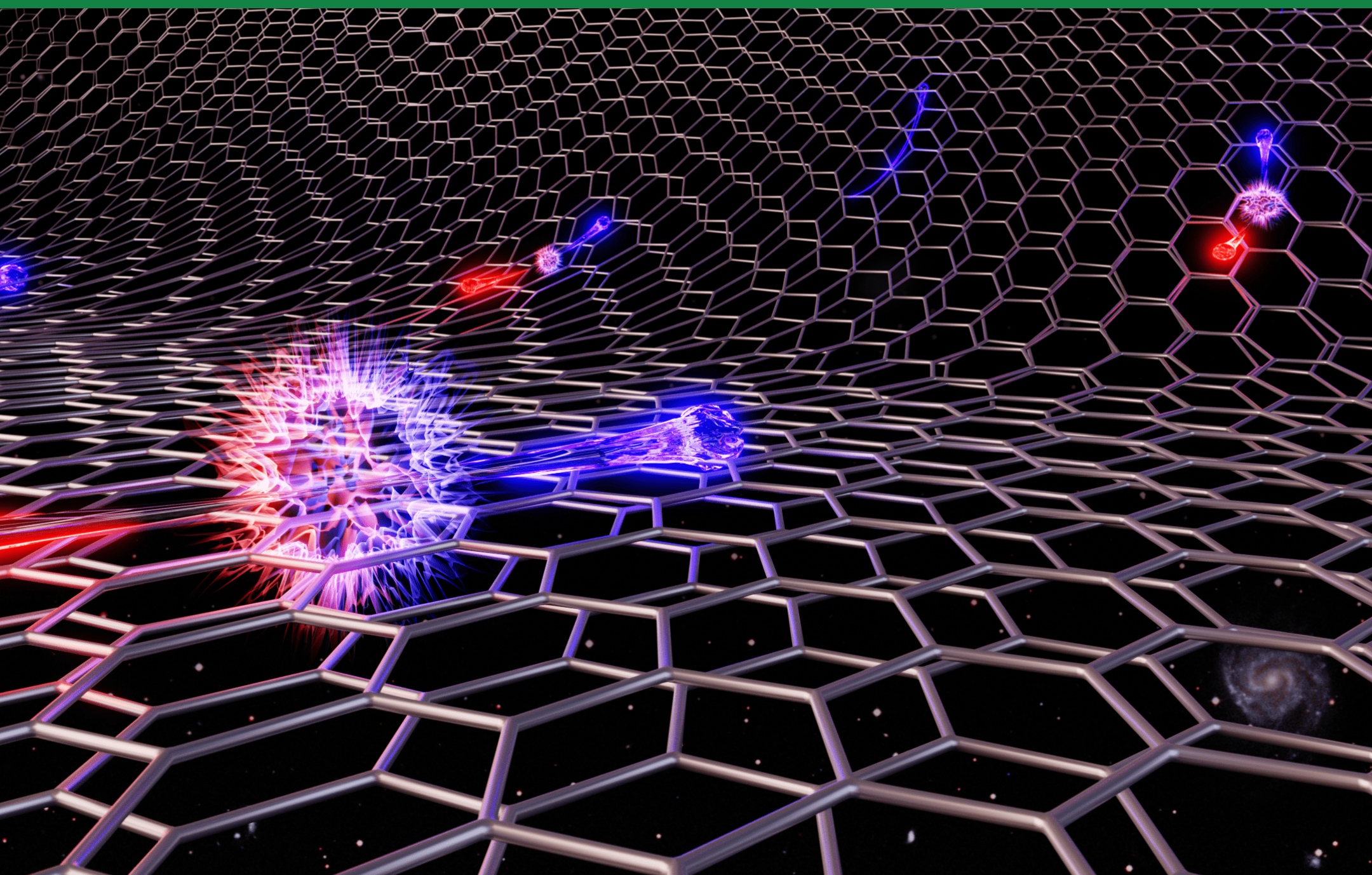
ICFO International School on the Frontiers of Light

New Horizons in Quantum Materials

27-30 June, 2022

Barcelona



Student talks
Monday 27 June, 16:30-18:00

1.Arpit Arora *Nanyang Technological University, Singapore*	Quantum metric plasmons: The role of quantum geometry in intrinsic bulk non-reciprocal plasmonics
2.Jonathan Atteia *University of Duisburg-Essen, Germany*	Beating Fabry-Pérot interference pattern in a magnonic scattering junction in the graphene quantum Hall ferromagnet
3.Subhajit Sinha *Tata Institute of Fundamental Research, India*	Berry curvature dipole senses topological transition in a moire´ superlattice.
4.Viviane Zurdo Costa *University of Maryland, USA*	Giant Effects of Interlayer Interaction on Valence-Band Splitting in Transition Metal Dichalcogenides
5.Luiz Gustavo Mendonça *Aeronautics Institute of Technology, Brazil*	Engineering of Excitons in transition metal dichalcogenides double monolayer heterostructures
6.Cristina Magdalena Vaca *Yachay Tech University, Ecuador*	Electronic and transport properties of graphene decorated with alkali metals
7.Katya Fouka *Leiden University, The Netherlands*	Can we employ disorder to filter topological Quantum Spin Hall Effect edge states?
8.Shroddha Mukhopadhyay *Polytechnic University of Catalonia, Spain*	Nonlinear conversion efficiency enhancement in gold grating nanostructure

1.Quantum metric plasmons: The role of quantum geometry in intrinsic bulk non-reciprocal plasmonics

Wavefunction engineering holds immense potential to reveal new possibilities in light-matter interaction. Here, we unveil one such possibility by illustrating a new class of plasmons – quantum metric plasmons (QMPs), in strongly interacting Fermi liquids. QMPs are intrinsically non-reciprocal, i.e., $\omega(q) \neq \omega(-q)$, in the bulk. This is in contrast to currently available schemes utilizing out of equilibrium driving or magnetohydrodynamics for non-reciprocal plasmonic responses. We show that QMPs are passively generated by bulk directional currents in presence of broken parity and time reversal symmetries. Interestingly, we find that QMPs can even thrive in symmetric bands by responding to the symmetry breaking order captured in wavefunction texture. We anticipate that QMPs can be realized in readily available parity-violating magnets, especially in moiré heterostructures where the quantum geometric responses are pronounced (e.g., twisted bilayer graphene heterostructures).

2.Beating Fabry-Pérot interference pattern in a magnonic scattering junction in the graphene quantum Hall ferromagnet

At filling factor $\nu=0,\pm1$, the ground state of graphene is a particular SU(4) ferromagnet which hosts a rich phase diagram along with several spin, pseudospin or ``entanglement'' magnon modes. Motivated by recent experiments, we study a $\nu=-1|0|-1$ Fabry-Pérot magnonic junction. If the ground state at $\nu=0$ is spin polarized, there exist two spin modes which interfere and create a beating pattern, while pseudospin modes are reflected. The same scenario occurs for pseudospin magnon if the $\nu=0$ ground state is pseudospin polarized. The observation of such an interference pattern would provide information on the low-energy anisotropies and thus on the ground state.

3.Berry curvature dipole senses topological transition in a moire´ superlattice.

Topological aspects of electron wavefunction play a crucial role in determining the physical properties of materials. Berry curvature and Chern number are used to define the topological structure of electronic bands. While Berry curvature and its effects in materials have been studied, detecting changes in the Chern number can be challenging, particularly changes in the valley Chern type. In this regard, twisted double bilayer graphene (TDBG) has emerged as a promising platform to gain electrical control over the Berry curvature hotspots and the valley Chern numbers of its flat bands. In addition, strain-induced breaking of the three-fold rotation (C_3) symmetry in TDBG, leads to a non-zero first moment of Berry curvature called the Berry curvature dipole (BCD), which can be sensed using the nonlinear Hall effect. We reveal, using TDBG, that the BCD detects topological transitions in the bands and changes its sign. In TDBG, the perpendicular electric field tunes the valley Chern number and the BCD simultaneously providing a tunable system to probe the physics of topological transitions.

References:
1. Sinha* and Adak* et al. (*: equal contribution), Nat. Phys., xx, (2022)

4.Giant Effects of Interlayer Interaction on Valence-Band Splitting in Transition Metal Dichalcogenides

Understanding the origin of valence band maxima (VBM) splitting in transition metal dichalcogenides (TMDs) is important because it governs the unique spin and valley physics in monolayer and multilayer TMDs. In this work, we present our systematic study of VBM splitting (Δ) in atomically thin MoS2 and WS2 by employing photocurrent spectroscopy. We found that VBM splitting in monolayer MoS2 and WS2 depends strongly on temperature, which contradicts the theory that spin−orbit coupling solely determines the VBM splitting in a monolayer TMD. We also found that the rate of change of VBM splitting with respect to temperature is the highest for monolayer (−0.14 meV/K for MoS2) and the rate decreases as the layer number increases (m ≈ 0 meV/K for 5 layers MOS2). Our density functional theory (DFT) and the GW with Bethe−Salpeter Equation GW-BSE) simulations agree with the experimental observations and demonstrate that the temperature dependence of VBM splitting in monolayer and multilayer TMDs originates from the changes in the interlayer coupling strength between the neighboring layers and substrates. We also found that VBM splitting depends on the layer numbers and the type of transition metals.

5.Engineering of Excitons in transition metal dichalcogenides double monolayer heterostructures

Two-dimensional materials, obtained from few-layers of van der Waals crystals, are still a growing research field as new crystals are synthetized and combined in complex heterostructures, making it a laboratory for novel phenomena in condensed matter physics, with soaring applications in technology due to electronic, optical, chemical and mechanical properties (to name a few). In particular, electron-hole bound states (excitonic states) in 2D semiconductors are very important when studying light-matter interactions, that plays an important role in optical devices. As composite bosons, excitons are susceptible to Bose-Einstein condensation, that was recently observed in double layers of transition metal dichalcogenides (TMDs). Double layers of TMDs can host both intralayer excitons and interlayer excitons. Intralayer excitons are similar to the monolayer ones, but are susceptible to the dielectric environment including the charge image effect of the opposite layer, and thus have a smaller binding energy. Interlayer excitons have an out-of-plane dipole moment and strongly depend on the separation distance between the layers.

Our work consists in the study of excitonic states (interlayer and intralayer) in Van der Waals bi-layered heterostructures to understand its properties with respect to dielectric media and layer separation using Chebyshev Polynomials as a basis for the exciton wave function to solve the Wannier Equation in the effective mass approximation and obtain physical quantities. For the electron-hole potential we solve the Poisson equation considering the double-layer geometry. We take advantage of recurrence properties of the Chebyshev Polynomials and also their simplicity to do semi-analytical kernel decompositions with fast convergence. We map out the dielectric and layer separations effects in the exciton binding energy, wave function and exciton Bohr radii to take in account the tunability of the bandgap of TMDs due to the dielectric environment, we calculate the exchange self-energy using the Semiconductor Bloch Equations (SBE) formalism, and with this result plus the binding energy we can predict the exciton energy position as function of the geometrical parameters of the system.

6.Electronic and transport properties of graphene decorated with alkali metals

A study of the effects of the adsorption of alkali metals in the transport properties of graphene, taking all the possible sites of adsorption, is essential to understand the storage mechanisms in carbon-based materials. In this work, we propose the analysis of the electronic and transport properties of graphene on alkali metals, Li and K, such as bands, the density of states, and conductance.

The configurations analyzed here are: a) Top site (on top of a carbon atom of the sublattice A of graphene), b) Hollow site (adatom in the center of the graphene hexagons), and c) Bridge site (adsorbate atom in the middle of the A-B bridge of the graphene carbon atoms). With this aim, we will use a tight-binding Hamiltonian model for p_z orbitals of graphene perturbed by the interaction with Li and K in the three mentioned inequivalent configurations. Then, we use Green's function equation of motion method to calculate the corresponding band structures and density of states. The numerical calculations to obtain the quantum conductance are performed with Kwant, the quantum simulation package of python. We find that the bands are up or down shifted with respect to pristine graphene, indicating doping with electrons. For the Top and Bridge cases, the AB symmetry breaking produced in this configuration generates small bandgaps. The bands of the Hollow sites show a downshifting of the Fermi level and preserve the Dirac cones nature from the pristine graphene. Finally, the perturbation of the Fermi velocities observed in the bands is translated to the V-shaped conductance, preserving its growth rate with the absolute value of the energy for pristine graphene.

7.Can we employ disorder to filter topological Quantum Spin Hall Effect edge states?

Quantum Spin Hall insulators are particularly attractive materials due to the intrinsic appearance of robust conducting surface states. They represent a new quantum state of matter and offer the potential of realizing dissipationless spin current devices, making them appealing from both a fundamental and applied point of view. In realistic devices, multiple such states co-exist at the surface, but only one pair can be considered ‘topologically’ protected from back-scattering. Thus, the desired robust pair is buried under ‘trivial’ conductance. Would the presence of disorder suppress the conductance of the trivial states, enabling us to capture the topological states? Studying the effect of disorder on the electronic transport of nanoribbons, we show that trivial conductance vanishes for strong enough disorder and topological protection survives even when a disorder-induced band gap closing occurs.

8.Nonlinear conversion efficiency enhancement in gold grating nanostructure

Metal nanostructures are known to exhibit light-matter interaction enhancement under a broad range of irradiation wavelengths by means of plasmonic resonances and have large-scale applications in imaging, sensing, solar cells, surface enhanced spectroscopy etc. Despite their high absorption in the visible and near infrared range, metals are highly nonlinear materials. Resonant metal nanostructures (nanolayers, gratings, nanoantennas or nanoparticles), can largely improve efficiencies of nonlinear optical processes like second and third harmonic generation (SHG and THG) from metal surfaces. At the nanoscale, the conventional approximations used in most of the theoretical models describing the light-matter interactions are not always applicable, so the surface and volume contribution to the nonlinear signal has to be revised.

Here we investigate the second and third harmonic generation and enhancement in the opaque region of a gold nano-grating designed to have a resonance at the fundamental wavelength around 800 nm. We present a combined experimental and theoretical approach based on a detailed microscopic hydrodynamic model that relies on temporal and spatial derivatives and accounts for competing surface, magnetic, and bulk nonlinearities arising from both free (conduction) and bound (valence) electrons. We measure the TM and TE components of the SH signal at 400 nm as a function of the fundamental beam polarization, tuning the fundamental wavelength around the resonance and compared with the predictions of out theoretical model. Experimental value of the relative enhancement induced by the grating with respect to SHG from a planar gold nanolayer gives an enhancement factor of 1000 at the central resonant wavelength, perfectly in agreement with the predictions of our model. The same model predicts a 500-enhancement factor for the THG with respect to the plain gold layer.

Student talks
Tuesday 28 June, 16:30-18:00

9.Shuai Fu *Max Planck Institute, Germany*	Ultrafast Charge Separation and Long-lived Photogating Effect at van der Waals Interfaces
10.Adewale Adejimi *Leibniz Institute of Photonic Technology, Germany*	Analysis of Brownian Motion of Nanoparticles using Imaging Flow Cytometry
11.David Barcons *ICFO, Spain*	Engineering high quality graphene superlattices via ion milled ultra-thin etching masks
12.Aaron Sternbach *Columbia University, USA*	Quenched excitons and charge transfer carriers in WSe2/RuCl3 heterostructures revealed by multi-messenger nanoscopy
13.Roshan Krishna Kumar *ICFO, Spain*	Extreme shift of the Fermi surface and schwinger-like pair production in graphene-based moiré superlattices
14.Alexander Senichev *Purdue University, USA*	Single-Photon Emitters in Silicon Nitride for Integrated Quantum Photonics
15.Giulia Piccinini *Scuola Normale di Pisa, Italy*	CVD-based twisted bilayer graphene
16.Lukman Kamarudin *International Islamic University, Malasya*	A High Sensitivity Electrically Tunable Fiber Bragg Grating Coated with Carbon Conductive Paint

9.Ultrafast Charge Separation and Long-lived Photogating Effect at van der Waals Interfaces

Vertically stacked van der Waals (vdW) heterostructures composed of graphene and transition metal dichalcogenides are of fundamental research interest and underpin many state-of-the-art optoelectronic applications. Interfacial processes, e.g., charge transfer (CT) and recombination in vdW heterostructures, play a critical role in determining device performance, yet have remained largely elusive.

Here, we investigate the interfacial processes between atomically thin layers on sub-picosecond timescales by using the graphene-WS2 vdW heterostructure as a model system. To this end, we complementarily measure the ultrafast photoconductivity change in graphene by terahertz (THz) spectroscopy and the excited-state dynamics in WS2 by transient absorption (TA) spectroscopy following photoexcitation. The unique combination of THz and TA spectroscopies allows us to independently track the nonequilibrium hot carrier dynamics in the graphene and excited state dynamics in WS2, and thus provides a comprehensive understanding of the interfacial processes. Depending on the excitation wavelength, either graphene or the entire heterostructure is excited. Accordingly, we observe a transition in CT efficiency and mechanism by tuning the pump photon energy across the A-exciton resonance of WS2. For sub-A-exciton excitation, a relatively inefficient (~1%) hot electron transfer from graphene to WS2 governs the CT process via photothermionic emission. In contrast, a relatively efficient (~5%) direct hole transfer from the valence band of WS2 to graphene occurs for above-A-exciton excitation. Following the CT process, we show that the injected or photogenerated electrons in WS2 can only occupy the excited states in WS2 for ~1 ps and get trapped in defect states for over ~1 ns. This results in a long-lived photogating effect in graphene. As such, our study demonstrated the bright side of defects: although typically detrimental to electrical devices, defects can be beneficial for optoelectronics. Our results unveil the complex interfacial dynamics at vdW interfaces, and provide new insights for further optimizing photodetector performance by e.g., defect engineering.

10.Analysis of Brownian Motion of Nanoparticles using Imaging Flow Cytometry

Brownian motion is a stochastic process that describes the random motion of suspended particles in a fluid. The velocity distribution of nanoparticles depends on their sizes, as smaller particles diffuse faster than larger particles. In return, information on these particle properties can be derived by tracking the displacement of individual particles on a pixel-to-pixel matching. In our work, we utilize imaging flow cytometry with darkfield transmission microscopy to measure the Brownian motion characteristics of individual gold nanoparticles in a particle cloud. The positions of all particles are measured for each frame with sub-pixel precision. Each nanoparticle is tracked over the field of view of a self-focusing microfluidic chip. The resulting displacement distribution profile can be measured and analysed using a statistical approach on both the single-particle level as well as for the entire particle cloud. Nanoparticles with a diameter of 250nm were observed over 800 individual frame-to-frame measurements. The Histogram distribution obtained fits the gaussian distribution, which confirms Brownian motion. The particle diameter was calculated from the derived diffusion coefficient. Our results are in good agreement with reference measurements obtained using Nanosight Nanoparticle Tracking Analyser.

11.Engineering high quality graphene superlattices via ion milled ultra-thin etching masks

The first observation of Hofstadter butterflies in graphene Moiré superlattices [1], and more recently, the discovery of superconductivity in MATBG[2], has attracted the community towards the study of these systems. Even though Moiré superlattices show very interesting phenomena, they lack basic tuning knobs, namely lattice symmetry and potential strength. Several groups have put effort in pushing nanofabrication techniques to engineer artificial graphene superlattices, but periods below 40 nm remain challenging [3-4].

We develop a new nanopatterning technique able to achieve sub-20 nm period lattices. Our technique combines He focused ion beam (FIB) indirect milling of suspended membranes with reactive ion etching (RIE), achieving ultimate FIB resolution and damage free patterning.

Employing this technique, we create artificial superlattices down to 18 nm period, approaching the length scales in MATBG.

Also, by engineering a non-bipartite superlattice (a Kagomé superlattice in our case), we demonstrate a clear electron-hole symmetry breaking in single layer graphene.

Our technique opens the path to engineer exotic phenomena in single layer graphene, with symmetries not accessible in Moiré superlattices and dimensions well below the state of the art in nanofabrication.

[1] Ponomarenko, L. A., et al. Nature, 497.7451, 594-597, (2013)
[2] Cao, Yuan, et al. Nature 556.7699, 43-50, (2018)
[3] Forsythe, Carlos, et al., Nature nanotechnology, 13.7, 566-571, (2018)
[4] Huber, Robin, et al., Nano letters 20.11, 8046-8052, (2020)

12.Quenched excitons and charge transfer carriers in WSe2/RuCl3 heterostructures revealed by multi-messenger nanoscopy

We investigate heterostructures composed of monolayer WSe2 stacked on RuCl3 using a combination of scanning tunneling spectroscopy (STS), broadband nano spectroscopy and nano-imaging from THz to visible frequencies and local photoluminesce (PL) spectroscopy. Our observations reveal itinerant carriers in the heterostructure prompted by charge transfer across the interface. Our experimental results are compared with density functional theory (DFT). Our local optical measurements show that the charge-transfer doping vanishes while excitonic resonances exhibit near-total recovery in 'nano-bubbles', where WSe2 and RuCl3 are separated by nanometer distances. The observed heterogeneous profiles of free and itinerant carriers underscore the utility of local spectroscopies.

13.Extreme shift of the Fermi surface and schwinger-like pair production in graphene-based moiré superlattices

In thermodynamic equilibrium, current in metallic systems is carried by electronic states near the Fermi energy, whereas the filled bands underneath contribute little to conduction. Here, we describe a very different regime in which carrier distribution in graphene and its superlattices is shifted so far from equilibrium that the filled bands start playing an essential role, leading to a critical-current behavior. The criticalities develop upon the velocity of electron flow reaching the Fermi velocity. Key signatures of the out-of-equilibrium state are current-voltage characteristics that resemble those of superconductors, sharp peaks in differential resistance, sign reversal of the Hall effect, and a marked anomaly caused by the Schwinger-like production of hot electron-hole plasma. The observed behavior is expected to be common to all graphene-based superlattices.

14.Single-Photon Emitters in Silicon Nitride for Integrated Quantum Photonics

Solid-state quantum emitters are fundamental resources for photon-based quantum information technologies. They can serve as on-demand single-photon sources, components of atomic memories, quantum repeaters, and quantum sensors. Scalable photonic platforms capable of hosting intrinsic or embedded sources of single-photon emission are of particular interest for the realization of integrated quantum photonic circuits. Our group has recently discovered bright, stable, linearly polarized, and high-purity sources of single-photon emission in nitrogen-rich SiN operating at room temperature [1]. We also develop an approach to realize planar waveguides made of low-autofluorescing SiN with intrinsic quantum emitters and demonstrate the single-photon emission coupling into the waveguide mode [2]. The observed emission coupling from these emitters is found to be in line with numerical simulations. The coupling of the single-photon emission to a waveguide mode is confirmed by second-order autocorrelation measurements of light outcoupled off the photonic chip by grating couplers. The results of our work pave the way toward the realization of scalable, technology-ready quantum photonic integrated circuitry efficiently interfaced with solid-state quantum emitters.

[1] A. Senichev, Z.O. Martin, S. Peana, D. Sychev, X. Xu, A.S. Lagutchev, A. Boltasseva, V.M. Shalaev, Room-temperature single-photon emitters in silicon nitride, Sci. Adv. 7, 50 (2021)
[2] A. Senichev, S. Peana, Z. O. Martin, O. Yesilyurt, D. Sychev, A. S. Lagutchev, A. Boltasseva, V. M. Shalaev, Silicon nitride waveguides with intrinsic single-photon emitters for integrated quantum photonics, arXiv:2205.08481 (2022)

15.CVD-based twisted bilayer graphene

Twisted bilayer graphene (TBG) is certainly the major driving force of the novel paradigm of twistronics, which aspires at understanding and engineering the emergent electronic properties of twisted two-dimensional materials.

On one hand, large twist-angles ensure electronic decoupling between graphene layers, giving the possibility to control the carrier distribution in each layer with double-gates, while on the other hand, small twist-angles lead to strong interlayer coupling, causing flat bands and correlated phases near the so-called magic angle.

In this work, we investigate both the large and small twist-angle regime, by using arrays of graphene crystals which are synthesized via chemical vapor deposition (CVD) on copper and which share the same orientation. CVD-based TBG simultaneously offer a deterministically-selectable twisting, a device-scale uniform twist angle, and an atomically-clean interlayer interface.

First, we employ dual-gated 30°-TBG to demonstrate simultaneous ultra-high mobility and conductivity, unattainable in a single-layer of graphene. We find quantitative agreement with a simple phenomenology of parallel conduction between two pristine graphene sheets, with a gate-controlled carrier distribution. Based on the parallel transport mechanism, we then introduce a method for in situ measurements of the chemical potential (μ) of the two layers. In particular, by keeping one of the layers charge-neutral, it is possible to probe μ in the other one with a resolution in the meV range (comparable to hBN-spaced structures). This twist-enabled approach, neither requiring a dielectric spacer, nor separate contacting, has the potential to greatly simplify the measurement of thermodynamic quantities in graphene-based systems of high current interest.

Then, we investigate small-angle TBG, manually assembled from separated CVD graphene single-crystals. Via low-temperature dual-gated magnetotransport we demonstrate the presence of a 2.4°-twisted superlattice. This is confirmed by the observation of density-independent Brown-Zak oscillations coexisting with multiple Landau fans at low temperature, and surviving up to tens of Kelvin. The existence of superlattice effects serves also as proof of high interface cleanness and twist-angle uniformity in CVD-based TBG.

16.A High Sensitivity Electrically Tunable Fiber Bragg Grating Coated with Carbon Conductive Paint

This project reports the development of a unique electrically tunable optical fiber Bragg grating (FBG) that is enabled by carbon conductive paint, which has high voltage responsiveness and only requires a simpler fabrication process. The carbon conductive paint-coated FBG attached to a metal electrode was used to apply voltage and induced heat and physical stress to the fiber. The wavelength shift of the fiber is proportional to the applied voltage in a linear fashion. The maximum voltage delivered to the devices was up to 5.0 V in the increasing and decreasing process to test its tunability criteria. The proposed sensor illustrated good voltage sensitivity by 0.98 nm/V and 0.92 nm/V for increasing and decreasing voltage, respectively. The FBG coated with carbon conductive paint resulted in as much as 7 nm wavelength shift when applied to voltage. This advanced electrical tunable sensor that has been proposed is exceptionally well suited for a wide variety of applications, including optoelectronic circuits and wavelength control waveguides.

Student talks
Wednesday 29 June, 16:30-18:00

17.Heng Zhang *Max Planck Institute, Germany*	Highly mobile hot holes in Cs2AgBiBr6 double perovskite
18.Dilan Israel Perez *Autonomous University, Spain*	Microscopic model for the charge transfer in graphene/WS2 van der Waals heterostructure
19.Alexandra Mestre Torà *ETH Zürich, Swiss*	Gate-defined ring in magic-angle twisted bilayer graphene
20.Matthew Feuer *University of Cambridge, UK*	Identification of Janus exciton complexes in a charge-tuneable WSeS monolayer
21.Anad Kumar *Friedrich Schiller University Jena, Germany*	Site Selective Fabrication of Single Photon Emitters in hexagonal-Boron Nitride
22.Majid Zahedian *University of Stuttgart, Germany*	Improving spin-photon entanglement via dynamic control
23.Michael Scheer *Princeton University, USA*	Magic angles in twisted bilayer graphene near commensuration: towards a hyper-magic manifold
24.Md Mahmudul Hasan *Vilnius University, Poland*	UV MR femtosecond laser-induced breakdown spectroscopy for various materials' chemical analysis

17.Highly mobile hot holes in Cs2AgBiBr6 double perovskite

Highly mobile hot charge carriers are a prerequisite for efficient hot-carrier optoelectronics requiring long-range hot carrier transport. Yet hot carriers are typically much less mobile than cold ones as a result of heightened carrier-phonon scattering. Here, we report enhanced hot carrier mobility in Cs2AgBiBr6 double perovskite. Following photo-excitation, hot carriers generated with excess energy exhibit boosted mobility, reaching a 4-fold enhancement compared to cold carriers at an excess energy of ~1.5 eV and a long-range hot-carrier transport length beyond 200 nm. By optical pump-IR push-Terahertz probe spectroscopy and frequency-resolved photoconductivity measurements, we provide experimental evidence that the conductivity enhancement originates primarily from hot holes which experience reduced momentum scattering compared to their cold states. We rationalize our observation by considering (quasi-)ballistic transport of thermalized hot holes with energies above an energetic threshold in Cs2AgBiBr6. Our findings render Cs2AgBiBr6 a fascinating platform for studying the fundamentals of hot carrier transport and its exploitation towards efficient hot carrier-based optoelectronic devices.

18.Microscopic model for the charge transfer in graphene/WS2 van der Waals heterostructure.

Van der Waals heterostructures exhibit fascinating electrical properties such as ultrafast charge separation after photoexcitation. Nonetheless, the fundamental understanding of charge transfer in these materials remains unclear. Here we present a microscopic many-particle model to reveal the relevant microscopic charge transfer channels in WS2-graphene heterostructures. Based on a tight binding description around the K symmetry points, we unveil the origin of the experimentally-measured charge-separated state. In particular, we reveal that the slow electron transfer can be traced back to the high energy barrier of this process and the fundamentally weak strength of this tunneling process. Finally, we discuss how to extend our model to describe charge transfer in the whole Brillouin zone. Such a description would allow us to investigate the importance of other charge-transfer channels that might become relevant with finite twist angles.

19.Gate-defined ring in magic-angle twisted bilayer graphene

We present a ring in magic-angle twisted bilayer graphene (MATBG) encapsulated in hexagonal boron nitride. Exploiting the high tunability of MATBG, we use three gates to electrostatically define a ring, which is presumably in a superconducting state. When applying a perpendicular B-field, B-periodic oscillations of the critical current through the ring are observed. The period matches the flux quanta of h/e when normalized to the inner radius of the ring. We discuss the origin of the oscillations and attempt to use the device to study the nature of superconductivity in MATBG.

20.Identification of Janus exciton complexes in a charge-tuneable WSeS monolayer

Janus transition metal dichalcogenides (J-TMDs) have different chalcogens on the two surfaces of the monolayer, which creates an inherent out-of-plane asymmetry. This provides an in-built electric field within a single monolayer and therefore holds the promise of generating long-lived, dipolar excitons while preserving bright, direct-bandgap optical transitions in a uniform potential landscape. Despite recent progress in fabricating high-quality J-TMDs, signatures of excitonic emission have thus far been limited to broad photoluminescence peaks resulting in ambiguous identification of the excitonic states. In this talk, I will present our work on the first integration of a WSeS J-TMD monolayer into a fully encapsulated, charge-controllable device. Encapsulation in hexagonal boron nitride results in the narrowest photoluminescence linewidths reported to date (< 10 meV at 4 K), while gate-dependent reflection contrast measurements allow for the unambiguous assignment of the neutral exciton and negatively charged exciton complexes. We measure a similar exchange energy splitting (7 meV) between the inter- and intra-valley negative trions as for conventional TMDs and the exciton g-factors we observe agree with those expected for direct-bandgap excitons at the K valleys. By identifying J-TMD exciton complexes via reflectance contrast and photoluminescence spectroscopy, this work lays the ground work for more mature optoelectronic applications, such as gas sensing and photo-voltaic energy harvesting.

21.Site Selective Fabrication of Single Photon Emitters in hexagonal-Boron Nitride

Single-photon emitters in solid-state systems have received a lot of attention as a potential building block for numerous quantum technology applications. The discovery of defect-based single-photon emitters in hexagonal-Boron Nitride (hBN) brings attention due to its fascinating optical and physical properties, such as a wide range of transition energy at room temperature and under ambient conditions. However, the localized placement of these emitters in the hBN lattice is still not very well understood and thus the integration of these emitters with optical and electronic platforms is still suffering from challenges. In present, we demonstrate the localization fabrication of defect-based color centers in hBN by electron beam irradiation using scanning electron microscopy with sub-micron lateral precision. Emitters based on the carbon complexes have been activated or de-activated by irradiation of electron beam. A density functional theory, coupled with an experimental emission line at 575 nm, reveals the presence of a carbon-based defect that is being activated at the emission line. Our results indicate that these emitters have a high statistical yield in the framework of deterministic fabrication, which is the most crucial step toward the realization of quantum integrated devices based on the quantum emitters in 2D materials

22.Improving spin-photon entanglement via dynamic control

The nitrogen-vacancy center in diamond is one of the well-studied color centers. It has two stable charge states, namely NV0 and NV- that allow selective excitation optically in low temperatures. A spin-photon entanglement scheme has been demonstrated with NV- charge state. A repump laser pulse at 575nm avoids the parasitic effect of the NV0 charge state. However, the repump pulse causes spectral diffusion of the excited state of NV- which lowers the rate and fidelity of the entanglement. This problem is solved via dynamic control of the NV center using FPGA (Field-Programmable Gate Array). In this case, not only the repump pulse is efficiently applied to cause less spectral diffusion but also making real-time decisions save time and enhance the rate of entanglement.

23.Magic angles in twisted bilayer graphene near commensuration: towards a hyper-magic manifold

The Bistritzer-MacDonald continuum model (BM model) describes the low-energy moir\'e bands for twisted bilayer graphene (TBG) at small twist angles. We derive a generalized continuum model for TBG near any commensurate twist angle, which is characterized by a complex inter-layer hopping at commensurate AA stackings (rather than the real hopping in the BM model), a real inter-layer hopping at commensurate AB/BA stackings, and a global energy shift. The complex phase of the AA stacking hopping and the twist angle together define a single angle parameter ϕ_0. We compute the model parameters for the first six distinct commensurate TBG configurations, among which the 38.2° configuration may be within experimentally observable energy scales. We identify the first magic angle for any ϕ_0 at a condition similar to that of the BM model. At this angle, the lowest two moir\'e bands at charge neutrality become flat (except in the vicinity of the $\bGamma_M$ point) and retain fragile topology, but lose particle-hole symmetry. We further identify a hyper-magic manifold in the parameter space at $\phi_0=\pm\pi/2$, where many moir\'e bands around charge neutrality (often 7 or more) become flat simultaneously. The lowest two moir\'e flat bands in the hyper-magic manifold have fragile (trivial) topology when close to (far from) the chiral limit with zero AA hopping.

24.UV and IR femtosecond laser-induced breakdown spectroscopy for various materials' chemical analysis.

The main purpose of this work is to find different parameters of various materials by UV (355 nm) and IR (1064 nm) femtosecond laser-induced breakdown spectroscopy and to analyze those values.