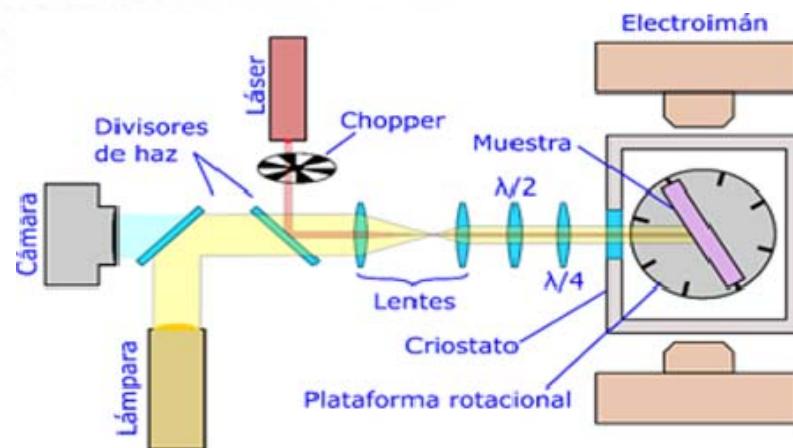
Espectroscopía de Fotocorriente



Jorge Quereda



Daniel Vaquero



Optoelectrónica en Materiales 2D



<http://nanotech.usal.es/>



Vito Clericò



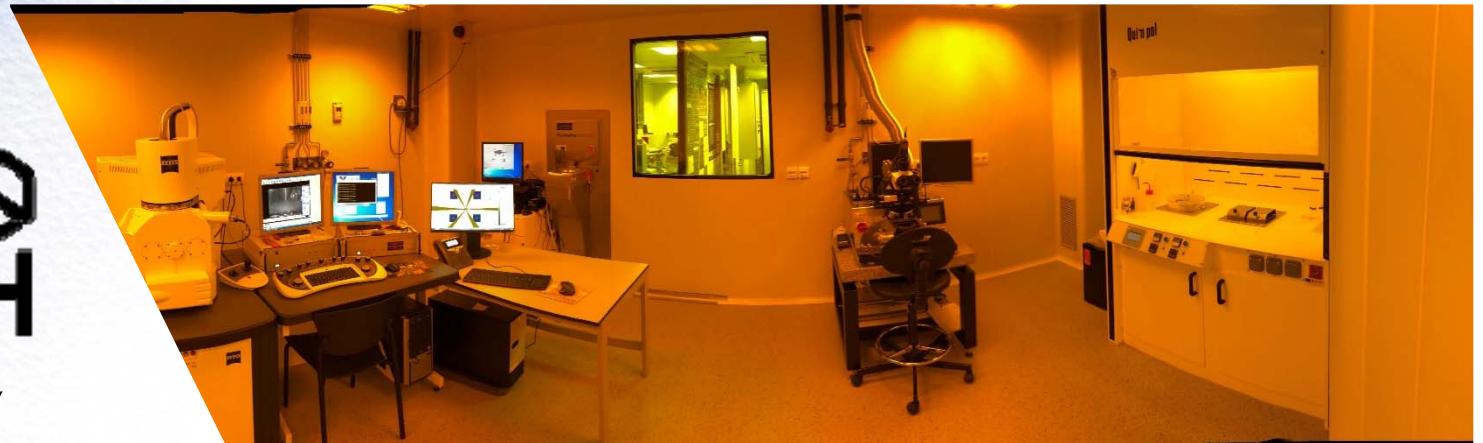
Juanan Delgado-Notario



Adrián Martín



Juan Salvador



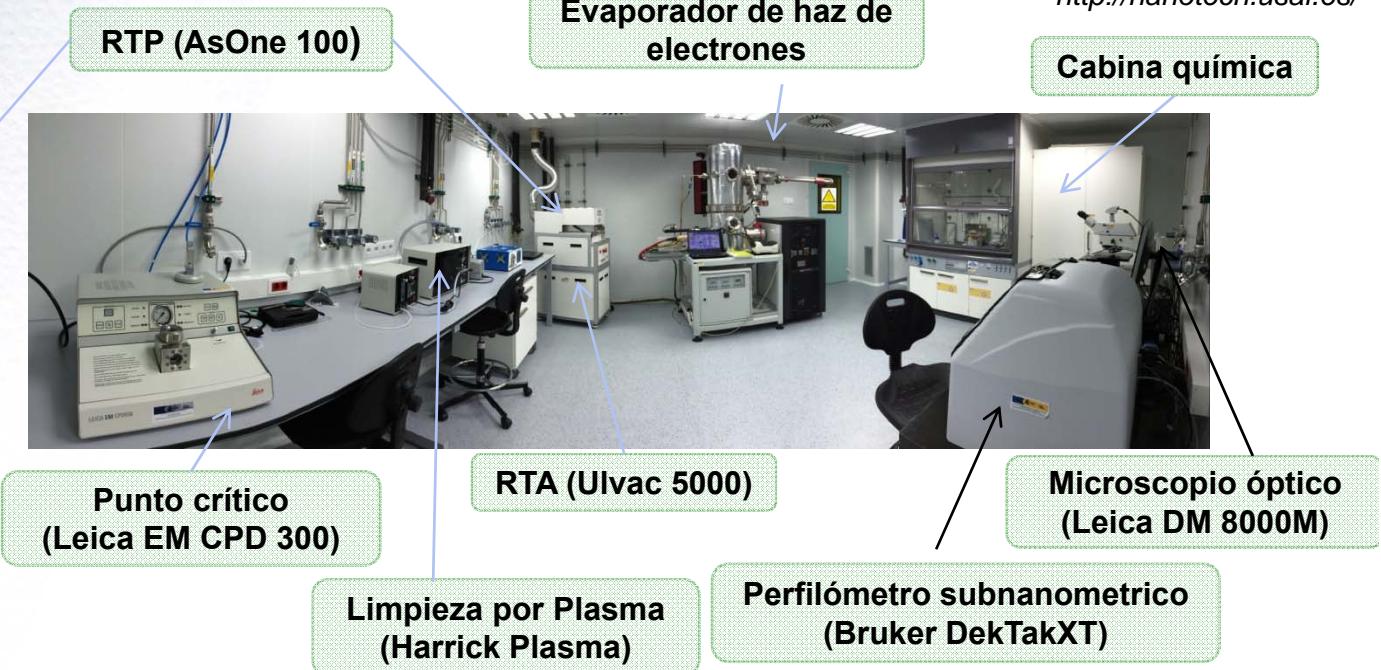
Sala Blanca de Nanotecnología

Sala blanca de Nanotecnología

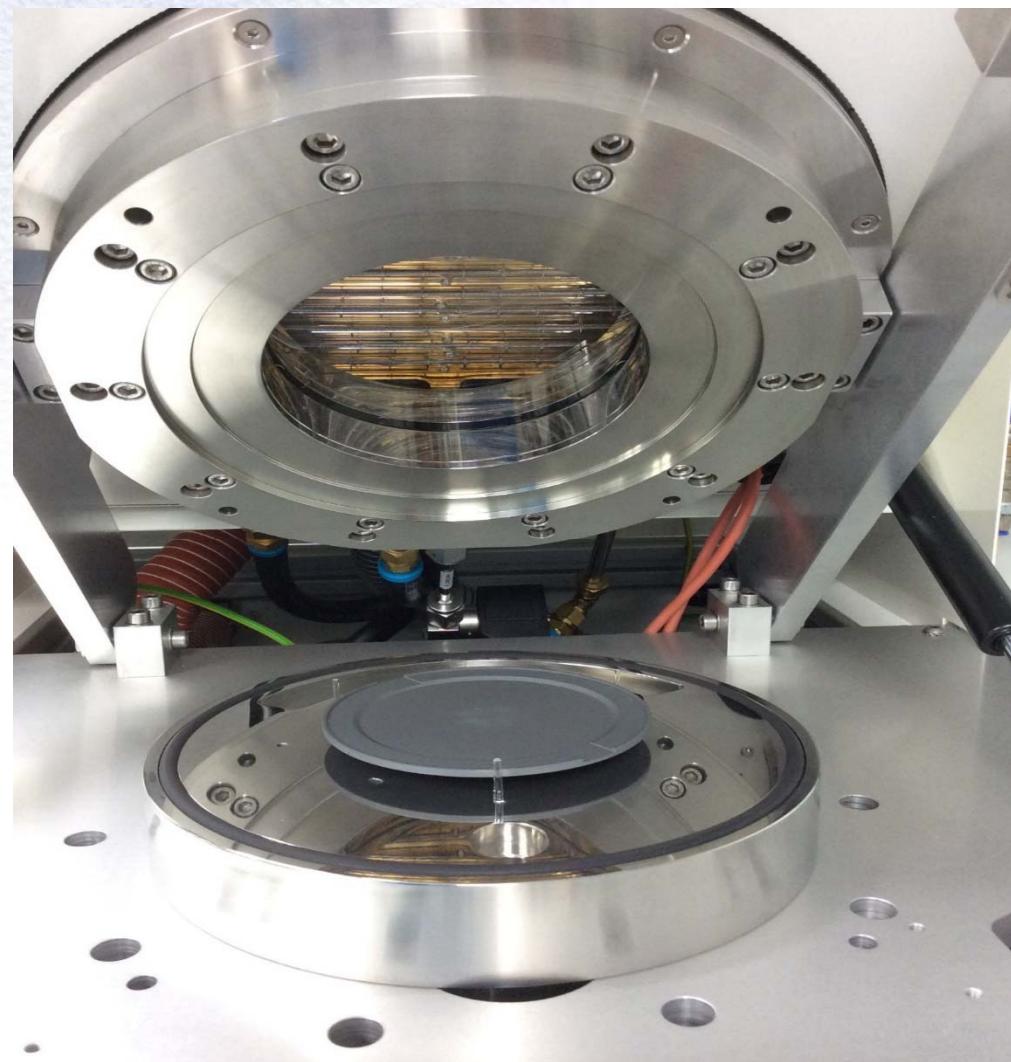
- 200 metros cuadrados repartidos entre las plantas -2 y -3 del Edificio de I+D+i
- Tres salas clasificadas: Vestidor y Evaporación (ISO 7 – Clase 10.000) y Sala Litografía (ISO 6 – Clase 1.000).
- Sala Técnica (ICP y Microraman) y Sala de Gases sin clasificar.
- Sistemas de seguridad de última generación en detección, corte y absorción de gases tóxicos.
- Diseñada para trabajar con especial eficiencia en grafeno y materiales 2D.



Principales equipamientos

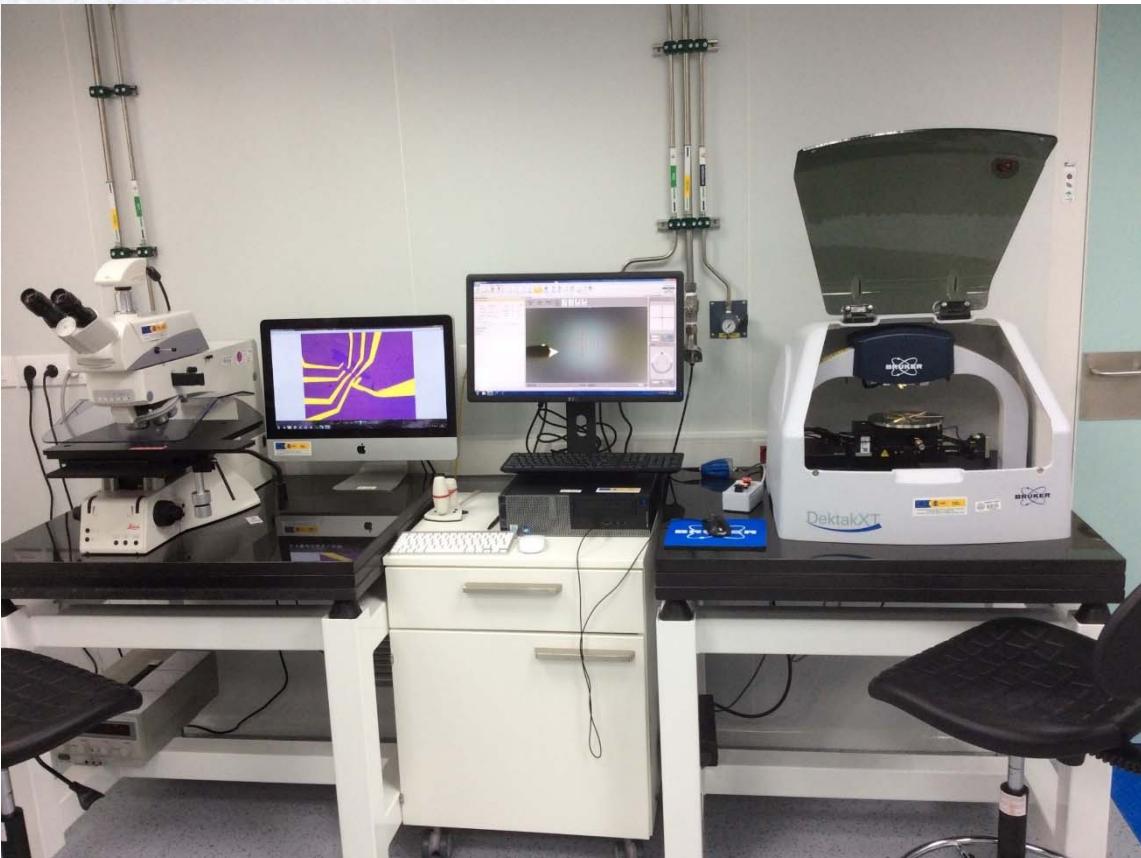


RTP (AsOne 100)



- Rampas 200°C/s hasta 1500 °C
- Automático hasta 200 steps
- Obleas 4 "
- Alta vacío < 10⁻⁶ mbar
- Nitrógeno
- Helio
- Argón
- Oxígeno (RTO)

DektakXT – 3D (Bruker) DM8000 – (LEICA)



Perfilómetro:

- Sub-nanométrico
- 3D
- Patrones calibrados NIST 7 nm y 1 micra.

Microscopio óptico

- 5x, 10x, 20x, 50x y 100x
- Luz led blanca y UV
- Oblicua
- Sub-micron

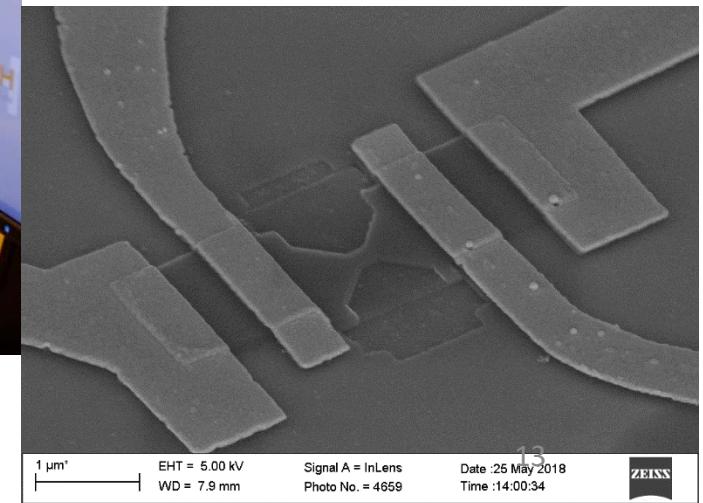
Microscopio SEM y Litografía por haz de electrones

Sigma – FE-SEM - ZEISS



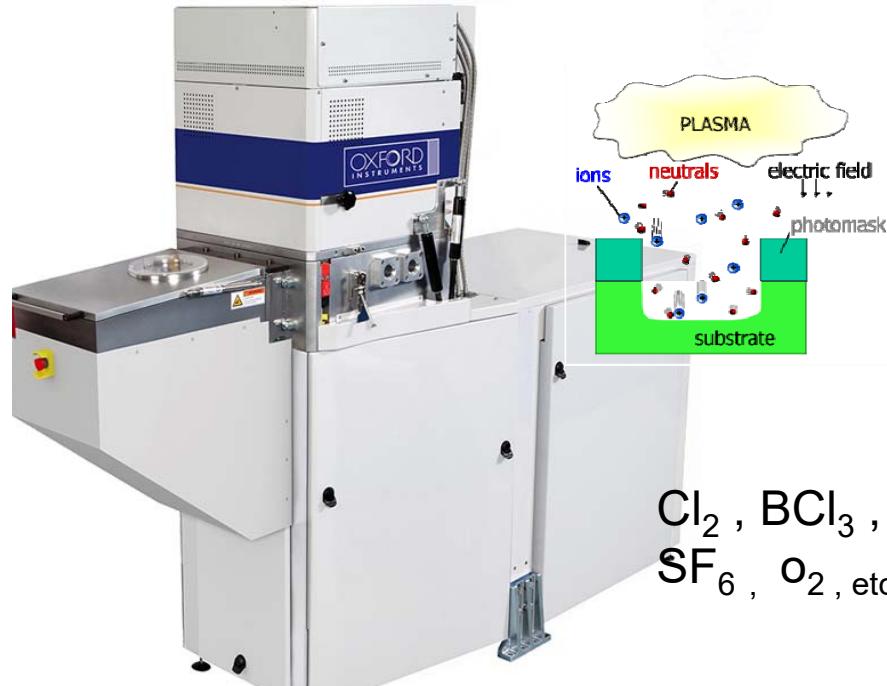
FE-SEM

- 30 KV
- HAZ : 2 nm
- IN-LENS – alta resolución

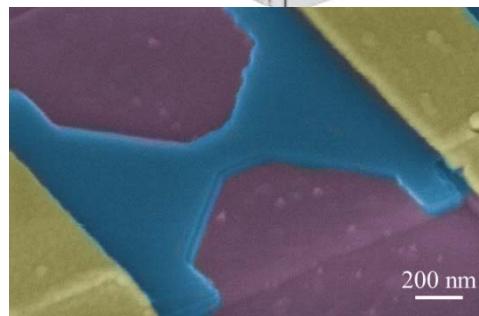


Principales equipamientos

ICP/RIE Ataque por Plasma

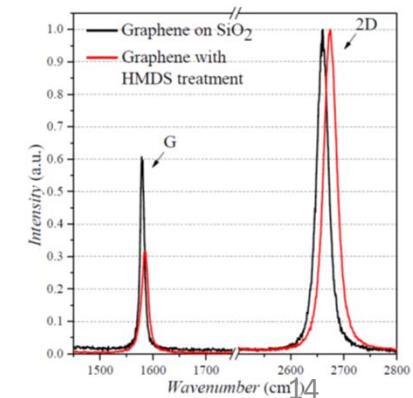
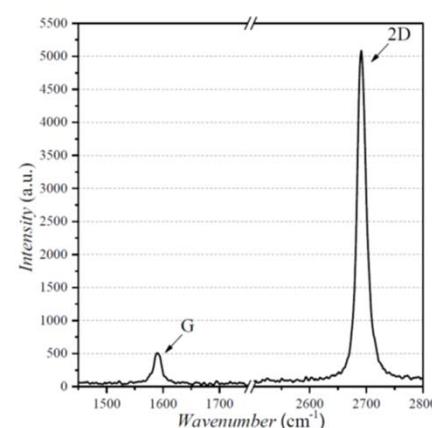


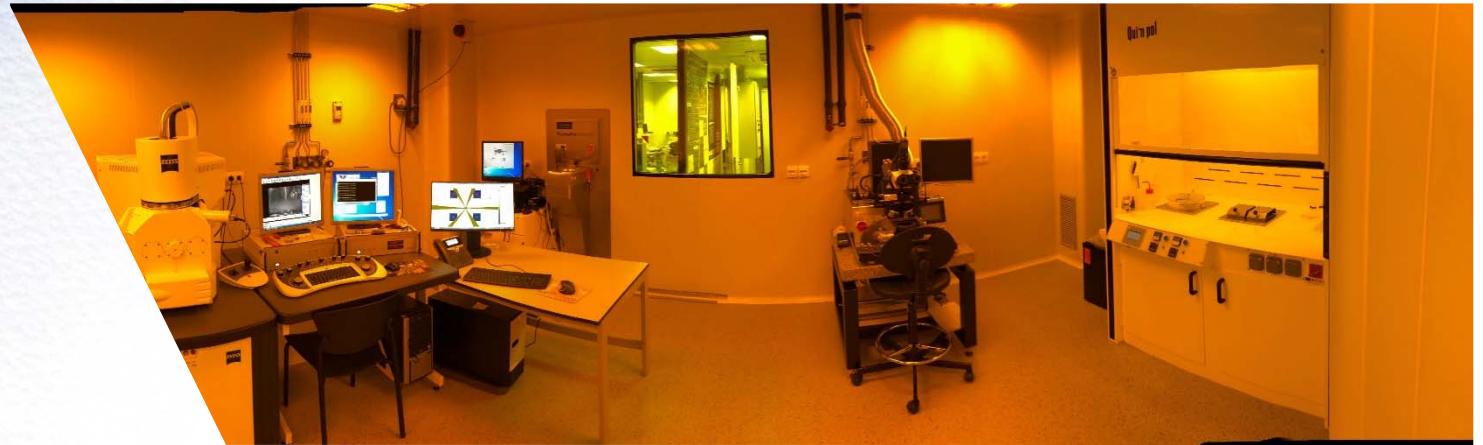
Cl_2 , BCl_3 , H_2 , CH_4
 SF_6 , O_2 , etc



Reunión de Nanolito - 13 de noviembre
de 2020

Espectroscopía Micro-Raman (R-G –IR)



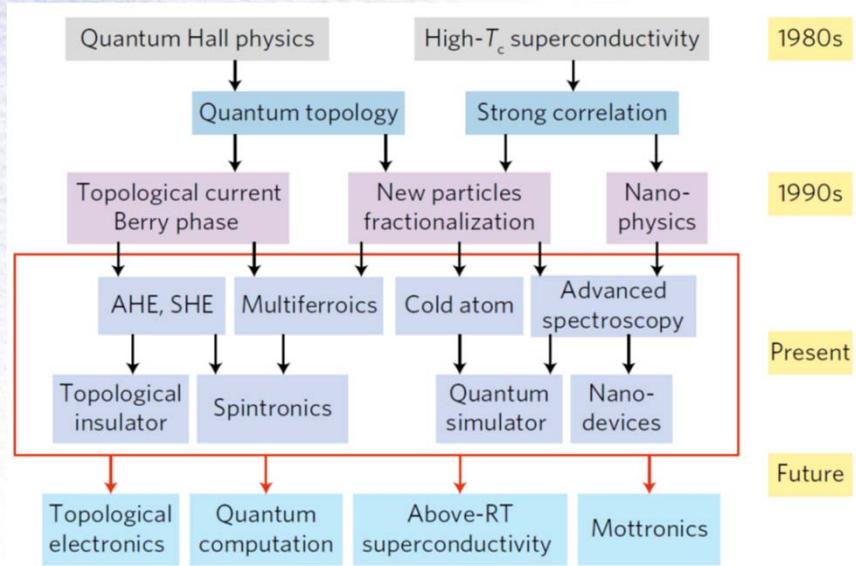


Materiales Cuánticos:

Grafeno y aislantes topológicos

Materiales cuánticos

Baja Dimensionalidad + Fenómenos emergentes + Topología no trivial



nature
physics

REVIEW ARTICLES

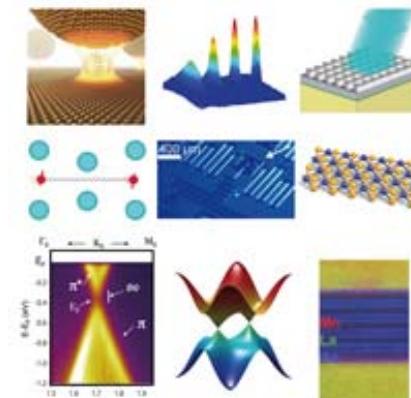
PUBLISHED ONLINE: 30 OCTOBER 2017 | DOI: 10.1038/NPHYS4302

The physics of quantum materials

B. Keimer^{1*} and J. E. Moore^{2,3*}

The physical description of all materials is rooted in quantum mechanics, which describes how atoms bond and electrons interact at a fundamental level. Although these quantum effects can in many cases be approximated by a classical description at the macroscopic level, in recent years there has been growing interest in material systems where quantum effects remain manifest over a wider range of energy and length scales. Such quantum materials include superconductors, graphene, topological insulators, Weyl semimetals, quantum spin liquids, and spin ices. Many of them derive their properties from reduced dimensionality, in particular from confinement of electrons to two-dimensional sheets. Moreover, they tend to be materials in which electrons cannot be considered as independent particles but interact strongly and give rise to collective excitations known as quasiparticles. In all cases, however, quantum-mechanical effects fundamentally alter properties of the material. This Review surveys the electronic properties of quantum materials through the prism of the electron wavefunction, and examines how its entanglement and topology give rise to a rich variety of quantum states and phases; these are less classically describable than conventional ordered states also driven by quantum mechanics, such as ferromagnetism.

Revista de
FÍSICA
una publicación de la RSEF - Sociedad de Física
Editorial Universidad Complutense
FECYT



REVIEW ARTICLES

PUBLISHED ONLINE: 25 SEPTEMBER 2017 | DOI: 10.1038/NPHYS4274

nature
physics

Emergent functions of quantum materials

Yoshinori Tokura^{1,2*}, Masashi Kawasaki^{1,2} and Naoto Nagaosa^{1,2}

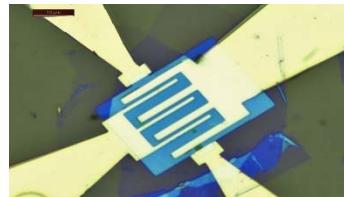
Materials can harbour quantum many-body systems, most typically in the form of strongly correlated electrons in solids, that lead to novel and remarkable functions thanks to emergence—collective behaviours that arise from strong interactions among the elements. These include the Mott transition, high-temperature superconductivity, topological superconductivity, colossal magnetoresistance, giant magnetoelectric effect, and topological insulators. These phenomena will probably be crucial for developing the next-generation quantum technologies that will meet the urgent technological demands for achieving a sustainable and safe society. Dissipationless electronics using topological currents and quantum spins, energy harvesting such as photovoltaics and thermoelectrics, and secure quantum computing and communication are the three major fields of applications working towards this goal. Here, we review the basic principles and the current status of the emergent phenomena and functions in materials from the viewpoint of strong correlation and topology.

Revista de la Física de la Materia Condensada
que incluye las siguientes secciones:
• Noticias de la Física
• Noticias de la Revista
• Noticias del Instituto
• Noticias de Iberfísica
• Noticias de la RSEF
• Noticias, Pioneras de la Física y Héroes de la Física

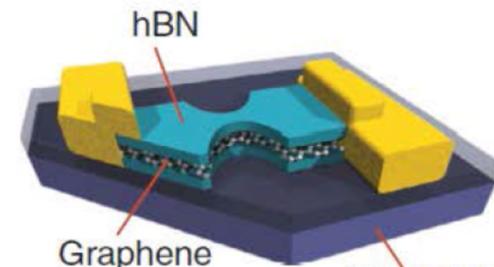


Materiales Cuánticos: Materiales 2D y aislantes topológicos

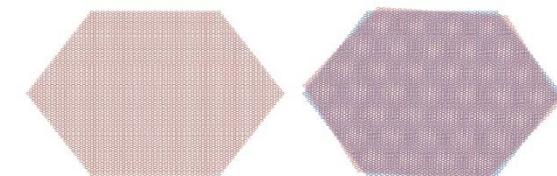
1. GFETs para detección de Terahercios



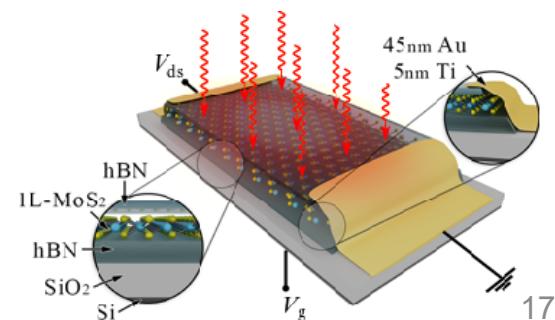
2. Nanoconstricciones en Grafeno y aislantes topológicos



3. Ruptura de la simetría en heteroestructuras de materiales 2D

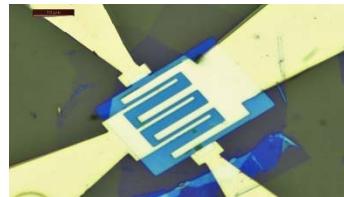


4. Optoelectrónica en Materiales 2D con baja simetría

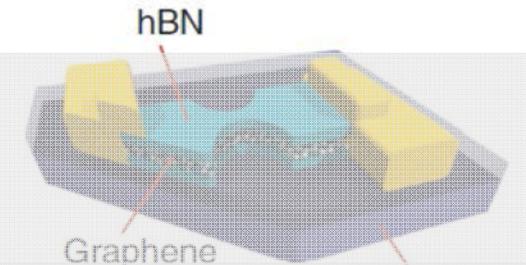


Materiales Cuánticos: Materiales 2D y aislantes topológicos

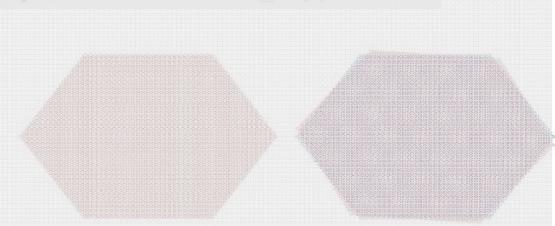
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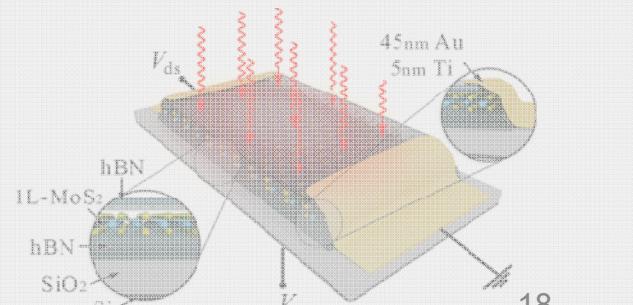
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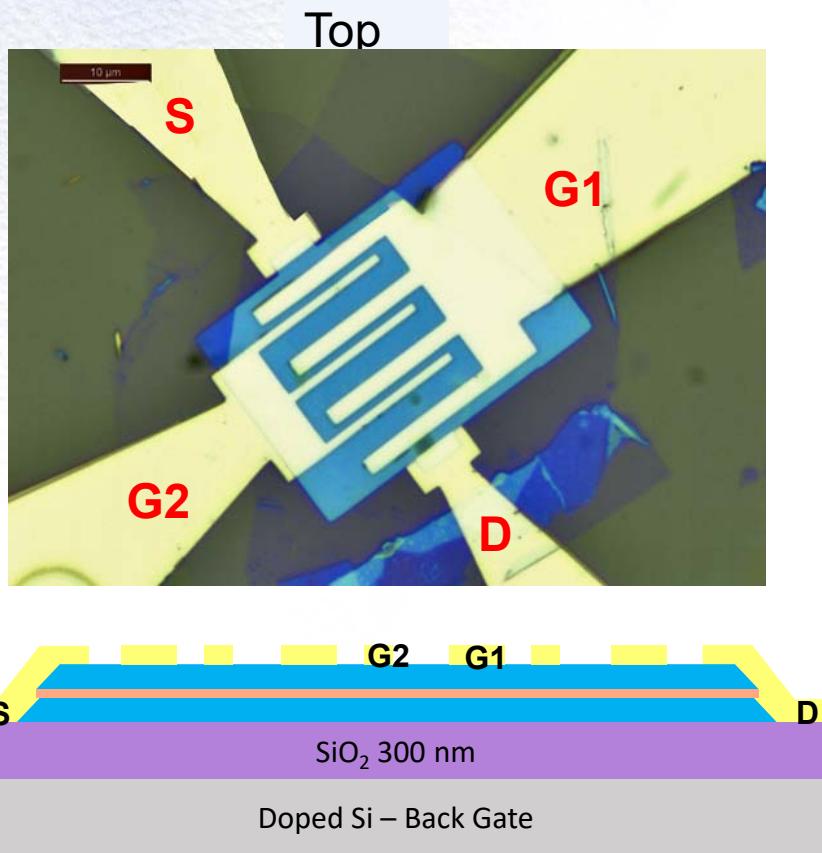


4. Optoelectrónica en Materiales 2D con baja simetría



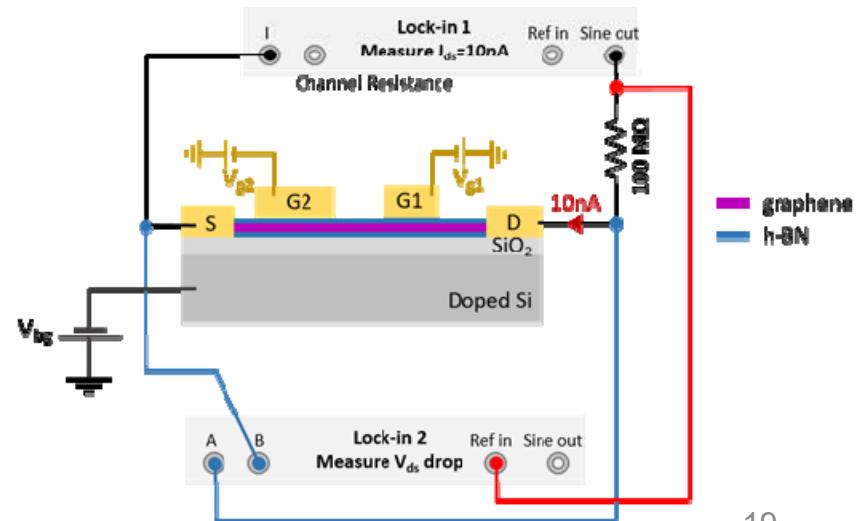
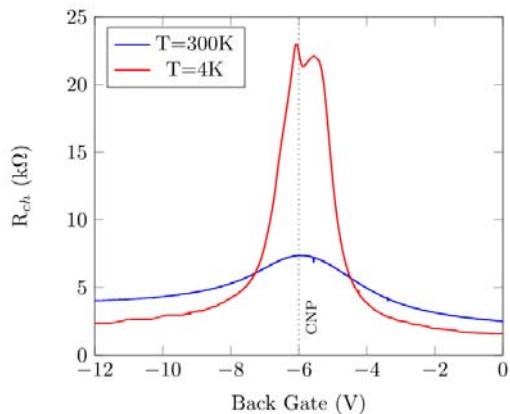


Transistores FET de Grafeno con dobles puertas asimétricas (ADGG)



$\mu \sim 30000 \text{ cm}^2 \text{V}^{-1} \text{s}^{-1}$ at 300K

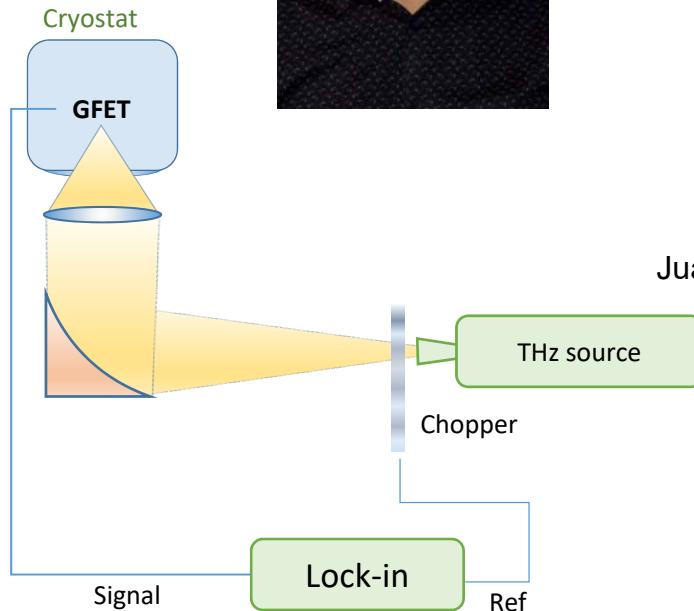
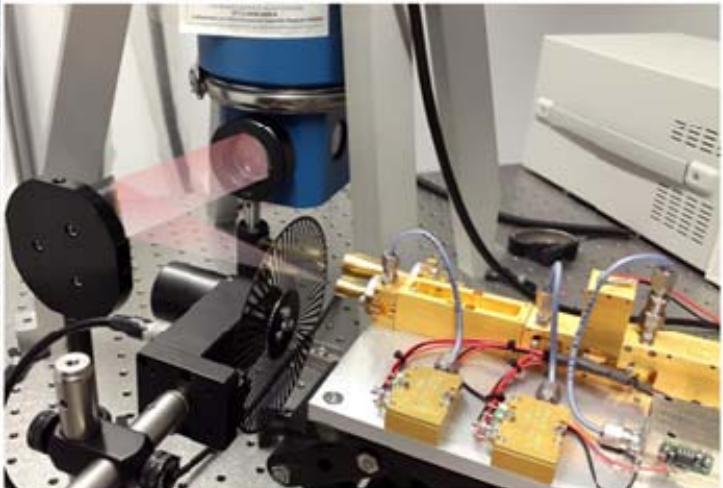
$\mu \sim 250000 \text{ cm}^2 \text{V}^{-1} \text{s}^{-1}$ at 4K



Laboratorio de Terahercios



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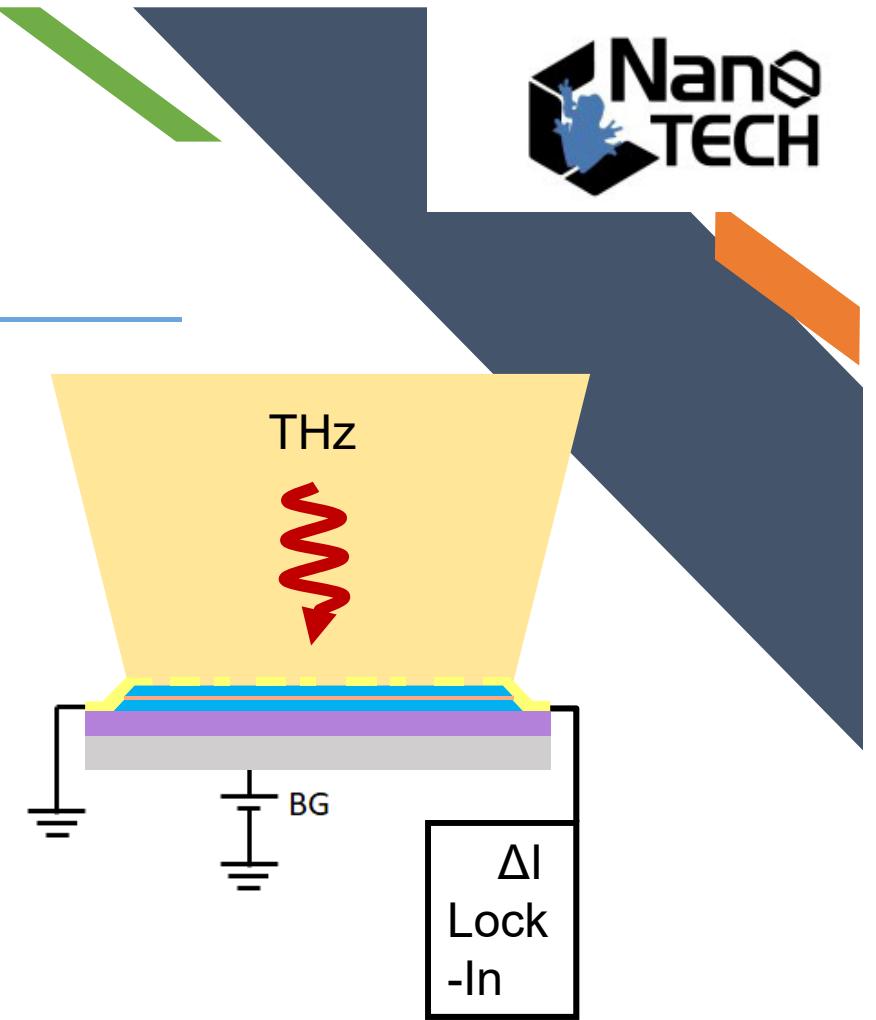
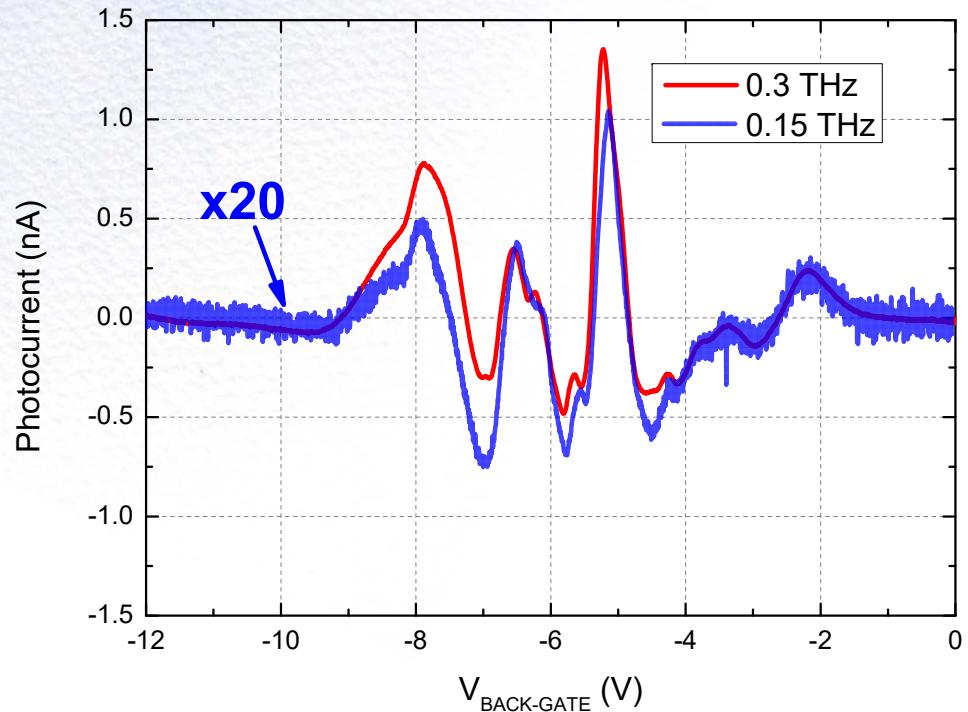


Yahya M. Meziani



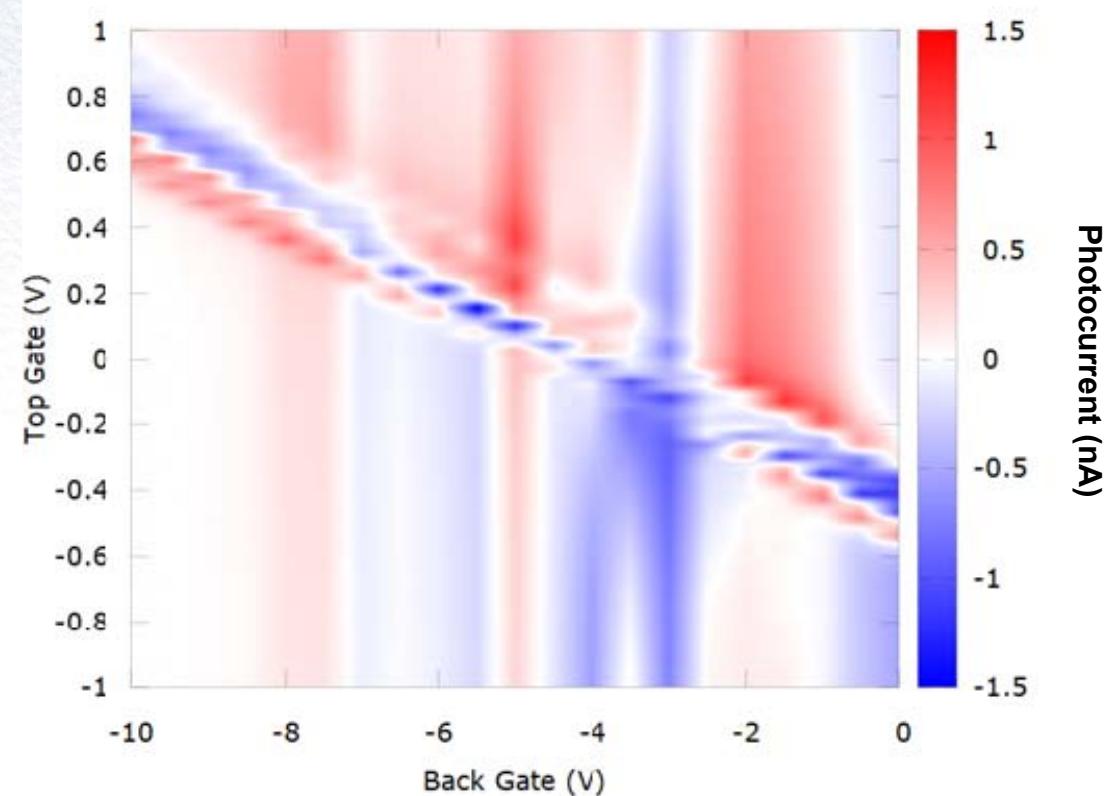
Juanan Delgado-Notario

ADGG-GFET – Medidas de THz



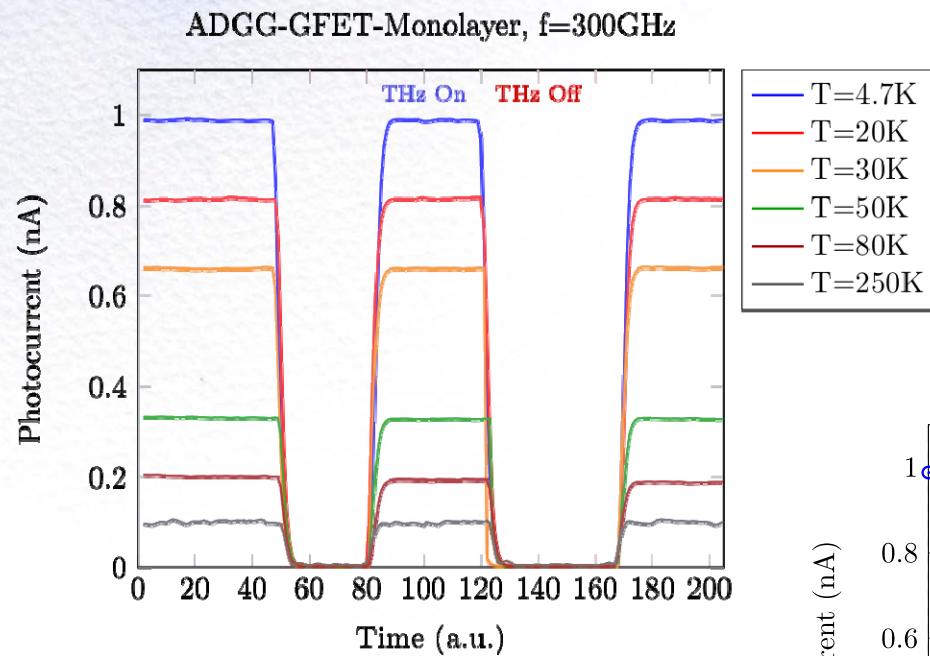
Detección a 0.15 y 0.3 THz a 4 K

ADGG-GFET – Medidas de THz

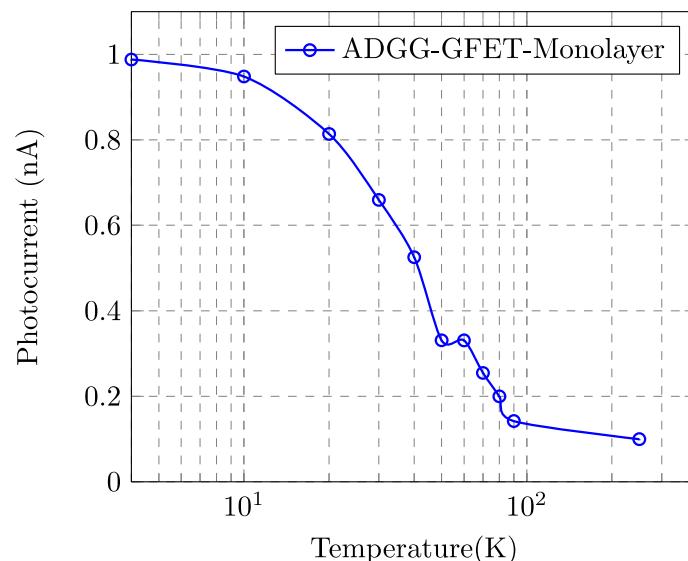
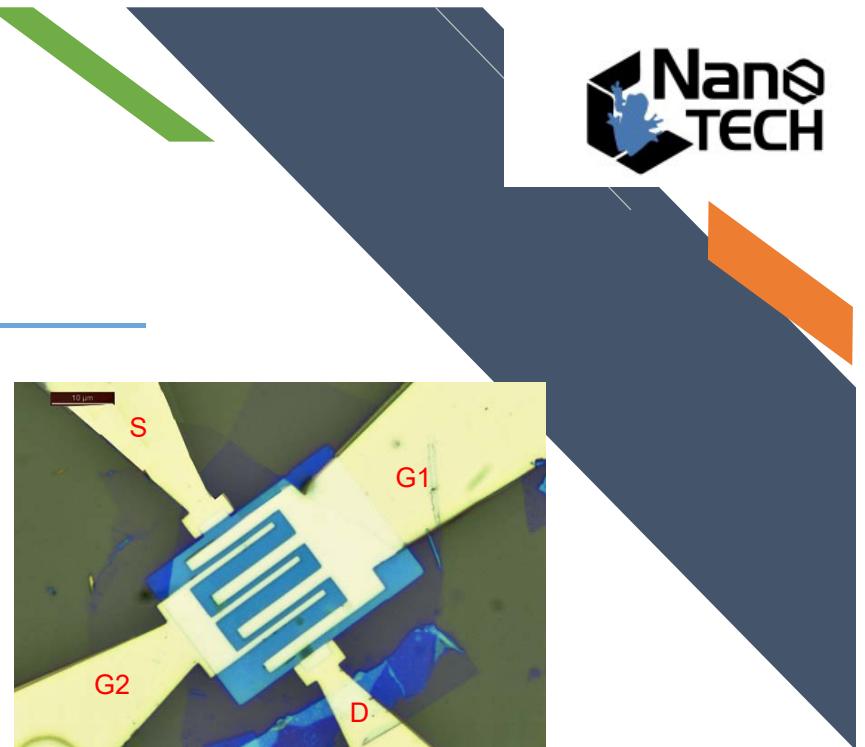


Efectos de las puertas superiores e inferiores sobre la photocorriente a 0,3 THz a bajas temperaturas (4K)

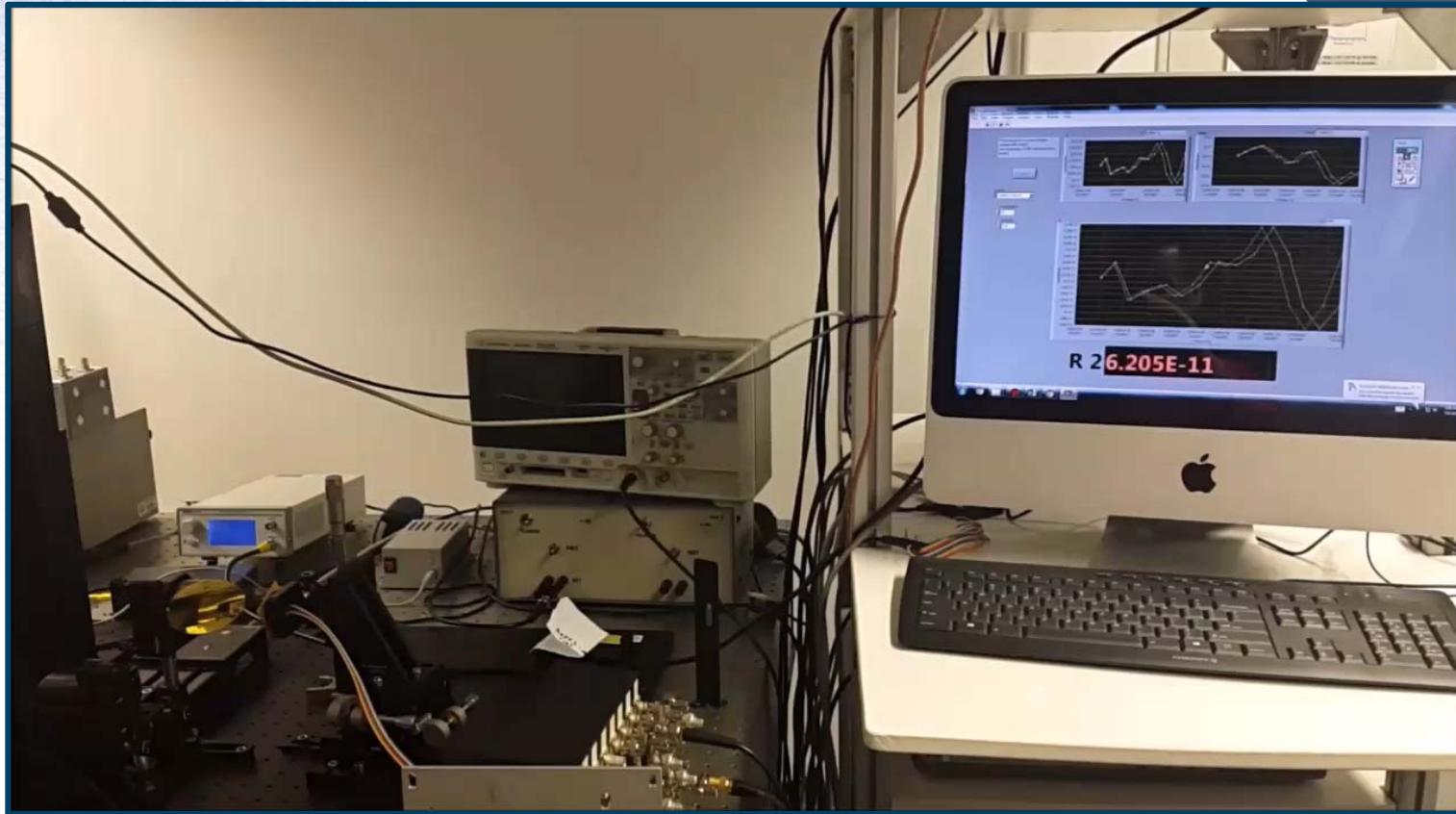
ADGG-GFET – Medidas de THz



Detección a temperatura ambiente de radiación de 0.3 THz con un ADGG-GFET.

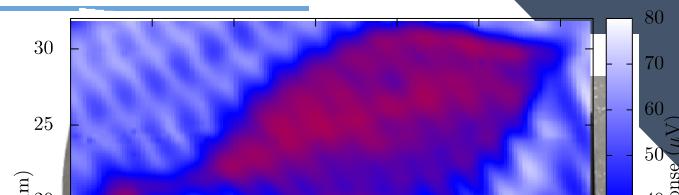


ADGG-GFET – THz a temperatura ambiente





THz Inspección e Imagen



Asymmetric dual-grating gates graphene FET for detection of terahertz radiations

Cite as: APL Photonics 5, 066102 (2020); <https://doi.org/10.1063/5.0007249>

Submitted: 10 March 2020 . Accepted: 26 May 2020 . Published Online: 09 June 2020

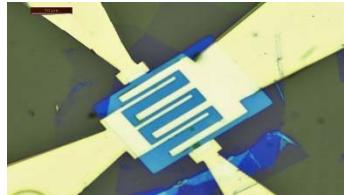
J. A. Delgado-Notario , V. Clericò , E. Diez , J. E. Velázquez-Pérez , T. Taniguchi, K. Watanabe , T. Otsuji , and Y. M. Meziani



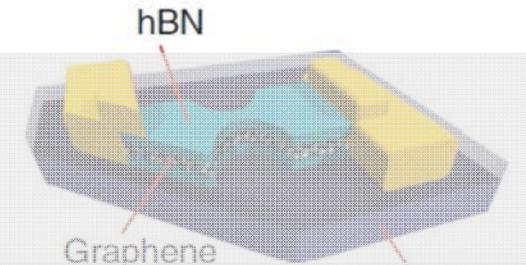
0.3 THz and visible image

Materiales Cuánticos: Materiales 2D y aislantes topológicos

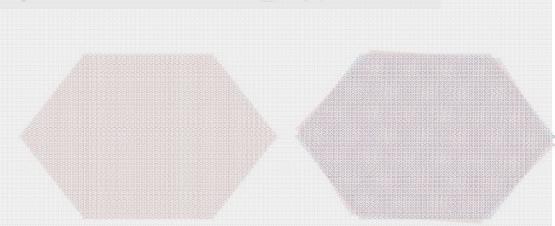
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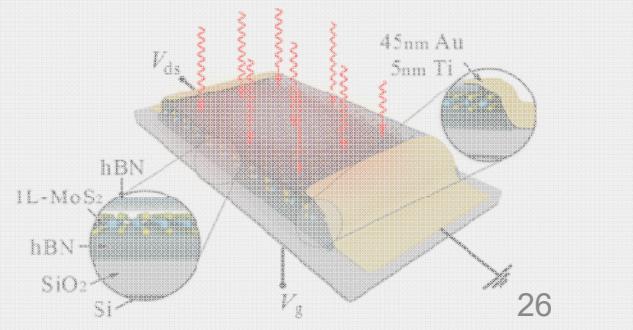
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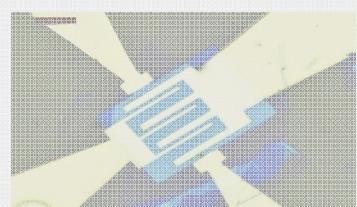


4. Optoelectrónica en Materiales 2D con baja simetría

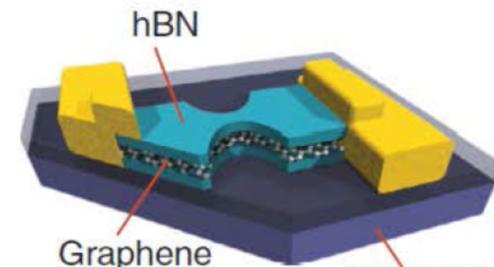


Materiales Cuánticos: Materiales 2D y aislantes topológicos

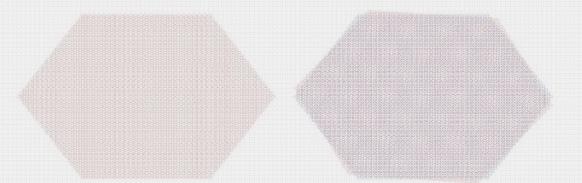
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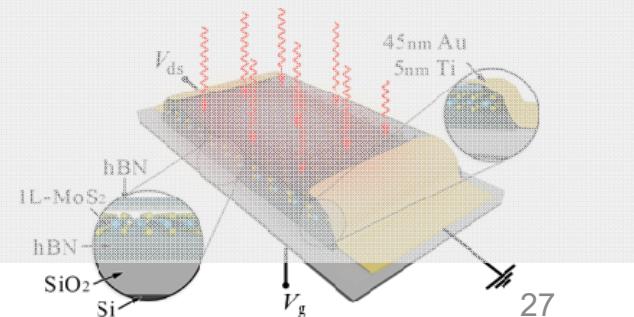
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4. Optoelectrónica en Materiales 2D con baja simetría



GRAPHENE NANOCONSTRICtIONS

nature
physics

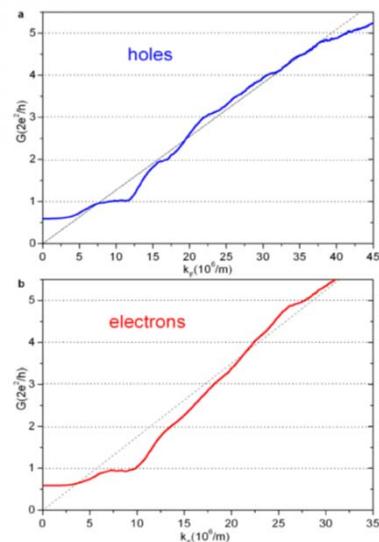
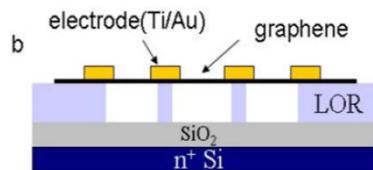
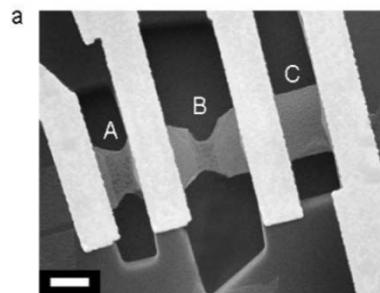
LETTERS

PUBLISHED ONLINE: 5 JUNE 2011 | DOI: 10.1038/NPHYS2009

2009

Quantized conductance of a suspended graphene nanoconstriction

Nikolaos Tombros^{1,2*}, Alina Veligura², Juliane Junesch², Marcos H. D. Guimarães²,
Ivan J. Vera-Marun², Harry T. Jonkman¹ and Bart J. van Wees²



$$\mu > 500.000 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$$

- Current annealing “fabrication”
- No constriction control
- No linear dependence

State of the Art



ARTICLE
Received 28

Size
cons

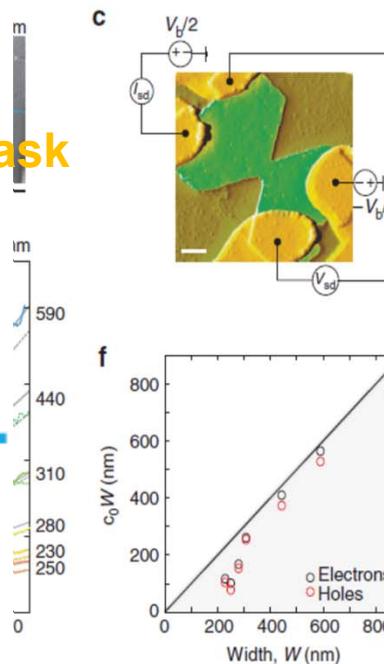
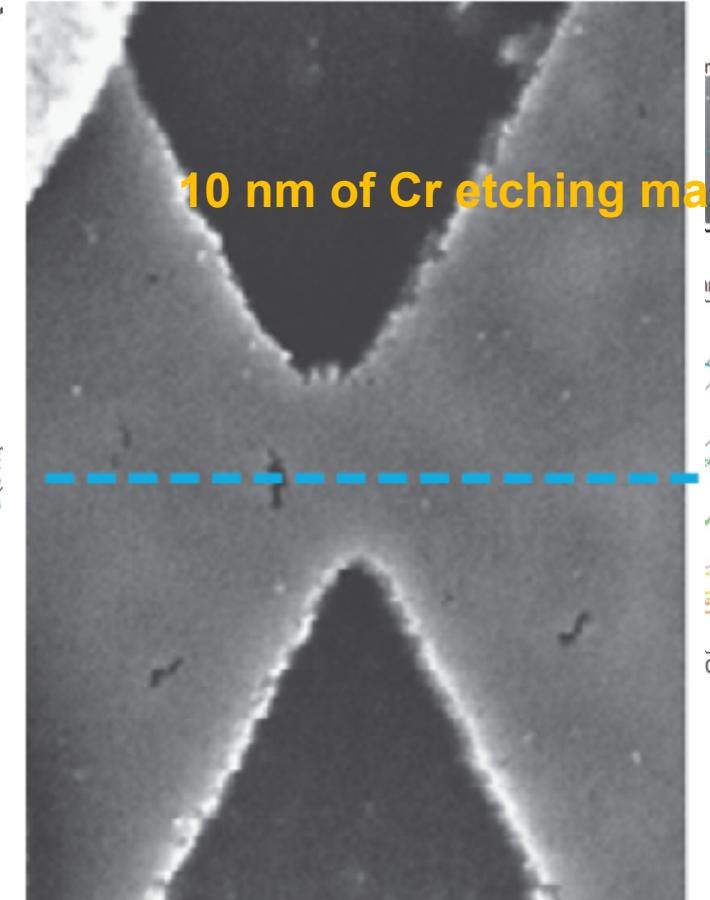
B. Terrés¹,
S.V. Rotki¹

GRAPHENE NANOCSTRICCTIONS

nature
COMMUNICATIONS

310 nm 1526 OPEN graphene

C. Watanabe⁴, T. Taniguchi⁴,



$$\mu > 100.000 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$$

$$G = \frac{4e^2}{\pi h} W k_F t \rightarrow t = 0.56$$

- Large edge roughness
- Far from perfect ballistic transport ($t = 1$)

State of the Art



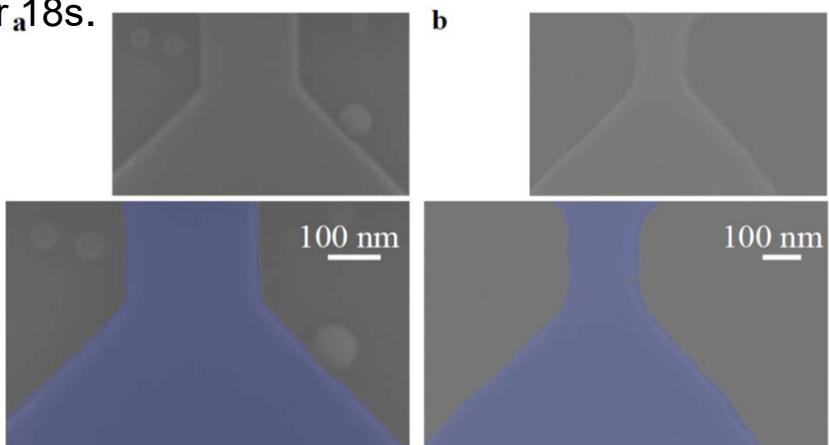
GRAPHENE NANOCONSTRICtIONS

CRYO-ETCHING TO AVOID METAL ETCHING MASK



PMMA mask ICP/RIE SF₆/Ar etching

T= -110 °C Ar/SF6 (10/40 sccm) P=6 mtorr
for 18s.

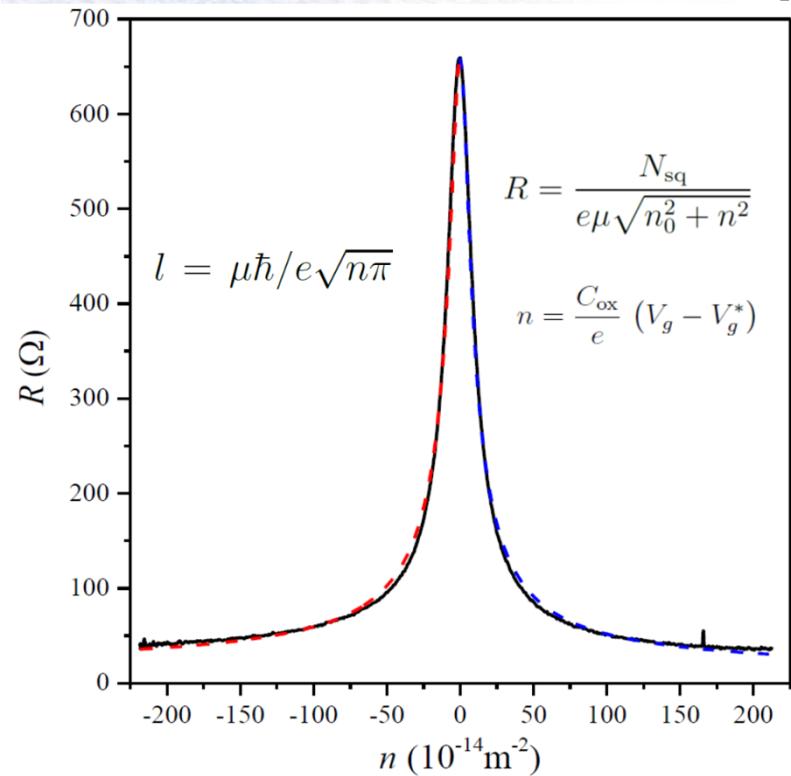


Unprecedented control of edge roughness

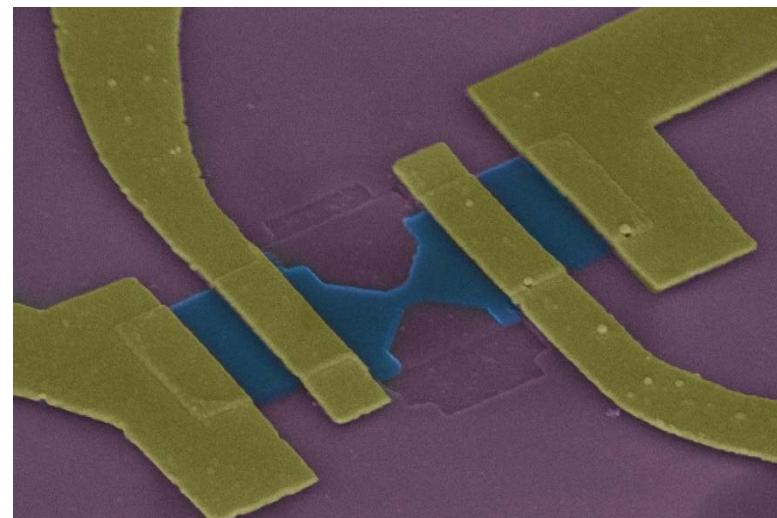


Vito Clericò

CRYO-ETCHING: Transport (1/3)

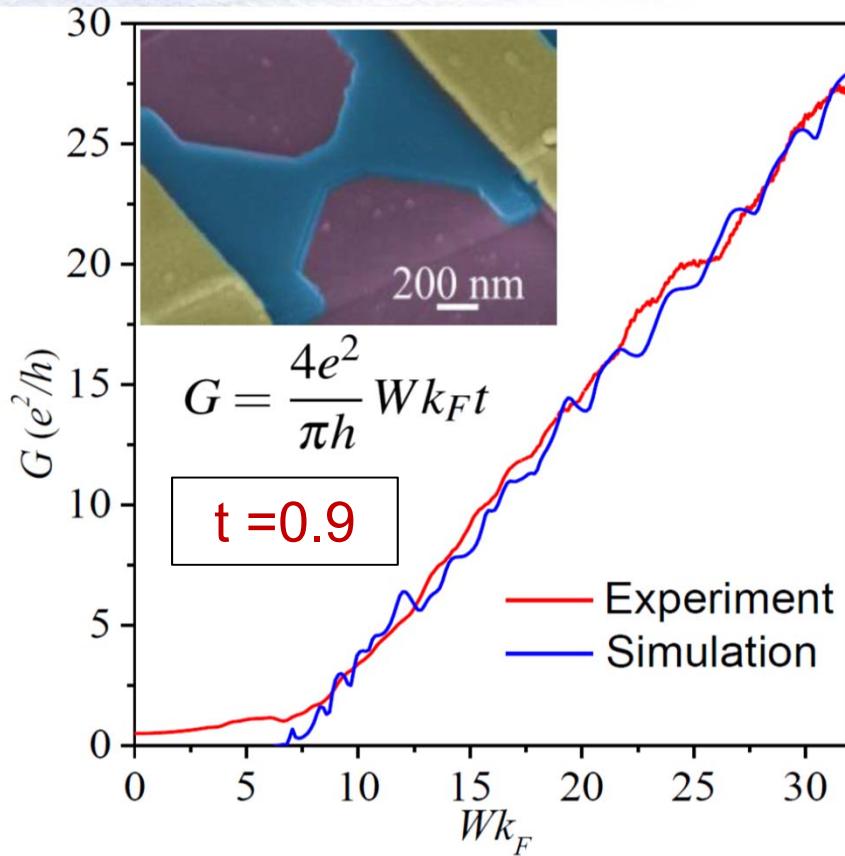


- High Mobility @ RT $\mu > 150.000 \text{ cm}^2 \text{V}^{-1} \text{s}^{-1}$
- Mean free path @ RT $l > 1,5 \mu\text{m}$
- Residual doping @ RT $n_0 \sim 3,3 \cdot 10^{10} \text{ cm}^{-2}$



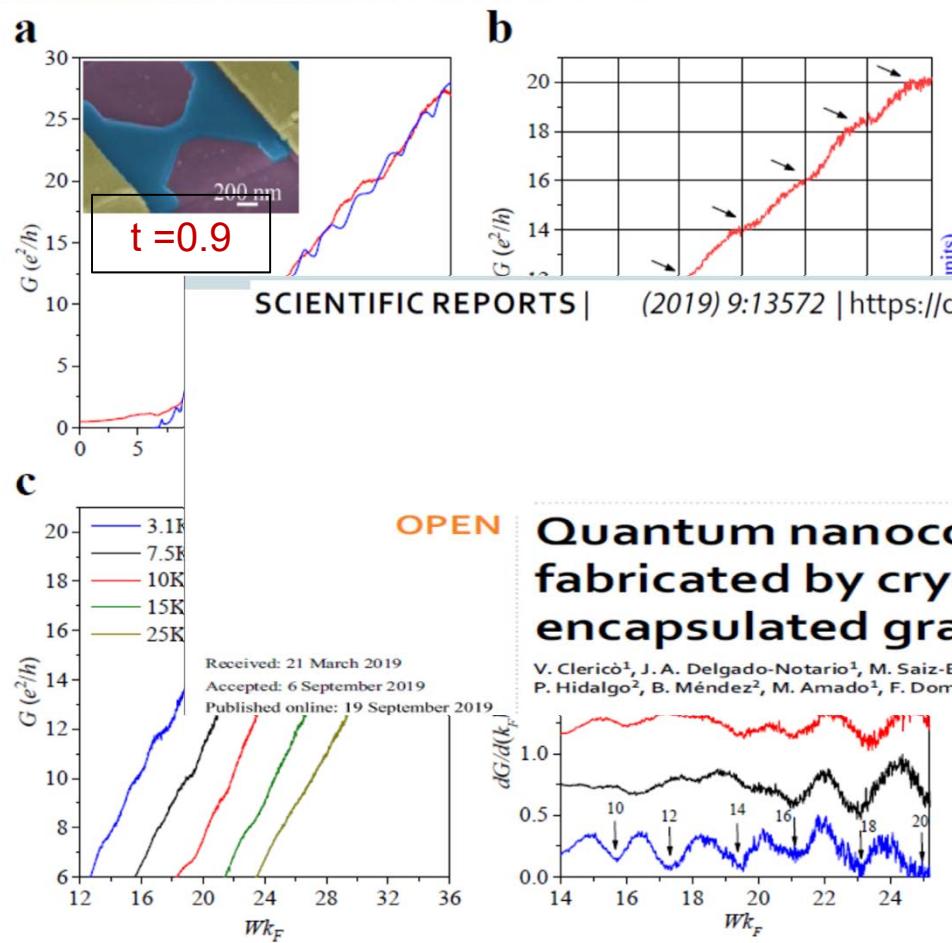
GRAPHENE NANOCSTRICCTIONS

CRYO-ETCHING: Transport & Theory(2/3)



- Tight-binding Approach (1 orbital per C atom)
- Quantum Transmitting Boundary Method
C. S. Lent and D. J. Kirkner, J. Appl. Phys. 67 (1990) 6353
- Edge profile obtained from AFM measurements
- Threshold value $W k_F^0$ due to residual doping
 $n_0 \sim 3.3 \cdot 10^{10} \text{ cm}^{-2} \rightarrow W k_F^0 = \sqrt{\pi n_0} W \sim 6.7$.
- **Linear dependence of $W k_F$**
- **Almost perfect ballistic transport $\rightarrow t=0.9$**
- **Good agreement between the experimental and simulated conductance.**

GRAPHENE NANOCONSTRICtIONS



CRYO-ETCHING: Transport (3/3)

- Six plateaus of quantized conductance separated by $2 e^2/h$

SCIENTIFIC REPORTS
nature research

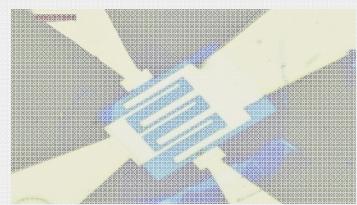
| 6, 18, 20

d minima in the transconductance.

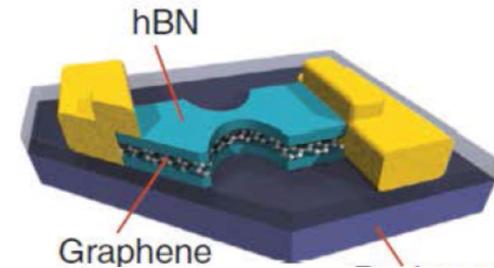
- Temperature dependence confirm size quantization !!

Materiales Cuánticos: Materiales 2D y aislantes topológicos

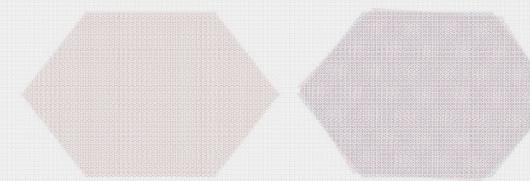
1. GFETs para detección de Terahercios



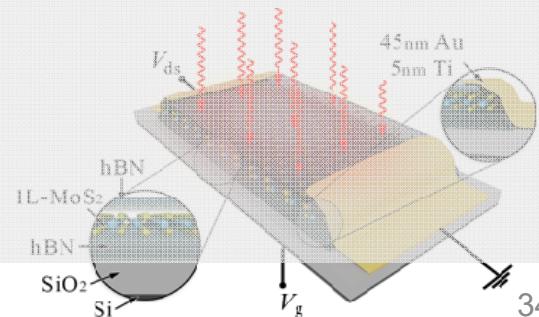
2. Nanoconstricciones en Grafeno y aislantes topológicos



3. Ruptura de la simetría en heteroestructuras de materiales 2D

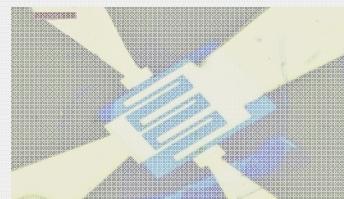


4. Optoelectrónica en Materiales 2D con baja simetría

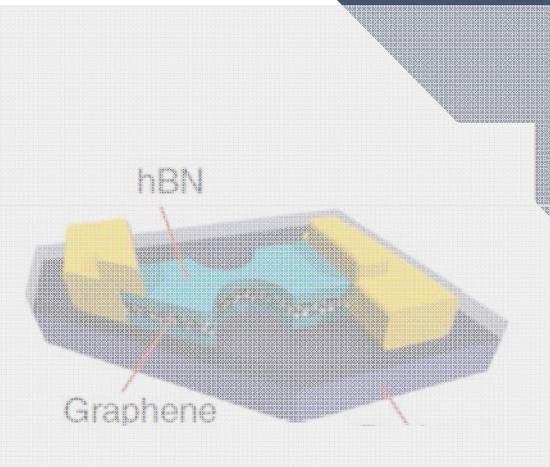


Materiales Cuánticos: Materiales 2D y aislantes topológicos

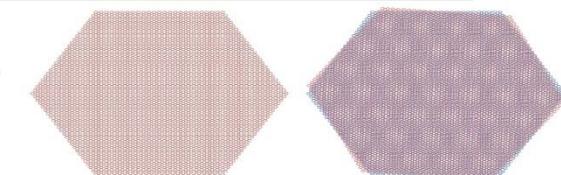
1. GFETs para detección de Terahercios



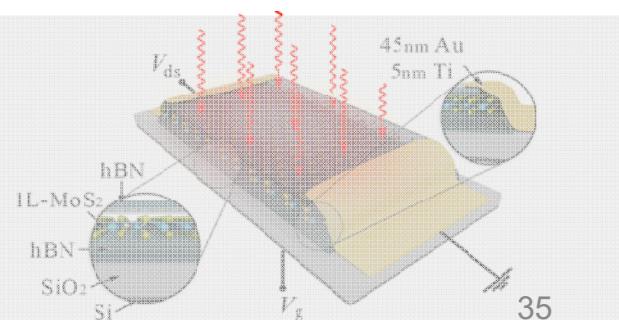
2. Nanoconstricciones en Grafeno y aislantes topológicos



3. Ruptura de la simetría en heteroestructuras de materiales 2D



4. Optoelectrónica en Materiales 2D con baja simetría





HIBRIDACION DE ESTADOS LATERALES

RESEARCH

TOPOLOGICAL MATTER

Absence of evidence for chiral Majorana modes in quantum anomalous Hall-superconductor devices

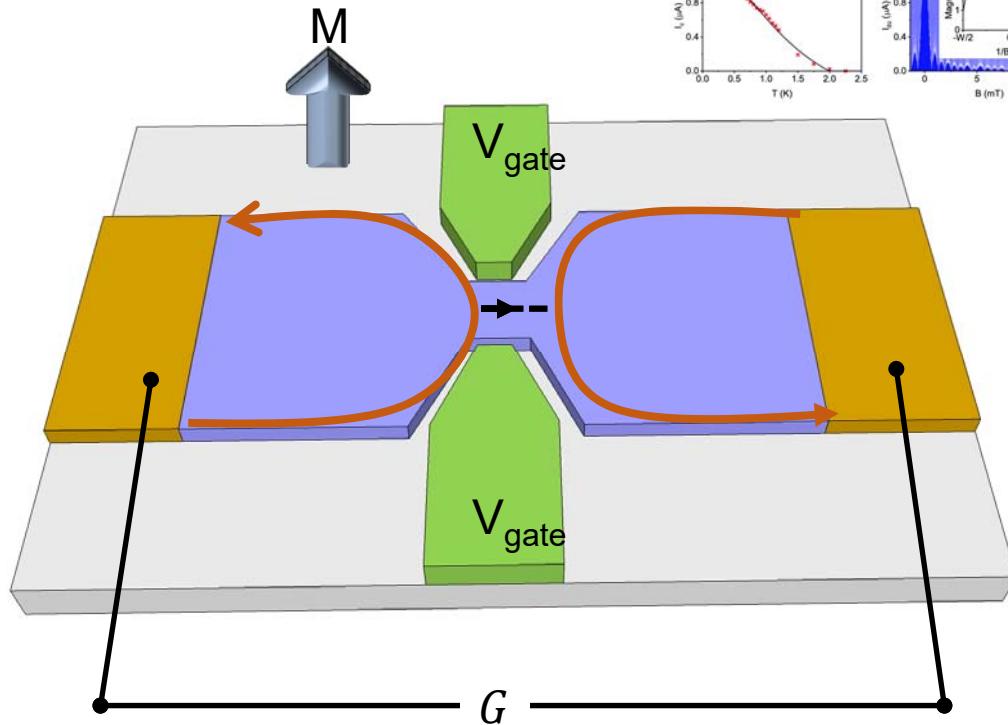
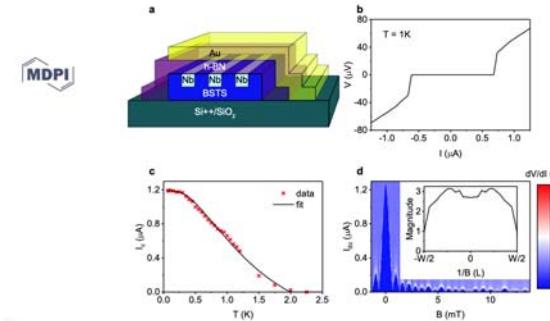
Morteza Kayyalha^{1*}, Di Xiao^{1*}, Ruoxi Zhang^{1*}, Jaeho Shin¹, Jue Jiang¹, Fei Wang¹, Yi-Fan Zhao¹, Run Xiao¹, Ling Zhang¹, Kajetan M. Fijałkowski^{2,3}, Pankaj Mandal^{2,3}, Martin Wimmerlein^{2,3}, Charles Gould^{2,3}, Qi Li¹, Laurens W. Molenkamp^{2,3}, Moses H. W. Chan^{1†}, Nitin Samarth^{1†}, Cui-Zu Chang^{1†}



Article

Induced Topological Superconductivity in a BiSbTeSe₂-Based Josephson Junction

Bob de Ronde¹, Chuan Li¹, Yingkai Huang² and Alexander Brinkman^{1,*}



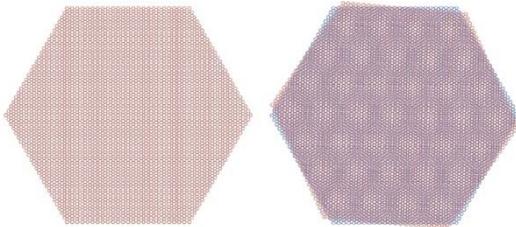
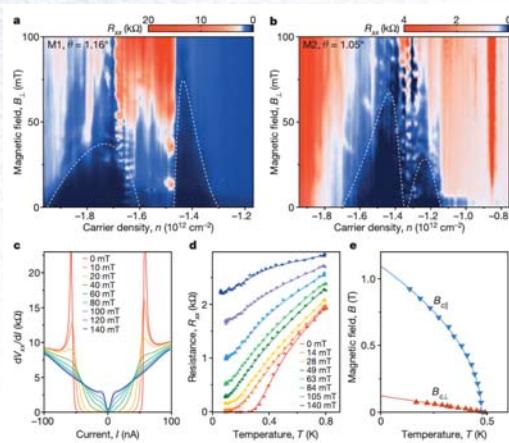
VALLEYTRONICS EN MATERIALES 2D

ARTICLE

doi:10.1038/nature26160

Unconventional superconductivity in magic-angle graphene superlattices

Yuan Cao¹, Valla Fatemi¹, Shiang Fang², Kenji Watanabe³, Takashi Taniguchi³, Efthimios Kaxiras^{2,4} & Pablo Jarillo-Herrero¹



Article

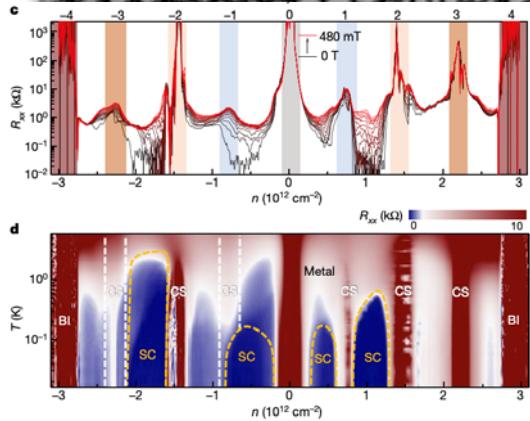
Superconductors, orbital magnets and correlated states in magic-angle bilayer graphene

<https://doi.org/10.1038/s41586-019-1695-0>

Nicolas Lu¹, Petr Strelcova¹, Wei Yang¹, Ming Xia¹, Mohammed Ali Aslam¹, Ipsita Das¹, Carles Urgell¹, Kenji Watanabe², Takashi Taniguchi², Guangyu Zhang¹, Adrian Bachtold¹, Allan H. MacDonald² & Dmitri K. Efetov^{1*}

Received: 15 March 2019

Accepted: 12 August 2019



nature
physics

ARTICLES

<https://doi.org/10.1038/s41567-020-1062-6>

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Electrically tunable correlated and topological states in twisted monolayer-bilayer graphene

Shaowen Chen^{1,2,*}, Minhao He^{1,3,*}, Ya-Hui Zhang⁴, Valerie Hsieh⁵, Zaiyao Fei^{1,3},
K. Watanabe³, T. Taniguchi³, David H. Cobden³, Xiaodong Xu^{1,3,7,8}, Cory R. Dean^{1,10,12} and
Matthew Yankowitz^{1,3,6}

RESEARCH

GRAPHENE

Emergent ferromagnetism near three-quarters filling in twisted bilayer graphene

Aaron L. Sharpe^{1,3,*}, Eli J. Fox^{2,3,*}, Arthur W. Barnard³, Joe Finney³, Kenji Watanabe⁴,
Takashi Taniguchi⁴, M. A. Kastner^{2,3,5,6,7}, David Goldhaber-Gordon^{3,2,†}

RESEARCH

RESEARCH ARTICLE

SUPERCONDUCTIVITY

Tuning superconductivity in twisted bilayer graphene

Matthew Yankowitz¹, Shaowen Chen^{1,2,*}, Ihryhoriy Polshyn³, Yuxuan Zhang³,
K. Watanabe³, T. Taniguchi³, David Graf³, Andrea F. Young^{3,1}, Cory R. Dean^{1,†}

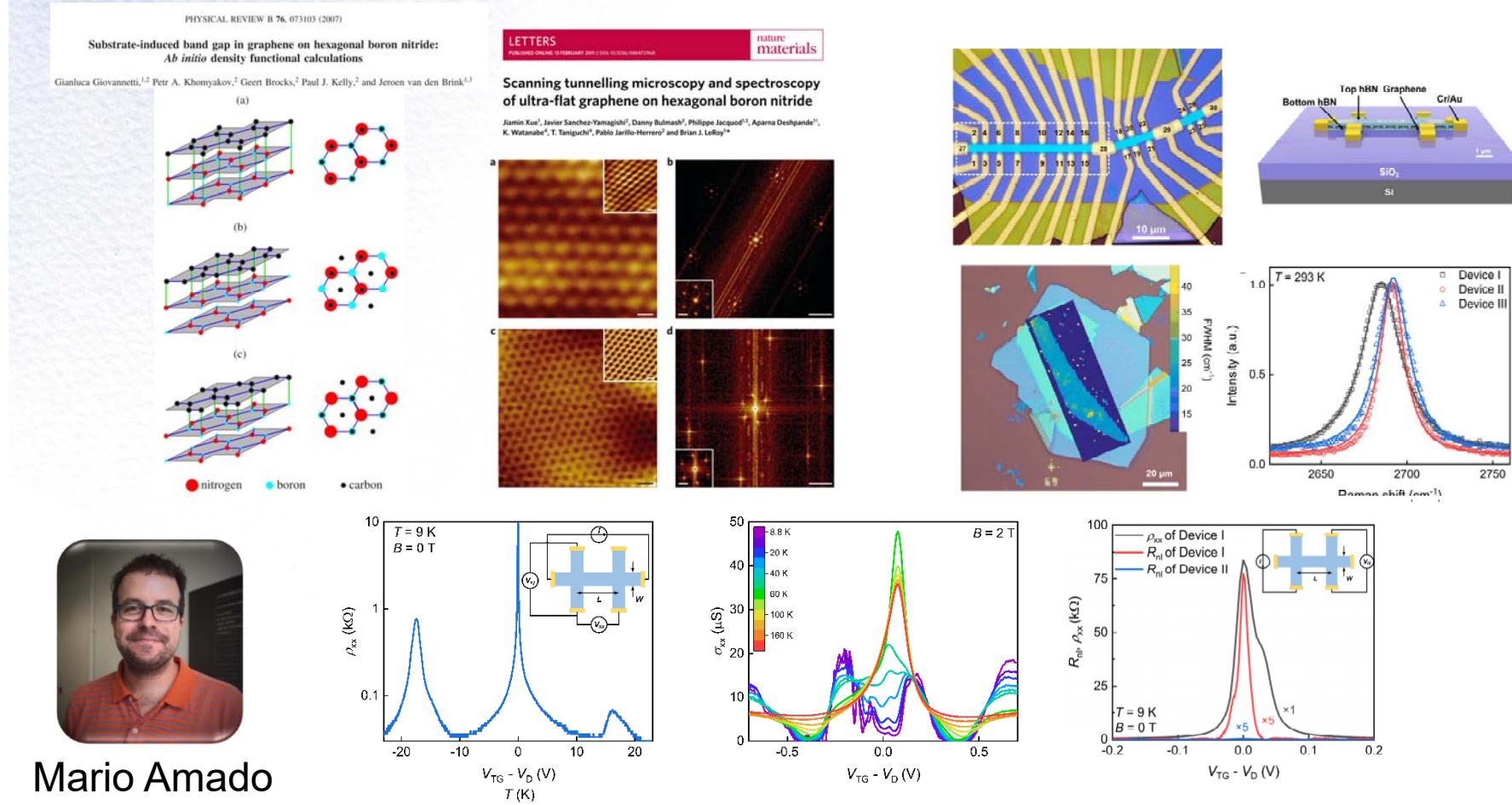
SCIENCE ADVANCES | RESEARCH ARTICLE

MATERIALS SCIENCE

Correlated insulating and superconducting states in twisted bilayer graphene below the magic angle

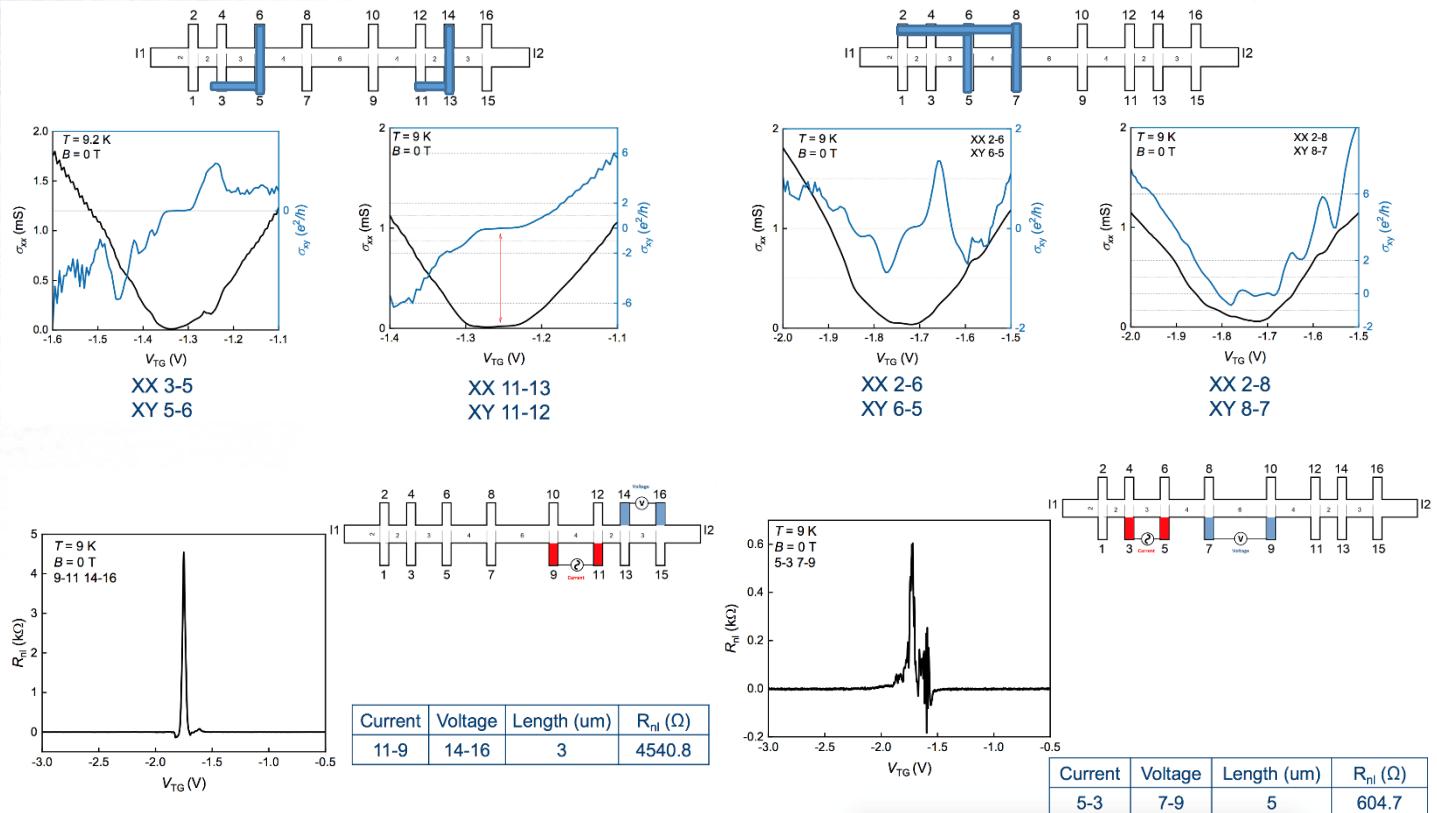
Emilio Codecido¹, Qiyue Wang², Ryan Koester¹, Shi Che³, Haidong Tian¹, Rui Lv¹, Son Tran¹,
Kenji Watanabe³, Takashi Taniguchi³, Fan Zhang^{2*}, Marc Bockrath^{1*}, Chun Ning Lau^{1*}

VALLEYTRONICS EN MATERIALES 2D



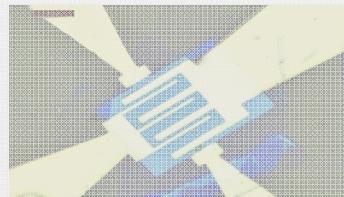
Mario Amado

VALLEYTRONICS EN MATERIALES 2D

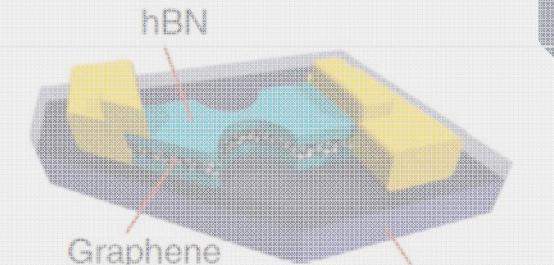


Materiales Cuánticos: Materiales 2D y aislantes topológicos

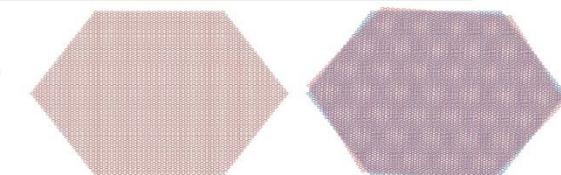
1. GFETs para detección de Terahercios



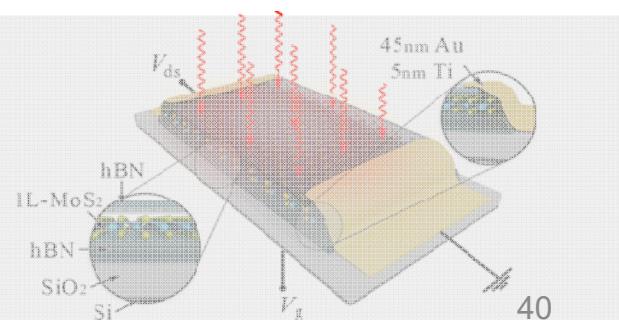
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3. Ruptura de la simetría en heteroestructuras de materiales 2D

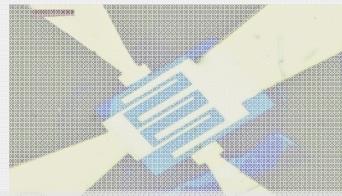


4. Optoelectrónica en Materiales 2D con baja simetría

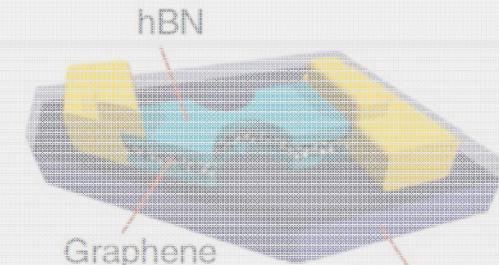


Materiales Cuánticos: Materiales 2D y aislantes topológicos

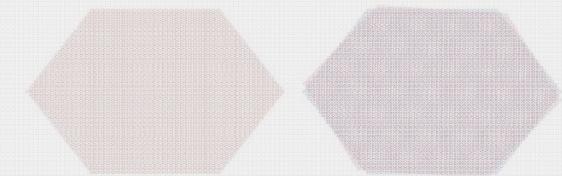
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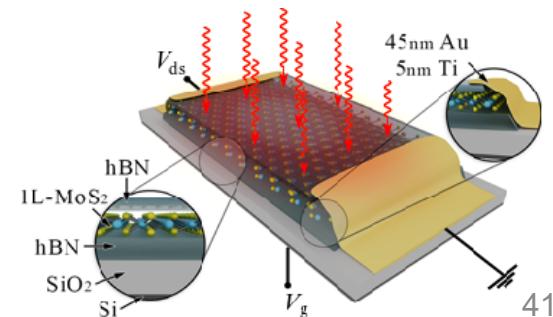
2. Nanoconstricciones en Grafeno y aislantes topológicos



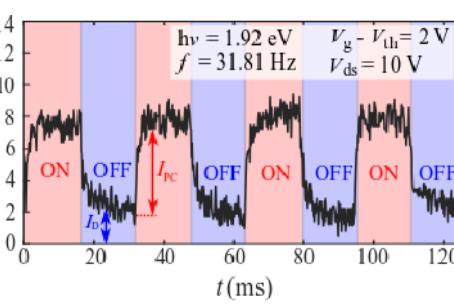
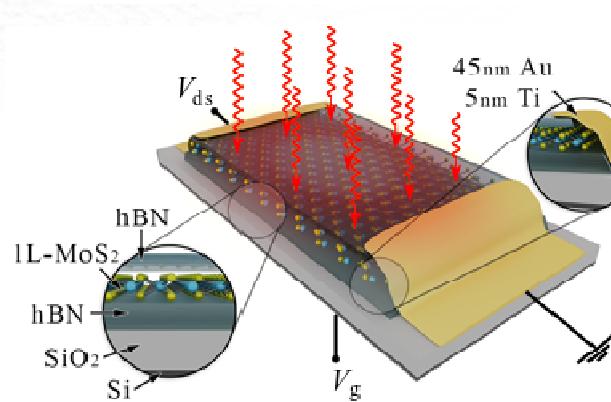
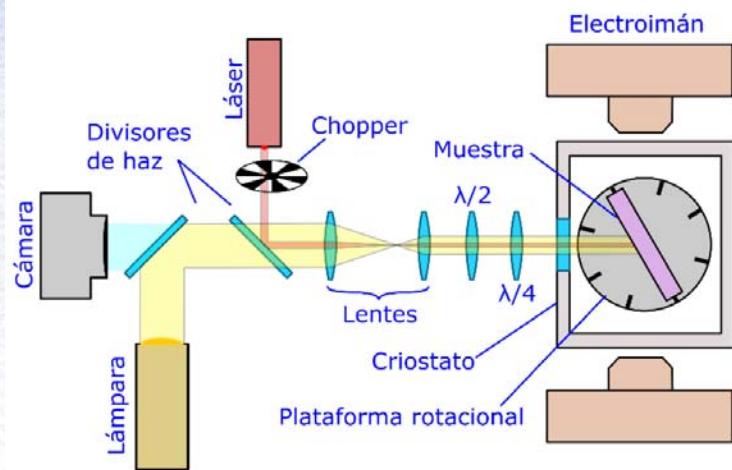
3. Ruptura de la simetría en heteroestructuras de materiales 2D



4. Optoelectrónica en Materiales 2D con baja simetría



Optoelectronics in 2D materials



Daniel Vaquero

Control parameters

- Illumination wavelength
- Polarization / helicity
- Light incidence angle
- Temperature
- Electric fields
- Magnetic field



Jorge Quereda

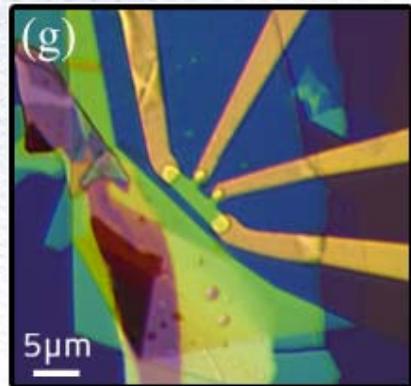
A typical measurement: Photocurrent spectroscopy

1. Light is absorbed through electronic interband transitions.
2. Carrier density increases.
3. Device conductivity increases.

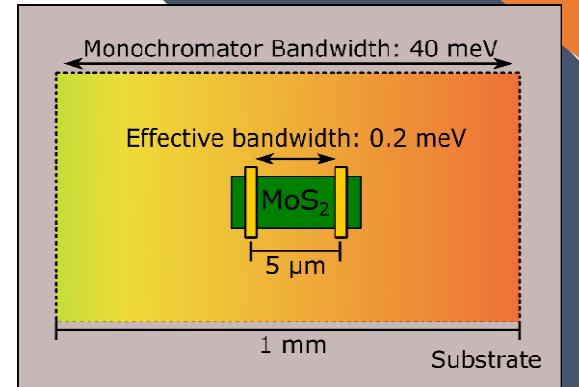


Photocurrent spectroscopy

Resolution limited by sample quality



- Ultrasharp spectral features (5 meV FWHM)
- Simple alignment: The whole sample is exposed to light.



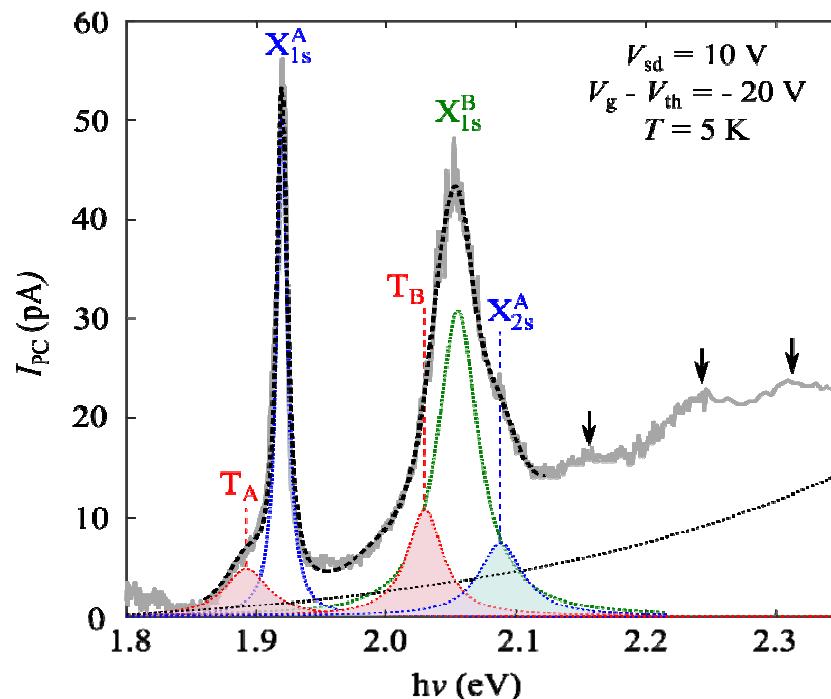
ARTICLE

<https://doi.org/10.1038/s42005-020-00460-9>

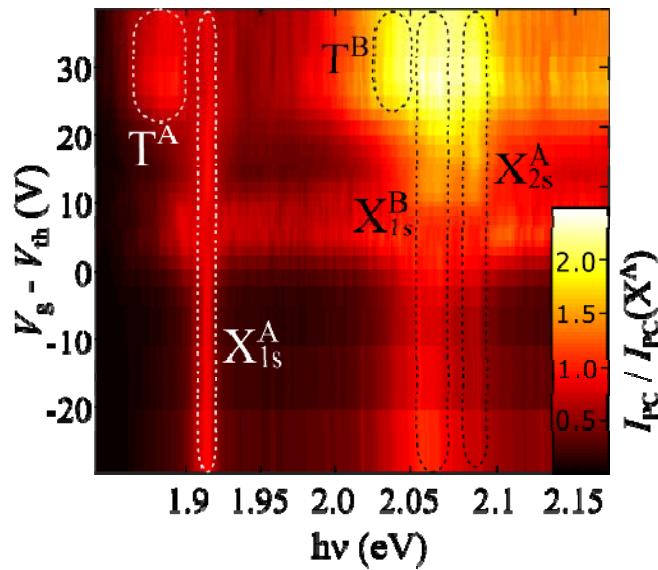
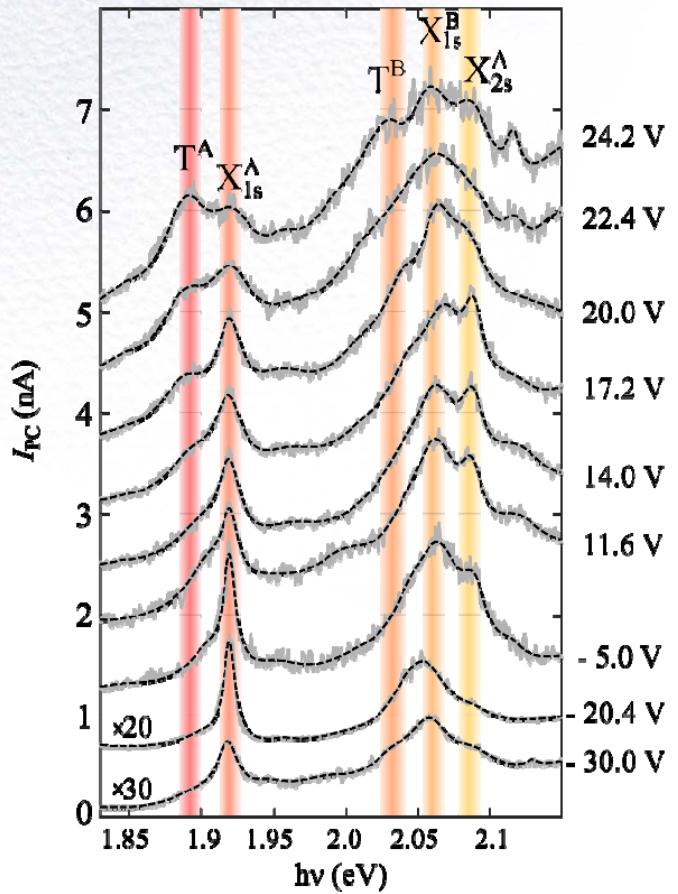
OPEN

Excitons, trions and Rydberg states in monolayer MoS₂ revealed by low-temperature photocurrent spectroscopy

Daniel Vaquero¹, Vito Clericò¹, Juan Salvador-Sánchez¹, Adrián Martín-Ramos¹, Elena Díaz², Francisco Domínguez-Adame², Yahya M. Meziani¹, Enrique Diez¹ & Jorge Quereda^{1*}



Gate modulation of excitons and trions





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