Nicolás Cabrera University Institute of Materials Science

Activity Report 2019

Universidad Autónoma de Madrid

Campus Internacional excelencia UAM CSIC

INSTITUTO NICOLÁS CABRERA

FACULTAD DE CIENCIAS

www.uam.es/inc

Cover: Herko van der Meulen

CONTENT

Welcome

Dear reader:

During the year 2019, we have organized the Nicolás Cabrera Summer School 2019 Isabel Guillamón, Leni Bascones and me. The Summer School has been a success, with great media impact, also thanks to the assistance of Pablo Jarillo Herrero. The BBVA Foundation has covered the event, issuing a press release with interviews to some prominent speakers. The School 2020 already has speakers of the highest prestige confirmed and the meeting promises to be a success.

It has been time to write this report in a very tense and sad situation, to which has been added the sudden death of our colleague and friend Professor Juan José Sáenz, one of the organizers of the 2007 Summer School. Juanjo (Mole) organized School XIV and we are already on XXVII.

When we return to normal, which will be very soon, we can hold the elections in accordance with our internal rules. This activity report will be the last with the current board. A few days ago, the agreement with FBBVA for the organization of colloquia and schools for the next three years was signed. We always appreciate the effort that FBBVA makes in the School, but we must also thank the perseverance of all the organizers of the Schools and the other activities of the Institute. Their enthusiasm and dedication to this activity are the most important ingredients for us to take advantage of and enjoy the School and the INC.

We all know the importance we place at the end of stories and perhaps it is worth remembering at this time the differences between experience and memory. The experience of all these years has been enormously fruitful, with many "happy endings" to remember, and we now only wish the best to the next board.

Hermann Suderow
Director of the INC

Nicolás Cabrera Summer School

The Nicolás Cabrera Summer School is celebrated annually since 1994 and has been supported by the BBVA Foundation's "Frontiers of Science and Technology" program since 2002.

The BBVA Foundation worked on the media coverage of the school, editing videos that can be seen at this link.

The 2019 Summer School, directed by Elena Bascones, Isabel Guillamón and Hermann Suderow, was entitled "Driving the road towards room temperature superconductivity with electronic interactions" on September 8-13, 2019 in Miraflores de la Sierra. The aim of the Summer School was to present a new overview of the state of the art in HTc superconductivity bringing together the main actors in the field. A panoramic view was provided and recent advances gained from experiments and theory were expanded. New developments in materials synthesis, new experimental probes with high resolution under extreme conditions and theoretical methods were discussed. These methods have found new clues to high-temperature superconductivity and had a major impact on materials science.

The School dealt with the following subjects:

- Materials, mechanisms and non-equilibrium properties
- Normal state properties: Nematicity, charge and spin density waves.
- Pairing in iron based superconductors.
- Correlations and superconductivity in twisted bilayer graphene.
- Pair density wave, pseudo gap and fluctuations in curates.
- Topological superconductors and odd pairing.
- Correlation in superconducting heavy fermions.

The school was held at the UAM residence "La Cristalera" where it takes place every year. A total of 69 people attended, from 12 different countries, 14 women and 55 men. In addition to 25 speakers and 3 organizers, the school has been attended by 41 postdoctoral students and researchers (only 22 of them with Spanish affiliation).

On this occasion, the format of the School chosen by the organizers, who have insisted on the speakers to explain the substance of the different themes and present their most recent activity, and the large number of experts who presented their most innovative activities, has been be very conducive to bringing out new aspects of research in the field. There is no doubt that the School has made a notable contribution to frontier research in the field, training the youngest and establishing new links between experts, who have discovered new ways of approaching their research.
As on other occasions, the quality of the talks has been accompanied by a high level of internationalization, the participation of post-doctoral researchers, the award of numerous scholarships so that students from all over the world can participate, and a notable media interest.

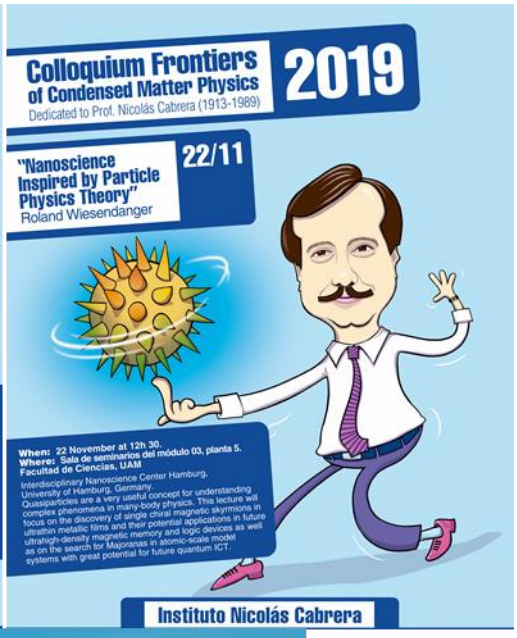
Group photo of the 2019 Nicolás Cabrera Summer School.

The list of speakers included:

- Annica BLACK-SCHAFFER. Uppsala University, Sweden.
- Greg S. BOEBINGER. National High Magnetic Field Laboratory, USA.
- Andrés CANO. Institut Neel, CNRS &UGA, France.
- Antony CARRINGTON. University of Bristol, UK.
- Amalia COLDEA. University of Oxford, UK.
- Andrey CHUBUKOV. University of Minnesota, USA.
- JC Seamus DAVIS. University of Oxford, UK.
- Dmitri K. EFETOV. Institute of Photonic Sciences, Barcelona, Spain.
- Claudio GIANNETTI. Univesitá Cattolica del Sacro Cuore, Brescia, Italia.
- Przemyslaw GRZYBOWSKI. ICFO and Adam Mickiewicz University, Poznań, Poland.
- Francisco GUINEA. IMDEA Nanociencia, Madrid, Spain.
- Stephen HAYDEN, University of Bristol, UK.
- Pablo JARILLO-HERRERO. Massachusetts Institute of Technology, USA.
- Bernhard KEIMER. Max Plank Institute for Solid State Research, Stuttgart, Germany.
- Eun-Ahn KIM. Cornell University, USA.
- Yuji MATSUDA. Kyoto University, Japan.
- Alexandre POURRET, Université Grenoble, France.
- Cyril PROUST, Laboratory of Intense Magnetic Fields-Toulouse, France.
- Teresa PUIG. Institute of Materials Science of Barcelona, Spain.
- Mohit RANDERIA, The Ohio State University, USA.
- Filip RONNING. Los Alamos National Lab, USA.
- Jörg SCHMALIAN. Karlsruhe Institute of Technology, Germany.
- Nandini TRIVEDI, The Ohio State University, USA.
- Belén VALENZUELA. Institute of Materials Science of Madrid, Spain.
- Peter WAHL. University of Saint Andrews, UK.
- Hai-Hu WEN. Nanjing University, China.

Colloquia

During 2019 we have continued the cycle of conferences "Frontiers of Condensed Matter Physics", in collaboration with FBBVA, dedicated to Professor Nicolás Cabrera. We have brought together three scientists that we have chosen due to the relevance of their recent activities and their projection. This year, Elke Scheer, “Visualizing the persistent response of driven oscillators”, Roland Wiesendanger, “Nanoscience inspired by particle theory” have participated in this initiative and Jukka Pekola, “Quantum thermodynamics and calorimetry in nano-electronic circuits”.
Professors, researchers and students agree in affirming that the scientific impact of the presentations of these speakers has been very outstanding, due to the current importance of the topic discussed, the relevance of the speakers on the subject and their availability.

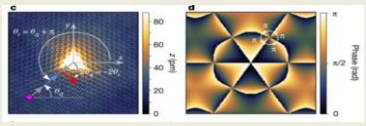


Science at INC

The articles of the INC are found on the website of the Institute. We mention below some publications that we wanted to highlight, for the magazine in which they have been published, and the theme.

Measuring the Berry phase of graphene from wavefront dislocations in Friedel oscillations. C. Dutreix, H. González Herrero, I. Brihuega, M. I. Katsnelson, C. Chapelier & V. T. Renard. Nature **574**, 219, (2019).

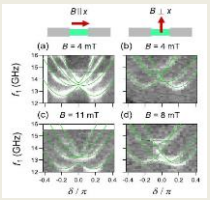
Electronic band structures dictate the mechanical, optical and electrical properties of crystalline solids. Their experimental determination is therefore crucial for technological applications. Although the spectral distribution in energy bands is routinely measured by various techniques, it is more difficult to access the topological properties of band structures such as the quantized Berry phase, gamma, which is a gauge-invariant geometrical phase accumulated by the wavefunction along an adiabatic cycle.



nature

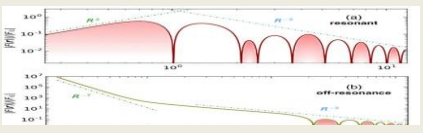
Spin-Orbit Splitting of Andreev States Revealed by Microwave Spectroscopy. L. Tosi, C. Metzger, M. F. Goffman, C. Urbina, H. Pothier, S. Park, A. Levy Yeyati, J. Nygard and P. Krogstrup. Physical Review X **9**, 011010, (2019). We perform microwave spectroscopy of Andreev states in superconducting weak links tailored in an InAs-Al (core-full shell) epitaxially grown nanowire. The spectra present distinctive features with bundles of four lines crossing when the superconducting phase difference across the weak link is 0 or pi. We interpret these features as arising from zero-field spin-split Andreev states.

PHYSICAL REVIEW X



Light Induced Inverse-Square Law Interactions between Nanoparticles: “Mock Gravity” at the Nanoscale. J. Luis-Hita, M. I. Marqués, R. Delgado Buscalioni, N. de Sousa, L. S. Froufe Pérez, F. Scheffold and J. J. Sáenz. Physical Review Letters **123**, 143201, (2019).

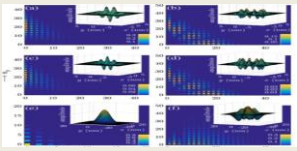
The interaction forces between identical resonant molecules or nanoparticles, optically induced by a quasimonochromatic isotropic random light field, are theoretically analyzed. In general, the interaction force exhibits a far-field oscillatory behavior at separation distances larger than the light wavelength. However, we show that the oscillations disappear when the frequency of the random field is tuned to an absorption Frohlich resonance, at which the real part of the particle's electric polarizability is zero.



Physical Review Letters
moving physics forward

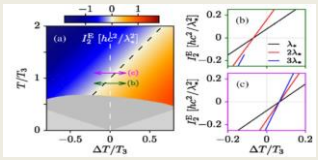
Quenching of Exciton Recombination in Strained Two-Dimensional Monochalcogenides. J.J. Esteve Paredes, S. Parkde, J.J. Palacios. Physical Review Letters **123**, 077402, (2019).

We predict that long-lived excitons with very large binding energies can also exist in a single or few layers of monochalcogenides such as GaSe. Our theoretical study shows that excitons confined by a radial local strain field are unable to recombine despite electrons and holes coexisting in space. The localized single-particle states are calculated in the envelope function approximation based on a three-band k. p Hamiltonian obtained from density-functional-theory calculations.



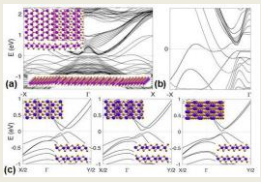
Nonequilibrium System as a Demon. Rafael Sánchez, Janine Splettstoesser and Robert S. Whitney. Physical Review Letters **123**, 216801, (2019).

Maxwell demons are creatures that are imagined to be able to reduce the entropy of a system without performing any work on it. Conventionally, such a Maxwell demon's intricate action consists of measuring individual particles and subsequently performing feedback. We show that much simpler setups can still act as demons: we demonstrate that it is sufficient to exploit a nonequilibrium distribution to seemingly break the second law of thermodynamics.



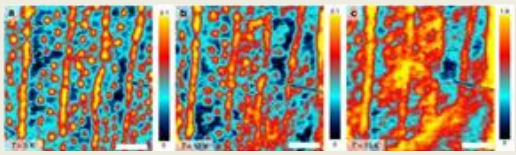
Laser-Beam-Patterned Topological Insulating States on Thin Semiconducting MoS2. H. Mine, A. Kobayashi, T. Nakamura, T. Inoue, S. Pakdel, D. Marian, E. González Marin, S. Maruyama, S. Katsumoto, A. Fortunelli, J. J. Palacios, and J. Haruyama. Physical Review Letters **123**, 146803, (2019).

Identifying the two-dimensional (2D) topological insulating (TI) state in new materials and its control are crucial aspects towards the development of voltage-controlled spintronic devices with low-power dissipation. Members of the 2D transition metal dichalcogenides have been recently predicted and experimentally reported as a new class of 2D T1 materials, but in most cases edge conduction seems fragile and limited to the monolayer phase fabricated on specified substrates.



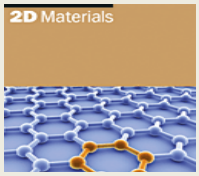
Attractive interaction between superconducting vortices in tilted magnetic fields A. Correa, F. Mompean, I. Guillamón, E. Herrera, M. García Hernández, T. Yamamoto, T. Kashiwagi, K. Kadowaki, A. I. Buzdin, H. Suderow & C. Munuera. Communication Physics **2**, 31, (2019).

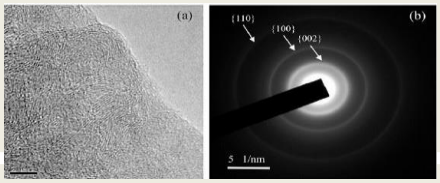
Many practical applications of high Tc superconductors involve layered materials and magnetic fields applied on an arbitrary direction with respect to the layers. When the anisotropy is very large, Cooper pair currents can circulate either within or perpendicular to the layers.



A fast synthesis route of boron-carbon-nitrogen ultrathin layers towards highly mixed ternary B-C-N phases. F. Leardini, N. Jimenez Arévalo, I. J. Ferrer, José Ramón Ares, Pablo Molina, Cristina Gómez Navarro, et al. 2D Materials **6**, 035015 (2019)

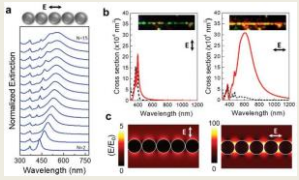
We report a direct and fast synthesis route to grow boron-carbon-nitrogen layers based on microwave-assisted plasma enhanced chemical vapour deposition (PECVD) by using methylamine borane as a single source molecular precursor. This easy and inexpensive method allows controlled and reproducible growth of B-C-N layers onto thin Cu foils.





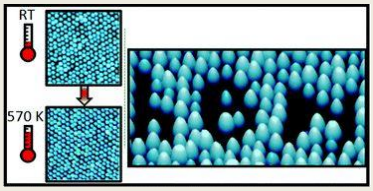
Hybrid Plasmonic-Ferroelectric Architectures for Lasing and SHG Processes at the Nanoscale. M. O. Ramírez, P. Molina, A. Gómez-Tornero, D. Hernández-Pinilla, L. Sánchez-García, S. Carretero-Palacios, L.E. Bausá. Advanced Materials, **31**, 1901428, (2019).

Coherent light sources providing sub-wavelength confined modes are in ever more demand to face new challenges in a variety of disciplines. Scalability and cost-effective production of these systems are also highly desired. The use of ferroelectrics in functional optical platforms, on which plasmonic arrangements can be formed, is revealed as a simple and powerful method to develop coherent light sources with improved and novel functionalities at the nanoscale.



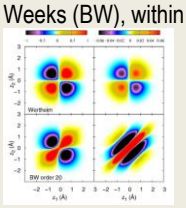
Pseudo-ordered distribution of Ir nanocrystals on h-BN. A. J. Martinez Galera and J. M. Gómez Rodriguez. Nanoscale **11**, 231, (2019)

A 2D material consisting of a pseudo-ordered distribution of Ir nanocrystals supported on a h-BN/Rh(111) surface is presented here. The particular spatial distribution of the Ir nanoparticles is achieved thanks to the existence of a large variety of adsorption positions within the pores of the h-BN/Rh(111) nanomesh template with hexagonal symmetry.



Structure factor of fluctuating interfaces: From liquid surfaces to suspended graphene. José Hernández-Muñoz, Pedro Tarazona, Rafael Ramírez, Carlos P. Herrero, and Enrique Chacón. Physical Review B **100**, 195424, (2019).

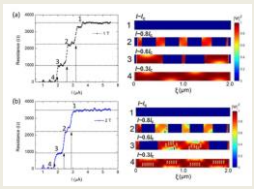
We obtain the density-density correlation structure in molecular dynamics (MD) simulations of graphene, and analyze it within the capillary wave theory (CWT), developed for fluid surfaces, to describe the thermal corrugations of the graphene sheet with a wave-vector-dependent surface tension gamma(q(x)). The density correlation function (from the atomic positions) is compared with the theoretical prediction by Bedeaux and Weeks (BW), within the CWT, in terms of gamma(q(x)) and the density profile.



Physical Review B
condensed matter and materials physics

Three-Dimensional Superconducting Nanohelices Grown by He+-Focused-Ion-Beam Direct Writing. R. Cordoba, D. Mailly, R. Rezaev, Ekaterina I. Smirnova, Oliver G. Schmidt, Vladimir M. Fomin, Uli Zeitler, Isabel Guillamón, Hermann Suderow and José Mª De Teresa. Nano Letters, **19**, 8597 (2019).

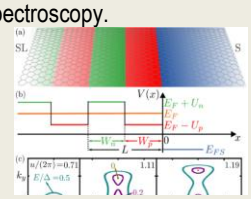
Novel schemes based on the design of complex three-dimensional (3D) nanoscale architectures are required for the development of the next generation of advanced electronic components. He focused-ion-beam (FIB) microscopy in combination with a precursor gas allows one to fabricate 3D nanostructures with an extreme resolution and a considerably higher aspect ratio than FIB-based methods, such as Ga+ FIB-induced deposition, or other additive manufacturing technologies.



NANO LETTERS

Dirac point formation revealed by Andreev tunneling in superlattice-graphene/superconductor junctions. Shirley Gómez Páez, Camilo Martínez, William J. Herrera, Alfredo Levy Yeyati, and Pablo Burset.
Physical Review B **100,** 205429 (2019)

A graphene superlattice is formed by a one-dimensional periodic potential and is characterized by the emergence of new Dirac points in the electronic structure. The group velocity of graphene's massless Dirac fermions at the new points is drastically reduced, resulting in a measurable effect in the conductance spectroscopy.



Physical Review B
condensed matter and materials physics

Young researchers meeting

The Young researchers meeting 2019 took place in December in Miraflores de la Sierra with the participation of INC doctoral students at the La Cristalera residence. During the conference, the “Young researchers prize in materials science” award was presented, which this year, by decision of the jury, has received the first prize in Laura Sánchez García for her work “Plasmon-induced dual-wavelength operation in a Yb3 + laser ”Carried out in collaboration with Mariola O. Ramírez, Rosa María Solé, Joan J. Carvajal, Francesc Díaz and Luisa E. Bausá, and published in Light: Science & Applications 8, 14 (2019). The second and third prize remained deserted.

The jury, appointed by the INC Management Committee and made up of professors D. Herko van der Meulen, Dª. Francesca María Marchetti and D. Alfredo Levy Yeyati, met on December 16, 2019 to propose, among the participants and based on the regulations of the awards, the winning candidates.

During the day the following conferences were also presented:

- *"Adenovirus major core protein condenses DNA in clusters and bundles, modulating genome release and capsid internal pressure", Natalia Martin González (Dpto. de Física de la Materia Condensada)*
- *"Optoelectronic tweezers for water and aqueous bio-droplets manipulation: moving, trapping, splitting and merging", Andrés Puerto (Dpto. de Física de Materiales)*
- *"Incorporation of Ge and S into wide band-gap kesterite for solar cells", Andrea Ruíz Perona (Dpto. de Física Aplicada)*
- *"Straintronics in 2D materials", Invited talk* Andrés Castellanos-Gómez (Instituto de Ciencia de Materiales de Madrid)
- *"Quenching of Exciton Recombination in Strained Two-Dimensional Monochalcogenides", Juan Esteve-Paredes (Dpto. de Física de la Materia Condensada)*
- *"From quantum anomalous Hall phases to topological metals in interacting decorated honeycomb lattices", Manuel Fernández (Dpto. de Física Teórica de la Materia Condensada)*
- *"Ultrathin transparent B-C-N layers grown on titanium substrates with excellent electro-catalytic activity for the oxygen evolution reaction", Nuria Jiménez-Arévalo (Departamento de Física de Materiales)*
- *"Impedance spectroscopy in optoelectronic devices", Alba Díaz-Lobo (Dpto. de Física Aplicada)*
- *"Interfacial Spin-Orbit Coupling: New Platform for Superconducting Spintronics", César González-Ruano (Dpto. de Física de la Materia Condensada)*

A poster session was also organized, which was very lively.

Prizes for undergraduate students

The Nicolás Cabrera Institute, and the departments of Condensed Matter Physics, Theoretical Physics of Condensed Matter, Materials Physics, Applied Physics and the Center for Condensed Matter Physics, in order to attract physics students to the groups of Research and disseminating the scientific work of the Institute, awarded eight prizes for students of physics, who carry out research work. Students worked at the Institute. Some of these students are already working in the Institute's laboratories. The students who won the award are:

- Gañán Mora, Antonio: "*Propiedades ópticas de colorantes orgánicos caracterizadas mediante STM*".
- Fernández García, Alejandro: "*Síntesis de óxido de tungsteno soportado mediante el método de SOL-GEL*"
- Tabares López, Cristián: "*Microscopía de Fuerza Atómica*"
- Agüi Salcedo, Santiago: *"Ultracold Polarized Fermi gases"*
- Gómez Gutierrez, Mario: *"Transporte electrónico en nano-hilos semiconductores con contactos superconductores"*
- Melero Martínez, Paula: "*Novel nanostructures for diagnosis of cardiovascular system"*
- Matute Fernández Cañadas, Francisco Jesús: *"Andreev spin qubits"*
- Ivañez Ballesteros, Pilar: *"Transferencia radiactiva de calor"*

Publications

P. Mateos-Gil, P. Tarazona, M. Velez: *Bacterial cell division: modeling FtsZ assembly and force generation from single filament experimental data.* FEMS microbiology reviews **43**, 73, (2019).

N. Akhtar, G. Anemone, D. Farias, et al: *Fluorinated graphene provides long lasting ice inhibition in high humidity.* Carbon **41**, 451, (2019).

C. Rodriguez, A. Muñoz Noval, V. Torres Costa, et al: *Visible Light Assisted Organosilane Assembly on Mesoporous Silicon Films and Particles.* Materials **12**, 1, (2019).

M. Moratalla, J. Gebbia, M.A. Ramos, et al: *Emergence of glassy features in halomethane crystals.* Physical Review B **99**, 024301, (2019).

D. Moreno-Cerrada, C. Rodriguez, F. Moreno-Martín, et al.: *Loading the dice: The orientation of virus-like particles adsorbed on titanate assisted organosilanized surfaces.* Biointerphases **14**, 011001, (2019).

L. Tosi, C. Metzger, M. F. Goffman, et al: *Spin-Orbit Splitting of Andreev States Revealed by Microwave Spectroscopy.* Physical Review X **9**, 011010, (2019).

A. J. Martinez Galera, J.M. Gómez Rodriguez.: *Structural and Electronic Properties of 3,4,9,10-Perylene Tetracarboxylic Dianhydride on h-BN/Rh(110).* Journal of Physical Chemistry C **129**, 1866, (2019).

P. Hofmann, M. Ugeda, A. Tamtogl, et al: *Strong-coupling charge density wave in a one-dimensional topological metal.* Physical Review B **99**, 035438, (2019).

L. Sánchez García, M.O. Ramirez, R.M. Solé, et al: *Plasmon-induced dual-wavelength operation in a Yb3+ laser.* Light-Science & Applications **8**, 14, (2019).

N. Nicoara, J. M. Gómez-Rodriguez, J. Mendez *Growth of PTCDA Films on Various Substrates Studied by Scanning Tunneling Microscopy and Spectroscopy* Physica Status Solidi B-Basic Solid State Physics **256**, 1800333, (2019).

P. Pellacani, V. Torres-Costa, F. Agulló Rueda, et al.: *Laser writing of nanostructured silicon arrays for the SERS detection of biomolecules with inhibited oxidation.* Colloids and Surfaces B-Biointerfaces **174**, 174 (2019).

E.A.A. Pogna, A. I. Chumakov, C. Ferrante, et al: *Tracking the Connection between Disorder and Energy Landscape in Glasses Using Geologically Hyperaged Amber.* Journal of Physical Chemistry Letters **10**,427, (2019).

A. J. Martinez Galera, J. M. Gomez Rodriguez: *Pseudo-ordered distribution of Ir nanocrystals on h-BN* Nanoscale **11**, 231, (2019).

C. Morales, A. Black, F. J. Urbanos, et al*:* *Study of the Interface of the Early Stages of Growth under Quasi-Equilibrium Conditions of ZnO on Graphene/Cu and Graphite.* Advanced Materials Intervaces **6**, 1801689, (2019).

G. Anemone, A. Al Taleb, G. Benedek, et al: *Electron-Phonon Coupling Constant of 2H-MoS2(0001) from Helium-Atom Scattering.* Journal of Physical Chemistry C **123**, 3682, (2019).

E. Floresa, S. Yoda, C. Morales, et al: *Pyrite thin films on amorphous substrates:*

Interaction with the substrate and doping effects.
Thin Solid Films **672**, 138, (2019).

R. Avriller, I. R. Seoane Souto, A. Martin Rodero, et al.:
Buildup of vibron-mediated electron correlations in molecular junctions.
Physical Review B **99**, 121403, (2019).

J. Diez Albar, M. Jimenez Sanchez, J. M. Gomez Rodriguez:
Nanowriting with Clusters on Graphene on Ru (0001).
Journal of Physical Chemistry C **123**, 5525, (2019).

T. Jonckheere, J. Rech, A Zazunov, et al.:
Giant Shot Noise from Majorana Zero Modes in Topological Trijunctions.
Physical Review Letters **122,** 097003, (2019).

M. Gonzalez Pinto, J. Renner, D. de las Heras, et al:
Defects in vertically vibrated monolayers of cylinders.
New Journal of Physics **21,** 033002, (2019).

A. Correa, F. Mompean, I. Guillamon, et al:
Attractive interaction between superconducting vortices in tilted magnetic fields.
Communication Physics **2,** 31, (2019).

L. Chirolli, E. Prada, F. Guinea, et al:
Strain-induced bound states in transition-metal dichalcogenide bubbles.
2D Materials **6,** 025010, (2019).

H. González Herrero, E. Cortes del Rio, P. Mallet, et al:
Hydrogen physisorption channel on graphene: a highway for atomic H diffusion
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