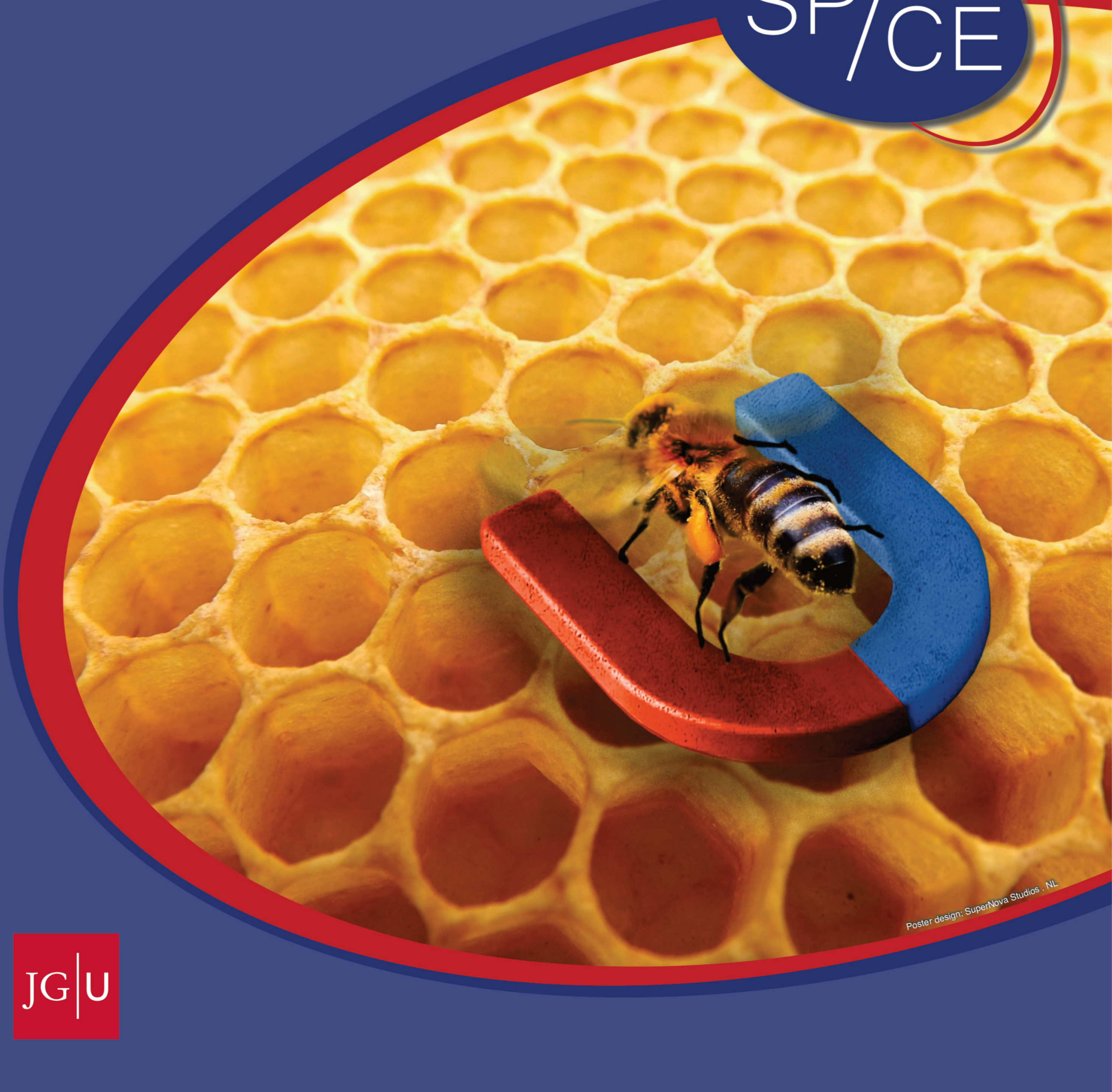
SPICE Online Workshop

August 4th - 7th 2020, Mainz, Germany

2D VAN DER WAALS SPIN SYSTEMS



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2D VAN DER WAALS SPIN SYSTEMS

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Speaker Abstracts

Tuesday, August 4th, 09:20

Magnon transport in 2D (anti-)ferromagnets

Bart VAN WEES
University of Groningen

In recent years it was demonstrated that magnons can be efficient transporters of spins, making new devices and functionalities possible with (insulating) magnonic systems. I will give an introduction into magnon spin transport in ferro/ferri/and anti-ferrro magnetic systems. I will discuss how charge current information can be transformed into (electronic) spin information by the spin Hall effect, which can then generate a magnon spin current in the ferrimagnetic insulators yttrium iron garnet (YIG) [1]. Magnon spins can then be detected via the inverse spin Hall effect, and converted back into a charge signal. These experiments have led to a better understanding of electrically and thermally induced magnon currents (spin Seebeck effect) and emphasize the role of the nonequilibrium magnon chemical potential as the driving force for magnon currents [2] Based on these concepts a magnon transistor geometry was fabricated in which the magnon density was controlled by a magnon injecting gate electrode [3]. It was also shown that magnons in antiferromagnets can effectively transport spins, and experiments demonstrated this in multi-layer 2D Van der Waals antiferromagnets[4] I will discuss our recent results on magnon spin caloritronics, including magnon spin Seebeck effect and anomalous Nernst effects, in CrBr3 based ferromagnetic van der Waals systems.

[1] J. Cornelissen et al., Nat. Phys. 11, 1022 (2015)
[2] J. Cornelissen et al., Phys. Rev. B94, 014412 (2016)
[3] J. Cornelissen et al., Phys. Rev. Lett. 120, 097702 (2018)
[4] Xing et al., Phys. Rev. X9, 011026 (2019)
[5] Liu et al., Phys. Rev. B 101, 205407 (2020)

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Tuesday, August 4th, 10:30

Spin transport in mangetic 2D materials and heterostructures

Wei HAN
Peking University

The two-dimensional (2D) van der Waals magnets have provided new platforms for exploring quantum magnetism in the flatland and for designing 2D ferromagnet-based spintronics devices.

In this talk, I will discuss the spin transport in magnetic 2D materials and their heterostructures. Firstly, I will discuss magnon-mediated spin transport in an insulating 2D van der Waals antiferromagnetic MnPS3. Long distance magnon transport over several micrometers is observed in quasi-2D MnPS3. The transport of magnons could be described using magnon-dependent chemical potential, and long magnon relaxation length of several micrometers are obtained. Then, I will discuss the spin transport in a metallic 2D van der Waals ferromagnetic Fe0.29TaS2 and its heterostructures. Via systematically measuring Fe0.29TaS2 devices with different thickness, it is found that the dominant AHE mechanism is skew scattering in bulk single crystal, and the contribution from intrinsic mechanism emerges and become more relevant as the Fe0.29-TaS2 thickness decrease. The spin-dependent scattering at the Fe0.29TaS2/superconductor interface will be also discussed, which reveals a large magnetoresistance that can be explained by the anisotropic Andreev reflection..

Tuesday, August 4th, 11:10

Spin-orbit torques based on topological spin texture and magnon

Hyunsoo YANG
National University of Singapore

Layered topological materials such as topological insulators (TIs) and Weyl semimetals are a new class of quantum matters with large spin-orbit coupling, and probing the spin texture of these materials is of importance for functional devices. We reveal spin textures of such materials using the bilinear magneto-electric resistance (BMR), which depends on the relative orientation of the current with respect to crystallographic axes [1,2]. We also visualize current-induced spin accumulation in topological insulators using photocurrent mapping [3]. Topological surface states (TSS) dominated spin orbit torques are identified in Bi2Se3 [4], and magnetization switching at room temperature using Bi2Se3 as a spin current source is demonstrated [5]. Nevertheless, the resistive nature of TIs can cause serious current shunting issues, leading to a large power consumption. In order to tackle this issue, we propose two approaches.

Weyl semimetals have a larger conductivity compared to TIs and they can generate a strong spin current from their bulk states. The Td-phase Weyl semimetal WTe2 can be produced with high quality, simplifying interfacial studies and facilitating device applications. Utilizing the magneto-optical Kerr microscopy, we show the current-driven magnetization switching in WTe2/NiFe with a low current density and a low power [6].

The current shunting issue can be also overcome by the magnon-mediated spin torque, in which the angular momentum is carried by precessing spins rather than moving electrons. Magnon-torque-driven magnetization switching is demonstrated in the Bi2Se3/NiO/Py devices at room temperature [7]. By injecting the electric current to an adjacent Bi2Se3 layer, spin currents were converted to magnon torques through an antiferromagnetic insulator NiO. The presence of magnon torque is evident for larger values of the NiO-thickness where magnons are the only spin-angular-momentum carriers. The demonstration reveals that the magnon torque is sufficient to control the magnetization, which is comparable with previously observed electrical spin torque ratios of TIs [5].

CONTINUES ON NEXT PAGE

Looking towards the future, we hope that these studies will spark more works on harnessing spin currents from topological materials and revealing interesting spin textures at topological material/magnet interfaces. All magnon-driven magnetization switching without involving electrical parts could be achieved in the near future. The results will invigorate magnon-based memory and logic devices, which is relevant to the energy-efficient control of spin devices.

[1] P. He et al., Nat. Phys. 14, 495 (2018)
[2] P. He et al., Nat. Comm. 10, 1290 (2019)
[3] Y. Liu et al., Nat. Comm. 9, 2492 (2018)
[4] Y. Wang et al., Phys. Rev. Lett. 114, 257202 (2015)
[5] Y. Wang et al., Nat. Comm. 8, 1364 (2017)
[6] S. Shi et al., Nat. Nano. 14, 945 (2019)
[7] Y. Wang et al., Science 366, 1125 (2019).

Tuesday, August 4th, 13:30

2D Magnets, Heterostructures, and Spintronic Devices

Cheng GONG
University of Maryland

Magnetism, one of the most fundamental physical properties, has revolutionized significant technologies such as data storage and biomedical imaging, and continues to bring forth new phenomena in emerging materials and reduced dimensions. The recently discovered magnetic 2D van der Waals materials (hereafter abbreviated as “2D magnets”) provide ideal platforms to enable the atomic-thin, flexible, lightweight magneto-optic and magnetoelectric devices. The seamless integration of 2D magnets with dissimilar electronic and photonic materials further opens up exciting possibilities for unprecedented properties and functionalities. In this tutorial, I will start with the fundamentals on 2D magnetism, and continue to speak on our experimental observation of 2D ferromagnet, analyze the current progress and the existing challenges in this emerging field, and show how we push the boundary by exploring the potential of 2D antiferromagnets for spintronics.

Tuesday, August 4th, 14:40

Graphene-based van der Waals heterostructures for Spintronics

Juan F. SIERRA
ICN2

In recent years, spin-based technologies, in which information is carried by spin instead of charge, have become promising for “beyond-CMOS” devices. Graphene and other two dimensional materials have rapidly established themselves as intriguing building blocks for spintronics applications [1]. Because of the graphene intrinsic low spin-orbit interaction, spins can flow snugly through its crystal lattice over long distances, resulting in an ideal spin channel. At the same time, the graphene’s low spin-orbit interaction inhibits the manipulation of spins, which is the cornerstone for successfully implementing spin-based devices. Nevertheless, this bottleneck can be overcome by combing graphene with other layered materials in artificial van der Waals heterostructures. In this talk, I will present a set of experiments where we study the spin-relaxation in graphene-transition metal dichalcogenides heterostructures [2]. In such van der Waals systems, spin-orbit coupling in graphene is enhanced by proximity effects. As a consequence, the spin dynamics becomes anisotropic [2, 3], with a spin relaxation that depends on the spin orientation. Furthermore, we demonstrate an efficient spin-charge interconversion driven by the Spin Hall effect and inverse spin galvanic effect at room temperature [4].

[1] W. Han et al., Nature Nanotechnology 9, 794 (2014)
[2] L. A. Benítez, J. F. Sierra et al., Nature Physics 14, 303 (2018)
[3] L. A. Benítez, J. F. Sierra et al., APL Materials 7, 120701 (2019)
[4] L. A. Benítez, W. Savero Torres, J. F. Sierra, et al., Nature Materials 19, 170 (2020)

Tuesday, August 4th, 15:40

Proximity induced spin-orbit coupling and magnetism in graphene

Alexei KAVERZIN
University of Groningen

With a reference to our experimental observations I will discuss how proximity effects modify the spin transport phenomena in graphene when it is placed in the vicinity of other layered materials. For example, the combination of graphene and TMDs results in the presence of large spin-orbit interaction imprinted from TMD into graphene with the emergence of spin manipulation mechanisms including conversion between spin and charge currents. I will highlight our recent results obtained on a van der Waals heterostructure of graphene and anti-ferromagnetic material CrSBr. The presence of CrSBr introduces a large exchange interaction in graphene such that its conductivity becomes spin polarised with the polarisation of approximately 14%. This implies that spin current is generated in graphene on CrSBr with efficiency close to that of the conventional ferromagnetic materials. Overall, we experimentally demonstrate the functionality of various building blocks that can be used for assembly of spin-based devices made out of layered materials only.

Tuesday, August 4th, 16:20

Orbital Hall effect in 2D materials

Tatiana G. RAPPOPORT
UFRJ

The field of spintronics blossomed in the last decade, driven by the use of spin-orbit coupling to generate and manipulate spin currents in non-magnetic materials. In these systems, the efficient conversion between charge and spin currents is mediated by spin-orbit. Great progress in the manipulation of the orbital angular momentum of light has also been achieved in the last decades, leading to a large number of relevant applications. Still, electron orbitals in solids were less exploited, even though they are known to be essential in several underlying physical processes in material science. The orbital-Hall effect (OHE), similarly to the spin-Hall effect (SHE), refers to the creation of a transverse flow of orbital angular momentum that is induced by a longitudinally applied electric field. The OHE has been explored mostly in three dimensional metallic systems, where it can be quite strong. However, several of its features remain unexplored in two-dimensional (2D) materials.

We then investigate the OHE in multi-orbital 2D insulators, such as transition metal dichalcogenides. We show that the OHE in these systems is associated with exotic momentum-space orbital textures. This intrinsic property emerges from the interplay between orbital attributes and crystalline symmetries and does not rely on the spin-orbit coupling. Our results indicate that multi-orbital 2D materials can display robust OHE that may be used to generate orbital angular momentum accumulation, and produce strong orbital torques that are of great interest for developing novel spin-orbitronic devices.

Tuesday, August 4th, 17:00

Spin current effects in 2D magnets/heavy metal bilayers

Jing SHI
UC Riverside

2D van der Waals (vdW) magnetic materials offer exciting new opportunities to study interfacial phenomena arising from or enhanced by the atomically flat interfaces. I will present our recent studies on three types of bilayer systems composed of vdW magnet and Pt: Cr2Ge2Te6/Pt, Fe3GeTe2/Pt, and Pt/CI3. In each bilayer, the exfoliated vdW magnet consists of 10's atomic layer units and the sputtered 5 nm Pt layer is either below or above the vdW magnet. In Cr2Ge2Te6/Pt and Pt/CI3, both Cr2Ge2Te6 and CI3 are insulating, we use induced magneto-transport properties in Pt to probe the spin states and magnetic domains in the insulating magnets [1-3]. Unlike these two insulating magnets, Fe3GeTe2 is a metallic ferromagnet which has the highest Curie temperature among all 2D vdW magnets, strong perpendicular magnetic anisotropy, and more resistive than Pt; therefore, it is an excellent 2D magnet for investigating the spin-orbit torque effects. We demonstrate that Fe3GeTe2/Pt has a spin-orbit torque efficiency comparable with that in the best bilayers made with 3D magnets and the Fe3GeTe2 magnetization can be switched with a relatively low critical current density [4]. These excellent properties show great potential of 2D materials for spintronic applications.

[1] B. Niu, T. Su, et al., Nano Lett. 20, 553 (2020). DOI: 10.1021/acs.nanolett.9b04282
[2] M. Lohmann, et al., Nano Lett. 19, 2397 (2019). DOI: 10.1021/acs.nanolett.8b05121
[3] T. Su, et al., 2D Materials 7, 045006 (2020). DOI:10.1088/2053-1583/ab9dd5
[4] M. Alghamdi, M. Lohmann, et al., Nano Lett. 19, 4400 (2019). DOI: 10.1021/acs.nanolett.9b01043

Wednesday, August 5th, 09:30

Optical spectroscopy of 2-dimensional antiferromagnetic materials

Hyeonsik CHEONG
Sogang University

Magnetism in low dimensional systems is a fascinating topic for the fundamental physics as well as for possible applications in future spintronic devices. Although ferromagnetic 2-dimensional (2D) materials are attracting the most interest, antiferromagnetic 2D materials are equally interesting for the rich physics they reveal. However, antiferromagnetic ordering is much more difficult to investigate because the lack of net magnetization hinders easy detection of antiferromagnetic ordering. Neutron scattering, which is a powerful tool to detect antiferromagnetic order in bulk materials, cannot be used for atomically thin samples due to the small sample volume. Raman spectroscopy has proven to be a powerful tool to detect antiferromagnetic ordering by monitoring magnetically induced changes in the Raman spectrum. In this talk, I will review recent achievements in the study of antiferromagnetism in 2 dimensions using Raman spectroscopy. FePS3 exhibits an Ising-type antiferromagnetic ordering down to the monolayer limit, in good agreement with the Onsager solution for 2-dimensional order-disorder transition. The transition temperature remains almost independent of the thickness from bulk to the monolayer limit, indicating that the weak interlayer interaction has little effect on the antiferromagnetic ordering. On the other hand, NiPS3, which shows an XXZ-type antiferromagnetic ordering in bulk, exhibits antiferromagnetic ordering down to 2 layers with a slight decrease in the transition temperature, but the magnetic ordering is suppressed in the monolayer limit. A Heisenberg-type antiferromagnet MnPS3 also exhibits ordering down to 2 layers with a small decrease in the transition temperature. Furthermore, a recent discovery of a peculiar excitonic transition that exhibit a dramatic decrease of the linewidth below the transition temperature will be reported.

Wednesday, August 5th, 10:10

Thin layers of $CrBr_3$ and CrI_3: reconaissance ventures into 2D magnetism

Maciej KOPERSKI
National University of Singapore

The magnetism of chromium has been investigated for almost a century now, providing substantial knowledge about its electronic configuration. Extensive research has been conducted regarding the physics of valence electrons from d-shell, which is fundamentally important for understanding the mechanisms of magnetic ordering. Interestingly, chromium atom, exhibiting a stable electronic configuration exempting from Hund's rules, has half-filled 3d shell, which leads to manifestation of robust magnetic effects in a variety of structures. Recently, attention has been refocused on chromium trihalides ($CrCl_3$, $CrBr_3$ and CrI_3), which constitute a group of electrically insulating layered materials displaying magnetic ordering at low temperatures, as established by inspection of bulk crystals carried out few decades ago. The progress of mechanical exfoliation techniques, performed in a controlled argon atmosphere, enables now isolation of thin layers (down to monolayers) and their incorporation in van der Waals heterostructures.

Initial reports demonstrated layer-dependent ferromagnetic and anti-ferromagnetic order below Curie temperature using Kerr rotation measurements as magnetization probe. These appealing findings motivate further study to uncover the underlying microscopic mechanisms. One possible path to learn about the electronic structure and characteristics of electronic states via optical methods involves investigations of emission and absorption processes. Here, we present detailed optical studies of exfoliated films of $CrBr_3$ and CrI_3 to demonstrate that the emergent interband luminescence has molecular-like character (most likely due to formation of Frenkel-type excitons) and the details of the structure of emission resonances can be explained by Franck-Condon principle involving multiple phonon modes. The photoluminescence studies unveil unambiguous signatures of coupling between the magnetic moments of Cr^{3+} ions with band carriers, offering insight into fundamental properties of these novel magnetic structures and opening up new routes for potential applications of 2D systems.

Wednesday, August 5th, 11:10

Spin systems in transition metal phosphous trichalcogenide van der Waals materials

Efrat LIFSHITZ
Technion

Magnetism is a topic of a wide interest since the discoveries of motors/generators, through magneto-resistance and up to modern times, where low dimensional materials offer a support for new magnetic phenomena. The talk will focus on the influence of magnetic moments and magnetism on the optical magneto-properties of semiconductors in an ultimate two-dimensional limit found in van der Waals transition metal phosphorous tri-chalcogenides. A few types of magnetic properties will be discussed: the long-range magnetic order, ferromagnetism, anti-ferromagnetism or special spin textures; an interfacial developed Rashba spin-orbit effect; nuclear spin Overhauser effect; magnetic polaron, all gaining special stabilization by the size confinement and a shape anisotropy. The mentioned intrinsic fields lead to a lift of energy or momentum degeneracy at band-edge states with selective spin orientation in the ground or/and excited state, being of a special interest in emerging technologies of spin-electronics and quantum computation. The lecture will include the study of long-range magnetic order and valley effects in single layer of metal phosphor tri-chalcogenide compounds. Metal phosphor tri-chalcogenides with the general chemical formula MPX3 (M=metal, X=chalcogenide) closely resembling the metal dichalcogenides, but the metal being paramagnetic elements, while one-third of them are replaced by phosphor pairs. The metal ions within a single layer produce a ferromagnetic or anti-ferromagnetic arrangement, endowing those materials with unique magnetic and magneto-optical properties. Most recent magneto-optical measurements will be reported, exposing the existence of valley degree of freedom in a few MPX3 (e.g., FePS3, MnPS3), that reveals a protection of the spin helicity of each valley however, the coupling to an anti-ferromagnetism lifts the valleys' energy degeneracy. The phenomenon was also examined in magnetically doped diamagnetic MPX3 layers. The results indicated the occurrence of coupling between photo-generated carriers and magnetic impurities and the formation of magnetic polaron.

[1] A.K. Budniak, N.A. Killilea, S.J. Zelewski, M. Sytnyk, Y. Kauffmann, Y. Amouyal, R. Kudrawiec, W. Heiss, E. Lifshitz; Small, 2020, 16 (1), 1905924

[2] M. Shentcis, A.K. Budniak, R. Dahan, Y. Kurman, X. Shi, M. Kalina, H.H. Sheinfux, M. Blei, M.K. Svendsen, Y. Amouyal, F. Koppens, S. Tongay, K.S. Thygesen, E. Lifshitz, F.J.G. de Abajo, L.J. Wong, I. Kaminer; Under revision in Nature Photonics

Wednesday, August 5th, 11:50

ARPES studies of candidate van der Waals ferromagnets

Phil KING
University of St Andrews

Control over materials thickness down to the single-atom scale has emerged as a powerful tuning parameter for manipulating not only the single-particle band structures of solids, but increasingly also their interacting electronic states and phases. Recently, magnetism has emerged as the new frontier in the area of 2d materials. Here, I will show how direct measurement of the electronic structure using angle-resolved photoemission (ARPES) can lead to valuable insight not only on the question of whether a 2d material does in fact exhibit long-range magnetic order, but also on the microscopic mechanisms of the magnetic ordering when it occurs. First, I will consider the example of epitaxial monolayers of VSe2.1 Our ARPES measurements, combined with x-ray magnetic circular dichroism (XMCD), demonstrate that a putative magnetic order is prevented from occurring by the formation of a robust charge density wave,2 which gaps the complete Fermi surface thus removing a Stonor-like channel for ferromagnetism. The instability can be expected to be nearby in phase space, however, and we show how ferromagnetism can be induced via proximity coupling with a ferromagnetic Fe layer.3 Second, I will show ARPES results from bulk Cr2Ge2Te6, which is an established van der Waals ferromagnet,4 where long-range order has been shown to persist to the bilayer thickness.5 From ARPES, we identify atomic- and orbital-specific band shifts upon cooling through TC. From these, together with XMCD, we identify the states created by a covalent bond between the Te 5p and the Cr eg orbitals as the primary driver of the ferromagnetic ordering in this system, while it is the Cr t2g states that carry the majority of the spin moment. This reflects a rather direct observation of how 90° superexchange leads to ferromagnetism, and demonstrates how an experimental band-structure perspective can give important insight even in a “local moment" magnetic system.

[1] Rajan et al., Phys. Rev. Materials 4 (2020) 014003
[2] Feng et al., Nano Lett. 18 (2018) 4493
[3] Vinai et al., Phys. Rev. B 101 (2020) 035404
[4] Carteaux et al., J. Phys. Condens. Mat. 7 (1995) 69
[5] Gong et al., Nature 546 (2017) 265
[6] Watson et al., Phys. Rev. B 101 (2020) 205125

Wednesday, August 5th, 12:30

New Developments on Chromium Trihalides 2D Ferromagnets

David SORIANO
Radboud University

The discovery of 2D ferromagnets in 2017 has opened new ways to explore novel physical phenomena at the nanoscale. In the first part of my talk, I will briefly discuss the recent advances in chromium trihalides, from fundamentals to applications.[1] In the second part, I will focus on our recent work regarding the role of Coulomb interactions in the intralayer exchange, the electrical tunability of interlayer magnetism in bilayer CrI3,[2] and the exchange proximity effects in van der Waals heterostructures containing chromium trihalides.[3,4]

[1] Magnetic Two-Dimensional Chromium Trihalides: A Theoretical Perspective. D. Soriano, M. I. Katsnelson, and J. Fernández-Rossier. Submitted to Nano Letters.

[2] Magnetic polaron and antiferromagnetic-ferromagnetic transition in doped bilayer CrI3. D. Soriano, and M. I. Katsnelson. Phys. Rev. B 101, 041402(R) (2020)

[3] Van der Waals Spin Valves. C. Cardoso, N. A. García-Martínez, and J. Fernández-Rossier. Phys. Rev. Lett. 121, 067701 (2018)

[4] Exchange-bias controlled correlations in magnetically encapsulated twisted van der Waals dichalcogenides. D. Soriano, and J. L. Lado. arXiv:2006.09953

Wednesday, August 5th, 14:00

Giant Nonlinear Anomalous Hall Effect

Adam WEI TSEN
University of Waterloo

TBA

Wednesday, August 5th, 14:40

Spin galvanic effects and magnetization dynamics in layered vdW systems

Simran SINGH
Carnegie Mellon University

The van der Waals (vdW) based layered materials and their heterostructures are a modular platform to probe spin related phenomena such as spin-charge interconversion, spin-orbit torques and magnetization dynamics. I will discuss the spin-charge interconversion in vdW bonded few-layer graphene/Platinum (Gra/Pt) heterostructures where we observe a large spin-charge interconversion signal. The spin Hall effect (SHE) in Pt and spin diffusion in graphene layers cannot explain the large spin-charge interconversion signals observed in our heterostructures. This indicates that a mechanism of spin-to-charge conversion other than the SHE (ISHE) is dominant in our devices. Based on previous photoemission studies on the Pt/Gr interface, it is plausible to ascribe the spin-charge interconversion observed in these Pt/Gr interfaces to the Rashba effect.

The layered Weyl semimetal candidate, WTe2, is predicted to host large spin-galvanic effects which can be used to efficiently manipulate the magnetization state of a magnetic system. I will discuss our recent results showing an efficient magnetization switching of a layered ferromagnet system driven by the charge current induced spin currents in WTe2. Time permitting, I will also briefly discuss low temperature broadband magnetization dynamics studies of a layered anti-ferromagnetic system which are aimed at probing the magnetic energy landscape of the layered magnetic systems.

Wednesday, August 5th, 15:40

Observation of magnetic skyrmions and their current-driven dynamics in van der Waals heterostructures

Seonghoon WOO
IBM

Since the discovery of ferromagnetic two-dimensional (2D) van der Waals (vdW) crystals, significant interest on such 2D magnets has emerged, inspired by their appealing properties and integration with other 2D family for unique heterostructures. In known 2D magnets, spin-orbit coupling (SOC) stabilizes perpendicular magnetic anisotropy (PMA). Such a strong SOC could also lift the chiral degeneracy, leading to the formation of topological magnetic textures such as skyrmions through the Dzyaloshinskii-Moriya interaction (DMI). In this talk, we present the experimental observation of Néel-type chiral magnetic skyrmions and their lattice (SkX) formation in a vdW ferromagnet Fe3GeTe2 (FGT). We demonstrate the ability to drive individual skyrmion by short current pulses along a vdW heterostructure, FGT/h-BN, as highly required for any skyrmion-based spintronic device. Using first principle calculations supported by experiments, we unveil the origin of DMI being the interfaces with oxides, which then allows us to engineer vdW heterostructures for desired chiral states. Our finding opens the door to topological spin textures in the 2D vdW magnet and their potential device application.

Wednesday, August 5th, 16:20

Interface induced magnetism and skyrmions in layered heterostructure materials

Kang L. WANG
UCLA

Layered materials have recently been investigated for exploring magnetic properties. This talk will discuss the magnetism of layered materials including those of magnetic doped materials as well the interface proximity-induced ferromagnetism by proximity with antiferromagnetic materials. We will begin by describing layered magnetic doped topological insulators (TI), SbBiTe, for achieving quantum anomalous Hall. Then we will discuss the proximity-induced magnetism in doped and undoped TIs when interfaced with different kinds of antiferromagnets, such as CrSb and MnTe, with a perpendicular and an in-plane Nel orders, respectively. Antiferromagnets interfaced with a magnet is shown being to yield skyrmions, whose topological charge can be controlled by cooling under applied magnetic fields. Atomically thin 2-D van der Waals magnetic materials (FeGeTe and alike) also have drawn significant interests. We observed interface Nel-type skyrmions in FeGeTe/WeTe2 heterostructures from the topological Hall effect below the temperature of 150 K, with the varying sizes for different temperatures, and the skyrmions were also confirmed by Lorentz transmission electron microscopy. A Dzyalosinskii-Moriya interaction with an energy of 1.0 mJ/m2, obtained from the aligned and stripe-like domain structure, is shown to be sufficiently large to support and stabilize the skyrmions.

Thursday, August 6th, 09:00

Intrinsic 2D-XY ferromagnetism in a van der Waals monolayer

Amilcar BEDOYA-PINTO
Max Planck Institute, Halle

Long before the recent fascination with two-dimensional materials, the critical behaviour and universality scaling of phase transitions in low-dimensional systems has been a topic of great interest. Recent experiments on layered magnetic systems show that a sizable out-of-plane magnetic anisotropy is able to stabilize 2D long-range ferromagnetic order, as demonstrated in CrI3, CrBr3, Fe3GeTe2 and Cr2Ge2Te6 [1], while a spontaneous magnetic ordering has remained elusive for an in-plane 2D magnetic system in the monolayer limit. Here, we construct a nearly ideal easy-plane system, a CrCl3 monolayer grown on Graphene/6H-SiC (0001), which exhibits ferromagnetic ordering as unambiguously determined by element-specific X-ray magnetic dichroism [2]. Hysteretic behaviour of the field-dependent magnetization is sustained up to a temperature of 10 K, and angular dependent measurements evidence a clear in-plane easy axis, unlike all other van der Waals monolayer magnets reported to date. The origin of the easy-plane anisotropy is discussed in terms of a non-zero orbital moment and a trigonal distortion of the CrCl3 unit cell. Moreover, the analysis of the critical exponents of the temperature-dependent magnetization show a scaling behaviour that is characteristic of a 2D-XY system. These observations suggest the first realization of a finite-size Berezinskii-Kosterlitz-Thouless (BKT) phase transition in a quasi-freestanding monolayer magnet with a XY universality class; accessible through the bottom-up growth of a van der Waals layer with an in-plane hexagonal crystal symmetry and negligible substrate interaction..

[1] K. S. Burch, D. Mandrus, J. G. Park, Nature. 563, 47–52 (2018)
[2] A. Bedoya-Pinto et al., arXiV https://arxiv.org/abs/2006.07605 (2020)

Thursday, August 6th, 09:40

Electrostatic Control of Magnetism in Van Der Waals Ferromagnets

Ivan VERZHBITSKIY
National University of Singapore

Control of magnetism via electric fields is a long-standing exciting challenge of fundamental significance for future spintronic devices. Recent discovery of two-dimensional magnetism in van der Waals systems such as CrI3, Fe3GeTe2, and Cr2Ge2Te6 (CGT) highlights their unique potential as a platform to probe the interplay between charge and magnetic ordering [1]. Here, we report the first observation of carrier-induced ferromagnetic order in heavily doped thin crystals of CGT [2]. Upon degenerate electron doping, the CGT transistor exhibits clear hysteresis in the magnetoresistance (MR), which is a distinctive signature of ferromagnetism. Surprisingly, the hysteresis persists up to 200 K, which is in contrast to undoped CGT whose Curie temperature is only 61 K. We demonstrate that the Curie temperature can be modulated over 140 K by altering the electron density. Further, we find the magnetic easy-axis of doped CGT to lie within the plane of the crystal. This is in stark contrast to the out-of-plane magnetic easy-axis of the pristine CGT. We attribute these changes to emergence of the double-exchange interaction mediated by free carriers. This mechanism dominates over superexchange interaction, which is responsible for the ferromagnetic order in undoped CGT. Our calculations show that the magnetic anisotropy energy changes sign in degenerate doping limit, in agreement with our experimental observations. Our findings reveal a unique role of the electric field in tailoring the magnetic anisotropy and leading exchange interaction in semiconducting 2D ferromagnets.

[1] Gibertini, M.; Koperski, M.; Morpurgo, A. F. & Novoselov, K. S. Magnetic 2D materials and heterostructures. Nat. Nanotechnol. 14, 408–419 (2019).

[2] Verzhbitskiy, I.; Kurebayashi, H.; Cheng, H.; Zhou, J.; Khan, S.; Feng, Y. P. & Eda, G. Controlling the magnetic anisotropy in Cr2Ge2Te6 by electrostatic gating. Nat. Electron. (2020), DOI:https://doi.org/10.1038/s41928-020-0427-7.

Thursday, August 6th, 10:40

van der Waals layered magnetic semiconductors

Young Hee LEE
Sungkyunkwan University

The ferromagnetic state in van der Waals two-dimensional (2D) materials has been reported recently in the monolayer limit. Intrinsic CrI3 and CrGeTe3 semiconductors reveal ferromagnetism but the Tc is still low below 60K. In contrast, monolayer VSe2 is ferromagnetic metal with Tc above room temperature but incapable of controlling its carrier density. Moreover, the long-range ferromagnetic order in doped diluted chalcogenide semiconductors has not been demonstrated at room temperature. The key research target is to realize the long-range order ferromagnetism, Tc over room temperature, and semiconductor with gate tunability. Here, Ferromagnetic order is manifested using magnetic force microscopy up to 360K, while retaining high on/off current ratio of ~105 at 0.1% V-doping concentration. The V-substitution to W siteskeep a V-V separation distance of 5 nm without V-V aggregation, scrutinized by high-resolution scanning transmission-electron-microscopy. More importantly, the ferromagnetic order is clearly modulated by applying a back gate. We also observe a ferromagnetic hysteresis loop together with oscillatory behavior at room temperature in diluted V-doped WSe2, while maintaining the semiconducting characteristic of WSe2 with a high on/off current ratio of five orders of magnitude. Our findings open new opportunities for using two-dimensional transition metal dichalcogenides for future spintronics.

Thursday, August 6th, 11:20

Emergent properties of 2D magnets and their heterostructures explored by MBE

Masaki NAKANO
University of Tokyo

Bottom-up molecular-beam epitaxy (MBE) provides a complementary approach to top-down mechanical exfoliation in 2D materials research. A great success lies in the application of MBE-grown large-area monolayer films to ARPES and STM/STS studies, unveiling emergent monolayer properties of various 2D materials. Considering the research history of semiconductors and oxides, however, one of the biggest advantages of MBE-based approach should be to create novel material systems unachievable by bulk-based approach and examine their transport phenomena, although such examples are very much limited presumably due to difficulties in making high-enough quality samples.

We have recently developed a fundamental route to layer-by-layer epitaxial growth of a wide variety of 2D materials and their heterostructures on insulating substrates by MBE [1-7], opening a door for exploration of emergent transport phenomena of 2D materials arising at the monolayer limit and at the interface between dissimilar materials even based on hardly-cleavable, chemically-unstable, and/or thermodynamically-metastable compounds. In this presentation, I will introduce our recent achievements in particular on the MBE-grown 2D magnets and their heterostructures, including observation of the emergent itinerant 2D ferromagnetism with intrinsic spin polarization in hardly-cleavable compound that are missing in its bulk counterpart [4], as well as control of its magnetic properties by the magnetic proximity effect across the van der Waals interface [7].

[1] M. Nakano et al., Nano Lett. 17, 5595 (2017))
[2] Y. Wang et al., Appl. Phys. Lett. 113, 073101 (2018).
[3] Y. Kashiwabara et al., Adv. Funct. Mater. 29, 1900354 (2019).
[4] M. Nakano et al., Nano Lett. 19, 8806 (2019).
[5] Y. Tanaka et al., Nano Lett. 20, 1725 (2020).
[6] H. Matsuoka et al., Rhys. Rev. Research 2, 012064(R) (2020).
[7] H. Matsuoka et al., submitted.

Thursday, August 6th, 14:00

A perspective on the synthesis and modifications of 2D transition metal dichalcogenides by vacuum methods

Matthias BATZILL
University of South Florida

In this tutorial talk, I am introducing the concept of van der Waals epitaxy of transition metal dichalcogenides (TMDs) and the endeavor of finding potentially ferromagnetic 2D materials. Epitaxial mono- or few-layer films allow detailed measurement of electronic structure by angle resolved photoemission and thus determine layer dependent properties and the role of interlayer interactions of the properties. In addition, scanning tunneling microscopy can give information on the growth process and defect structures in the films. We discuss selected cases of TMDs. For VSe2 we suggest a competition between charge density and ferromagnetic ordering for the ground state. While in CrTe2 the ground state may be the semiconducting 1H-phase rather than the sought metallic and possibly ferromagnetic 1T-phase. Formation of ultrathin intercalation compounds are also discussed as a potential ultrathin ferromagnets. Finally, we discuss properties of defects in TMDs and how these may help in inducing magnetic properties. The incorporation of magnetic dopants may be one approach and recent reports suggest the possibility of diluted ferromagnetic 2D semiconductors. While there are many unanswered questions, a controlled vacuum synthesis and characterization of monolayer materials is an important aspect to find new materials..

Thursday, August 6th, 15:30

Defect-induced magnetism in a 2D noble metal dichalcogenide

Ahmet AVSAR
EPFL

Defects are ubiquitous in solids and often introduce new properties that are absent in pristine materials especially at their low-dimensional limits [1]. For example, atomic-scale disorder in two-dimensional (2D) transition metal dichalcogenides is often accompanied by local magnetic moments, which can conceivably induce long-range magnetic ordering in these otherwise non-magnetic materials. In this talk, I will present magneto-transport properties of ultrathin PtSe2 crystals down to monolayer thickness and demonstrate the emergence of such extrinsic magnetism [2]. Electrical measurements supported by first-principles calculations and aberration-corrected transmission electron microscopy imaging of point defects show the existence of either ferromagnetic or anti-ferromagnetic ground state orderings depending on the number of layers in this ultra-thin material. By combining this defect-induced magnetism with unique thickness-dependent electronic properties of PtSe2 emerging from the strong coupling between layers [3], I will discuss its potential integration into several 2D spintronics device applications [4].

[1] D. Rhodes et al., Nat. Mater. 18, 541-549 (2019)
[2] A. Avsar et al., Nat. Nanotechnol., 14, 674-678 (2019)
[3] A. Ciarrocchi, A. Avsar, D. Ovchinnikov and A. Kis, Nat Commun., 9, 919 (2018)
[4] A. Avsar et al., Rev. Mod. Phys., 92 (2), 021003 (2020)

Thursday, August 6th, 16:10

New Opportunities for Charge and Spin in the 2D Magnet RuCl3

Kenneth BURCH
Boston University

Precise control of electronic charge at the nanoscale has been crucial in creating new phases of matter and devices. Here I will present results on the 2D magnet RuCl3 that demonstrate it is able to induce large charge on short length scales in other materials. I will discuss its ability to work with various systems, and potential for control via relative twist angle. I will also review the limitations of this technique in terms of ultimate charge doping and homogeneity. Time permitting I will briefly discuss the unique magnetic excitations in this system useful for topological computing, and implications for heterostructures of RuCl3 with other 2D magnets.

Thursday, August 6th, 16:50

Magneto-Raman Spectroscopy to Identify Spin Structure in Low-Dimensional Quantum Materials

Angela R. HIGHT WALKER
NIST

Raman spectroscopy, imaging, and mapping are powerful non-contact, non-destructive optical probes of fundamental physics in graphene and other related two-dimensional (2D) materials, including layered, quantum materials that are candidates for use in the next quantum revolution. An amazing amount of information can be quantified from the Raman spectra, including layer thickness, disorder, edge and grain boundaries, doping, strain, thermal conductivity, magnetic ordering, and unique excitations such as charge density waves. Most interestingly for quantum materials is that Raman efficiently probes the evolution of the electronic structure and the electron-phonon, spin-phonon, and magnon-phonon interactions as a function of temperature, laser energy, and polarization. Our unique magneto-Raman spectroscopic capabilities will be detailed, enabling diffraction-limited, spatially-resolved Raman measurements while simultaneously varying the temperature (1.6 K to 400 K), laser wavelength (tunability from visible to near infrared), and magnetic field (up to 9 T) to study the photo-physics of nanomaterials. Additionally, coupling to a triple grating spectrometer provides access to low-frequency (down to 6 cm-1, or 0.75 meV) phonon and magnon modes, which are sensitive to coupling. By utilizing electrical feedthroughs, studying the strain-dependent effects on magnetic materials utilizing MEMs devices is also a novel opportunity. Current results on intriguing quantum materials will be presented to highlight our capabilities and research directions. One example leverages the Raman spectra from α-RuCl3 to probe this Kitaev magnet and possible quantum spin liquid1. Within a single layer, the honeycomb lattice exhibits a small distortion, reducing the symmetry from hexagonal to orthorhombic. We utilize polarization-dependent Raman spectroscopy to study this distortion, including polarizations both parallel and perpendicular to the c-axis. Coupling of the phonons to a continuum is also investigated. Using Raman spectroscopy to probe magnetic phenomena in the antiferromagnetic metal phosphorus trichalcogenide family2, we highlight FePS3 and MnPSe3.

CONTINUES ON NEXT PAGE

Using magneto-Raman spectroscopy as an optical probe of magnetic structure, we show that in FePS3 one of the Raman-active modes in the magnetically ordered state is actually a magnon with a frequency of ≈3.7 THz (122 cm−1). In addition, the surprising symmetry behavior of the magnon is studied by polarization-dependent Raman spectroscopy and explained using the magnetic point group of FePS3. Using resonant Raman scattering, we studied the Neel-type antiferromagnet MnPSe3 through its ordering temperature and also as a function of applied external magnetic field. Surprisingly, the previously assigned one-magnon scattering peak showed no change in frequency with an increasing in-plane magnetic field. Instead, its temperature dependence revealed a more surprising story. Combined with first-principle calculations, the potential origin of this Raman scattering will be discussed.

Finally, the magnetic field- and temperature-dependence of an exciting ferromagnetic 2D material, CrI3, will be presented3. We report a magneto-Raman spectroscopy study on multilayered CrI3, focusing on two new features in the spectra which appear below the magnetic ordering temperature and were previously assigned to high frequency magnons. Instead, we conclude these modes are actually zone-folded phonons. We observe a striking evolution of the Raman spectra with increasing magnetic field applied perpendicular to the atomic layers in which clear, sudden changes in intensities of the modes are attributed to the interlayer ordering changing from antiferromagnetic to ferromagnetic at a critical magnetic field. Our work highlights the sensitivity of the Raman modes to weak interlayer spin ordering in CrI3.

[1] PHYSICAL REVIEW B 100, 134419 (2019)
[2] PHYSICAL REVIEW B 101, 064416 (2020)
[3] https://arxiv.org/abs/1910.01237 (in press @Nature Comm)

Friday, August 7th, 09:00

Inside Nature: Decisions & Editorial Process

Tobias ROEDEL
Nature

Scientific publishing is an integral part of the scientific endeavor. The number of publications has increased steadily over the last years due to a metrics-driven 'publish-or-perish' culture and an increase in research funding in certain countries. At Nature, we strive to filter only the most significant advances and to communicate their impact to a broad audience – beyond the specialized community. Our assessment of significance is based on objective criteria, but our final decisions are not devoid of subjectivity. As our editorial decisions can be controversial, I will present the editorial process behind these decisions. Feel free to contact me at 'tobias.roedel@nature.com' if you have questions or criticism.

Friday, August 7th, 10:10

Quantum Phase Transition and Ising Superconductivity in transition metal dichalcogenides

Jianting YE
University of Groningen

Many recent discoveries on novel electronic states were made on 2D materials. Especially, by making artificial bilayer systems, new electronic states such as superconductivity and ferromagnetism have been reported. This talk will discuss quantum phase transitions and Ising superconductivity induced in 2D transition metal dichalcogenides. Using ionic gating, quantum phases such as superconductivity can be induced by field-effect on many 2D materials. In transition metal dichalcogenides, Ising-like paring states can form at K and K' point of the hexagonal Brillouin zone. Also, we will discuss how to couple two Ising superconducting states through Josephson coupling by inducing superconductivity symmetrically in a suspended bilayer. This method can access electronic states with broken local inversion symmetry while maintaining the global inversion symmetry [3]. Controlling the Josephson coupling and spin-orbit coupling is an essential step for realizing many exotic electronics states predicted for the coupled bilayer superconducting system with strong spin-orbit interactions.

[1] Lu, J. M. Zheliuk O, et al., Science 350 1353 (2015)
[2] Lu, J. M. Zheliuk O, et al., Proceedings of the National Academy of Sciences 115 3551 (2018)
[3] Zheliuk O, Lu, J. M., et al., Nature Nanotechnology 14 1123 (2019)

Friday, August 7th, 10:50

Intrinsic magnetic topological states in MnBi2Te4

Jing WANG
Fudan University

Here, we predict the tetradymite-type compound MnBi2Te4 and its related materials host topologically nontrivial magnetic states. The magnetic ground state of MnBi2Te4 is an antiferromagetic topological insulator state with a large topologically non-trivial energy gap (0.2 eV). It presents the axion state, which has gapped bulk and surface states, and the quantized topological magnetoelectric effect. It has several advantages over the previous proposals on realizing the topological magnetoelectric effect. The intrinsic magnetic and band inversion further lead to quantum anomalous Hall effect in odd layer MnBi2Te4 thin film with combined inversion and time-reversal symmetry breaking, which has been recently observed in experiments. The high quality intrinsic MnBi2Te4 together with other magnetic/superconducting 2D materials provides fertile ground for exploring exotic topological quantum phenomena.

We further show the Moire superlattice of twisted bilayer MnBi2Te4 exhibits highly tunable Chern bands with Chern number up to 3. We show that a twist angle of 1 degree turns the highest valence band into a flat band with Chern number ±1, that is isolated from all other bands in both ferromagnetic and antiferromagnetic phases. This result provides a promising platform for realizing time-reversal breaking correlated topological phases, such as fractional Chern insulator and p+ip topological superconductor

Friday, August 7th, 11:30

Exotic Spin transport in two-dimensional topological materials

José Hugo GARCIÁ
ICN2

The manifestations of spin-orbit coupling in two-dimensional materials with reduced symmetries, such as MoTe2 or WTe2 in their 1T' or 1Td phases, can lead to hitherto unexplored ways to control the electronic spins. In this talk, I will present numerical simulations that demonstrate that due to a combination of a persistent canted spin texture and hotspot of the berry curvature, transition metal dichalcogenides show a tunable canted spin Hall effect. The canting angle depends on the microscopic spin-orbit coupling parameters and can be tuned through the electronic environment. Moreover, the persistent spin texture spam over a broad energy range allowing for long spin relaxations even in the metallic regime. These findings vividly emphasize how crystal symmetry governs the intrinsic spin phenomenology and how it can be exploited to broaden the range and efficiency of spintronic functionalities. We also propose specific experimental guidelines for the confirmation of the effect.

Poster Abstracts

Spin pumping from Ni80Fe20 into monolayer TMD

Himanshu BANGAR
Indian Institute of Technology Delhi

Two-dimensional (2D) transition metal dichalcogenides (TMDs) have received considerable attention in recent years due to their unique properties and tremendous potential for device applications [1]. TMDs posses a direct bandgap [2] and a large spin-orbit coupling (SOC) strength [3] in the monolayer form, which makes them promising for spintronics. In the ferromagnetic resonance (FMR) condition, ferromagnet (FM) pumps pure spin current from FM to the adjacent nonmagnetic layer (NM). In this work, we probe the efficiency of spin pumping from Ni80Fe20 (Py) into various monolayer TMDs (MoS2, MoSe2, WS2, WSe2) used as a spin sink. Py of different thickness was deposited using UHV magnetron sputtering on the commercially purchased monolayer TMD samples on the c-cut sapphire substrate. Spin pumping is studied using FMR setup for excitation frequency of 2-10 GHz. The FMR measurements clearly show enhanced damping in the case of tungsten (W) based TMD/Py samples. We calculated the spin mixing conductance ($g_{\uparrow\downarrow}$) and found it to be approximately eight times in the case of WS2/Py (7.28×10^{18} m^{-2}) as compared to MoS2/Py (1.86×10^{18} m^{-2}) samples. The interfacial magnetic anisotropy energy density (K_S) is plotted with $g_{\uparrow\downarrow}$, and it can be observed that the K_S has a crucial role in the increased spin pumping. We attribute this to the d-d hybridization at the interface, which enhances interfacial SOC [4]. We have shown in this work that the spin pumping is much more significant in the case of W based! TMD/Py samples because of their larger SOC strength. This work establishes a way to regulate spin pumping with the SOC strength, which can lead to advances in spintronics based devices.

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[2] K. F. Mak et al., Phys. Rev. Lett. 105, 136805 (2010)
[3] Z. Y. Zhu. et al., Phys. Rev. B 84, 153402 (2011)
[4] L. Zhu, et al., Phys. Rev. Lett. 122, 077201 (2019).

Magnetism of FePc/Ag(110) + O2 Monolayer Phases

Fernando BARTOLOME
ICMA, Universidad de Zaragoza - CSIC

Iron-phtalocyanines (FePc) adsorbed onto a Ag(110) substrate self-assemble into different monolayer phases going from rectangular to different oblique phases, with increasing molecular density. We have investigated the oxygen uptake capability of the different phases and their associated magneto-structural changes. Our study combines scanning tunneling microscopy and spectroscopy (STM/STS), X-ray magnetic circular dichroism (XMCD), and density functional theory (DFT) calculations. STM measurements reveal that the oxygenation reaction of the FePc/Ag(110) generally involves a displacement and a rotation of the molecules, which affects the electronic state of the Fe centers. The oxygen intercalation between FePc and the substrate is greatly obstructed by the steric hindrance in the high-density phases, to the point that a fraction of oblique phase molecules cannot change their position after oxydizing. Depending on the oxidation state and adsorption geometry, the STS spectra evidence clear differences in the Fe local density of states, which are mirrored in the XAS and XMCD experiments. Particularly, XMCD spectra of the oxidized phases reflect the distribution of FePc species (non-oxygenated, oxygenated-rotated and oxygenated-unrotated) in the different cases. Sum rule analysis yields the effective spin and orbital magnetic moments of Fe in the different FePc species. Upon oxygenation, the magnetic moment of FePc molecules increases about an order of magnitude, reaching mTOT~2.2 μB per Fe atom.

2D magnetic crystal: An ab initio study of MnPS3

Magdalena BIROWSKA
University of Warsaw, Faculty of Physics, Poland

Atomically thin, magnetic materials have gained a lot of attention since 2017, when the first 2D ferromagnet was reported [1]. This breakthrough has triggered research on 2D magnetic materials [2]. They are not only important from a fundamental point of view -to understand the theory of magnetism in reduced dimensions-, but also for technological applications. However, probing the magnetic order of the 2D systems by conventional magnetic experimental setups is very challenging. On the other hand, it is well known, that even in the single layer limit, semiconducting two-dimensional materials strongly absorb light. Therefore, optical spectroscopy is a good method for their characterization. In order to shed light on the intriguing phenomena of 2D magnetism, we present comprehensive theoretical investigations of the optical properties of the van der Waals layered material MnPS3, which is one important example from the large family of transition metal phosphorus trisulfide (MPS3)[3]. Our study reveals, that the interband absorption spectrum, which is proportional to the imaginary part of the dielectric function, is very similar for different possible magnetic states of MnPS3. On the other hand, the calculated effective masses of electrons and holes exhibit an anisotropic behaviour and they strongly depend on the magnetic order. Aforementioned properties are reflected in the binding energy of excitons in the studied systems. The impact of the magnetic order on electronic band gap is also revealed, and indirect character of electronic band gap is confirmed as the groundstate of bulk system. Aforementioned results demonstrate that the magnetic order of 2D materials can be indirectly inferred via optical measurements. The study was accomplished thanks to the funds allotted by the National Science Centre, Poland within the framework of the research project ‘SONATA12’ no. UMO-2016/23/D/ST3/03446. Access to computing facilities of TU Dresden ZIH for the project ”TransPheMat”, PL-Grid Polish Infrastructure for Supporting Computational Science in the European Research Space, and of the Interdisciplinary Center of Modeling (ICM), University of Warsaw are gratefully acknowledged.

[1] B. Huan et al., Nature 546, p. 270-273 (2017)
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Exfoliated CrPS4 with promising photoconductivity

Adam BUDNIAK
Technion - Israel Institute of Technology

Layered semiconductors attract significant attention due to their diverse physical properties controlled by their composition and the number of stacked layers. Herein, large crystals of the ternary layered semiconductor chromium thiophosphate (CrPS4) are prepared by a vapor transport synthesis. Optical properties are determined using photoconduction, absorption, photoreflectance, and photoacoustic spectroscopy exposing the semiconducting properties of the material. A simple, one-step protocol for mechanical exfoliation onto transmission electron microscope grid is developed [1,2] and multiple layers are characterized by advanced electron microscopy methods, including atomic resolution elemental mapping confirming the structure by directly showing the positions of the columns of different elements' atoms. CrPS4 is also liquid exfoliated and in combination with colloidal graphene, an ink-jet printed photodetector is created. This all-printed graphene/CrPS4/graphene heterostructure detector demonstrates specific detectivity of 8.3×108 (D*). This study shows a potential application of both bulk crystal as well as individual flakes of CrPS4 as active components in light detection, when introduced as ink printable moieties with a large benefit for manufacturing [1].

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3d Transition Metal Clusters on Defected Graphene

Xin CHEN
Department of Physics and Astronomy, Uppsala University

Adsorbing transition metal atoms on defected graphene is reported as one of the best routines to introduce magnetism to graphene. In this contribution, based on a Born-Oppenheimer molecular dynamics simulation, we investigated the self-assembled processes of transition metal hexamers X6 (X = Cr, Mn, Fe) on mono-/divacancy graphene and discussed the fundamental electric and magnetic properties of the resulting X6 on graphene structures. Interestingly, the ground state Cr6 and Fe6 hexamers on divacancy graphene shows quite small energy difference between in-plane and out-of-plane magnetism, and it can be easily manipulated by external electric field. By applying finite electrical field, the magnetic axes can be switched between in-plane and out-of-plane, which property promises applications in electric field assisted magnetic recording and quantum computing. We have also investigated the insight of the easy magnetic axes switch, and revealed that d orbitals of the transition metal atoms trapped in the vacancy site play a dominated role.

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Electronics without bridging components

Victor Manuel GARCIA-SUAREZ
University of Oviedo

We propose a new paradigm of electronic devices based only on two electrodes separated by a gap, i.e. without any functional element bridging them. We use a tight-binding model to show that, depending on the type of material of the electrodes and its structure, several electronic functionalities can be achieved: ohmic behaviour, rectification, negative differential resistance, spin-filtering and magnetoresistance. in particular, we show that it is possible to deliver a given functionality by changing the coupling between the surface and bulk states and between the surface states across the gap, which dramatically changes the current-voltage characteristics. these results prove that it is possible to have functional electronic and spintronic elements on the nanoscale without having physical components bridging the electrodes.

Charge - spin conversion in layered semimetal

Md Anamul HOQUE
Chalmers University of Technology

A spin-polarized current source using nonmagnetic layered materials is promising for next-generation all-electrical spintronic science and technology. Here, we electrically created a spin polarization in a layered semimetal TaTe2 via the charge-spin conversion process. Using a hybrid device of TaTe2 in a van der Waals heterostructure with graphene, the spin-polarization in TaTe2 is efficiently injected and detected by nonlocal spin-switch, Hanle spin precession, and inverse spin Hall effect measurements. Systematic experiments at different bias currents and gate voltages in a vertical geometry prove the TaTe2 as a nonmagnetic spin source at room temperature. These findings demonstrate the possibility of making an all-electrical spintronic device in two-dimensional van der Waals heterostructure, which can be essential building blocks in energy-efficient spin-orbit technology.

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Magnetic proximity in graphene/CGT heterostructure

Bogdan KARPIAK
Chalmers University of Technology

Engineering 2D material heterostructures by combining the best of different materials in one ultimate unit can offer a plethora of opportunities in condensed matter physics. Here, in the van der Waals heterostructures of the ferromagnetic insulator Cr2Ge2Te6 and graphene, our observations indicate an out-of-plane proximity-induced ferromagnetic exchange interaction in graphene. The perpendicular magnetic anisotropy of Cr2Ge2Te6 results in significant modification of the spin transport and precession in graphene, which can be ascribed to the proximity-induced exchange interaction. Furthermore, the observation of a larger lifetime for perpendicular spins in comparison to the in-plane counterpart suggests the creation of a proximity-induced anisotropic spin texture in graphene. Our experimental results and density functional theory calculations open up opportunities for the realization of proximity-induced magnetic interactions and spin filters in 2D material heterostructures and can form the basic building blocks for future spintronic and topological quantum devices.

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Magnetic investigations in VSe2 and CrSe2 nanorods

Daljit KAUR
DAV University, Jalandhar

2D materials are either monolayer or few layers of 3D van der Waals materials (graphite, MoS2, MoSe2, WSe2, CrI3 etc.) which can be easily cleaved in perpendicular direction by simple and cost effective exfoliation techniques. The magnetic behaviour in these 2D materials was not studied until 2017, when two independent experiments have found intrinsic ferromagnetism (FM) in monolayers of two different van der Waals (vDW) systems (Cr2Ge2Te3 and CrI3) at low temperature (<60 K). The search of prospective 2D materials with ferromagnetic or antiferromagnetic ordering, by first principle calculations has found many such magnetic systems like $Fe3GeTe_2$, CrSiTe3, $CrSe_2$, $CrTe_2$, VSe_2, RuCl3, MnPS3, CoO_2, EuOBr, $FeBr_2$, FeI_2, FeTe, FeSe etc. which are now of particular research interest in this area. We have synthesized FM VSe2 and AFM CrSe2 nanorods by hydrothermal method. The structural and magnetic characterizations have been done. The self-reversed magnetic hysteresis (SRMH) is observed for M-H curve of VSe2 at lower temperature of 50 K, while at room temperature (300 K) diamagnetic ordering is observed. SRMH is generally observed if there are two magnetic phases present in the sample such that one magnetic phase gets negatively exchange coupled with the other ferromagnetic phase leading to reversed hysteresis loop. CrSe2 exhibits paramagnetic character at both 300 K and 50 K but AFM exchange coupling has been confirmed by modified Curie-Weiss curve fit on both χ-T and 1/χ-T graphs.

Epitaxial growth of van der Waals magnets

Roland KAWAKAMI
The Ohio State University

We have been investigating the epitaxial growth and magnetic properties of van der Waals magnets: $MnSe_2$, VSe_2, and $MnBi_2Se_4$. $MnSe_2$ is a room temperature ferromagnet and we have recently grown this material on Bi_2Se_3 layers. We have demonstrated the growth of VSe_2 on GaAs(111) to form a 2D-3D hybrid structure. Initial magnetic measurements show the presence of ferromagnetic signals at room temperature. For $MnBi_2Se_4$, we developed a method for epitaxially stabilizing the trigonal phase, which is the desired structure for topological properties. We will show our magnetic and ARPES results.

Electron correlations and spin excitations in CrI3

Liqin KE
Ames Laboratory, U.S. Department of Energy

The recent advancement of magnetic two-dimensional (2D) van der Waals materials adds new magnetic functionality to the already vast appeal of the 2D materials family. The magnetism in these materials is very sensitive to, and can be controlled by pressure, stacking arrangement, and external magnetic and electrical fields. Such unprecedented tunability offers novel opportunities to design and construct dramatically new energy- efficient spin-based devices. Despite serious effort, the nature of the magnetic interactions and role of electron correlation effects in these spatially confined systems remains elusive. In this work, using CrI3 as a model system, we show that the electronic structure calculated with nonlocal electron correlations goes beyond the usual band theory and yields spin excitations consistent with inelastic neutron scattering measurements. Our discovery may resolve the previous conflicting observations regarding the existence of the Dzyaloshinskii-Moriya interaction, which is a crucial ingredient for topological magnons and topological Skyrmions in these materials.

Intercalating sodium atoms in a vdWs magnet

Safe KHAN
UCL

Two-dimensional (2D) van der Waals (vdWs) single crystals, belonging to the family of lamellar ternary chalcogenides (i.e: $Cr_2Ge_2Te_2$ and $Cr_2Si_2Te_6$) and chromium halides (i.e: CrI_3 and $CrBr_3$), have recently attracted a great deal of interest due to the presence of long-range magnetic order in the 2D limit, which offers new potential avenues in the field of spintronics. However, a limiting factor of these 2D magnets is that the Curie temperature (T_c) lies towards the low temperature limit. Recently, efforts have been made to enhance the T_c by ionic-gel and electrostatic gating. In this poster, I will present our initial experimental results of enhancement of the T_c and manipulation of the magnetic anisotropy in sodium (Na) intercalated $Cr_2Ge_2Te_2$ measured by two different experimental procedures, magneto-transport and ferromagnetic resonance.

Tuning the nonreciprocal resistance of BiTeBr

Mátyás KOCSIS
Department of Physics, BUTE

Recently the bulk form of BiTeBr (and the BiTeX group in general) at- tracted considerable attention, as it is a noncentrosymmetric polar con- ductor with gigantic Rashba spin-orbit interaction [1][2][3]. BiTeBr is also a very attractive candidate to implement into 2D Van Der Waals heterostructures, e.g. it can be used to inject spins into graphene using the Rashba-Edelstein effect. We created thin layers of BiTeBr, in particu- lar nanodevices were produced, where electron density can be varied by an ionic-liquid gate. We report nonreciprocal electrical signals[1], the strength of which can be tuned by gating, as a signature of gigantic Rashba-type spin orbit interaction.

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Molecular Beam Epitaxy of Self-Intercalated Transition Metal Tellurides

Kinga LASEK
University of South Florida

An inspection of the compositional phase diagrams of the early- transition metal tellurides shows the existence of several structurally closely related compositions. In addition to the widely studied ditellurides, common compounds are also self-intercalated transition metal tellurides. These compounds share the dichalcogenide's layer structure but have additional transition metals in between these layers, which makes them challenging to discern from the dichalcogenides for ultrathin films. Meanwhile, the identifications of self-intercalation compounds in molecular beam epitaxy grown multilayer chalcogenides is crucial towards the utilization of their intriguing quantum and layer dependent properties. Here we present the successful growth of monolayer ditellurides, including CrTe2, a compound that is only metastable in its bulk form, and a few-layer thick intercalation compounds of the three early transition metal (Cr, V, and Ti) tellurides. In a combined experimental and computational study, we showed that for Cr- and V- tellurides, structures consistent with M3Te4 were found, while for Ti-telluride, the intercalants may only have local ordering. These findings create novel perspectives for the exploitation of 2D layered self-intercalation compounds as a 'building block' of vdW heterostructures, including heterostructures combining proximity coupling to ferromagnetic layers.

Thickness dependent magnetic transition of MnPS3

Soo Yeon LIM
Sogang University

MnPS3 is one of 2-dimensional (2D) van der Waals (vdW) layered magnetic materials with antiferromagnetism below Néel temperature (TN). The magnetic ordering in a Heisenberg-type system should not exist in the monolayer limit according to the Mermin-Wagner theorem, and TN is expected to approach 0 K rapidly as the thickness is reduced. We tried to investigate the TN of the Heisenberg-type 2D magnetic vdW material MnPS3 as a function of the number of layers. We prepared exfoliated MnPS3 from monolayer to bulk on SiO2/Si substrates. Raman spectroscopy was performed to identify the antiferromagnetic transition. We cooled the exfoliated samples in a micro-cryostat to 22 K using liquid He. The broadening and abrupt redshift of a phonon peak at 155 cm–1 were observed near TN, which indicates the antiferromagnetic transition. TN is found to decrease only slightly from ~78 K for bulk to ~ 66 K for 3L. The small reduction of TN in thin MnPS3 approaching the 2D limit implies that the interlayer vdW interaction is playing an important role in stabilizing magnetic ordering in layered magnetic materials.

Tunable RT FM in 1L V-WS2 & V-WSe2 via CVD

Mingzu LIU
The Pennsylvania State University

Diluted magnetic semiconductors (DMS), realized through substitutional doping of spin-polarized transition metals into semiconducting systems, have attracted intense interests in the scientific community. The capability of experimental modulation of spin dynamics brought by DMS offers great promise for fabricating novel magneto-electric/optical devices, especially for two-dimensional (2D) systems such as transition metal dichalcogenides (TMDs) that enable indirect-to-direct bandgap transition and activate valley degrees of freedom. Here we describe tunable room-temperature ferromagnetic orders in semiconducting vanadium-doped tungsten disulfide and tungsten diselenide (V-WS2, V-WSe2) monolayers achieved by a reliable solution-based chemical vapor deposition (CVD) method. The vanadium dopant concentration is highly controllable within a wide range up to ~10 at% in both materials, and room-temperature ferromagnetism has been confirmed with various techniques.

Magnon Hall Effect in CrI3-based vdW systems

Francisco MUNOZ
Universidad de Chile

Magnonic excitations in the 2D van der Waals (vdW) ferromagnet CrI3 are studied. We find that bulk magnons exhibit a nontrivial topological band structure without the need for the Dzyaloshinskii-Moriya interaction. This is shown in vdW heterostructures, consisting of single-layer CrI3 on different 2D materials such as MoTe2, HfS2, and WSe2. We find numerically that the proposed substrates substantially modify the out-of-plane magnetic anisotropy on each sublattice of the CrI3 subsystem. The induced staggered anisotropy, combined with a proper band inversion, leads to the opening of a topological gap of the magnon spectrum. Since the gap is opened non symmetrically at the K+ and K− points of the Brillouin zone, an imbalance in the magnon population between these two valleys can be created under a driving force. This phenomenon has a close analogy to the so-called valley Hall effect and is thus termed the magnon valley Hall effect.

2D ferromagnetic materials above room temperature

Tianxiao NIE
Beihang University

Since the discovery of single-layer graphene in 2004, two-dimensional (2D) van der Waals (vdW) materials represented by it have demonstrated excellent electrical, magnetic, mechanical and optical physical properties under the structure of one or several layers of atomic thickness. Based on these superior properties, 2D-layered vdW ferromagnetic materials have become the basis for constructing low-dimensional spintronics devices, in which Fe3GeTe2 (FGT), Cr2Ge2Te6 and CrI3 as the main representative materials exhibit strong perpendicular magnetic anisotropy and other important characteristics in single layer. However, the Curie temperature (Tc) of above materials has not reached room temperature yet, which has greatly hinderer the subsequent development for device application. Therefore, recently researchers have been committed to explore 2D vdW ferromagnetic materials for room-temperature Tc in both theory and experiment. Here, we report that the interfacial engineering effect could effectively increase the Tc of the 2D vdW ferromagnetic material FGT from 230 K to 400 K, through heteroepitaxy with topological insulator of Bi2Te3. A theoretical calculation was further carried out to describe the magnetic properties by using first-principles calculations and the self-consistent Hubbard U approach (DFT+Uscf) together with the Monte Carlo (MC) simulations. After combination with Bi2Te3, the intralayer interactions in FGT was calculated to dramatically increase compared to that in pure FGT, well explaining the Tc enhancement. Our res! ults may open up a new door to benefit the magnetic order in the 2D limit and realize spintronic devices based on 2D-layered vdW ferromagnetic materials with room temperature performances towards industrialization.

Realistic modelling of monolayer NbS2 and NbSe2

Sergey NIKOLAEV
Tokyo Institute of Technology

Layered transition metal dichalcogenides constitute a unique class of materials offering an exceptionally rich phase diagram and serving as a testbed for investigating various quantum phenomena. For example, the competition between charge density wave and superconductivity has been reported in 1H-NbSe2, while the absence of the charge order has been confirmed in the superconducting 1H-NbS2. It is popularly believed that the two states tend to suppress each other, but the origin of their coexistence in NbSe2 remains unclear. Theoretical studies of electronic properties in NbSe2 and NbS2 have been focusing mostly on the electron–phonon coupling, whereas the influence of electron correlations and spin-orbit coupling is largely unexplored. Based on realistic models constructed from first-principles calculations, we investigate their interplay in monolayer NbS2 and NbSe2.

TMDC/Graphene an ab initio study

Armando PEZO
Federal University of ABC

In this work we attempt to study the interaction between monolayers of Transition Metal Dichalcogenides and Graphene by means of Density Functional Theory. The increasing interest in obtaining new physics by forming Van Der Waals heterostructures lead to new directions in a variety of subjects in condensed matter physics. Very recently it was found that twisted bilayer graphene could develop a superconducting phase by rotating one sheet respect to another by a magic angle, in our case, we rotate a TMDC monolayer respect to graphene to obtain interesting results on the so-called Spin Orbit Proximity effects which could play an important role in future studies of theses materials for both theoretical and practical purposes.

Tunneling spectroscopy of few-monolayer NbSe2

Charis QUAY
Université Paris-Saclay

We perform a spectroscopic study of NbSe2 superconducting flakes of different thicknesses from bilayer up to 25 monolayers using van der Waals tunnel junctions. We measure the quasi-particle density of states as a function of an in-plane magnetic field up to 33T. In few-monolayer NbSe2, where the density of states is well-described by a single band superconductor, the field acts on the spin degrees of freedom only, and at low field the superconductivity is protected by Ising spin-orbit coupling. The energy gap, extracted from the tunnelling spectra, as a function of the magnetic field follows the behaviour predicted for Ising-protected superconductors. However, close to the critical field, which for bilayers has been found to be as large as 30T, much larger than the Pauli limit, superconductivity appears to be more robust than expected. This observation could be explained by subdominant triplet order parameter coupled, at high field, to the singlet order parameter. Indeed, recent calculations indicate field-induced parity-mixing in NbSe2..

Morphology control of monolayer transition metal dichalcogenides by MBE

Akhil RAJAN
University of St Andrews

The 2D transition metal dichalcogenides (TMDs) host a wide range of material properties, with the metallic systems of particular interest for the interacting electronic states and phases which these host. How such states evolve when the material is thinned to the single-layer limit is a key question in the study of 2D materials. This necessitates the fabrication of high-quality single-layer TMDs. Although typically achieved via exfoliation from bulk crystals, thin-film growth techniques such as molecular beam epitaxy (MBE) are being increasingly explored as a route to growth of high-quality and large-area TMD monolayers. Here, we investigate the MBE growth of monolayers of VSe2, TiSe2 and NbSe2 on highly oriented pyrolytic graphite (HOPG) substrates. Relaxed substrate-epilayer interaction at the interface due to van-der-Waals epitaxy means that large-area monolayers can be grown on highly lattice mismatched substrates without strain and misfit dislocations. Through this, we identify the key drivers and influence of the adatom kinetics that control the epitaxial growth of TMDs, realizing four distinct morphologies of the as-grown compounds. We use this to determine optimized growth conditions for the fabrication of high-quality monolayers, ultimately realizing the largest grain sizes of monolayer TMDs that have been achieved to date via MBE growth.

Scanning NV Magnetometry of 2D Magnetism

Patrick REISER
University of Basel

Scanning magnetometry using the nitrogen-vacancy (NV) center in diamond is a powerful tool to study magnetism at the nanoscale and has provided novel insights into the magnetic order of 2D van der Waals (vdW) spin systems. The electronic spin of the NV center is a magnetic field sensor that allows for nanoscale, quantitative imaging of magnetic stray fields. We embed the single spin into all-diamond AFM tips and achieved a spatial resolution of around 50 nm. The resulting magnetic stray field maps of a sensitivity below \mu T/\sqrt{Hz} allow the quantitative reconstruction of the underlying magnetization of vdW magnets down to the monolayer limit. By that, we determined the magnetization of the 2D ferromagnet CrI3 quantitatively for the first time and shed light on the antiferromagnetic interlayer coupling of this material. Furthermore, the spatial resolution enables us to observe spin textures on the nanoscale and facilitates the understanding of their physical origin. We recently extended our work to other members of the chromium trihalide family and give an outlook to studying spin textures and spin waves in 2D magnets using NV magnetometry. By that, we will provide a solid basis for both future fundamental studies on low-dimensional magnetism and prospective spintronic development in the field vdW magnetism.

Datta-Das Spin FET under various magnetic fields

Kingshuk SARKAR
Tel Aviv University

A Datta-Das spin field-effect transistor is built of a heterostructure with a Rashba spin-orbit interaction (SOI) at the interface (or quantum well) separating two possibly magnetized reservoirs. The particle and spin currents between the two reservoirs are driven by chemical potentials that are (possibly) different for each spin direction. These currents are also tuned by varying the strength of the SOI, which changes the amount of the rotation of the spins of electrons crossing the heterostructure. Here we investigate the dependence of these currents on additional Zeeman fields on the heterostructure and on variations of the reservoir magnetizations. In contrast to the particle current, the spin currents are not necessarily conserved; an additional spin polarization is injected into the reservoirs. If a reservoir has a finite (equilibrium) magnetization, then we surprisingly find that the spin current into that reservoir can only have spins that are parallel to the reservoir magnetization, independent of all the other fields. This spin current can be enhanced by increasing the magnetization of the other reservoir and can also be tuned by the SOI and the various magnetic fields. When only one reservoir is magnetized then the spin current into the other reservoir has arbitrary tunable size and direction. In particular, this spin current changes as the magnetization of the other reservoir is rotated. The optimal conditions for accumulating spin polarization on an unpolarized reservoir are to either apply a Zeeman field in addition to the SOI or to polarize the other reservoir.

Spectroscopy of Layered SCs with vdW Tunnel Jcns

Hadar STEINBERG
Hebrew University of Jerusalem

We fabricate tunnel junctions by placing insulating of van der Waals (vdW) barriers on top of layered superconductors. The junctions exhibit a hard gap [1], and reveal the vortex-bound states and the structure of the 2nd band in NbSe2 [2]. Measuring two-layer NbSe2 at in-plane fields up to 30 T, the junctions confirm its stability vs. in-plane field, in agreement with the Ising model. Defect states, ubiquitous in semiconducting tunnel-barrier, are found to hybridize with the superconductor and form Andreev bound states, which are observed in the sub-gap tunneling signature. Evolution of these states in-plane magnetic field shows that these Andreev bound states have a singlet ground state, consistent with a small charging energy [3]. Using gated graphene as a source electrode, the defect dot can be gated [4]. We demonstrate how gated defect states can be used for spectroscopy of the NbSe2 two-band structure.

[1] Dvir, T., et al., Spectroscopy of bulk and few-layer superconducting NbSe2 with van der Waals tunnel junctions. Nature Communications, 2018. 9(1): p. 598

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[4] Keren, I., et al., Quantum-Dot Assisted Spectroscopy of Degeneracy-Lifted Landau Levels in Graphene. arxiv:2006.09812v, 2020

Measurement of spin-orbit interaction strength

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To study the short-range van der Waals proximity effects in graphene based devices the bilayer graphene is ideal as by applying perpendicular electric displacement field (D) it will become a layer polarized insulator and the electronic states in it are strongly localized [1]. Here we investigate bilayer Graphene/WSe2 heterostructures encapsulated in hBN. In such devices the WSe2 enhance layer selectively the spin-orbit coupling (SOC) in graphene with proximity effect which was shown with weak antilocalization measurements [2] and spin valve measurements [3]. To study the SOC quantitatively quantum hall effect (QHE) measurements offers a novel way [4,5]. We have studied the QHE at different fixed magnetic fields as a function of D and n, using dual gated devices. We observed Landau level crossings at different D from which the SOC parameters can be extracted.

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Efecto de la Carga en la estructura del Au60

Alfredo TLAHUICE
UANL

En este estudio se realizaron cálculos basados en la Teoría del Funcional de la Densidad. Se ha encontrado que dependiendo de la carga, el Au60 puede formar estructuras compactas o huecas. Se calculan las propiedades vibracionales y estructurales, mediante el modelo de poliedros para determinar la distribución de las distancias y ángulos. Este estudio permite cuantificar el grado de distorsión de la estructura y relacionarla con sus propiedades vibracionales y eolectrónicas.

Spin injection enhancement and spin-anisotropy in

Jesus Carlos TOSCANO FIGUEROA
University of Manchester

Tunneling spin injection on graphene is possible by using different materials as barriers[1-3]. However, the growth of ultra-thin tunnel barriers leads to the creation of pinholes, which in turn causes direct ohmic contact and a large suppression of spin polarization. This occurs due to a fundamental limitation known as the resistance mismatch problem[4], which limits spin injection when the resistance of an injector contact, is lower than the spin resistance of the graphene channel. This is the result of contact-induced spin relaxation, which greatly decreases the measured spin signals[5]. In this work, we demonstrate an alternative approach to grow ultra-thin tunnel barrier contacts made by oxidizing aluminium on top of previously functionalized graphene. We show that molecular functionalization of graphene allows the growth of smooth, high quality tunnel barriers, leading to contacts with increased spin injection efficiency and enhanced spin signals by one order of magnitude. The functionalization process consists on the laser activated physisorption of benzoyl peroxide (BPO) molecules on graphene. This laser-controlled photoreaction enables us to control both the spatial location and the degree of functionalization, as visualized by Raman spectroscopy maps via the intensity ratio of and peaks (ID/IG). We assess the quality of the oxide barriers using atomic force microscopy, charge transport and spin transport measurements. We also present the indication of i) paramagnetic moment formation[6] and ii) indication of spin relaxation time anisotropy[7] in our functionalized graphene channel. These results open the path towards engineering spintronic devices with spatially controlled functionalization and efficient tunnel contacts.

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Molecular Hopping in a 2D Carbon Monoxide Film

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Carbon monoxide (CO) molecules adsorbed on metal surfaces have been extremely studied to unravel catalysis and surface molecular structures in last decades. Also, CO has been used as one of standard molecules to perform single-molecule manipulation. Two-dimensional artificial CO lattices had provided topological electronic states. In this study, we focus on a dens-packed (1.4×1.4) lattice of CO monolayer film grown on Cu(111), which was first observed 40 years ago using low-energy electron diffraction and believed to be a stable and robust lattice. However, the film was found to be continuously moving via simultaneous correlated lateral hopping of CO molecules from top to bridge and bridge to top sites. All experimental data were obtained using low-temperature (4.6 K) ultra-high vacuum scanning tunneling microscopy. Hopping models and DFT calculations unraveled the hopping mechanism [1].

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DMI of 2D Janus Structure

Hongxin YANG
Chinese Academy of Sciences

The Dzyaloshinskii-Moriya interaction (DMI), which only exists in noncentrosymmetric systems, is responsible for the formation of exotic chiral magnetic states. However, it is absent in most theoretical predictions and experiments for two-dimensional (2D) magnetic thin films so far. Here, using first-principles calculations, we demonstrate that significant DMI can be obtained in a series of Janus monolayers of manganese dichalcogenides MnXY (X/Y = S, Se, Te, X ≠ Y) with broken inversion symmetry. In particular, the DMI amplitudes of MnSeTe and MnSTe are comparable to those of state-of-the-art ferromagnet/heavy metal (FM/HM) heterostructures. We find that the DMI of these Janus monolayers is dominated by the heavy chalcogen atoms. In addition, atomistic spin simulations show that various chiral spin textures including spin helix and skyrmion can be stabilized without external field in the MnXY monolayers. The present results pave the way for new device concepts utilizing chiral magnetic structures in the emerging 2D ferromagnetic materials

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Effect of the strain on the transverse conductivity of Sr2RuO4

Meghdad YAZDANI HAMID
Ayatollah Boroujerdi University

In this paper, we consider the effect of strain and spin-orbit coupling (SOC) on the Hall conductivity of two-dimensional superconductor Sr2RuO4 that is experimentally revealed its time reversal symmetry is broken. There are numerous SC gap models for this material that we focus on the most favored ones. We find that the behavior of these pairings are different under strain and SOC that can be measurable in experiments for identifying the type of the order parameter of this material.

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Bismuth-based flexible magnetic sensors

Yevhen ZABILA
Institute of Nuclear Physics PAS

Despite the extensive studies of magnetotransport properties and magnetic phenomena in single material thin films, some of them are still objects of great interest for spintronics technology. Semi-metallic bismuth with its unique features reveals high magnetoresistance (MR) and strong Hall effect even at room temperature. Furthermore, at higher magnetic fields the MR of bulk Bi is larger than that of multilayers exhibiting GMR effect. It is possible because of much lower electron effective mass of bismuth in comparison to other metals. It results in electron mean free path (λ) of the order of micrometers which is lower only than λ of graphene. These properties can be used in design and fabrication of magnetic field sensors. This contribution describes modification of Bi thin film structure and its influence on magnetotransport properties. Thin bismuth films with different thicknesses were prepared on kapton substrates by thermal evaporation at ultrahigh vacuum. Then the films were annealed in high vacuum in the temperature range from RT to melting temperature. The film morphology and crystallographic structure were studied with scanning electron microscopy (SEM) and X-ray diffraction. The transport properties (magnetoresistance and Hall effect) were measured with standard four-point probe technique at magnetic fields up to 20 kOe. Low-temperature magnetoresistance measurements were carried out at field up to 70kOe and temperature down to 5K. The temperature dependent XRD measurements allowed to determine the temperature at which the film loses the continuity and the process of dewetting is initiated. This measurements showed at higher annealing temperature grain recrystallization accompanied by grain sizes growth, confirmed also by SEM images. The increase of grain sizes resulted in the significant increase of the magneto- and Hall- resistance due to the lower defect concentration. Both effects showed opposite Bi thickness dependence; the magnetoresistance value saturaterd for thicker films while Hall resistance reached the higher

CONTINUES ON NEXT PAGE

value for film thicknesses close to discontinuity threshold. These properties are beneficial for construction of flexible magnetic field and strain sensors. Our research of the magnetotransport properties of bismuth layers deposited on polymeric substrates [1] opens the path for applications in flexible electronics. However, development of elastic magnetic sensors requires consideration of several phenomena that are of minor importance in case of rigid bulk materials. Due to the fact that the metalic layer is subjected to unsteady mechanical stresses, deposition of the magnetic sensor onto 12µm thick non-rigid substrate creates a numerous problems, and the strain sensitivity is the first effect which have to be discussed. The thermoelectric effect is the second effect that also have to be considered in order to minimize thermal errors. These aspects will be discussed more detailed in this contribution.

[1] M. Melzer et al. Adv. Mater. 2015, 27, 1274-1280 Acknowlegements This work was supported by the National Centre for Research and Development within LIDER V program, Poland (project Nr.: LIDER/008/177/L-5/13/NCBR/2014).

Conventional and unconventional CSC in WTe2

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Chalmers University of Technology

An outstanding feature of topological quantum materials is their novel spin topology in the electronic band structures with an expected large charge-to-spin conversion efficiency. Here, we report a charge current-induced spin polarization in the type-II Weyl semimetal candidate WTe2 and efficient spin injection and detection in a graphene channel up to room temperature. Contrary to the conventional spin Hall and Rashba-Edelstein effects, our measurements indicate an unconventional charge-to-spin conversion in WTe2, which is primarily forbidden by the crystal symmetry of the system. Such a large spin polarization can be possible in WTe2 due to a reduced crystal symmetry combined with its large spin Berry curvature, spin-orbit interaction with a novel spin-texture of the Fermi states. We demonstrate a robust and practical method for electrical creation and detection of such a spin polarization using both charge-to-spin conversion and its inverse phenomenon and utilized it for efficient spin injection and detection in a graphene channel up to room temperature. These findings open opportunities for utilizing topological Weyl materials as non-magnetic spin sources in all-electrical van der Waals spintronic circuits and for low-power and high-performance non-volatile spintronic technologies.

List of Contributions - Talks

Surname	Name	Talk Title
Avsar	Ahmet	Defect-induced magnetism in a 2D noble metal dichalcogenide
Batzill	Matthias	A perspective on the synthesis and modifications of 2D transition metal dichalcogenides by vacuum methods
Bedoya-Pinto	Amilcar	Intrinsic 2D-XY ferromagnetism in a van der Waals monolayer
Burch	Kenneth	New Opportunities for Charge and Spin in the 2D Magnet RuCl3
Cheong	Hyeonsik	Optical spectroscopy of 2-dimensional antiferromagnetic materials
Garciá	José Hugo	Exotic Spin transport in two-dimensional topological materials
Gong	Cheng	2D Magnets, Heterostructures, and Spintronic Devices
Han	Wei	Spin transport in mangetic 2D materials and heterostructures
Hee Lee	Young	van der Waals layered magnetic semiconductors
Hight Walker	Angela R.	Magneto-Raman Spectroscopy to Identify Spin Structure in Low-Dimensional Quantum Materials
Kaverzin	Alexey	Proximity induced spin-orbit coupling and magnetism in graphene
King	Phil	ARPES studies of candidate van der Waals ferromagnets
Koperski	Maciej	Thin layers of CrBr3 and CrI3: reconaissance ventures into 2D magnetism
Lifshitz	Efrat	Spin systems in metal phosphorous trichalcogenide 2D van der Waals materials
Nakano	Masaki	Emergent properties of 2D magnets and their heterostructures explored by MBE

Surname	Name	Talk Title
Rappoport	Tatiana	Orbital Hall effect in 2D materials
Roedel	Tobias	Inside Nature: Decisions & Editorial Process
Shi	Jing	Spin current effects in 2D magnets/heavy metal bilayers
Sierra	Juan	Graphene based van der Waals heterostructures for spintronics
Singh	Simran	Spin galvanic effects and magnetization dynamics in layered vdW systems
Soriano	David	New Developments on Chromium Trihalides 2D Ferromagnets
Tsen	Adam Wei	Giant Nonlinear Anomalous Hall Effect
Van Wees	Bart	Magnon transport in 2D (anti-)ferromagnets
Verzhbitskiy	Ivan	Electrostatic Control of Magnetism in Van Der Waals Ferromagnets
Wang	Kang	Interface induced magnetism and skyrmions in layered heterostructure materials
Wang	Jing	Intrinsic magnetic topological states in MnBi2Te4
Woo	Seonghoon	Observation of magnetic skyrmions and their current-driven dynamics in van der Waals heterostructures
Yang	Hyunsoo	Spin-orbit torques based on topological spin texture and magnon
Ye	Jianting	Quantum Phase Transition and Ising Superconductivity in transition metal dichalcogenides

List of Contributions - Poster

Surname	Name	Poster Title
Bangar	Himanshu	Spin pumping from Ni80Fe20 into monolayer TMD
Bartolome	Fernando	Magnetism of FePc/Ag(110) + O2 Monolayer Phases
Birowska	Magdalena	2D magnetic crystal: An ab initio study of MnPS3
Budniak	Adam	Exfoliated CrPS4 with promising photoconductivity
Chen	Xin	3d Transition Metal Clusters on Defected Graphene
Garcia-Suarez	Victor Manuel	Electronics without bridging components
Hoque	Md Anamul	Charge - spin conversion in layered semimetal
Karpiak	Bogdan	Magnetic proximity in graphene/CGT heterostructure
Kaur	Daljit	Magnetic investigations in VSe2 and CrSe2 nanorods
Kawakami	Roland	Epitaxial growth of van der Waals magnets
Ke	Liqin	Electron correlations and spin excitations in CrI3
Khan	Safe	Intercalating sodium atoms in a vdWs magnet
Kocsis	Mátyás	Tuning the nonreciprocal resistance of BiTeBr
Lasek	Kinga	Molecular Beam Epitaxy of Self-Intercalated Transition Metal Tellurides
Lim	Soo Yeon	Thickness dependent magnetic transition of MnPS3
Liu	Mingzu	Tunable RT FM in 1L V-WS2 & V-WSe2 via CVD
Munoz	Francisco	Magnon Hall Effect in CrI3-based vdW systems

Surname	Name	Talk Title
Nie	Tianxiao	2D ferromagnetic materials above room temperature
Nikolaev	Sergey	Realistic modelling of monolayer NbS2 and NbSe2
Pezo	Armando	TMDC/Graphene an ab initio study
Quay	Charis	Tunneling spectroscopy of few-monolayer NbSe2
Rajan	Akhil	Morphology control of monolayer transition metal dichalcogenides by MBE
Reiser	Patrick	Scanning NV Magnetometry of 2D Magnetism
Sarkar	Kingshuk	Datta-Das Spin FET under various magnetic fields
Steinberg	Hadar	Spectroscopy of Layered SCs with vdW Tunnel Jcns
Szentpéteri	Bálint	Measurement of spin-orbit interaction strength
Tlahuice	Alfredo	Efecto de la Carga en la estructura del Au60
Toscano Figueroa	Jesus Carlos	Spin injection enhancement and spin-anisotropy in
Yamada	Toyo Kazu	Molecular Hopping in a 2D Carbon Monoxide Film
Yang	Hongxin	DMI of 2D Janus Structure
Yazdani Hamid	Meghdad	Effect of the strain on the transverse conductivity of Sr2RuO4
Zabila	Yevhen	Bismuth-based flexible magnetic sensors
Zhao	Bing	Conventional and unconventional CSC in WTe2