VNiVERSiDAD D SALAMANCA
CAMPUS DE EXCELENCIA INTERNACIONAL

800 AÑOS
1218 ~ 2018

WORKSHOP NANOLITO 2017

Sala de Presentaciones - 1ª Planta

Edificio I+D+i - Universidad de Salamanca
c/ Espejo, 2. 37007 Salamanca

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Program and Abstracts

CRESTED GPNT Graphene Nanotech rednanolito TECNOVAC

Nanodevices based on graphene and 2D materials

25 and 26 January 2017
SALAMANCA

Nanolito is the **Spanish Nanolithography Network**. It is an initiative sponsored by the Spanish Ministry of Economy and Competitiveness and has as an objective to promote knowledge transfer among the different partners involved in nanolithography.

This **workshop** will be oriented towards the use of nanolithography techniques in the fabrication and characterization of nanodevices based on graphene and other **2D materials**. Any applications based on nanofabrication techniques with these materials as nanopore membranes are also welcome. We aim to have a relaxed meeting in which we can all share our recent advances and results in these field and identify which are the main unsolved problems in the nanolithography processing of these materials.

INVITED SPEAKERS

Francisco Guinea (IMDEA, Madrid)
Frank Koppens (ICFO, Barcelona)
Andrés Castellanos (IMDEA, Madrid)
Adrian Bachtold (ICFO, Barcelona)
Fernando Calle (ISOM, Madrid)
Amaia Zurutuza (Graphenea, Donostia)
Mario Amado (Univ. Cambridge)
José María de Teresa (ICMA, Zaragoza)
Sergio Pezzini (HMFL, Radboud Univ. Nijmegen)
Ricardo García (ICMM, Madrid)
Gemma Rius (CNM, Barcelona)
Luis Hueso (Nanogune, Donostia)
Mar García Hernández (ICMM)
Alberto García (GPNT)
Philippe Godignon (CNM/Barcelona)
Pablo Alonso (Universidad Oviedo)
Marianna Sledzinska (ICN2, Barcelona)
Cesar Merino (Grupo Antolín, Burgos) Francisco Domínguez-Adame (UCM, Madrid)
Alberto Rivera-Calzada (UCM, Madrid)

SCIENTIFIC COMMITTEE

Enrique Diez (USAL, Salamanca)
José María De Teresa (ICMA, Zaragoza)
Soraya Sangiao (INA, Zaragoza)
Gemma Rius (CNM, Barcelona)
Albert Romano (UB, Barcelona)
Clivia Sotomayor (ICN2, Barcelona)
Ricardo García (ICMM, CSIC, Madrid)
José Luis Prieto (ISOM-UPM, Madrid)
Santos Merino (Tekniker, País Vasco)
José Ignacio Martín (UNIOVI, Asturias)
Luis Hueso (nanoGUNE, San Sebastián)
José Luis Vicent (UCM, Madrid)

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WEDNESDAY, 25TH JUANUARY 2017

14:45-15:00 **Opening**

	Chairman: J.M. Cerveró
15:00-15:50	**F. Guinea (IMDEA, Madrid)** – *Strains and electrons in two dimensional materials.*
15:50-16:10	**F. Koppens (ICFO, Barcelona)** – *Quantum plasmonics, polaritons and strong light-matter interactions with 2D material heterostructures.*
16:10-16:30	**F. Calle (ISOM, Madrid)** – *Supercapacitors based in 3D graphene foams.*
16:30-16:50	**G. Balakrishnan (Warwick, UK)** – *Topological and Dirac materials: Bulk crystals to Nanomaterials.*

17:00-17:30 **Coffee Break and Poster Session**

	Chairman: A. Castellanos
17:30-17:50	**M. Amado (CAMBRIDGE Univ., UK)** – *Tailoring magnetic graphene proximity coupled to ferromagnetic insulators.*
17:50-18:10	**J. M. de Teresa (ICMA, Zaragoza)** – *Weak localization in wafer-scale graphene.*
18:10-18:30	**F. Domínguez-Adame (UCM, Madrid)** – *Thermoelectric response of graphene quantum rings.*
18:30-18:50	**M. Sledzinska (ICN2, Barcelona)** – *Nano scale thermal transport in 2D materials.*
18:50-19:10	**A. Rivera-Calzada (UCM, Madrid)** – *Planar nanostructures of ferromagnetic manganites by e-beam lithography.*
19:10-19:30	**L. Hueso (Nanogune, Donostia)** – *A 2D field-effect spin transistor.*

19:30-20:00 **Visit of Nanolab Facilities.**
21:00 **Conference dinner at Hospedería Colegio Fonseca.**

THURSDAY, 26TH JANUARY 2017

	Chairman: L. Hueso
9:00-9:30	**A. Castellanos (IMDEA, Madrid)** – *2D Materials and Devices.*
9:30-9:50	**S. Pezzini (HMFL, Nijmegen)** – *Van der Waals heterostructures in high magnetic fields.*
9:50-10:10	**R. García (ICMM, Madrid)** – *Advanced Scanning Probe Lithography for nanopatterning and nanoelectronics.*
10:10-10:30	**A. Bachtold (ICFO, Barcelona)** – *Mechanical resonators based on graphene and TMDs.*
10:30-10:50	**G. Rius (CNM, Barcelona)** – *Micro and Nanofabrication for Graphene Electronics.*
10:50-11:10	**P. González (U. Oviedo)** – *Acoustic terahertz graphene plasmons revealed by photocurrent nanoscopy.*

11:10-11:45 **Coffee Break and Poster Session**

	Chairman: F. Domínguez-Adame
11:45-12:00	**V. Clericó (U, Salamanca)** – *Fabrication and characterization of Graphene and Graphene Oxide/hBN heterostructures.*
12:00-12:15	**R. Frissenda (IMDEA, Madrid)** – *Bandgap tuning of single-layer transition metal dichalcogenides under biaxial strain.*
12:15-12:30	**P. Gant (IMDEA, Madrid)** – *Novel method to measure electrical properties of two dimensional materials based on carbon fibres.*
12:30-12:45	**S. Mañas (UV, Valencia)** – *Transition metal dichalcogenides in the 2D limit: Enhanced superconductivity in atomically-thin 2H-TaS2 layers.*

Clossing Session: Graphene Industry in Spain

	Chairman: M. Velazquez
12:45-13:05	**M. G. Hernández (Graphene Flagship, ICMM Madrid)** – *Spanish alliance on graphene.*
13:05-13:25	**A. Zurutuza (Graphenea, Donostia)** – *Requirements for graphene-based devices.*
13:25-13:45	**N. Campos (Graphene Square, Avilés)** – *New trends in CVD methods for the synthesis of large-area bidimensional materials beyond graphene.*
13:45-14:05	**C. Merino (Grupo Antolín, Burgos)** – *Graphene Related Materials from Grupo Antolin and their use for transport applications.*
14:05-14:25	**A. García (GPNT, Zaragoza)** – *Synthesis of epitaxial graphene on SiC for electronic applications.*

14:25-14:30 **Closing meeting**
14:30 **Conference lunch at Hospedería Colegio Fonseca and Farewell**

Wednesday
25th January 2017

Strains and electrons in two dimensional materials

Francisco Guinea[1,2]

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[2]Condensed Matter Physics, University of Manchester, UK

Recent theoretical and experimental studies of the properties of strains and electrons in graphene and other two dimensional materials will be reviewed, including:

i) formation of bubbles,

ii) anharmonicity, quenched disorder and ripples, and

iii) formation of quantum dots and dynamics of excitons in semiconducting materials.

Quantum plasmonics, polaritons and strong light-matter interactions with 2d material heterostructures

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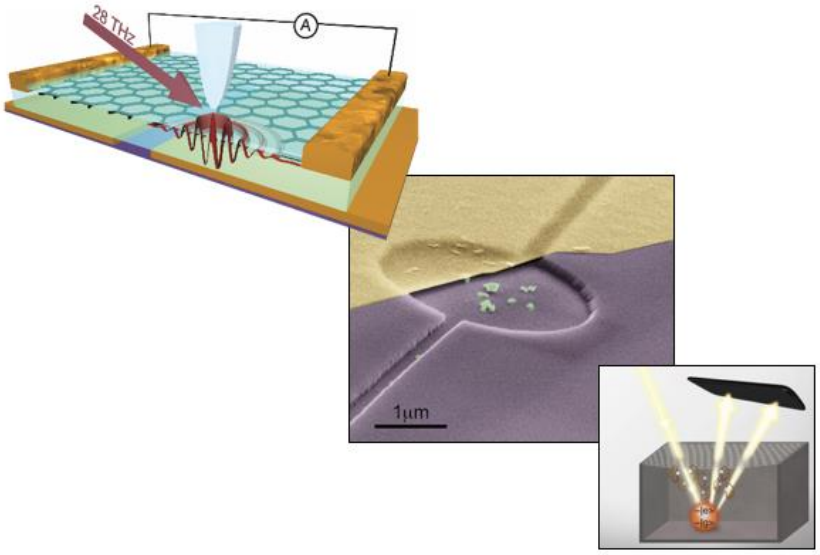
The control of polaritons are at the heart of nano-photonics and opto-electronics. Two-dimensional materials have emerged as a toolbox for in-situ control of a wide range of polaritons: plasmons, excitons and phonons. By stacking these materials on top of each other, heterostructures of these materials can be controlled at atomic scale, with extremely high quality and clean interfaces.

In this talk, we will show several examples of 2d material heterostructure devices with novel ways of exciting, controlling and detecting polaritons [1,2,3]. We challenge the limits of quantum light-matter interactions [5,6] as well as extremes in propagating plasmon confinement, down to the scale of a few nanometers.

The advances on ultra-high quality materials allow for plasmon propagation at extremely small electron densities, with de Broglie wavelength above 50 nm. This is an excellent platform for testing quantum theories of the dynamic response of the electron system, including spatial dispersion and electron-electron correlation effects.

Finally, we present novel results on Super-Planckian energy transfer between hot electrons and hyperbolic phonon polaritons [7]. Future directions on new directions in quantum materials will be addressed.



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[1] Near-field photocurrent nanoscopy on bare and encapsulated graphene. A. Woessner et al., Nature Communications (2016)
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[3] Ultra-confined acoustic THz graphene plasmons revealed by photocurrent nanoscopy. Alonso-Gonzalez et al., Nature Nanotechnology (2016)
[4] Real-space mapping of tailored sheet and edge plasmons in graphene nanoresonators. Nikitin et al., Nature Photonics (2016)
[5] Electro-mechanical control of optical emitters using graphene. Reserbat-Plantey et al.,Nature Communications (2016)
[6] Electrical Control of Optical Emitter Relaxation Pathways enabled by Graphene. K.J. Tielrooij et al., Nature Physics (2015)
[7] Super-Planckian electron cooling in a van der Waals stack. Principi et al., Arxiv 1608.01516 (2016)

Supercapacitors based in 3D graphene foams

Fernando Calle[1,2*], J. Pedrós[1,2], A. Boscá[1,2], S. Ruiz-Gómez[3], L. Pérez[3], J. Martínez[1,4]

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Graphene stands out by many different properties (electrical, optical, structural, mechanical, thermal, etc.), which combinations allow to improve device performance or enable new applications. Perhaps, energy storage by means of supercapacitors and batteries is the main short-term field in which graphene will be exploited.

Graphene can be prepared by several techniques. Chemical vapor deposition (CVD) using catalytic metal foils or films has demonstrated very good results for quality single or few-layer 2D graphene. Similarly, 3D graphene structures are grown by CVD on Cu or Ni metal foams or sponges, showing a high surface useful for supercapacitor electrodes. The graphene foam (GF) processing involves material growth, substrate removal and, eventually, functionalization. We are using plasma enhanced CVD to grow the graphene coating on a metal foam acting as a catalytic mesh. The coating thickness depends on the metal substrate and the growth conditions (gases ratio, growth time, etc.). A free-standing GF is obtained by wet etching the metal substrate. Finally, the GF may be functionalized by different techniques and materials (polymerisation, electrodeposition, sol-gel), either to modify the graphene properties and/or to provide robustness to the 3D structure.

In this work we will discuss several demonstrations of GF-based electrodes for supercapacitors, either by filling the GF with a hierarchical polymer nanostructure [1], or different oxides by electrodeposition [2] or sol-gel. GFs may also be exploited to enhance the properties of batteries and other energy applications, as well as in sensors, environment and biomedicine.

Acknowledgement. This work has been supported by Repsol (Inspire) and Ministerio de Economía y Competitividad (Project ENE2013-47904-C3-1).

References

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Topological and Dirac materials: Bulk crystals to Nanomaterials

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To make headway in understanding the physics of materials, high quality single crystals are essential. In this talk, I will present an overview of the investigations at Warwick on single crystals of various materials obtained by different techniques. I will also describe the study of crystals of some Topological Insulators, 2D layered and Dirac materials. Recent advancements made in the production and study of some Topological Insulators in the form of nanomaterials will also be presented.

Tailoring magnetic graphene proximity coupled to ferromagnetic insulators

Mario Amado[1*], Yang Li[1], Lauren McKenzie-Sell[1], Jason Robinson[1]

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The recent discovery of the quantum anomalous Hall effect (QAHE) in magnetically doped topological insulators in the milikelvin regime represents breakthrough in the field of spintronics[1]. Theoretically, the QAHE should occur in graphene proximity coupled to a ferromagnetic insulator[2] but with the promise of much higher operating temperatures for practical applications. Hints of proximity-induced magnetism in graphene coupled to yttrium iron garnet (YIG) films have been reported[3] although the QAHE remains unobserved; the lack of a fully developed plateau in graphene/YIG devices can be attributed to poor interfacial coupling and therefore a dramatically reduced magnetic proximity effect

Here we report the deposition and characterisation of epitaxial thin-films of YIG on lattice-matched gadolinium gallium garnet substrates by pulsed laser deposition. YIG films are characterized by X-ray diffraction, atomic force microscopy vibrating sample magnetometry and ferromagnetic resonance in order to check is quality. Pristine exfoliated graphene flakes coupled to transition metal dichalcogenides are transferred mechanically onto the YIG. The induced magnetization of the 2D-like heterostructure is reported by means of electrical (low temperature magnetoresistance measurements in Hall-bar-like configuration) measurements The results correlate the effects of YIG morphology on the electronic properties and magnetization of graphene.

References

[1] C.Z. Chang et al., Science **340**, 167 (2013) and C.Z. Chang et al., Nature Materials **14**, 473 (2015).

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Figures

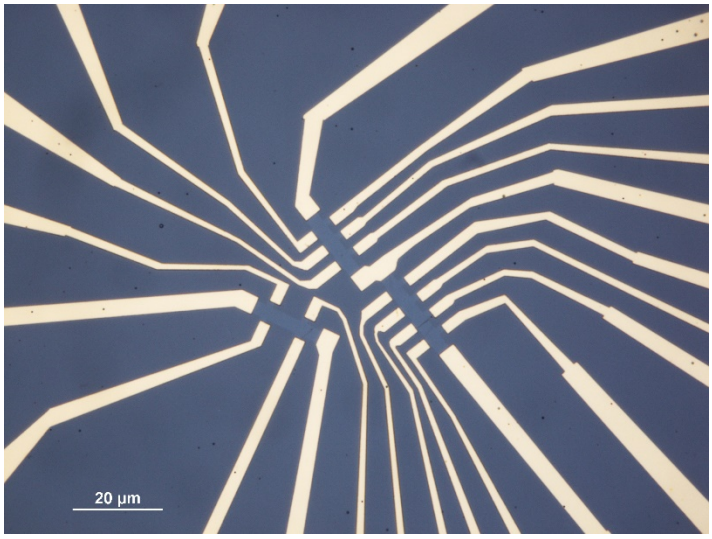

Figure 1: Electron micrograph of three h-BN-encapsulated graphene flakes in a Hall-bar-like configuration deposited on YIG.

Weak localization in wafer-scale graphene

Inés Serrano-Esparza[1], Soraya Sangiao[2], A. Ballestar[3], L. Serrano-Ramón[3], A. García-García[3,4], Philippe Godignon[4], A. Zurutuza[5], A. Centeno[5], **José María De Teresa[1,2,*]**

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Previous studies have shown evidence of the subtle interplay amongst the elastic (intra-valley and intervalley) and inelastic scattering lengths to determine weak localization (WL) phenomena in graphene [1]. Further investigations of WL can help to understand the scattering mechanisms in the different types of graphene. In the present contribution, we will start by reviewing the current understanding of WL in graphene and will subsequently proceed to show the experiments performed in our lab to investigate WL phenomena in wafer-scale graphene. In one set of experiments, metal contacts are first grown and CVD-graphene is later transferred and structured to produce devices such as those shown in Figure 1 (left). In another type of experiments, epitaxial graphene grown on SiC is first structured into Hall-type bars and, subsequently, metal contacts are grown as shown in Figure 1 (right). The magnetotransport results indicate the presence of WL below T~50 K in both types of samples [2]. From the obtained results, the relevant scattering lengths and their temperature dependence have been determined. The possible origin of the different values of the scattering lengths found for different types of graphene and different experimental situations will be discussed.

References

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Figures

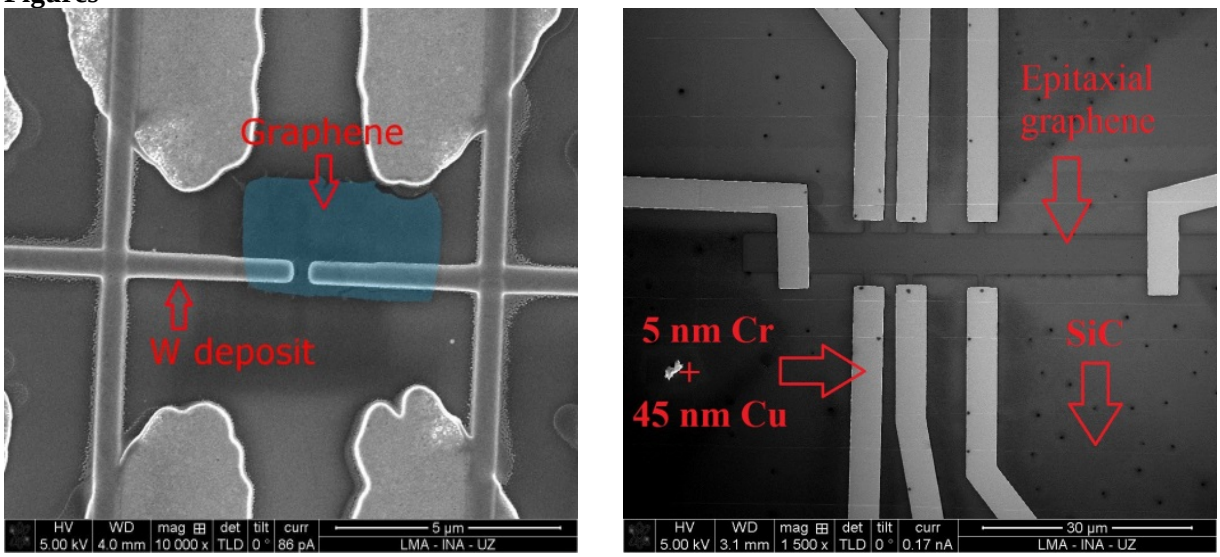

Figure 1: LEFT: SEM imaging of CVD-graphene on top of metal contacts. RIGHT: SEM imaging after lithography to establish metal contacts to epitaxial graphene grown on SiC substrate.

Thermoelectric response of graphene quantum rings

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We study the thermoelectric properties of rectangular graphene rings connected symmetrically or asymmetrically to the leads. The system consists of a square graphene ring connected symmetrically or asymmetrically to two leads, as shown in the left panel of Fig. 1. We assume that the leads are two semi-infinite armchair graphene nanoribbons with $N \neq 3n-1$, N being the number of hexagons across the nanoribbon and n a positive integer. In this case the band structure has a width-dependent gap and the corresponding dispersion relation near the gap is parabolic [1, 2].

We focus our attention to the figure of merit $ZT = S^2 \sigma T / \kappa$, which reflects the thermoelectric efficiency of the system. Here S is the Seebeck coefficient, and σ and κ are the electric and thermal conductances at a given temperature T, respectively. We have numerically found that the transmission patterns can be grouped into two categories, depending on the value of N. If $N = 3n-2$ the transmission coefficient displays resonant peaks, whose shape is Lorentzian close to the resonance energy for both configurations (Breit-Wigner line-shapes). A typical example is shown in the middle panels of Fig. 1, corresponding to $w = 15.0$ nm, i.e., $N = 61$, for both symmetric (dashed line) and asymmetric (solid line) rings. When $N = 3n$ the transmission coefficient strongly depends on the symmetry of the ring. As shown in the right panels of Fig. 1, for $w = 15.5$ nm, i.e., $N = 63$, the transmission coefficient for symmetrically connected rings only presents Breit-Wigner line-shapes (dashed line). On the contrary, if the ring is connected asymmetrically, the transmission coefficient shows Fano line-shapes (solid line). When the nanoribbon width is increased, the one-mode energy region shrinks, but the transmission features remain qualitatively unchanged. We observe that the figure of merit is enhanced when the chemical potential matches a Fano anti-resonance (see the peaks at about 60 and 72 meV in the lower right panel Fig. 1). We have found that such resonances can always be induced by a side-gate voltage applied between the two arms of the ring, even in symmetric rings.

References

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Figures

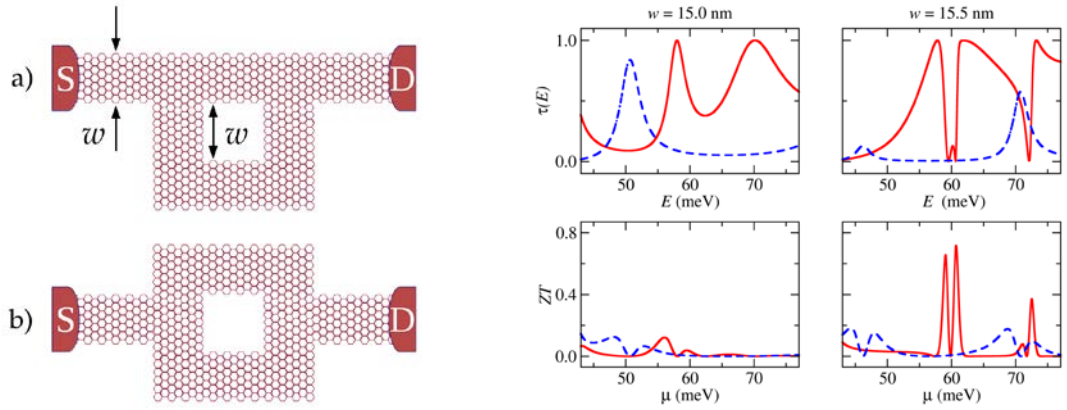

Figure 1: LEFT: Schematics of the device connected a) asymmetrically and b) symmetrically to leads. RIGHT: Transmission and figure of merit for symmetric (dashed lines) and asymmetric (solid lines) rings. Left and right panels correspond to w=15.0 nm and w=15.5 nm, respectively.

Nanoscale thermal transport in 2D materials

M. Sledzinska[1], B. Graczykowski[1], D. Saleta Reig[1,7], M. Placidi[2], A. El Sachat[1], J.S. Reparaz[1], F. Alzina[1], B. Mortazavi[3], R. Quey[4], L. Colombo[5], S. Roche[1,6], and C. M. Sotomayor Torres[1,6]

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2D materials, such as graphene and transition metal dichalcogenides, have already attracted a lot of attention because of their optical and electrical properties [1]. They show good room-temperature carrier mobility with a high on-off ratio making them perfect candidates for nano-electronics. However, despite these exciting properties, the future of 2D materials will depend on the progress in fabrication of nano-devices and ensuring their efficient operation.

We have employed the contactless Raman thermometry [2], previously successful for measuring thermal conductivity of thin silicon membranes, for the free-standing MoS_2 and graphene samples. For the MoS_2 samples the measurements revealed a strong reduction in thermal conductivity down to 0.5 W/mK in the in-plane direction. The results were explained using finite elements method simulations for a polycrystalline film [3]. In case of graphene, the slight reduction of thermal conductivity was explained by the presence of defects, which can be seen in the pronounced Raman D peak.

In this work we also address the issue of nanofabrication by developing a technique for transferring large areas of the CVD-grown, MoS_2 nanosheets from the original substrate to another arbitrary substrate and onto holey substrates, in order to obtain free-standing structures. The method consists of a polymer- and residue-free, surface-tension-assisted wet transfer, in which we take advantage of the hydrophobic properties of the MoS_2. The method yields better quality transferred layers, with fewer cracks and defects, and less contamination than the widely used PMMA-mediated transfer and allows fabrication of few-nm thick, free-standing structures with diameters up to 100 μm [3].

Understanding thermal properties of graphene and MoS_2 can give an insight on the thermal transport in ultra-thin semiconducting films, especially taking into account grainsizes in polycrystalline materials. The possibility of tailoring thermal conductivity by controlling the grainsizes in the nanomaterials offers multiple applications for the future devices.

References

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[3] Sledzinska, M. et al., 2D Mater. **3** (2016) 035016

Planar nanostructures of ferromagnetic manganites by e-beam lithography

G. Orfila, D. Sanchez-Manzano, M. Rocci, C. Leon, A. Rivera-Calzada, J. Santamaria.

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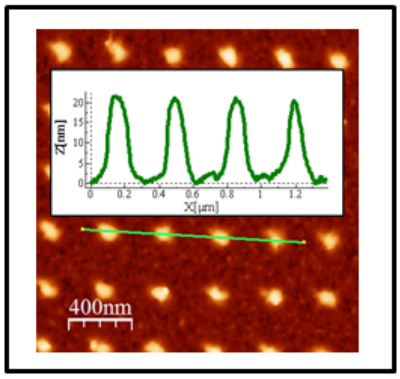
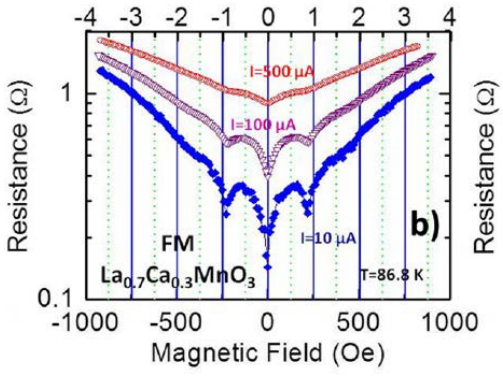
The field of correlated oxides has rapidly expanded in recent years mostly fueled by the emergent electronic states nucleating at epitaxial interfaces combining different oxides. However, most of the work so far has been done on large area thin films or in devices patterned to allow perpendicular CPP transport. Little work, so far, has been devoted to planar nanostructures, where interesting effects may arise when lateral dimensions are reduced to match characteristic length scales. The processing of thin films into planar nanostructures using electron beam lithography may enable new device concepts for advanced applications. In this presentation we show examples of lateral nanostructures of manganites $La_{0.7}Sr_{0.3}MO_4$ (LSMO) and $La_{0.7}Ca_{0.3}MO_3$ (LCMO) thin films. We will describe control of the vortex matter in the high Tc superconductor $YBa_2Cu_3O_7$ (YBCO) by pinning of the vortex lattice by an ordered array of LCMO nanodots. This pinning effect exploits the long range suppression of the superconductivity occurring at the interface between manganites and cuprates. As a second example of oxide nanostructures we present a nanoscale LSMO wire with a 90º angle shape, which promotes the nucleation of domain walls. TMR-like switch of the magnetoresistance will be presented, which results from the large domain wall resistivity due to the large spin polarization of the wire.





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A two-dimensional field-effect spin transistor

Luis E. Hueso[1,2*], Wenjing Yan[1], Oihana Txoperena[1], Félix Casanova[1,2]

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The integration of the spin degree of freedom in charge-based electronic devices has revolutionised both sensing and memory capability in microelectronics [1]. However, any further development in spintronic devices requires electrical manipulation of spin current for logic operations. The approach followed so far, inspired by the seminal proposal of the Datta and Das spin modulator [2], has relied on the spin-orbit field as a medium for electrical control of the spin state [3]. However, the still standing challenge is to find a material whose spin-orbit-coupling (SOC) is weak enough to transport spins over long distances, while also being strong enough to allow their electrical manipulation.

In this talk I will show a radically different approach in the form of an atomically thin van der Waals heterostructure [4], which combines the superior spin transport properties of graphene [5] with the strong SOC of the semiconducting MoS_2 [6].

Our results show how the spin transport in the graphene channel is modulated between ON and OFF states by tuning the spin absorption into the MoS_2 layer with a gate electrode. Our demonstration of a spin field-effect transistor using two-dimensional materials identifies a new route towards spin logic operations for beyond CMOS technology [7].

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Thursday
26th January 2017

2D Materials and Devices

Andres Castellanos-Gomez[1*]

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In this talk I will review the recent progress on the application of atomically thin crystals different than graphene on optoelectronic devices. The current research of 2D semiconducting materials has already demonstrated the potential of this family of materials in optoelectronic applications [1-4]. Nonetheless, it has been almost limited to the study of molybdenum- and tungsten- based dichalcogenides (a very small fraction of the 2D semiconductors family). Single layer molybdenum and tungsten chalcogenides present large direct bandgaps (~1.8 eV). Alternative 2D semiconducting materials with smaller direct bandgap would be excellent complements to the molybdenum and tungsten chalcogenides as they could be used for photodetection applications in the near infrared. Furthermore, for applications requiring a large optical absorption it would be desirable to find a family of semiconducting layered materials with direct bandgap even in their multilayer form.

Here I will summarize the recent results on the exploration of novel 2D semiconducting materials for optoelectronic applications: black phosphorus [5-7], TiS_3 [8, 9] and franckeite [12]. Recent efforts towards tuning the optoelectronic properties of 2D semiconductors by strain engineering will be also discussed [10, 11].

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Figures

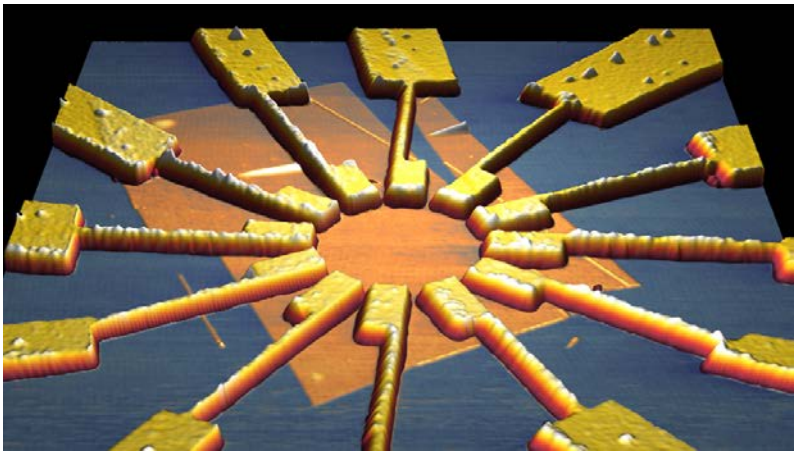

Figure 1: Atomic force microscopy image of a TiS_3 device with electrodes arranged at different angles to probe the in-plane anisotropy.

Van der Waals heterostructures in high magnetic fields

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High magnetic field sources represent a fundamental tool of characterization for condensed-matter systems, often leading to the realization of new phenomena and exotic states of matter [1]. In recent years, the assembly of two-dimensional (2D) crystals into artificial heterostructures held together by van der Waals forces is opening up unique opportunities for the realization of novel electronic properties [2]. In our talk we will discuss several results we obtained by studying gate-tunable electrical transport devices based on high-quality 2D heterostructures in the presence of strong magnetic fields and cryogenic temperatures.

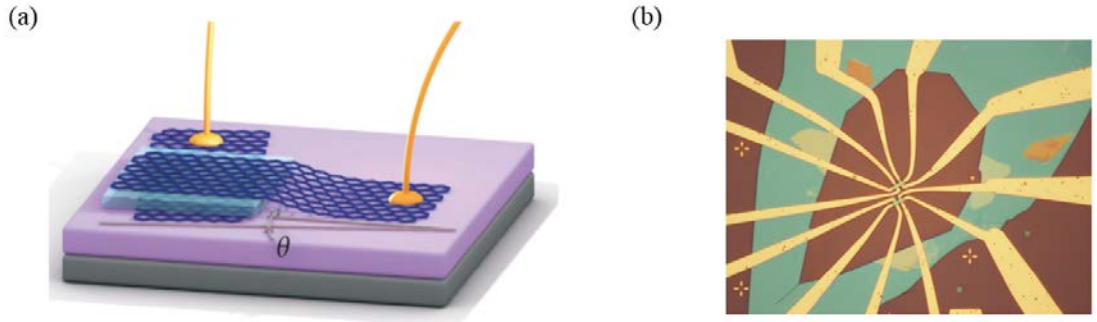

Figure 1: (a) Schematic diagram of a Gr/hBN/Gr tunneling device as the one studied in Ref.[3]. (b) Optical microscopy image of two Hall bar devices fabricated on an aligned graphene/hBN stack.

This work has been done in collaboration with S. Wiedmann and U. Zeitler at the HFML in Nijmegen, and A. Mishchenko and collaborators from the University of Manchester.

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Advanced Scanning Probe Lithography for nanopatterning and nanoelectronics

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The nanoscale control afforded by scanning probe microscopes has prompted the development of a wide variety of scanning probe-based patterning methods. Some of these methods have demonstrated a high degree of robustness and patterning capabilities that are unmatched by other lithographic techniques. However, the limited throughput of scanning probe lithography has prevented their exploitation in technological applications. Here, we review the fundamentals of scanning probe lithography and its use in materials science and nanotechnology[1]. We focus on the methods and processes that offer genuinely lithography capabilities. Specifically, we describe the applications of oxidation SPL for nanopatterning and device fabrication of nanoscale field-effect transistors, molecular architectures and two-dimensional electronic materials.

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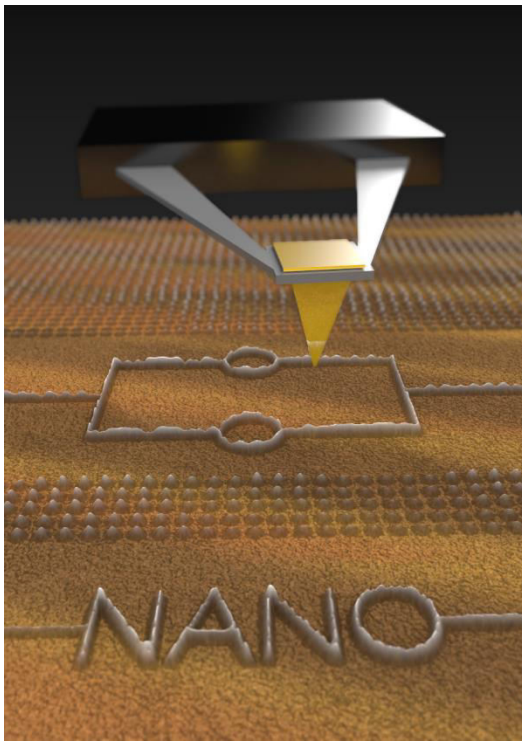

Scheme of scanning probe lithography

Mechanical resonators based on graphene and TMDs

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When a graphene layer is suspended over a circular hole, the graphene vibrates as a music drum. However, such a graphene drum has an extremely small mass. Another difference is the quality factor Q, which becomes extremely large in graphene resonators at cryogenic temperature (Q above 1 million). Because of this combination of low mass and high quality factor, the motion is enormously sensitive to external forces. Here, we couple the graphene resonator to a superconducting cavity via the radiation pressure interaction. The superconducting cavity allows us to transduce the graphene motion with unprecedented sensitivity. We sideband cool the graphene motion to an average phonon occupation that approaches the quantum ground-state. We show that the graphene resonator is a fantastic force sensor with a sensitivity approaching the fundamental limit imposed by thermo-mechanical noise. We find that energy decays in a way that has thus far never been observed nor predicted. As the energy of a vibrational mode freely decays, the rate of energy decay switches abruptly to lower values, in stark contrast to what happens in the paradigm of a system directly coupled to an environmental bath. Our finding is related to the hybridization of the measured mode with other modes of the resonator. Our work opens up new possibilities to manipulate vibrational states, engineer hybrid states with mechanical modes at completely different frequencies, and to study the collective motion of this highly tunable system.

Figure

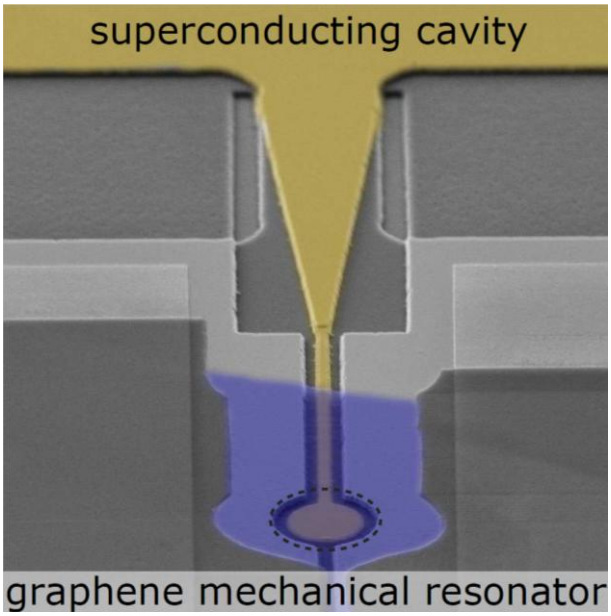

Figure 1: Circular graphene resonator coupled to a superconducting cavity

Micro and Nanofabrication for Graphene Electronics

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Relevant examples of synthesis and device fabrication technology applied to graphene materials will be presented. Special attention will be devoted to the application of micro and nanopatterning techniques to obtain graphene based electronic devices. At the IMB-CNM, an integral approach on graphene technology is currently implemented.

For instance, optimization of the processing of epitaxial graphene on SiC (EG-SiC) is applied to all available synthetic materials, i.e. in the form of 1) full coverage [1], 2) isolated flakes [2] and 3) selectively grown [3] graphene materials. Additionally, their combination with both conventional and unconventional planar technology techniques include device fabrication methods such as, respectively, ion implantation for gating and local anodic oxidation by atomic force microscope for device resistance tuning [4].

Apart from conventional synthesis by chemical vapor deposition (CVD) on Cu, up to 4" wafer scale, other examples of micro-nanostructured graphene materials which could be presented are the use of plasma enhanced CVD for the synthesis of porous vertically oriented graphene sheets. These so-called carbon nanowalls have been applied as electrode materials for supercapacitor devices [5] and Li-ion batteries [6]. Alternatively, original methods such as thermal graphitization of ultrathin diamond-like carbon membranes patterned by focused ion beam induced deposition could be also introduced [7].

Additional works on processing such as delamination and transfer techniques as well as integration of transistors, both at wafer scale, based on CVD graphene, for biomedical applications, or single wall carbon nanotubes [8], for chemical sensing, can be shown. These are examples of the capability for batch fabrication of micro-nanoelectronic devices and systems.

Finally, other examples of innovative nanofabrication strategies and nanoelectronic applications of 2D materials, such as applying block copolymer (BCP) masks to graphene (Fig. 1), for its quantum confined electronic performance, and graphene oxide (GO), for RRAM devices (Fig. 2), are some of the most recent investigations under development at the IMB-CNM.

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Figures

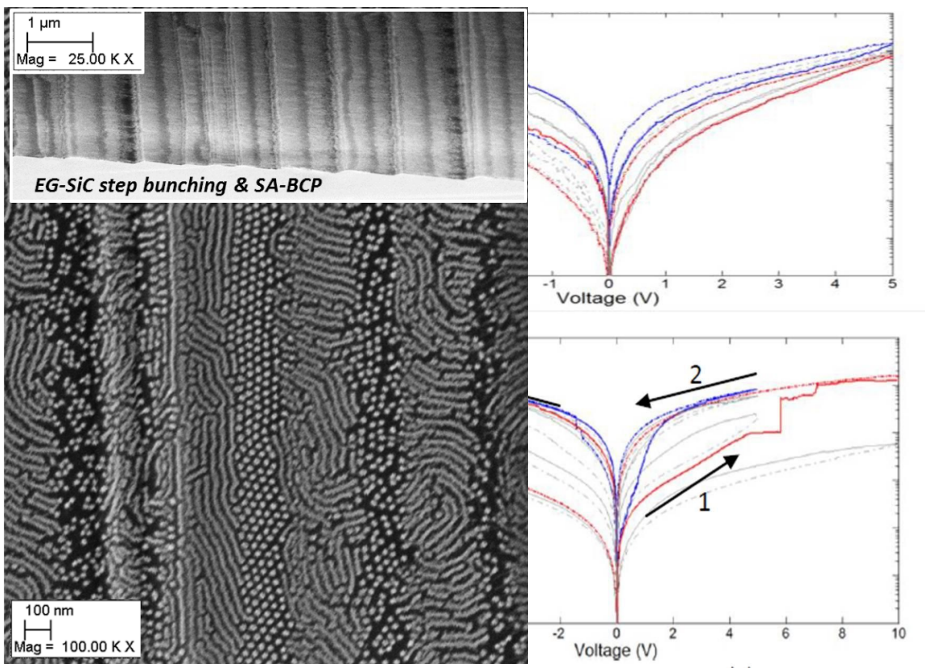

Figure 1: LEFT: Top view SEM image of thermally annealed 2L0 thick Nanostrength EO® C35 PS-b-PMMA on Si-face EG-SiC after sequential infiltration synthesis plus plasma O_2, for high contrast directed self-assembly BCP observation; e.g. of a characteristic closely-packed (ordered) array of dots (center stripe). Top inset is a cross section of the same sample, to show the typical step bunching of EG-SiC and formation of terrace suprastructured stripes. Figure 2: RIGHT: I/V curves of MIM devices with ten GO deposition cycles. The diversity of observed resistive switching behaviours suggests that efficient GO film should be thicker and grain size more uniform to provide a more robust operation.

Thursday 26th 10:50-11:10

Acoustic THz graphene plasmons revealed by photocurrent nanoscopy

Pablo Alonso-González[1,2], Alexey Y. Nikitin[1,3], Yuanda Gao[4], Achim Woessner[5], Mark B. Lundeberg[5], Alessandro Principi[6], Nicolò Forcellini[7], Wenjing Yan[1], Saül Vélez[1], Andreas. J. Huber[8], Kenji Watanabe[9], Takashi Taniguchi[9], Luis E. Hueso[1,3], Marco Polini[10], James Hone[4], Frank H. L. Koppens[5,11], and Rainer Hillenbrand[3,12]

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The interaction of terahertz (THz) radiation with graphene has a vast application potential in many technologies, including imaging, communications, sensing, or photo-detection, among others. Recently, it has been shown that the excitation of localized THz plasmons in graphene can strongly enhance light-matter interactions, opening the door to more efficient optoelectronic devices. Here, we will present on the first visualization of propagating graphene plasmons (GPs) at THz frequencies, which can also be controlled by metallic (split) gates. Intriguingly, due to the coupling of GPs with the metal gate underneath we observe a linearization of the plasmon dispersion (thus revealing acoustic plasmons), which comes along with an extreme confinement of the plasmon fields [1]. These extraordinary GPs properties are very promising for sensing and communication technologies. To map the THz GPs, we introduce nanoscale-resolved THz photocurrent nanoscopy as a novel tool for studying fundamental and applied aspects of local THz photocurrent generation with a resolution of 25 nm, nearly 4 orders of magnitude below the diffraction limit.

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Fabrication and characterization of Graphene and Graphene Oxide/hBN heterostructures

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Graphene (G) is a promising material for devices because of its amazing electrical properties. Mechanical exfoliation continues to give graphene flakes with the best properties and for this reason it is very interesting for studying new physical properties [1]. Epitaxial growth or CVD [2] are postulated as a very good alternative methods to produce graphene in an industrial scale but the main disadvantage is the cost of production. Graphene oxide (GO) is the cheapest and industrial scalable derivative of graphene. GO is synthesized by chemical exfoliation of graphite or carbon nanofibers [3]. GO is often reduced by chemical agents [4] or thermal annealing [5] to restore the carbon lattice and to remove the structural defects and distortions.

It is known that the electron mobility of graphene based devices is extremely influenced by the substrate [6]. Therefore an appropriate substrate should be used for high quality graphene based devices. Hexagonal boron nitride (hBN) is an isomorph of graphite composed of alternating B and N atoms in a honeycomb lattice. Because of its band structure, this compound is an insulating and relatively inert. The above features makes it an excellent candidate to perform such as devices.

In this work, we present the fabrication and characterization of vertically stacked graphene based heterostructure. Two different devices have been fabricated by mechanical cleavage method followed by layer-by-layer transfer techniques. The first one is hBN/G/hBN sandwich type supported on a Si-SiO_2 substrate. For comparative purpose, the second heterostructure have been fabricated by using GO instead of G. As we know, this is the first time that an hBN/GO/hBN heterostructure is reported. The method to produce it is similar to that employed for graphene. However, the main differences between them are that the mechanical exfoliation of graphene oxide is carried out in presence of water and the flakes were deposited on a surface of PDMS instead of Si-SiO_2. The water helps the exfoliation of GO and prevents the cleavage of the flakes while PDMS favors the transference process. In order to remove the oxygen groups and to restore the carbon lattice of the GO, the heterostructure has been annealed at 1200 ºC. The devices thus obtained have been characterized by using Raman Spectroscopy and I-V electrical measurements.

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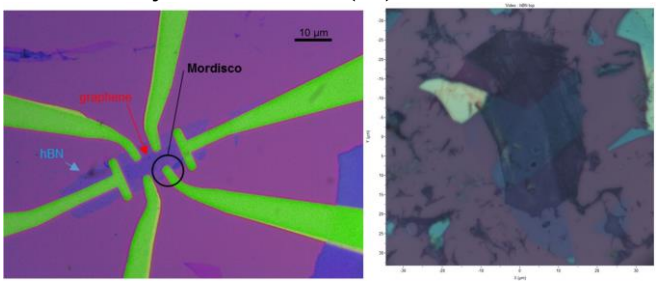

Figure 1: LEFT: Optical image of hBN/graphene heterostructure with a constriction of 300 nm. RIGHT: Optical image of hBN/GO/hBN heterostructure.

Acknowledgement
Authors thanks Junta de Castilla y Leon for funding this research with the project SA045U16.

Bandgap tuning of single-layer transition metal dichalcogenides under biaxial strain

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Strain engineering has been proposed as a promising route to modify the electronic and optical properties of two-dimensional (2D) materials [1]. These materials can stand to large mechanical deformations, of the order of 10%, while conventional 3D semiconductors tend to break at moderate deformations of 0.5-1.5%. Another key feature of strain engineering of 2D materials stands in the way in which they can be strained. In fact, while 3D systems are typically stressed by epitaxial growing them onto substrates with a certain lattice parameter mismatch, strain in 2D systems can be applied by stretching [2] or bending [3]. Experiments on MoS_2 single-layer and few-layers flakes have already demonstrated that the optical band gap can be changed of 50 meV/% for uniaxial strain and of 100 meV/% for biaxial strain. Most of these strain engineering experiments to date, however, study uniaxial tensile strain under static conditions and, apart from few exceptions, are limited to MoS_2. In this talk I will present results on biaxial straining, both tensile and compressive, of single-layer transition metal dichalcogenides (TMDC). We studied the effect of strain on mechanically exfoliated flakes of monolayer MoS_2 deposited on different polymeric substrates. We apply the strain exploiting the large mismatch between the thermal expansion coefficients of the polymeric substrates and the fabricated TMDCs flake deposited on top. We studied the substrate dependency of the strain transfer efficiency and we find that for substrates with Young's modulus larger than 1 GPa, biaxial strain can be applied reproducibly without slippage. We investigate the effects of strain on the optical properties of single-layers MoS_2, $MoSe_2$, WS_2 and WSe_2 and we observe a redshift of the optical band gap of these 2D TMDCs for increasing tensile strain. The observed bandgap shifts as a function of substrate extension/compression follow the order $MoSe_2 < MoS_2 < WSe_2 < WS_2$, i.e. with WS_2 providing the largest bandgap tunability and $MoSe_2$ the lowest. This method can be readily applied to other 2D materials and be used to vary the strain in real time.

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NOVEL METHOD TO MEASURE ELECTRICAL PROPERTIES OF TWO DIMENSIONAL MATERIALS BASED ON CARBON FIBRES

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In the last years, the research field of two-dimensional (2D) materials has grown tremendously due to the exceptional opto-electronic properties of these materials and the possibility to use them in novel devices and applications [1-3]. In order to investigate the transport properties and electrical behaviour of 2D materials based nanodevices, metallic electrodes are typically used. To fabricate this kind of samples with 2D flakes, two techniques are mainly followed. In the first approach, the electrodes are evaporated on top the flake using clean room techniques. In the second method, called deterministic transfer, the flake is aligned with the pre-patterned metallic electrodes and then transferred [4]. Both of these methods are time-consuming, non-reversible and can lead to surface contamination of the 2D material.

In this work, we present an alternative method to make electrical measurements of 2D materials in a fast, reproducible and non-invasive way. We use carbon fibre (C-fibres) tips, instead of electrodes, to contact the flakes directly without damaging them. At this end, we prepared samples transferring MoS_2 flakes on Au substrate and SiO_2 substrate to measure transport both out-of-plane (using one C-fibre to measure from MoS_2 to Au) and in-plane (using two C-fibres to measure on the MoS_2) as a function of the number of layers of MoS_2. Additionally, we characterised the optoelectronic properties of MoS_2 flakes and measured the gate-dependence of the current-voltage characteristics.

In conclusion, C-fibres can be used as a procedure to perform fast and local measurements of the electrical properties of a 2D material without damaging the samples. This method could be interesting to easily measure vertical transport and to test new and unknown samples without the necessity of the usual fabrication methods.

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Transition metal dichalcogenides in the 2D limit: Enhanced superconductivity in atomically-thin 2H-TaS_2 layers

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Graphene [1] is one of the most studied materials due to its unique properties such as hardness, flexibility and high electric and thermal conductivity. However, probably the best quality of graphene is that it has opened the field to many other 2D crystals [2], including superconductors and topological insulators.

In this work, the synthesis and characterization of metal chalcogenides are discussed. As an example, thickness-dependent Raman spectra of ZrX_2 (X = S, Se) and transport measurements in thin layers of 2H-TaS_2 are presented. While no thickness dependence is observed in ZrX_2 [3], in 2H-TaS_2, it is observed a superconducting temperature (Tc) enhancement by decreasing the number of atomic layers (from 0.6 K in the bulk sample to ca. 2K in a ~3 nm layer, as can be seen in Figure 1) [4]. This behaviour is the opposite of the one reported in other 2D superconductors, as $NbSe_2$ [5]. This effect can be interpreted on the basis of a simple band model and on optical phonons localized in each plane; it shows that the tunneling between the bands decreases the effectiveness of the pairing interaction that in turn is mediated by in-plane phonons.

This result may bring superconductivity into the flatland for their future use in magnetic sensors or low energy applications.

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Figures

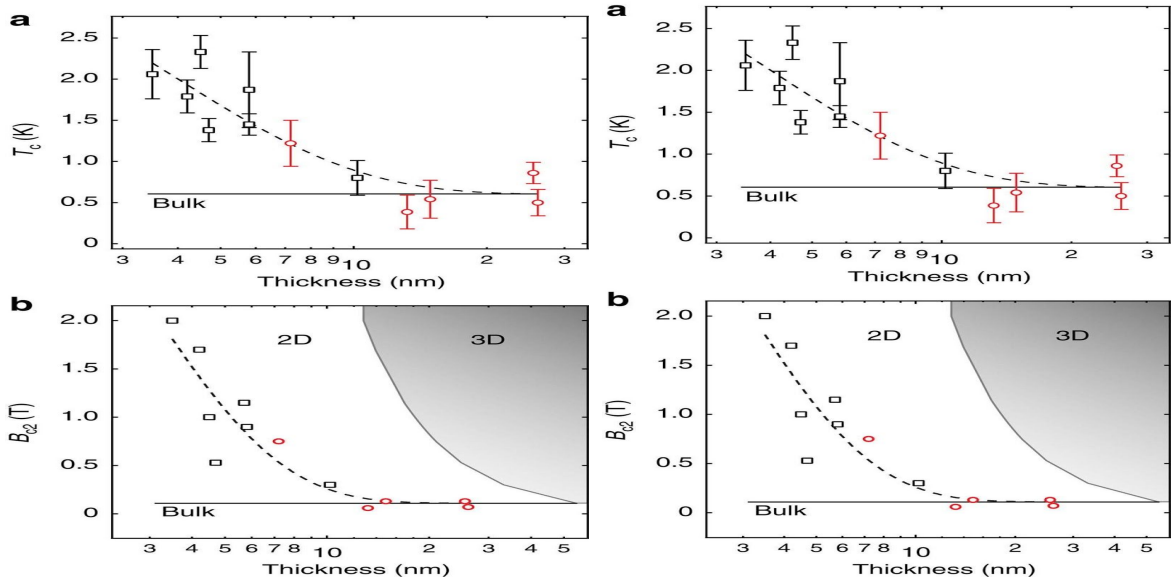

Figure 1: (a) Variation of T_c as a function of the thickness of the TaS_2 flakes. Devices exhibiting a non-zero residual resistance below T_c are plotted in red. The error bars are given by the temperatures at 10 and 90% of the normal state resistance. The solid

black line marks the bulk T_c of 600 mK. The black dotted line is an exponential trend line, fit to the data starting at the bulk limit. **(b)** Variation of Bc_2 as a function of flake thickness. The red circles mark the same devices in **a** having residual resistance. The black solid line indicates the bulk limit upper critical field of 110 mT. The grey solid line plots the Ginzburg-Landau coherence lengths, calculated from the *y* axis B_{c2} values, and marks the edge of the 2D limit.

SPANISH ALLIANCE ON GRAPHENE
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Abstract

SPANISH ALLIANCE ON GRAPHENE

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During the last months, the Spanish Alliance on Graphene, has come into light as a result of the activities launched by Excellence network GRAPHENET. The association aims to represent the interests of the industrial group of graphene producers and end users in Spain. We will present the good praxis code, agreed by the main Spanish producers, for the labeling of graphene. Acceptance of the code is associated to the membership of graphene producers to the Alliance and will easy the path to the incorporation of graphene in the formulations and industrial processes.
However, the scope of the Alliance is not limited to the industrial partners and academic groups are also welcome, as we aim also to create synergies between both groups and also incorporatet he technological centers to the activity in 2D materials.
Information on the latest news on strategical calls will be also delivered.

Requirements for graphene-based devices

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Graphene and other 2D materials have attracted a huge interest from the research community due to their extraordinary properties. It is expected that these properties will be translated into industrial applications in the future. However, at present graphene is at a research stage and many technological challenges have been identified before graphene can become a commercial success. The integration of graphene into the semiconductor industry is one of these challenges and device fabrication is one of the most critical parts. In addition, the surrounding environment[1] such as the substrate, surface adsorbates and the atmosphere (air composition, humidity, etc.) have a large impact on the graphene. Therefore, most probably encapsulation might be required for the final product. The performance of graphene field effect devices (GFETs) was found to improve considerably using aluminum oxide as encapsulating layer on top of the graphene.[2] The GFETs had a very low hysteresis and much lower doping levels. In addition, a passivated graphene channel was integrated into a coplanar waveguide to make an optoelectronic mixer for radar and radio-communication systems.[3] The passivation of graphene devices was also demonstrated on a scale of 100mm where 500 GFETs were tested.[4]

Alternatively, a non-contact characterisation method would be ideal to electrically characterize the graphene material,[5] specially as a non-destructive quality control method for graphene.

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New trends in CVD methods for the synthesis of large-area bidimensional materials beyond graphene

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In the last years, an increasing interest in two dimensional materials beyond graphene is becoming apparent caused by the new possibilities of application that emerge from their outstanding electrical, optical and mechanical properties. In particular, most of the recent works in the field deal with issues as their band-gap tunning [1] and the tailored properties of heterostructures created by combining graphene, hexagonal boron nitride and/or transition metal dichalcogenides, (TDMCs) such as molybdenum disulfide or diselenide [2].

Up to the date, mechanical exfoliation has been the most widely used technique to obtain these heterostructures, presenting problems as poor repeatability, low throughput and high cost, which hinder the scalability of the process, being the synthesis of these materials with large area homogeneity a major challenge.

To overcome those problems, chemical vapor deposition has been repeatedly proposed for the synthesis of two-dimensional materials beyond graphene (see, for example [3]), given that it is a well established technique for the obtaining of the last. However, adapting this well-known method for the synthesis of other two-dimensional materials is not trivial, and often will require the modification of the systems employed to carry out the CVD growth.

Our aim is to review the main current challenges to grow these 2d materials by means of CVD, as well as the solutions proposed by Graphene Square Inc. to overcome them, which have been taken into account in the design of brand new scientific equipment optimized for this task.

Specifically, the custom-designed models which appear in Figure 1 will be presented, optimized for the synthesis of graphene, h-BN and TMDCs from chip to wafer-scale on various substrates by using gas-phase or solid precursors and metal organic sources.

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Figures

Figure 1: TCVD-RF100CA and TCVD-DC100CA for the synthesis of graphene, h-BN and TMDCs.

Graphene Related Materials from Grupo Antolin and their use for transport applications

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Graphene Related Materials obtained from GANF carbon nanofibres are being used by Grupo Antolin Ingeniería for developing different applications for transport industry. The automotive and graphene producer company is involved in different research projects with additional industrial partners related to aeronautics and automotive activities, and besides collaborating with several universities and research centers. A review of these projects is being presented.

Significant differences between graphene oxides obtained by oxidation of graphite (GO) and GANF carbon nanofibers (NGO) have been observed. XPS measurements demonstrated that chemical composition of graphene oxide obtained by oxidation of graphite and GANF nanofibers is quite different. The percentage of COOH groups attached to NGO is twice that for GO. Conversely, the percentage of hydroxyl or epoxy groups localized at the basal plane is higher for GO than for NGO. The nanoplatelet size and the surface electric charge also presented important differences. The nanosheet size was determined by SEM and Dynamic light scattering (DLS) while the surface electric charge was obtained by Zeta Potential measurements. Results demonstrated that graphene oxide sheets obtained from graphite are bigger and present higher surface electric charge than those synthesized from GANF carbon nanofibers[1,2].

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Synthesis of epitaxial graphene on SiC for electronic applications

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Decomposition of silicon carbide (SiC) at high temperatures [1] is an effective route to synthesize wafer-scale single-crystal graphene [2]. The underlying process in the surface graphitization of SiC is the preferential sublimation of Si atoms at high temperature (T), typically above T=1500ºC. Graphene nucleation, coupling with the buffer layer and morphology are strongly influenced by the experimental conditions and the intrinsic properties of the substrates, such as polar face, quality, miscut angle and doping. In this talk we will summarize several of our recent results for producing graphene on SiC based on previous research [2, 3]. Furthermore, we will present technological solutions such as ion implantation (see Figure 1) for bottom gating, opening new avenues towards the fabrication of graphene-based devices.

Figures

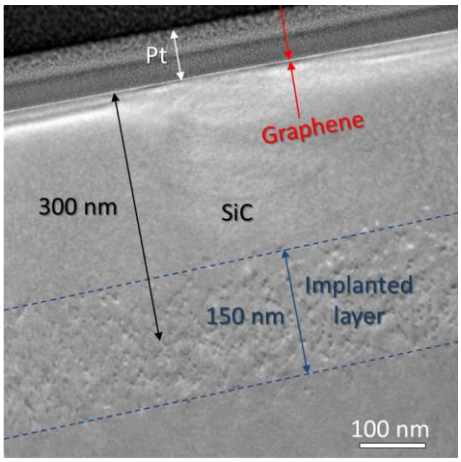

Figure 1: Cross-sectional transmission electron microscopy micrograph of a selected SiC sample covered with graphene, showing a buried conductive layer fabricated via ion (nitrogen) implantation.

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POSTERS

Electrical and optical properties of LSMO/ Monolayer MoS_2 photodiodes

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Two dimensional (2D) transition metal dichalcogenides (TMDs) and artificial van der Waals heterostructures made from these materials have been experimentally and theoretically investigated as promising candidates for novel photovoltaic and optoelectronic devices due to their excellent optical and electrical properties[1,2]. Very recently, many experimental efforts have been made on the fabrication and study of 2D-2D heterostructures,like for example MoS_2-WS_2 and graphene-MoS_2[3,4] and 2D-3D heterostructures, such as graphene-Si. Nevertheless, the interaction between two dimensional material and transition metal complex oxides has not been largely investigated so far. In this work, we investigate heterostructures made of 3D lanthanum strontium manganite oxide (LSMO) and 2D monolayer MoS_2 and report their photodiode behavior.

Here, we report the photodiode behavior in LSMO (p type)/monolayer MoS_2 (n type) heterostructures fabricated by deterministic transfer of mechanically exfoliated flake and transfered to LSMO[5]. Under illumination, an obvious photocurrent (and photovoltage) is generated by the photovoltaic effect. The photocurrent and photoresponsivity are dependent both on the incident light wavelength and power density. The device displays short-circuit currents up to 0.4 nA and open-circuit voltages up to 400 mV. Measuring as a function of incident optical power density, we find that the open-circuit voltage and short-circuit current depend linearly and logarithmically, respectively, on power density, confirming an ideal photodiode behavior.

In conclusion, we have investigated the electrical and optoelectronic properties of LSMO/monolayer MoS_2 heterostructures. Our work may benefit to the integration of two-dimensional materials with metal complex oxides. This might contribute to developments in the area of van der Waals heterostructures and it will provide novel applications in electronics and optoelectronics.

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FABRICATION OF HYBRID SYSTEMS: SUSPENDED GRAPHENE / SUPERCONDUCTOR

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Motivated by the growing interest in topological superconductors, in this work we are developing a suspended graphene / superconductor hybrid system. In these systems, being in contact with a superconducting material. (Nb), graphene acquires superconducting properties due to the proximity effect [1].

Our hybrid systems consist on a graphene flake suspended over a superconducting bridge. The graphene flakes (figure 1A) have been obtained by mechanical exfoliation and characterized by Raman spectroscopy. The superconducting bridge is fabricated using electron beam lithography, optical lithography and DC magnetron sputtering. To improve the electrical contact between the superconducting Niobium bridge and the graphene flake, we have deposited a capping layer of Palladium [2]. Atomic force microscopy and scanning electron microscopy are used in order to choose the more suitable nanofabrication process. Preliminary electrical characterization is shown (figure 1B).

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Figures

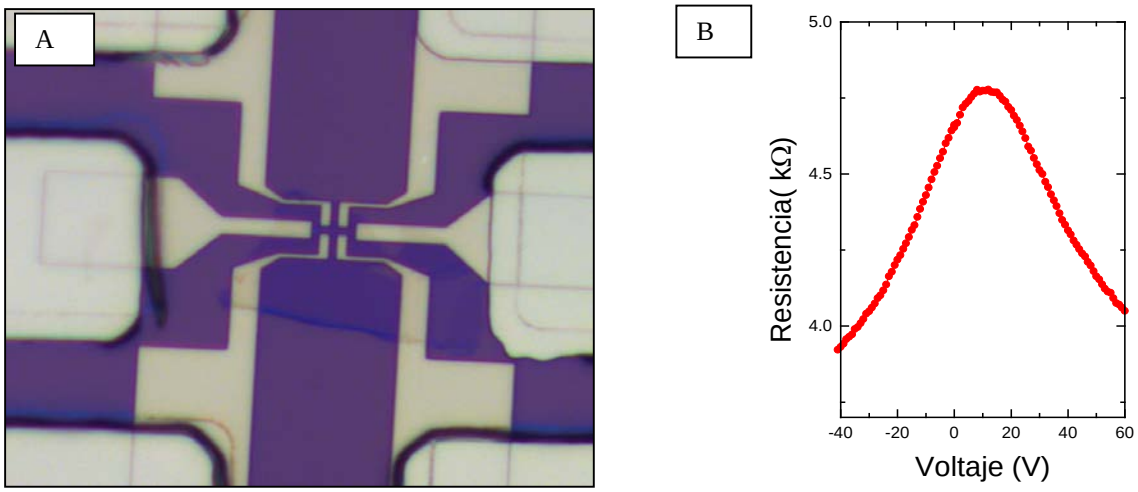

Figure 1. A) Optical image of a graphene flake on PDMS. B) Resistance vs gate voltage of a suspended graphene flake over the bridge at room temperature.

Fabrication of Lumped Element Kinetic Inductance Detectors for millimeter and sub-millimeter Astronomy

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Space instrumentation is a crucial aspect for advances in Astrophysics and Cosmology. The new space missions and ground-based telescopes require a new generation of detectors for achieving the needed sensibilities. In our work, we fabricated and characterized Lumped Element Kinetic Inductance Detectors, LEKIDs, designed for millimeter and sub-millimeter radiation sensing [1]. The LEKIDs are superconducting microresonators, with slightly different resonant frequencies, all coupled to a common feedline. The incidence of the incoming radiation breaks Cooper pairs in the superconductor, thus modifying the superconducting kinetic inductance and resistance of the resonators. This in turn changes the resonance properties, providing the detection mechanism of the sensors.

The kinetic inductance of the detectors, and hence their sensitivities, scales inversely proportional to the film thickness. Also, the geometrical configuration of the the geometrical configuration of the inductive meander lines(width, thickness and distance) provides the impedance seen by the incoming radiation which influences the optical coupling. These facts limit the devices design and fabrication developments are needed. Several demonstrators for space and earth-based observations have been fabricated, see Figure 1. Fabrication process includes DC magnetron sputtering with confocal configuration, laser and electron beam lithography and etching techniques. Preliminary cryogenic characterization demonstrates the optical sensitivity of our devices.

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Figure

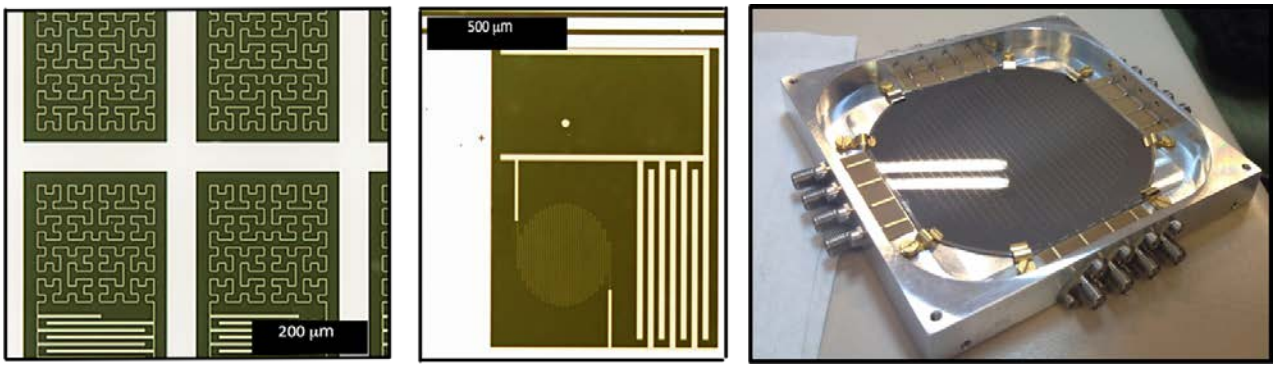

Figure 1: Some examples of the nanofabricated devices. The third picture is a NIKA2 1mm Array, fabricated by the typical NIKA process [2].

Graphene-based devices for bio-sensing platforms

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Biosensing systems became ubiquitous in recent years in medical and biomedical research, spanning a large range of health applications, from prognosis and/or diagnosis of diseases, to personalized medicine. The possibility of increased integration and miniaturization, often in microfluidic platforms, for mass production at economic cost, with enhanced performance (specificity, sensitivity and fast response) will pave the way for yet another boost in the use of biosensors in clinical practice and in point-of-care/point-of-use diagnosis and therapy.

The 2D carbon honeycomb lattice in graphene provides a surface of extreme sensitivity to electric fields and charges, thus suggesting its use for molecular detection based on electronic transducing. However, graphene high sensitivity and chemical stability comes at the cost of a poor analyte selectivity. Therefore, the fabrication of biosensors based on graphene interfaces requires surface functionalization. In this work, we immobilize probe molecules on CVD graphene surfaces for specific biorecognition of two important analyte types – antigens (proteins) and DNA. Two types of devices were fabricated: electrolyte-gated field-effect transistors (FETs), with a receded, integrated gate architecture (Fig.1A) and electrochemical microelectrode arrays (Fig.1B). The electrical signal in case of the graphene FETs is the shift in the Dirac point of the transfer curves, as a function of analyte concentration. Electrochemical detection is based on Electrochemical Impedance Spectroscopy and Cyclic Voltammetry measurements using 2 mM $Fe(CN)6^{3-/4-}$ redox probes. The devices were fabricated in the clean-room at the 200 mm wafer scale using standard photolithography technology [1].

A graphene immuno-FET is developed by immobilization of antibodies to specifically detect the biomarkers related with the hemorrhagic transformation of ischemic stroke. The probe immobilization is achieved via a pyrene-derivative linker, attached to the graphene surface via π-π interaction of the pyrene group and providing, at the other end of the molecule, a succinimidyl ester group that reacts with a primary amine from the protein antibody. The device was able to detect the biomarker (MMP-9) in concentrations down to 0.01 ng/mL, in a range up to 10 ng/mL. Compared with existing MMP-9 immunoassays our immuno-FET has similar or higher sensitivity and, because it is based on a much simpler label-free protocol than conventional methods, has a much shorter time to diagnostic [2].

The nucleic acid sensor is developed by immobilization of single-stranded DNA (25 nucleotides long) on the pyrene derivative-functionalized graphene transistor channel. Hybridization with complementary DNA (cDNA) was detected down to 1 aM, with a saturation attained at 100 fM and sensitivity to single nucleotide polymorphism (SNP). Graphene electrochemical sensors functionalized with the same DNA sequence (but without the linker) were successful in detection of cDNA in the range 5 pM to 50 nM with SNP sensitivity.

These results open the possibility for fabrication of sensors, using standard clean-room technology, with high sensitivity and low cost, that may be used in health, environment and food industries.

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Figures

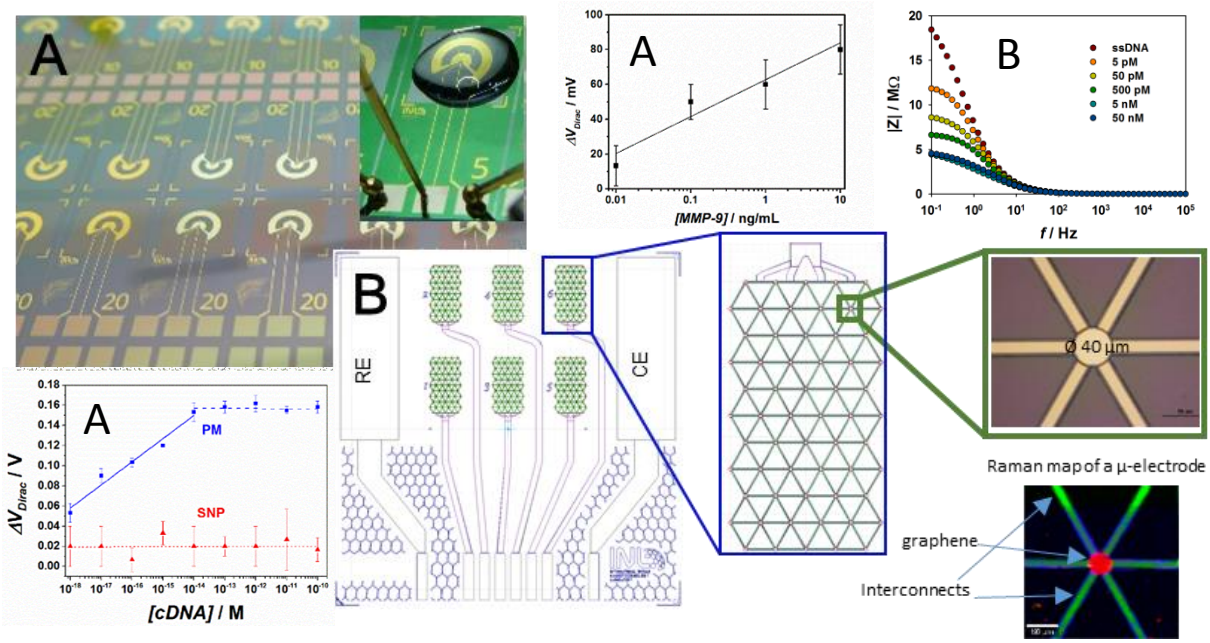

Figure 1:
Two types of devices were fabricated at the 200 mm wafer scale – A: Functionalized electrolyte-gated graphene FETs fabricated at 200 mm wafer scale were used to detect the protein biomarker MMP-9 and c-DNA, with attomolar detection limit and SNP sensitivity. B: Graphene on Au microelectrode arrays were used to detect DNA by EIS, with pM sensitivity.

Sub-Terahertz detection and imaging using Strained silicon FET

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The development of novel materials, concepts and device designs for the generation and detection of terahertz radiation using semiconductors [1] has recently fuelled the research of room temperature THz sensors. Plasma waves based transistors (PWT) with submicron gate length are under extensive investigations [2-4]. We investigated room temperature detection by using Strained Silicon Modulation field effect transistor. Experimental results show a good level of response to terahertz radiation at 300 GHz and 150 GHz (Fig.1). Competitive performance parameters were obtained (NEP and responsivity) in comparison with other detectors.

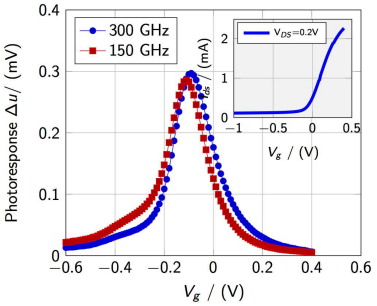

Fig1: Photoresponse vs. gate voltage under excitation of 150 GHz (red square) and 300 GHz (blue dotted) for Device with Lg=500nm. Inset shows the corresponding transfer characteristics

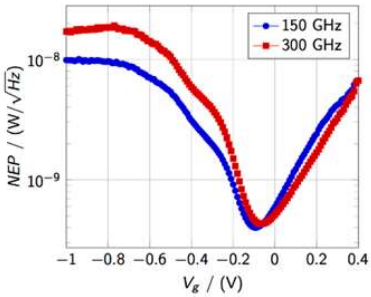

Fig.2: Noise equivalent power as a function of the gate voltage of Device with Lg=500nm and under different THz excitations: 150 GHz (blue dotted), 3000 GHz (red square), T=300K.

Enhancement of the photoresponse signal by imposing a dc drain-to-source current (I_{ds}) was observed experimentally and terahertz imaging features was demonstrated. A 2D numerical study was performed using Synopsys TCAD [5] to understand the response found in THz measurements. Simulation results show a non-resonant response in agreement with measurements showing a significant impact of the I_{ds} applied on the THz response. The bias current induces a large asymmetry degree in the boundary conditions of the plasma waves and, accordingly, a significant enhancement of the detector responsivity is observed [6].

Acknowledgments: This work was financially supported by the MINECO/FEDER Research Grant #TEC2015-65477-R and FEDER/Junta de Castilla y León Research Grant #SA045U16. Y.M. Meziani acknowledge the financial support from RIEC nation-wide Collaborative Research Project, Sendai Japan.

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Graphene characterization by THz-TDS spectroscopy

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Graphene is a revolutionary material with excellent properties making it one of the most promising materials for the development of new transistors, sensor or transparent devices [1-2]. It shows higher mobility at room temperature [3] which makes it an excellent candidate for THz-FETs devices [4]. There are several ways to produce graphene [5]. Graphene exfoliation is the best way to produce high quality graphene but it is inviable to produce it on an industrial scale. CVD graphene is an alternative towards production of high quality graphene for electronic applications at the industrial scale. Due to the difficulty of obtain high quality graphene samples, it is essential the use of non-contact characterization techniques for identification of the flakes and for mapping of the geometrical conductivity [6].

Terahertz Time Domain Spectroscopy (THz/TDS) is a new technique for material characterization in the Terahertz range. Terahertz (THz) radiation has several advantages: It's a non-invasive and non-ionizing radiation, many materials have unique fingerprints in the THz range, and it is possible to obtain images with relative good resolution. THz-TDS is a non-contact technique making it a promising technique for material characterization (conductivity, mobility, permittivity…) [7].

We report on room temperature THz-TDS characterization of graphene flakes obtained by CVD and exfoliated methods. Two band absorptions were found in both samples at approx. 0.5 THz and 1 THz (Figures 1 - 2). There is a good agreement between both results. Peaks are good defined, and cannot be identified as water absorption peaks.

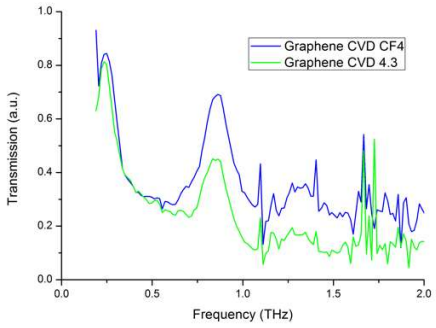

Fig 1. Transmission signal vs. frequency for different samples of Graphene CVD

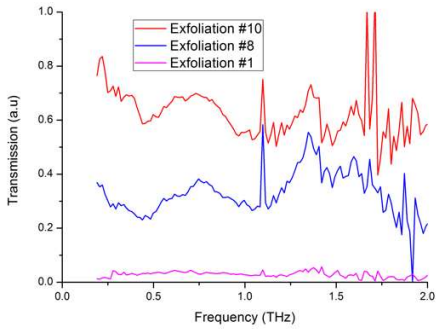

Fig 2. Transmission signal vs. frequency in exfoliated graphene.

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Raman Characterization of Graphene Oxide based heterostructures

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Graphene Oxide (GO) has recently become an attractive building block for fabricating graphene-based functional materials, this is because it possesses unique set of properties arising from oxygen functional groups that are introduced during chemical oxidation of the starting materials. GO is usually synthesized by oxidation of graphite or carbon nanofibers [1] by means of the Staudenmaier or the Hummers methods and it is often reduced by chemical agents [2] or thermal annealing [3] to restore the carbon lattice and to remove the structural defects and distortions.

Raman spectroscopy is an appropriate technique to study graphene based materials because the grade of defects, the crystallite size and the number of layers can be obtain from the first and the second order spectra. The Raman spectrum of GO presents two interbands in the region of 1000-1800 cm^{-1} related with crystallinity and edge defects [3]. In a previous work we have demonstrated that the position and intensity of these bands depend on the oxidation degree of GO and can be used to study the evolution of GO chemical structures during thermal annealing process. It is well stablished the effect of the substrate in the electronic properties of graphene. In order to prevent this effect an insulating material between the substrate and the flake of graphene must be used. Hexagonal boron nitride (hBN) is an isomorph of graphite composed of alternating B and N atoms in a honeycomb lattice. Because of its band structure, this compound is an insulating and relatively inert and makes it an excellent candidate to perform such as devices.

In this work, we present the fabrication and the Raman characterization of vertically stacked hBN-GO-hBN. The method to produce it is similar to that employed for graphene [4]. However, the main differences between the fabrication procedures are that the mechanical exfoliation of GO is carried out in presence of water and the flakes were deposited on a surface of PDMS instead of Si-SiO_2. The water induces the exfoliation of GO and prevents the cleavage of the flakes while PDMS favors the transference process. In order to remove the oxygen groups and to restore the carbon lattice of the GO, the heterostructure has been annealed from 100 to 1200 ºC.

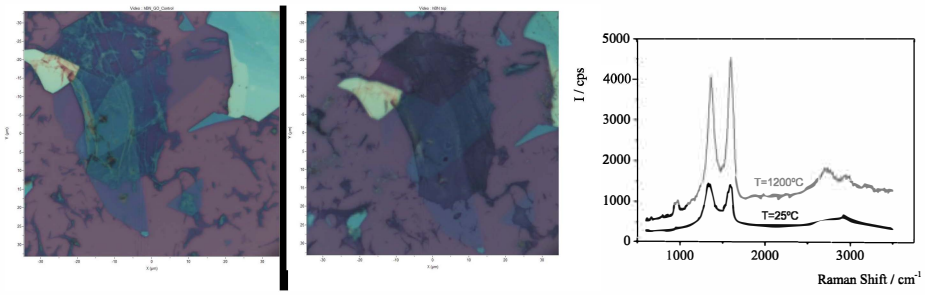

Figure 1. Optical Images of Graphene Oxide Heterostructure at room temperature (LEFT) and annealed at 1200 ºC (MIDDLE). Raman spectra of different heterostructures (RIGHT).

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