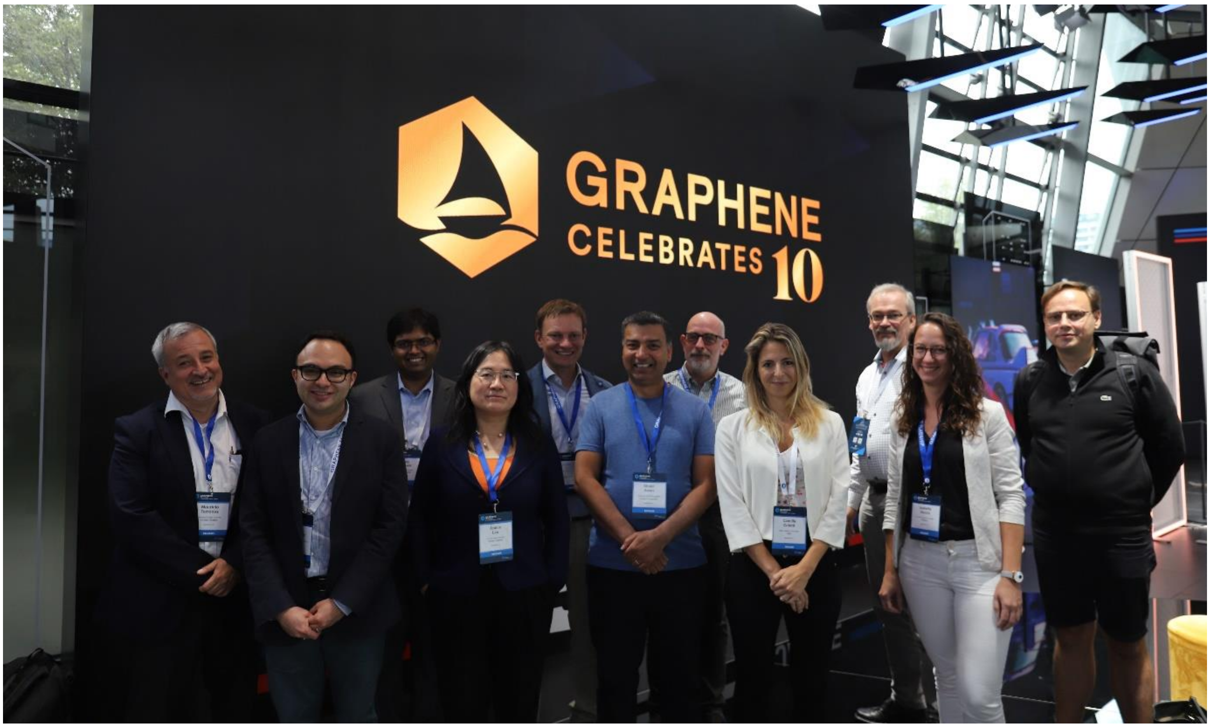
The 7th Graphene Flagship EU-US Workshop *on Graphene and related 2D materials*

BMW Welt, Munich (Germany)

9 September 2022



Workshop report

The 7th EU-US Workshop on Graphene and related 2D Materials was held on 9 September 2022 at the BMW Welt, Munich (Germany).

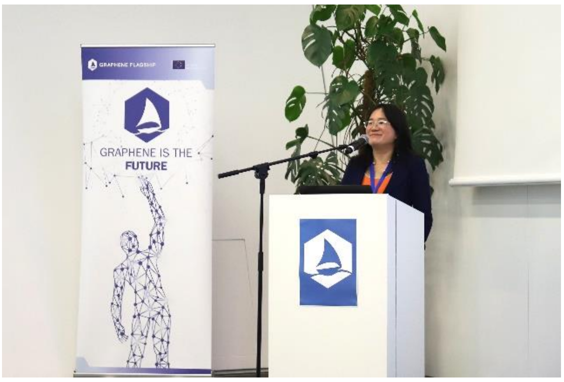
> **Workshop chairs:** Vladimir Falko (Manchester University, UK), Klaus Ensslin (ETH, Switzerland), Joshua Robinson (Pennsylvania State University, US), Mauricio Terrones (Pennsylvania State University, US)

The Workshop aimed at being an open forum to bring together leading researchers from the US and Europe to discuss cutting-edge research in graphene and related 2D materials, facilitating scientific exchanges and enhancing synergies within the community. The main objective of this workshop was to maintain interactions with overseas partners and continue to foster exchange of experiences, practices and ideas related to the current and emerging topics associated with the physico-chemical fundamentals involving materials synthesis and application development of graphene and related 2D materials in the fields of sensors, energy storage systems and opto-electronic devices.

This is a follow up to the US-EU Workshop held online on 12-14 May, 2021, in occasion of the annual "Graphene and Beyond: From Atoms to Applications" Workshop, which the Graphene Flagship co-organised with the 2D Crystal Consortium at Penn State University.

Overview of the workshop activities

The workshop has been organised in close connection to the Graphene Week 2022, half as part of the Graphene Flagship main conference and half in a close setting to foster discussions on future collaborations. As part of the Graphene Week 2022 conference programme, the first part welcomed the conference attendees. The second part of the workshop gathered about 15 participants, coming from different academic institutions.



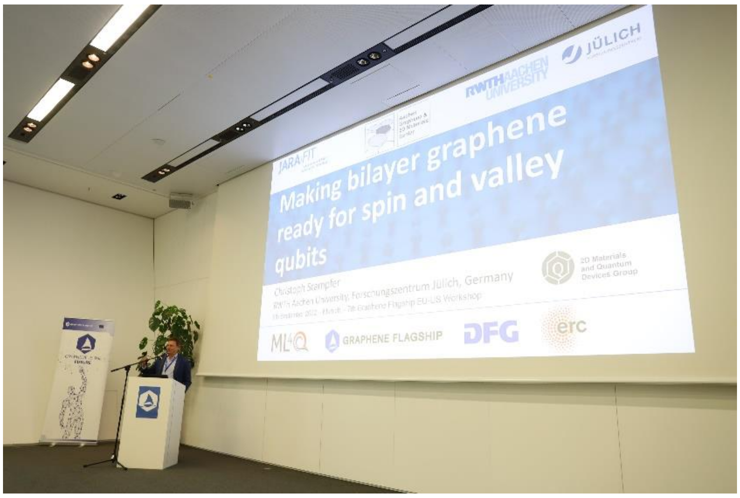
The workshop covered topics related to graphene and related materials fundamental characteristics, fine tuning of the materials' properties and applications in quantum technologies. The breath of the research involved in these areas is proven by the large variety of related subjects covered during the workshop, which included:

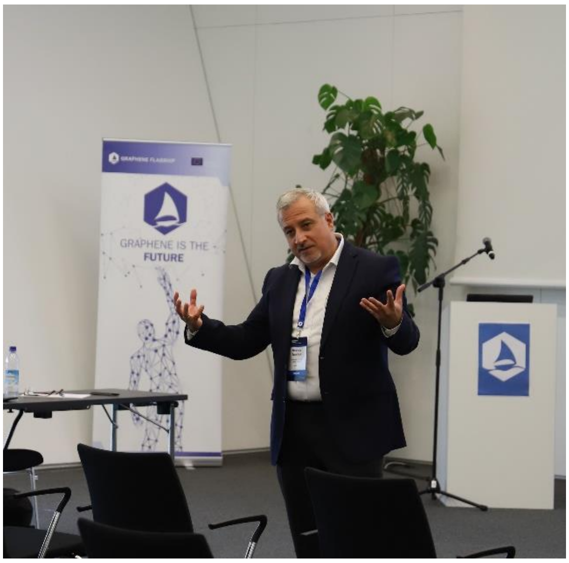
- Spin and valley qubits implemented by bilayer graphene
- Zeeman effects investigations
- Aberration-corrected HRSTEM studies of 2D materials to describe the catalytic effects of edges vacancies and local strain
- Doping and alloying in 2D material monolayers and relative applications in magnetism as well as in electronic transport
- Controlled generation of vacancies and defect engineering
- Elzerman technique to study the time dynamics of excited state via a capacitively coupled charge sensor in bilayer graphene
- Josephson junctions
- Graphene-based memory technology and spinorbitronics.

Overall, speakers gave 8 talks, four from each side, that have shown the excellent research and exciting results arising from the activity of each group involved. The selection of the scientific speakers was done by the two groups of organizers.

All presentations stimulated questions and discussions around perspective new projects and possibilities for future collaboration between the Graphene Flagship and the US partners.

Discussions were around how can Europe and the US collaborate involvoing 2D materials for the Chips and Science Acts in both reagions. The participants were agreed to review more information about possible funding opportunities for scientific exchanges. It was concluded that these type of meetings benefit both regions and they should continue in the future.





Programme

Indicated time corresponds to the Central European Summer Time (CEST) zone (Paris, Brussels time)

11:15 – 12:45	**Plenary session EU-US workshop (open to all Graphene Week conference participants) – Auditorium** *Chair*: Camilla Coletti	
11:15	Jairo Velasco	Giant Orbital Magnetic Moments in Trilayer and Monolayer Graphene
11:35	Mauricio Terrones	Defects in 2D materials: From Magnetism to Catalysis and Bioapplications
11:55	Klaus Ensslin	Quantum devices in graphene
12:15	Dmitri Efetov	Plethora of Many-Body Ground States in Magic Angle Twisted Bilayer Graphene
12:45 – 13:30	**Lunch**	
13:30 – 16:00	**Close session EU-US workshop (workshop delegates only) – Room BC1** *Chair*: Mauricio Terrones	
13:30	Deep Jariwala	Two-Dimensional Semiconductors for Low-Power Logic and Memory
13:45	Chun Ning (Jeanie) Lau	Two-Dimensional Semiconductors and Superconductors
14:00	Camilla Coletti	Twisted bilayer and few-layer rhombohedral graphene via chemical vapor deposition
14:15	Christoph Stampfer	Making bilayer graphene ready for spin and valley qubits
14:30 – 15:30	**Discussion on common challenges and collaborations** Moderators: Klaus Ensslin and Mauricio Terrones	
15:30	**Coffee break**	
16:00	**Workshop ends**	

List of speakers and participants

Title	Last name	First name	Institution	Country
Prof.	Terrones	Mauricio	The Pennsylvania State University	USA
Assoc. Prof.	Velasco	Jairo	Department of Physics University of California, Santa Cruz	USA
Assoc. Prof.	Jariwala	Deep	Department of Electrical and Systems Engineering University of Pennsylvania	USA
Prof.	Lau	Chun Ning	Ohio State University, Department of Physics	USA
Prof.	Ensslin	Klaus	ETH Zurich	Switzerland
Prof.	Kinaret	Jari	Chalmers University of Technology	Sweden
Prof.	Efetov	Dmitri	Ludwig-Maximilians-University of Munich	Germany
Prof.	Stampfer	Christoph	RWTH Aachen University	Germany
Dr.	Coletti	Camilla	Istituto Italiano di Tecnologia	Italy
Dr.	Brunel	David	THALES	France
Prof.	Dash	Saroj	Chalmers University of Technology	Sweden
Dr.	Motealleh	Azadeh	LayerOne AS	Norway
Dr.	Eqtesadi	Siamak	LayerOne AS	Norway
Dr.	Diamante	Letizia	Cambridge Graphene Centre	United Kingdom
Dr.	Vacchi	Isabella Anna	European Science Foundation	France

BOOK OF ABSTRACTS

<u>**Giant Orbital Magnetic Moments in Trilayer and Monolayer Graphene**</u>

Jairo Velasco
University of California Santa Cruz, Unites States

Short biography:

Jairo Velasco Jr. is an Associate Professor of Physics at the University of California Santa Cruz. His research interests include the study of electronic properties and structure of 2D materials. He received his PhD in physics from the University of California Riverside in 2012. He was then a University of California President's Postdoctoral Fellow in the Department of Physics at the University of California Berkeley from 2012-2015. Dr. Velasco is also a recipient of the NSF early CAREER award.

Abstract:

The harnessing and manipulation of electronic states in quantum materials has the potential to revolutionize computation, sensing, storage, and communications, thus impacting multiple facets of our everyday lives. In this talk I will discuss my group's recent experiments with trilayer graphene (TLG) and monolayer graphene (MLG), highly versatile carbon-based quantum materials with electronic properties that are promising for quantum information processing and quantum sensing. Specifically, I will focus on two sets of experiments that utilize confinement, nanoscale visualization, and spectroscopy to reveal new Zeeman effects based on topological and relativistic magnetic moments possessed by TLG and MLG surface states. In one experiment, we use point spectroscopy at the atomic scale to measure a giant and tunable topological magnetic moment for the electrons in TLG devices. [1]Because inversion symmetry is broken in TLG, the degenerate valley states in this system can be split through the coupling of the electron's topological magnetic moment with an external magnetic field. This enables a new avenue for quantum information processing and storage. In a second experiment, we use the scanning tunneling microscope to trap MLG electrons with high angular momentum in a circular quantum dot. We find these confined ultra-relativistic electrons also possess giant orbital magnetic moments that exhibit a Zeeman effect in response to an external magnetic field. This response can be leveraged for the development of a new type of magnetic field sensor. The results from our experiments advance fundamental understanding of carbon-based quantum material devices towards their potential use for future quantum technologies.

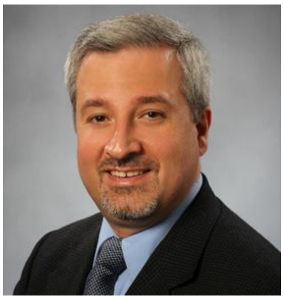
1. Ge, Z. et al. Control of Giant Topological Magnetic Moment and Valley Splitting in Trilayer Graphene. Physical Review Letters 127, 136402, doi:10.1103/PhysRevLett.127.136402 (2021)

Defect control in 2D materials: Magnetism, bio-applications and catalysis

Mauricio Terrones

Department of Physics, Department of Chemistry, Department of Materials Science and Engineering and Center for 2-Dimensional & Layered Materials. The Pennsylvania State University, United States

Short biography:



Mauricio Terrones, obtained his B.Sc. degree in Engineering Physics with first class honors at Universidad Iberoamericana, and was distinguished as the Best Student of Mexico in Engineering Physics in 1992. In 1994 he started his doctorate degree with Sir Prof. Harold W. Kroto (Nobel Laureate, FRS), and received his D.Phil. degree from University of Sussex in 1998. He has co-authored more than 600 publications in international journals, and counts with more than 75,000 citations to his work (His H index is 118; Google Scholar H=133). He has published in *Nature, Science, Phys. Rev. Lett., Nano Lett., Nature Nanotechnology, Nature Materials, Nature Communications, Nature Chemistry, ACS Nano, PNAS, Science Advances, etc.* Some of his accomplishments include: 1) Fellow of APS, AAAS, TWAS and RSC; 2) Highly Cited Researcher (WoS; 2017-present); 3) The Jubilee Professorship at Chalmers University of Technology (Sweden; 2016), 4) Visiting Fellow, Trinity College, University of Cambridge (UK; 2012), 5) "The Somiya Award for International Collaboration" (IUMRS; 2009), 6) "The Japan Carbon Award for Innovative Research" (Japan Carbon Society; 2008), 7) "TWAS Prize in Engineering Science," Academy of Sciences of the Developing World, 8) UNESCO-Javed Huasain Prize for Young Scientists and Albert Einstein Medal (France, 2001), 9) Alexander von Humboldt Fellowship, Max-Planck-Institut für Metallforschung (Stuttgart, Germany), 10) The Best Student of Mexico Award (Mexico, 1992).

He is Evan Pugh University Professor, the Verne M. Willaman Professor of Physics and Distinguished Professor of Physics, Chemistry and Materials Science & Engineering at Penn State University. He is also the Founder Director of the Center for 2-Dimensional and Layered Materials at Penn State, and the NSF-IUCRC Center for Atomically Thin Multifunctional Coatings (ATOMIC). He is also the Editor-in-Chief of the journal Carbon (IF=9.594). Mauricio works on 1- and 2-Dimensional materials, including carbon nanotubes, graphene, boron nitride and chalcogenide monolayers (e.g. WS2, MoS2, NbS2 , etc).

Abstract:

A long-standing puzzle in the field of Two-dimensional (2D) materials is the effect and understanding of different types of defects in their electronic, magnetic, catalytic and optical properties. In this talk an overview of different defects in TMD and hBN monolayers will be presented. We will emphasize doping and alloying in monolayers of MoS2, WS2, and WSe2 and describe their implications in magnetism, as well as in electronic transport. We will also describe the catalytic effects of edges, vacancies and local strain observed in hBN and MoxW(1-x)S2 monolayers by correlating the hydrogen evolution reaction (HER) with aberration corrected scanning transmission electron microscopy (AC-HRSTEM). Our findings demonstrates that it is now possible to use 2D materials for the fabrication of more effective catalytic substrates, however, defect control is required to tailor their performance. By studying photoluminescence spectra, atomic structure imaging, and band structure calculations, we also demonstrate that the most dominating synthetic defect—sulfur monovacancies in TMDs, is responsible for a new low temperature excitonic transition peak in photoluminescence 300 meV away from the neutral exciton emission. We further show that these neutral excitons bind to sulfur mono-vacancies at low temperature, and the recombination of bound excitons provides a unique spectroscopic signature of sulfur mono-vacancies. Finally, the electronic effects of C-H defects within TMDs will be discussed, as p-type doping could be controlled by the presence of C within TMDs.

References
[1] K. Fujisawa, et al. ACS Nano 15, 9658 (2021).
[2] F. Zhang, et al. Advanced Science 7, 24 (2020).
[3] F. Zhang, et al. PNAS 117, 19685 (2020).
[4] Y. Lei, et al. Materials Today 51, 108 (2021).

Quantum devices in graphene

Klaus Ensslin
ETH Zurich, Switzerland

Short biography:

Klaus Ensslin studied physics at the University of Munich and at ETH Zurich and obtained his PhD from the Max Planck Institute for Solid State Research in Stuttgart. He continued as a postdoc at the University of California in Santa Barbara and at the University of Munich. Since 1995 he is Professor at ETH Zurich. In 2010 be became director of the National Center of Research on "Quantum Science and Technology".
The research of Klaus Ensslin focuses on quantum effects in solid state system. How can small quantum systems be fabricated and experimentally controlled? How could quantum technology revolutionize our information society and other aspects of modern devices?

Abstract:

Electrostatically defined quantum dots in bilayer graphene offer a promising platform for spin qubits with presumably long coherence times due to low spin- orbit coupling and low nuclear spin density. We employ a capacitively coupled charge sensor to study the time dynamics of the excited state using the Elzerman technique. We find that the relaxation time of the excited state is of the order of milliseconds. We perform single-shot readout of our two-level system which is an important step for developing a quantum information processor in graphene.
We also present quantum devices fabricated on magic-angle-twisted bilayer graphene and demonstrate operation of a Josephson junction and a SQUID. This work was done in collaboration with Lisa Maria Gächter, Rebekka Garreis, Chuyao Tong, Max Josef Ruckriegel, Folkert Kornelis de Vries, Annika Kurzmann, Wister Wei Huang, Elias Portoles, Giulia Zheng, Peter Rickhaus, Shuichi Iwakiri, Takashi Taniguchi, Kenji Watanabe, and Thomas Ihn.

1. Chuyao Tong, Rebekka Garreis, Angelika Knothe, Marius Eich, Agnese Sacchi, Kenji Watanabe, Taka shi Taniguchi, Vladimir Fal'ko, Thomas Ihn, Klaus Ensslin, and Annika Kurzmann, "Tunable valley splitting and bipolar operation in graphene quantum dots", Nano Lett. 21, 1068 (2021)
2. Rebekka Garreis, Angelika Knothe, Chuyao Tong, Marius Eich, Carolin Gold, Kenji Watanabe, Takashi Taniguchi, Vladimir Fal'ko, Thomas Ihn, Klaus Ensslin, Annika Kurzmann, "Shell Filling and Trigonal Warping in Graphene Quantum Dots", Phys. Rev. Lett. 126, 147703 (2021)
3. F. K. de Vries, E. Portoles, G. Zheng, T. Taniguchi, K. Watanabe, T. Ihn, K. Ensslin, and P. Rickhaus, "Gate-Defined Josephson Junctions in Magic-Angle Twisted Bilayer Graphene", Nature Nano 16, 760 (2021)
4. P. Rickhaus, F. de Vries, J. Zhu, E. Portolés, G. Zheng, M. Masseroni, A. Kurzmann, T. Taniguchi, K. Wantanabe, A. H. MacDonald, T. Ihn, and K. Ensslin, "Correlated Electron-Hole State in Twisted Double-Bilayer Graphene", Science 373, 1257 (2021)
5. Annika Kurzmann, Yaakov Kleeorin, Chuyao Tong, Rebekka Garreis, Angelika Knothe, Marius Eich, Christopher Mittag, Carolin Gold, Folkert K. de Vries, Kenji Watanabe, Takashi Taniguchi, Vladimir Fal'ko, Yigal Meir, Thomas Ihn, Klaus Ensslin, «Kondo effect and spin-orbit coupling in graphene quantum dots», Nat. Comm. 12, 6004 (2021)
6. Chuyao Tong, Annika Kurzmann, Rebekka Garreis, Wei Wister Huang, Samuel Jele, Marius Eich, Lev Ginzburg, Christopher Mittag, Kenji Watanabe, Takashi Taniguchi, Klaus Ensslin, and Thomas Ihn, «Pauli Blockade of Tunable Two-Electron Spin and Valley States in Graphene Quantum Dots», Phys. Rev. Lett. 128, 067702 (2022)
7. Lisa Maria Gächter, Rebekka Garreis, Chuyao Tong, Max Josef Ruckriegel, Benedikt Kratochwil, Folkert Kornelis de Vries, Annika Kurzmann, Kenji Watanabe, Takashi Taniguchi, Thomas Ihn, Klaus Ensslin, Wister Wei Huang, «Single-shot readout in graphene quantum dots», PRX Quantum 3, 020343 (2022)
8. Elías Portolés, Shuichi Iwakiri, Giulia Zheng, Peter Rickhaus, Takashi Taniguchi, Kenji Watanabe, Thomas Ihn, Klaus Ensslin, and Folkert K. de Vries, «A Tunable Monolithic SQUID in Twisted Bilayer Graphene», arXiv:2201.13276

Plethora of Many-Body Ground States in Magic Angle Twisted Bilayer Graphene

Dmitri Efetov
LMU Munich, Germany

Short biography:

Prof. Dr. Dmitri K. Efetov (M) received a Diploma (M.Sc.) in Physics from ETH Zurich (CH) in 2007. Subsequently Dmitri earned a M.A., M. Ph. and Ph.D. in Physics from Columbia University (USA) in 2014, under the supervision of one of the pioneers of graphene Prof. Dr. Philip Kim, with a thesis titled "Towards inducing superconductivity into graphene". Dmitri then worked as a Postdoctoral Researcher at the Massachusetts Institute of Technology (MIT, USA) in the group of Prof. Dr. Dirk Englund, developing ultra-fast microwave thermometry and single photon detectors based on graphene. Since 2017 Dmitri was an Assistant Professor and Group Leader at ICFO (SP), and since 2021 is a Full Professor (W3) and Chair of Solid State Physics at LMU Munich (GER), with a research program that concentrates on the investigation of novel "moiré materials" at the intersection of condensed matter physics, optics and quantum science. Prof. Efetov received the Charles H. Towns Award for his outstanding research achievements during his PhD, the Obra Social "laCaixa" Junior Leader Fellowship, an ERC Starting Grant, was a finalist of the LaVanguardia Science Prize, for his ground-breaking discovery of new states in "magic" angle graphene and received the IUPAP Early Career Scientist Prize in Semiconductor Physics, for ground-breaking fundamental investigations of novel insulating, superconducting and topological phases in graphene based systems and their applications. He is the leader of the 2D-SIPC project in the EUs Quantum Technology Flagship, as well as a member of its Science and Engineering board. He also is a Core-Member of the Munich Center of Quantum Science and Technology and Head of the Quantum Technology Park Cleanroom of the Munich Quantum Valley.

Abstract:

Twist-angle engineering of 2D materials has led to the recent discoveries of novel many-body ground states in moiré systems such as correlated insulators, unconventional superconductivity, strange metals, orbital magnetism and topologically nontrivial phases. These systems are clean and tuneable, where all phases can coexist in a single device, which opens up enormous possibilities to address key questions about the nature of correlation induced superconductivity and topology, and allows to create entirely novel quantum phases with enhanced interactions. In this talk we will introduce some of the main concepts underlying these systems, concentrating on magic angle twisted bilayer graphene (MATBG) and show how symmetry-broken states emerge at all integer electron fillings [1]. We further will discuss recent experiments including screened interactions [2], Chern insulators [4], magnetic Josephson junctions [4], quantum criticality [5], re-entrant correlated insulators at high magnetic fields [6] and discuss some of the avenues for novel quantum sensing applications [7].

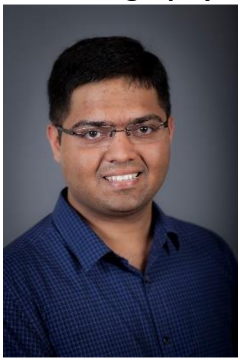
[1] Nature, 574, 653 (2019).
[2] Nature, 583, 375–378 (2020).
[3] Nature Physics, 17, 710 (2021).
[4] arXiv:2110.01067 (2021).
[5] arXiv:2108.07753 (2021).
[6] arXiv:2201.09260 (2021).
[7] arXiv:2111.08735 (2021).

Two-Dimensional Semiconductors for Low-Power Logic and Memory

Deep Jariwala

Department of Electrical and Systems Engineering, University of Pennsylvania, United States

Short biography:



Deep Jariwala is an Assistant Professor in the Department of Electrical and Systems Engineering at the University of Pennsylvania (Penn). Deep completed his undergraduate degree in Metallurgical Engineering from the Indian Institute of Technology Banaras Hindu University and his Ph.D. in Materials Science and Engineering at Northwestern University. Deep was a Resnick Prize Postdoctoral Fellow at Caltech before joining Penn to start his own research group. His research interests broadly lie at the intersection of new materials, surface science and solid-state devices for computing, opto-electronics and energy harvesting applications in addition to the development of correlated and functional imaging techniques. Deep's research has been widely recognized with several awards from professional societies, foundations and funding agencies as well as cited > 15000 times.

Abstract:

The isolation of a growing number of two-dimensional (2D) materials has inspired worldwide efforts to integrate distinct 2D materials into van der Waals (vdW) heterostructures. While a tremendous amount of research activity has occurred in assembling disparate 2D materials into "all-2D" van der Waals heterostructures and making outstanding progress on fundamental studies, practical applications of 2D materials will require a broader integration strategy. I will present our ongoing and recent work on integration of 2D materials with 3D electronic materials to realize logic switches and memory devices with novel functionality that can potentially augment the performance and functionality of Silicon technology. First, I will present our recent work on gate-tunable diode1 and tunnel junction devices2 based on integration of 2D chalcogenides with Si and GaN. Following this I will present our recent work on non-volatile memories based on Ferroelectric Field Effect Transistors (FE-FETs) made using a heterostructure of MoS2/AlScN3, 4 and I also will present our work on Ferroelectric Diode devices also based on thin AlScN.5

References:

1. Miao, J.; Liu, X.; Jo, K.; He, K.; Saxena, R.; Song, B.; Zhang, H.; He, J.; Han, M.-G.; Hu, W.; Jariwala, D. Nano Letters 2020, 20, (4), 2907-2915.
2. Miao, J.; Leblanc, C.; Liu, X.; Song, B.; Zhang, H.; Krylyuk, S.; Davydov, A. V.; Back, T.; Glavin, N.; Jariwala, D. arXiv preprint arXiv:2111.06396 2021.
3. Liu, X.; Wang, D.; Kim, K.-H.; Katti, K.; Zheng, J.; Musavigharavi, P.; Miao, J.; Stach, E. A.; Olsson, R. H.; Jariwala, D. Nano Letters 2021, 21, (9), 3753-3761.
4. Kim, K.-H.; Oh, S.; Fiagbenu, M. M. A.; Zheng, J.; Musavigharavi, P.; Kumar, P.; Trainor, N.; Aljarb, A.; Wan, Y.; Kim, H. M. arXiv preprint arXiv:2201.02153 2022.
5. Liu, X.; Zheng, J.; Wang, D.; Musavigharavi, P.; Stach, E. A.; Olsson III, R.; Jariwala, D. Applied Physics Letters 2021, 118, (20), 202901.

Two-Dimensional Semiconductors and Superconductors

Chun Ning (Jeanie) Lau
Department of Physics, The Ohio State University, United States

Short biography:

Chun Ning (Jeanie) Lau is a Professor in the Department of Physics at The Ohio State University. She received her BA in physics from University of Chicago in 1994, and PhD in physics from Harvard in 2001. She was a research associate at Hewlett Packard Labs in Palo Alto from 2002 to 2004, before joining University of California, Riverside in 2004 as an assistant professor. She was promoted to associate professor in 2009 and full professor in 2012. Starting 2017 she moved to The Ohio State University. The honors and awards she has received include the NSF CAREER award, the PECASE award, Kavli Fellow and APS Fellow. She currently serves as an Associate Editor at Nano Letters and ACS Nanoscience Au. Her research focuses on quantum phenomena and properties of quantum materials, in particular, graphene and other two-dimensional systems.

Abstract:

The interplay between quantum confinement, symmetries, spin-orbit interactions and electronic interactions gives rise to a rich variety of correlated phenomena in van der Waals heterostructures. Here I will present our recent works on this topic, including tunable transport of charges and Cooper pairs in quasi-1D topological insulators, tunable spin-orbit coupling in 2D semiconductors, and strongly renormalized band velocity and experimental evidence for strong-coupled superconductivity that is enabled by quantum geometry in twisted bilayer graphene.

Twisted bilayer and few-layer rhombohedral graphene via chemical vapor deposition

Camilla Coletti
[1]*Center for Nanotechnology Innovation @ NEST, Istituto Italiano di Tecnologia, Pisa, Italy*
[2]*Graphene Labs, Istituto Italiano di Tecnologia, Genova, Italy*

Short biography:

Camilla Coletti is a tenured Senior Scientist of the Istituto Italiano di Tecnologia (IIT) and principal investigator of the research line 2D Materials Engineering. She is the coordinator of the Center for Nanotechnology Innovation (CNI@NEST) of Pisa and of the Graphene Labs. She is in IIT since 2011 after being an Alexander von Humboldt postdoctoral fellow at the Max Planck Institute for Solid State Research of Stuttgart (Germany). She received her PhD degree from the University of South Florida in 2007 and her MS degree from the University of Perugia in 2004 (with honors, both in Electrical Engineering). She is expert in the synthesis of highly-crystalline 2D materials via chemical vapour deposition (CVD) and in the investigation of their electronic, chemical and structural properties. Her research is focused on: (i) synthesis and integration of scalable 2D materials for optoelectronics and photonics; (ii) engineering the interface and properties of 2D heterostructures. In her work she applies her background of surface scientist to impact science and technology of 2D materials. Since 2020 she is Faculty Board Member for the PhD in Nanoscience at the Scuola Normale Superiore (SNS) of Pisa and throughout the years she has been a university lecturer for several courses at the Master's and PhD level (University of Pisa, University of Genova, SNS) and a lecturer at Summer/Winter Schools. Overall, she is author of more than 150 peer-reviewed publications, edited 1 book, contributed to several book chapters, filed several international patents (holds 5) and delivered more than 50 invited talks at international conferences.

Abstract:

In this talk I will discuss synthetic approaches based on chemical vapor deposition (CVD) as well as deterministic assembly of CVD-graphene that allow one to obtain highly-crystalline twisted bilayer graphene as well as few-layer rhombohedral (ABC-stacked) graphene [1-4]. The properties of these materials in terms of twist angle homogeneity and electrical transport will be discussed.

References:
1. S. Pezzini, V. Miseikis, G. Piccinini, S. Forti, S. Pace, R. Engelke, F. Rossella, K. Watanabe, T. Taniguchi, P. Kim, C. Coletti, Nano Letters 20, 5, 3313–3319, (2020).
2. G. Piccinini, V. Mišeikis, K. Watanabe, T. Taniguchi, C. Coletti, S. Pezzini, Phys. Rev. B 104, L241410 (2021).
3. G. Piccinini, V. Miseikis, P.Novelli, K. Watanabe, T. Taniguchi, M. Polini, C. Coletti, S. Pezzini, Nano Letters 22, 13, 5252-5259 (2022).
4. C. Bouhafs, S. Pezzini, F.R. Geisenhof, N. Mishra, V. Mišeikis, Y. Niu, C. Struzzi, R.T. Weitz, A.A. Zakharov, S. Forti, C. Coletti, Carbon 177, 282-290 (2021).

Making bilayer graphene ready for spin and valley qubits

Christoph Stampfer
JARA-FIT and 2nd Institute of Physics, RWTH Aachen University, Germany
Peter Grünberg Institute (PGI-9), Forschungs-zentrum Jülich, Germany

Short biography:

Christoph Stampfer is Professor of Experimental Solid State Physics at the RWTH Aachen University and researcher at the Forschungszentrum Jülich. His primary interests include graphene and 2D materials research, quantum transport, and Raman spectroscopy. He holds a Dipl.-Ing. degree in Technical Physics from the TU Vienna (Austria) and a Ph.D. in Mechanical Engineering from the ETH Zurich (Switzerland). He was a PhD student in the Micro and Nano Systems group at the ETH Zurich from 2003 to 2007 and postdoc at the Solid State Laboratory (Ensslin-Group at ETH Zurich) from 2007 to 2009. From 2009 till 2013 he was JARA-FIT Junior Professor at the RWTH Aachen and the Forschungszentrum Jülich. He has been awarded with an ERC Starting Grant to work on "Graphene Quantum Electromechanical Systems" in 2011, was a member of the Young Scientist community of the World Economic Forum and received in 2018 an ERC Consolidator Grant to work on "2D Materials for Quantum Technologies". He is founding member of the Aachen Graphene & 2D Materials Center (www.graphene.ac) and he is also co-founder of phyphox (www.phyphox.org), a free physics App designed to improve science teaching on a global scale.

Abstract:

Graphene and bilayer graphene (BLG) are attractive platforms for quantum circuits with potential applications in the area of quantum information. This has motivated substantial efforts in studying quantum dot devices based on graphene and bilayer graphene. A major challenge in this context is the missing band-gap in graphene, which does not allow to confine electrons by means of electrostatics making displacement field-gapped BLG particularly interesting.
Here we present gate-controlled single and double quantum dots in electrostatically gaped BLG [1- 5]. We show a remarkable degree of control of our devices, which allow realizing electron-hole and electron-electron double quantum dot systems with single-electron occupation. In both, the single and double quantum dot devices, we reach the very few electron/hole regime, we are able to extract excited state energies and investigate their evolution in a parallel and perpendicular magnetic field. Finally, I will show data on BLG quantum dots allowing investigating the spin-valley coupling in bilayer graphene [4] as well as spin lifetimes [5]. Our work paves the way for the implementation of spin and valley-qubits in graphene.

References:

[1] L. Banszerus, B. Frohn, A. Epping, D. Neumaier, K. Watanabe, T. Taniguchi, and C. Stampfer, Nano Lett. 18, 4785 (2018)
[2] L. Banszerus, S. Möller, E. Icking, K. Watanabe, T. Taniguchi, C. Volk, and C. Stampfer, Nano Lett. 20, 2005 (2020)
[3] S. Möller, L. Banszerus, A. Knothe, C. Steiner, E. Icking, S. Trellenkamp, F. Lentz, K. Watanabe, T. Taniguchi, L. Glazman, V. Fal'ko, C. Volk, and C. Stampfer, Phys. Rev. Lett. 127, 256802 (2021)
[4] L. Banszerus, S. Möller, C. Steiner, E. Icking, S. Trellenkamp, F. Lentz, K. Watanabe, T. Taniguchi, C. Volk, and C. Stampfer, Nature Communications 12, 5250 (2021)
[5] L. Banszerus, K. Hecker, S. Möller, E. Icking, K. Watanabe, T. Taniguchi, C. Volk, and C. Stampfer, Nature Communications 13, 3637 (2022)