IPS Meeting 2020 - Reloaded
21 December & online

Institute of Physics Singapore

Live Program

(status: December 22, 2020, 18:32SGT)

Contents

1 Plenary sessions **2**
P1: Optical Micromanipulation with Meta-fluidics and Meta-structure 2
P2: Advances in Nonlinear Integrated CMOS Photonics 3
P3: Quantum Information Processing with Bosonic Modes in Circuit QED 3
P4: Infrared metrology with visible light: the power of quantum correlations 4
P5: From ultrafast spin currents to spintronics THz emitters and subpicosecond giant spin injection in semiconductors 5
P6: Ultrafast dynamics across 2D materials interfaces 6

2 Posters **7**

3 Technical Sessions **31**
T1: Topological Systems 1 31
T2: Mesoscopics 34
T3: Quantum Computation 38
T4: Photonics 1 41
T5: Topological Systems 2 44
T6: Theory of Quantum States 47
T7: Neuromorphic Computing 49
T8: Materials 1 52
T9: Strong correlations 55
T10: Classical vs. Quantum 58
T11: Perovskites 60
T12: Atomic and Optical Physics 63
T14: Multiscale percolation 65
T15: Photonics 2 68
T16: Materials 2 71
T17: Dirac Systems 74
T18: 2D Semiconductors and Photonics 76
T19: Machine Learning 79
T20: Quantum Applications 82

4 Committees **84**

Author List **85**

1 Plenary sessions

We have six distinguished plenary speakers this year – with a nice overview of recent activities in physical sciences in Singapore. You would find them live-streamed via zoom or over youtube - you can find the respective session on our youtube channel at https://www.youtube.com/channel/UCNwJRvAbXB-FXHBolj3F-Jw.

P1: Optical Micromanipulation with Meta-fluidics and Meta-structure

Assoc. Prof. QIU Cheng-Wei
Electrical and Computer Engineering,
National University of Singapore

21 December, 9:00am, Session 1

Abstract

This talk will demonstrate fundamental physics and origin, as well as experimental results, of extraordinary optical force phenomena, including negative pulling force, tunable lateral force, chiral force, negative radiation torque, and force application in biomedical applications. A comprehensive insight will be provided toward how to structure the light beams in meta-fluidics and meta-photonics, and how to tailor light-matter interaction to realize functionalized micromanipulations. The microfluidic chamber serves as a very powerful means to construct a coordinated light lattice, by the judicious interplay between optical force and drag force. Novel materials, like phase-change materials, chiral, and graphene, are also explored as new means. We also extend the previous micromanipulation toward nanomanipulation for sub-1nm particles, and propose novel scheme of synchronized dual barriers to sort out nanoparticles with single-digit nanometer precision. Furthermore, we shed a light to the recent advance in metasurface as a promising technology to structure complex lights so as to provide unexpected manipulation of nanoparticle.

P2: Advances in Nonlinear Integrated CMOS Photonics

Assoc. Prof. Dawn TAN
Engineering Product Development,
Singapore University of Technology and Design

21 December, 9:45am, Session 1

Abstract

Nonlinear optics processes rely strongly on the nonlinear figure of merit and magnitude of the nonlinearity of the platform. Nonlinear integrated optics further allow high field localization that facilitates high nonlinear phase acquisition at low powers. CMOS-compatible ultra-silicon-rich nitride devices possess large Kerr nonlinearity and absence of two-photon absorption at telecommunications wavelengths. These advantageous properties have enabled the demonstration of high gain amplifiers and soliton-effects in USRN devices. Nonlinear USRN Bragg gratings are further demonstrated to possess three orders of magnitude larger group velocity dispersion compared to photonic waveguides. Time-resolved measurements reveal high-order Bragg soliton dynamics as well as observation of compression and fission triggered by large third-order dispersion. We further discuss device designs enabling close to ten-fold soliton-effect temporal, as well as the implementation of integrated spectro-temporal compression systems.

P3: Quantum Information Processing with Bosonic Modes in Circuit QED

Asst. Prof. Yvonne GAO
Centre for Quantum Technologies and Department of Physics,
National University of Singapore

21 December, 11:00am, Session 2

Abstract

Over the past decade, the circuit quantum electrodynamics technology has emerged as one of the leading contenders for practical quantum computation. In particular, bosonic quantum states stored in superconducting microwave cavities provide highly robust and versatile building blocks for hardware-efficient quantum error-correction and information processing. In this talk, I will introduce some of the recent scientific achievements demonstrated in this framework and discuss the strategy for realising universal quantum computation and other related applications using bosonic modes in circuit QED.

P4: Infrared metrology with visible light: the power of quantum correlations

Dr. Leonid Krivitsky
Institute of Materials Research and Engineering (IMRE),
A*STAR

21 December, 11:45am, Session 2

Abstract

Infrared (IR) optical range is important for material characterization and sensing. Also, imaging in the IR range yields superior image contrast with low scattering losses. IR metrology is widely used in petrochemical, pharma, biomedical, homeland security, and other areas.

Even though there are well-developed conventional IR metrology methods, the remaining challenges are associated with the high cost and low efficiency of IR light sources and detectors. To mitigate these issues, we are developing new quantum-enabled techniques that allow us to retrieve the properties of materials in the IR range from measurements of visible range photons.

Our approach uses the nonlinear interference of frequency correlated photons produced via spontaneous parametric down-conversion (SPDC) [1, 2]. We generate one photon in the visible range and its correlated counterpart in the IR range. Then we build an interferometric setup around the SPDC source and observe the interference of visible photons. The visibility and phase of the observed interference depend on the properties of the IR photon, which interacts with the sample. Thus, we can infer the properties of the sample in the IR range from measurements of visible range photons.

In a series of experiments, we demonstrate applications of this method in IR spectroscopy [1-4], optical coherence tomography (OCT) [5], polarimetry [6], and wide-field microscopy [7, 8]. In all these demonstrations, we infer the IR properties of the samples from the measurements of the interference pattern in the visible range using off-shelve components. We are thus making IR measurements more affordable for practical applications.

References

[1] D. Kalashnikov, et al., Nature Photonics 10, 98 (2016).
[2] A. Paterova, et al., Scientific reports 7, 42608 (2017).
[3] A. Paterova, et al., New Journal of Physics 20, 043015 (2018).
[4] A. Paterova and L. Krivitsky, Light: Science & Applications 9:82 (2020).
[5] A. Paterova, et al., Quantum Science & Technology 3, 025008 (2018).
[6] A. Paterova, et al., Opt. Express 27, 2589-2603 (2019).
[7] A. Paterova, et al., Appl. Phys. Lett. 117, 054004 (2020) – Editor's Pick.
[8] A. Paterova et al., Science Advances 6:eabd0460 (2020).

P5: From ultrafast spin currents to spintronics THz emitters and subpicosecond giant spin injection in semiconductors

Asst. Prof. Marco BATTIATO
School of Physical and Mathematical Sciences,
Nanyang Technological University

21 December, 2:00pm, Session 3

Abstract

In 2010 I proposed the existence of out-of-equilibrium spin current pulses [1-3] and that they could explain the origin of the ultrafast demagnetisation. [4] A number of experimental works have confirmed such picture [5-8] and realised predictions such as the transfer of magnetisation in the non-magnetic substrate and the ultrafast increase of magnetisation. [5-6] The most interesting application was the development of the now widely known spintronics THz emitters. [8] Spintronics THz emitters have attracted a lot of attention, because of the wide and continuum spectrum as well as their ease of both production and use over alternative technologies. Few years ago I made another prediction: the possibility of injecting these ultrashort spin current pulses from a ferromagnetic metal into a semiconductor. [9] By taking advantage of the strongly out-of-equilibrium electronic distribution, such ultrashort spin currents pulses were predicted to be injected into a semiconductor with a huge intensity and high spin polarisation. We have recently proved this experimentally [11] by producing ultrashort spin current pulses into cobalt, injecting them into monolayer MoS2 and measuring emitted THz radiation. As predicted, we observed a giant spin current, orders of magnitude larger than typical injected spin current densities in modern devices. Such current pulses have the possibility of becoming the carriers of information in future spintronics running at unprecedented frequencies above the THz regime.

Acknowledgements

As many authors contributed to the presented results, please see the cited references for a comprehensive list.

References

[1] M. Battiato, K. Carva, P.M. Oppeneer, Phys Rev. Lett. 105, 027203 (2010).
[2] M. Battiato, K. Carva, P.M. Oppeneer, Phys Rev. B 86, 024404 (2012).
[3] M. Battiato, P. Maldonado, P.M. Oppeneer, J. Appl. Phys. 115, 172611 (2012).
[4] E. Beaurepaire, J.-C. Merle, A. Daunois, and J.-Y. Bigot, Phys. Rev. Lett. 76, 4250 (1996).
[5] A. Melnikov et al., Phys. Rev. Lett. 107, 076601 (2011).
[6] D. Rudolf, . . . M. Battiato, et al., Nature Comm. 3, 1037 (2012).
[7] A. Eschenlohr, M. Battiato, et al., Nature Mater. 12, 332 (2013).
[8] T. Kampfrath, M. Battiato, et al, Nature Nanotechnol. 8, 256 (2013).
[9] M. Battiato and K. Held, Phys Rev. Lett. 116, 196601 (2016).
[10] M. Battiato J. Phys. Condens. Matter 29, 174001 (2017).

[11] L. Cheng, . . ., M. Battiato et al., Nature Physics (2019).

P6: Ultrafast dynamics across 2D materials interfaces

Assoc. Prof. EDA Goki
Department of Physics,
National University of Singapore

21 December, 2:45pm, Session 3

Abstract

One of the most remarkable features of van der Waals heterostructures based on two-dimensional (2D) materials is the ultrafast photo-induced interlayer charge transfer, which is known to occur in sub-picosecond time scales. Such ultrafast dynamics offers promise for the realization of novel hot carrier optoelectronic devices where non-thermalized or "hot" photocarriers are harnessed to achieve unconventional functions. In this talk, I will discuss a few examples of hot carrier optoelectronic phenomena in heterostructures of 2D transition metal dichalcogenides and our approach to probing the ultrafast dynamics of the system through steady-state photocurrent and quantum yield measurements. First, I will discuss near-infrared-to-visible light upconversion in an electrically biased 2D materials heterostack. Second, I will highlight our observation of unexpected photoresponse of these devices arising from exciton-exciton annihilation (EEA). I will show how EEA can result in highly energetic electrons and holes due to significantly uneven distribution of annihilation energies.

2 Posters

Although we can not replicate the interactive nature of a poster session in this online format, we try to emulate it by providing links to the poster provided by the authors.

During the preliminary programme phase, if you find your link is missing here, please ensure that you uploaded it via easychair and eventually notify the organizers.

PO.10 Parabolic Transformation of the Lorentz Group (link)

Mark Goh* (National University of Singapore)

It is well known that the Lorentz group is isomorphic to the special linear group SL(2,C) and the Möbius transformations of the complex plane. However, there exists a unique transformation known as the parabolic transformation in which there is only one fixed point in the plane whereas the Lorentz group consisting of boosts and rotations each have two fixed points. It can be shown that for a given velocity/Lorentz boost, there exists a unique angle of rotation that would result in only 1 fixed point.

PO.14 Universality of the Sznajd Model with Anticonformity on a Fully-Connected Network

Roni Muslim*, Rinto Anugraha, Sholihun Sholihun, Muhammad Farchani Rosyid (Universitas Gadjah Mada)

In this work, we study the opinion dynamics of the Sznajd model in sociophysics with an additional property of anticonformity on a fully-connected network. In the large system size N, we consider the dynamics of four spins according to the original Sznajd's rule. We perform both analytical calculation and numerical simulations to find the transition points. We obtain the agreement results between the analytical and the numerical methods. By varying N, we also estimate the critical exponents of the systems in the vicinity of the transition point and reveal that there is a universality in the Sznajd model. Our results suggest that the model belongs to the mean-field Ising universality class model.

PO.16 Simulating the effects of inelastic self-interacting dark matter on the structure of a Milky Way halo

Kun Ting Eddie Chua*, Karia Dibert, Mark Vogelsberger, Jesus Zavala (Institute of High Performance Computing)

The standard cold dark matter (CDM) model has demonstrated success in describing formation and evolution of large-scale structure in the universe, but encounters various problems at sub-galactic scales. These include the missing satellites problem and the cusp-core discrepancy in low-mass galaxies. By considering dark matter particles that strongly self-interact, self-interacting dark matter (SIDM) can be useful for addressing these issues. Although previous SIDM simulations mainly considered elastic collisions, theoretical considerations motivate the existence of multi-state dark matter. In this work, we consider a two-state inelastic SIDM model, where excited to ground state transitions are exothermic and impart velocity kicks related to the mass splitting between the states. We examine the impact of such inelastic self-interactions on the structure of a simulated Milky Way-size dark matter halo, and perform a comparative analysis between CDM, elastic SIDM, and inelastic SIDM models. We find that the energy injection resulting from inelastic self-interactions lead to the formation of a larger core, and reduce the central densities at an earlier redshift compared to elastic SIDM. Additionally, inelastic collisions isotropize the dark matter orbits, resulting in lower velocity anisotropy than the elastic SIDM counterpart. The velocity distribution of dark matter particles at the location of the Sun in the inelastic SIDM model shows a significant departure from the CDM model, and falls more steeply at high speeds. The velocity kicks imparted during inelastic collisions also produce unbound high-speed ground-state particles with velocities more than 500 km/s throughout the halo. These effects imply that inelastic self-interacting dark matter models could be distinguished from CDM or elastic self-interacting models through direct dark matter detection experiments.

PO.20 Measurement-device-independent quantification of irreducible entanglement

Bai Chu Yu, Yu Guo, Xiao Min Hu, Bi Heng Liu*, Yu Chun Wu*, Yun Feng Huang, Chuan Feng Li, Guang Can Guo (University of Science and Technology of China)

The certification of entanglement dimensionality is of great importance in characterizing quantum systems. Recently, it is pointed out that quantum correlation of high-dimensional states can be simulated with a sequence of lower-dimensional states. Such cheating strategy may render existing characterization protocols unreliable—the observed entanglement may not be a truly high-dimensional one. Here, we introduce the notion of irreducible entanglement to capture its dimensionality that is indecomposable in terms of lower-dimensional entanglement. We prove this new feature can be detected in a measurement-device-independent manner with an entanglement witness protocol. To demonstrate the practicability of this technique, we experimentally apply it on a 3-dimensional bipartite state and the result certifies the existence of irreducible (at least) 3-dimensional entanglement.

PO.21 Blue on blue: blue fluorescing aluminium molybdate for methylene blue sensing (link)

Nuur Hasanah* (Millennia Institute)

This report presents an easy method of thermally depositing molybdenum oxide (MoO_3) onto a binary metal oxide (Al_2O_3). This was done by (1) irradiating a graphene oxide (GO) film with a focused laser beam through a solution containing aluminium cations (2) heating Mo vapours onto the laser-cut sample using a hotplate. The hybrid sample is then characterised using Fluorescence Microscope (FM), Raman Spectroscopy, Photoluminescence Spectroscopy (PL), Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), Energy dispersive X-ray (EDX) and X-ray Photoelectron Spectroscopy (XPS). It is found that the hybrid sample can bring about localised surface plasmon resonance (LSPR) which enhances signals of molecules through surface enhanced Raman scattering (SERS) effect. For this reason, its applicability for sensing of Methylene blue (MB) is proposed. Remarkably, it is able to sense MB, even at a miniscule concentration of 10^{-16} mol/L. To conclude, using this hybrid sample of Al-Mo, a simple, inexpensive and responsive MB sensor is created.

PO.22 Origin and Enhancement of Large Spin Hall Angle in Weyl Semimetals LaAlX (X=Si, Ge) (link)

Truman Ng* (National University of Singapore)

The origin of strong spin Hall effect (SHE) in recently discovered a family of Weyl semimetals, LaAlX (X=Si, Ge) is studied using the first-principles with Wannier approaches. We show that the strong intrinsic SHE in LaAlX originates from the multiple slightly anticrossings of nodal lines and points near EF due to their high mirror symmetry and large spin-orbit interaction. It is further found that both the electrical and thermal means can enhance the spin Hall conductivity (SH). However, the former also increases the electrical conductivity (c), while the latter decreases it, and as a result, such independent tuning SH and c by the thermal means can greatly enhance the spin Hall angle (proportional to SH c), a figure of merit of charge-to-spin current interconversion of spin-orbit torque devices. The underlying physics of such independent changes of the spin Hall and electrical conductivity and enhancement of spin Hall angle by thermal means is revealed through the band-resolved and k-resolved spin Berry curvature. Our finding offers a new way to search high SHA materials for room-temperature spin-orbitronics applications.

PO.24 Exchange Bias in an Antiferromagnetic/Ferromagnetic van der Waals Heterostructure (link)

Rui Zhu, Wen Zhang*, Wei Shen, Andrew Wee* (Department of Physics, National university of Singapore)

Exchange bias, manifesting as a shift of the hysteresis loop of the ferromagnetic (FM) material along the magnetic field axis, was first discovered in Co nanoparticles surrounded by their native antiferromagnetic (AF) oxide by Meiklejohn and Bean in 1956. Since then, such an effect has been optimized and widely become an indispensable mechanism in modern magnetic storage technologies. Apart from the conventional exchange-biased metallic multilayers, a variety of AF/FM systems have also shown exchange bias, where the interfacial exchange interaction between the adjacent AF and FM layers dominates. However, it remains unclear whether an AF/FM van der Waals (vdW) interface can host this effect. Here, we present the first demonstration of the exchange-bias effect in layered $CrCl_3$/FGT vdW heterostructures via anomalous Hall effect (AHE) measurements. Excitingly, we found an exchange-bias shift in the Rxy-H loops, with the bias field of over 50 mT at 2.5 K, comparable to or even higher than conventional metallic multilayers. Its magnitude is moreover tunable by adjusting the field-cooling process, revealing the crucial role of the weakly anisotropic AF $CrCl_3$ - with its spin alignment sensitive to the cooling magnetic field - in the generation and magnitude of exchange bias in such a vdW heterostructure. Being the first in the field, this work is expected to trigger explosive investigations onto similar structures for spintronic applications, given the apparent advantages of vdW magnets such as controllable exfoliated thickness and mechanical flexibility.

PO.25 Graphene Oxide: Making a Potential Difference (link)

Malcolm Sow* (NUS High School)

With the growing need for renewable energy sources, blue energy, is a promising avenue for exploration. Recently, graphene oxide (GO) has gained more attention in this field of research due to its numerous negatively-charged polar groups, and has been the subject of recent studies. Here we tested the electrical potential generated by a 0.5 mm x 0.5 mm GO membrane samples by partially submerging them in DI water, returning a 0.8 V/cm^2 yield. Charges on the GO surface acted as trapping sites for ions in the solution, creating a positively-charged surface, and leaving a negatively-charged solution. As a result, electric potential difference generated via charge separation is achieved. This was followed by the alteration of many aspects of the experiments, such as using a focused-laser beam to pattern channels on the sample, using salt water and connecting multiple samples in a series circuit. All three factors increased the potential generated by the GO samples used, up to a voltage yield of 1.2 V/cm^2. The voltage generated by a pristine GO sample is relatively high as compared to recent studies on blue energy using GO, which returned yields of 0.4 – 0.7 V/cm^2. The alterations made to the experiments further enhance the potential generated, making the GO cells comparable to a AAA battery and presenting the possibility of a more compact, flexible and efficient energy source. More varieties of laser-cut patterns and actual trials using real seawater would be required to test the real-life applications and usefulness of such a power source.

PO.35 Cyclotron production of no carrier added theranostic radionuclide 186Re

Mayeen Khandaker*, Kotaro Nagatsu, David Bradley (Sunway University)

186Re (T1/2 = 89.24 h, E ($\beta-$)mean= 346.7 keV, I ($\beta-$)mean = 92.59%), a mixed beta and γ-emitter shows great potential to be used as an active material in theranostic applications due to its suitable physico-chemical properties. It is worth mentioning that a number of processes can be used for the production of 186Re; the dominant one is the neutron activation on different materials via the use of nuclear reactor but this route provides 186Re in carrier added form with low specific activity. Due to the low specific activity radionuclides production via (n,γ) process, methods of enhancing the specific activity of 186Re by other means are desirable. Fortunately, cyclotrons offer no carrier-added (NCA) and high specific activity production of numerous radionuclides. High specific activity is generally required for radiolabeling of tumor-specific antibodies. Therefore, cyclotrons can be used as an alternative to nuclear reactors for the production of 186Re via 186W(p,d,3He,4He; x) reactions. To be able to select the best possible nuclear reaction and optimize the production route one should know the excitation function for the selected main reaction as well as for the competing reactions. An accurate knowledge of nuclear reaction cross sections plays a crucial role for the NCA production of desired radionuclide by cyclotron. Thus, we performed a detailed study on the excitation functions of natW(p,d,3He; x) reactions to optimize the parameters for the NCA production of 186Re by using an external beam line of the AVF-930 cyclotron of the National Institute of Radiological Sciences (NIRS), Japan. Physical thick target yields for the investigated reaction products were deduced from the measured cross-sections, and optimum parameters for NCA production of 186Re are recommended from the knowledge of the deduced physical yield.

PO.37 2D materials imaging with single electron transistor (link)

Jinpei Zhao*, Sourav Mitra, Chrong Haur Sow, Konstantin Novoselov*, Jens Martin* (Leibniz Institute for Crystal Growth)

Single electron transistor(SET) is a device where a quantum dot capacitively couples to two leads. The current going through the dot can be modulated by surrounding electrostatic potential which is known as Coulomb blockade effect. When SET is implemented with a scanning tip, it can measure surface potential, local electronic compressibility(i.e. many body density of state) of 2D materials. Here we use a special scheme to fabricate SET tips. We evaporate aluminum on a sharp quartz tip to build leads and quantum dot, meanwhile, with in situ oxidation to form tunnel junctions between leads and quantum dot. After this we can get a SET tip with ∼100 nm spatial resolution and ∼μV voltage sensitivity. We have showed preliminary result which is the surface potential distribution on a silicon chip with SiO_2 layer, it shows roughly 50 mV potential variance.

PO.42 Particle-in-cell simulation of plasmons (link)

Jeremy Lim*, Wenjun Ding, Hue Do, Xiong Xiao, Zackaria Mahfoud, Jason Png, Michel Bosman, Lay Kee Ang*, Lin Wu* (Institute Of High Performance Computing)

Plasmons are collective oscillations of the electrons in conducting media such as metals. In many cases of interest, plasmons are typically characterized by solving the Maxwell equations, where the electromagnetic response can be described by the bulk permittivity. Motivated by the physical similarity of plasmas and oscillating conduction electrons, we present a particle-in-cell-based method of simulating plasmons. By tracking the particle position and momentum through time, which are in turn connected to the electromagnetic fields through current, we demonstrate the capability of this novel approach in elucidating information on the formation of the plasmons. Specifically, we demonstrate plasmon formation in gold nanoribbons through laser irradiation and single-electron excitation. Lastly we investigate the non local effects of ultra-small nanoparticles approaching quantum limit.

PO.45 Contactless characterization of superconducting films (link)

Lijiong Shen*, Andreas Aigner, Jianwei Lee, Cesare Soci, Christian Kurtsiefer (Centre for Quantum Technologies, NUS)

There is a growing interest in the development of superconducting nanowire single-photon detectors (SNSPD), made by etching meander patterns on thin superconducting films, as they have high detection efficiencies of more than 90%, and low timing jitters down to a few picoseconds. An important metric when selecting candidate materials for SNSPDs is the critical temperature of the superconducting film. Typical methods to measure the critical temperature requires direct contact with the films, which risks damage and reduces the usable area of the films. In this work, we develop a contactless method to measure the superconducting critical temperature using a Colpitts oscillator. We position the inductor coil of a Colpitts oscillator near the superconducting film to induce an eddy current within it. The film acts as a perfect diamagnet when it is superconducting, effectively lowering the overall inductance of the combined oscillator-film system. However, the film abruptly loses its perfect diamagnetism as it transits between its superconducting and conducting state. This results in a corresponding change in the resonant frequency of the system which can be easily observed, allowing us to identify the state transition and its associated critical temperature. We successfully resolved the state transition of two NbTiN films with thicknesses of 5.8 nm and 66 nm. The same technique can be extended to study the influence of the external magnetic field on the superconducting states as well.

PO.47 Phase Transition and Transient Magnetization of Two Opinion Dynamics Models in Sociophysics

Rinto Anugraha*, Roni Muslim, Indri Yanti (Universitas Gadjah Mada)

In this work, we consider two models in sociophysics dynamics called the 2D Sznajd-Stauffer model and 1D Biswas-Sen model using Ising-like spin system in square lattice with the size N. In the first model, we investigate the competition between the two different opinions (up and down opinions) by putting an opinion as a whole blockaded by the other one. By applying the rule of the opinion change in the 2D Sznajd-Stauffer model, it is well known that the final state is homogeneous, either all spins in the up or in the down state. Therefore, we vary the average ensemble magnetization at the final state as a function of the initial density of one opinion, and then we found that there is a smooth and a continuous transition from a homogeneous state to another homogeneous one. The dependence of the transition point on the system size is also investigated. By measuring the average relaxation time for a fixed system size, we consider the dynamics when the time simulation is set smaller than the relaxation one, in order to avoid the homogeneous states. Here, we discuss properties of the transient magnetization in details. In the second model, we show in the Biswas-Sen model the phase transition of the final magnetization as a function of the initial magnetization. The critical point of the transition might depend on the system size.

PO.51 Testing Random Numbers with Machine Learning

Zestin Tay*, Valerio Scarani (National University of Singapore)

The quality of a random number generator (RNG) could potentially be evaluated via Machine Learning (ML): given a series of outputs of an alleged RNG, the ML algorithm is trained to guess the subsequent output. In this project, we implement Artificial Neural Networks (ANNs) to search for possible patterns that may occur in a set of sequences previously generated by a simple Pseudo-Random Number Generator (PRNG) - the Linear Feedback Shift Register (LFSR) - and then predict the next output of the PRNG. In our current implementation, the network is capable of predicting the subsequent outputs of up to a 25-bit register (whose output has a period of 33554431), after learning from a set of 10000 100-bit sequences.

PO.53 Multi-peak property in 3D nodal-point semimetals under field emission (link)

Wei Jie Chan*, Yee Sin Ang*, Ricky Ang* (SUTD)

The modelling of the field emission process, of an N-node nodal-point semimetal, across a Schottky-Nordheim potential barrier, is studied under the Dirac cone approximation, with an immediate replenishment carrier assumed to be injected at the Fermi level, for each emitted carrier. From the derivation of the generalised current density, we extract out the main driving factors of the total energy distribution and observe an elusive multi-peak property. In particular, by tuning over a range of parameters, F, T and Fermi level, the behaviour of the total energy distribution, of a nodal-point semimetal, determines the energy transport of the emission process. Consequently, this allow nodal-point semimetals to be benchmark by the current density, against conventional metals, where nodal-point semimetals are shown to be a better alternative over its conventional counterparts, under certain parameters.

PO.55 Heavy Metal Filtration Using a Capacitive Deionization System in Graphene Oxide-Based Supercapacitors

Ardhi Haq*, Catur Prihatmoko, Amirul Hakim (Gadjah Mada University)

The high content of heavy metals in the water used by batik artisans certainly causes pollution to the environment around the population. The heavy metals in question are such as Lead (Pb), Cadmium (Cd) whose levels reach 0.2349 mg/L for lead and 0.0064 mg/L for cadmium in wastewater used by batik artisans. Though these dangerous elements if entered into the body of living things like humans can cause various diseases such as cancer, gene mutations, and complications. One method for separating heavy metals is CDI or Capacitive Deionization which is a separation with 2 electrodes parallel to give a potential difference to the solution. In this study, the process of increasing the absorption of heavy metals is examined using the CDI method with a Graphene-based electrode with polyacrylonitrile (PAN) nanofiber that can increase the nanofiber conductivity to 1.36 mS cm^{-1}. The results stated that the capacitance of the PAN/rGO capacitor has a value of 2.9×10^{-2} F so it is classified as a supercapacitor. In the conductivity screening test, the difference between the initial and final conductivity in the PAN capacitor is 1.1×10^2 μs, while the PAN/rGO capacitor is 5.2×10^2 μs. In the transmittance test, the PAN/rGO capacitor has an intensity value of 90% while the fluorescence test is worth 3000. With this result, the PAN/rGO capacitor has the potential to be further developed in heavy metal waste filtering technology.

PO.57 Van der Waals Heterostructures with tunable tunneling behavior enabled by MoO_3 surface functionalization

Yanan Wang*, Du Xiang, Yue Zheng, Jing Gao, Wei Chen (national university of singapore)

Heterostructures of two-dimensional (2D) materials represent a powerful material platform that has essentially defined the technological foundation for all modern electronic and optoelectronic devices. Although most of the reported heterostructures devices exhibit extraordinary electronic and optoelectronic properties, it depends on the proper combination of selected materials, which limits the broad tunability of the devices. Here, we demonstrate a vertical van der Waals heterostructures (vdWHs) device, which is composed of MoS_2 and $MoTe_2$, can function as a backward tunneling diode, photovoltaic cell and photodetector through surface functionalization of MoO_3. The realization of this backward tunneling diode is attributed to the band alignment variation from type II to type III via in situ MoO_3 functionalization. Furthermore, the power conversion efficiency of this vdWHs based photovoltaic device is significantly enhanced by nearly 4 times, benefiting from the more efficient photocarrier separation after MoO_3 decoration. The enhanced photovoltaic effect can be retained even after air exposure, revealing the excellent air stability. Meanwhile, the modified vdWHs device exhibits the photodetecting property with photocurrent responsivity of around 2 A/W and EQE about 400%. This work promises surface functionalization as an effective approach to broaden the device functionality of 2D heterostructures in electronics and optoelectronics.

PO.59 Distinguishing Two Modes

Chee Wei Soh* (National University of Singapore)

We consider the problem in which an optical mode is sent from Alice to Bob. Suppose that the signal sent is promised to be in either one of two modes, Bob can use probabilistic discrimination to identify which of the two modes was sent. The maximal probability of a correct guess is given by the Helstrom bound, which is dependent on the relative overlap of the two states. It can further be deduced that in general, the probability of discriminating two Fock states are higher than that of two coherent states. Using linear programming, we will be able to determine the optimal optical modes that give the highest probability of discrimination.

PO.61 Out-of-plane homojunction enabled high performance SnS_2 lateral phototransistor

Jing Gao*, Hang Yang, Hongying Mao, Du Xiang, Wei Chen (National University of Singapore)

Two-dimensional (2D) materials have been extensively applied in electronic and optoelectronic devices due to their unique and extraordinary electrical and optical properties. Among them, tin disulfide (SnS_2) has attracted enormous research interests due to their low-cost, earth-abundant, environment friendly properties as well as superior performance as photodetectors. Here, we demonstrate an outstanding in-plane SnS_2 phototransistor with an out of plane built-in electric field enabled by MoO_3 surface functionalization. The photocarriers are generated and effectively separated by the vertical electric field, leading to a high photoresponsivity of $2.3*10^3$ A/W, photoconductive gain of $> 10^5$, external quantum efficiency exceeding 8%. It also demonstrates a low noise power density, revealing an ultrasensitive photodetection with specific detectivity up to $3.2*10^{12}$ Jones. The formation of the out of plane built-in electric field is validated by the output electrical transport measurement of SnS_2 vertical transistor, and further corroborated by in situ ultraviolet photoelectron spectroscopy and X-ray photoelectron spectroscopy characterizations. Our findings promise surface functionalization as an effective approach to induce an internal electric field in 2D multilayer SnS_2 towards its application in high performance photodetection.

PO.72 A versatile setup for tunable optical potentials with BECs

Koon Siang Gan*, Francesca Tosto* (National University of Singapore)

Bose-Einstein Condensates (BECs) in optical potentials are a great platform for simulating and studying complex quantum systems. There have been many experiments which utilise red and blue detuned lasers to simulate simple structures like a ring or disc. Yet, more complicated light structures require more elaborate and clever ways of manipulating the atom cloud. Here we present a setup which utilises a Digital Micromirror Device (DMD) which is able to create elaborate light structures.

We further demonstrate by loading atoms into some of these structures together with a tunable light sheet for thickness control. Such a setup is potentially able to study 1D physics such as a ring structure.

PO.76 The CQT group III machine

Jinchao Mo*, Xianquan Yu, Ting You Tan, Steven Touzard, Travis Nicholson* (Centre for Quantum Technologies, NUS department of physics)

An ultracold gas of group III atoms could enable highly accurate atomic clocks, new tests of fundamental physics, and novel quantum many body states; however, no group III atom has been cooled to ultracold temperatures. In this presentation, we describe our apparatus for cooling group III atoms to the ultracold regime.

PO.78 The NUS CQT strontium machine

Steven Touzard*, Ravinraj Ramaraj, Rui Wang, Travis Nicholson* (Centre for Quantum Technologies, NUS department of physics)

Ultracold strontium has been used for a variety of interesting experiments in recent years, such as highly accurate atomic clocks, quantum simulations of condensed matter systems, precision gravity measurements, and quantum information. At NUS we are constructing a strontium apparatus to study many of these phenomena. Here we describe our new apparatus and future plans for this system.

PO.80 Harnessing exciton-exciton annihilation in two-dimensional semiconductors

Eric Linardy*, Dinesh Yadav, Danielle Vella, Ivan A Verzhbitskiy, Kenji Watanabe, Takashi Taniguchi, Fabian Pauly, Maxim Trushin, Goki Eda* (National University of Singapore)

Two-dimensional transition metal dichalcogenide (TMD) has exhibited highly efficient exciton-exciton annihilation (EEA). The energy released by this process has previously been harnessed for light upconversion in both 2D TMD and their heterostructures. Here, we demonstrate the possibility of exploiting efficient EEA mechanism for energy harvesting application by utilizing metal-insulator-semiconductor (MIS) van der Waals heterostructures device. The MIS device exhibit significant photoresponse under illumination of laser with photon energy below the quasiparticle bandgap of the monolayer TMD despite the high exciton binding energy and insulator energy barrier. By applying kinetic model to our power-dependence measurement of photocurrent and photoluminescence response, we attribute EEA as the origin of the significant photoresponse under illumination below quasiparticle bandgap. Additionally, DFT modelling was utilized to model the energy distribution of electron and holes generated by EEA. Our study demonstrates the feasibility of harnessing EEA in 2D semiconductor-based optoelectronic devices.

PO.88 Highly efficient on-chip plasmonic detectors based on Cu/p-Si Schottky diodes (link)

Fangwei Wang*, Thorin Jake Duffin, Vijith Kalathingal, Christian A. Nijhuis* (National University of Singapore)

The integration of plasmonic devices with complementary metal oxide semiconductor (CMOS) technology holds the potential towards a new generation of ultra-dense interconnects1-4. One of the major challenges is the lack of CMOS-compatible surface plasmon detectors, which should operate at room temperature and achieve high plasmon-electron conversion efficiency5-6. In order to develop CMOS-compatible surface plasmon detectors, different approaches have been demonstrated including electron-hole separation7, hot electron injection8, and optical rectification9. One of the reasons why we are interested in Schottky diodes is the lower Schottky barrier height compared to the energy bandgap of silicon, which allows the detection wavelength of Schottky diodes be extended to near-infrared wavelength8. Schottky diodes have been demonstrated as plasmonic detectors before. But only their responsivity was reported while the plasmon-electron conversion efficiency remained elusive. Metal-insulator-metal tunnelling junctions (MIM-TJs) were also used as highly efficient plasmon detectors via plasmon-assisted tunnelling (PAT) process10. However, the materials used for top electrode was Au, which is not CMOS-compatible. Instead, Al and Cu are commonly used in silicon electronics. Herein, a highly efficient, on-chip, CMOS compatible plasmonic Schottky photodetector (Cu/p-Si diode) based on hot carrier injection mechanism was presented. The Schottky barrier height was determined to be around 0.50 eV fitted by thermionic emission model at different temperatures ranging from 140 K to 300 K. In order to measure plasmon-electron conversion efficiency, a plasmonic source based on Al/AlOx/Cu tunnelling junction and a plasmonic detector based on Cu/p-Si diode were integrated with a single Cu plasmonic waveguide. The overall efficiency (electron-plasmon-electron) was around 1.2 %, which was one order higher than the MIM-TJs counterparts (0.1%). The plasmon-electron detection mechanism is believed to be hot carrier injection including three steps: 1) hot carriers creation by plasmon decay. 2) hot carriers diffusion to Schottky interface. 3) hot carriers injection over Schottky barrier. The photoresponse of Schottky diodes was also measured by focusing laser at the end of the Cu waveguide to excite plasmon at λ=1.55 μm.

References 1. Goykhman, I.; Desiatov, B.; Levy, U., Silicon Plasmonics. In Plasmonics: Theory and Applications, Shahbazyan, T. V.; Stockman, M. I., Eds. Springer Netherlands: Dordrecht, 2013; pp 149-166. 2. Goykhman, I.; Desiatov, B.; Khurgin, J.; Shappir, J.; Levy, U., Locally Oxidized Silicon Surface-Plasmon Schottky Detector for Telecom Regime. Nano Letters 2011, 11 (6), 2219-2224. 3. Walters, R. J.; van Loon, R. V. A.; Brunets, I.; Schmitz, J.; Polman, A., A silicon-based electrical source of surface plasmon polaritons. Nature Materials 2009, 9, 21. 4. Zhang, H.; Zhang, R.; Schramke, K. S.; Bedford, N. M.; Hunter, K.; Kortshagen, U. R.; Nordlander, P., Doped Silicon Nanocrystal Plasmonics. ACS Photonics 2017, 4 (4), 963-970. 5. Dorodnyy, A.; Salamin, Y.; Ma, P.; Plestina, J. V.; Lassaline, N.; Mikulik, D.; Romero-Gomez, P.; Morral, A. F. i.; Leuthold, J., Plasmonic Photodetectors. IEEE Journal of Selected Topics in Quantum Electronics 2018, 24 (6), 1-13. 6. Berini, P., Surface plasmon photodetectors and their applications. Laser & Photonics Reviews 2014, 8 (2), 197-220. 7. Goodfellow, K. M.; Chakraborty, C.; Beams, R.; Novotny, L.; Vamivakas, A. N., Direct On-Chip Optical Plasmon Detection with an Atomically Thin Semiconductor. Nano Lett 2015, 15 (8), 5477-81. 8. Akbari, A.; Tait, R. N.; Berini, P., Surface plasmon waveguide Schottky detector. Opt. Express 2010, 18 (8), 8505-8514. 9. Stolz, A.; Berthelot, J.; Mennemanteuil, M. M.; Colas des Francs, G.; Markey, L.; Meunier, V.; Bouhelier, A., Nonlinear photon-assisted tunneling transport in optical gap antennas. Nano Lett 2014, 14 (5), 2330-8. 10. Du, W.; Wang, T.; Chu, H.-S.; Nijhuis, C. A., Highly efficient on-chip direct electronic–plasmonic transducers. Nature Photonics 2017, 11 (10), 623-627.

PO.90 Coupling Monolayer WS_2 with a Photonic Polymer Waveguide Through Mode-Center Placement (link)

Justin Zhou*, Angelina Frank, Ivan Verzhbitskiy, James Grieve, José Viana-Gomes, Alexander Ling, Goki Eda (National University of Singapore)

The core requirement and challenge for integrated hybrid photonic platforms is effective coupling between the guided mode of a photon-routing structure and a photo-active material. In traditional (e.g. silicon nitride) platforms, the mode center is inaccessible and one must allude to emitter placement adjacent to the waveguide which significantly limits the interaction between material and platform. Here, we overcome this limitation through successful integration of an atomically thin 2D material (WS_2 on hBN) into the mode center of a novel elastomeric single-mode rib waveguide. We verify waveguide-emitter coupling by various means: observing polarization-dependent excitation of the integrated emitter as well as polarization-dependent extinction in transmission measurements. The device's elasticity, mild fabrication conditions and low-resource requirements make this platform promising for sensing, rapid-prototyping and mechanical tuning as well as for the integration of additional structures such as plasmonic nanospheres and for further chemical functionalization. Representative for room-temperature curing polymers, this work opens up new ways for the integration of (single-photon) emitters into polymer-based optical circuits.

PO.91 Magnetic field effects on biological material

Kaisheng Lee* (Nanyang technological university)

Magnetoreception is the ability of certain organisms to sense magnetic fields and utilise the information. It has been observed widely across phyla, from higher vertebrates like birds for migration, to magnetotactic bacteria for passive alignment to Earth's field lines. However, the mechanisms with which this sense employs has largely been unknown. While the link between migratory tendencies and magnetoreception has been well-established, the implementation of such studies tend to be limited by migratory seasons or require specialised staging areas. We improve upon a scaled-down experimental setup to investigate the magnetic sense in Periplaneta americana, the american cockroach, by a previous study by M. Vacha. We show that the American cockroach is sensitive to directional shifts in the magnetic north, confirming a magnetic sense in a non-migratory species, suggesting a function unrelated to navigation. Using a reductionist approach, we probe deeper into the biological effects on a cellular level. The C2C12 mouse myoblast cell line was used with the figure of merit being cell proliferation. Using our configuration of protocols and methodology, it is shown that Pulsed Electro-Magnetic Fields (PEMFs) have a negative effect on proliferation. The main frequency components utilised (3.3-16.6 kHz) are orders of magnitudes lower than the radio-frequencies (MHz) known to disrupt avian magnetoreception, showing that the current models for magnetoreception are unable to explain these observations.

PO.93 Switching rate measurements in self-assembled tunnel junctions

Hippolyte P.A.G. Astier*, Yingmei Han, Cameron Nickle, Ziyu Zhang, Thorin J. Duffin, Zhe Wang, Dongchen Qi, Enrique del Barco, Damien Thompson, Christian A. Nijhuis* (Department of Chemistry, National University of Singapore, 3 Science Drive 3, Singapore 117543)

The field of molecular electronics has recently reached a stage where technological functionalities have successfully been integrated into molecular-junction-based devices, in particular in films consisting of a self-assembled monolayer (SAM). Diodes1, transistors, optical switches, and spintronics components have been demonstrated using self-assembled molecular junctions2. The switching mechanism depends on several factors, i.e. the thermodynamic and stochastic nature of the chemical transition as well as the junction's topography. Theoretically, the mechanisms underlying these transitions have been studied3,4 but practical investigations are absent because of a lack of stable solid-state molecular switches.

In this presentation, I will report on the characterisation of the switching transition in a new type of molecular switch. The molecule is composed of a head unit with halide counterions and an alkane backbone which ensures the SAM formation. Interestingly, the switching mechanism relies on both the migration of the counterions and the dimerisation of the head units within the SAM in an intermolecular reaction. I will present experimental procedures to characterise the transition, the switching performance and speed of the devices. I will show how such measurements give deeper insight into the mechanisms at play in the junction both in terms of chemistry and device topography.

1 Vilan, A., Aswal, D., & Cahen, D. (2017). Large-Area, Ensemble Molecular Electronics: Motivation and Challenges. Chemical Reviews, 117(5), 4248–4286. https://doi.org/10.1021/acs.chemrev.6b00595

2 Jeong, H., Kim, D., Xiang, D., & Lee, T. (2017). High-Yield Functional Molecular Electronic Devices. ACS Nano, 11(7), 6511–6548. https://doi.org/10.1021/acsnano.7b02967

3 Migliore, A., & Nitzan, A. (2013). Irreversibility and Hysteresis in Redox Molecular Conduction Junctions. J. Am. Chem. Soc. https://doi.org/10.1021/ja401336u

4 Migliore, A., & Nitzan, A. (2011). Nonlinear Charge Transport in Redox Molecular Junctions: A Marcus Perspective. https://doi.org/10.1021/nn202206e

PO.94 Heat, particle and chiral currents in a boundary driven bosonic ladder in the presence of gauge field (link)

Bo Xing*, Xiansong Xu, Vinitha Balachandran, Dario Poletti (Singapore University of Technology and Design)

Quantum systems can undergo phase transitions and show distinct features in different phases. The corresponding transport properties can also vary significantly due to the underlying quantum phase. We investigate the transport behaviour of a two-legged bosonic ladder in a uniform gauge field, which is known to have a Meissner-like phase and a vortex phase in the absence of dissipation. The ladder is coupled to bosonic baths at different temperatures, and we study it using the non-equilibrium Green's function method. In particular, we show the presence of a chiral current and how it is affected by the temperature bias and the dissipation strength. We also demonstrate that the opening of a gap between the lower and upper energy band results in the possibility of tuning heat and particle transport through the ladder. We show that for system parameters for which the ground state is in a vortex phase, the system is more sensitive to external perturbations.

PO.95 Interaction-impeded relaxation in the presence of finite temperature baths

Ryan Tan*, Xiansong Xu*, Dario Poletti* (Singapore University of Technology and Design)

We study the interplay between interactions and finite temperature dephasing baths. We consider a double well with strongly interacting bosons coupled, via the density, to a bosonic bath. Such a system, when the bath has infinite temperature and instantaneous decay of correlations, relaxes with an emerging algebraic behavior with exponent 1/2. Here we show that, because of the finite temperature baths and of the choice of spectral densities, such an algebraic relaxation may occur for a shorter duration and the characteristic exponent can be lower than 1/2. These results show that the interaction-induced impeding of relaxation is stronger and more complex when the bath has both finite temperature and/or non-zero time scale for the decay of correlations.

PO.98 QRAKEN: Quantum Random Keys via Entanglement

Hermanni Heimonen*, Tobias Haug, Kishor Bharti (Centre for Quantum Technologies)

In a Bell-scenario Alice and Bob make independent measurements on their respective systems and receive some measurement outcomes. Violating a Bell-inequality guarantees at least some measurement outcomes to be truly random, created by the act of measurement. Based on this, we have implemented a certified quantum random number generator on the IBM Q hardware. The package runs Bell-experiments on quantum computers, from which it calculates the amount of randomness in the string of outcomes. It then extracts that amount of randomness and outputs a string of bits certified to be random.

We test and compare various IBM processors and find the device with highest key rate. We also present a parallel implementation of the code that runs maximally many qubit pairs for a given topology.

This first release of the QRAKEN let's anyone generate and access truly random numbers from the comfort of their homes. The software can be downloaded and installed at https://github.com/HermanniH/QR
.

PO.101 Hybrid Quantum Systems of Atoms and Superconductors

Hoang Long Nguyen*, Alessandro Landra*, Christoph Hufnagel*, Yung Szen Yap, Rangga Perdana Budoyo, Rainer Helmut Dumke (Centre for Quantum Technologies)

Quantum computing is at the brink of becoming viable. However still many challenges exist. An efficient platform for quantum computing has to be build on qubit realizations following the DiVincenzo criteria like long coherence times, scalability, high performance gate operations as well as low error readout. One prominent candidate to fulfill this demand are qubits based on superconducting circuits. However compare to other potential candidates like neutral atoms, the coherence time is short. In our experiment, we work towards merging the benefits of superconducting quantum circuits with ultra cold atoms. We store 5×10^8 ^{87}Rb atoms for up to 790s in a cryogenic environment with a base temperature reaching 15mK. On the mK Platform we have installed a superconducting 3D cavity which is able to magnetically store atoms as well as house a in house developed transmon qubit. Based on this setup we have proposed previously a protocol to transfer the state of a superconducting qubit to an neutral atom.

PO.102 Observation of Protected Photonic Edge States Induced By Real-Space Topological Lattice Defects (link)

Qiang Wang*, Haoran Xue, Baile Zhang, Yidong Chong (Nanyang Technological University)

Topological defects (TDs) in crystal lattices are elementary lattice imperfections that cannot be removed by local perturbations, due to their real-space topology. In the emerging field of topological photonics, photonic topological edge states arise from the nontrivial topology of the band structure defined in momentum space and are generally protected against defects. Here we show that adding TDs into a valley photonic crystal generates a lattice disclination that acts like a domain wall and hosts photonic topological edge states. Unlike previous topological waveguides, the disclination forms an open arc and functions as a free-form waveguide connecting a pair of TDs of opposite topological charge. This interplay between the real-space topology of lattice defects and momentum-space band topology provides a novel scheme to implement large-scale photonic structures with complex arrangements of robust topological waveguides and resonators.

PO.107 Coherence of a dynamically decoupled single neutral atom (link)

Chang Hoong Chow*, Boon Long Ng*, Christian Kurtsiefer* (CQT)

Long qubit coherence and efficient atom-photon coupling are essential for advanced applications in quantum communication. One technique to maintain coherence is dynamical decoupling, where a periodic sequence of refocusing pulses is employed to reduce the interaction of the system with the environment. We experimentally study the implementation of dynamical decoupling on an optically-trapped, spin-polarized 87 Rb atom. We use the two magnetic-sensitive $5S_{1/2}$ Zeeman levels, $F = 2, m_F = -2$ and $F = 1, m_F = -1$ as qubit states, motivated by the possibility to couple $F = 2, m_F = -2$ to $5P_{3/2}$ the excited state $F' = 3, m'_F = -3$ via a closed optical transition. With shorter spacing between the refocusing pulses, we manage to extend the coherence time from 38(3) μs to around seven milliseconds. We also observe a strong correlation between the motional state of the atom and the efficiency of the refocusing.

PO.109 Forward scattered field in the nonlinear saturated regime (link)

Chang Chi Kwong*, Thomas Wellens, Kanhaiya Pandey, David Wilkowski (Nanyang Technological University)

Using the flash effect, the forward scattered field in the nonlinear saturated regime is studied experimentally. At large saturation, elastic and inelastic scatterings by the atoms both contribute to the attenuation of the transmitted beam. Using the flash effect [1, 2], the forward scattered light can be measured experimentally. The power of the forward scattered light and the timescale of the flash are consistent with the fact that only the elastic scatterings contribute to the forward scattered field.

[1] M. Chalony, R. Pierrat, D. Delande, and D. Wilkowski, Phys. Rev. A 84, 011401(R) (2011) [2] C. C. Kwong, T. Yang, M. S. Pramod, K. Pandey, D. Delande, R. Pierrat, and D. Wilkowski, Phys. Rev. Lett. 113, 223601 (2014)

PO.110 Effects of non-uniform magnetic field on the spin current of strongly dissipatively driven XXZ spin chains

Kang Hao Lee*, Dario Poletti* (SUTD)

In XXZ chains, spin transport can be significantly suppressed when the anisotropy in the chain

and the bias of the dissipative driving are large enough. This phenomenon of negative differential

conductance is caused by the formation of two oppositely polarized ferromagnetic domains at the

edges of the chain. Here we consider the effect of a non-uniform, or disordered, magnetic field. We

show that, while in general disorder reduces the current, in the regime of negative differential con-
ductance disorder can enhance currents. This effect is limited and more pronounced in shorter spin
chains. We consider different types of disorder distributions: uniform, algebraic and dichoto-mous.
Analyzing in detail the effects of dichotomous disorder we find a resonant behavior with peaks of
currents related to avoided crossings in the energy spectrum of the spin chain. Furthermore, by
studying the effect of all possible configurations of the magnetic field, we find a configuration which
results in a very strong spin current rectification, thus turning the spin chain into an effective diode.

PO.111 Two-dimensional CoSe structures: Intrinsic magnetism, nonsymmorphic magnetic nodal line, and antiferromagnetic metal state

Bo Tai*, Weikang Wu*, Yalong Jiao, Xiaolong Feng, Jianzhou Zhao, Yunhao Lu, Xian-Lei Sheng, Shengyuan A. Yang (Singapore University of Technology and Design)

The interplay between magnetism, band topology, and electronic correlation in low dimensions has been a fascinating subject of research. Here, we propose two-dimensional (2D) material systems which demonstrate such an interesting interplay. Based on first-principles calculations and structural search algorithms, we identify three lowest energy 2D CoSe structures, termed as the alpha-, beta-, and gamma-CoSe. We show that alpha- and gamma-CoSe are ferromagnetic metals. They possess rich topological band features, including the nonsymmorphic magnetic nodal line, the magnetic Weyl point, and the magnetic Weyl loop. Remarkably, all these features are robust against spin-orbit coupling. Meanwhile, beta-CoSe is a rare example of a 2D antiferromagnetic metal, which is related to a Fermi surface nesting feature for its three conduction band valleys. The possible phase transitions and the
experimental aspects have been discussed.

PO.113 Trapping Sodium Atoms in Optical Tweezers for NaK Molecules

Krishna Chaitanya Yellapragada*, Xiu Quan Quek, Mohammad Mujahid Aliyu, Wei Hong Yeo, Swarup Das, Huanqian Loh* (Centre for Quantum Technologies)

Ultracold polar molecules are highly sought after because of their ability to provide anisotropic long-range dipolar interactions, long spin coherence times and rich internal structure. These properties make them ideal candidates to construct quantum simulators where the dipolar interactions can be utilized to engineer Hamiltonians. We choose NaK molecules as they possess a large electric dipole moment, and we move towards forming them via magneto-association and stimulated Raman adiabatic passage of Na and K atoms trapped in individual optical tweezers. Trapping sodium atoms in optical tweezers is not so trivial due to the light shifts observed in optical tweezers when compared to Rb and Cs. This makes trapping sodium atoms in an optical tweezer trap quite challenging. The trapping is made possible using a method that involves modulation between the cooling and trapping light, so that the atom can remain trapped without being heated away. We present our work on trapping sodium atoms in optical tweezers and report on general experimental progress.

PO.114 Janus PtSSe and graphene heterostructure with tunable Schottky barrier

Liemao Cao*, Yee Sin Ang*, Qingyun Wu*, Lay Kee Ang* (Singapore University of Technology and Design)

Janus transition metal dichalcogenides with a built-in structural cross-plane asymmetry have recently emerged as a new class of two-dimensional materials with a large cross-plane dipole. By using the density functional theory calculation, we report the formation of different Schottky barriers for Janus PtSSe and graphene based van der Waals heterostructures, where the Schottky barrier height (SBH) and type of

contact can be controlled by adjusting the interlayer distance, by applying an external electric field, and by having multiple layers of Janus PtSSe. It is found that the effects of tuning are more prominent for SPtSe/graphene as compared to SePtS/graphene. Besides, a transition from n-type Schottky contact to p-type Schottky contact and to Ohmic contact is also observed in the SPtSe/Gr heterostructure for different SPtSe stackings from 1 layer, to 2- and 3-layers, respectively. Our findings indicate that the SPtSe/graphene heterostructure is a suitable candidate for applications that require a tunable SBH.

PO.115 Design of metal contacts for monolayer Fe3GeTe2 based devices

Qingyun Wu*, Yee Sin Ang, Liemao Cao, Lay Kee Ang* (Singapore University of Technology and Design)

Using ab initio density functional calculations, we study the interfacial properties of the Fe3GeTe2 monolayer in contact with the Au, Cu, In, Cr, Ti, and Ni metal substrates. It is found that Cr, Ti, and Ni bind strongly with Fe3GeTe2, in contrast to Au, Cu, and In. By analyzing the density of states, charge redistribution, and tunneling barrier, it is suggested that the commonly used Au, Cu, In, and Cr electrodes are insufficient for the electron and spin injection. Ti and Ni metal substrates are proposed to have good electronic transparency to the Fe3GeTe2 monolayer. The Ni substrate is found to have a large spin injection to the Fe3GeTe2 monolayer in addition to its excellent electron injection. Our results indicate that Ni is a promising electrode for the Fe3GeTe2 monolayer to form current in-plane devices, thus shedding light on the optimal selection of metal electrodes for the development of next generation spintronic devices based on atomically thin nanomaterials.

PO.119 Compact numerical modelling to evaluate outdoor surface temperature in tropical residential environments

Dexter Huang* (Agency for Science, Technology and Research (A*STAR))

Outdoor surface temperature is an essential parameter for understanding building energy consumption as well as outdoor thermal comfort. This physical quantity can be evaluated using the surface energy-balance equation which involves short-wave solar radiation, long-wave sky radiation, thermal-radiation exchange, thermal conduction, and air convection. In this work, we propose a compact numerical model for efficiently calculating surface temperatures on three-dimensional building geometries in a typical residential environment in Singapore. The calculated results are in good agreement with the on-site measurements. Moreover, we adopted a machine-learning approach to further improve the efficiency of predicting the surface temperature of roof surfaces in the same cluster of buildings. The corresponding methodology and preliminary results will be presented in this conference.

PO.122 Construction of a Portable Atomic Gravimeter

Fong En Oon*, Rainer Dumke* (Centre for Quantum Technologies)

We are constructing an absolute atomic gravimeter (Rubidium) with the aim to be deployed in remote locations, such as volcanic site to measure gravity changes due to magma flow. The experiment systems are fitted into a 80cmX80cmX180cm portable platform, and is capable of fully controlled/monitored by computer remotely after an initial set-up. We have finished constructed all the experiment physical packages and obtained our test mass-rubidium atomic cloud in the micro-kelvin region, we are pushing forward the experiment to measure the local gravitational acceleration in the designed 10-9Δg level.

PO.127 Phase stabilization of a coherent fibre network by single-photon counting (link)

Salih Yanikgonul*, Guo Ruixiang, Angelos Xomalis, Anton N. Vetlugin, Giorgio Adamo, Cesare Soci, Nikolay I. Zheludev (Nanyang Technological University)

Coherent optical fibre networks are extremely sensitive to thermal, mechanical and acoustic noise, which requires elaborate schemes of phase stabilization with dedicated auxiliary lasers, multiplexers and photodetectors. This is particularly demanding in quantum networks operating at the single-photon level. Here we propose a simple method of phase stabilization based on single-photon counting and apply it to quantum fibre networks implementing single-photon interference on a lossless beamsplitter and coherent perfect absorption on a metamaterial absorber. As a proof of principle, we show dissipative single-photon switching with visibility close to 80%. This method can be employed in quantum networks of greater complexity without classical stabilization rigs, potentially increasing efficiency of the quantum channels.

PO.128 Robust Self-Testing of Quantum Systems via Noncontextuality Inequalities

Kishor Bharti* (CQT)

Characterising unknown quantum states and measurements is a fundamental problem in quantum information processing. In this Letter, we provide a novel scheme to self-test local quantum systems using non-contextuality inequalities. Our work leverages the graph-theoretic framework for contextuality introduced by Cabello, Severini, and Winter, combined with tools from mathematical optimisation that guarantee the unicity of optimal solutions. As an application, we show that the celebrated Klyachko-Can-Biniciogglu-Shumovsky inequality and its generalisation to contextuality scenarios with odd n-cycle compatibility relations admit robust self-testing.

PO.129 Local certification of programmable quantum devices of arbitrary high dimensionality

Kishor Bharti* (CQT)

The onset of the era of fully-programmable error-corrected quantum computers will be marked by major breakthroughs in all areas of science and engineering. These devices promise to have significant technological and societal impact, notable examples being the analysis of big data through better machine learning algorithms and the design of new materials. Nevertheless, the capacity of quantum computers to faithfully implement quantum algorithms relies crucially on their ability to prepare specific high-dimensional and high-purity quantum states, together with suitable quantum measurements. Thus, the unambiguous certification of these requirements without assumptions on the inner workings of the quantum computer is critical to the development of trusted quantum processors. One of the most important approaches for benchmarking quantum devices is through the mechanism of self-testing that requires a pair of entangled non-communicating quantum devices. Nevertheless, although computation typically happens in a localized fashion, no local self-testing scheme is known to benchmark high dimensional states and measurements. Here, we show that the quantum self-testing paradigm can be employed to an individual quantum computer that is modelled as a programmable black box by introducing a noise-tolerant certification scheme. We substantiate the applicability of our scheme by providing a family of outcome statistics whose observation certifies that the computer is producing specific high-dimensional quantum states and implementing specific measurements.

PO.132 Single-photon Avalanche Diodes for Scalable Integrated Quantum Photonics (link)

Salih Yanikgonul*, Victor Xu Heng Leong, Jun Rong Ong, Leonid Krivitsky (Nanyang Technological University)

Integrated quantum photonics is recognized as a key enabling technology on the road towards scalable quantum networking schemes. However, many state-of-the-art integrated photonics demonstrations still require the coupling of light to external photodetectors. On-chip silicon single-photon avalanche diodes (SPADs) provide a viable solution as they can be seamlessly integrated with photonic components and operated with high efficiencies and low dark count rates at temperatures achievable with thermoelectric cooling. We design and simulate a class of silicon waveguide-based SPADs on a SOI platform for visible wavelengths. In our presentation, we share our simulation results as well as preliminary characterization results for our avalanche photodiodes both in linear-mode and Geiger-mode operation.

PO.133 Sb_2S_3 Crystallization

Poh*, Li Lu*, Robert Edward Simpson* (SUTD)

Antimony trisulfide (Sb_2S_3) is gaining interest due to its large change in optical properties in the visible spectrum and low optical absorption. This repeatable optical switching ability results from structural phase transitions between amorphous and crystalline states when subjected to various forms of heat.

In this study of Sb_2S_3 , we aim to understand the mechanism of the change from the as-deposited amorphous to the crystalline state. Our investigation utilizes the Kissinger analysis approach to acquire the activation energy for the crystallization process. We will also further discuss a densification effect that was observed during crystallization.

We acknowledge support from the AME Programmatic Grant for spatial light modulators (grant # A18A7b0058).

PO.134 Microresonators enhance long-distance quantum information processing in chiral quantum networks

Wai-Keong Mok*, Davit Aghamalyan, Jiabin You, Tobias Haug, Leong-Chuan Kwek (Center for Quantum Technologies)

Chiral quantum networks provide a prominent platform for realizing quantum information processing and quantum communication, with entanglement being a key resource in such applications. On the other hand, microresonators serve as an efficient photonic interface for light-matter interactions. Here, we describe how microresonators can enhance long-distance quantum information processing in chiral quantum networks in various situations: (1) Transport of multipartite entangled states between spatially distant quantum nodes, where the resonators enhance the transport fidelity to as high as 0.954; (2) Long-distance entanglement generation between two quantum nodes, where the presence of resonators provide additional controllability which significantly improves concurrence to up to 0.969; (3) High-fidelity quantum state transfer of qubit without requiring time-dependent interactions. Robustness of our protocols to experimental imperfections such as fluctuations in inter-nodal distance, imperfect chirality, detunings and qubit relaxations are also demonstrated.

PO.138 Perovskite light-emitting field-effect transistors operating at room temperature (link)

Maciej Klein*, Li Jia, Subodh G. Mhaisalkar, Annalisa Bruno, Cesare Soci (Nanyang Technological University)

In recent years, metal-halide perovskites have attracted significant attention of scientists not only due to high efficiency of turning photons into electricity in photovoltaic devices but also converting electrons into light in light-emitting diodes [1]. However, a performance of light-emitting field-effect transistors, optoelectronic devices that combine light emission with electronic switching, is still far from expectations. The poor lateral charge transport associated to ionic transport and organic cation polarization effects hinder their operation at room temperature [2-4]. In this work, we demonstrate thermally evaporated $CH_3NH_3PbI_3$ perovskite [5] light-emitting field-effect transistors yield balanced ambipolar charge carrier injection and lower non-radiative recombination at room temperature. Both electrons and holes field-effect mobilities are respectively one order and two orders of magnitude higher as compared to the ones measured in spin-coated devices reported by us previously [3]. Furthermore, improved $CH_3NH_3PbI_3$ active layer morphology combined with high-frequency modulation of the gate voltage allow to shift electroluminescence emission range to temperatures over 300 K.

[1] M. Lu, Y. Zhang, S. Wang, J. Guo, W. W. Yu, A. L. Rogach, Metal Halide Perovskite Light-Emitting Devices: Promising Technology for Next-Generation Displays, Adv. Funct. Mater. 2019, 29, 1902008. [2] X.Y. Chin, D. Cortecchia, J. Yin, A. Bruno, C. Soci, Lead Iodide Perovskite Light-Emitting Field-Effect Transistor, Nat. Commun. 2015, 6, 7383. [3] F. Maddalena, X. Y. Chin, D. Cortecchia, A. Bruno, C. Soci, Brightness Enhancement in Pulsed-Operated Per-

ovskite Light- Emitting Transistors, ACS Appl. Mater. Interfaces 2018, 10, 37316−37325. [4] J. Zaumseil, Recent Developments and Novel Applications of Thin Film, Light-Emitting Transistors, Adv. Funct. Mater. 2019, 1905269. [5] J. Li, H. Wang, X. Y.Chin, HA Dewi, K Vergeer, T W Goh, J H Lew, K Ping Loh C Soci, T C Sum, H Bolink, N. Mathews, S. Mhaisalkar, A Bruno, Highly efficient thermally co-evaporated perovskite solar cells and mini-modules, under revision

PO.146 Expressibility and trainability of parameterized analog quantum systems for machine learning applications (link)

Supanut Thanasilp*, Jirawat Tangpanitanon, Marc-Antoine Lemonde, Dimitris Angelakis* (Centre for Quantum Technologies)

Parameterized quantum evolution is the main ingredient in variational quantum algorithms for near-term quantum devices. In digital quantum computing, it has been shown that random parameterized quantum circuits are able to express complex distributions intractable by a classical computer, leading to the demonstration of quantum supremacy. However, their chaotic nature makes parameter optimization challenging in variational approaches. Evidence of similar classically-intractable expressibility has been recently demonstrated in analog quantum computing with driven many-body systems. A thorough investigation of trainability of such analog systems is yet to be performed. In this work, we investigate how the interplay between external driving and disorder in the system dictates the trainability and expressibility of interacting quantum systems. We show that if the system thermalizes, the training fails at the expense of the a large expressibility, while the opposite happens when the system enters the many-body localized (MBL) phase. From this observation, we devise a protocol using quenched MBL dynamics which allows accurate trainability while keeping the overall dynamics in the quantum supremacy regime. Our work shows the fundamental connection between quantum many-body physics and its application in machine learning. We conclude our work with an example application in generative modeling employing a well studied analog many-body model of a driven Ising spin chain. Our approach can be implemented with a variety of available quantum platforms including cold ions, atoms and superconducting circuits.

PO.147 Observation of the annealing-induced phase-transition in monolayer-MoS_2 on gold film (link)

Xinmao Yin*, Andrew T. S. Wee* (National University of Singapore)

The polymorphic features of two-dimensional transition metal dichalcogenides materials such as Molybdenum Disulfide (MoS_2) exhibit unique and fascinating optical and transport properties with immense potential in device applications. Here, we report the structural phase transition of monolayer MoS_2 from the trigonal semiconducting 1H-phase to the distorted octahedral quasi-metallic 1T'-phase. Of which, we observe a tunable inverted gap ($\sim$0.50eV) and a fundamental gap ($\sim$0.10eV) in quasi-metallic monolayer-MoS_2. Using spectral-weight transfer analysis, we find that the inverted gap is attributed to the strong charge-lattice coupling in 2D-TMDs. Using a comprehensive experimental study involving transport, Raman, photoluminescence (PL) and synchrotron-based photoemission spectroscopy (PES), supported by theoretical calculations, we monitor the 1H-to-1T' phase-transition in monolayer-MoS_2/Au as a result of high-temperature annealing and study the changes in its optical and electronic properties. We made further clarifications that the effects of electron-doping from gold, further facilitated by the presence of interfacial tensile strain, are the primary mechanisms which result in this 1H-1T' structural phase transition, thus resulting in the formation of the inverted and fundamental gaps. Results from our study highlight the pivotal role that charge-lattice coupling play that lead to the intrinsic properties of the inverted and fundamental gaps and polymorphism of MoS_2, thereby unleashing new possibilities for the use of 2D-transition metal dichalcogenide-based device fabrication.

PO.148 High–Yield Phase–Transition Transition Metal Dichalcogenides on Metallic Substrates (link)

Chi Sin Tang, Xinmao Yin, Andrew Thye Shen Wee* (National University of Singapore)

2D transition metal dichalcogenides (2D–TMDs) and their unique structural phases such as the semiconducting 1H and quasi–metallic 1T′ phases show intriguing optical and electronic properties. With the favorable quasi–metallic nature of 1T′–phase 2D–TMDs, the 1H–to–1T′ phase engineering processes is an important discipline that can be utilitzed for novel device applications. We present a high–yield 1H–to–1T′ phase transition of monolayer–MoS_2 on Cu and monolayer–WSe_2 on Au carried out through an annealing–based process. A series of experimental and first–principles study is conducted to study the mechanism for the phase transition process. The yield in 1T'-phase is increased through an enhancement in interfacial hybridizations by an increase in interfacial binding energy, charge transfer, shorter interfacial spacing, and weaker bond strength.

PO.151 Temperature dependent study of the spectroscopic g−factor and magnetic relaxation in Sr2FeMoO6

Rajasree Das*, Ushnish Chaudhuri, Ramanathan Mahendiran (NUS)

Room temperature ferromagnet Sr2FeMoO6 particles which is a potential candidate for magnetoresistive and spintronic devices, is synthesized in a controlled inert atmosphere to minimize the concentration of antisite (AS) defects by sol-gel method. We report a detailed study of both static (using PPMS-VSM) and dynamic (Ferromagnetic Resonance (FMR)) magnetic properties. Static magnetization data alone cannot speak about whether Fe is in +3 or +2 valance state in this double perovskite sample, thus a broadband FMR study is needed to address this issue. Furthermore, modulation of the resonance field and linewidth with temperature (370-50K) elucidates the intrinsic and extrinsic magnetic nature of the sample which is vital for future application purposes. The FMR measurements at selected temperatures were done in two different ways, firstly varying the dc magnetic field at constant microwave frequency and secondly the applied field was fixed while the microwave frequency was varied in the broad range. The observations suggest that at low temperature damping of magnetization precession deviates from the intrinsic damping, which is in principle anisotropic with temperature, and extrinsic damping parameters plays dominating roles.

PO.158 Transition metal based trimetallic oxide 2D nanostructures for efficient water oxidation

Hemam Rachna Devi*, Chen Zhong, Karuna Kar Nanda (Nanyang Technological University)

Search of a solution to fulfil the increasing energy demand and great concern regarding environmental pollution caused by fossil fuels leads to immense attention on energy conversion and storage devices. Electrochemical water splitting which includes hydrogen evolution reaction (HER) and oxygen evolution reaction (OER) serve as suitable alternatives for the inevitable issues. Compared to HER, the later has a much complex reaction kinetics involving multiple electron transfer process, thereby leading to challenge in designing an efficient catalyst for OER. Ru and Ir based oxides have been considered as potential electrocatalysts to drive OER. However, they suffer from drawbacks like high cost being rare earth elements and unstable irrespective of acidic or alkaline medium. Herein, we have synthesized 2-dimensional (2D) trimetallic Co, Ni and Mn based oxides nanostructures using simple one pot solution technique which show enhanced current density, low onset and overpotential, excellent stability and low Tafel slope suggesting more favourable electron transfer kinetics. The as-synthesized catalyst is comparable or better than the state of art catalyst. Moreover, the catalyst is eco-friendly and cost-effective. Hence, transition metal-based oxides catalyst can be a potential candidate for water oxidation.

PO.159 Fabrication of Pristine Graphene Nanochannels for Ionic and Water transport measurements

Mordjann Souilamas*, Massimo Spina*, Nathan Ronceray, Kittipitch Yooprasertchuti, Slaven Garaj* (National University of Singapore)

Novel patterning and transfer methods for 2D materials have allowed the fabrication of more and more sophisticated heterostructures. At the nanoscale, the smallest of details will impact the cleanliness of the devices, which is essential when studying nanofluidics. We will present the bottom-to-top fabrication of angstrom-scale graphene channels to study the flow of confined ions in water. In particular, we study electrophysiology as it occurs in human cells' membranes thanks to gated graphene nanochannels.

PO.160 Chalcogenides for Optical Neural Network

Ting Yu Teo*, Mario Miscuglio, Volker Sorger, Robert Simpson (Singapore University of Technology and Design)

With electronics struggling to keep pace with Moore's law, Photonics computing schemes are gaining traction. This is prevalent in the field of neuromorphic engineering, where all- Optical Neural Networks (ONN) are proposed to replace the purely electrical neural network. The overall architecture of an ONN consists of layers of interconnected optical perceptrons. Each perceptron contains (a) Weights, that enable the network to perform vector matrix multiplication and (b) Non-linear Activation Function (NLAF), which prunes or retains the input depending on its relevance. Implementing these features would require reconfigurable photonic devices. One possible solution is to incorporate chalcogenide materials into these devices. This is because the optical properties can be efficiently tuned with multiple mechanisms. Here, we identify suitable optical properties displayed by chalcogenides to develop both the Weights and NLAF. Preliminary simulation results show that the large change in refractive index and extinction coefficient induced by phase transition could be adopted in modulators to give different weighted values. Moreover, simulating optical non-linearities of chalcogenides as the NLAF on TensorFlow offers comparable accuracy results as those commonly used NLAFs in machine learning algorithms. These findings suggest the possibility of adopting chalcogenides into the weights and NLAF of an optical neural network.

PO.161 Antimony Trisulphide (Sb_2S_3) Hybrid Multi-Bit Memory Device

Li Tian Chew*, Robert Simpson, Chao Sung Lai, Ting Yu Teo, Li Lu, Jose C Martinez, Hui Ling Poh, Asim Senapati (SUTD)

The objective of this work is to create an antimony trisulphide (Sb_2S_3) hybrid multi-bit memory device. Sb_2S_3 is a phase change material that can also behave as a ReRAM. We report the electrical switching characteristics of Sb_2S_3-based memory devices. Ionic diffusion through Sb_2S_3 occurs when an electric voltage is applied. We show that a single Sb_2S_3 memory cell has potential for two-bit data storage, and the hybrid memory concept is, therefore, useful for high-density data storage applications. The device resistance changes by several orders of magnitude and can endure more than 10,000 write-erase cycles. We believe that these multi-bit memory devices will also be useful in solid-state artificial neural networks.

PO.162 Modifications of Newton's Second law of motion

Amritpal Nafria* (Lovely Professional University)

This paper proposed a more general expression to Newton's second law of motion (F=ma) to calculate the net force acting on the bodies when it encounters various external factors such as air resistance, friction, gravity etc. This paper practically observes that weighing scale reading calculates variation of all external factors. Besides external factors, the net force is a sum of two parts. In first part, we apply force till the body stays stationary and in second part, the applied force exceeds and the body accelerates. It is noticed that weighing scale is used to calculate weight, which actually is vertical downward force when bodies stay stationary. Hence, it is practically examined that it should be used to calculate net force applied on a body, till it stays stationary both vertically and horizontally. Whereas, the suggestive expression to study the net applied force for accelerated bodies is 'F=r+ma', where 'r' is the reading of the weighing scale which includes the applied force till body stays stationary and the effect of various external factors.

PO.163 Optical Lattice Setup for the Study of Disorder and Interactions in a Two-Dimensional Fermi Gas (link)

Athira Krishnan Sreedevi*, Andy Neo*, Kai Dieckmann* (Centre for Quantum Technologies)

A quantum system with impurities and defects distinct itself from its classical counterpart and exhibit many interesting phenomena. A classical particle traveling in a chaotic landscape is characterize by diffusion. However, in a quantum system the particle wave function can exhibit different behaviors. In the case of Anderson localization, the diffusion can become absent in the presence of a disordered potential. Ultracold atoms in an optical lattice is an excellent platform to simulate such system as it is highly tunable. We outline our method in constructing a 2-dimensional optical square lattice for Lithium-6 Fermi gas with random speckle potential to investigate Anderson tight binding model and other disorder phenomena.

(notes)

3 Technical Sessions

For the technical sessions, we kept the topical groups the program committee has selected before the lockdown. Wherever we received a link to the presentations from the authors, we provide it in this program.

During the preliminary programme phase, if you find your link is missing here, please ensure that you uploaded it via easychair and eventually notify the organizers.

T1: Topological Systems 1

T1.142 Quantum state transfer via acoustic edge states in a 2D optomechanical array (link)

Marc-Antoine Lemonde*, Vittorio Peano, Peter Rabl, Dimitris Angelakis (Center for quantum technologies)

We propose a novel hybrid platform where solid-state spin qubits are coupled to the acoustic modes of a two-dimensional array of optomechanical nano cavities. Previous studies of coupled optomechanical cavities have shown that in the presence of strong optical driving fields, the interplay between the photon-phonon interaction and their respective inter-cavity hopping allows the generation of topological phases of sound and light. In particular, the mechanical modes can enter a Chern insulator phase where the time-reversal symmetry is broken. In this context, we exploit the robust acoustic edge states as a chiral phononic waveguide and describe a state transfer protocol between spin qubits located in distant cavities. We analyze the performance of this protocol as a function of the relevant system parameters and show that a high-fidelity and purely unidirectional quantum state transfer can be implemented under experimentally realistic conditions. As a specific example, we discuss the implementation of such topological quantum networks in diamond based optomechanical crystals where point defects such as silicon-vacancy centers couple to the chiral acoustic channel via strain.

T1.31 COUPLING BETWEEN EXCITON-POLARITON CORNER MODES MEDIATED THROUGH EDGE STATES (link)

Rimi Banerjee*, Subhaskar Mandal, Timothy Liew (Nanyang Technological University)

In recent years there has been a surge of interest in using exciton-polaritons to realize first order topological bandstructures [1-2]. These topological states are well-isolated from disorder and so seem ideal candidates for preserving information. However, this also means that they are well-isolated from each other and so it is hard to imagine coupling together multiple topological states, which would likely be prerequisite for some information processing elements (e.g., two-input logic gates).

Here we consider theoretically the realization of a second order topological polariton bandstructure, which gives rise to zero-dimensional localized corner states in a polariton lattice. Due to the topological nature, information can be trapped in the corner even in the presence of disorder. We show that in the presence of polariton-polariton scattering, polaritons can scatter from a pumped corner state into an edge state, which again scatter back to another adjacent corner. In this way, we find that as a nonlinear driven-dissipative system exciton-polaritons offer a unique opportunity for realizing spatially localized topological states that can be coupled together.

References [1] Bardyn, et al., Phys. Rev. B, 2015, 91, 161413(R). [2] Klembt, et al., Nature, 2018, 562, 7728.

T1.105 (INVITED) Electrically Pumped Topological Laser with Valley Edge Modes (link)

Yongquan Zeng*, Udvas Chattopadhyay*, Baile Zhang*, Yidong Chong*, Qi Jie Wang* (Nanyang Technological University)

Quantum cascade lasers (QCLs) are compact electrically-pumped light sources in the technologically important mid-infrared and terahertz (THz) frequency. Recently, the concepts of topological photonics have given rise to a new type of lasing utilizing topologically-protected photonic modes that can efficiently bypass corners and defects. Here, we report the first demonstration of an electrically-pumped THz QCL based on topologically-protected valley edge states. Unlike previous topological lasers that relied on large-scale features to impart topological protection, we employ a compact valley photonic crystal design. Lasing with regularly-spaced emission peaks occurs in a sharp-cornered triangular cavity, even with the introduction of perturbations. This is the first laser based on valley edge states and opens the door to practical use of topological protection in electrically-driven laser sources.

T1.124 (INVITED) Tunable photonics wide band gap phase change material (link)

Li Lu*, Parikshit Moitra, Ramon Paniagua-Dominguez, Vytautas Valuckas, Sander F. G. Reniers, Harish N. S. Krishnamoorthy, Arseniy I. Kuznetsov, Yuqing Jiao, Cesare Soci, Robert Simpson* (Singapore University of Technology and Design)

Phase change materials (PCMs) have drawn attention for tunable photonics applications in recent years due to their large and non-volatile refractive index change [1]. The optical response results from a structural transition between amorphous and crystalline states. This phase transition can be very fast, on a sub-ns scale [2]. The most well studied PCM, Ge2Sb2Te5, has a large refractive index but is highly absorbing in the visible spectrum. Thus, for visible and near-infrared tunable photonics applications, an alternative phase change material with a wide band gap is sought. We introduce a wide band gap phase change material called antimony trisulphide (Sb2S3). The band gap is 2.0 eV for amorphous state and 1.7 eV for crystalline state [3]. The refractive index is approximately 2.85 and 3.5 for amorphous and crystalline states respectively with low optical absorption in the visible and NIR spectrum. Thus, Sb2S3 is a promising material for reprogrammable visible and N-IR photonics.

In this talk, I will demonstrate antimony trisulphide's application in a range of different photonics devices. Firstly, hyperbolic metamaterials will be discussed. By changing the structural phase of the PCM, we can control the rate of spontaneous emission of fluorescent molecules, and this is useful for controlling single photon emitter. Secondly, I will show how Sb2S3 can be used to reconfigure InP waveguide devices [4]. We can achieve optical switching at 1550 nm in photonics integrated circuits. Finally, all dielectric Sb2S3 nanoantenna arrays will be introduced. This device is based on a Huygens' metasurface [5] and operates in transmission mode. We can control the phase of the light to steer an incident beam by 10 ° at a wavelength of 840 nm. These results suggest that Sb2S3 is promising for a wide range of tunable photonics applications in the visible and NIR spectrum.

Li Lu is grateful for his scholarship from Singapore Ministry of Education (MOE). We acknowledge support from the AME Programmatic Grant for spatial light modulators (grant # A18A7b0058) and the Temasek Lab seed funding the tuneable hyperbolic metamaterials for single photon source applications.

Reference [1] Wuttig, M., H. Bhaskaran, and T. Taubner. ”Phase-change materials for non-volatile photonic applications.” Nature Photonics 11.8 (2017): 465. [2] Waldecker, Lutz, et al. ”Time-domain separation of optical properties from structural transitions in resonantly bonded materials.” Nature materials 14.10 (2015): 991. [3] Dong, Weiling, et al. ”Wide Bandgap Phase Change Material Tuned Visible Photonics.” Advanced Functional Materials (2018): 1806181. [4] Van der Tol, Jos JGM, et al. ”Indium phosphide integrated photonics in membranes.” IEEE Journal of Selected Topics in Quantum Electronics 24.1 (2017): 1-9. [5] Yu, Ye Feng, et al. ”High–transmission dielectric metasurface with 2π phase control at visible wavelengths.” Laser & Photonics Reviews 9.4 (2015): 412-418.

T2: Mesoscopics

T2.43 An S-Matrix approach for predicting the phonon specularity parameter

Zhun-Yong Ong* (Institute of High Performance Computing)

The probability of the phonon being specularly scattered by a boundary is determined by its specularity parameter which, in addition to the boundary structure, depends on the phonon momentum, direction and polarization. However, existing theories of phonon scattering cannot predict the mode-dependent specularity parameter in spite of its importance for understanding heat conduction in semiconductor thin films and nanowires [1]. In this talk, we describe how our recently developed S-matrix approach [2], which is developed from the Atomistic Green's Function (AGF) method [3] and yields the scattering amplitudes for reflected and transmitted phonons, can be used to solve this longstanding problem of predicting the more-resolved specularity parameter. We illustrate the advantages of our approach through two examples. In the first example, we study the phonon specularity in graphene depends on edge chirality and explain why specularity is reduced for the ideal armchair edge, shedding light on the findings by Wei, Chen and Dames [4]. In the second example, we provide direct evidence that the specularity is significantly different between reflected and transmitted phonons at the graphene grain boundary [5]. Our S-matrix method resolves some of the current difficulties in analyzing how edges and interfaces can be modified to control phonon scattering.

References: 1. G. Chen, Nanoscale Energy Transport and Conversion (Oxford University Press, Oxford, 2005). 2. Z.-Y. Ong, "Atomistic S-matrix method for numerical simulation of phonon reflection, transmission and boundary scattering," Phys. Rev. B 98, 195301 (2018). 3. Z.-Y. Ong and G. Zhang, "Efficient approach for modeling phonon transmission probability in nanoscale interfacial thermal transport," Phys. Rev. B 91, 174302 (2015); Z.-Y.Ong, "Tutorial: Concepts and numerical techniques for modeling individual phonon transmission at interfaces," J. Appl. Phys. 124, 151101 (2018). 4. Z. Wei, Y. Chen, and C. Dames, "Wave packet simulations of phonon boundary scattering at graphene edges," J. Appl. Phys. 112, 024328 (2012). 5. D. Li and A. J. H. McGaughey, "Phonon dynamics at surfaces and interfaces and its implications in energy transport in nanostructured materials — an opinion paper," Nanoscale Microsc. Thermophys. Eng. 19, 166 (2015).

T2.118 Super-Andreev re ection and longitudinal shift of pseudospin-one fermions (link)

Xiaolong Feng*, Ying Liu, Zhi Ming Yu, Zhongshui Ma, Lay Kee Ang, Yee Sin Ang, Shengyuan A. Yang (Singapore University of Technology and Design)

Novel fermions with a pseudospin-1 structure can be realized as emergent quasiparticles in condensed matter systems. Here, we investigate its unusual properties during the Andreev reflection at a normal-metal/superconductor (NS) interface. We show that distinct from the previously studied pseudospin-1/2 and two dimensional electron gas models, the pseudospin-1 fermions exhibit a strongly enhanced Andreev reflection probability, and remarkably, can be further tuned to approach perfect Andreev reflection with unit efficiency for all incident angles, exhibiting a previously unknown super-Andreev reflection effect. The super-Andreev reflection leads to perfect transparency of the NS interface that strongly promotes charge injection into the superconductor, and directly manifests as a differential conductance peak which can be readily probed in experiment. Additionally, we find that sizable longitudinal shifts exist in the normal and Andreev reflections of pseudospin-1 fermions. Distinct from the pseudospin-1/2 case, the shift is always in the forward direction in the subgap regime, regardless of whether the reflection is of retro- or specular type.

T2.3 Matter Waves in Disorder: Localization, Thermalization and Condensation (link)

Christian Miniatura* (CNRS)

Because of their high degree of control and tunability, quantum gases have become versatile model systems to study effects originating from many different fields of physics such as condensed matter, quantum information, quantum hydrodynamics and even high-energy physics. The physics of disordered systems has not escaped the trend with the observation of coherent backscattering and Anderson localization [1,2]. When interactions are additionally present, disordered gases offer even richer phenomena [3,4]. Another important, yet poorly understood problem, is the long-time limit of the out-of equilibrium dynamics of weakly interacting quantum gases in disordered potentials, for which two main scenarios exist. In the first one, an atomic cloud is prepared as a spatially narrow wave packet whose spreading is followed in time. In this configuration, the nature of the system's dynamics at asymptotically long times remains debated, though theoretical works suggest that the cloud keeps expanding indefinitely. In the second one, the cloud is prepared in a plane-wave state at constant density (global excitation) and the interesting dynamics takes place in momentum space. At long times, a thermalization process is expected due to atomic collisions but the precise nature of the equilibrated state, resulting from the complicated interplay between interactions and disorder, is largely unknown. In the absence of disorder, thermalization has been extensively studied for waves, and in particular for optical waves, obeying the nonlinear Schrödinger equation within the framework of weak turbulence (WT) theory [5,6]. It was found that the system generically equilibrates to a thermal Rayleigh-Jeans distribution maximizing entropy [7,8], a problem recently extended to WT in confining potentials [9]. For strongly disordered systems, this thermalization process needs further analysis since the density of states (DoS) is dramatically altered at low energies where a possible condensation process would occur. This is the question we address in the present talk [10]. By considering a weakly-interacting plane matter wave released in a two-dimensional (2D) speckle potential, we show that the equilibrium momentum distribution achieved by the matter wave at long times is a thermal Rayleigh-Jeans distribution. This result is analogous to WT, except that the system state is made random by the disorder and not imposed as such at the beginning. Furthermore, we find that in contrast to usual 2D WT, the equilibrium distribution also exhibits, for specific values of the disorder strength and of the initial velocity, a large-scale coherent structure. This condensate coexists with the background of thermalized atoms and disappears at vanishing disorder [10].

[1] F. Jendrzejewski et al., Nature Phys. 8, 398 (2012). [2] F. Jendrzejewski et al., Phys. Rev. Lett. 109, 195302 (2012). [3] M. P. A. Fisher, P. B. Weichman, G. Grinstein, and D. S. Fisher, Phys. Rev. B 40, 546 (1989). [4] C. D'Errico et al., Phys. Rev. Lett. 113, 095301 (2014). [5] S. V. Nazarenko, Wave Turbulence, LNP Vol. 825

(Springer, Berlin, 2011). [6] A. Picozzi et al., Phys. Rep. 542, 1 (2014). [7] C. Connaughton et al., Phys. Rev. Lett. 95, 263901 (2005). [8] C. Sun, S. Jia, C. Barsi, S. Rica, A. Picozzi, and J. W. Fleischer, Nature Phys. 8, 470 (2012). [9] P. Aschieri, J. Garnier, C. Michel, V. Doya, and A. Picozzi, Phys. Rev. A 83, 033838 (2011). [10] N. Cherroret, T. Karpiuk, B. Grémaud, and C. Miniatura, Phys. Rev. A 92, 063614 (2015).

T2.65 Transparency of DNA interaction with monolayer graphene on different substrates

Milan Blaskovic*, Slaven Garaj (Centre for Advanced 2D Materials)

Graphitic surfaces have shown significant potential in single-molecule detection applications due to excellent mechanical and electronical properties, as well as their functionalization possibilities [1]. In addition, it has been shown that interaction of single layer of graphene with surrounding molecules is strongly affected with the choice of underlying supporting substrate, which could as well affect interactions with DNA molecules [2]. We investigated temperature dependence of interactions of individual single-stranded DNA oligomers with two graphitic surfaces, HOPG surface, and CVD grown monolayer graphene supported on SiO2/Si substrate, inside a liquid environment, where we identified and quantified (1) all the relevant forces contributing to the total interactions, and (2) differences in measured forces at different surfaces. By using atomic force microscopy (AFM), we measured force vs. distance curves for the interaction between a DNA tethered on a AFM tip and graphitic surfaces (Fig 1). We observed characteristic plateaus in the curves, which are associated with peeling (near-equilibrium detachment) of the DNA molecule from the surface. Single-molecule forces were measured at range of temperatures (5°C – 45°C) in pH 7 PB buffer solution with added 0.03M of NaCl. Measurements were combined with measurements of macroscopic properties of water interacting with underlying surfaces - interfacial free energies at different temperatures. Linear increase of molecular forces with changes in interfacial energies at different temperatures suggested that changes in total force are attributed to changes in hydrophobic interactions and uncovered intimate connection between nanoscopic parameters (measured force) and macroscopic parameters (interfacial free energy). The total interaction is the combination hydrophobic, van der Waals, and entropic-elastic forces. From intercepts on y-axis, in the limit when hydrophobic interaction goes to zero, for the first time, we could detect values of vdW forces of DNA nucleotides with graphitic surfaces (15-20 pN monolayer graphene, 35-40 pN HOPG). We observe (2) striking differences in vdW forces between surfaces of single layer graphene and bulk HOPG interacting with individual DNA molecules, indicating translucency of graphene to molecular interactions. The insight obtained from our experiments can be used to modulate DNA-graphene interaction and possibly control to movement of individual biomolecule; to completely eliminate interactions for nanopore-based DNA sequencing

T2.66 Coupling 2D Materials to Elastomer Waveguides

James A Grieve*, Filip Auksztol, Daniele Vella, Ivan Verzhbitskiy, Kian Fong Ng, Yi Wei Ho, José Viana-Gomes, Goki Eda, Alexander Ling (Centre for Quantum Technologies, NUS)

We demonstrate the optical coupling of a monolayer of the transition metal dichalcogenide MoS_2 to a single-mode rib waveguide, defined in a flexible polymer chip. The device is fabricated via a simple casting technique, allowing us to encapsulate the monolayer within the guided mode. Packaging in this way can simplify the handling and addressing of an otherwise fragile material. We demonstrate the ability to guide arbitrary linear polarizations, enabling us to probe the optical selection rules associated with the excitons in this material. Such a hybrid platform holds interesting prospects for the integration of a variety of layered materials into optical systems.

T3: Quantum Computation

T3.100 Robust inference of memory structure for efficient quantum modelling of stochastic processes (link)

Matthew Ho*, Mile Gu, Thomas Elliott (Nanyang Technological University, Singapore)

Complex, stochastic processes underpin quantitative science. It is therefore of paramount importance to study and understand the behaviour of such processes for the crucial twin purposes of modelling and prediction. These tasks are typically resource-intensive, motivating the need for methods that ameliorate these requirements. A promising recent development to this end [1,2], using a cross-disciplinary blend of tools from quantum and complexity science, has highlighted that quantum simulators can operate with much smaller memories than the minimal possible classical models [3,4], while providing equally accurate predictions.

Presently, these efficient quantum models are designed with prior knowledge of the minimal classical model, necessitating the use of classical model inference algorithms when applied to real data. Here, we introduce a new inference protocol specifically designed for constructing quantum models, circumventing certain drawbacks of the classical approach that need not manifest in the quantum domain [5]. Crucially, our protocol can be used to both blindly infer efficient quantum models of a given pattern or time series, and bounds on the associated structural complexity. We show that our protocol is robust to statistical imperfections arising from finite data, and does not require any smoothing of probabilities typically associated with classical algorithms. Our results form a key step in the application of this emerging field to real world systems.

References:

[1] M. Gu, K. Wiesner, E. Rieper, and V. Vedral, Nature Communications 3, 762 (2012). [2] F. C. Binder, J. Thompson, and M. Gu, Physical Review Letters 120, 240502 (2018). [3] J. P. Crutchield and K. Young, Physical Review Letters 63, 105 (1989). [4] C. R. Shalizi and J. P. Crutchfield, Journal of Statistical Physics 104, 817 (2001). [5] M. Ho, M. Gu, and T. J. Elliott, arXiv:1911.02767 (2019).

T3.70 Assessing fault-tolerant conditions for the surface code implemented with noisy devices (link)

Jing Hao Chai*, Hui Khoon Ng (Centre of Quantum Technologies)

Fault-tolerant quantum computation (FTQC) allows us to attain arbitrary accuracy for quantum computational problems at arbitrary scale. A major component for FTQC is fault-tolerant quantum error correction (FTQEC), which has the ability to remove errors from the computation without disturbing the quantum state, as long as not too many errors occur during the computation. Surface code is a FTQEC candidate which has influenced many current quantum computing architectures and one of the reasons for its appeal is the better accuracy threshold value compared to existing concatenated codes, which places a less stringent demand on quality of gate operations in order to achieve FTQC.

We consider existing literature for the estimated value of the accuracy threshold, and conclude that the accuracy threshold value for the surface code cannot be compared fairly with concatenated codes as the underlying assumptions used to derive this value is starkly different for the two types of the FTQC schemes. Furthermore, the accuracy threshold for the surface code has only been derived for the situation of the probabilistic noise, which is only a special type of noise model that does not fully capture all the characteristics of possible noise processes that can affect the physical devices used to implement FTQC.

We attempt to extend the existing proof of a non-zero accuracy threshold value for the surface code under probabilistic noise to the case where noise can be described as CPTP maps, and find it does not show that such a non-zero value exists. This work makes the point that while a threshold value exists for the surface code under probabilistic noise model, we do not yet know whether it exists for more general noise models. It highlights the additional work that remains to be done in order to show that surface codes are truly viable for a FTQC scheme.

T3.79 Hybrid Metasurfaces and Meta-optomechanics

C.W. Qiu* (National University of Singapore)

Metasurfaces and 2D materials have been developing as two important candidates in the interfacial engineering. The synergies between those two domains hold great promises in manipulating light-matter interaction. In this tutorial talk, I will review and report some of the most recent developments in this field of interfacial engineering, via the artificially constructed hybridized structures of ultrathin thickness compared to the wavelength. In particular, the low-dimension and high-frequency scaling may promise a lot more applications, while the challenges in design principle and fabrication capability will become critical limits. The atomic thickness of 2D monolayers provides many interesting physical properties, while also limits the sufficient interaction with the light. Hence, nano-patterned metasurfaces are deployed with 2D monolayers to modulate and structure novel light behavior. We also show meta-optomechanics using spin-to-orbit conversion enabled by metasurfaces.

T3.143 (INVITED) Quantum supremacy in periodically-driven interacting quantum systems (link)

Dimitris Angelakis*, Jirawat Tangpanitanon, Supanut Thanasilp, Marc-Antoine Lemonde, Ninnat Dangniam (Centre for Quantum Technologies)

We provide evidences that generic isolated periodically-driven interacting quantum systems, when thermalized, cannot be efficiently simulated on a classical computer. Our analysis is based on Eigenstate Thermalization Hypothesis and strongly-held conjectures in the complexity theory. We give examples of disordered Ising chains driven by a global magnetic field and the Bose-Hubbard chain with modulated hopping. We show that quantum supremacy can be achieved faster in those systems compared to random quantum circuits with the same topology. Applications of our protocol in probing phases of matter are discussed.

T3.131 (INVITED) Near-term quantum algorithms for linear systems of equations

Kishor Bharti* (CQT)

Solving linear systems of equations is essential for many problems in science and technology, including problems in machine learning. Existing quantum algorithms have demonstrated the potential for large speedups, but the required quantum resources are not immediately available on near-term quantum devices. In this work, we study near-term quantum algorithms for linear systems of equations of the form Ax=b. We investigate the use of variational algorithms and analyze their optimization landscapes. There exist types of linear systems for which variational algorithms designed to avoid barren plateaus, such as properly-initialized imaginary time evolution and adiabatic-inspired optimization, suffer from a different plateau problem. To circumvent this issue, we design near-term algorithms based on a core idea: the classical combination of variational quantum states (CQS). We exhibit several provable guarantees for these algorithms, supported by the representation of the linear system on a so-called Ansatz tree. The CQS approach and the Ansatz tree also admit the systematic application of heuristic approaches, including a gradient-based search. We have conducted numerical experiments solving linear systems as large as 2300×2300 by considering cases where we can simulate the quantum algorithm efficiently on a classical computer. These experiments demonstrate the algorithms' ability to scale to system sizes within reach in near-term quantum devices of about 100-300 qubits.

T4: Photonics 1

T4.29 Designing a spatial filter for compact ruggedized entangled photon sources

Ali Anwar*, Chithrabhanu Perumangatt, Alexander Ling (Centre for Quantum Technologies, National University of Singapore)

Entanglement is one of the basic building block of quantum information. The nonlinear optical process called spontaneous parametric down conversion is commonly used for the generation of entangled photons in various degrees of freedom. Sources of photonic entanglement in polarization are widely exploited in testing fundamental principles of quantum mechanics as well as novel quantum technologies. Applications in quantum communication demands the use of entangled photon sources with more optomechanical stability and less complexity. The detection of transmitted entangled photons in quantum communication systems depends on the quality of spatial mode at the source output. In satellite quantum communication, entangled photons suffer from diffraction and scattering during their propagation through atmosphere, which reduces the chances of signal detection. Here, we discuss the design of a short single-mode fiber module of length approximately 5-10 cm, which act as a spatial filter for the output of entangled photon source. With a particular bending geometry, we have verified that polarization entanglement of photons is maintained during propagation through the fiber. Such simple and easy-mountable fiber modules could be an alternative for spatial filtering systems containing complex optics in the engineering of compact entangled photon sources.

T4.89 Towards Quantum Nanophotonic Devices Using Nitrogen Vacancy Centres in Diamond Nanoprobes

Prithvi Gundlapalli*, Victor Leong, Leonid Krivitsky (NUS Physics)

Scalable quantum nanophotonic devices would enable the practical implementation of quantum networks. We report on the progress of coupling the photon emission of a single nitrogen vacancy (NV) centre in a diamond nanoprobe into a photonic circuit based on silicon nitride (SiN) waveguides. The NV centre is positioned by an atomic force microscope (AFM) on top of an SiN microring resonator, which enhances the coupling of the emission into the nanophotonic device. These photons are then coupled to a bus waveguide and into an external optical fibre. We present our initial findings as well as details of our setup that integrates a confocal microscope and a fibre-waveguide coupling system with an AFM.

T4.32 Dressed quantum well as a Terahertz emitter (link)

Subhaskar Mandal*, Kevin Dini, Oleg Kibis, Timothy C. H. Liew (Nanyang Technological University, Singapore)

We consider theoretically the realization of a tunable terahertz light emitting diode from a quantum well with dressed electrons placed in a highly doped p-n junction. in the considered system the strong resonant dressing field forms dynamic Stark gaps in the valence and conduction bands and the electric field inside the p-n junction makes the QW asymmetric. It is shown that the electrons transiting through the light induced Stark gaps in the conduction band emit photons with energy directly proportional to the dressing field. This scheme is tunable, compact, and shows a fair efficiency.

T4.84 Nanocavity Modes in Plasmonic Tunnel Junctions: Roughness Enhanced Outcoupling

Vijith Kalathingal*, Thorin J Duffin, Andreea Radulescu, Christian A Nijhuis* (CA2DM, Department of Chemistry, National University of Singapore)

Electrical excitation of plasmons in nanoscale tunnel junctions is a versatile probe for the optical frequency fluctuations associated with inelastic tunnelling. Near-field interaction of these highly confined nanocavity modes with metal/dielectric nanostructures is mostly unexplored in junction plasmonics[1]. Here we investigate roughness induced scattering of surface plasmon polariton (SPP) modes confined to 1-2 nm of the metal-insulator-metal tunnel junctions (MIM-TJs). This ultrahigh spatial confinement of the plasmon modes in MIM-TJs (MIM-SPPs) results in large translational momentum mismatch (factor > 10) with SPPs at the metal-dielectric interface or free-space radiation. Theoretically, MIM-SPP excitation efficiency is limited to 10% of the inelastic tunnelling and momentum mismatch between MIM-SPPs and SPPs/photons further restricts the ultimate efficiency of MIM-TJs as efficient plasmon sources. In this study, we quantitatively analyse the pivotal role played by the junction roughness in outcoupling MIM-SPP modes via momentum matching in MIM-TJs. Importantly, junction roughness effectively reduces the thickness of the MIM-TJ electrodes, significantly enhancing the outcoupling due to lowered electromagnetic screening for MIM-SPPs[2]. Using the finite element method, we developed a two-step dipole model for analysing the MIM-SPP excitation and outcoupling in Au-AlOx-Al tunnel junctions. Overall plasmon outcoupling efficiency from MIM-TJ is evaluated as the ratio of energy converted as SPPs and photons to the total electromagnetic power generated within the MIM-TJ. It is observed that the electron-plasmon conversion efficiency is significantly enhanced up to 1.5%, which is 3-4 orders of magnitude higher than recent theoretical estimates performed neglecting the contributions of roughness in the outcoupling process[3]. The simulation results are further corroborated by analytical calculations of MIM-TJ dispersion and the local density of optical states (LDOS) for the smooth and rough case. Junction roughness features are considered as polarisable ellipsoids with polarisability axis normal to the tunnel junction, and near-field dipole-roughness interaction alters the effective magnitude of the source dipole. Computed LDOS for the rough MIM-TJ is compared with the smooth case to quantify the roughness induced outcoupling efficiency of MIM-SPP to SPPs/photons. The study presented here demonstrates a methodical analysis of roughness induced electron to plasmon conversion and is pertinent to recently emerged discussion on the ultimate efficiency of MIM-TJs as plasmon sources for on-chip applications. References 1.Wei, L., et al. Phys. Rev. Lett. 121(19), 193901(2018) 2.Gruhlke, R. W., et al. Phys. Rev. Lett. 56(26), 2838(1986) 3.Parzefall, M. and L. Novotny ACS Photonics, 5(11), 4195(2018)

T4.145 Spectral Control of Perovskite Optical Properties with Metasurfaces (link)

Giorgio Adamo*, Jingyi Tian*, Matteo Degani*, Bhumika Chaudhary*, Harish N S Krishnamoorthy*, Daniele Cortecchia*, Maciej Klein*, Cesare Soci* (Centre for Disruptive Photonic Technologies, TPI, SPMS & Energy Research Institute @ NTU (ERI@N), NTU)

We show that nanostructuring and hybridization of perovskites with metasurfaces allow to engineer radiative emission properties, structural colour and light scattering, providing new opportunities to control emissivity and directivity of light-emitting devices. We report more than one order of magnitude increase in photoluminescence (PL) and reduction in the decay lifetime in MAPbI3, when the emission peak of the perovskite matches the metasurface resonance, in comparison to the unstructured films on glass substrate by hybridizing the perovskite films with plasmonic metamaterials. Furthermore, we have identified a new class of hybrid perovskite materials for reconfigurable/actively tunable dielectric metamaterials and report, for the first time, an experimental demonstration of its highly tunable optical response by both structural and phase variations around room temperature. We show that nanostructuring of perovskite films with metasurface designs, in combination with the temperature-induced structural phase transitions of the intrinsic perovskite material, provide a simple and versatile mechanism to engineer and actively control their optical response. Our findings provide new opportunities for realizing actively tunable, large area perovskite metasurfaces with structural colour, radiative emission properties and directivity control on-demand.

T5: Topological Systems 2

T5.81 (INVITED) Higher-order Dirac fermions in three dimensions (link)

Wu Weikang*, Zhi-Ming Yu, Xiaoting Zhou, Y. X. Zhao, Shengyuan A. Yang (Singapore University of Technology and Design)

Relativistic massless Weyl and Dirac fermions exhibit the isotropic and linear dispersion relations to preserve the Pioncare symmetry, the most fundamental symmetry in high energy physics. In solids, the counterparts of the Pioncare symmetry are crystallographic symmetries, and hence, it is natural to explore generalizations of Dirac and Weyl fermions in compatible with they crystallographic symmetries, and then the new physics coming along with them. Here, we study an important kind of generalization, namely massless Dirac fermions with higher-order dispersion relations protected by crystallographic-symmetries in three-dimensional nonmagnetic systems. We perform a systematic search over all 230 space groups with time-reversal symmetry and spin-orbit coupling considered. We find that the order of dispersion cannot be higher than three, i.e., only the quadratic and cubic Dirac points (QDPs and CDPs) are possible. We discover previously unknown classes of higher-order Dirac points, including the chiral QDPs with Chern numbers $|C| = 4$ and the QDPs/CDPs without centrosymmetry. Especially the chiral QDPs feature four extensive surface Fermi arcs and four chiral Landau bands, and hence leads to observable signatures in spectroscopic and transport experiments. We further show that these higher-order Dirac points represent parent phases for other exotic topological structures. Via controlled symmetry breaking, QDPs and CDPs can be transformed into double Weyl points, triple Weyl points, charge-2 Dirac points or Weyl loops. Using first-principles calculations, we also identify possible material candidates, including alpha-TeO_2 and YRu4B4, which realize the predicted nodal structures.

T5.36 (INVITED) Circuit Realization of a Four Dimensional Topological Insulator (link)

You Wang*, Hannah Price, Baile Zhang, Yidong Chong (Nanyang Technological University)

We use electric circuits to experimentally realise a 4D topological lattice for the first time. The circuit connectivity is engineered to realise the high spatial dimensionality, and the choice of components maps the circuit to a 4D quantum Hall lattice model in symmetry class AI (time-reversal-invariant scalar bosons without extra spatial symmetry). Class AI is topologically trivial in three or lower spatial dimensions, so 4D is the lowest possible dimension for achieving a Class AI topological insulator. We use impedance measurements to probe the local density of states, and hence observe topological surface states associated with a nonzero second Chern number but vanishing first Chern numbers. No topological surface states are observed for different circuit parameters that correspond to a conventional insulator phase. This experiment paves the way to the use of electric circuits for exploring high-dimensional topological models.

T5.54 Nonlinearity protected topology in Su-Schrieffer-Heeger model (link)

Thomas Tuloup*, Raditya Weda Bomantara*, Ching Hua Lee, Jiangbin Gong* (NUS Department of Physics)

The Su–Schrieffer–Heeger (SSH) model is maybe the simplest model to exhibit non-trivial topology, and as such has seen many variations in order to study further aspects of topological matter. Here, we study the effect a diagonal nonlinearity on the topological properties of the system, in the presence of a chiral symmetry breaking perturbation. Such nonlinearity can be achieved through Kerr nonlinearity in optics, and leads to the appearance of additional energy bands, and in the case of strong nonlinear terms, to the almost recovery of the energy bands of the chiral symmetric SSH model, hinting for a recovery of some topological properties of the standard SSH model. Furthermore, using nonlinear adiabatic perturbation theory, we determine a correction to the Zak phase, allowing for almost quantized Zak phases in the perturbative limit, and more strikingly, to the quantization of the sum of all Zak phases in the system for a significant range of chiral symmetry breaking terms. Such quantized quantity is often the sign of potentially deeper and exciting physical insights. By studying the model in real space, we highlight the breakdown of bulk-boundary correspondence, with the existence of several new topological phases where delocalized bulk states are replaced by strongly localized solitons in the bulk. Some of these phases possess very exciting properties such as the presence of near-degenerate edge states in spite of the presence of a chiral symmetry breaking perturbation. These soliton states can finally be explained as the result of the interplay between nonlinear effects and topological features of the associated linear system.

T5.6 (INVITED) A Study of Topological Insulators and Correlated Plasmons (link)

Thomas Whitcher*, Andrivo Rusydi (National University of Singapore)

Recently, it has been shown that electron correlation plays an important role in generating unconventional plasmons in highly-correlated electron systems. Electrons in topological insulators, on the other hand, are massless and insensitive to non-magnetic scattering due to their protection by time-reversal symmetry, which makes them appealing platforms for hosting exotic plasmonic excitations. Using a combination of angle-dependent spectroscopic ellipsometry and angle-resolved photoemission spectroscopy as a function of temperature and supported by first-principles calculations, we reveal new correlated plasmonic excitations and significant Fermi level shifts, accompanied by spectral weight transfer in the topological insulator, Bismuth Selenide (Bi_2Se_3) and its Antimony and Indium doped variants. Our results show the importance of electronic correlations in determining the electronic structure of these materials and that the appearance of correlated plasmons in these materials is dependent on their topologically insulating state.

T5.5 The Effect of Moiré Superstructures on Topological Edge States in Twisted Bismuthene Homojunctions (link)

Jian Gou*, Longjuan Kong, Xiaoyue He, Yuli Huang, Jiatao Su, Sheng Meng, Kehui Wu, Lan Chen, Andrew T S Wee (National University of Singapore)

Creating and controlling the topological properties of two-dimensional topological insulators is important for spintronic device applications. Here, we successfully realize the growth of bismuth homostructures consisting of monolayer bismuthene and single layer black-phosphorus-like Bi (BP-Bi) on the HOPG surface. Combining scanning tunneling microscopy/spectroscopy with non-contact atomic force microscopy, Moiré superstructures with twisted angles in the bismuth homostructure and the modulation of topological edge states of bismuthene were observed and studied. First-principles calculations reproduced the Moiré superlattice, and the structure fluctuation is ascribed to the different stacking modes between bismuthene and BP-Bi, resulting in spatially distributed interface interactions in the bismuth homostructure. More importantly, the modulation of topological edge states is directly related to the variation of interlayer interactions. Our results suggest a promising pathway to tailor the topological states through interfacial interactions.

T6: Theory of Quantum States

T6.97 Tomography of non-Markovian noise

Mikolaj Paraniak* (CQT)

Noise is one of the crucial obstacles to realization of useful Quantum Information Processing systems. Ability to model noise accurately will help minimize its adverse effects and bring us closer to realizing systems able to perform computational tasks beyond reach of classical systems. In our work, we focus on reconstructing a specific type of noise model - CPTP channel with a bath, which makes the dynamics of system non-Markovian in general. In our approach, we assume the effects of noise on the system are described by CPTP channel acting on a composite system-bath space, and a fixed bath state

$$rho_B$$

, to which environment relaxes over time. Then the effects of the noise on the system are captured by the map acting over time on a composite space, with tracing out the bath part at the end. The tomographic scheme that we have developed uses information from process tomography at multiple time-steps, thus going around the experimental inaccessibility of the bath.

T6.11 The transition from quantum field theory to one-particle quantum mechanics and a proposed interpretation of Aharonov-Bohm effect

Benliang Li* (southwest jiaotong university)

In this article we demonstrate a sense in which the one-particle quantum mechanics (OPQM) and the classical electromagnetic four-potential arise from quantum field theory (QFT). In addition, the classical Maxwell equations are derived from a QFT scattering process, while both classical electromagnetic fields and potentials serve as mathematical tools to approximate the interactions among elementary particles described by QFT physics. Furthermore, a plausible interpretation of the Aharonov-Bohm (AB) effect is raised within the QFT framework. We provide a quantum treatment of the source of electromagnetic potentials and argue that the underlying mechanism in the AB effect can be understood via interactions among electrons described by QFT where the interactions are mediated by virtual photons.

T6.87 (INVITED) Sequentially Constrained Monte Carlo Sampler for Quantum States (link)

Rui Han*, Weijun Li, Hui Khoon Ng, Berge Englert* (Centre for Quantum Technologies)

A random sample of quantum states with specific properties could be useful in many scenarios. However, the quantum state space has highly complicated boundaries in high dimension due to the positivity constraint, and it is challenging to incorporate the specific properties into the sampling algorithm. In this paper, we present the Sequentially Constraint Monte Carlo (SCMC) as a powerful method for sampling of quantum states according to any desired property as long as it could be described by an inequality. For illustration, we apply this method for the sampling of quantum states with bound entanglement, high-dimensional quantum states with desired posterior distribution, and uniformly distributed quantum states in regions bounded by the likelihood function. These examples evidently demonstrate that the SCMC sampler is not only efficient and reliable, it is also capable to overcome the curse of dimensionality.

T6.103 (INVITED) Noise, not squeezing, boosts synchronization in the deep quantum regime (link)

Hermanni Heimonen*, Wai-Keong Mok, Leong Chuan Kwek (Centre for Quantum Technologies)

Synchronization phenomena occur throughout nature. The van der Pol oscillator has been a paradigmatic model to investigate synchronization. Here we study the oscillator with additional single-photon dissipation inthe deep quantum regime (defined to be $\gamma_2/\gamma_1 > 10$), and we contrast it with the quantum regime at $\gamma_2/\gamma_1 \approx 1$. Our results show that in this regime: (i) the effect of squeezed driving effect on frequency entrainment is stronglysuppressed, (ii) single-photon dissipation boosts synchronization, (iii) synchronization is bounded, and (iv) the limit-cycle is robust and insensitive to strong driving. We use these physical properties to define the crossoverto the deep quantum regime. We also propose a synchronization measure based on directional statistics whichis analytically calculated. These results reflect the intrinsic physical differences between synchronization in the quantum and deep quantum regimes.

T6.121 (INVITED) Long-distance dynamical entanglement generation in chiral quantum networks (link)

Davit Aghamalyan*, Wai-Keong Mok*, Jiabin You*, Leong-Chuan Kwek (IHPC, A*STAR)

Chiral quantum networks provide a promising route for realising quantum information processing and quantum communication. Here, we describe how two distant quantum nodes of chiral quantum network become dynamically entangled by a photon transfer through a common 1D chiral waveguide. We harness the directional asymmetry in chirally-coupled single-mode ring resonators to generate entangled state between two atoms. We report a concurrence of up to 0.969, a huge improvement over the 0.736 which was suggested and analyzed in great detail in Ref. [1]. This significant enhancement is achieved by introducing microtoroidal resonators which serve as efficient photonic interface between light and matter. Robustness of our protocol to experimental imperfections such as fluctuations in inter-nodal distance, imperfect chirality, various detunings and atomic spontaneous decay is demonstrated. Our proposal can be utilised for long-distance entanglement generation in quantum networks which is a key ingredient for many applications in quantum computing and quantum information processing.

T7: Neuromorphic Computing

T7.99 (INVITED) Spin-based Neuromorphic Computing

S.N Piramanayagam* (Nanyang Technological University, Singapore)

The electronics industry is facing two trends: (i) Moore's law, which was a well-laid path to scale the transistor size and pack more transistors per chip, is getting stagnated. Therefore, researchers are looking at new materials such as spin-based materials and architectures that are different from von Neumann architecture for the growth of the semiconductor industry. (ii) Artificial intelligence (AI) is widely adopted in consumer electronics. However, the power consumed by the method in which AI is implemented is a significant problem. Therefore, researchers are looking at alternative methods for implementing AI. Neuromorphic computing, which draws inspiration from the brain – which is a power-efficient computing system, is considered as a potential alternative [1]. Competitors of spin-based technologies, such as resistive RAM, phase-change RAM, etc., have their place and disadvantages for neuromorphic computing [2]. Spin-based devices also have their unique advantages for neuromorphic computing and are gaining attention in the recent past [3-4]. As the brain has neurons for processing and synapses for memorizing, neuromorphic computing also requires the construction of synthetic neurons and synaptic devices. Grollier and her group have extensively worked on using spin-torque oscillators (STO) as neurons. A neuron array of 4 STOs, interacting with each other, has been used to demonstrate vowel recognition [3]. Anomalous Hall Effect (AHE) based demonstration of the synaptic function of Co/Ni multilayers has been made by Fukami et al [4]. However, the field of spin-based neuromorphic computing is wide open and is at the early stages. For example, the synaptic function of Co/Ni multilayers has been demonstrated in a large device where the multi-domain state, as measured by AHE has been carried out whereas multi-level resistive state using tunneling magnetoresistance is critical for neuromorphic computing. In this talk, the speaker will talk about various aspects of spin-based neuromorphic computing. Nevertheless, the talk will mainly focus on the synaptic elements based on domain wall devices, where controlled pinning is essential to achieve multi-level resistance [5]. Examples of synaptic devices made using Co/Pd multilayers and Co/Ni multilayers will be shown. The prospects and challenges will be highlighted

REFERENCES 1) Wright CD, Hosseini P, Diosdado JAV. Beyond von–Neumann computing with nanoscale phase–change memory devices. Advanced Functional Materials. pp2248-54, vol 23 (2013). 2) Yu S, Wu Y, Jeyasingh R, Kuzum D, Wong H-SP. An electronic synapse device based on metal oxide resistive switching memory for neuromorphic computation. IEEE Transactions on Electron Devices. Vol 58, pp. 2729-31 (2011). 3) Fukami S, Borders WA, Kurenkov A, Zhang C, DuttaGupta S, Ohno H. Use of analog spintronics device in performing neuromorphic computing functions. 2017 Fifth Berkeley Symposium on Energy Efficient Electronic Systems & Steep Transistors Workshop (E3S)2017. p. 1-3. 4) Torrejon J, Riou M, Araujo FA, Tsunegi S, Khalsa G, Querlioz D, et al. Neuromorphic computing with nanoscale spintronic oscillators. Nature 547 428 (2017) 5) J.L. Tin, W.L. Gan, F. Tan, N.R. Sernicola, W.S. Lew and S.N. Piramanayagam, "Synaptic element for neuromorphic computing using a magnetic domain wall device with synthetic pinning sites", J. Phys. D: Appl. Phys. Vol.52 445001 (2019).

T7.15 (INVITED) Preparing quantum states with a quantum neuromorphic platform (link)

Sanjib Ghosh*, Timothy Liew (Nanyang Technological University)

We develop a scheme of quantum reservoir state preparation, based on a quantum neural network framework, which takes classical optical excitation as input and provides desired quantum states as output. We theoretically demonstrate the broad potential of our scheme by explicitly preparing a range of intriguing quantum states, including single-photon states, Schrödinger's cat states, and two-mode entangled states. This scheme can be used as a compact quantum state preparation device for emerging quantum technologies.

T7.152 Destabilizing Inefficient Equilibria via Bifurcations in Evolutionary Games (link)

Stefanos Leonardos*, Georgios Piliouras*, Costas Courcoubetis*, Iosif Sakos* (Singapore University of Technology and Design)

Cryptocurrency mining in Proof of Work (PoW) blockchains is raising concerns due to its extensive environmental footprint. Widely considered as a barrier to their mass adoption, blockchains strive to overcome the bottleneck of energy waste and transition to environment-friendly alternatives like Proof of Stake (PoS). However, with PoW miners reluctant to change due to short-term individual rationality considerations and network effects, the new technologies fail to reach the critical mass of adoption that will self-sustain their growth.

Motivated by these concerns, our goal is to construct mechanisms that will destabilize inefficient - yet individually rational - equilibria in decentralized social systems and networks. Our design space is limited by the restrictions that such mechanisms need to be temporal and economically feasible, yet able to create permanent effects in the non-stationary environments in which agents typically interact. Furthermore, miners do not behave as standard expected utility maximizers and blockchain networks are subject to erratic boom and bust cycles that render classic equilibration concepts powerless.

To break this deadlock, we leverage recent insights in physics steming from the intersection of bifurcation theory and online learning. The resulting dynamics that describe the evolution of the population match observed behavioral patterns by miners. By fine-tuning an appropriate control variable, we develop hysteresis and optimal control mechanisms that can trigger such transitions from undesirable - but currently prevailing - equilibria to socially optimal states in which the preferable technology is adopted. The control variable that enables the transition is costly for the designer, yet it needs to be supported only for a limited period of time. After the reinforcement learning process (rate of adoption) reaches a pivotal state - bifurcation or critical mass - the system undergoes an abrupt change: existing equilibria disappear and the population converges to the desired state independently of the value of the control variable. Critically, our results are robust: to account for the extreme model uncertainty in the nascent blockchain space, we stress our working assumptions and show that our findings remain valid under different economic parameters and model uncertainty. We discuss alternative implementations of the above concepts in the particular blockchain context and illustrate our findings with examples.

T7.12 Universal self correcting computing with disordered neural networks (link)

Huawen Xu*, Sanjib Ghosh, Michal Matuszewski, Timothy Chi Hin Liew* (Nanyang Technological University)

We show theoretically that neural networks based on disordered systems allow the realization of Toffoli gates. A Toffoli gate is a binary logic gate with three inputs and three outputs, which flips the third input if and only if the first two inputs are 1. One of the most remarkable features of neural networks is their ability to operate with noisy data. Noise in input signals is self corrected for by the networks, such that the obtained Toffoli gates are in principle cascadable, where their universality would allow for arbitrary circuits without the need of additional error correcting codes. We further find that the networks can directly simulate composite circuits, such that they are a highly efficient platform allowing circuits to operate in a single step, minimizing the delay of signal transport between elements and error correction overhead. As an example, we consider the full adder circuit. The architecture is generic, with potential applications in ultracold atomtronic systems, nonlinear optical cavities, and exciton-polariton systems. These findings suggest that small scale neural networks based on driven-dissipative disordered systems can be used as building blocks (e.g., Toffoli gates and composite modules like full adders) for efficient universal self correcting computing.

T8: Materials 1

T8.13 (INVITED) Physical property modulation in 2D TMDs homo- and hetero-structures via pressure engineering

Juan Xia* (University of Science and Technology of China)

Two-dimensional (2D) transition metal dichalcogenides (TMDs) and their van der Waals heterostructures (vdWs HSs), exhibit attractive optical and optoelectronic properties thanks to the different band alignments and interlayer interactions. Further, their sensitivity to interlayer distance allows effective tuning of material properties through external modulation of lattice parameters. Therefore, it is of both fundamental and practical importance to explore interlayer excitons in vdWs HSs, especially their dynamic response and underlying mechanisms to different tuning techniques. So far, only limited changes in lattice parameters have been achieved (e.g., less than 2% volume change using strain engineering, or 5% interlayer spacing using piston-cylinder setup), hampering effective tuning of physical properties in vdWs HSs. In this talk, we demonstrate effective tuning of the excitonic states by controlling the interlayer distance in TMDs vdWs HSs, and further tune the interlayer spacing and thus the band structure using hydrostatic pressure. In addition, we perform density functional theory (DFT) calculations and achieve good agreement with the experimental observations, revealing a pressured-induced changeover in the band structure of the HSs. This may offer new insights into the strong interlayer interaction and electron-phonon coupling in TMDs via pressure engineering, which can be exploited for designing new excitonic devices based on 2D vdWs HSs.

T8.8 Numerical Study of MWCNT Nanoparticles for Turbulent Convective Heat Transfer Application of a Pipe Flow

Md Insiat Islam Rabby*, Farzad Hossain, S.A.M Shafwat Amin, Afshana Morshed, A.K.M. Sadrul Islam, Ayman Khan (Universiti Putra Malaysia)

Researches involving mixing very little amount of nano-sized solid additives to base fluid have gained popular interest to develop enhanced convective heat transfer techniques which are essential for the equipments that deal with high heat load. The dispersion of solid particles in such nanofluids changes the thermo physical properties of the working fluid such as viscosity, thermal conductivity, density and specific heat. Therefore nanofluids have enhancement potentiality in heat transfer performance compared to normal working fluids to reduce the high heat load from equipments. In this study, convective heat transfer of turbulent nanofluids in developed region of a pipe was numerically investigated using finite volume method and single phase approach. MWCNT nanoparticles with different volume fraction (1% - 5%) were used to mix with water to produce water based nanofluids. The heat transfer was analysed for a range of Reynolds numbers from 5000 to 10000 with a constant heat flux 500 W/m2 applied on the pipe wall. Results demonstrate 10% to 52% enhancement in heat transfer coefficient with the presence of 1 to 5% nanoparticles concentration, respectively, in comparison to pure water. Meanwhile, results in terms of Nusselt number show an increment of 7% to 25% as compared to pure water for the same range of nanoparticles concentration, respectively. From this study, it can be concluded that water-based MWCNT nanofluids provide enhancement of heat transfer coefficient and Nusselt Number for turbulent pipe flow compared to pure base fluid water.

T8.44 First-principles determination of thermal expansion coefficients of low-symmetry crystals via a Gruneisen method (link)

Chee Kwan Gan* (Institute of High Performance Computing)

Phonon anharmonicity is responsible for important thermal properties such as expansion coefficient and thermal conductivity. Here we present an efficient generalized method[1-5], based on the Gruneisen approach, to calculate the thermal expansion coefficients (TECs) of low-symmetry crystal system. This method avoids the extensive free energy search in the lattice parameter space required by the quasi-harmonic approximation that has an unfavorable scaling where Ni**p phonon calculations are usually performed, p is the number of cell parameters (e.g., p = 1 for a cubic cell and p = 4 for a low-symmetry monoclinic cell). N=5 is typically the number of lattice parameter values scanned in each cell dimension. Here we show that it is possible to perform a number of phonon calculations that is proportional to p (typically 2p+1) [1]. The concept of thermal expansion tensor of low-symmetry crystals such as a monoclinic cell is presented and found to be different from the commonly known lattice-parameter TECs reported for high-symmetry cells such as a cubic cell. The relationship between two TEC concepts are presented which allows a convenient conversion between theory and experiment. Our theory is applied to a recently reported monoclinic NiS3 crystal phase where the TEC tensor of a monoclinic system is calculated for the first time using density functional theory and phonon calculations. A negative TEC tensor component is found and attributed to elastic properties through the elastic compliances and not the population of the negative Gruneisen parameters. The success of our work demonstrated for the monoclinic cell implies all (i.e., seven) crystal types could now be treated within the same formalism.

[1] C. K. Gan and K. T. E. Chua, J. Phys.: Condens. Matter 31, 265401 (2019). [2] C. K. Gan and C. H. Lee, Comput. Mater. Sci. 151, 49 (2018). [3] C. H. Lee and C. K. Gan, Phys. Rev. B 96, 035105 (2017). [4] C. K. Gan and Y. Y. F. Liu, Phys. Rev. B 94, 134303 (2016). [5] C. K. Gan, J. R. Soh, and Y. Liu, Phys. Rev. B 92, 235202 (2015).

T8.82 Enhanced charge to spin conversion in ion implanted heavy metal

Rohit Medwal*, T Shibata, Utkarsh Shashank, Surbhi Gupta, K Asokan, Y Fukuma, Rajdeep Rawat (Nanyang Technological University)

The generation of pure spin current and its injection in the ferromagnets has become essential for low-power magnetization switching, domain wall motion, skyrmion motion, and tunable nano-oscillators. Designing materials with large charge to spin conversion is much needed to design the efficient pure spin current source. Increasing the scattering sites in magnetic and non-magnetic nanostructures by ion implantation provides an advance pathway to improve the spin to charge interconversion efficiency. Thus, we proposed and demonstrate that the charge to spin conversion efficiency of Pt becomes 3 times after implantation. Both, line-shape analysis and current-driven modulation of damping measurements confirmed 3-fold enhancement in the charge to spin current conversion efficiency. Low-temperature spin transport measurements unveil side-jump scattering as the extrinsic mechanism behind improved charge to spin conversion efficiency. We show this enhanced charge to spin current conversion in implanted materials and provide a way of engineering the charge to spin conversion efficiency by controlled ion implantation

T8.85 Growth of Nb-Doped Monolayer WS_2 by Liquid-Phase Precursor Mixing (link)

Ziyu Qin, Leyi Loh*, Junyong Wang, Xiaomin Xu, Qi Zhang, Benedikt Haas, Carlos Alvarez, Hanako Okuno, Justin Zhou Yong, Thorsten Schultz, Norbert Koch, Jiadong Dan, Stephen John Pennycook, Dawen Zeng, Michel Bosman, Goki Eda* (National University of Singapore)

Controlled substitutional doping of two-dimensional transition-metal dichalcogenides (TMDs) is of fundamental importance for their applications in electronics and optoelectronics. However, achieving p-type conductivity in MoS_2 and WS_2 is challenging because of their natural tendency to form n-type vacancy defects. Here, we report versatile growth of p-type monolayer WS_2 by liquid-phase mixing of a host tungsten source and niobium dopant. We show that crystallites of WS_2 with different concentrations of substitutionally doped Nb up to 1014 cm−2 can be grown by reacting solution-deposited precursor film with sulfur vapor at 850 °C, reflecting the good miscibility of the precursors in the liquid phase. Atomic-resolution characterization with aberration-corrected scanning transmission electron microscopy reveals that the Nb concentration along the outer edge region of the flakes increases consistently with the molar concentration of Nb in the precursor solution. We further demonstrate that ambipolar field-effect transistors can be fabricated based on Nb-doped monolayer WS_2.

T9: Strong correlations

T9.67 Transport through a single-site Bose-Hubbard model strongly coupled to two reservoirs (link)

Tianqi Chen*, Chu Guo, Vinitha Balachandran, Dario Poletti* (Singapore University of Technology and Design)

We investigate the non-equilibrium transport properties in a single-site Bose-Hubbard model coupled to two thermal baths at different finite temperatures for different coupling strengths. The effect of the bath can be modeled as two decoupled chains of harmonic oscillators using the thermofield-based transformation and chain-mapping technique with matrix product states (TCMPS). This numerical method provides an exact analysis of the system in the strong system-bath coupling regime. We numerically explore the effect of on-site interactions as well as the strong system-bath couplings on the system properties. We also directly probe the non-Markovianity during the time evolution by studying the non-monotonicity of the trace distance between two different initial states.

T9.34 Graph-theory treatment of one-dimensional strongly repulsive fermions (link)

Jean Decamp*, Jiangbin Gong, Huanqian Loh, Christian Miniatura* (Centre for Quantum Technologies)

One-dimensional atomic mixtures of fermions can effectively realize spin chains and thus constitute a clean and controllable platform to study quantum magnetism. Such strongly correlated quantum systems are also of sustained interest to quantum simulation and quantum computation due to their computational complexity. In this work, we exploit spectral graph theory to completely characterize the symmetry properties of one-dimensional fermionic mixtures in the strong interaction limit. We also develop a powerful method to obtain the so-called Tan contacts associated with certain symmetry classes. In particular, compared to brute force diagonalization that is already virtually impossible for a moderate number of fermions, our analysis enables us to make unprecedented efficient predictions about the energy gap of complex spin mixtures. Our theoretical results are not only of direct experimental interest, but also provide important guidance for the design of adiabatic control protocols in strongly correlated fermion mixtures.

T9.92 Novel magnetic phases in the Shastry-Sutherland Kondo-lattice model

Nyayabanta Swain*, Munir Shahzad, Kipton Barros, Pinaki Sengupta (Nanyang Technological University)

We study the Kondo-lattice model on the Shastry-Sutherland(SS) lattice to explore various magnetic phases stabilised in this lattice. We uncover the weak-coupling instabilities of this model for different chemical potential values corresponding to the quadratic band crossings and van Hove singularities. Further, we use a sophisticated kernel polynomial method to carry out large-scale numerical simulations and establish the existence of various magnetic phases, and their effect on electronic transport on the SS lattice. Our results indicate that the coupling between the spin and charge degrees of freedom of the electrons on the frustrated SS lattice gives rise to richer magnetic phases than those studied within effective spin-only models.

T9.86 Anti-chiral edge states in Heisenberg ferromagnet on a honeycomb lattice

Dhiman Bhowmick*, Pinaki Segupta* (Nanyang Technological University)

We demonstrate the emergence of anti-chiral edge states in a Heisenberg ferromagnet with Dzyaloshinskii-Moriya interaction(DMI) on a honeycomb lattice with in-equivalent sub-lattices. The DMI, which acts between atoms of the same species, differs in magnitude for the two sub-lattices, resulting in a shifting of the energy of the magnon bands in opposite directions at the two Dirac points. The chiral symmetry is broken and for sufficiently strong asymmetry, the band shifting leads to anti-chiral edge states (in addition to the normal chiral edge states) in a rectangular strip where the magnon current propagates in the same direction along the two edges. This is compensated by a counter-propagating bulk current that is enabled by the broken chiral symmetry. We analyze the resulting magnon current profile across the width of the system in details and suggest realistic experimental probes to detect them. Finally, we propose a material that can potentially exhibit such anti-chiral edge states.

T9.19 Assembly of 2N entangled fermions into multipartite composite bosons (link)

Zakarya Lasmar*, P. Alexander Bouvrie, Adam S. Sajna, Malte C. Tichy, Paweł Kurzyński* (Adam Mickiewicz University, Poznań, Poland
Centre for Quantum Technologies, Singapore)

A many-body system made of an even number of fermionic constituents can collectively behave in a bosonic way. The simplest example of such systems is the one made of two fermions. In fact, this example was heavily studied so far, and it is unanimously accepted that entanglement plays a crucial role behind the bosonic quality of its collective behaviour. However, if we consider four fermions, they can behave like two bipartite bosons or further assemble into a single four-partite bosonic molecule. In general, 2N fermions can take many possible arrangements which might be treated as composite bosons. In this talk, I will aim to answer the question: what determines which fermionic arrangement is going to be realized in a given situation and can such arrangement be considered truly bosonic? I will discuss an entanglement-based method to assess bosonic quality of fermionic arrangements and apply it to study how the ground state of the extended one-dimensional Hubbard model changes as the strength of intra-particle interactions increases.

T9.137 Emergent Fermi surface in a many-body non-Hermitian Fermionic chain (link)

Sen Mu*, Ching Hua Lee*, Linhu Li, Jiangbin Gong* (Department of Physics, National University of Singapore)

Quantum degeneracy pressure (QDP) underscores the stability of matter and is arguably the most ubiquitous many-body effect. The associated Fermi surface (FS) has broad implications for physical phenomena, ranging from electromagnetic responses to entanglement entropy area law violations. Given recent fruitful studies in condensed-matter physics under effectively non-Hermitian descriptions, it becomes urgent to study how QDP and many-body interactions interplay with non-Hermitian effects. Through a prototypical critical one-dimensional fermionic lattice with asymmetric gain or loss, a real-space FS is shown to naturally emerge, in addition to any existing FS in momentum space. We carefully characterize such real-space FS with entropy scaling, by a renormalized temperature that encapsulates the interplay between thermal excitations and non-hermiticity. Nearest-neighbor repulsion is also found to induce competing charge density wave that may erode the real-space FS. The underlying physics surrounding criticality and localization is further analyzed with complex spectral evolution of the system from periodic boundary condition to open boundary condition. Our findings can be experimentally demonstrated with ultracold fermions loaded in a suitably designed optical lattice.

T10: Classical vs. Quantum

T10.30 (INVITED) Collisional Quantum Thermometry

Stella Seah*, Stefan Nimmrichter, Daniel Grimmer, Jader Pereira Santos, Valerio Scarani, Gabriel Teixeira Landi (National University of Singapore)

We introduce a general framework for thermometry based on collisional models, where ancillas probe and measure the temperature of the environment through an intermediary system. This allows for the generation of correlated ancillas even if they are initially independent. Using a minimal qubit model as an example, we show that measuring individual ancillas can already lead to an improved sensitivity over the thermal Cramer-Rao bound for ancillas in a thermal state. In addition, collective measurements of the ancillas using our scheme would naturally lead to superlinear scalings of the Fisher information. This feature can generate significant precision enhancements in the limit of weak system-ancilla interactions. Our approach sets forth the notion of collisional metrology and may inspire further advances in quantum thermometry.

T10.39 (INVITED) Devices in Superposition

Asaph Ho*, Valerio Scarani (Centre for Quantum Technologies, National University of Singapore)

We consider measurement devices with quantum descriptions that couple with a system in the same manner Schrodinger cat states do, and study the effect on the system in terms of its evolution when the device is kept in a superposition state by the Zeno effect. Our model considers the system and device initialized in a separable state and then evolving unitarily under an interaction Hamiltonian for a short time before the strong projective measurements on the device begin at regular and very short time intervals. We consider the cases where the device is initialized in a state which is included in the measurement basis, and the case where the device is measured in an arbitrary basis. We show that in the former case, the system evolves unitarily under an effective Hamiltonian $H_{eff} = \langle\phi|H|\phi\rangle$, where $|\phi\rangle$ is the initial state of the device. Finally, we apply the results of our analysis to two specific cases: the atom and field system in Brune et al (1996) and a Stern-Gerlach system with a modified Hamiltonian.

T10.144 (INVITED) Speed of distribution of quantum entanglement (link)

Tanjung Krisnanda*, Tomasz Paterek (Nanyang Technological University)

Quantum speed limit sets the minimum time required for evolving a quantum state and therefore also its properties. Here we present the time bound for the aim of distributing quantum entanglement between two principal objects both via direct as well as indirect interactions (via a mediating system). We show that the indirect interaction setting cannot beat the direct interaction setting in terms of entangling speed. Furthermore, the correlation between the mediator and the principal objects is required for optimal distribution. From the perspective of speeding up the creation of correlations, we discuss that both energy and correlated mediators play similar roles. We present briefly a simple application of the quantum speed limit to charging of quantum batteries and compare the direct and indirect interaction settings.

T10.130 How to Teach AI to Play Bell Non-Local Games: Reinforcement Learning

Kishor Bharti* (CQT)

Motivated by the recent success of reinforcement learning in games such as Go and Dota2, we formulate Bell non-local games as a reinforcement learning problem. Such a formulation helps us to explore Bell non-locality in a range of scenarios. The measurement settings and the quantum states are selected by the learner randomly in the beginning. Still, eventually, it starts understanding the underlying patterns and discovers an optimal (or near-optimal) quantum configuration corresponding to the task at hand. We provide a proof of principle approach to learning quantum configurations for violating various Bell inequalities. The algorithm also works for non-convex optimization problems where convex methods fail, thus offering a possibility to explore optimal quantum configurations for Bell inequalities corresponding to large quantum networks. We also implement a hybrid quantum-classical variational algorithm with reinforcement learning.

T10.71 Negativity of quasiprobability distributions as a measure of nonclassicality

Kok Chuan Bobby Tan*, Seongjeon Choi*, Hyunseok Jeong* (Seoul National University)

We demonstrate that the negative volume of any s-paramatrized quasiprobability, including the Glauber-Sudashan P-function, can be consistently defined and forms a continuous hierarchy of nonclassicality measures that are linear optical monotones. These measures therefore belong to an operational resource theory of nonclassicality based on linear optical operations. The negativity of the Glauber-Sudashan -function in particular can be shown to have an operational interpretation as the robustness of nonclassicality. We then introduce an approximate linear optical monotone, and show that this nonclassicality quantifier is computable and is able to identify the nonclassicality of nearly all nonclassical states.

T11: Perovskites

T11.120 (INVITED) Optical Property, Excitonic States and Structural Stability of Hybrid Perovskites (link)

Ze Xiang Shen* (Nanyang Technological University)

Hybrid Organic-Inorganic Perovskites are a new class of functional materials that may find applications in various technologically important areas. They are particularly suited for large scale applications due to the fact that they can be easily synthesized by solution method. Due to the better moisture and illumination stability, layered perovskites can be the next generation of materials for solar light-harvesting applications, as well as for light emitting diodes (LEDs). Besides, extended chemical engineering possibilities allows obtaining advanced perovskite materials with desirable functional properties, such as tunable band gap, strong exciton-phonon coupling, white light emission, spin-related effects, etc. A good understanding of the fundamental properties is essential for developing new 2D perovskite-based technologies. In this talk, our recent results on 2D perovskites will be reported, including the crystal and electronic structures; the excitonic states and interactions. The properties of the materials under low temperature and high pressure will also be reported, and a brief discussion on the challenges in the fundamental properties of the layered perovskites will be made.

T11.117 Highly efficient thermally co-evaporated mini-modules

Jia Li*, Hao Wang*, Herlina Arianita Dewi*, Nripan Mathews*, Subodh Mhaisalkar*, Annalisa Bruno* (ERI@N, NTU)

Small area metal-halide perovskite solar cells (PSCs), since their advent in 2009, have reached record power conversion efficiency (PCE) of 25.2%, which is been already “inches-close” to the crystalline silicon solar cells (PCE of 26.7%). On the other hand the development of perovskite solar modules (PSMs) is needed to accelerate this technology into mass production. In this work, thermal co-evaporation of MAPbI3 active layers has been optimized to achieve high uniformity over large area and thus produce high-performance devices. With the effort of optimizing stoichiometry of MAPbI3, effective surface and interfacial treatments by methylamine iodine and potassium acetate and light-dispersion minimization by lithium fluoride coating , the small-area PSCs (active area of 0.16 cm^2) and mini-modules (active area 21 cm^2) achieved record PCEs of 20.28% and 18.13% respectively. The un-encapsulated PSCs were able to retain 90% of their initial PCE under continuous illumination at 1 sun (AM 1.5G) for over 100 h and the un-encapsulated PSMs retained ¿95% efficiency in a dark environment with 30% humility for over 60 days. Looking towards both tandem applications and building integrated photovoltaic (BIPV), we have also demonstrated thermally co-evaporated perovskite semi-transparent PSCs and PSMs. Coloured small-area PSCs showed consistent PCEs around 16% for a set of colours spanning the whole visible range and a 16 cm^2 semi-transparent PSMs showed PCE of 11.22% .

T11.116 (INVITED) Semitransparent Perovskite Solar Cells for Perovskite-Silicon Tandems (link)

Herlina Arianita Dewi*, Hao Wang, Jia Li, Maung Thway, Fen Lin, Armin G. Aberle, Nripan Mathews, Subodh Mhaisalkar, Annalisa Bruno* (ERI@N, NTU)

Tandem solar cells (SCs) based on perovskite and silicon represent an exciting possibility for a breakthrough in photovoltaics to overcome the theoretical limit of commonly used silicon single junction due to more efficient light absorption 1. The visible light region will be harnessed by perovskite top cell, while the infrared part is to be utilized by the silicon bottom cell. Therefore, one crucial factor to obtain high efficient tandem SCs is the development of high performing perovskite top cells, while still maintaining their suitable near-infrared transparency. To answer that specific requirement, we have developed highly efficient semi-transparent perovskite solar cells (PSCs) employing Cs0.05(MA0.17FA0.83)0.95Pb(I0.83Br0.17)3 as well as FA0.87Cs0.13PbI2Br with bandgap of 1.58 eV and 1.72 eV respectively, enabling PCEs well above 17% and 14% for both PSCs bandgaps 2. Investigation on the PSCs thermal, shelf-life time, and operating stability will be further assessed. Four terminal tandem PCE of 25.5% can be obtained by combining the semi-transparent PSCs (1.58 eV) with an industrial-relevant cost n-type Si SCs. The four terminal tandem field operating conditions have been evaluated by varying the light intensity, reaching a record efficiency of 26.6 % on low-light intensity region as compared to 1 sun illumination. How the tandem power conversion efficiency depends on the measurements schemes will also be discussed 3.

References: 1. Werner, J.; Niesen, B.; Ballif, C., Perovskite/Silicon Tandem Solar Cells: Marriage of Convenience or True Love Story? – An Overview. Advanced Materials Interfaces 2018, 5 (1), 1700731. 2. Dewi, H. A.; Wang, H.; Li, J.; Thway, M.; Sridharan, R.; Stangl, R.; Lin, F.; Aberle, A. G.; Mathews, N.; Bruno, A.; Mhaisalkar, S., Highly Efficient Semitransparent Perovskite Solar Cells for Four Terminal Perovskite-Silicon Tandems. ACS Applied Materials & Interfaces 2019, 11 (37), 34178-34187. 3. Dewi, H. A.; Wang, H.; Li, J.; Thway, M.; Lin, F.; Aberle, A. G.; Mathews, N.; Mhaisalkar, S.; Bruno, A., Four-Terminal Perovskite on Silicon Tandem Solar Cells Optimal Measurement Schemes. Energy Technology n/a (n/a), 1901267.

T11.140 Detection of Electron Paramagnetic Resonance in La0.6Ca0.4MnO3 using a copper 'stripcoil'

Ushnish Chaudhuri*, Amit Chanda, Ramanathan Mahendiran (National University of Singapore)

Electron paramagnetic resonance (EPR) in Mn-perovskites has been extensively studied using microwave cavity perturbation technique at a fixed resonance frequency of the cavity, typically 9.8 GHz.Conventional EPR spectrometers record the field derivative of the microwave power absorbed by the sample while dc magnetic field (Hdc) is swept through resonance. In this study, we illustrate an alternate method to detect EPR in a sample of La0.60Ca0.40MnO3 by measuring the effective changes in magnetoimpedance (MI) of a copper stripcoil surrounding the sample. Traditionally, MI is measured by passing radio frequency (rf) currents through a sample while Hdc is varied to obtain magnetoresistance (ΔR/R0) and magnetoreactance (ΔX/X0) using an impedance analyzer.In this method, rf current from an impedance analyzer flows through a stripcoil surrounding the sample which creates an rf magnetic field inside it, along its axial direction.During the field sweep, ΔR/R0 shows an abrupt increase that is accompanied by a dip in ΔX/X0 at a critical value of Hdc, Hc, when f $\geq$ 0.9 GHz. Hc increased linearly with frequency (f) of the current in the stripcoil, satisfying the EPR relation f = (γ/2π)Hc where γ is the gyromagnetic ratio.

T11.106 Novel properties in Hydrophobic Two-Dimensional Perovskite (C16H33NH3)2PbI4 under High Pressure (link)

Yulia Lekina*, Andrew Yun Ru Ng, Han Sen Soo, Zexiang Shen* (Nanyang Technological University)

Two-Dimensional hybrid organic-inorganic halide perovskites are promising materials for solar energy, LED, lasing and other applications, particularly due to their relatively good moisture stability. Incorporation of a highly hydrophobic long organic cation, such as hexadecylamine, further improves the stability, making the perovskites practically insoluble in water. Although devices are hardly used under pressures significantly exceeding atmospheric, investigating properties of the materials under compression is of great importance because this is a direct and powerful tool to alter crystal structure and so the properties. Two-dimensional perovskites undergo dramatic changes under compression up to 10 GPa, such as narrowing the band gap by 0.5 eV. Moreover, because of their heterogenic (organic and inorganic) and anisotropic (in-plane and out-of-plane) nature, 2D perovskites exhibit more complex response to compression than their three dimensional counterparts.

In this work we present high-pressure optical and Raman spectroscopic study of hexadecylamine lead iodide (C16H33NH3)2PbI4, which shows greatly improved stability due to its hydrophobic nature. The typical red shift of optical features with pressure was observed, and new excitonic peaks appeared in the PL and absorption spectra above 2 GPa. Crystal domains with a few µm in size were formed under pressure. Notably, the domain features were conserved after pressure release, and we attribute this to be related to the long hexadecylamine cation.

T12: Atomic and Optical Physics

T12.153 Singlet Pathway to the Ground State of Ultracold Polar Molecules (link)

Anbang Yang*, Sofia Botsi*, Sunil Kumar*, Sambit Pal, Mark Lam, Ieva Cepaite, Andrew Laugharn*, Kai Dieckmann* (CQT,National University of Singapore)

We demonstrate a two-photon pathway to the ground state of 6Li40K molecules that involves only singlet-to-singlet optical transitions. We start from a molecular state which contains a significant admixture from the singlet ground state potential by selecting the Feshbach resonance for molecule association. With the only contributing singlet state to the molecular state being fully stretched and with control over the lasers polarization we address a sole hyperfine component of the excited A1Σ+ potential without resolving its hyperfine structure. This scheme ensures access to only one ground state hyperfine component with sufficient Franck-Condon factors and moderate laser powers for both coupling transitions. Its implementation results in large and balanced Rabi frequencies, a favorable condition for the coherent transfer to the ground state. We perform dark resonance spectroscopy to precisely determine the transition frequencies of the states involved. The strong dipolar nature of 6Li40K is revealed by Stark spectroscopy, as it is necessary for the study of dipolar interactions in an optical lattice.

T12.123 (INVITED) Self-homodyne detection of a narrow EIT signal using the superflash effect (link)

Chetan Sriram Madasu, Chang Chi Kwong, David Wilkowski*, Kanhaiya Pandey* (Nanyang Technological Universty)

In this paper, we study the coherent superflash of light in three-level systems. In a two-level system, when a far detuned incident probe is suddenly switched-off, superflash of light is observed due to week absorption and strong phase rotation of the probe. This kind of regime also occurs in the narrow EIT window in a Λ-type system. We show that the superflash of light in a Λ-type system can be used to measure two-photon detuning up to two orders of magnitude more precisely than the width of the EIT window. This has potential applications in metrology like compact coherent population trapping clocks.

T12.75 (INVITED) An ultrastable superradiant laser based on a hot atomic beam

Travis Nicholson*, Haonan Lu, Xianquan Yu, Steven Touzard, Murray Holland (Centre for Quantum Technologies, NUS department of physics)

Ultrastable lasers are at the core of atomic clocks, tests of fundamental physics, and novel quantum simulators. Highly stable laser light has traditionally been generated with cavity stabilization, and considerable improvements in this technology would be difficult. An alternative to cavity stabilization is lasers based on superradiance from narrow optical resonances in atoms. Unfortunately, superradiant lasers have so far relied on cold atoms, which makes these lasers large, expensive, and unsuitable for many applications. With the aim of creating superradiant lasers that are more accessible and more useful for applications, we propose a superradiant laser based on one of the simplest atom sources, namely a hot atomic beam. Despite the large Doppler

profile of this beam, we find that both quantum synchronization and superradiance allow for ultrastable emission that can easily achieve linewidths below 1 Hz. Meanwhile the output power is several orders of magnitude greater than cold atom superradiant lasers and competitive with cavity stabilized systems. The hardware needed to achieve this laser is much simpler than both cold atom superradiant lasers and silicon-cavity-stabilized lasers, making our design far easier to realize in physics laboratories. Furthermore, the system is likely to be less sensitive to vibrations, making it more applicable in field applications than existing ultrastable lasers.

T14: Multiscale percolation

T14.27 (INVITED) Blue Energy Harvesting by Ionic Mobility Engineering in sub-nm Graphene Nanochannels

Massimo Spina*, Nathan Ronceray, Mordjann Souilamas, Slaven Garaj (NUS)

Nanochannels based on carbon materials have been intensively studied in the last decade because of their promising application in nanofiltration [1, 2] and the novel physical phenomena arising between graphitic surfaces at the nanoscale [3–6]. More recently, atomically-smooth graphitic channels with sub-nm heights have been fabricated and used to investigate the physics of ions and water molecules in slits comparable to the smallest ion sizes. It has been shown that water flows very fast inside those channels [3], while ionic mobilities are influenced by the distortion of their hydration shells within the narrow channels [4].

In this work, we investigated ionic flow in atomically-smooth graphitic channels with height ranging from 7Å to 35nm. We show that the mobilities of ions in such confinements do not scale with hydration shell in a simple fashion, and we further explored the role of the surface charge, physical confinement and chemical interactions. Engineering ionic mobilities within the graphitic channels, we could induce strong current driven by the salinity gradient. Such osmotic power generators – driven by mobility engineering, rather than surface charge – are more resilient on the variation of chemical environment and show orders of magnitude increase in osmotic power density compared to commercial membranes.

Referneces 1. S. Hong et al., Nano Lett. 17, 728–732 (2017). 2. J. Abraham et al., Nat. Nanotechnol. 12, 546–550 (2017). 3. B. Radha et al., Nature. 538, 222–225 (2016). 4. A. Esfandiar et al., Science. 358, 511–513 (2017). 5. E. Secchi, A. Niguès, L. Jubin, A. Siria, L. Bocquet, Phys. Rev. Lett. 116, 154501 (2016). 6. Q. Xie et al., Nat. Nanotechnol. 13, 238–245 (2018)

T14.58 Probing equilibrium DNA knots

Rajesh Kumar Sharma, Ishita Agrawal, Liang Dai, Patrick Doyle*, Slaven Garaj* (National University of Singapore)

DNA knots serve as an ideal model to gauge the structural and dynamic properties of biopolymers. In addition, knots can also limit with the functionality of modern genomic technologies, such as nanopores, resulting in erroneous results. Recently we reported the detection of complex DNA knots in solutions. Here we demonstrate controlled sliding of DNA knots by tuning the size of nanopores and surrounding chemical environment, which is crucial to evaluate the equilibrium structure and dynamics of DNA knots. Through our experiments and simulations, we show that by controlling experimental conditions, equilibrium DNA knots can be probed. Moreover, we quantify the sliding of knots as a function of nanopore diameter and show elimination of knot sliding with increased nanopore diameter. Our results open up an opportunity for statistically significant biophysical investigation of knots in single biomolecules, generating unprecedented insights useful from both scientific and technological perspectives.

We acknowledge the financial support from the following grants: NRF, PMO Singapore (Award No. NRF-NRFF2012–09 and NRF-CRP13–2014–03), A*Star RIE2020 AMMM Grant, and Singapore-MIT Alliance for Research and Technology Centre.

T14.52 Giant streaming currents in 2D nanopores

Yanwen Yuan*, Kittipitch Yooprasertchuti*, Slaven Garaj* (Center for Advanced 2D materials, National University of Singapore)

2D nanopore is a nano-sized pore in atomically thin 2D materials. Unlike nanochannels, 2D nanopore's channel length is much smaller than its radius, which leads to emergence of new phenomenon in nanofluidic systems. Here we will present our observations of the pressure-driven ionic currents for different ions and physical parameters in 2D nanopores. The observed streaming currents show significant enhancement and qualitatively different behaviors compared to the nanochannels. Finally, we will present the theoretical model and discuss about different applications of this new phenomenon.

T14.48 Elastocapillary switch in 2D material-based nanochannels (link)

Nathan Ronceray*, Massimo Spina, Vanessa Chou, Slaven Garaj (National University of Singapore)

Low dimensional nano-objects such as nanopores (0D), nanotubes (1D) and nanochannels (2D) allow the confinement of fluids down to the nanometre scale, giving rise to novel physical phenomena [1] such as ultra-fast water flow [2,3]. The capillary pressure that builds up during the wetting of such systems is inversely proportional to the confinement size, reaching over 1,000 atmospheres for nanometre-sized systems [4]. While capillary effects are often undesirable as they can cause damage, we engineered nanostructures to achieve their control. To do so, we implemented van der Waals heterostructure assembly to fabricate nanochannels [5] with atomically smooth yet flexible 2D walls. Using capillarity as a switch, we control the mechanical state of the channel: closed due to van der Waals interactions or open in a stiffness-dominated configuration. Remarkably, we achieve switchable devices which combine the atomic smoothness of 2D materials with a lateral size over 500 nanometres, allowing optical imaging. The drying and filling of the channels were recorded under a fast camera. This study provides new insights on the mechanical properties of 2D materials, their interplay with nanoscale capillarity and confined liquid flow as well as a novel platform for optofluidic systems.

References: 1. Bocquet, Lydéric, and Elisabeth Charlaix. "Nanofluidics, from bulk to interfaces." Chemical Society Reviews 39.3 (2010) 2. Secchi, Eleonora, et al. "Massive radius-dependent flow slippage in carbon nanotubes." Nature 537.7619 (2016) 3. Xie, Quan, et al. "Fast water transport in graphene nanofluidic channels." Nature nanotechnology 13.3 (2018) 4. Van Honschoten, Joost W., et al. "Capillarity at the nanoscale." Chemical Society Reviews 39.3 (2010) 5. Radha, B., et al. "Molecular transport through capillaries made with atomic-scale precision." Nature 538.7624 (2016)

T14.56 STERIC EFFECT ON ELECTROOSMOTIC FLOW IN NANOCHANNELS

Rajni* (Jindal Global University)

Fluids in nanoconfinements, such as nanochannels exhibit strong interactions due to electric double layer (EDL) overlap. Electroosmotic flow (EOF) describes the motion of fluids due to the presence of an EDL. Ions in fluids have considerable finite size represented by steric factor, which is comparable to Debye length of EDLs in nanochannels, thus making them impossible to neglect. Steric effect has been shown to influence EDL overlapping [S. Das and S. Chakraborty, Physical Review E, vol. 84, p. 012501, 2011] and electrocapillarity in nanochannels [Rajni, J. M. Oh and I. S. Kang, Physical Review E, vol. 93(6), p. 063112, 2016]. In this study, the electroosmotic flow for systems not less than 10 nm are investigated using the continuum approach. At this scale, the van der Waals force cease to be significant over the electrostatic forces, thus it is appropriate to use continuum approach. For inclusion of steric effect in the formulation, asymmetric ion size model proposed by [Y. Han, S. Huang, and T. Yan, Journal of Physics: Condensed Matter, vol. 26, p. 284103, 2014] has been used. The influence of steric factor on electroosmotic flow behavior in nanochannels is studied. The variation of electroosmotic velocity and mobility with respect to steric effect and nanochannel widths has been examined.

T15: Photonics 2

T15.149 (INVITED) Manipulation of single photon quantum states by coherent perfect absorption in a fiber network (link)

Anton Vetlugin*, Ruixiang Guo*, Giorgio Adamo*, Cesare Soci*, Nikolay Zheludev* (University of Southampton)

We demonstrate manipulation of single photon quantum states in a fully-fiberized network containing a coherent perfect absorber. By changing a position of the absorber in the network, we selectively absorb either a symmetric or anti-symmetric part of the photon spatial wave function while transmitting the opposite part. The quantum network is represented by a double folded Mach-Zehnder interferometer where the first passage corresponds to a quantum states filtering by the absorber, while the second one allows us to measure the output state of the photon. As the absorber we exploit either plasmonic metamaterial or nanolayer of chromium deposited on cleaved end facet of the optical fiber. To overcome phase noise devastating for fiber networks operating in a quantum regime, we developed an independent phase stabilization loop based on a laser at a different wavelength and a home-made analogue feedback circuit. Manipulation of quantum light states is a key component in quantum information protocols, including quantum computation schemes with dual-rail encoding and coherent quantum communication.

T15.33 (INVITED) Optical frequency reference for Nanosatellite mission (link)

Sapam Ranjita Chanu*, Aaron Strangfeld, Markus Krutzik., Alexander Ling (Centre to Quantum Technology, NUS,117543 Singapore)

We report on our recent progress in the ongoing Optical frequency reference development for space mission. This reference is based on the Doppler free spectroscopy of rubidium vapour cell. Indeed, we propose to produce a compact 10 cm x 10 cm x 10 cm, simple and robust quantum technology to generate optical reference for space application like optical metrology, relativistic geodesy and quantum sensor based navigation. In particular, we realize the spectroscopy with a miniaturized 5mm long cell with 3 mm optical windows using a DFB lasers. We achieved the locking of the frequency reference by giving specific attention to the modulation, stabilization of the laser light by carefully designing a compact optical distribution and control module. We aim to monitor and characterise the laser performance over long timescales and study all the systematic effects to counteract any relative frequency drifts of the laser.

T15.69 (INVITED) Silicon Waveguide Single-Photon Avalanche Detectors for Integrated Quantum Photonics (link)

Salih Yanikgonul*, Victor Leong*, Jun Rong Ong*, Leonid Krivitsky* (Institute of Materials Research and Engineering)

Chip-scale photonics devices are important candidates for implementing key features of a future quantum internet, however many recent demonstrations still require the coupling of light to external single-photon detectors. Major improvements in device footprint and scalability could be achieved if these photodetectors reside on the same chip and couple directly to the photonic waveguides. On-chip silicon single-photon avalanche diodes (SPADs) provide a viable solution as they can be seamlessly integrated with photonic components, and operated with high efficiencies and low dark counts at temperatures achievable with thermoelectric cooling. Here we report the design, simulation [1,2] and early characterization results of silicon waveguide-based SPADs for visible wavelengths where many relevant quantum systems, including trapped ions and color centers in diamond, operate.

[1] S. Yanikgonul, V. Leong, J. R. Ong, C. E. Png, and L. Krivitsky, "2D Monte Carlo simulation of a silicon waveguide-based single-photon avalanche diode for visible wavelengths," Opt. Express 26, 15232-15246 (2018) [2] S. Yanikgonul, V. Leong, J. R. Ong, C. E. Png, and L. Krivitsky, "Simulation of Silicon Waveguide Single-Photon Avalanche Detectors for Integrated Quantum Photonics," IEEE Journal of Selected Topics in Quantum Electronics 26, 2, 1-8 (2019)

T15.125 MXene-Based High-Performance All-Optical Modulators for Actively Q-Switched Pulse Generation

Yunzheng Wang*, Qing Wu, Weichun Huang, Meng Zhang, Han Zhang (Singapore University of Technology and Design)

Q-switched fiber lasers have been integral tools in science, industry and medicine due to their advantages of flexibility, compactness and reliability. All-optical strategies to generate ultrashort pulses are being obtained considerable attention as they can modulate the intracavity Q-factors without employing costly and complex electrically-driven devices. Here, we propose a high-performance all-optical modulator for actively Q-switched pulse generation based on a microfiber knot resonator deposited with V2CTx MXene. The V2CTx MXene is fabricated by a selective etching method and deposited onto an MKR utilizing the optical deposition method. Experimental results show that the obtained Q-switching pulses exhibit a wide adjustment range of repetition rate from 1 kHz-20 kHz, a high signal-to-background contrast ratio of 55 dB and a narrow pulse width of 8.82 μs, indicating great potentials of providing a simple and viable solution in photonic applications.

T15.83 The role of surface roughness in surface plasmon excitation in metal-insulator-metal tunnelling junctions

Thorin Jake Duffin*, Vijith Kalathingal*, Andreea Radulescu*, Christian A. Nijhuis* (Chemistry, NGS, NUSNNI-Nanocore, National University of Singapore)

Electrical excitation of surface plasmon polaritons (SPPs) by metal-insulator-metal tunnelling junctions (MIM-TJs) has been demonstrated to be a viable micro- and nanoscale technology that can be integrated to implement complementary functionality in optoelectronic circuitry on-chip, all without bulky optical components. Overall total MIM-TJ induced SPP excitation efficiency can be broken down into: MIM-TJ cavity mode (MIM-SPP) excitation efficiency, and then MIM-SPP outcoupling to waveguide SPP mode efficiency. Theoretically, overall SPP excitation efficiency is believed to be limited at 10^{-8} plasmons per electron, with an MIM-SPP outcoupling efficiency of 10^{-7}. We have recently experimentally demonstrated that the MIM-SPP outcoupling efficiency in MIM-TJs can be as high as 10%, which has attracted controversy. In this work we have theoretically and experimentally explored surface roughness and electrode thickness, and show that surface topology plays a crucial role in out-coupling MIM-SPP. By introducing surface roughness (from atomic force microscopy – AFM) into simulations and comparing to experimental light emission measurements of roughened MIM-TJs, we find that the MIM-SPP mode can be not only efficiently momentum-matched to the daughter radiative and plasmonic modes, but also have increasing spatial mode overlap due to peak-to-valley roughness causing non-uniform electrode thickness inducing a reduced effective electromagnetic thickness. We explore how different physical parameters enable different outcoupling pathways of the MIM-SPP mode, and experimentally demonstrate that changing electrode thickness can control SPP mode excitation at different interfaces. By a careful treatment of initial MIM-SPP mode excitation and grain boundary-scale surface roughness-induced momentum matching to daughter modes, MIM-SPP outcoupling efficiencies of 10% and higher can be readily achieved in MIM-TJs, resolving 40 years of theoretical and experimental controversy and offering design parameters to further optimise MIM-TJ SPP excitation efficiency.

T16: Materials 2

T16.150 Difference of crystalline Sb2Te3 films growth by sputtering and pulsed laser deposition (link)

Jing Ning*, Jose C. Martinez, Jamo Momand, Paulo S. Branicio, Bart J. Kooi, Robert Simpson* (Singapore University of Technology and Design)

High quality Van der Waals chalcogenides are important for phase change data storage, thermoelectrics, and spintronics. Here, we combine statistical design of experiments and density functional theory (DFT) to explain how the out-of-equilibrium epitaxial deposition methods can improve the crystal quality of Sb2Te3. We found the factors influencing the crystal quality were very different in RF sputtering and Pulsed laser deposition (PLD) methods. An additional thin polycrystalline Sb2Te3 buffer layer most significantly improved the crystal quality for PLD grown films. However, deposition temperature is more significant than seed layer in sputtered films. This difference deserves attraction as both methods are out-of-thermal-equilibrium plasma-based methods. Time-dependent density functional theory molecular dynamics was performed to study this difference resulting from the excitation energy of the plasma. The PLD plasma is much higher energy than the RF plasma, this increase the adatom diffusion length of deposited atoms as they have higher electronic energy. Thus, the electron excitation dominates the adatom diffusivity for PLD, while the adatom diffusivity is determined by the thermal temperature for RF sputtering with lower plasma energy. These results provide a reasonable explanation for the wide-ranging observation of Sb2Te3 and superlattice crystal qualities in the literature. It might be a guide to grow high quality crystals of Sb2Te3, its superlattices, and related materials in different deposition methods.

We acknowledge the support from the Singapore Ministry of Education (MoE) for "Electric field induced transitions in chalcogenide monolayers and superlattices" project (grant # T2MoE1730).

T16.26 Boosted design and study of nanomaterials by HPXPS

Lukasz Walczak* (PREVAC sp. z o.o.)

Unique features of nanomaterials make attractive in various fields such as energy conversion/storage, environment, biosensors, catalysis and nanoelectronics [1-6]. The future development prospects and challenges in the new materials can be boosted by high pressure X-ray spectroscopy (HPXPS). Innovative and compact HPXPS platform will be presented, in order to permit design and characterization of nanomaterials in the UHV and high pressure (HP) conditions. We will report some results using HPXPS technique. Also we will introduce EA15 HP1 and EA15 HP50 electron analysers, based on high end technology, offering a high quality and stable UHV and HP performance. The compact construction allows the connection of different techniques at versatile configurations as well as the incorporation of IR and other analysis techniques. As the platform can be used to atomic layer deposition on substrate at the different temperatures and pressures. The HPXPS platform can be operated in the multimode by SPECTRIUM software, which can offer fully automated processes. Main features of the software will be presented.

References: [1] G Han et al. Nano Energy 66 (2019) 104088, [2] L. Fu et al. PRL 123 (2019) 138001, [3] R. Kawamura Nat Commun 10 (2019) 4880, [4] G Han et al. Nano Energy 66

(2019) 104088, [5] B. Liu and J. Liu, TrAC 121 (2019) 115690, [6] A. Porkovich et al. ACS Nano (2019) 1936-0851.

T16.73 Flexible Artificial Multiferroic for Magnetoelectric Devices

Avinash Chaurasiya, Pikesh Pal, Joseph Vimal Vas, Durgesh Kumar, Anil Kumar Singh, S.N. Piramanayagam, Rohit Medwal*, Rajdeep Singh Rawat* (Nanyang Technological University)

Controlling magnetism by the electric field using multiferroic composite is highly desirable to achieve an energy-efficient memory device. In this direction, efforts were made to design flexible artificial multiferroic by solution casting method to achieve magnetoelectric coupling. The different weight percent (wt %) nickel ferrite (NFO) nanoparticles (NPs) prepared were dispersed in the polyvinylidene fluoride (PVDF) matrix. Thereafter, the synthesized artificial multiferroic composite, subjected to the structural and magnetic measurement to investigate the evolution of the ferroelectric β-phase fraction of PVDF and successful loading of NiFe2O4 nanoparticles. M-H loops for different Wt % loading of NiFe2O4 nanoparticles show that magnetic moment increased linearly with the loading of magnetic nanoparticles. X-ray diffraction (XRD) and X-ray photoelectron spectroscopy (XPS) studies revealed the formation of the NiFe2O4 phase. As the loading of the magnetic nanoparticles in the PVDF matrix increases from 10 wt % to 40 wt %, the dielectric strength of the composite increases, which is confirmed by dielectric as well as impedance spectroscopy measurement. The coercive electric field for the multiferroic composite was found about 7 V measured from I-V measurement. The leakage current for 40 wt % composite decreased with the increase in the loading concentration of magnetic nanoparticles. The magnetocapacitance shows the linear response for the 10 wt % composite while for 40 wt % linear response transforms to loop like behaviour confirming the presence of magneto-electric coupling in 40 wt% NiFe2O4 embedded nanoparticles. The switchable response of magnetocapacitance with significant magnetoelectric coupling makes the device suitable for flexible wearable field controlled electronic devices and magnetic sensors with the dual control.

T16.74 Effects of Structural Phase Transition on Thermoelectric Performance in Lithium-Intercalated Molybdenum Disulfide (Li-MoS_2) (link)

Hong Kuan Ng, Anas Abutaha, Damien Voiry, Ivan Verzhbitskiy, Yongqing Cai, Gang Zhang, Yi Liu, Jing Wu, Manish Chhowalla, Goki Eda*, Kedar Hippalgaonkar* (Institute of Materials Research and Engineering, A*STAR)

Layered transition metal dichalcogenides (TMDCs) intercalated with alkali metals exhibit mixed metallic and semiconducting phases with variable fractions. Thermoelectric properties of such mixed-phase structure are of great interest because of the potential energy filtering effect, which can enhance Seebeck coefficient and thermelectric performance due to the alteration of energy-dependent scattering. The thermoelectric properties of mixed-phase Li-MoS_2 are studied as a function of its phase composition tuned by in-situ thermally driven deintercalation. We find that the sign of Seebeck coefficient changes from positive to negative during initial reduction of the 1T/1T′ phase fraction, indicating crossover from p- to n-type carrier conduction. These anomalous changes in Seebeck coefficient, which cannot be simply explained by the effect of deintercalation-induced reduction in carrier density, can be attributed to the hybrid electronic

property of the mixed-phase Li-MoS_2. Our work shows that careful phase engineering can be a promising route towards achieving thermoelectric performance in TMDCs.

T17: Dirac Systems

T17.112 (INVITED) Two-dimensional antiferromagnetic Dirac fermions in monolayer TaCoTe2

Si Li, Shengyuan Yang* (Singapore University of Technology and Design)

Dirac points in two-dimensional (2D) materials have been a fascinating subject of research. Recently, it has been theoretically predicted that Dirac points may also be stabilized in 2D magnetic systems. However, it remains a challenge to identify concrete 2D materials which host such magnetic Dirac points. Here, based on first-principles calculations and theoretical analysis, we propose a stable 2D material, the monolayer TaCoTe2, as an antiferromagnetic (AFM) 2D Dirac material. We show that it has an AFM ground state with an out-of-plane Néel vector. It hosts a pair of 2D AFM Dirac points on the Fermi level in the absence of spin-orbit coupling (SOC). When the SOC is considered, a small gap is opened at the original Dirac points. Meanwhile, another pair of Dirac points appear on the Brillouin zone boundary below the Fermi level, which are robust under SOC and have a type-II dispersion. Such a type-II AFM Dirac point has not been observed before. We further show that the location of this Dirac point as well as its dispersion type can be controlled by tuning the Néel vector orientation.

T17.41 Anomalous Suppression of Higher-order Nonlinear Response in 3D Dirac Semimetals (link)

Jeremy Lim*, Yee Sin Ang*, Francisco Garcia de Abajo, Ido Kaminer, Lay Kee Ang*, Liang Jie Wong* (Nanyang Technological University)

Three dimensional Dirac semimetals are often thought to share the same essential physics as 2D Dirac materials like graphene. Here, we present a surprising feature of 3D Dirac semimetals that sets them apart from their 2D counterparts: the absence of nonlinear intraband response beyond the third order at near-zero temperatures at or close to a critical field strength. Using complementary analytical theory and nonperturbative time-domain simulations, we show that this effect is robust against changes in incident field polarization and remains significant even at finite temperatures. Additionally, we identify regimes where 3D Dirac semimetals effectively function as bulk versions of 2D Dirac semimetals with the potential for superior performance in terms of high-harmonic generation. Our work fills a vital gap in understanding the nonlinear response of Dirac electrons, and paves the way for the development of chip-integrable, nanophotonic devices and optoelectronics based on Dirac materials in the technologically important terahertz regime

T17.108 (INVITED) Observation of an unpaired photonic Dirac point

Liu Gui-Geng, Zhou Peiheng, Yang Yihao*, Xue Haoran, Ren Xin, Lin Xiao, Sun Hong-Xiang, Bi Lei, Chong Yidong*, Zhang Baile* (Nanyang Technological University)

At photonic Dirac points, electromagnetic waves are governed by the same equations as two-component massless relativistic fermions. However, photonic Dirac points are known to occur in pairs in "photonic graphene" and other similar photonic crystals, which necessitates special precautions to excite only states near one of the Dirac points. Systems hosting unpaired photonic Dirac points are significantly harder to realize, as they require broken time-reversal symmetry.

Here, we report on the first observation of an unpaired Dirac point in a planar two-dimensional photonic crystal. The structure incorporates gyromagnetic materials, which break time-reversal symmetry; the unpaired Dirac point occurs when a parity-breaking parameter is fine-tuned to a topological transition between a photonic Chern insulator and a conventional photonic insulator phase. Evidence for the unpaired Dirac point is provided by transmission and field-mapping experiments, including a demonstration of strongly non-reciprocal reflection. This photonic crystal is suitable for investigating the unique features of two-dimensional Dirac states, such as one-way Klein tunneling.

T17.139 (INVITED) Insight into Two-Dimensional Borophene: Five-Center Bond and Phonon-Mediated Superconductivity

Zhibin Gao*, Jian-Sheng Wang (National University of Singapore)

We report a previously unknown monolayer borophene allotrope and we call it super-B with a flat structure based on ab initio calculations. It has good thermal, dynamical, and mechanical stability compared with many other typical borophenes. We find that super-B has a fascinating chemical bond environment consisting of standard sp, sp2 hybridizations, and delocalized five-center three-electron π bond, called $\pi(5c-3e)$. This particular electronic structure plays a pivotal role in stabilizing the super-B chemically. By extra doping, super-B can be transformed into a Dirac material from pristine metal. Like graphene, it can also sustain tensile strain smaller than 24%, indicating superior flexibility. Moreover, due to the small atomic mass and large density of states at the Fermi level, super-B has the highest critical temperature Tc of 25.3 K in single-element superconductors at ambient conditions. We attribute this high Tc of super-B to the giant anharmonicity of two linear acoustic phonon branches and an unusually low optic phonon mode. These predictions provide new insight into the chemical nature of low dimensional boron nanostructures and highlight the potential applications of designing flexible devices and high Tc superconductors.

T17.77 Excitonic Energy Transfer in 2D Perovskite/Monolayer WS_2 (link)

Qi Zhang*, Eric Linardy, Goki Eda* (National University of Singapore)

Two-dimensional (2D) organic-inorganic hybrid perovskite is a re-emerging material with strongly excitonic absorption and luminescence properties that are attractive for nanophotonics and optoelectronics. Similar to other excitonic 2D semiconductors, the excitons in 2D perovskite nanosheets are expected to exhibit near-field coupling with nearby excitonic systems. Here we report on experimental observation of excitonic energy transfer in van der Waals heterostructures consisting of 2D hybrid perovskite ([C6H5C2H4NH3]2PbI4) and monolayer WS_2. Photoluminescence excitation spectroscopy with WS_2 exciton emission in the detection channel reveals a distinct ground exciton absorption feature of perovskite, evidencing energy transfer from perovskite to WS_2. At the resonance peak of perovskite, the emission from WS_2 was enhanced by a factor of 2 8. This observation suggests that the energy transfer occurs not only from the top-most layer but also from the lower layers of perovskite. We further discuss the emergence of a peculiar sub-gap low energy emission peak which may be attributed to the interfacial hybridization between WS_2 and the organic moiety of perovskite.

T18: 2D Semiconductors and Photonics

T18.96 (INVITED) Remote control of excitons in two-dimensional semiconductors (link)

Maxim Trushin* (National University of Singapore)

An optically excited semiconductor is a home for excitons – the quasiparticles composed of electrons and holes bound together by Coulomb forces. The excitons containing an excess electron or hole are also known as charged excitons or trions. Absence of internal volume in two-dimensional (2D) semiconductors results in a great exposure of 2D excitons to the environment that offers several interesting opportunities to control the excitonic properties externally. In this talk, I'll address the following particular ways to realize such a remote control: (i) tuning electron-hole Coulomb interactions by external screening [1,2]; (ii) imposing exciton-phonon coupling by a substrate with strong polaronic (electron-phonon) interactions [3,4]. The conditions necessary to realize each opportunity will be summarized and justified theoretically with a few particular examples.

[1] M. Trushin, Tightly bound excitons in two-dimensional semiconductors with a flat valence band, Phys. Rev. B 99, 205307 (2019). [2] Z. Qiu, M. Trushin, H. Fang, I. Verzhbitskiy, S. Gao, E. Laksono, M. Yang, P. Lyu, J. Li, J. Su, M. Telychko, K. Watanabe, T. Taniguchi, J. Wu, A.H. Castro Neto, L. Yang, G. Eda, S. Adam, J. Lu, Giant gate-tunable bandgap renormalization and excitonic effects in a 2D semiconductor, Science Advances 5, eaaw2347 (2019). [3] M. Trushin, S. Sarkar, S. Mathew, S. Goswami, P. Sahoo, Y. Wang, J. Yang, W. Li, J.L. MacManus-Driscoll, M. Chhowalla, S. Adam, T. Venkatesan, Evidence of Rotational Froehlich Coupling in Polaronic Trions, Phys. Rev. Lett. 125, 086803 (2020). [4] S. Sarkar, S. Goswami, M. Trushin, S. Saha, M. Panahandeh-Fard, S. Prakash, S. J. R. Tan, M. Scott, K. P. Loh, S. Adam, S. Mathew, T. Venkatesan, Polaronic Trions at the MoS_2/SrTiO3 Interface, Advanced Materials 31, 1903569 (2019).

T18.126 (INVITED) Cooperative orbital moments and edge magnetotransport in monolayer WTe2 (link)

Arpit Arora*, Likun Shi, Justin Song (Nanyang Technological University)

Recently, monolayer WTe2 was found to be another novel material hosting time-reversal symmetry protected dissipationless edge channels that persist at even high temperatures of up to 100 K. We investigate the Quantum Spin Hall edge in monolayer 1T'-WTe2 under an applied magnetic field and show that the magnetotransport properties are strongly influenced by the inevitable loss of inversion center. We find that interplay between the corresponding inversion symmetry breaking mechanisms gives rise to an anomalous gap opening in the edge spectrum affected by the cyclotron motion of the electrons under an external magnetic field and is much larger than the conventional orbital contribution, similar to what we see in HgTe. This anomalous contribution leads to a specific orientation of the magnetic field where the magnetoresistance is maximum, which is determined by the relative magnitude of effective Lande g-factors at the edge for out of plane and in-plane magnetic field. Also, we argue that the orientation of maximum magnetoresistance can be tuned by an external electric field as the applied electric field will change the strength of couplings those leading to breaking of inversion symmetry, which further influences the gap size due to a perpendicular magnetic field.

T18.141 Exploiting the Rich Dielectric Function of Chalcogenide Topological Insulators for Nanophotonics (link)

Harish N S Krishnamoorthy*, Giorgio Adamo*, Jun Yin, Alexander Dubrovkin, Vassili Savinov, Nikolay Zheludev, Cesare Soci* (Centre for Disruptive Photonic Technologies, TPI, SPMS, Nanyang Technological University)

We show that chalcogenide based topological insulator crystals exhibit a rich variety in the optical response function. By using a combination of ellipsometry and infrared spectroscopy measurements, we determine the dielectric function of topological insulator crystals of various compositions belonging to the Bi2xSb2(1 x)Te3ySe3(1 y) family. In the visible part of the spectrum, interband transitions within the bulk give rise to regions with real(ε)¡0 and real(ε)¿0, but with high absorption. While one may be inclined to use the former for plasmonic nanophotonics, we show that the high values of losses essentially wipes out any difference in optical response between the two regions. As we move into the infrared part of the spectrum, the losses reduce while the polarizability of the material becomes extremely high with material refractive indices between 7 and 8, making such materials useful for dielectric nanophotonic architectures. We exploited this high material refractive index in a nanoslit array geometry to create complex resonances featuring poloidal currents. These materials also feature an ultrathin (3 nm thick) topologically protected surface layer which exhibits strong optical conductivity in the mid-infrared region wherein suitable spectral windows with low optical losses from surface and bulk could be identified for potential nanophotonic applications, for example, by exploiting poloidal currents induced in the nanoslit array geometry to couple to the topological surface states.

T18.17 Polarity tunable trionic electroluminescence in monolayer WSe_2 (link)

Junyong Wang*, Goki Eda (National University of Singapore)

Monolayer WSe_2 exhibits luminescence arising from various types of exciton complexes due to strong many-body effects. In this talk, I will present the selective electrical excitation of positive and negative trions in van der Waals metal-insulator-semiconductor (MIS) heterostructure consisting of few-layer graphene (FLG), hexagonal boron nitride (hBN), and monolayer WSe_2. The unbalanced injection of electrons and holes is achieved via field-emission tunneling and electrostatic accumulation. The device exhibits planar electroluminescence from either positive trion X+ or negative trion X- depending on the bias conditions. We show that hBN serves as a tunneling barrier material allowing selective injection of electron or holes into WSe_2 from FLG layer. Our observation offers prospects for hot carrier injection, trion manipulation and on-chip excitonic devices based on 2D semiconductors.

T18.63 (INVITED) Elecrtic Field Control of Ferromagnetism in a van der Waals Semiconductor (link)

Ivan Verzhbitskiy*, Hidekazu Kurebayashi, Haxia Cheng, Jun Zhou, Safe Khan, Yuan Ping Feng, Goki Eda* (National University of Singapore)

Electrostatic manipulation of magnetism in semiconductors has been attracting a great deal of interest due to its prospects in future spintronics. The recent discovery of two-dimensional magnetism in van der Waals systems like CrI3, Fe3GeTe2, and Cr2Ge2Te6 (CGT) highlights the unique potential of ferromagnetic layered compounds as an ideal platform to probe the interaction between charge and magnetic ordering. Here, we report the first observation of ferromagnetic order induced in heavily doped thin crystals of CGT. Upon strong electron doping, our CGT-based electric double-layer devices show a clear metallic behavior contrary to the insulator-like behavior of pristine, un-doped CGT. Surprisingly, the doped CGT exhibits hysteresis in magnetoresistance (MR), a clear signature of ferromagnetism, at temperatures as high as 200 K. This is in clear contrast to the pristine CGT whose Curie temperature is only 61 K. In addition, our measurements show that the magnetic easy-axis of doped CGT is aligned within the plane of the crystal, in contrast to the out-of-plane alignment of the pristine CGT. We attribute these changes to the emergence of the double-exchange interaction mediated by the free carriers. This mechanism dominates over the super-exchange interaction, which is responsible for the ferromagnetic order in undoped CGT. Our observations reveal a unique role of the electric field in altering the dominant mechanism of the magnetic exchange interaction.

T19: Machine Learning

T19.18 (INVITED) Overlap measurements of infinite-dimensional quantum states for quantum-enhanced machine learning (link)

Chi-Huan Nguyen*, Ko-Wei Tseng, Jaren Gan, Gleb Maslennikov, Dzmitry Matsukevich* (Centre for Quantum Technologies)

Estimation of overlap between quantum states is a ubiquitous task in quantum information processing protocols and has great significance for quantum machine learning applications. Implementing the overlap measurement with the standard discrete-variables approach in noisy intermediate-scale quantum computers requires scaling the number of physical qubits and entanglement gates with the dimensions of the Hilbert space. Hybrid quantum computation offers an alternative approach, whereby utilizing both discrete and continuous variables, a gate-based overlap measurement in an infinite-dimensional system with constant circuit depth can be realized. Here, we experimentally demonstrate the overlap measurement using this approach in a system of two trapped Yb 171 ions. We employ the nonlinear interaction between the internal and motional degrees of freedom to enact a controlled-swap gate between two motional modes. To illustrate the versatility of our method, we measure the overlap between a variety of quantum states: Fock states, coherent states, squeezed states, and cat states. We also discuss how to employ the overlap test in an unsupervised quantum-enhanced k-means algorithm.

T19.136 Cellular Laser Mode Analysis of Cancer Model using Machine Learning

Wen Sun, Zhen Qiao, Randall Jie Ang, Yu-Cheng Chen* (Nanyang Technological University)

Biolasers is an emerging technology offering distinct advantages over fluorescence-based detection in terms of narrow linewidth, distinct signals, and strong intensity. Thanks to the strong optical feedback provided by optical cavity, a small change in the gain induced by the underlying biological processes is significantly amplified, leading to a drastic change in the laser output characteristics. As such, laser modes possess the huge potential to identify cellular changes in abnormal (cancer) cells by imaging single cellular lasing modes. However, the high chaotic and complex variation of laser modes makes it challenging for practical applications. By integrating with machine learning, laser modes could be trained and classified more precisely for cancer analysis. In this work, laser modes generated from Fabry Perot (FP) cavities within artificial cancer cell models were analyzed using machine learning. Various sizes of dye-doped artificial nucleus and nucleus-cell ratio were fabricated to serve as the cancer cell model. By sandwiching the artificial cell modes in FP cavities with fixed cavity lengths, we found that the output laser mode pattern and orders change remarkably with the cell dimension. Furthermore, the experimental data were trained in a convolution neural network (CNN)-based machine learning system, then the prediction of cell modes from the output laser modes were implemented. The results demonstrated a prediction with high accuracy, showing the potential of this novel method to be applied for biophysical studies and cellular mechanics.

T19.2 Optimal Machine Intelligence at the Edge of Chaos (link)

Ling Feng*, Lin Zhang, Choy Heng Lai (National University of Singapore)

It has long been suggested that the biological brain operates at some critical point between two different phases, possibly order and chaos. Despite many indirect empirical evidence from the brain and analytical indication on simple neural networks, the foundation of this hypothesis on generic non-linear systems remains unclear. Here we develop a general theory that reveals the exact edge of chaos is the boundary between the chaotic phase and the (pseudo)periodic phase arising from Neimark-Sacker bifurcation. This edge is analytically determined by the asymptotic Jacobian norm values of the non-linear operator and influenced by the dimensionality of the system. The optimality at the edge of chaos is associated with the highest information transfer between input and output at this point similar to that of the logistic map. As empirical validations, our experiments on the various deep learning models in computer vision demonstrate the optimality of the models near the edge of chaos, and we observe that the state-of-art training algorithms push the models towards such edge as they become more accurate. We further establishes the theoretical understanding of deep learning model generalization through asymptotic stability.

T19.46 Machine learning engineering of quantum current states in circuits with lumped parameters (link)

Tobias Haug*, Rainer Dumke, Leong-Chuan Kwek, Christian Miniatura, Luigi Amico (Centre for Quantum Technologies)

The design, accurate preparation and manipulation of quantum states in quantum circuits are essential operational tasks at the heart of quantum technologies. Nowadays, circuits can be designed with physical parameters that can be controlled with unprecedented accuracy and flexibility. However, the generation of well-controlled current states is still a nagging bottleneck, especially when different circuit elements are integrated together. In this work, we show how machine learning can effectively address this challenge and outperform the current existing methods. To this end, we exploit deep reinforcement learning to prepare prescribed quantum current states in circuits composed of lumped elements within a short time scale and with a high fidelity. To highlight our method, we show how to engineer bosonic persistent currents as they are relevant in different quantum technologies as cold atoms and superconducting circuits. With our approach, quantum current states characterised by a single winding number or entangled currents with two winding numbers can be prepared superseding the existing protocols. In addition, we generate quantum states entangling a larger set of different winding numbers. This way, our deep reinforcement learning scheme provides solutions for known challenges in quantum technology and opens new avenues for the control of quantum devices.

T19.49 Transfer learning for neural-network quantum states (link)

Remmy Zen*, Duy Hoang Long My, Ryan Tan, Frederic Hebert, Mario Gattobigio, Christian Miniatura, Dario Poletti*, Stephane Bressan* (National University of Singapore)

Neural-network quantum states have shown great potential for the study of many-body quantum systems. In statistical machine learning, transfer learning designates protocols reusing features

of a machine learning model trained for a problem to solve a possibly related but different problem. We propose to evaluate the potential of transfer learning to improve the scalability of neural-network quantum states and to find the quantum critical points. We devise and present physics-inspired transfer learning protocols, reusing the features of neural-network quantum states learned for the computation of the ground state of a small system for systems of larger sizes. We implement different protocols for restricted Boltzmann machines on general-purpose graphics processing units. This implementation alone yields a speedup over existing implementations on multi-core and distributed central processing units in comparable settings. We empirically and comparatively evaluate the efficiency (time) and effectiveness (accuracy) of different transfer learning protocols as we scale the system size in different models, different quantum phases, and to find the quantum critical points. Namely, we consider both the transverse field Ising and Heisenberg XXZ models in one dimension, and also in two dimensions for the latter, with system sizes up to 128 and 8×8 spins. We also find the quantum critical points for transverse field Ising model in one, two, and three dimensions. We empirically demonstrate that some of the transfer learning protocols that we have devised can be far more effective and efficient than starting from a neural-network quantum states with randomly initialized parameters.

T19.135 Recent progress in Deep Learning Fiber Imaging and Label Free Super-resolution Imaging

Eng Aik Chan*, Changyan Zhu, Carolina Rendon Barraza, Guanghui Yuan, Yidong Chong, Cesare Soci, Nikolay Zheludev (Nanyang Technological University)

Deep learning is an increasingly popular technique used in many domains of Physics. I will present on the recent progress we made in deep learning projects in the Center for Disruptive Photonic Technologies.

T20: Quantum Applications

T20.40 Generating Quantum Random Numbers on a Cubesat (SpooQy-1) (link)

Ayesha Reezwana*, Tanvirul Islam, James A. Grieve, Christoph Wildfeuer, Alexander Ling (Centre for Quantum Technologies)

Random number generators drawing on the intrinsic randomness of quantum processes are expected to play a vital role in future secure communication architectures, and their eventual deployment throughout these networks is anticipated. We report here on the development and deployment of a quantum random number generator (QRNG) based on the generation of entangled photon-pairs on-board a nanosatellite (SpooQy-1) deployed in Low Earth Orbit. Spontaneous entangled-pair generation events are known to be vacuum-coupled, and consequently occur at random intervals. This signal forms the entropy source for our QRNG. Sequences of random bits generated using our QRNG before and after launch are analyzed, revealing good uniformity consistent with a random distribution. In this contribution, we describe the randomness generation methodology and its operation on-board the nanosatellite. Randomness test results and prospects for future QRNGs will also be discussed.

T20.68 (INVITED) Infrared metrology with visible light

Anna Paterova*, Hongzhi Yang, Desmond Toa, Dmitry Kalashnikov, Leonid Krivitsky (IMRE A*STAR)

Infrared (IR) wavelength is a region of big interest, where a number of molecules has fingerprint properties, which are useful in material characterization and sensing applications. In our work we develop a novel technique for IR measurements, which requires using only accessible light sources and detectors operating in the visible range. The technique is based on the interference of correlated photon pairs generated via spontaneous parametric down conversion (SPDC). In SPDC, a photon from the pump laser generates a pair of correlated photons within a nonlinear crystal. One photon of the pair can be generated in the visible range, and the other in the IR range. The interference pattern of the visible photons depends on amplitudes and phases of the IR photons, which are used to probe the properties of the medium under study. Hence, by observing the interference of the visible photons we infer the IR properties of the media, without direct measurements of IR light.

T20.28 (INVITED) Polarization Entangled Photon Sources for Satellite-based Quantum Communication Systems (link)

Chithrabhanu Perumangatt*, Alexander Lohrmann, Alexander Ling (Centre for quantum technologies)

Bright, robust and compact entangled sources are the prime pre-requisites for satellite-based quantum communications. We present two compact sources of polarization entangled photons based on spontaneous parametric down conversion (SPDC) of a laser beam in a periodically poled potassium titanyl phosphate (PPKTP) crystal. In the first source, we present a method to convert position correlated photon pairs into a polarization entanglement. This is achieved by individually manipulating the polarization state of photons generated in different parts of a nonlinear crystal and putting them in coherent superposition. We experimentally demonstrate another source of polarization entangled photon-pairs where we use a broadband, free running laser diode as pump. In this design, the PPKTP crystal is placed within a linear beam-displacement interferometer and emits photon-pairs based on type-0 spontaneous parametric downconversion. This experiment demonstrates a pathway toward observing gigacount rates of polarization entangled photon pairs by using high-power free-running laser diodes with fast multiplexed detectors.

T20.23 (INVITED) Bidirectional clock synchronization with a single photon pair source (link)

Jianwei Lee*, Lijiong Shen, Adrian Nugraha Utama, Antia Lamas-Linares, Christian Kurtsiefer (Centre for Quantum Technologies)

We demonstrate a point-to-point clock synchronization protocol based on bidirectionally propagating photons produced in spontaneous parametric down-conversion (SPDC). Compared to a previous implementation [1], we use only one photon pair source and a partially reflective surface to establish the synchronization channel. Tight timing correlations between photon pairs are used to determine the single, and round-trip times (RTT) measured by two remote clocks, providing sufficient information necessary to achieve a distant independent synchronization, secure against symmetric delay attacks. As an initial demonstration, we show that the coincidence signature useful for determining RTT can be derived from photons reflected off a bare fibre end without additional optics. Our technique allows the synchronization of multiple remote clocks with a single reference clock co-located with the source, without requiring additional pair sources, in a client/server configuration suitable for synchronizing a network of clocks.

[1] Lee, J., Shen, L., Cerè, A., Troupe, J., Lamas-Linares, A., & Kurtsiefer, C. (2019). Symmetrical clock synchronization with time-correlated photon pairs. Applied Physics Letters, 114(10), 101102.

4 Committees

Program Committee

Dario Poletti, SUTD

Cesare SOCI, SPMS, NTU

KOH Wee Shing, IHPC, A*STAR

Shaffique ADAM, Yale-NUS College and CA2DM, NUS

Christian KURTSIEFER, CQT and Physics Dept, NUS

Organizing Committee

Dario POLETTI, SUTD (Conference Chair)

YANG Shengyuan, SUTD

Cesare SOCI, SPMS, NTU

KOH Wee Shing, IHPC, A*STAR

Christian KURTSIEFER, CQT and Physics Dept, NUS

Special thanks for help with logistics and technical support to

Author List

Aberle, Armin G., 61
Abutaha, Anas, 72
Adamo, Giorgio, 23, 43, 68, 77
Aghamalyan, Davit, 25, 48
Agrawal, Ishita, 65
Aigner, Andreas, 11
Aliyu, Mohammad Mujahid, 21
Alvarez, Carlos, 54
Amico, Luigi, 80
Amin, S.A.M Shafwat, 52
Ang, Lay Kee, 11, 22, 34, 74
Ang, Randall Jie, 79
Ang, Ricky, 12
Ang, Yee Sin, 12, 22, 34, 74
Angelakis, Dimitris, 26, 31, 39
Anugraha, Rinto, 7, 12
Anwar, Ali, 41
Arora, Arpit, 76
Asokan, K, 53
Astier, Hippolyte P.A.G., 17
Auksztol, Filip, 37

Baile, Zhang, 74
Balachandran, Vinitha, 18, 55
Banerjee, Rimi, 31
Barraza, Carolina Rendon, 81
Barros, Kipton, 55
Battiato, Marco, 5
Bharti, Kishor, 19, 23, 24, 39, 59
Bhowmick, Dhiman, 56
Blaskovic, Milan, 36
Bomantara, Raditya Weda, 45
Bosman, Michel, 11, 54
Botsi, Sofia, 63
Bouvrie, P. Alexander, 56
Bradley, David, 10
Bressan, Stephane, 80
Bruno, Annalisa, 25, 60, 61
Budoyo, Rangga Perdana, 19

C. Martinez, Jose, 71
C. Tichy, Malte, 56

Cai, Yongqing, 72
Cao, Liemao, 22
Cepaite, Ieva, 63
Chai, Jing Hao, 38
Chan, Eng Aik, 81
Chan, Wei Jie, 12
Chanda, Amit, 61
Chattopadhyay, Udvas, 32
Chaudhary, Bhumika, 43
Chaudhuri, Ushnish, 27, 61
Chaurasiya, Avinash, 72
Chen, Lan, 46
Chen, Tianqi, 55
Chen, Wei, 13, 14
Chen, Yu-Cheng, 79
Cheng, Haxia, 78
Chew, Li Tian, 29
Chhowalla, Manish, 72
Chi Hin Liew, Timothy, 51
Choi, Seongjeon, 59
Chong, Yidong, 19, 32, 44, 81
Chou, Vanessa, 66
Chow, Chang Hoong, 20
Chua, Kun Ting Eddie, 7
Cortecchia, Daniele, 43
Courcoubetis, Costas, 50

Dai, Liang, 65
Dan, Jiadong, 54
Dangniam, Ninnat, 39
Das, Rajasree, 27
Das, Swarup, 21
Decamp, Jean, 55
Degani, Matteo, 43
del Barco, Enrique, 17
Devi, Hemam Rachna, 27
Dewi, Herlina Arianita, 60, 61
Dibert, Karia, 7
Dieckmann, Kai, 29, 63
Ding, Wenjun, 11
Dini, Kevin, 41
Do, Hue, 11

Doyle, Patrick, 65
Dubrovkin, Alexander, 77
Duffin, Thorin J, 42
Duffin, Thorin J., 17
Duffin, Thorin Jake, 15, 69
Dumke, Rainer, 23, 80
Dumke, Rainer Helmut, 19

Eda, Goki, 6, 15, 16, 37, 54, 72, 75, 77, 78
Elliott, Thomas, 38
Englert, Berge, 47

F. G. Reniers, Sander, 32
Feng, Ling, 80
Feng, Xiaolong, 21, 34
Feng, Yuan Ping, 78
Frank, Angelina, 16
Fukuma, Y, 53

Gan, Chee Kwan, 53
Gan, Jaren, 79
Gan, Koon Siang, 14
Gao, Jing, 13, 14
Gao, Yvonne, 3
Gao, Zhibin, 75
Garaj, Slaven, 28, 36, 65, 66
Garcia de Abajo, Francisco, 74
Gattobigio, Mario, 80
Ghosh, Sanjib, 50, 51
Goh, Mark, 7
Gong, Jiangbin, 45, 55, 56
Gou, Jian, 46
Grieve, James, 16
Grieve, James A, 37
Grieve, James A., 82
Grimmer, Daniel, 58
Gu, Mile, 38
Gui-Geng, Liu, 74
Gundlapalli, Prithvi, 41
Guo, Chu, 55
Guo, Guang Can, 8
Guo, Ruixiang, 68
Guo, Yu, 8
Gupta, Surbhi, 53

Haas, Benedikt, 54
Hakim, Amirul, 13
Han, Rui, 47
Han, Yingmei, 17
Haoran, Xue, 74
Haq, Ardhi, 13
Hasanah, Nuur, 8
Haug, Tobias, 19, 25, 80
He, Xiaoyue, 46
Hebert, Frederic, 80
Heimonen, Hermanni, 19, 48
Hippalgaonkar, Kedar, 72
Ho, Asaph, 58
Ho, Matthew, 38
Ho, Yi Wei, 37
Holland, Murray, 63
Hong-Xiang, Sun, 74
Hossain, Farzad, 52
Hu, Xiao Min, 8
Huang, Dexter, 22
Huang, Weichun, 69
Huang, Yuli, 46
Huang, Yun Feng, 8
Hufnagel, Christoph, 19

I. Kuznetsov, Arseniy, 32
Islam, Tanvirul, 82

J. Kooi, Bart, 71
Jeong, Hyunseok, 59
Jia, Li, 25
Jiao, Yalong, 21
Jiao, Yuqing, 32
Jose C Martinez, , 29

Kalashnikov, Dmitry, 82
Kalathingal, Vijith, 15, 42, 69
Kaminer, Ido, 74
Khan, Ayman, 52
Khan, Safe, 78
Khandaker, Mayeen, 10
Kibis, Oleg, 41
Klein, Maciej, 25, 43
Koch, Norbert, 54
Kong, Longjuan, 46

Krishnamoorthy, Harish N S, 43, 77
Krisnanda, Tanjung, 58
Krivitsky, Leonid, 4, 24, 41, 68, 82
Krutzik., Markus, 68
Kumar, Durgesh, 72
Kumar, Sunil, 63
Kurebayashi, Hidekazu, 78
Kurtsiefer, Christian, 11, 20, 83
Kurzy[Pleaseinsertintopreamble]ski, Pawe[Pleaseinsertintopreamble], 56
Kwek, Leong Chuan, 48
Kwek, Leong-Chuan, 25, 48, 80
Kwong, Chang Chi, 20, 63

Lai, Chao Sung, 29
Lai, Choy Heng, 80
Lam, Mark, 63
Lamas-Linares, Antia, 83
Landi, Gabriel Teixeira, 58
Landra, Alessandro, 19
Lasmar, Zakarya, 56
Laugharn, Andrew, 63
Lee, Ching Hua, 45, 56
Lee, Jianwei, 11, 83
Lee, Kaisheng, 17
Lee, Kang Hao, 20
Lei, Bi, 74
Lekina, Yulia, 62
Lemonde, Marc-Antoine, 26, 31, 39
Leonardos, Stefanos, 50
Leong, Victor, 41, 68
Leong, Victor Xu Heng, 24
Li, Benliang, 47
Li, Chuan Feng, 8
Li, Jia, 60, 61
Li, Linhu, 56
Li, Si, 74
Li, Weijun, 47
Liew, Timothy, 31, 50
Liew, Timothy C. H., 41
Lim, Jeremy, 11, 74
Lin, Fen, 61
Linardy, Eric, 15, 75
Ling, Alexander, 16, 37, 41, 68, 82
Liu, Bi Heng, 8
Liu, Yi, 72
Liu, Ying, 34
Loh, Huanqian, 21, 55
Loh, Leyi, 54
Lohrmann, Alexander, 82
Lu, Haonan, 63
Lu, Li, 24, 29, 32
Lu, Yunhao, 21

Ma, Zhongshui, 34
Madasu, Chetan Sriram, 63
Mahendiran, Ramanathan, 27, 61
Mahfoud, Zackaria, 11
Mandal, Subhaskar, 31, 41
Mao, Hongying, 14
Martin, Jens, 10
Maslennikov, Gleb, 79
Mathews, Nripan, 60, 61
Matsukevich, Dzmitry, 79
Matuszewski, Michal, 51
Medwal, Rohit, 53, 72
Meng, Sheng, 46
Mhaisalkar, Subodh, 60, 61
Mhaisalkar, Subodh G., 25
Miniatura, Christian, 35, 55, 80
Miscuglio, Mario, 28
Mitra, Sourav, 10
Mo, Jinchao, 14
Moitra, Parikshit, 32
Mok, Wai-Keong, 25, 48
Momand, Jamo, 71
Morshed, Afshana, 52
Mu, Sen, 56
Muslim, Roni, 7, 12
My, Duy Hoang Long, 80

N. S. Krishnamoorthy, Harish, 32
Nafria, Amritpal, 29
Nagatsu, Kotaro, 10
Nanda, Karuna Kar, 27
Neo, Andy, 29
Ng, Boon Long, 20

Ng, Hong Kuan, 72
Ng, Hui Khoon, 38, 47
Ng, Kian Fong, 37
Ng, Truman, 9
Nguyen, Chi-Huan, 79
Nguyen, Hoang Long, 19
Nicholson, Travis, 14, 15, 63
Nickle, Cameron, 17
Nijhuis, Christian A, 42
Nijhuis, Christian A., 15, 17, 69
Nimmrichter, Stefan, 58
Ning, Jing, 71
Novoselov, Konstantin, 10

Okuno, Hanako, 54
Ong, Jun Rong, 24, 68
Ong, Zhun-Yong, 34
Oon, Fong En, 23

Pal, Pikesh, 72
Pal, Sambit, 63
Pandey, Kanhaiya, 20, 63
Paniagua-Dominguez, Ramon, 32
Paraniak, Mikolaj, 47
Paterek, Tomasz, 58
Paterova, Anna, 82
Pauly, Fabian, 15
Peano, Vittorio, 31
Peiheng, Zhou, 74
Pennycook, Stephen John, 54
Perumangatt, Chithrabhanu, 41, 82
Piliouras, Georgios, 50
Piramanayagam, S.N, 49
Piramanayagam, S.N., 72
Png, Jason, 11
Poh, , 24
Poh, Hui Ling, 29
Poletti, Dario, 18, 20, 55, 80
Price, Hannah, 44
Prihatmoko, Catur, 13

Qi, Dongchen, 17
Qiao, Zhen, 79
Qin, Ziyu, 54
Qiu, C.W., 39
Qiu, Cheng-Wei, 2
Quek, Xiu Quan, 21

Rabby, Md Insiat Islam, 52
Rabl, Peter, 31
Radulescu, Andreea, 42, 69
Rajni, , 66
Ramaraj, Ravinraj, 15
Ranjita Chanu, Sapam, 68
Rawat, Rajdeep, 53
Rawat, Rajdeep Singh, 72
Reezwana, Ayesha, 82
Ronceray, Nathan, 28, 65, 66
Rosyid, Muhammad Farchani, 7
Ruixiang, Guo, 23
Rusydi, Andrivo, 45

S. Branicio, Paulo, 71
S. Sajna, Adam, 56
Sadrul Islam, A.K.M., 52
Sakos, Iosif, 50
Santos, Jader Pereira, 58
Savinov, Vassili, 77
Scarani, Valerio, 12, 58
Schultz, Thorsten, 54
Seah, Stella, 58
Segupta, Pinaki, 56
Senapati, Asim, 29
Sengupta, Pinaki, 55
Shahzad, Munir, 55
Sharma, Rajesh Kumar, 65
Shashank, Utkarsh, 53
Shen, Lijiong, 11, 83
Shen, Wei, 9
Shen, Ze Xiang, 60
Shen, Zexiang, 62
Sheng, Xian-Lei, 21
Shi, Likun, 76
Shibata, T, 53
Sholihun, Sholihun, 7
Simpson, Robert, 28, 29, 32, 71
Simpson, Robert Edward, 24
Singh, Anil Kumar, 72
Soci, Cesare, 11, 23, 25, 32, 43, 68, 77, 81

Soh, Chee Wei, 14
Song, Justin, 76
Soo, Han Sen, 62
Sorger, Volker, 28
Souilamas, Mordjann, 28, 65
Sow, Chrong Haur, 10
Sow, Malcolm, 9
Spina, Massimo, 28, 65, 66
Sreedevi, Athira Krishnan, 29
Strangfeld, Aaron, 68
Su, Jiatao, 46
Sun, Wen, 79
Swain, Nyayabanta, 55

Tai, Bo, 21
Tan, Dawn, 3
Tan, Kok Chuan Bobby, 59
Tan, Ryan, 18, 80
Tan, Ting You, 14
Tang, Chi Sin, 27
Tangpanitanon, Jirawat, 26, 39
Taniguchi, Takashi, 15
Tay, Zestin, 12
Teo, Ting Yu, 28, 29
Thanasilp, Supanut, 26, 39
Thompson, Damien, 17
Thway, Maung, 61
Tian, Jingyi, 43
Toa, Desmond, 82
Tosto, Francesca, 14
Touzard, Steven, 14, 15, 63
Trushin, Maxim, 15, 76
Tseng, Ko-Wei, 79
Tuloup, Thomas, 45

Utama, Adrian Nugraha, 83

Valuckas, Vytautas, 32
Vas, Joseph Vimal, 72
Vella, Daniele, 37
Vella, Danielle, 15
Verzhbitskiy, Ivan, 16, 37, 72, 78
Verzhbitskiy, Ivan A, 15
Vetlugin, Anton, 68
Vetlugin, Anton N., 23
Viana-Gomes, José, 16, 37
Vogelsberger, Mark, 7
Voiry, Damien, 72

Walczak, Lukasz, 71
Wang, Fangwei, 15
Wang, Hao, 60, 61
Wang, Jian-Sheng, 75
Wang, Junyong, 54, 77
Wang, Qi Jie, 32
Wang, Qiang, 19
Wang, Rui, 15
Wang, Yanan, 13
Wang, You, 44
Wang, Yunzheng, 69
Wang, Zhe, 17
Watanabe, Kenji, 15
Wee, Andrew, 9
Wee, Andrew T S, 46
Wee, Andrew T. S., 26
Wee, Andrew Thye Shen, 27
Weikang, Wu, 44
Wellens, Thomas, 20
Whitcher, Thomas, 45
Wildfeuer, Christoph, 82
Wilkowski, David, 20, 63
Wong, Liang Jie, 74
Wu, Jing, 72
Wu, Kehui, 46
Wu, Lin, 11
Wu, Qing, 69
Wu, Qingyun, 22
Wu, Weikang, 21
Wu, Yu Chun, 8

Xia, Juan, 52
Xiang, Du, 13, 14
Xiao, Lin, 74
Xiao, Xiong, 11
Xin, Ren, 74
Xing, Bo, 18
Xomalis, Angelos, 23
Xu, Huawen, 51
Xu, Xiansong, 18

Xu, Xiaomin, 54
Xue, Haoran, 19

Yadav, Dinesh, 15
Yang, Anbang, 63
Yang, Hang, 14
Yang, Hongzhi, 82
Yang, Shengyuan, 74
Yang, Shengyuan A., 21, 34, 44
Yanikgonul, Salih, 23, 24, 68
Yanti, Indri, 12
Yap, Yung Szen, 19
Yellapragada, Krishna Chaitanya, 21
Yeo, Wei Hong, 21
Yidong, Chong, 74
Yihao, Yang, 74
Yin, Jun, 77
Yin, Xinmao, 26, 27
Yooprasertchuti, Kittipitch, 28, 66
You, Jiabin, 25, 48
Yu, Bai Chu, 8
Yu, Xianquan, 14, 63
Yu, Zhi Ming, 34
Yu, Zhi-Ming, 44
Yuan, Guanghui, 81
Yuan, Yanwen, 66
Yun Ru Ng, Andrew, 62

Zavala, Jesus, 7
Zen, Remmy, 80
Zeng, Dawen, 54
Zeng, Yongquan, 32
Zhang, Baile, 19, 32, 44
Zhang, Gang, 72
Zhang, Han, 69
Zhang, Lin, 80
Zhang, Meng, 69
Zhang, Qi, 54, 75
Zhang, Wen, 9
Zhang, Ziyu, 17
Zhao, Jianzhou, 21
Zhao, Jinpei, 10
Zhao, Y. X., 44
Zheludev, Nikolay, 68, 77, 81
Zheludev, Nikolay I., 23
Zheng, Yue, 13
Zhong, Chen, 27
Zhou Yong, Justin, 54
Zhou, Jun, 78
Zhou, Justin, 16
Zhou, Xiaoting, 44
Zhu, Changyan, 81
Zhu, Rui, 9