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1 Schedule

Thursday, 30 Sept

8.45 AM	Registration (location TBD)			
9.00 AM	Opening Address (Grand Ballroom)			
9.10 AM	Plenary talk 1 by YAN Jie (Grand Ballroom)			
9.55 AM	Plenary talk 2 by Ranjan Singh (Grand Ballroom)			
10.40 AM	Coffee/Tea Break (loc TBD)			
11.15 AM	Technical Sessions			
	T1 (Sky Ballroom I) Topological Physics 1	T2 (Sky Ballroom II) Materials 1	T3 (Sky Ballroom III) Quantum Science 1	T4 (Grand Ballroom) Quantum Engineering 1
12.45 PM	Lunch break (loc tbd)			
1.30 PM	Exhibitor presentation by Tektronix (Grand Ballroom)			
2.00 PM	Technical Sessions			
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4.00 PM	Technical Sessions			
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5.30 PM	End of Thursday sessions			

Friday, 1 October

8:45 AM	Registration (loc TBD)		
9.00 AM	Plenary talk 3 by Javier Gomez Fernandez (Grand Ballroom)		
9.45 AM	Plenary talk 4 by José-Ignacio LATORRE (Grand Ballroom)		
10.30 AM	Coffee/Tea Break, Poster mounting		
11.00 PM	Technical Sessions		
	T13 (Grand Ballroom) Quantum Engineering - QEP 1.0 Symposium 1	T14 (Sky Ballroom I) General Physics 1	T15 (Sky Ballroom II) Atomic, Molecular, and Optical Physics
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1.30 PM	Exhibitor presentations (loc tbd)		
2.00 PM	Technical Sessions		
	T16 (Grand Ballroom) Quantum Engineering - QEP 1.0 Symposium 2	T17 (Sky Ballroom I) General Physics 2	T18 (Sky Ballroom II) Whitespace - post-deadline
3.30 PM	Coffee/Tea Break		
4.00 PM	PO1: Poster pitch session (Grand Ballroom)		
6.30 PM	End of Friday sessions		

2 Plenary sessions

Despite the crayz times we find ourselves in, we are honoured to have four distinguished plenary speakers this year – with a nice overview of recent activities in physical sciences in Singapore. Some of the topics are not really our daily business, but we hope you can sit back and enjoy the wide scope of topics physicists are working on!

P1: A Novel SARS-CoV-2 Immunoassay Based on Force-Dependent Dissociation of Molecular Complexes

Prof. YAN Jie
Department of Physics and Mechanobiology Institute, National University of Singapore

Thursday, 30 September, 9:10am, Venue: Grand Ballroom

Abstract

To contribute to the fight against covid-19, we have been developing rapid SARS-CoV-2 antigen and antibody immunoassay technologies, featured with high-sensitivity, high-specificity, and low-cost, which can be used for laboratory test, point-of-case test, and home-based test. Unlike most of the current immunoassays that rely on detecting the binding affinity difference between specific and nonspecific molecular interactions at equilibrium, the assay developed by our team is based on the difference in the force-dependent dissociation kinetics between specific and non-specific biomolecular complexes. The force quickly removes the non-specifically formed complexes, leaving the remaining ones mainly the complexes formed with specific biomolecular interactions. This mechanism leads to mechanically enhanced specificity, with the signal-to-noise ratio increasing exponentially with time. Our team also developed methods to detect the remaining biomolecular complexes at a near-single-molecule level, achieving high detection sensitivity. Based on this physical principle, we have developed rapid test kits that can be completed within 30 minutes requiring a small sample volume ($< 20\,\mu$L), for both SARS-CoV-2 infection and antibodies produced from a past SARS-CoV-2 infection or from recent vaccination against SARS-CoV-2. By mixing the SARS-CoV-2 nucleocapsid proteins with saliva or mid-turbinate swab sample, laboratory results have shown that the SARS-CoV-2 test kit can detect the nucleocapsid proteins at a concentration 300 times lower than most of the currently applied SARS-CoV-2 rapid test kits. The antibody test kit can detect the presence of IgG antibody against the receptor binding domain (RBD) of SARS-CoV-2 within seven days after receiving the first dose of Pfizer or Moderna vaccine and quantify the dynamics of the level of RBD-targeting antibodies post vaccination. Preliminary results obtained from a small-scale preclinical study of RBG antibodies produced by vaccination with different vaccines will be presented.

P2: On-chip terahertz topological photonics for 6G communication

Assoc. Prof. Ranjan Singh
Division of Physics and Applied Physics, Nanyang Technological University, Singapore

Thursday, 30 September, 09:55am, Venue: Grand Ballroom

Abstract

The fifth generation (5G) communication network has provided a breakthrough platform to fulfil needs at individual and societal levels enabling enhanced broadband mobile communications, Internet of Things (IoT), autonomous vehicles, and virtual reality. However, considering the unsatiated quest for new services and development of new technologies in the next decade demands a vision beyond 5G: The 6G communications. The holy grail of 6G communication would be to achieve data bit rate of terabits per second (Tbps), which is two orders of magnitude higher than 5G. Several widely anticipated artificial intelligence and cloud-based future services including education, healthcare, smart cities, aviation, entertainment, autonomous driving, precious manufacturing, and holographic communications will critically depend on massive-connectivity, real-time could computing, and high-speed communication with drastically reduced latency. To develop the architecture of wireless communication that could drive these potential applications the only viable solution is to push the frontier of the radiofrequency (RF) spectrum in order to access larger bandwidth. Terahertz (THz) carrier frequencies are the last frontier of the RF spectrum that are envisioned to facilitate 6G communication. I will share our recent findings on using lossless topological photonic crystal waveguide interconnects and ultra-high Q cavity on a silicon platform for developing chip scale THz photonic devices that support more than 50 Gbps data transmission and extremely low-energy modulation.

P3: The biomaterial age

Asst. Prof. Javier Gomez Fernandez
Engineering Product Development
Singapore University of Technology and Design

Friday, 1 October 9:00am, Venue: Grand Ballroom

Abstract

A dramatic transformation is necessary to reach a sustainable society revolving around controlling and using biological materials and designs. This biomaterial age ushers an entirely new technological paradigm favoring the development of circular economic models and sustainable societies, and it will be key to some of the greatest achievements of humanity in the next century. This talk will present more than a decade of work, from the early studies on solid-state physics to the recent advances on biomimetic materials for the rapid, sustainable, and affordable production of manufacturing systems and economies integrated within ecological cycles.

P4: Quantum computation for real

Prof. José-Ignacio Latorre, Centre for Quantum Technoloies
National University of Singapore

Friday, 1 September, 09:45am Venue: Grand Ballroom

Abstract

Quantum computing devices are making steady progress. The battle for a preferred platform for qubits is far from being decided. Quantum algorithms are badly needed, as designing circuits that provide any quantum advantage is anything but trivial.

Yet, the quantum computing field is taken by storm. Governments and corporations compete to gain some control on this constantly changing race. We'll try to summarize the present status of the quantum computing landscape.

3 Posters

(poster instructions to be generated).

PO.8 Intrinsic Polarization Coupling in 2D α-In_2Se_3 toward Artificial Synapse with Multi-mode Operations

Jing Gao*, Wei Chen (NUS)

Emulating advanced synaptic functions of the human brain with electronic devices contributes an important step toward constructing high-efficiency neuromorphic systems. Ferroelectric materials are promising candidates as synaptic weight elements in neural network hardware due to their controllable polarization states. However, the increased depolarization field at the nanoscale and the complex fabrication process of the traditional ferroelectric materials hamper the development of high-density, low power and highly sensitive synaptic devices. Here we report the implementation of 2D ferroelectrics α-In_2Se_3 as an active channel material to emulate typical synaptic functions. The α-In_2Se_3-based synaptic device features multi-mode operations, enabled by the coupled ferroelectric polarization under various voltage pulses applied at both drain- and gate-terminals. Moreover, the energy consumption can be reduced to $\approx$1 pJ by using high-κ dielectric (Al_2O_3). The successful control of ferroelectric polarizations in α-In_2Se_3 and its application in artificial synapses are expected to inspire the implementation of 2D ferroelectric materials for future neuromorphic systems.

PO.9 An Atomtronic Experimental Setup for Engineering Quantised Circulations

Koon Siang Gan* (Nanyang Technological University)

The growing field of Atomtronics studies atomic systems analogous to electronic circuits and components, and is an important frontier for fundamental research and the development of new quantum technologies. A key ingredient in typical Atomtronics experiments is persistent currents, formed by a superfluid BEC. These persistent currents in ring structures play an important role in Atomtronics as it forms the basis of many interesting Atomtronic systems such as ring lattices and stacked rings. However current methods become increasingly inadequate with the increased complexity of Atomtronic systems. Hence, a novel method for generating circulations is proposed and numerically simulated. A ring composed of 6 equal segments has its individual segments imprinted with a distinct phase value. The results show that certain sets of phase sequences can produce circulations of 1 and 2 after a merging and relaxation of the segments. An Atomtronic experimental setup which produces a Rubidium-87 Bose-Einstein Condensate was also constructed to test this protocol in the near future. A Digital Micromirror Device (DMD) is used to create various arbitrary optical potentials to confine the BEC in addition to a vertical lattice. A matter-wave interference experiment is performed to demonstrate the capabilities of our system.

PO.11 Anomalous Nernst Effect and Joule Magnetostriction in ferromagnetic $La_{0.5}Sr_{0.5}CoO_3$ synthesized by microwave irradiation

Manikandan Marimuthu, Arup Ghosh, Mahendiran Ramanathan* (National University of Singapore)

Ferromagnetic metallic oxides have potential applications in spincaloric devices which utilize the spin property of charge carriers for interconversion of heat and electricity through spin Seebeck or anomalous Nernst effect or both. In this work, we synthesized polycrystalline $La_{0.5}Sr_{0.5}CoO_3$ by microwave irradiation method and studied its transverse thermoelectric voltage (Nernst thermopower) and change in the linear dimension of the sample (Joule magnetostriction) in response to external magnetic fields. In addition, magnetization, temperature dependences of electrical resistivity and longitudinal Seebeck coefficient (Sxx) in absence of an external magnetic field were also measured. The sample is ferromagnetic with a Curie temperature of T_C = 247 K and shows a metal like resistivity above and below T_C with a negative sign of Sxx suggesting charge transport due to electrons. Magnetic field dependence of the Nernst thermopower (Sxy) at a fixed temperature shows a rapid increase at low fields and a tendency to saturate at high fields as like the magnetization. Anomalous contribution to Sxy was extracted from total Sxy measured and it exhibits a maximum value of 0.21 μV/K at 180 K for H = 50 kOe, which is comparable to the value found in single crystal for a lower Sr content. The Joule magnetostriction is positive, i.e., the length of the sample expands along the direction of the magnetic field and it does not saturate even at 50 kOe. The magnetostriction increases with decreasing temperature below T_C and reaches a maximum value of 500 ppm at T $\leq$ 40 K. The coexistence of significant magnitudes of the anomalous Nernst thermopower and magnetostriction in a single compound has potential applications for thermal energy harvesting and low-temperature actuators, respectively.

PO.12 Weyl-triplons in $SrCu_2(BO_3)_2$

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

We propose that Weyl triplons are expected to appear in the low energy magnetic excitations in the canonical Shastry-Sutherland compound, $SrCu_2(BO_3)_2$, a quasi-2D quantum magnet. Our results show that when a minimal, realistic inter-layer coupling is added to the well-established microscopic model describing the excitation spectrum of the individual layers, the Dirac points that appear in the zero-field triplon spectrum of the 2D model split into two pairs of Weyl points along the k_z direction. Varying the strength of the inter-layer DM interaction and applying a small longitudinal magnetic field results in a range of band-topological transitions accompanied by changing numbers of Weyl points. We propose inelastic neutron scattering along with thermal Hall effect as the experimental techniques to detect the presence of Weyl-node in the triplon spectrum of this material. We show that the logarithmic divergence in the second derivative in thermal Hall conductance near phase transition from regime Weyl-points to a regime with topologically gapped bands as well as a finite slope in the thermal Hall conductance as a function of magnetic field at zero magnetic field are promising evidences for the presence of Weyl-triplons.

PO.13 Comparison of visibility of Near-infrared non-degenerate and degenerate entangled photon pairs through telecommunication fiber

Rui Wang*, Rui Ming Chua, Chithrabhanu Perumangatt, Alexander Ling* (CQT)

For practical quantum communications, the efficiency of the entire system (source, quantum channel and detectors) must be taken into account. In many urban environments, the quantum channel in the form of telecommunication optical fiber (e.g. G.652D) are available, but the detectors in this range have low efficiency. We investigate the possibility that for campus-type communications, entangled photons in the Near-Infrared Range (NIR) can be transmitted successfully while preserving entanglement. We demonstrate the distribution of degenerate and non-degenerate entangled photon pair of wavelength around 810 nm through standard telecom fiber. This technique could benefit from high efficiency of the single photon detector designed in the NIR and better performance of compact setup around 810 nm. In this work, we measure the excitation and eliminating high-order modes in telecom fiber between different situations, and obtain high quality entanglement (visibility is 89.6% based on raw data). We will discuss possible paths to getting even higher entanglement quality.

PO.14 Using a software-controlled active quenching approach to test custom fabricated integrated APD

Subash Sachidananda*, Prithvi Gundlapalli*, Victor Leong*, Leonid Krivitsky*, Alexander Ling* (Centre for Quantum Technologies, NUS)

Most active quench circuits designed for single-photon avalanche detectors are designed with either discrete components which lack the flexibility of dynamically changing the control parameters, or with custom ASICs which require a long development time and high cost. Here, we discuss a software-controlled active quench approach implemented using a System-on-Chip (SoC), which integrates both an FPGA and a micro-controller. We take advantage of the FPGA's speed and configuration capabilities to vary the quench and bias parameters dynamically over a wide range, thus allowing our circuit to operate with a wide variety of APDs. We use our circuit to characterize a commercial APD and our own fabricated integrated APD, and present some results on metrics such as dark counts, deadtime, etc. In particular, we show how the active quench circuit helps to stop the breakdown voltage drift experienced by our custom integrated APDs and instantly restore them to their nominal state. We also discuss how the FPGA-based design can be modified to support large-scale automated testing of many devices.

PO.17 Z2-projective translational symmetry protected topological phases

Yue-Xin Huang*, Yu Xin Zhao*, Shengyuan Yang* (Singapore University of Technology and Design)

Symmetry is fundamental to topological phases. In the presence of a gauge field, spatial symmetries will be projectively represented, which may alter their algebraic structure and generate novel physics. We show that the Z2 projectively represented translational symmetry operators adopt a distinct anticommutation relation. As a result, each energy band is twofold degenerate, and carries a varying spinor structure for translation operators in momentum space, which cannot be flattened globally. Moreover, combined with other internal or external symmetries, they give rise to exotic band topologies. Particularly, with the inherent time-reversal symmetry, a single fourfold Dirac point must be enforced at the Brillouin zone corner. By breaking one primitive translation, the Dirac semimetal is shifted into a special topological insulator phase, where the edge bands have a Möbius twist. Our work opens an arena of research for exploring topological phases protected by projectively represented space groups.

PO.19

PO.21 Correlation-driven topological and valley states in monolayer VSi_2P_4

Si Li, Qianqian Wang, Shengyuan Yang* (Singapore Univerity of Technology and Design)

Electronic correlations could have signicant impact on the material properties. They are typically pronounced for localized orbitals and enhanced in low-dimensional systems, so two-dimensional (2D) transition metal compounds could be a good platform to study their effects. Recently, a new class of 2D transition metal compounds, the $MoSi_2N_4$-family materials, have been discovered, and some of them exhibit intrinsic magnetism. Here, taking monolayer VSi_2P_4 as an example from the family, we investigate the impact of correlation effects on its physical properties, based on the first-principles calculations with the DFT+U approach. We nd that different correlation strength can drive the system into a variety of interesting ground states, with rich magnetic, topological and valley features. With increasing correlation strength, while the system favors a ferromagnetic semiconductor state for most cases, the magnetic anisotropy and the band gap type undergo multiple transitions, and in the process, the band edges can form single, two or three valleys for electrons or holes. Remarkably, there is a quantum anomalous Hall (QAH) insulator phase, which has a unit Chern number and has its chiral edge states polarized in one of the valleys. The boundary of the QAH phase correspond to the half-valley semimetal state with fully valley polarized bulk carriers. We further show that for phases with the out-of-plane magnetic anisotropy, the interplay between spin-orbit coupling and orbital character of valleys enable an intrinsic valley polarization for electrons but not for holes. This electron valley polarization can be switched by reversing the magnetization direction, providing a new route of magnetic control of valleytronics. Our result sheds light on the possible role of correlation effects in the 2D transition metal compounds, and it will open new perspectives for spintronic, valleytronic and topological nanoelectronic applications based on these materials.

PO.23 Far-field Casimir-Polder Repulsions and Where to Find Them

Khatee Zathul Arifa*, Martial Ducloy, David Wilkowski, Bing Sui Lu* (School Of Physical and Mathematical Sciences, Nanyang Technological University)

We consider the problem in which a two-level excited atom interacts with a Chern insulator through the resonant Casimir-Polder (CP) interaction. A Chern insulator (CI) is a two-dimensional topological insulator that breaks time reversal symmetry and exhibits quantum anomalous Hall effect, i.e., the static limit of its Hall conductance is quantised in units of e^2/h. The resonant CP forces arise from the energy shifts of the atom's excited state, and these forces oscillate between being attractive and repulsive at different separation distances. This oscillatory behaviour is most pronounced when the interaction frequency coincides with the frequency of the CI's Van Hove singularity. We also observe that for a right circularly polarised excited atom that is located in the vicinity of a CI with Chern number $C = -1$, the CP energy shift decays monotonically with distance, which implies that it is possible to generate repulsive CP forces over a long range of separation distances. On the other hand, the CP energy shift decays in an oscillatory manner in the far-field regime when an identical atom is placed in the vicinity of a $C = 1$ Chern insulator. As this phenomenon is highly sensitive to the sign of the Chern number, it provides a novel way of detecting materials with nonzero Chern numbers. Most importantly, we believe it will aid in the quest for detecting and engineering repulsive CP forces in mesoscopic systems.

References

[1] K. Z. Arifa, M. Ducloy, D. Wilkowski, and B.-S. Lu, "Casimir-Polder interaction between a two-level quantum emitter and a Chern insulator" (manuscript in preparation).

[2] B.-S. Lu, K. Z. Arifa, and X. R. Hong, "Spontaneous emission of a quantum emitter near a Chern insulator: Interplay of time-reversal symmetry breaking and Van Hove singularity." Phys. Rev. B 101, 205410 (2020).

PO.25 Local Activation of Non-locality with Negative Bits

Kelvin Onggadinata*, Pawel Kurzynski, Dagomir Kaszlikowski* (Centre for Quantum Technologies)

Quantum theories possess the ability to achieve stronger correlation than local realistic model as shown through the violation of Bell-CHSH inequality. Moreover, Popescu and Rohrlich showed that there exists a no-signalling and non-local model, known as PR-box, that could saturate a higher score in the Bell-CHSH function. Understanding how quantum theory and PR-box could achieved higher non-local correlations have been a long-standing question in the quantum foundation and quantum information field. In this work, we show a purely local protocol to upgrade local realistic correlations to genuine non-local correlations if only one local party has access to a negative probability bit (nebit), i.e., a bit taking "0" with probability of $1 + \Delta$ and "1" with probability $-\Delta$. The minimal amount of nebit's negativity Δ required for the upgrade can serve as a measure of non-locality. The upgrade bears a striking resemblance to ordinary local unitary operations in quasi-stochastic formulations of quantum theory, mathematically equivalent to positive stochastic processes controlled by nebits. This suggests that nebits can be interpreted as units of quantum departure from classical physics as well.

PO.28 Spatial Control over Stable Light-Emission from AC-Driven CMOS-Compatible Quantum Mechanical Tunnel Junctions

Fangwei Wang*, Thanh Xuan Hoang, Hong-Son Chu, Christian A. Nijhuis* (CA2DM)

The potential application of quantum mechanical tunnel junctions as sub-diffraction light or surface plasmon sources has been explored for decades, but it has been challenging to create devices with sub-wavelength spatial control over the light or plasmon excitation. This paper describes spatial control over the electrical excitation of surface-plasmon polaritons (SPPs) and photons in large-area junctions of the form of Al-AlOX-Cu CMOS-compatible tunnel junctions. We achieved nanoscale spatial control (smallest feature sizes of 150 nm) by locally fine-tuning the thickness of the AlOX tunneling barrier resulting in large local tunneling currents and associated SPP excitation rates. Mostly, plasmonic tunnel junctions are studied under DC operation with a relatively large applied bias voltage (and associated currents) to observe light emission at optical frequencies. Large voltages risk device failure and reduce device lifetimes. Here we show that AC operation substantially increases the stability of the plasmonic tunnel junctions. Under DC conditions, slow processes that lead to device failure (e.g., undesirable electromigration leading to shorts) readily occur, thus limiting the device decay time to 9.2 h; but under AC operation, such processes are slow with respect to the voltage changes prolonging the decay time beyond 18.0 h.

PO.30 Fock State-enhanced Expressivity of Quantum Machine Learning Models

Beng Yee Gan*, Daniel Leykam, Dimitris G. Angelakis (Centre for Quantum Technologies)

The data-embedding process is one of the bottlenecks of quantum machine learning, potentially negating any quantum speedups. In light of this, more effective data-encoding strategies are necessary. We propose a photonic-based bosonic data-encoding scheme that embeds classical data points using fewer encoding layers and circumventing the need for nonlinear optical components by mapping the data points into the high-dimensional Fock space. The expressive power of the circuit can be controlled via the number of input photons. Our work shed some light on the unique advantages offers by quantum photonics on the expressive power of quantum machine learning models. By leveraging the photon-number dependent expressive power, we propose three different noisy intermediate-scale quantum-compatible binary classification methods with different scaling of required resources suitable for different supervised classification tasks.

PO.32 Bio-magnetic compass in cockroaches

Kaisheng Lee* (Nanyang technological university)

Many animals display sensitivity to external magnetic field, but it is only in the simplest organisms that the sensing mechanism is understood. Here we report on behavioural experiments where American cockroaches (Periplaneta americana) were subjected to periodically rotated external magnetic fields with a period of 10 min. The insects show increased activity when placed in a periodically rotated Earth-strength field, whereas this effect is diminished in a twelve times stronger periodically rotated field. We analyse established models of magnetoreception, the magnetite model and the radical pair model, in light of this adaptation result. A broad class of magnetite models, based on single-domain particles found in insects and assumption that better alignment of magnetic grains towards the external field yields better sensing and higher insect activity, is shown to be excluded by the measured data. The radical-pair model explains the data if we assume that contrast in the chemical yield on the order of one in a thousand is perceivable by the animal, and that there also exists a threshold value for detection, attained in an Earth-strength field but not in the stronger field.

PO.33 Thermodynamic performance of a periodically driven harmonic oscillator correlated with the baths

Tianqi Chen*, Dario Poletti* (Singapore University of Technology and Design)

We consider a harmonic oscillator under periodic driving and coupled to two harmonic oscillator heat baths at different temperatures. We use the thermofield transformation with chain mapping for this setup which allows us to study the unitary evolution of the system and the baths up to a time long enough to see the emergence of periodic steady state in the system. We characterize this periodic steady state and we show that, by tuning the system and the bath parameters, one can turn this system from an engine to an accelerator or even to a heater. The possibility to study the unitary evolution of system and baths also allow us to evaluate the steady correlations that build between the system and the baths, and correlations that grow between the baths.

PO.39 Rectification in Spin Chains

Kang Hao Lee* (SUTD)

In XXZ chains, spin transport can be significantly suppressed when the interactions in the chain and the bias of the dissipative driving at the boundaries are large enough. We explore different mechanisms of varying spin transport such as the use of local magnetic fields or applying different interactions on segmented halves of the chain. We show that these mechanisms give rise to a spin rectification effect.

PO.41 The finite-key security of quantum key expansion

John Khoo*, Charles Ci Wen Lim (National University of Singapore)

A typical assumption in quantum key distribution analysis is the presence of an authenticated classical channel. However, some shared secrecy must be consumed in order to use this channel, which therefore affects the final secret key rate. Quantum key expansion is the composition of authentication and quantum key distribution: using initial shared secret to authenticate a quantum key distribution protocol, producing a net gain in shared secret data. In this work, we study the finite-key effects of authentication on the overall process of quantum key expansion in a composable security framework. We focus on ultimate bounds and explicit near-optimal constructions for authentication and universal hashing, and compare the performance of various strategies and constructions via numerical simulation, which also incorporates more rigorous analysis of information reconciliation leakage and hash functions for reconciliation verification and privacy amplification. Particular attention is paid to the setting of authenticating multiple messages of possibly different lengths, which is the setting in realistic protocols, and in key streaming.

PO.50 Designing an optical ground station in an urban environment for satellite-based quantum communication

Clarence Liu*, Srihari Sivasankaran, Esther Wong, Peng Kian Tan, Moritz Mihm, Christian Kurtsiefer, Alexander Ling (National University of Singapore)

There are various challenges to the installation of an optical ground station (OGS) in an urban environment for satellite-based quantum communication. These challenges arise from receiving background skylight at the optical receiver and transmitting the quantum signal through the atmosphere. In this contribution, we present our results in the determination of the atmospheric seeing in Singapore at a wavelength of 780nm. We show that by implementing a robust pointing and tracking (PAT) that considers the atmospheric seeing results in the design of an OGS, satellite-based quantum key distribution (QKD) can be carried out in Singapore.

PO.61 Room Temperature Commensurate Charge Density Wave on Epitaxially Grown Bilayer 2H-Tantalum Sulfide on Hexagonal Boron Nitride

Wei Fu*, Jingsi Qiao, Xiaoxu Zhao (IMRE@A*STAR)

The breaking of multiple symmetries by periodic lattice distortion at a commensurate charge density wave (CDW) state is expected to give rise to intriguing interesting properties. However, accessing the commensurate CDW state on bulk TaS_2 crystals typically requires cryogenic temperatures (77 K), which precludes practical applications. Here, we found that heteroepitaxial growth of a 2H-tantalum disulfide bilayer on a hexagonal-boron nitride (h-BN) substrate produces a robust commensurate CDW order at room temperature, characterized by a Moiré superlattice of 3×3 TaS_2 on a 4×4 h-BN unit cell. The CDW order is confirmed by scanning transmission electron microscopy and Raman measurements. Theoretical calculations reveal that the stabilizing energy for the CDW phase of the monolayer and bilayer 2H-TaS_2-on-h-BN substrates arises primarily from interfacial electrostatic interactions and, to a lesser extent, interfacial strain. Our work shows that engineering interfacial electrostatic interactions in an ultrathin van der Waals heterostructure constitutes an effective way to enhance CDW order in two-dimensional materials.

PO.64 Impact of S-vacancies on charge injection at metal-MoS_2 electrical contacts

Fabio Bussolotti*, Jing Yang, Hiroyo Kawai, Calvin Pei Yu Wong, Kuan Eng Johnson Goh (Institute of Materials Research & Engineering (IMRE))

Two-dimensional semiconducting transition metal dichalcogenides (TMDC) have attracted considerable scientific attention, with promises for applications in novel optoelectronics [1] and quantum computing [2]. Fabrication of electrical contacts with metals represents the major obstacle towards TMDCs' full technological transition, often resulting in high contact resistance and poor electronic devices' performance. Despite intense experimental [3] and theoretical efforts [4], the impact of lattice defects in TMDCs on the electrical transport properties across the interface with metallic electrodes remains still unclear. In this contribution, we will report on our recent findings on the impact of S-vacancies on the electronic properties of MoS_2 monolayer, a prototypical TMDC for electronics, interfaced with conductive materials [5]. Supported by photoemission spectroscopy measurements and theoretical calculations, our study identifies S-vacancies gap states and related Fermi level pinning as the main origin of large electron injection barrier ($\gtrsim$0.5 eV) across the MoS_2/metal interface whereas no significant limitation is found for hole conduction. These results highlight the importance of S-vacancies in TMDC-based electronics, and their implications for device production and performance optimization will be presented and discussed.

References [1] Bussolotti, F.; Kawai, H.; Ooi, Z. E.; Chellappan, V.; Thian, D.; Pang, A. L. C; Goh K. E. J. Nano Futures 2018, 2, 032001. [2] Goh, K E. J.; Bussolotti, F.; Lau, C. S.; Kotekar-Patil, D.; Ooi, Z. E.; Chee, J. Y. Adv. Quant. Mat. 2020, 3, 1900123. [3] Gong, C.; Colombo, L.; Wallace, R. M.; Cho, K. Nano Lett. 2014, 14, 1714. [4] Yang, J.; Kawai, H.; Wong, C. P. Y.; Goh K.E.J. J. Phys. Chem. C 2019, 123, 2933. [5] Bussolotti, F.; Yang, J.; Kawai, H.; Wong, C. P. Y.; Goh K.E.J. ACS Nano 2021, 15, 2686.

PO.65 Compact Strontium atomic source with the Zeeman slower based on double-frequency and cross-polarization

Jianing Li*, Swarup Das, Chang Chi Kwong, David Wilkowski (Nanyang Technological University)

The preparation for high-efficiency cold atomic source is the fundamental step for many studies in the areas of quantum sensing and quantum simulation. We design and demonstrate a new scheme of Zeeman slower based on double-frequency and cross-polarization to enhance a cold ^{88}Sr atom source. By using permanent magnets in 2D magneto-optical trap (MOT) and taking the advantage of the magnetic field profile of the 2D MOT, two slopes can be utilized so that the efficiency of the experiment system can be improved. With the Zeeman slower, we build up a compact setup to prepare cold strontium atoms and demonstrate precision measurement based on atomic interferometer, which can produce a large atomic flux of 1.5×10^9 atom/s.

PO.68 Trap-limited space-charge limited current in thin film

Chun Yun Kee*, Yee Sin Ang*, Lay Kee Ang* (SUTD)

The charge transport characteristic of organic semiconductor is one of the key attributes that affects the performance of organic electronics and optoelectronic devices. Typically, the carrier mobility is estimated by fitting current-voltage data with space-charge limited transport models [1]. In this regard, the accuracy of estimation and the phenomenon identified relies heavily on the models adopted. Previous works have shown that factors such as material properties [2–4] and geometry [5,6] can lead to different scaling behaviour and prefactor of the transport current. Considering an exponential trap distribution [3], we formulate – based on a Green's function approach [6] – the SCLC model for three types of contact geometries relevant to 2D thin film with each results in a Cauchy-type singular integral equation. Our results show that the prefactor exhibits a dependence of $l = T_c/T$, where T is the temperature and T_c is a parameter characterizing the exponential spread in energy of the traps. Upon solving the integral equations, the prefactors for different contact geometries can be evaluated. The 2D SCLC model developed here shall offer a practical tool for the refined estimation of carrier mobility of ultrathin organic semiconductor field-effect transistor under different contact geometries.

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PO.69 Simulation of Non-Maximally Entangled States Using One Bit of Communication

Peter Sidajaya*, Baichu Yu, Valerio Scarani* (Centre for Quantum Technologies)

From Bell's theorem we know that local hidden variables could not simulate the behaviour of an entangled state measured using projective measurements. However, by adding one bit of communication between the parties, it is possible to simulate the behaviour of a maximally entangled state (singlet) [1]. Here we examine the case for a non-maximally entangled state. We use an Artificial Neural Network (ANN) constrained by locality and supplemented by one bit of communication to generate a protocol mimicking the behaviour of a non-maximally entangled state as closely as possible. Our results suggest that it might be possible to simulate the behaviour using only one bit, with an average relative entropy of around 0.0005 between the behaviour and our protocol for the state $\cos(\pi/16)|01\rangle - \sin(\pi/16)|10\rangle$. Having obtained a close heuristic protocol, we are currently trying to create an analytical protocol.

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PO.73 High-pressure Response in Two-dimensional Perovskites with Fluorinated Organic Spacers

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Two-dimensional (2D) Organic-Inorganic halide perovskites (OIHP) have emerged as a potential replacement for its 3D counterpart in perovskite solar cells (PSC) due to its enhanced stability. However, the presence of the large organic spacer cation hinders the charge transport, which lowers the power conversion efficiency in 2D OIHP. A fluorine organic spacer, obtained by substituting a fluorine atom with a hydrogen atom in the benzene ring, has provided a solution by enhancing orbital interactions and charge transport within the inorganic layers and applying external pressure on the perovskite has shown to alter its structural and optoelectronic properties. These two areas have generated great interest as they could potentially create a new approach to dive deeper and generate a better understanding of the properties of 2D OIHP. However, these two areas have never been reported together. In my work, it is demonstrated applying high pressure causes a significant bandgap narrowing in both perovskites. When a fluorine atom is substituted in $(PEA)_2PbI_4$, the intermolecular bonds between each molecule are stronger than without the presence of the fluorinated organic cation under the same pressure conditions for both the organic and inorganic framework of the perovskite. However, we also showcase that this substitution process does not significantly affect the bandgap of the perovskite.

PO.77 Mutually unbiased bases in light of absolutely entangled sets of states

Pooja Jayachandran*, Adam Burchardt, Baichu Yu, Valerio Scarani* (Centre for Quantum Technologies, NUS)

Entanglement relies on defining the partition– a global basis change can always map an entangled stated into product. A set of quantum states is said to be absolutely entangled if at least one state remains entangled for any definition of subsystems. Examples of finite absolutely entangled sets (AES) include complete sets of mutually unbiased bases (MUBs). Owing to their projective 2-design property, complete sets of MUBs in dimension d (if exists) are said to have a fixed amount of entanglement. We show that for entanglement measures such as entropy of entanglement and logarithmic negativity, the total entanglement of the complete set of MUBs in $d = 4$ are minimized for the standard construction (obtained by finite fields method) and maximized for the iso-entangled MUBs, and discuss challenges in generalizing to higher dimensions. We also provide preliminary results on the AES character of subsets of the complete set of MUBs in $d = 4$.

PO.81 An organic-inorganic hybrid perovskite containing copper paddle-wheel clusters: properties and prospects.

Ksenia Chaykun*, Benny Febriansyah, Yulia Lekina*, Zexiang Shen* (Nanyang Technological University)

Hybrid organic-inorganic perovskites are promising materials for the development of optoelectronic devices. Over the past ten years, significant progress has been made in the field of creating thin-film solar cells, light-emitting diodes, and sensors based on this class of materials. An important feature of perovskites is the simplicity of synthesis and scaling. However, a significant problem of using this material is the poor environmental stability. Introducing copper complexes into the perovskites structure is one of the ways to improve the stability. In this work, properties of $Cu[(O_2C–(CH_2)_3\text{-}NH_3)_2]PbBr_4$ perovskite were investigated under high pressure and variable temperature. Two phase transitions were detected by means of Raman spectroscopy at 1.5 and 9.5 GPa. Correlation of the optical properties with the structural changes is discussed. Further prospects for the study and application of copper-containing perovskite are proposed.

PO.82 Atomtronic Datta-Das transistor using ultracold Strontium atoms

Chetan Sriram Madasu*, Mehedi Hasan, Ketan Rathod, Chang Chi Kwong, David Wilkowski* (Nanyang Tehcnological University)

We report an experimental demonstration of atomtronic Datta-Das transistor in free space with ultracold strontium atoms as the (spin) carriers. Datta-Das transistor is a device in which the spin current from source to drain is controlled by the gate voltage similar to a conventional FET where electric charge current from source to drain is controlled by the gate voltage. In the experiment, we simulate a beam of spin-polarized atoms passing through a gate region made of three co-planar gaussian beams coupling the tripod scheme and measure their final spin. We use the ratio of Rabi frequencies of the tripod lasers as a gate parameter, the analogue of the gate voltage, to characterize the atomtronic Datta-Das transistor. We show that the spin rotation can be controlled well and it is robust to a wide range of velocities of the atoms. We also discuss about the sensitivity of the spin rotation to the geometry of the laser beams.

PO.83 Novel Nanomaterial Solar Water Heater

Balakrishnan Naveen Mani Kumar*, Dhanabalan Jeevakaarthik*, Krishnan Nithesh*, Lakshmikanth Devesh*, R E Simpson* (Singapore University of Technology and Design (SUTD))

The intrinsic properties of a pure material determine its optical and thermal characteristics. Customising these characteristics through the application of specialised coatings allows for the creation of composite materials better optimised for their intended application. Solar water heating is both conceptually and practically one of the easier methods to harness the sun's energy. Heat captured by water can be applied to other processes or systems, or heated water/steam can be used directly in residential or industrial contexts.

$Ag\text{-}Sb_2S_3$ (Black Silver) is a metamaterial first synthesised in 2018 and is capable of near-perfect absorption in the visible and near infrared (VIS-NIR) spectrum. The plasmon-enhanced, polarisation-insensitive, omnidirectional broadband absorption in the VIS-NIR spectrum and forgiving fabrication process are attractive qualities for use in the absorber role of Solar Water Heating Systems (SWHSs).

In this report, we provide an experimental characterisation of the optical and thermal properties of $Ag\text{-}Sb_2S_3$. We also test the theoretical efficacy of $Ag\text{-}Sb_2S_3$ SWHS designs through simulation. The design investigation was primarily carried out using finite element analysis and verified with real-testing. We establish that in a one-to-one comparison, incorporating $Ag\text{-}Sb_2S_3$ in a SWHS results in a significant increase in output water temperature. Ultimately, this work demonstrates the scope of opportunity and benefits spectrally-engineered nano-photonic surfaces like $Ag\text{-}Sb_2S_3$ hold for the development and improvement of SWHSs.

PO.88 Advances in Quantum Metrology for precise measurements

Arunava Majumder*, Harshank Shrotriya, Leong-Chuan Kwek (Indian institute of technology Kharagpur)

Quantum metrology overcomes standard precision limits and has the potential to play a key role in quantum sensing. Conventional bounds to measurement precision such as the shot-noise limit are not as fundamental as the Heisenberg limits and can be beaten with quantum strategies that employ 'quantum tricks' such as squeezing and entanglement. Bipartite entangled quantum states with positive partial transpose (PPT), are usually considered to be too weakly entangled for applications. In the very 1st paper related to the usefulness of PPT states in metrology, the respected authors provided a specific strategy, Entanglement assisted strategy(EAS), for a family of PPT states claiming to have the highest possible accuracy, obtained from convex optimization. However, we, in our article, provided a modified strategy named "sequential" Ancilla assisted strategy(SAAS). We, through detailed calculation and plots, showed It can outperform the previous strategy for the same family of PPT states and can be applied to any family of states. Further, we reiterate the fact that sequential strategies are completely distinct from the repetition of an experiment multiple times. If we add repetitions to the experiment the Quantum Fisher Information(QFI) scales linearly in the number of repetitions, the concept of having sequences in both "EAS" and Ancilla assisted strategy can quadratically increase the QFI in the number of sequences and thus can scale in total $\mathcal{O}(n^3)$(n=number of sequences as well as repetitions) and provide a greater advantage in metrology and sensing e.g. in magnetometry, gravitational wave detection, etc. Furthermore, we investigate the role of noise.

PO.92 A Variational Quantum approach to learn quantum gates from time-independent Hamiltonians

Arunava Majumder*, Dylan Lewis, Sougato Bose (Indian institute of technology Kharagpur)

We present a Variational Quantum (VQA) framework to tackle the problem of finding time-independent dynamics generating target unitary evolutions. Such generators will typically contain highly non-local interactions, which can be difficult to realize in a given physical setup. The natural dynamics generating a Toffoli gate involve non-local three-qubit interactions, which are not easily implemented in experimental architectures. The method we followed is distinct from techniques such as quantum control and gate compilation and our approach can be applied in near-term devices also. For the optimization purpose, we used a very special kind of ansatz known as HVA(Hamiltonian variational ansatz) which can directly encode the parameters of a given Hamiltonian and can efficiently bypass the "barren plateaus" phenomenon. But for large circuits, the effect of "barren plateaus" is still noticeable. In the first step, we need to consider a general Hamiltonian, with the minimum number of qubit-qubit interactions(e.g. two in the case of Toffoli), which can generate the same dynamics as the original one. In the second step, we have to go through some given criteria to minimize the number of parameters or local terms in the designed Hamiltonian. Lastly, we need to perform optimization using multiple trotterization steps such that fidelity between the natural dynamics and actual unitary remains greater than at least 0.99 to satisfy the threshold for surface code(on the order of 1%). This work has been previously done by researchers using classical supervised learning(Obtained fidelity-0.98). We have done it recently using QML and achieved greater fidelity(0.999).

PO.93 Optical Ranging with Subthreshold Laser

Peng Kian Tan*, Xi Jie Yeo, Li Jiong Shen, Christian Kurtsiefer (Centre for Quantum Technologies)

Conventional optical ranging, or lidar, requires timing modulated light sources to provide the timing correlations needed for time-of-flight measurements. This modulation opens up vulnerabilities to spoofing attacks as well as being non-stealth. We propose and implement the use of a stationary light source, via a subthreshold laser diode exhibiting thermal photon bunching, in optical range finding with preliminary measurements demonstrating its viability.

PO.94 Dielectric Engineering for 2D Materials Based Functional Devices

Tengyu Jin*, Wei Chen* (National University of Singapore)

Dielectric engineering for the integration of high-k gate dielectrics with two-dimensional (2D) semiconducting channel materials is essential for high-performance and low-power functional electronics. However, recently reported 2D devices usually rely on deposited or transferred insulators as the dielectric layer, resulting in various challenges in device compatibility and fabrication complexity. Here, we demonstrate a controllable and reliable oxidation process to turn 2D semiconductor HfS_2 into native oxide, HfO_x, which shows good insulating property and a clean interface with HfS_2. We then incorporate the HfO_x/HfS_2 heterostructure into functional devices. We report a reconfigurable WSe_2 optoelectronic device that can function as nonvolatile memory and artificial synapse in a single device, enabled by an asymmetric floating gate (AFG) that can continuously program the device into different homojunction modes. Our work provides a simple and effective approach for integrating high-k dielectrics into 2D material-based functional devices.

PO.97 Tunable carrier-mediated ferromagnetism in a Van der Waals semiconductor up to room temperature

Jiawei Liu*, Barbaros Özyilmaz* (National University of Singapore)

Combining the electrical tunability of a semiconductor with the nonvolatility of a ferromagnet, ferromagnetic semiconductors are promising for spin-based logic devices. Although such co-functionality has been pursued via extrinsic doping of nonmagnetic semiconductors for decades, ferromagnetic order up to room temperature remains unfulfilled. Here, taking advantage of layered Van der Waals semiconductors' ability to accommodate intercalation doping with little detriment to lattice coherency, we achieve ferromagnetism in Co-doped black phosphorous up to room temperature while retaining the semiconducting features. Gate tunable, carrier-mediated room-temperature ferromagnetism is corroborated by its performance as a robust ferromagnetic contact in semiconducting tunnelling spin-valves and by a large anisotropic magnetoresistance. We demonstrate that the electric field can select the dominant majority/minority spins by displacing the Fermi level across the BP bandgap, allowing both gate-controllable inversion and suppression of the tunnelling magnetoresistance on demand. In addition to delivering a new type of ferromagnetic semiconductor this work establishes a general route to engineer ferromagnetism in atomically thin layered materials, thus extending the applications of magnetic semiconductors envisaged so far.

PO.110 Detecting chaotic-coherent light emission mixture with interferometric photon-correlations

Xi Jie Yeo*, Peng Kian Tan, Christian Kurtsiefer (Centre for Quantum Technologies)

Second-order photon-correlation measurements $g^{(2)}$ have been used as a method to classify light into bunched, coherent, and antibunched. However, a light source exhibiting bunching statistics $g^{(2)}(0) > 1$, is not always indicative of an absence of coherent light. We investigate the interferometric photon-correlations of light emitted from a 760 nm Distributed Bragg Reflector (DBR) laser, at currents below the threshold, near the threshold, and slightly above the threshold. Our experimental results show chaotic light behavior at a current below threshold, a chaotic-coherent light mixture at a current near the threshold, and dominantly coherent light at a current slightly above threshold, despite exhibiting bunching statistics $g^{(2)}(0) > 1$ at all 3 currents.

PO.118 Accelerated Design of Radiation Tolerant High Entropy Alloys

Glenn Lim*, Matthew Lloyd*, Robert Simpson* (Singapore University of Technology and Design)

In many countries nuclear power will be an integral part of the effort to decarbonise the production of electricity. The next generation of fission and fusion reactors is dependent on the development of high performance, radiation tolerant materials. The components of a fusion reactor will experience particularly extreme conditions, including very high operating temperatures ($> 1200\,^{\circ}$C), exposure to high energy He/H plasma and intense neutron irradiation. These extreme operating conditions require novel materials solutions for a variety of reactor components. High Entropy Alloys (HEAs) are a class of material which have been shown to offer a superior resistance to radiation damage, as well as many other attractive properties. But developing new HEAs is challenging due to the wide space of compositions and the high computational expenditure required to perform ab-initio calculations for the full range of alloy compositions.

In this project, we aim to accelerate the development of HEAs by pre-screening a wide range of compositions for radiation tolerant properties. To do this, thin-film samples will be produced by co-sputtering to create a variable composition spread. Combined heavy-ion and He-ion irradiation at high temperatures will be performed to simulate the conditions of a plasma facing component in a fusion reactor. Post-irradiation examination will be performed using a range of different high-throughput techniques including Transient Grating Spectroscopy (TGS) to measure the thermal diffusivity and Young's Modulus at different positions within the composition spread. Understanding the change in these material properties is vital for the safe and effective operation of a fusion power station. We estimate that by applying this new approach to alloy design we can characterise the properties of up to 400 alloy compositions per day.

PO.120 A route for wafer scale h-BN integration into Si-technology

Salim El Kazzi*, Vejay Girija Jagadeesan*, Ya Woon Lum*, Utkur Mirsaidov (National University of Singapore)

With the advent of the 5 nm technological node and beyond, the microelectronic industry is considering more and more the use of 2D (two-dimensional) materials as alternative constituents of the MOSFET (Metal oxide semiconductor field effect transistor). In an ideal 2D-based transistor, hexagonal Boron Nitride is believed to be the most promising passivation layer which would allow the formation of defect-free interfaces at the channel level. Nevertheless, like the case of most of the 2D materials, the main challenge is to produce high quality single crystal h-BN layers at a wafer-scale level. Despite the promising studies of the h-BN synthesis on large area metal foils, an integration route to grow h-BN on Si-compatible substrates is always preferred. The challenge would remain however to find suitable substrates which are stable in high temperature environments and insure the good compatibility of the used precursors for h-BN deposition. In this context, we choose in this study to report on the wafer-scale CVD (Chemical Vapor Deposition)growth of h-BN on Ge (germanium) substrates. Ge is known to be easily grown on Si and thus a hope to provide the first monolithic integration of h-BN on Si substrates would be possible. Second, the good solubility of B and N with Ge insures the possibility of the BN molecule formation on the surface by choosing the right precursors. We have started in our work by optimizing the annealing preparation of Ge that is known to be very unstable at high temperatures After Ge preparation, a borazine flux is supplied into the CVD chamber and an h-BN film was deposited. The Raman signal of the sample before and after the deposition. A clean Raman peak is shown at $1345\,\mathrm{cm}^{-1}$ which clearly attests the film formation of h-BN on the Ge surface. In summary, we have developed a new way to grow h-BN on a Ge substrate which is a Si-compatible substrate. We will focus during the conference on our results on the Ge preparation. Then the route to achieve monolayer 100% exactly oriented h-BN grains is proposed. This method is not only a step further to the integration of h-BN for electronic applications but can be extended to other areas especially in photonics and quantum spin technology where Ge is already considered as an ideal material system.

PO.121 Thresholds of concatenated dynamical decoupling sequences

Jiaan Qi*, Xiansong Xu, Dario Poletti, Hui Khoon Ng (Yale-NUS college)

Dynamical decoupling is a family of control schemes that are capable of suppressing unwanted noise in quantum systems subjected to unknown interaction. Under ideal circumstances where the control gates are noiseless, one is assumed to be capable of removing arbitrary orders of noise by a procedures called concatenation. Our work examined this concatenation procedure from the perspective of fault-tolerant quantum computation. We show that there exists breakeven points where concatenation will no longer work. Using the error phase formalism to characterize decoupling performance, we develop noise suppression criteria for the concatenated DD schemes with noisy control gates. We examine the behavior of the threshold under different noise models and with supporting numerical evidences.

PO.123 Focused ion beams tailored room-temperature color centers in hexagonal boron nitride

Yue Xu*, Soumya Sarkar, Jing Yang Chung, Manohar Lal, Sinu Mathew, T.Venky Venkatesan, Silvija Gradecak* (National University of Singapore)

Hexagonal boron nitride (hBN), a van der Waals crystal with a honeycomb structure similar to graphene but with ultra-wide bandgap ($\approx$ 6 eV), has been widely investigated as a dielectric substrate for 2D materials-based devices. More recently, hBN has emerged as a prominent candidate for quantum nanophotonics after the observation of a series of tunable single-photon emission. These emitters have been associated with mid-gap states that originate from atomistic defects in the hBN lattice. Here, we report the observation of near-infrared ($\approx$ 800 nm) photoluminescence

(PL) emission at room temperature in hBN caused by defects formed via focused He-ion beam irradiation. We tuned the PL intensity of the emitters by tailoring the defect generation in hBN as a function of the irradiation parameters. Raman spectroscopy and high-resolution scanning transmission electron microscopy imaging further confirm that the emerging PL response is correlated with point-defect states in hBN. We also demonstrate that similar results can be obtained by Ga-ion and Ne-ion irradiation, confirming the PL emission to be related to intrinsic structural defects in hBN. Our work presents a platform to precisely create and control defect-related color centers in hBN that can serve as building blocks for next-generation nanophotonic and potential quantum devices.

PO.125 Evaluation of 2D materials as potential barrier layers for the future metal interconnect technology

Ya Woon Lum, Salim El Kazzi*, Sergej Pasko, Oliver Whear, Saumitra Vajandar, Thomas Osipowicz, Utkur Mirsaidov (National University of Singapore)

Copper (Cu) has been used as the core metal interconnect in the fabrication of chips. However, Cu is also known to diffuse easily in the surrounding dielectric when electrical and thermal stress are applied [1]; something which could hinder the total interconnect RC delay performance. Barrier layers like TaN (Tantalum Nitride) and Ta (Tantalum) were hence inserted between the metal and the dielectric to block Cu diffusion. With the continuous need for scaling, the microelectronic industry is highlighting the need to find new barrier layers with a thickness less than 1.5 nm. And this seems to be very challenging for the TaN/Ta systems [2]. In this vein, we present here the use of the 2D (two-dimensional) family materials as potential barrier layer candidates for the future metal interconnects (Figure 1). These systems are atomically thin by nature and believed to help in reducing the Cu resistivity due to the van der Waals interactions at the Cu/2D interface [3]. To choose the right candidates for our application, our strategy consists of evaluating 4 main criteria presented in figure 1. To evaluate the blocking efficiency of our 2D materials, MOS capacitors were fabricated (Figure 2a) and the time-dependent dielectric breakdown (TDDB) method (Figure 2b) was used to compare the time-to-failure (TTF) between the different devices (Figure 2c). Figure 2d for instance shows the improvement of the medium time to failure (TTF50%) when a wafer-scale Aixtron-MOCVD 2D-WS_2 (tungsten disulfide) layer is inserted between the Cu and the SiO_2. This confirms the obvious barrier efficiency of the 2D layer. On the other hand, figure 3 is used to evaluate the impact of the 2D layer status before the metal deposition. The I-V characteristics (Figure 3a) of a WSe_2 (tungsten diselenide) MOSCAP fabricated directly after the 2D-growth shows a much higher leakage current compared to the one where the 2D surface is left 1 month under ambient conditions. This result can be explained by the Rutherford Backscattering (RBS) analysis that shows a lower Se/W ratio for the exposed sample (Figure 3b). This implies that a special care should be taken into account for these surfaces prior to any metal deposition. Besides the blocking efficiency, the impact of the 2D layer on the Cu resistivity was studied by 2 different methods (Figures 4a and 4b). The first one uses directly the four-point probe tool and another by fabricating bar-hall device structures. Figure 4c shows the results of the Cu resistivity measured on samples without a barrier layer and others with Ta and WS_2 barrier layers. First, we can notice that deduced resistivities using both methods follow the same trend and have similar values. More importantly, the resistivity of Cu is lowered when the 2D-WS_2 is inserted between the SiO_2 and the Cu which implies the benefit of the Cu/2D vdW interface. Lastly, we have evaluated the impact of the 2D layer on the Cu wettability and adhesion. As seen from Figure 5a, SEM (Scanning Electron Microscope) images shows a smoother 15 nm Cu surface when a 2D layer is used underneath the Cu. For adhesion test, a standard tape test was performed on Cu patterned films deposited on 2D WS_2/SiO_2 as shown in the schematic of Figure 5b. The number of Cu films removed in function of the peeling-off times are shown on Figure 5c. Despite the removal of 4 Cu films at the first 2 trials, no more devices were peeled off on the WS_2-based sample even after 10 times. On the other hand, no Cu films was peeled off on the sample where Cu is deposited directly on the SiO_2. This result shows an acceptable adhesion of the metal with the underneath 2D barrier layer and the promise of 2D material stability in Back-end-of-line processes where harsh environment like CMP (Chemical-mechanical Polishing) can be used. In summary, a first test campaign was conducted to evaluate the potential of 2D materials as barrier layers. These tests would allow us to choose the best 2D candidate for future barrier/liner layers. During the meeting, a follow up will be presented on the impact of the 2D growth conditions on these different characteristics.

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PO.132 Measured Quantum Devices

Jeongrak Son*, Peter Talkner, Juzar Thingna (Nanyang Technological University)

Measurements are a necessary evil when determining thermodynamic quantities in any quantum device. They induce back-actions that ultimately alter device operation. I'll present two devices, namely, a quantum Otto engine and a quantum battery, to discuss the role of measurements. For the engine, we will discuss two different monitoring schemes. One where we repeatedly interact the engine with an ancilla and infer the work/heat over several cycles using a single measurement. Another in which the engine is measured at the end of each stroke to obtain the heat and work. The former (aka repeated contacts) allows coherence to propagate between strokes which leads to a substantial improvement of the performance metrics (efficiency, power output, and reliability) of the engine as compared to the latter (aka repeated measurements), which kills coherence. A similar outcome is observed in the second device, i.e., a quantum battery, which we charge via an Otto engine. The battery's energy can be measured at the end of the prescribed number of engine cycles or be repeatedly measured after each cycle. The maximum extractable energy from the battery drastically reduces when monitored frequently despite the total energy of the battery remaining the same in both cases. Overall, the results highlight the role of coherence and the importance of measurements in quantum device performance.

PO.134 Band-tailored van der Waals heterostructure for multilevel memory and artificial synapse

Yanan Wang*, Wei Chen (national university of singapore)

Two-dimensional (2D) van der Waals heterostructure (vdWH)-based floating gate devices show great potential for next-generation nonvolatile and multilevel data storage memory. However, high program voltage induced substantial energy con- sumption, which is one of the primary concerns, hinders their applications in low- energy-consumption artificial synapses for neuromorphic computing. In this study, we demonstrate a three-terminal floating gate device based on the vdWH of tin disulfide (SnS_2), hexagonal boron nitride (h-BN), and few-layer graphene. The large electron affinity of SnS_2 facilitates a significant reduction in the program voltage of the device by lowering the hole-injection barrier across h-BN. Our floating gate device, as a non-volatile multilevel electronic memory, exhibits large on/off current ratio (105), good retention (over 104 s), and robust endurance (over 1000 cycles). Moreover, it can function as an artificial synapse to emulate basic synaptic func- tions. Further, low energy consumption down to 7 picojoule (pJ) can be achieved owing to the small program voltage. High linearity (< 1) and conductance ratio (80) in long-term potentiation and depression (LTP/LTD) further contribute to the high pattern recognition accuracy (90%) in artificial neural network simula- tion. The proposed device with attentive band engineering can promote the future development of energy-efficient memory and neuromorphic devices.

PO.137 Thermal-Field Emission of 3D Cadmium Arsenic

Wei Jie Chan*, Yee Sin Ang*, Ricky Ang* (Singapore University of Design and Technology)

The emergence of quantum materials with non-parabolic dispersions like graphene has signaled the beginning of a paradigm shift in the choice of materials for field emission. Like graphene, the unconventional Dirac conic band structure in cadmium arsenide Cd_3As_2, a 3D topological Dirac semimetal (TDS), hints a possibility of it being an excellent field emitter. This differing band structure allows the appearance of a non-trivial dual peak feature in its total energy distribution (TED), which can be utilized to garner a larger current density. The commonly used Murphy and Good (MG) model for thermal-field emission could not accurately model Cd_3As_2 due to its F^3 scaling law in the cold field emission limit. These findings show that Cd_3As_2, or other similar 3D TDS, has the potential to achieve a low turn-on field, which is a highly sought-after property in field emission physics.

PO.138 On transformation of quantum coherence into quantum entanglement

Sushamana Sharma* (JIET, Jodhpur (Rajasthan))

The literal meaning of coherence is the relationship between parts of something. In classical physics, on superposition of coherent waves of definite phase relation and same frequency, interference pattern is formed whose visibility is a measure of degree of coherence. The superposition and degree of coherence are related qualitatively as well as quantitatively. Coherence in the quantum systems responsible for their interference may be called as quantum coherence in analogous way. The superposition of different quantum states will give another valid quantum state of the whole system. For example, the superposition of classical bits $|0\rangle$ and $|1\rangle$ acts as the quantum bit (Qubit) in the quantum information processing. Quantum entanglement is very strange relation between two or more parties (spins of electron, polarization state, etc.). They share such a bond not physical that result of the measurement on one particle immediately reveals the outcome of the second particle in case of bipartite entangled state and results of the measurement made on two particle is enough to know the state of third particle in three particle entangled state. All these similarities between coherence and superposition in classical physics triggered to investigate the relationship in quantum physics. Fortunately there are some techniques to demonstrate the convertibility of quantum coherence and the entanglement. The incoherent operations on the coherent state of degree of coherence C_d can be transformed into entanglement. The zero coherence in the initial state will result in no entanglement after the application of incoherent operation. It is also discussed that the upper bound on the amount of entanglement in this generated state is the degree of coherence of initial state.

PO.139 Matrix Multiplicative Weights Updates in Quantum Zero-Sum Games: Conservation Laws & Recurrence

Rahul Jain, Georgios Piliouras, Ryann Sim* (Singapore University of Technology and Design)

Recent advances in quantum computing have led to increased interest in quantum game theory, which extends the scope of classical game theory into the quantum realm. This allows for the study of systems where quantum agents send a mixed state to a referee, who then determines their payoffs via a joint measurement on their states. While quantum versions of many seminal results in classical game theory (such as von Neumann's minmax theorem) have been shown to hold in the quantum context, much remains to be discovered about online learning in quantum games. In this paper, we focus on quantum zero-sum games under Replicator Dynamics - a widely studied evolutionary learning dynamic and its discrete analogue, Matrix Multiplicative Weights Update. When each player selects their state according to quantum replicator dynamics, we show that the system exhibits conservation laws in a quantum-information theoretic sense. Moreover, we show that the system exhibits Poincaré recurrence, meaning that almost all orbits return arbitrarily close to their initial conditions infinitely often. Our analysis generalizes previous results in the case of classical games.

PO.140 Pulsed perovskite light-emitting transistors

Maciej Klein*, Bryan Cheng, Annalisa Bruno, Cesare Soci* (Centre for Disruptive Photonic Technologies, Nanyang Technological University)

Perovskite light-emitting transistors (PeLETs) are unique devices that combine two optoelectronic functions: electrical switching and amplification with light emission. Moreover, PeLETs provide a versatile platform to study charge transport and recombination of charge carriers in hybrid organic-inorganic perovskites [1]. The intrinsic transport characteristics perovskites are extremely rich, as several effects play a role concomitantly: thermally-activated trapping, ionic motion, and organic cation polarization. These factors affect balanced ambipolar transport and long-term stability, preventing the devices to achieve their theoretical performance [2]. AC modulation of the gate voltage bias (pulsed operation) together with high film quality of the co-evaporated perovskites, have proved to be a viable route to overcome some of these limitations by minimization of ionic vacancy drift and organic cation polarization and improvement of charge carrier injection, leading to bright and stable light emission at room temperature and beyond [3-4]. In this work, we investigate charge transport properties of PeLETs under pulsed operation. We find that short (500 μs) gate voltage pulses greatly improve transistor electrical characteristics above 150 K. Under these conditions, electrical hysteresis is effectively reduced, and electron field-effect mobility increases by 5 orders of magnitude (approaching 1 cm^2/Vs at room temperature), illustrating how the understanding of fundamental transport mechanisms in hybrid organic-inorganic perovskites can lead to drastic improvements of device performance.

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PO.143 Interfacial phase change materials with improved stability: a comparison of $Ge_{45}Te_{52}S_3/Sb_2Te_3$ with $GeTe/Sb_2Te_3$ superlattices

Nur Qalishah Adanan*, Simon Wredh*, Jing Ning*, Yunzheng Wang*, Robert Edward Simpson* (Singapore University of Technology and Design (SUTD))

Chalcogenide superlattices composed of GeTe and Sb_2Te_3 layers are attractive for low energy switching phase change data storage1. However, interlayer atomic mixing been reported in such superlattices. The objective of this study is to increase the stability of these superlattices against intermixing. Recently, sulphur (S), was reported to stabilise the superlattice layers. Here, we compare the stability and switching speed of $Ge_{45}Te_{52}S_3/Sb_2Te_3$ superlattices with pure $GeTe/Sb_2Te_3$ superlattices. The superlattices were characterised using X-Ray diffraction (XRD), Raman spectroscopy, optical spectroscopy as a function of temperature, and using pump-probe transient laser reflectivity measurements. We find that the $Ge_{45}Te_{52}S_3/Sb_2Te_3$ superlattices are more stable than their $GeTe/Sb_2Te_3$ counterparts. Although the crystallisation temperature of $Ge_{45}Te_{52}S_3$ is lower than GeTe, its activation energy of 2.39eV is larger than the 2.31eV crystallisation activation energy of pure GeTe.2 The XRD pattern for the $Ge_{45}Te_{52}S_3/Sb_2Te_3$[1:4] superlattice indicates a decrease in the lattice spacing and an increase in layer ordering as compared the $GeTe/Sb_2S_3$[1:4] superlattice. Furthermore, the Raman spectrum for the S-doped superlattice has more distinct and narrow peaks when compared to the undoped $GeTe/Sb_2Te_3$[1:4] superlattice, which suggests better ordering on a local atomic scale. In addition, the optical properties of the $Ge_{45}Te_{52}S_3/Sb_2Te_3$[1:4] superlattice seem to be more stable than the $GeTe/Sb_2Te_3$[1:4] structure during heating. These results suggest that the $Ge_{45}Te_{52}S_3/Sb_2Te_3$ superlattice may provide a solution to the intermixing problem and allow high speed phase change data storage switching with low electrical currents, which is important for transistor-less two terminal memory devices.

References

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(2) Zhou, X.; Dong, W.; Zhang, H.; Simpson, R. E. A Zero Density Change Phase Change Memory Material: GeTe-O Structural Characteristics upon Crystallisation. Sci. Rep. 2015, 5 (May), 1–8. https://doi.org/10.1038/srep11150.

4 Technical Sessions

(some instructions for technical sessions to follow).

T1: Topological Physics 1

Time: Thursday 30 Sept, 11:15am; Venue: Sky Ballroom I; Chair: TBD
Time allocated for invited talks is 20 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T1.7 (INVITED) The fascinating properties of topological and non-Hermitian systems

Ching Hua Lee* (National University of Singapore)
11:15am – 11:35am

Robust boundary modes have been a central focus of condensed matter research for more than a decade. So far, there are two main mechanisms for robust boundary modes - topology and non-Hermiticity - with the latter leading to a variety of intriguing phenomena not known till recently. Besides gain or dissipation, open non-Hermitian systems exhibit a variety of interesting physical effects with no Hermitian analog. In particular, systems with asymmetric gain/loss experience the so-called non-Hermitian skin effect, where all eigenmodes localize at the boundaries. The resultant skin modes lead to modified topological invariants and, in higher dimensions, new families of skin-topological modes characterized by the spontaneous breaking of reciprocity. Their effective description implies an emergent non-locality that also leads to modified criticality, discontinuous Berry curvature, anomalous linear responses and unusual topological transitions that do not close the gap. My talk shall consist of two parts: 1) an introduction to recently discovered non-Hermitian phenomena and 2) an overview of synthetic realizations of topological and non-hermitian states via electrical circuits and quantum computers, particularly those from my group. These synthetic realizations form new avenues for bringing to reality various phenomena previously thought to only exist on paper.

T1.3 A mechanistic density functional theory for ecology across scales

Martin-Isbjoern Trappe*, Ryan Chisholm (Center of Quantum Technologies NUS)
11:35am – 11:50am

Our ability to predict the properties of a system typically diminishes as the number of its interacting constituents rises. This poses major challenges for understanding natural ecosystems, and humanity's effects on them. How do macroecological patterns emerge from the interplay between species and their environment? What is the impact on complex ecological systems of human interventions, such as extermination of large predators, deforestation, and climate change? The resolution of such questions is hampered in part by the lack of a holistic approach that unifies ecology across temporal and spatial scales. Here we use density functional theory, a computational method for many-body problems in physics, to develop a novel computational framework for ecosystem modelling. Our methods accurately fit experimental and synthetic data of interacting multi-species communities across spatial scales and can project to unseen data. Our mechanistic framework provides a promising new avenue for understanding how ecosystems operate and facilitates quantitative assessment of interventions.

T1.62 Establishing phonon mode connectivities using a complementary approach

Chee Kwan Gan* (Institute of High Performance Computing)
11:50am – 12:05pm

Characterization of electronic band and phonon band connectivities touches on the fundamentals of condensed matter physics that are related to the calculation of group velocities and Gruneisen parameters within the Brillouin zone. We propose an efficient algorithm that combines two complementary approaches[1]. The first approach uses the standard perturbation theory in quantum mechanics to provide an initial band connectivity that could be improved by a second approach based on the least-squares fits. This combination of a 'local' and 'global' approaches is shown to be effective in overcoming problems that arise naturally due to the degenerate modes[2]. Our method could be generalized to other problems in the conventional density functional theory calculations, photonic crystals, and tight-binding models.

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[2] C. K. Gan, Y. Liu, T. C. Sum, and K. Hippalgaonkar, Comput. Phys. Comm. 259, 107635 (2021).

T1.42 Topological machine learning for condensed matter physics and photonics

Daniel Leykam*, Dimitris Angelakis* (National University of Singapore)
12:05pm – 12:20pm

Topological data analysis (TDA) characterises large and complex datasets by measuring its "shape," defined by constructing families of graphs from the dataset and computing their topological invariants [1]. TDA's sensitivity to global data features combined with its robustness to noise and perturbations make it particularly promising for condensed matter physics applications including the detection of phase transitions. We provide a brief introduction to TDA and some applications in physics of current interest. We show how TDA can be used to characterise nonlocal features of electronic and photonic band structures including the shapes of their isoenergy surfaces and topological invariants of their Bloch functions. The topological features identified by TDA can be readily incorporated into optimisation methods to find lattice parameters producing band structures with desired topological features [2]. As another application, we show how TDA can identify image features useful for the machine learning-based detection of dark solitons from Bose-Einstein condensate density images. The features identified by TDA can be used as inputs to simple supervised classification approaches such as logistic regression, enabling the reliable detection of dark solitons at fraction of the compute time of neural network-based approaches [3].

References

[1] G. Carlsson, Topological methods for data modelling, Nature Rev. Phys. 2, 697 (2020).
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APL Photon. 6, 028102 (2021). [3] D. Leykam, I. Rondon, and D. G. Angelakis, Dark soliton detection using persistent homology, arXiv:2107.14594.

T1.18 Symmetry-Enforced Nodal Chain Phonons

Jiaojiao Zhu*, Weikang Wu*, Jianzhou Zhao*, Hao Chen*, Lifa Zhang*, Shengyuan A. Yang* (Singapore University of Technology and Design)
12:20pm – 12:35pm

Topological phonons in crystalline materials have been attracting great interest. However, most cases studied so far are direct generalizations of the topological states from electronic systems. Here, we reveal a novel class of topological phonons—the symmetry-enforced nodal-chain phonons, which manifest features unique for phononic systems. We show that with D2d little co-group at a nontime- reversal-invariant-momentum point, the phononic nodal chain is guaranteed to exist owing to the vector basis symmetry of phonons, which is a unique character distinct from electronic and other systems. Combined with the spinless character, this makes the proposed nodal-chain phonons enforced by symmorphic crystal symmetries. We further screen all 230 space groups, and find five candidate groups. Interestingly, the nodal chains in these five groups exhibit two different patterns: for tetragonal systems, they are one-dimensional along the fourfold axis; for cubic systems, they form a three-dimensional network structure. Based on rst-principles calculations, we identify K_2O as a realistic material hosting almost ideal nodal-chain phonons. We show that the effect of LO-TO splitting, another unique feature for phonons, helps to expose the nodal-chain phonons in K_2O in a large energy window. In addition, all the ve candidate groups have spacetime inversion symmetry, so the nodal chains also feature a quantized pi Berry phase. This leads to drumhead surface phonon modes that must exist on multiple surfaces of a sample.

T1.16 Higher-Order Nodal Points in Two Dimensions

Weikang Wu*, Ying Liu, Zhi-Ming Yu, Y. X. Zhao, Weibo Gao, Shengyuan A. Yang (Nanyang Technological University)
12:35pm – 12:50pm

A two-dimensional (2D) topological semimetal is characterized by the nodal points in its low-energy band structure. While the linear nodal points have been extensively studied, especially in the context of graphene, the realm beyond linear nodal points remains largely unexplored. Here, we explore the possibility of higher-order nodal points, i.e., points with higher-order energy dispersions, in 2D systems. We perform an exhaustive search over all 80 layer groups both with and without spin-orbit coupling (SOC), and reveal all possible higher-order nodal points. We show that they can be classified into two categories: the quadratic band touching point (QBTP) and the cubic band touching point (CBTP). All the 2D higher-order nodal points have twofold degeneracy, and the order of dispersion cannot be higher than three. QBTPs only exist in the absence of SOC, whereas CBTPs only exist in the presence of SOC. Particularly, the CBTPs represent a new topological state not known before. We show that they feature nontrivial topological charges, leading to extensive topological edge bands. Our work completely settles the problem of higher-order nodal points, discovers novel topological states in 2D, and provides detailed guidance to realize these states. Possible material candidates and experimental signatures are discussed.

T2: Materials 1

Time: Thursday 30 Sept, 11:15am; Venue: Sky Ballroom II; Chair: TBD
Time allocated for invited talks is 20 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T2.87 (INVITED) $MoSi_2N_4$ and WSi_2N_4 van der Waals 2D/2D Heterostructures: Promising Hybrid Materials for Solar Cell and Photocatalytic Applications

Che Chen Tho*, Yee Sin Ang*, Guangzhao Wang*, Lay Kee Ang* (Singapore University of Technology and Design)
11:15am – 11:35am

$MoSi_2N_4$ and WSi_2N_4 van der Waals 2D/2D Heterostructures: Promising Hybrid Materials for Solar Cell and Photocatalytic Applications

Che Chen Tho, L. K. Ang, Guangzhao Wang, Yee Sin Ang*

Singapore University of Technology and Design

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Recent discovery of two-dimensional (2D) MA_2Z_4 family, such as $MoSi_2N_4$ and WSi_2N_4, opens a new avenue towards the development of novel 2D material device technology[1, 2]. Due to their excellent air-stability, mechanical strength, and electrical properties, $MoSi_2N_4$ and WSi_2N_4 have been intensively studied recently[3, 4]. Particularly, unusual electronics and optical properties has been predicted in the van der Waals heterostructures (VDWH) of MA_2Z_4[5, 6]. In this work, we perform a first-principle Density Functional Theory (DFT) simulation to study the electronic structure, band alignment, optical absorption and solar cell maximum conversion efficiency of 2D/2D VDWH composed of $MoSi_2N_4$ and WSi_2N_4 interfaced with other 2D materials. Our study covers 49 species of VDWH in which $MoSi_2N_4$ and WSi_2N_4 are in contact with a large variety of 2D materials, including Graphene, various monolayer Transition Metal Dichalcogenide (TMD) of both metallic and semiconducting phases, Janus TMD, the monolayers of Boron Phosphide, Hexagonal Boron Nitride and Zinc Oxide, Trisodium Bismuthide and other members of the MA_2Z_4 family. Our broad-scope study uncovers multiple VDWHs with Type-II band alignment – a feature highly beneficial for charge separation and optoelectronic applications – and strong optical absorption in the visible regime, thus revealing the potential of 2D/2D heterostructures in optoelectronic applications. VDWHs of metal/semiconductor contact type with Ohmic and Schottky contacts of ultralow interface potential barrier are also identified, which are especially useful in the design of energy-efficient nanoelectronic devices. Our work offers a library of 2D/2D VDWH essential for the developments of MA_2Z_4-based electronic, photovoltaic and optoelectronic devices.

References: [1] Y.L. Hong, Z. Liu, L. Wang, T. Zhou, W. Ma, C. Xu, S. Feng, L. Chen, M.L. Chen, D.M. Sun, X.Q. Chen, H.M. Cheng, W. Ren, Chemical vapor deposition of layered two-dimensional MoSi(2)N(4) materials, Science, 369 (2020) 670-674. [2] Q. Wang, L. Cao, S.-J. Liang, W. Wu, G. Wang, C.H. Lee, W.L. Ong, H.Y. Yang, L.K. Ang, S.A. Yang, Y.S. Ang, Efficient Ohmic contacts and built-in atomic sublayer protection in $MoSi_2N_4$ and WSi_2N_4 monolayers, npj 2D Materials and Applications, 5 (2021) 71. [3] L. Cao, G. Zhou, Q. Wang, L.K. Ang, Y.S. Ang, Two-dimensional van der Waals electrical contact to monolayer $MoSi_2N_4$, Applied Physics Letters, 118 (2021) 013106. [4] B. Mortazavi, B. Javvaji, F. Shojaei,

T. Rabczuk, A. Shapeev, X. Zhuang, Exceptional piezoelectricity, high thermal conductivity and stiffness and promising photocatalysis in two-dimensional $MoSi_2N_4$ family confirmed by first-principles, Nano Energy, 82 (2021) 105716. [5] A. Bafekry, M. Faraji, A. Abdollahzadeh Ziabari, M.M. Fadlallah, C.V. Nguyen, M. Ghergherehchi, S.A.H. Feghhi, A van der Waals heterostructure of MoS_2/$MoSi_2N_4$: a first-principles study, New Journal of Chemistry, 45 (2021) 8291-8296. [6] C. Nguyen, N.V. Hoang, H.V. Phuc, A.Y. Sin, C.V. Nguyen, Two-Dimensional Boron Phosphide/MoGe2N4 van der Waals Heterostructure: A Promising Tunable Optoelectronic Material, The Journal of Physical Chemistry Letters, 12 (2021) 5076-5084.

T2.5 Electrically Detected Paramagnetic Resonance in Ag-paint Coated Polycrystalline DPPH

Yong Heng Lee*, Ushnish Chaudhuri, Ramanathan Mahendiran* (National University of Singapore)

11:35am – 11:50am

We describe a simple experimental method to detect electron paramagnetic resonance (EPR) in polycrystalline 2,2-diphenyl-1-picrylhydrazyl (DPPH) sample, the standard g-marker for EPR spectroscopy, without using a cavity resonator or a prefabricated waveguide. It is shown that microwave (MW) current injected into a layer of silver paint coated on an insulating DPPH sample is able to excite the paramagnetic resonance in DPPH. As the applied dc magnetic field H is swept, the high-frequency resistance of the Ag-paint layer, measured at room temperature with a single port impedance analyzer in the MW frequency range f = 1 to 2.85 GHz, exhibits a sharp peak at a critical value of the dc field (H = Hr) while the reactance exhibits a dispersion-like behavior around the same field value for a given f. Hr increases linearly with f. We interpret the observed features in the impedance to EPR in DPPH driven by the Oersted magnetic field arising from the MW current in the Ag-paint layer. We also confirm the occurrence of EPR in DPPH independently using a co-planar waveguide based broadband technique in the frequency range 2 – 4 GHz.

T2.128 Origin of Compositional Fluctuations in InGaN Light Emitting Diodes

Tara P. Mishra*, Jing Yang Chung, Zeyu Deng, Silvija Gradečak*, Stephen J. Pennycook*, Pieremanuele Canepa* (National University of Singapore)

11:50am – 12:05pm

The origin of the high resiliency of InGaN light emitting diodes (LEDs) to astoundingly high defect densities remains an open question. A popular theory is the presence of intrinsic In-clustering in InGaN quantum wells that are responsible for carrier localization. In this study, we use electron energy-loss spectroscopy (EELS) to develop a robust methodology of In-cluster quantification with sub-nanometer resolution. Using a first principles based multiscale computational models we obtained a statistical distribution of the compositional fluctuations in $In_xGa_{1-x}N$ LEDs at different indium concentrations. Our theoretical approach incorporates directly strain effects in $In_xGa_{1-x}N$ quantum wells resulting from the epitaxial growth. We develop an approach in which we use image processing tools to detect fluctuations in the quantum well region in both simulated and experimentally observed EELS micrographs. We show that although lower In content $In_xGa_{1-x}N$ with $x \approx 18\%$ LEDs mostly show compositional fluctuations in the limit of a random alloy, the distribution of compositional fluctuation drastically changes in $In_xGa_{1-x}N$ LEDs with higher In content ($\geq 24\%$). Therefore, a distinctly different mechanism for carrier localization can be expected for in $In_xGa_{1-x}N$ LEDs of different In content, which would ultimately affect the performance of the LEDs.

T2.114 Non-vertical bulk photovoltaic effect in centrosymmetric non-magnetic materials

Ying Xiong*, Li-Kun Shi, Justin C.W. Song* (Nanyang Technologocial University)
12:05pm – 12:20pm

Conventional bulk photovoltaic currents are only allowed in non-centrosymmetric materials. Furthermore, certain types of bulk photocurrents (e.g. linear injection and circular shift currents) are typically forbidden by time reversal symmetry. In this work, we demonstrate that by coupling to plasmonic fields with finite q wavevector, non-vertical interband transitions unblock the time-reversal forbidden linear injection and circular shift photocurrents even in non-magnetic materials that preserve inversion symmetry. Strikingly, these non-vertical photocurrents exhibit a Fermi surface resonant (FSR) effect and display a large peak when the photoexcitations take place near the Fermi level. The FSR effect directly arises from the selective excitation of charge carriers due to the collaborative effect of finite linear momentum transfer and the Fermi surface position. The non-vertical FSR photocurrents encodes important information of band geometry and is greatly enhanced when incorporated with nanophotonic structures. Our work thus proposes a way to probe the quantum geometry in centrosymmetric non-magnetic materials.

T2.112 High energy storge performances in dielectric films by defect and superparaelectric design

Hao Pan*, Xiao Renshaw Wang (nanyang technological university)
12:20pm – 12:35pm

Electrostatic energy storage based on high-performance dielectric capacitors is in great demand for modern electronic devices and electrical power systems. Developing high-energy-density, high-efficiency dielectric films with high breakdown strength, high polarization, and low hysteresis loss has arouse extensive interest and effort. First, we propose that in the high-polarization but low-breakdown-strength $BiFeO_3$-based films, a rational construction of deep-level Bi & O vacancy complexes realizes an enhancement of the resistivity by 4 orders of magnitude, leading to greatly improved breakdown strength and energy performances. Second, we demonstrate further enhancements of energy storage properties in the $BiFeO_3$-based relaxor-ferroelectric dielectric films with a superparaelectric design, in which the polar nanodomains are scaled down to polar clusters of several unit cells so that polarization switching hysteresis is nearly eliminated while relatively high polarization is maintained. We realize an ultrahigh energy density of 152 J cm^{-3} with greatly improved efficiency in the superparaelectric Sm-doped $BiFeO_3$-$BaTiO_3$ films. These strategies are generally applicable to optimize dielectric and other related functionalities of relaxor ferroelectrics.

T2.105 Magneto resistance for viscous electron flow in Corbino ring and Hall bar

Ramal Afrose* (National University of Singapore)

12:35pm – 12:50pm

Recent progress in the synthesis of very clean 2D systems with very low disorder and electron-phonon scattering has enabled the study of viscous hydrodynamic regime of electron transport. Magnetoresistance (MR) measurements promise to be a very potent probe for extracting physical parameters of this flow, like the coefficient of shear viscosity of the electron fluid. Here, we attempt to explain how MR is affected by viscous flow. We contrast the flow in two different channel geometries, the Corbino ring and the Hall bar, try to obtain exact solutions of the flow, and provide simple approximations that explain the physics at the interplay of viscous and non-viscous dissipations. We also look at graphene, and how MR is affected in a two-carrier model involving electrons and holes.

T3: Quantum Science 1

Time: Thursday 30 Sept, 11:15am; Venue: Sky Ballrom III; Chair: TBD
Time allocated for invited talks is 20 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T3.103 (INVITED) Provable superior accuracy in machine learned quantum models

Chengran Yang*, Andrew Garner, Feiyang Liu, Nora Tischler, Jayne Thompson, Man-Hong Yung*, Mile Gu*, Oscar Dahlsten* (Southern University of Science and Technology)
11:15am – 11:35am

In building models from big data, there is a constant trade-off between model precision and complexity. Forcing models to be simpler offers computational speedup by mitigating the curse of dimensionality, but often does so by sacrificing predictive accuracy. Here we show that quantum models enable a more favourable trade-off through machine learning techniques. We design a quantum model discovery algorithm that works directly off classical time-series data. We use it to infer dimensionally constrained quantum models whose accuracy we prove exceeds any classical counterpart. Moreover, we demonstrate this advantage can be realized on present-day hardware, yielding classically unattainable accuracy even in the presence of noise. These techniques illustrate the immediate relevance of quantum technologies to time-series analysis and offer a rare instance where the resulting advantage can be provably established.

T3.27 (INVITED) Qubit-efficient encoding schemes for binary optimisation problems

Benjamin Tan*, Marc-Antoine Lemonde, Supanut Thanasilp, Jirawat Tangpanitanon, Dimitris Angelakis (Centre for Quantum Technologies)
11:35am – 11:55am

We propose and analyze a set of variational quantum algorithms for solving quadratic unconstrained binary optimization problems where a problem consisting of n_c classical variables can be implemented on $\mathcal{O}(\log(n_c))$ number of qubits. The underlying encoding scheme allows for a systematic increase in correlations among the classical variables captured by a variational quantum state by progressively increasing the number of qubits involved. We first examine the simplest limit where all correlations are neglected, i.e. when the quantum state can only describe statistically independent classical variables. We apply this minimal encoding to find approximate solutions of a general problem instance comprised of 64 classical variables using 7 qubits. Next, we show how two-body correlations between the classical variables can be incorporated in the variational quantum state and how it can improve the quality of the approximate solutions. We give an example by solving a 42-variable Max-Cut problem using only 8 qubits where we exploit the specific topology of the problem. We analyze whether these cases can be optimized efficiently given the limited resources available in state-of-the-art quantum platforms. Lastly, we present the general framework for extending the expressibility of the probability distribution to any multi-body correlations.

T3.78 (INVITED) Sequentially constrained Monte Carlo sampler for quantum states

Berge Englert*, Jiangwei Shang*, Rui Han*, Weijun Li*, Hui Khoon Ng* (Yale-NUS College, and the Centre for Quantum Technologies, NUS)
11:55am – 12:15pm

A random sample of quantum states with specific properties is useful for various applications. 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) algorithm as a powerful method for sampling quantum states in accordance with any desired properties that can be described by inequalities. For illustration, we apply this method to the sampling of quantum states with bound entanglement, high-dimensional quantum states with a desired target distribution, and uniformly distributed quantum states in regions bounded by values of the problem-specific target distribution. These examples demonstrate that the SCMC sampler is not only efficient and reliable, it also overcomes the curse of dimensionality.

T3.60 Randomized benchmarking in the presence of time-correlated dephasing noise

Jiaan Qi*, Hui Khoon Ng* (Yale-NUS college)
12:15pm – 12:30pm

Randomized benchmarking has emerged as a popular and easy-to-implement experimental technique for gauging the quality of gate operations in quantum computing devices. A typical randomized benchmarking procedure identifies the exponential decay in the fidelity as the benchmarking sequence of gates increases in length, and the decay rate is used to estimate the fidelity of the gate. That the fidelity decays exponentially, however, relies on the assumption of time-independent or static noise in the gates, with no correlations or significant drift in the noise over the gate sequence, a well-satisfied condition in many situations. Deviations from the standard exponential decay, however, have been observed, usually attributed to some amount of time correlations in the noise, though the precise mechanisms for deviation have yet to be fully explored. In this work, we examine this question of randomized benchmarking for time-correlated noise—specifically for time-correlated dephasing noise for exact solvability—and elucidate the circumstances in which a deviation from exponential decay can be expected.

T3.52 Creating and concentrating quantum resource states in noisy environments using a quantum neural network

Tanjung Krisnanda*, Sanjib Ghosh, Tomasz Paterek, Timothy Liew* (Nanyang Technological University)
12:30pm – 12:45pm

Quantum information processing tasks require exotic quantum states as a prerequisite. They are usually prepared with many different methods tailored to the specific resource state. Here we provide a versatile unified state preparation scheme based on a driven quantum network composed of randomly coupled fermionic nodes. The output of such a system is then superposed with the help of linear mixing where weights and phases are trained in order to obtain desired output quantum states. We explicitly show that our method is robust and can be utilized to create almost perfect maximally entangled, NOON, W, cluster, and discorded states. Furthermore, the treatment includes energy decay in the system as well as dephasing and depolarization. Under these noisy conditions we show that the target states are achieved with high fidelity by tuning controllable parameters and providing sufficient strength to the driving of the quantum network. Finally, in very noisy systems, where noise is comparable to the driving strength, we show how to concentrate entanglement by mixing more states in a larger network.

T4: Quantum Engineering 1

Time: Thursday 30 Sept, 11:15am; Venue: Grand Ballroom; Chair: TBD
Time allocated for invited talks is 20 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T4.49 (INVITED) Quantum state classification using SWAP test

Ko-Wei Tseng*, Chi Huan Nguyen*, Jaren Gan*, Gleb Maslennikov*, Dzmitry Matsukevich* (Centre for Quantum Technologies, Natl. Uinv. of Singapore)
11:15am – 11:35am

We report experimental implementation of quantum machine learning algorithms for classification of the quantum state of a harmonic oscillator with a trapped ion quantum processor. We demonstrate an unsupervised K-means algorithm to classify a set of high dimensional quantum states into 3 different classes (coherent, squeezed, superposition of Fock states with 0 and 1 phonons). Using the acquired knowledge, we classify unknown quantum states using the supervised k-NN algorithm.

The quantum states of harmonic oscillators are encoded in the radial motional modes of two trapped ions. The experiments consist of two core elements: the universal embedding circuit based on the Eberly-Law algorithm allows us to prepare an arbitrary quantum state of a harmonic oscillator, and a constant-depth overlap measurement to estimate the overlap between unknown quantum states. Continuous variable approach allows more efficient encoding and manipulation of the quantum high dimensional quantum states and reduces the number of required trapped ions compared to traditional qubit approach.

T4.91 (INVITED) SpooQy-1: Long term operations and results

Ayesha Reezwana*, Tanvirul Islam, Su Yi Esther Wong, Chithrabhanu Perumangatt, Christoph Wildfeuer, Alexander Ling (Centre for Quantum Technologies)
11:35am – 11:55am

Spooqy-1 is a cube satellite developed at Centre for Quantum Technologies and deployed into low Earth orbit (LEO) on 17 June, 2019. The satellite is designed under cubesat constraints for the generation and detection of entangled photons in space .The primary payload of the satellite contains an entangled photon source based on spontaneous parametric down conversion along with a detection setup to measure the Bell-CHSH parameter, which determines the entanglement quality. The satellite is successfully operating in LEO even after being exposed to the harsh space conditions for the last two years. In this talk we will discuss the long term evaluation of the performance of Spooqy-1 including the entanglement measurement results.

T4.48 (INVITED) Anti-Hong-Ou-Mandel effect for bosons and fermions

Anton N. Vetlugin*, Ruixiang Guo, Cesare Soci, Nikolay I. Zheludev (Nanyang Technological University)
11:55am – 12:15pm

Two particles, interfering on a lossless beamsplitter, coalesce if their wavefunction possess bosonic symmetry (e.g, photons) and anti-coalesce if the wavefunction is of fermionic symmetry (e.g., electrons). This fundamental phenomenon, known as the Hong-Ou-Mandel effect, is revealed through observation of the ‘bosonic’ dip or ‘fermionic’ peak in coincidence counts measurement at output ports of the beamsplitter. Here, we demonstrate the reversed – anti-HOM effect with a lossy beamsplitter, where bosons anti-coalesce and fermions show coalescent-like behavior. We artificially create bosonic and fermionic states of light as pairs of entangled photons with symmetric and anti-symmetric wavefunctions which allows us to test quantum interference for particles of different nature in a single experiment. We observed that the presence of dissipation in the beamsplitter reverses quantum interference in such a way that peak in coincidences is measured for bosonic states while dip is measured‘ for fermionic states, in contrast to the conventional HOM effect. The ability to generate states of light with different statistics and manipulate their interference with dissipation offers important opportunities for quantum information and metrology.

T4.117 Noisy intermediate-scale quantum (NISQ) algorithms

Kishor Bharti* (CQT)
12:15pm – 12:30pm

A universal fault-tolerant quantum computer that can solve efficiently problems such as integer factorization and unstructured database search requires millions of qubits with low error rates and long coherence times. While the experimental advancement towards realizing such devices will potentially take decades of research, noisy intermediate-scale quantum (NISQ) computers already exist. These computers are composed of hundreds of noisy qubits, i.e. qubits that are not error-corrected, and therefore perform imperfect operations in a limited coherence time. In the search for quantum advantage with these devices, algorithms have been proposed for applications in various disciplines spanning physics, machine learning, quantum chemistry and combinatorial optimization. The goal of such algorithms is to leverage the limited available resources to perform classically challenging tasks. In this review, we provide a thorough summary of NISQ computational paradigms and algorithms. We discuss the key structure of these algorithms, their limitations, and advantages. We additionally provide a comprehensive overview of various benchmarking and software tools useful for programming and testing NISQ devices.

T5: Topological Physics 2

Time: Thursday 30 Sept, 2:00pm; Venue: Sky Ballrom I; Chair: TBD
Time allocated for invited talks is 20 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T5.1 (INVITED) Berry connection polarizability and third order Hall effect

Shengyuan Yang* (Singapore University of Technology and Design)
2:00pm – 02:20pm

One big achievement in modern condensed matter physics is the recognition of the importance of various band geometric quantities in physical effects. As prominent examples, Berry curvature and Berry curvature dipole are connected to the linear and the second-order Hall effects, respectively. We find that the Berry connection polarizability (BCP) tensor, as another intrinsic band geometric quantity, plays a key role in the third-order Hall effect. Based on the extended semiclassical formalism, we develop a theory for the third-order charge transport and derive explicit formulas for the third-order conductivity. Our theory is applied to the two-dimensional (2D) Dirac model to investigate the essential features of BCP and the third-order Hall response. We further demonstrate the combination of our theory with the first-principles calculations to study a concrete material system, the monolayer FeSe. Our work establishes a foundation for the study of third-order transport effects, and reveals the third-order Hall effect as a tool for characterizing a large class of materials and for probing the BCP in band structure.

Work supported by Singapore Ministry of Education AcRF Tier 2 (Grant No. MOE2019-T2-1- 001) and National research foundation CRP programme (NRF-CRP22-2019-0004).

T5.72 Propagation-induced radiation limits in three dimensional Dirac semimetal high harmonic generation

Jeremy Lim*, Yee Sin Ang*, Ricky Ang*, Liang Jie Wong* (Nanyang Technological University)

02:20pm – 02:35pm

Three dimensional Dirac semimetals (3D DSMs) have attracted much interest as highly efficient platforms for chip-scale, solid-state terahertz (THz) high harmonic generation (HHG). Here, we show that orders-of-magnitude enhancements in THz HHG can be obtained with longer propagation lengths resulting from increased film thicknesses. At the same time, our results reveal that an optimal film thickness exists, beyond which the output intensity and efficiency decreases drastically. We show that this is due to extremely subwavelength features in the current density that develop within the skin depth of the 3D DSM. Specifically, we find that the current density induced by the incident field experiences a phase-flip during propagation as a result of 3D DSMs' extreme nonlinearity. We show that this phenomenon can be understood as a propagation-induced dephasing effect. Our results highlight the importance of effects arising from light propagation on the nanoscale in the nonlinear optics of 3D Dirac semimetals, and suggest that this fundamental limit can be circumvented through appropriate material nanostructuring. Our work paves the way toward the development of efficient chip-scale sources of THz radiation based on highly nonlinear materials like bulk topological semimetals.

T5.96 Interaction-induced double-sided skin effect in an exciton-polariton system

Xingran Xu*, Huawen Xu, Subhaskar Mandal, Rimi Banerjee, Timothy C.H. Liew* (Nanyang Technological University)
02:35pm – 02:50pm

The non-Hermitian skin effect can be realized through asymmetric hopping between forward and backward directions, where all the modes of the system are localized at one edge of a finite 1D lattice. Here we show theoretically that in a finite chain of 1D exciton-polariton micropillars with symmetric hopping, the inherent nonlinearity of the system can exhibit a double-sided skin (bi-skin) effect based of the fluctuations of the system, where the modes of the system are localized at the two edges of the system. To show the topological origin of such modes, we calculate the winding number. The bi-skin effect can be detected experimentally as an intensity drop at one edge of the chain and an increase at the opposite edge upon an increase of the polariton density under continuous wave excitation.

T5.108 Skyrmions drive topological Hall effect in a Shastry–Sutherland magnet

Nyayabanta Swain*, Munir Shahzad, Georgii V. Paradezhenko, Anastasia A. Pervishko, Dmitry Yudin, Pinaki Sengupta (National University of Singapore)
02:50pm – 03:05pm

The Shastry-Sutherland model and its generalizations have been shown to capture emergent complex magnetic properties from geometric frustration in several quasi-two-dimensional quantum magnets. Using an sd exchange model, we show that metallic Shastry-Sutherland magnets exhibit topological Hall effect driven by magnetic skyrmions under realistic conditions. The magnetic properties are modelled with competing symmetric Heisenberg and asymmetric Dzyaloshinskii-Moriya exchange interactions, while a coupling between the spins of the itinerant electrons and the localized moments describe the magneto-transport behavior. We employ a novel machine learning technique and a complementary Monte Carlo simulation to investigate the magnetic phases, and provide evidence for field-driven skyrmion crystal formation in an extended range of Hamiltonian parameters. By constructing an effective tight-binding model of conduction electrons coupled to the skyrmion lattice, we clearly demonstrate the appearance of topological Hall effect. We further study effects of finite temperature on the magnetic and magneto-transport properties. Our results will be crucial in understanding experimental observation and designing new experiments to realise topological magneto-transport properties in metallic Shastry-Sutherland magnets.

T5.115 Mode Delocalization in Disordered Photonic Chern Insulator

Udvas Chattopadhyay*, Sunil Mittal, Mohammad Hafezi, Yidong Chong* (Nanyang Technological University)
03:05pm – 03:20pm

In disordered two-dimensional Chern insulators, a single bulk extended mode per band is predicted to exist up to a critical disorder strength, with all other bulk modes localized. This behavior contrasts with topologically trivial two-dimensional phases, whose modes are all immediately localized by disorder. Using a tight-binding model of a realistic photonic Chern insulator, we show that delocalized bulk eigenstates can be observed in an experimentally realistic setting. This requires the selective use of resonator losses to suppress topological edge states and acquiring sufficiently large ensemble sizes using variable resonator detunings.

T6: Materials 2

Time: Thursday 30 Sept, 2:00pm; Venue: Sky Ballrom II; Chair: TBD
Time allocated for invited talks is 20 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T6.129 (INVITED) Asymmetric correlated states in twisted monolayer-bilayer graphene

Mohammed M. Al Ezzi*, Alexandra Carvalho, Vladimir Falko, Kostya Novoselov, Antonio H. Castro Neto, Shaffique Adam (NUS)
2:00pm – 02:20pm

In twisted monolayer-bilayer graphene with a graphene monolayer stacked and twisted on top of bilayer graphene, massless and massive Dirac fermions hybridize. This heterostructure gives rise to topological electronic bands that are a unique platform to explore symmetry-broken correlated electronic states [1,2,3]. In this theoretical work, we first develop an analytical model to explain the observed asymmetry in formation of correlated states with respect to carrier density and displacement field. Using the linearized gap equation method, we then calculate the stability and critical temperature for different symmetry breaking phases, including spin density waves, charge density waves, and valley ordered phases. This work was supported by the Singapore NRF Investigator (NRF-NRFI06-2020-0003).

T6.122 Atomic-Scale Luminescence Centers in Strain-Engineered Long-Wavelength InGaN Light-Emitters

Jing-Yang Chung*, Zackaria Mahfoud, Li Zhang, Stephen Pennycook, Silvija Gradecak*, Michel Bosman* (National University of Singapore)
02:20pm – 02:35pm

A remarkable increase in the quantum efficiency of long-wavelength III-nitride light emitters has previously been demonstrated through the use of tensile-strained AlN interlayers to cap compressive-strained In-rich InGaN quantum wells (QWs). However, the structural non-uniformity within these strain-compensated heterostructures, and its effect on the local and overall optical properties, has not yet been satisfactorily addressed.

In this work, we use aberration-corrected scanning transmission electron microscopy (STEM) combined with cathodoluminescence (CL) in the STEM to study optical inhomogeneities resulting from various atomic-scale localization centers in red-emitting AlN capped InGaN/GaN QW devices. By probing the spectral response of individual InGaN QWs with nanometer spatial precision, we show that a secondary blueshifted emission originates within the QW near to the AlN interlayer. On the other hand, the presence of criss-crossing inversion domains intrinsically linked to the strain fields surrounding V-pits result in further distinct blueshifts. Finally, high intensity luminescence can be directly correlated to In-rich quantum dots spontaneously nucleated at intersecting V-pit regions. This study highlights the importance of controlling thickness modulation of interlayers and threading dislocation densities to ensure compositional and optical homogeneity in strain-compensated In-rich optoelectronic devices targeted for practical applications. Our results also suggest the nanoscopic origins for the significant emission wavelength shift with injection-current observed in red-emitting devices.

T6.111 Strain Induced Giant Injection Current in Twisted Bilayer Graphene

Arpit Arora*, Jian Feng Kong, Justin Song (Nanyang Technological University)
02:35pm – 02:50pm

We report giant strain-induced circular injection current (circular photogalvanic effect) in hBN encapsulated magic angle twisted bilayer graphene (TBG). Large circular injection currents arise from strong optical absorption between flat and remote bands which gives rise to asymmetric and large interband Berry curvature dipole density in presence of sublattice symmetry breaking and strain. These currents are extremely sensitive to strain and degree of alignment between hBN and graphene, and as a result, can be used as a probe to determine C3 and inversion symmetry breaking in TBG.

T6.36 Quantum Monte Carlo Simulations of the 2D Su-Schrieffer-Heeger Model

Bo Xing*, Wei-Ting Chiu, Dario Poletti, Richard Scalettar, George Batrouni (Singapore University of Technology and Design)
02:50pm – 03:05pm

Over the past several years, a new generation of quantum simulations has greatly expanded our understanding of charge density wave phase transitions in Hamiltonians with coupling between local phonon modes and the on-site charge density. A quite different, and interesting, case is one in which the phonons live on the bonds, and hence modulate the electron hopping. This situation, described by the Su- Schrieffer-Heeger (SSH) Hamiltonian, has so far only been studied with quantum Monte Carlo in one dimension. Here we present results for the 2D SSH model, show that a bond ordered wave (BOW) insulator is present in the ground state at half filling, and argue that a critical value of the electron-phonon coupling is required for its onset, in contradistinction with the 1D case where BOW exists for any nonzero coupling. We determine the precise nature of the bond ordering pattern, which has hitherto been controversial, and the critical transition temperature, which is associated with a spontaneous breaking of Z4 symmetry.

T6.29 Fractionalized Poisson-Boltzmann model for inhomogeneous electrolyte solution

Cherq Chua*, Chun Yun Kee*, Yee Sin Ang*, Lay Kee Ang* (Singapore University of Technology and Design)
03:05pm – 03:20pm

In an electrolyte solution, the inevitable presence of impurities could cause spatial inhomogeneity that affects the distribution of electrolyte ions and the electrical double layer (EDL). In this case, the potential profile is expected to deviate from the classic Poisson-Boltzmann (PB) model [1]. Recently, fractional dimensional calculus has been widely used in the modelling of complex systems with nonlocal or memory effects [2], such as electron emission from rough surface [3], electron transport in disordered organic semiconductor [4], and exciton binding energy in 2D materials [5]. By using Stillinger's fractional Laplacian operator [6], the modified

PB model with steric effect [7], previously developed by Borukhov et al, is generalized into the fractional-dimensional space to model the electrostatic behaviors of counter-ions in EDL. Based on the electroneutrality condition, a generalized fractional-dimensional Grahame equation is developed to describe the relation between the surface charge density and the surface potential. The fractional-dimensional model reveals that the screening of charged ions is reduced by the effects of spatial inhomogeneities, which leads to a slower spatially decaying electrostatic potential and a wider saturation layer when compared to the homogeneous limit. For a constant surface charge density, the surface potential is reduced but it does not significantly affect the distribution of the counter-ions. Our work shows how fractional dimensional modelling of counter-ions can lead to quantitatively different results when compared to the full-dimensional counterpart, thus offering a potential new tool to analyze the electrostatic interaction of ions for inhomogeneous electrolyte solution.

This research is funded by SUTD-ZJU VP 201303 and USA ONRG (N62909-19-1-2047).

References: [1] H. Butt, K. Graf and M. Kappl, Physics and Chemistry of Interfaces, 2003, pp. 42-56. [2] V. Tarasov, Comm. Nonlinear Sci. Numer. Simulat., vol. 20, p. 360–374, 2015. [3] M. Zubair, Y. S. Ang and L. K. Ang, IEEE Trans. Electron Devices, vol. 65, pp. 2089-2095, 2018. [4] M. Zubair, Y. S. Ang and L. K. Ang, IEEE Trans. Electron Devices, vol. 65, pp. 3421-3429, 2018. [5] S. Ahmad, M. Zubair, O. Jalil, M. Q. Mehmood, U. Younis. X. Liu, K. W. Ang and L. K. Ang, Phys. Rev. Applied, vol. 13, 064062. 2020. [6] F. Stillinger, J. Math. Phys., vol. 18, pp. 1224-1234, 1977. [7] I. Borukhov, D. Andelman and H. Orland, Phys. Rev. Lett., vol. 79, no. 3, pp. 435-438, 1997.

T6.54 Disorder in fluorinated hybrid organic- inorganic perovskites

Yulia Lekina*, Benny Febriansyah, Manshu Han, Ze Xiang Shen* (Nanyang Technological University, School of Physics and Mathematics)

03:20pm – 03:35pm

Hybrid halide perovskites have been in the spotlight as a potential solar cell absorber for over a decade. Recently, more attention has been paid to the low- and multi-dimensional counterparts due to their better stability and despite sacrificing some performance. Interestingly, functionalization, such as fluorination, of the organic cations showed significant improvement, ascribed to better crystallinity and/or more ordered structure along with the enhanced charge separation. However, the physical phenomena that may cause the improved performance are still underinvestigated. Intermolecular interactions and their relation to the ordering conditions and optical properties are of particular interest. In this work, three two-dimensional phenylethylammonium perovskite samples – non-fluorinated, mono-, and penta-fluorinated derivatives – were compared. We applied Raman spectroscopy under variable temperature to observe the evolution of the vibrational modes. Particular Raman modes – these related to the N-H bonds and the benzene ring – underwent significant changes, caused by the hydrogen bond and π-π interactions strengthening and the structure ordering. Single fluorine substituted sample appeared to be the most ordered at room temperature, while the penta-fluorinated one was the most disordered. The correlation of the disordering conditions with the optical properties was also discussed.

T7: Quantum Science 2

Time: Thursday 30 Sept, 2:00pm; Venue: Sky Ballrom III; Chair: TBD
Time allocated for invited talks is 20 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T7.106 (INVITED) Evidence of many-body localization in 2D from quantum Monte Carlo simulation

Nyayabanta Swain*, Ho Kin Tang, Darryl C. W. Foo, Brian J. J. Khor, Gabriel Lemarie, Fakher F. Assaad, Shaffique Adam, Pinaki Sengupta (National University of Singapore)
2:00pm – 02:20pm

We use the stochastic series expansion quantum Monte Carlo method, together with the eigenstate-to-Hamiltonian mapping approach, to map the localized ground states of the disordered two-dimensional Heisenberg model to excited states of a target Hamiltonian. The localized nature of the ground state is established by studying the spin stiffness, local entanglement entropy, and local magnetization. This construction allows us to define many body localized states in an energy resolved phase diagram thereby providing concrete numerical evidence for the existence of a many-body localized phase in two dimensions.

T7.89 Achieving fault tolerance against amplitude-damping noise

Akshaya Jayashankar*, My Duy Hoang Long*, Hui Khoon Ng*, Prabha Mandayam* (Department of Physics, Indian Institute of Technology Madras, Chennai, India)
02:20pm – 02:35pm

With the intense interest in small, noisy quantum computing devices comes the push for larger, more accurate–and hence more useful–quantum computers. While fully fault-tolerant quantum computers are, in principle, capable of achieving arbitrarily accurate calculations using devices subjected to general noise, they require immense resources far beyond our current reach. An intermediate step would be to construct quantum computers of limited accuracy enhanced by lower-level, and hence lower-cost, noise-removal techniques. This is the motivation for our work, which looks into fault-tolerant encoded quantum computation targeted at the dominant noise aicting the quantum device. Specifically, we develop a protocol for fault-tolerant encoded quantum computing components in the presence of amplitude-damping noise, using a 4-qubit code and a recovery procedure tailored to such noise. We describe a universal set of fault-tolerant encoded gadgets and compute the pseudothreshold for the noise, below which our scheme leads to more accurate computation. Our work demonstrates the possibility of applying the ideas of quantum fault tolerance to targeted noise models, generalizing the recent pursuit of biased-noise fault tolerance beyond the usual Pauli noise models. We also illustrate how certain aspects of the standard fault tolerance intuition, largely acquired through Pauli-noise considerations, can fail in the face of more general noise.

T7.51 Superpolynomial Quantum Enhancement in Polaritonic Neuromorphic Computing

Huawen Xu*, Tanjung Krisnanda, Wouter Verstraelen, Timothy Chi Hin Liew*, Sanjib Ghosh* (Nanyang Technological University)
02:35pm – 02:50pm

Recent proof-of-principle experiments have demonstrated the implementation of neuromorphic computing using exciton-polaritons, making use of coherent classical states [D. Ballarini et al., Nano Lett. 20, 3506 (2020)]. At the same time, it is expected that nonlinear exciton-polaritons can reach a quantum regime forming non-classical states. Here we consider theoretically the quantum nature of exciton polaritons and predict a superpolynomial quantum enhancement in image recognition tasks. This is achieved within experimentally accessible parameters.

T7.35 From ETH to algebraic relaxation of OTOCs in systems with conserved quantities

Vinitha Balachandran*, Giuliano Benenti*, Dario Poletti* (Singapore University of Technology and Design)
02:50pm – 03:05pm

The relaxation of out-of-time-ordered correlators (OTOCs) has been studied as a mean to characterize the scrambling properties of a quantum system. We show that the presence of local conserved quantities typically results in, at the fastest, an algebraic relaxation of the OTOC provided (i) the dynamics is local and (ii) the system follows the eigenstate thermalization hypothesis. Our result relies on the algebraic scaling of the infinite-time value of OTOCs with system size, which is typical in thermalizing systems with local conserved quantities, and on the existence of finite speed of propagation of correlations for finite-range-interaction systems. We show that time-independence of the Hamiltonian is not necessary as the above conditions (i) and (ii) can occur in time-dependent systems, both periodic or aperiodic. We also remark that our result can be extended to systems with power-law interactions.

T7.43 Optimal probes for global quantum thermometry

Wai Keong Mok*, Kishor Bharti, Leong Chuan Kwek, Abolfazl Bayat (National University of Singapore)
03:05pm – 03:20pm

Quantum thermodynamics has emerged as a separate sub-discipline, revising the concepts and laws of thermodynamics, at the quantum scale. In particular, there has been a disruptive shift in the way thermometry, and thermometers are perceived and designed. Currently, we face two major challenges in quantum thermometry. First, all of the existing optimally precise temperature probes are local, meaning their operation is optimal only for a narrow range of temperatures. Second, aforesaid optimal local probes mandate complex energy spectrum with immense degeneracy, rendering them impractical. Here, we address these challenges by formalizing the notion of global thermometry leading to the development of optimal tem- perature sensors over a wide range of temperatures. We observe the emergence of different phases for such optimal probes as the temperature interval is increased. In addition, we show how the best approximation of optimal global probes can be realized in spin chains, implementable in ion traps and quantum dots.

T7.102 Prethermalization and wave condensation in a nonlinear disordered Floquet system

Prosenjit Haldar, Sen Mu*, Bertrand Georgeot, Jiangbin Gong*, Christian Miniatura, Gabriel Lemarié* (Centre for Quantum Technologies, National University of Singapore)
03:20pm – 03:35pm

Periodically-driven quantum systems make it possible to reach stationary states with new emerging properties. However, this process is notoriously difficult in the presence of interactions because continuous energy exchanges generally boil the system to an infinite temperature featureless state. Here, we describe how to reach nontrivial states in a periodically-kicked Gross-Pitaevskii disordered system. One ingredient is crucial: both disorder and kick strengths should be weak enough to induce sufficiently narrow and well-separated Floquet bands. In this case, inter-band heating processes are strongly suppressed, and the system can reach an exponentially long-lived prethermal plateau described by the Rayleigh-Jeans distribution. Saliently, the system can even undergo a condensation process when its initial state has a sufficiently low total quasi-energy. These predictions could be tested in nonlinear optical experiments or with ultracold atoms.

T8: Quantum Engineering 2

Time: Thursday 30 Sept, 2:00pm; Venue: Grand Ballroom; Chair: TBD
Time allocated for invited talks is 20 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T8.46 (INVITED) Device-independent quantum key distribution with random key basis

Rene Schwonnek, Koon Tong Goh*, Ignatius William Primaatmaja, Ernest Ying Zhe Tan, Ramona Wolf, Valerio Scarani, Charles Ci Wen Lim* (National University of Singapore)
2:00pm – 02:20pm

Device-independent quantum key distribution (DIQKD) is the art of using untrusted devices to distribute secret keys in an insecure network. It thus represents the ultimate form of cryptography, offering not only information-theoretic security against channel attacks, but also against attacks exploiting implementation loopholes. In recent years, much progress has been made towards realising the first DIQKD experiments, but current proposals are just out of reach of today's loophole-free Bell experiments. Here, we significantly narrow the gap between the theory and practice of DIQKD with a simple variant of the original protocol based on the celebrated Clauser-Horne-Shimony-Holt (CHSH) Bell inequality. By using two randomly chosen key generating bases instead of one, we show that our protocol significantly improves over the original DIQKD protocol, enabling positive keys in the high noise regime for the first time. We also compute the finite-key security of the protocol for general attacks, showing that approximately $10^8 - 10^{10}$ measurement rounds are needed to achieve positive rates using state-of-the-art experimental parameters. Our proposed DIQKD protocol thus represents a highly promising path towards the first realisation of DIQKD in practice.

T8.76 (INVITED) A Practical Countermeasure against the Detector-Blinding Attack in Quantum Key Distribution

Lijiong Shen*, Christian Kurtsiefer (Centre for Quantum Technologies, NUS)
02:20pm – 02:40pm

In practical systems of quantum key distribution (QKD), the imperfection of physical devices opens security loopholes, which an eavesdropper would exploit. Single photon detectors are devices in the QKD system to measure the photons carrying quantum information. However, various single photon detectors have been reported controllable by a combination of bright continuous-wave illumination and optical pulses. Typically, this detector control scheme is called the detector-blinding attack, which has been successfully implemented on serval QKD systems and raises widespread concerns.

This work proposes a counter-measure against the detector-blinding attack by weakly coupling a light emitter to the single photon detector. Single photon detectors exposed to bright continuous-wave illumination are unable to count single photons. The legitimate receiver randomly switches on the lighter emitter at timings not predictable by the eavesdropper. By counting the excess photon-detection events created by the light emitter or ”fake state” events when the lighter emitter locally blinds the detector, it is not hard to detect the existence of the detector-blinding attack.

We experimentally demonstrated this counter-measure on a InGaAs-APD. The measurement result shows that our method could identify the detector-blinding attack efficiently in time, consequently, has a low impact on reducing detection signal photons carrying quantum information. In addition, the low cost and retrofittable to the existing QKD systems features made our counter-measure possibly the most practical one among all the existing techniques.

T8.127 RaspiQRNG: A do-it-yourself Quantum Random Number Generation on a Raspberry Pi

Jing Yan Haw*, Raymond Ho, Cassey Crystania Liang, Hong Jie Ng, Beverley Shi-Wyn Goh, Kenny Yuan Hao Kok, Joshua Wei-Ern Yong, Ding Chao Wong, Chao Wang, Charles Ci Wen Lim (Department of Electrical and Computer Engineering, National University of Singapore)
02:40pm – 02:55pm

Random numbers are indispensable resources in secure communication technologies. Quantum random number generators (QRNGs) are attractive solutions because quantum physics exhibit fundamentally probabilistic behaviour that cannot be predicted. However, from an end user's perspective, it is not a trivial task to verify the entropy origin of a QRNG. For instance, a fully device-independent QRNG, while guaranteeing certifiable private random numbers, requires a technically challenging loophole-free Bell test. For a device-dependent scenario, such as a commercial QRNG, the end-user will have to trust the manufacturer specification on the randomness generation processes. Here, we address this issue by proposing a simple, do-it-yourself approach in constructing a complete QRNG, providing transparency to the user to validate the entropy flow of the device. Our method involves only an LED as the entropy source, captured by a mobile-device grade camera with a customizable Python library. With a low-cost single-board computer Raspberry Pi, quantum entropy can be estimated and extracted on demand. A setup prototype, involving only very few optical elements, was developed from a final year Design Capstone project, which has achieved a real-time random bit generation rate of 0.4Mbit/s. Our results show appealing prospects as an affordable, user-oriented and open-source alternative to a QRNG system.

T8.26 Integrated avalanche photodetectors for visible light

Victor Xu Heng Leong*, Salih Yanikgonul, Shawn Yohanes Siew, Ching Eng Png, Leonid Krivitsky (Institute of Materials Research and Engineering, A*STAR)
02:55pm – 03:10pm

Integrated photodetectors are essential components of scalable photonics platforms for quantum and classical applications. However, most efforts in the development of such devices to date have been focused on infrared telecommunications wavelengths. Here, we report the first monolithically integrated avalanche photodetector (APD) for visible light. Our devices are based on a doped silicon rib waveguide with a novel end-fire input coupling to a silicon nitride waveguide. We demonstrate a high gain-bandwidth product of 234 ± 25 GHz at 20 V reverse bias measured for 685 nm input light, with a low dark current of 0.12 μA. We also observe open eye diagrams at up to 56 Gbps. This performance is very competitive when benchmarked against other integrated APDs operating in the infrared range. With CMOS-compatible fabrication and integrability with silicon photonic platforms, our devices are attractive for sensing, imaging, communications, and quantum applications at visible wavelengths

T8.31 Modelling and experimental simulation of satellite-based Quantum Key Distribution

Ali Anwar*, Srihari Sivasankaran, Chithrabhanu Perumangatt, Alexander Ling* (Centre for Quantum Technologies)

03:10pm – 03:25pm

Nano-satellites such as SpooQy-1, are capable of hosting entangled photon pair sources and operating successfully in space. Can the same sized satellites be used to distribute entangled photons from space to ground? In this contribution, we will share the experimental results of end-to-end testing for a satellite QKD system based on distributing entangled photons. These results are used to validate a mathematical model for satellite-to-ground QKD performance, that takes into account also the finite statistics of any actual satellite-to-ground link. We will also provide a status update on the progress in assembling the QKD system, and results from environmental testing.

T9: Photonics

Time: Thursday 30 Sept, 4:00pm; Venue: Sky Ballrom I; Chair: TBD
Time allocated for invited talks is 20 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T9.119 (INVITED) Amplified THz spin current from second-generation excitation in ferromagnet/heavy metal heterostructure

Piyush Agarwal, Yingshu Yang, Rohit Medwal, Hironori Asada, Yasuhiro Fukuma, Marco Battiato, Ranjan Singh* (NTU Singapore)
4:00pm – 04:20pm

Ferromagnet/heavy metal spintronic heterostructures have revolutionized the field of terahertz emission by providing the most efficient route of high bandwidth emission. However, since its discovery, the fundamental studies have so far been concentrating on the spin-excitation only from the photo-excited ferromagnetic layer. In contrast, the simultaneous unpolarized spin-excitation in the adjacent heavy metal layer provides an equally significant contribution. Here, by investigating the consequent terahertz emission property, we demonstrate that heavy metal provides a second-generation spin excitation source to the ferromagnetic layer. Moreover, the heterostructures with a higher thickness of the heavy metal even exceed the spin contribution from first-generation photo-excitation of the ferromagnet layer alone. The analytical model is developed to provide microscopic evidence of the convoluted process and underlines the generalized spin-transport mechanism. Such understanding of ultrafast physics is crucial for an augmented impact in modern terahertz generation and futuristic data-processing at an ultrafast timescale.

T9.107 Nonlinear Parametric Scattering of Exciton Polaritons in Perovskite Microcavities

Jinqi Wu, Sanjib Ghosh, Rui Su*, Antonio Fieramosca, Timothy C.H. Liew*, Qihua Xiong* (State Key Laboratory of Low-Dimensional Quantum Physics and Department of Physics, Tsinghua University)
04:20pm – 04:35pm

Comparing with pure photons, higher nonlinearity in polariton systems has been exploited in various proof-of-principle demonstrations of efficient optical devices based on the parametric scattering effect. However, most of them demand cryogenic temperatures limited by the small exciton binding energy of traditional semiconductors or exhibit weak nonlinearity resulting from Frenkel excitons. Lead halide perovskites, possessing both a large binding energy and a strong polariton interaction, emerge as ideal platforms to explore nonlinear polariton physics toward room temperature operation. Here, we report the first observation of nonlinear parametric scattering in a lead halide perovskite microcavity with multiple polariton branches at room temperature. Driven by the scattering source from condensation in one polariton branch, correlated polariton pairs are obtained at high k states in an adjacent branch. Our results strongly advocate the ability to reach the nonlinear regime essential for perovskite polaritonics working at room temperature.

T9.38 Broadband infrared spectroscopy based on quantum interferometry

Anna Paterova*, Zi Siang Desmond Toa, Hongzhi Yang, Leonid Krivitsky (Institute of Materials Research and Engineering A*STAR)
04:35pm – 04:50pm

Infrared (IR) spectroscopy is an important tool for material characterization, sensing and biomedical applications. One of the promising approaches to the IR spectroscopy is a method based on induced coherence phenomenon [1-3], which allows inferring the properties of a specimen at detection challenging IR range from the detection of visible light. IR spectroscopy with the detection of visible light was demonstrated in earlier works [3-6]. However, the short optical path of the IR light through the medium under study limited the sensitivity of those schemes.

Here, we introduce a new configuration of a nonlinear interferometry scheme for a broadband IR spectroscopy, where the optical path of the IR light through the medium is extended up to one order of magnitude comparing with the previous works. To do so we introduce the parabolic mirror into the nonlinear interferometer setup, which allows compensating for the transverse phases acquired by SPDC light generated at the forward pass of the pump beam through the nonlinear crystal. Therefore, the interference pattern is observed across the whole broadband frequency-angular spectrum of the SPDC light.

References [1] X. Y. Zou et al, “Induced coherence and indistinguishability in optical interference,” Phys. Rev. Lett. 67, 318–321 (1991). [2] G. B. Lemos et al, “Quantum imaging with undetected photons,” Nature 512, 409-412 (2014). [3] D. A. Kalashnikov et al, “Infrared spectroscopy with visible light,” Nat. Photonics 10, 98-101 (2016). [4] A. V. Paterova et al, “Nonlinear infrared spectroscopy free from spectral selection,” Sci. Rep. 7, 42608 (2017). [5] A. V. Paterova, L. A. Krivitsky, “Nonlinear interference in crystal superlattices,” Light Sci. Appl. 9, 82 (2020). [6] C. Lindner et al, “Nonlinear interferometer for Fourier-transform mid-infrared gas spectroscopy using near-infrared detection”, Opt. Exp. 29(3), (2021)

T9.24 Coupling Light to Higher Order Transverse Modes of a Near-Concentric Optical Cavity

Adrian Nugraha Utama, Chang Hoong Chow*, Chi Huan Nguyen, Christian Kurtsiefer (CQT)
04:50pm – 05:05pm

In the near-concentric regime, the transverse modes of an optical cavity have small mode volumes with a beam waist on the order of the atomic cross section. This shows potential for strong interaction between single atoms and light, which is a key component in distributed quantum computing architectures [1]. Furthermore, with centimetre-sized near-concentric cavities, the frequency spacing of the transverse modes ranges from tens of MHz to a GHz, matching well with the hyperfine or the Zeeman level splitting of an atom [2]. This near-degeneracy in resonant frequencies close to the critical point allows to explore the physics of atomic nonlinearities with multiple photonic modes strongly coupled to different hyperfine or magnetic energy levels of a quantum emitter.

In this work, we excite selectively the tightly focused higher order transverse modes of a near-concentric cavity by shaping the spatial profile of the incoming Gaussian beam [3]. A liquid-crystal spatial light modulator (SLM) is used to perform mode conversion by modulating the spatial phase profile. We investigate the conversion efficiency with our mode-matching procedure using a phase-SLM to excite a specific mode and a superposition of transverse modes. Despite the imperfections in the cavity alignment, the generation of a superposition of cavity modes has been shown with a high fidelity. Moreover, we show that a near-concentric cavity can support several transverse modes up to critical distances of a few μm.

[1] H. J. Kimble, Phys. Scr. 1998, 127 (1998) [2] C. H. Nguyen, A. N. Utama, N. Lewty, and C. Kurtsiefer, Phys. Rev. A 98, 063833 (2018) [3] A. N. Utama, C. H. Chow, C. H. Nguyen, and C. Kurtsiefer, Opt. Express 29, 8130-8141 (2021)

T9.15 Triply-degenerate point in three-dimensional spinless systems

Xiaolong Feng* (Singapore University of Technology and Design)
05:05pm – 05:20pm

We study the possibility of triply-degenerate points (TPs) that can be stabilized in spinless crystalline systems. Based on an exhaustive search over all 230 space groups, we find that the spinless TPs can exist at both high-symmetry points and high-symmetry paths, and they may have either linear or quadratic dispersions. For TPs located at high-symmetry points, they all share a common minimal set of symmetries, which is the point group T. The TP protected solely by the T group is chiral and has a Chern number of ± 2. By incorporating additional symmetries, this TP can evolve into chiral pseudospin-1 point, linear TP without chirality, or quadratic contact TP. For accidental TPs residing on a high-symmetry path, they are not chiral but can have either linear or quadratic dispersions in the plane normal to the path. We further construct effective $k \cdot p$ models and minimal lattice models for characterizing these TPs. Distinguished phenomena for the chiral TPs are discussed, including the extensive surface Fermi arcs and the chiral Landau bands.

T10: Materials 3

Time: Thursday 30 Sept, 4:00pm; Venue: Sky Ballrom II; Chair: TBD
Time allocated for invited talks is 20 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T10.10 (INVITED) Giant magnetoimpedance: From Mn-perovskites to organic molecules

Ramanathan Mahendiran* (National University of Singapore)
4:00pm – 04:20pm

Colossal magnetoresistance (CMR) discovered nearly three decades ago in Mn-perovskites (hole-doped $LaMnO_3$) triggered a flurry of activity in search of similar phenomenon in other oxides. However, majority of available reports deal with the magnetoresistance measured using a direct current or low-frequency current (f $<$ 1 kHz). While ac impedance in the frequency range 100 Hz to a few MHz range is often used to study dielectric relaxation and magnetocapacitance effect in insulating oxides, ac impedance in metallic oxides is seldom reported. Recent experimental work on the ac magnetoimpedance in the frequency range from 1 kHz to 3 GHz done in our lab has revealed many exciting phenomena: colossal magnetoresistance at low fields (40-90 % for H $\leq$ 1 kOe at room temperature), a transition from negative to positive magnetoresistance, and more excitingly current-driven electron spin resonance/ferromagnetic resonance. Our technique has a potential to probe spin dynamics in other magnetic systems. I will present results derived from hole-doped $RMnO_3$, double perovskites(Sr_2FeMoO_6, La_2NiMnO_6), insulating garnets (YIG) and in a paramagnetic DPPH molecule[1-3]. At the end, I will give an overview of the related methods explored for spintronic devices, and discuss current challenges.

References: 1. A. Chanda, U. Chaudhuri, and R. Mahendiran, Broadband magnetoresistance in La0.6Sr0.4Mn1-xGaxO3, J. App. Phys. 126, 083905 (2019) 2. R. Das, U. Chaudhuri, and R. Mahendiran, Microwave magnetotransport and microwave absorption in Sr_2FeMoO_6, ACS Applied Electronic Materials, in press (2021) https://doi.org/10.1021/acsaelm.1c00304 3. Y.H. Lee and R. Mahendiran, Electrically detected spin resonance in a DPPH molecule, J. Phys. Chem. C (in revision)

T10.53 Room Temperature Light-Mediated Long-Range Coupling of Excitons in Perovskites

Tanjung Krisnanda*, Qiannan Zhang, Kevin Dini, David Giovanni, Timothy Liew*, Tze Chien Sum* (Nanyang Technological University)
04:20pm – 04:35pm

Perovskites have been the focus of attention due to their multitude of outstanding optoelectronic properties and structural versatility. 2D halide perovskites such as $(C_6H_5C_2H_4NH_3)_2PbI_4$, or simply PEPI, form natural multiple quantum wells with enhanced light–matter interactions, making them attractive systems for further investigation. This work reports tunable splitting of exciton modes in PEPI resulting from strong light–matter interactions, manifested as multiple dips (modes) in the reflection spectra. While the origin of the redder mode is well understood, that for the bluer dip at room temperature is still lacking. Here, it is revealed that the presence of the multiple modes originates from an indirect coupling between excitons in different quantum wells. The long-range characteristic of the mediated coupling between excitons in distant quantum wells is also demonstrated in a structure design along with its tunability. Moreover, a device architecture involving an end silver layer enhances the two excitonic modes and provides further tunability. Importantly, this work will motivate the possibility of coupling of the excitonic modes with a confined light mode in a microcavity to produce multiple exciton-polariton modes.

T10.59 Quantum Engineering of 2D Semiconductors

Chit Siong Aaron Lau*, Kuan Eng Johnson Goh* (Institute of Materials Research and Engineering)

04:35pm – 04:50pm

2D transition metal dichalcogenides (TMDCs) have potential for quantum applications but progress has hindered by challenges to contact and dielectric engineering, especially at necessary cryogenic temperatures for quantum transport studies. Almost all reported works on 2D semiconductor-based quantum devices have relied on mechanical exfoliated materials that result in high quality flakes but have limited scalability due to the stochastic nature of exfoliation.

I will discuss our group's efforts in the use of indium alloy contacts to form high-quality contacts with scalable chemical vapour deposition (CVD) grown single- and bi-layer WS_2 devices, where we measure ultra-low contact resistances and Schottky barrier heights that persist down to 3 K. This allows for insights into the nature of the metal/semiconductor interface and quantum transport in the 2D semiconductor. Next, I will discuss our recent work on understanding dielectric influence on low-temperature carrier transport, where we isolated the influence of HfO_2 dielectric on 2D WS_2. We show that low-temperature carrier mobility is not charge impurity limited as previously thought, but instead due to another commonly overlook factor, interface roughness. We further demonstrate the first electrostatic gate defined quantum confinement with all-scalable approaches of CVD grown WS_2 and atomic layer deposition grown HfO_2.

Understanding low-temperature transport mechanisms is key to the design of increasingly complex 2D semiconductor-based quantum devices. Our demonstration of a gated quantum device using all scalable approaches is a significant breakthrough towards the use of 2D semiconductors for quantum information processing applications, which hitherto had only been realized with labour intensive exfoliation techniques that are limited to random micron-sized crystal flakes of variable thicknesses.

T10.109 Stability of a rolled-up conformation state for two-dimensional materials

Maxim Trushin*, Antonio H. Castro Neto (Centre for Advanced 2D Materials, NUS)

04:50pm – 05:05pm

When thin microscopic solid flakes are dispersed in an aqueous solution and subjected to sonication, a phase transition between flat and rolled-up conformation states may occur. The process is experimentally studied for functionalized graphene in our very recent paper [1]. Despite the rolling-up process is a promising pathway for the streamline production of nanostructures, there is no universal model able to predict stability of the rolled-up conformation state just out of the material parameters regardless the flakes' sizes. Here, we offer an elegant solution of the scroll stability problem, mapping all relevant interactions onto the Archimedean spiral — the most natural shape for any rolled-up elastic band (see a balance spring in watches). We find that the binding energy of scrolls (the energy needed to unroll the structure) does not depend on their size and is solely determined by the bending stiffness and interlayer adhesion. The model is therefore easy to scale from tens of nm to tens of microns, making it applicable to a broad range of materials. We study stability of such scrolls in aqueous solutions and offer several phase diagrams in terms of the ion concentration, zeta-potential, and material parameters to give a cue to experimenters at which external conditions the nanoscrolls are expected [2]. The model is also able to describe a more conventional way to increase stability of scrolls by entwining several scrolls at once, hence, forming a fiber [3].

[1] Mariana C. F. Costa et al., Advanced Materials 33, 2100442 (2021). [2] Maxim Trushin and A. H. Castro Neto, arXiv:2108.11910. [3] Valeria S. Marangoni et al., Materials Today Chemistry 21, 100542 (2021).

T10.98 Kondo effect below superconducting temperature in Co doped $NbSe_2$

Shangjian Jin* (Department of Physics, National University of Singapore)
05:05pm – 05:20pm

We study the transport behavior of Co doped $NbSe_2$ system at low temperature. Compared with undoped bulk $NbSe_2$, the superconducting transition temperature of Co-$NbSe_2$ is slightly suppressed. Surprisingly, superconductivity is destroyed at lower temperature. We attribute this to the Kondo effect with $T_K < T_c$. By combining a Kondo's model with the Aslamazov-Larkin formula, we fit the temperature and magnetic field dependence of resistivity successfully. A periodic Anderson model is then established to undersand the lower Kondo temprature TK and the magnetic filed dependence of critical SC temperature Tc. Moreover, the bulk Co-$NbSe_2$ shows an interesting BKT transition and magnetic spin-1 excitations in STM results. We are going to investigate these significant phenomena and undersand how topology palys a role in this system.

T10.85 The study of the growth of phosphorus on Ag(111) by molecular beam epitaxy

Yihe Wang, Shuo Sun, Wei Chen* (National University of Singapore)
05:20pm – 05:35pm

Phosphorene, which is known as black phosphorus (BP), possesses many extraordinary properties, such as high charge mobility and on/off ratio, and thickness-dependent direct bandgap from 0.3 eV to 2 eV. Recently, blue phosphorus (Blue P) with unique effects like fluorination-induced quantum spin Hall insulators synthesized by molecular beam epitaxy (MBE) fulfills the family of two-dimension (2D) phosphorene. BlueP has been synthesized on Au(111) with Si intercalation by MBE, which gives great hope for the preparation of new two-dimensional phosphorus. And Ag is considered as one of the most suitable substrates for the synthesis of BlueP in theory. However, the growth of phosphorus on Ag(111) is highly controversial. Different results would be obtained by the same conditions in the previous investigations. In this study, we explore the growth of phosphorus on Ag(111), which reveals the details of the formation of 2D phosphorus and the transition of different phases. The clear growth process of phosphorus can further promote the development for the synthesis of large-scale and high-quality 2D phosphorus.

T11: Quantum Science 3

Time: Thursday 30 Sept, 4:00pm; Venue: Sky Ballrom III; Chair: TBD
Time allocated for invited talks is 20 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T11.40 (INVITED) Bayesian Retrodiction Approach to Fluctuation Relations

Clive Aw*, Francesco Buscemi*, Valerio Scarani* (National University of Singapore)
4:00pm – 04:20pm

Irreversibility is usually captured by a comparison between the process that happens and a corresponding ”reverse process”. This comparison has been extensively studied through fluctuation relations. Here we revisit fluctuation relations from the standpoint, suggested decades ago by Watanabe, that the comparison should involve the prediction and the retrodiction on the unique process, rather than two processes. This approach recovers fluctuation relations like Jarzynski and Crooks for classical processes, and Tasaki and its generalisations for quantum processes. In fact, we conjecture that all known fluctuation relations can be recovered from a retrodictive narrative. The new perspective is also fruitful: bringing to the fore the connection between fluctuation relations and statistical divergences and clarifying that traditional assumptions on detailed physical mechanisms can be seen as the choice of a reference prior.

T11.34 Absolutely entangled sets of pure states for bipartitions and multipartitions

Baichu Yu*, Pooja Jayachandran, Adam Burchardt, Yu Cai, Nicolas Brunner, Valerio Scarani* (Center for Quantum Technology, Singapore)
04:20pm – 04:35pm

The notion of entanglement of quantum states is usually defined with respect to a fixed partition. Indeed, a global basis change can always map an entangled state to a separable one. The situation is however different when considering a set of states. A set of quantum states is said to be absolutely entangled, when at least one state in the set remains entangled for any definition of subsystems, i.e. for any choice of the global reference frame. In this work we investigate the properties of absolutey entangled sets (AES) of pure quantum states. For the case of a two-qubit system, we present a sufficient condition to detect an AES, and use it to construct families of N states such that N-3 (the maximal possible number) remain entangled for any definition of subsystems. For a general bipartition $d = d_1 d_2$, we prove that sets of $N > [(d_1+1)(d_2+1)/2]$ states are AES with Haar measure 1. Then, we define AES for multipartitions. We derive a general lower bound on the number of states in an AES for a given multipartition, and also construct explicit examples. In particular, we exhibit an AES with respect to any possible multipartitioning of the total system.

T11.2 Two-qubit sweet spots for capacitively coupled exchange-only spin qubits

Teck Seng Koh*, Mengke Feng, Lin Htoo Zaw (Nanyang Technological University)
04:35pm – 04:50pm

The implementation of high fidelity two-qubit gates is a bottleneck in the progress towards universal quantum computation in semiconductor quantum dot qubits. We study capacitive coupling between two triple quantum dot spin qubits encoded in the S=1/2, Sz=$-1/2$ decoherence-free subspace – the exchange-only (EO) spin qubits. We report exact gate sequences for CPHASE and CNOT gates, and demonstrate theoretically, the existence of multiple two-qubit sweet spots (2QSS) in the parameter space of capacitively coupled EO qubits. Gate operations have the advantage of being all-electrical, but charge noise that couple to electrical parameters of the qubits cause decoherence. Assuming noise with a 1/f spectrum, two-qubit gate fidelities and times are calculated, which provide useful information on the noise threshold necessary for fault-tolerance. We study two-qubit gates at single and multiple parameter 2QSS. In particular, for two existing EO implementations – the resonant exchange (RX) and the always-on exchange-only (AEON) qubits – we compare two-qubit gate fidelities and times at positions in parameter space where the 2QSS are simultaneously single-qubit sweet spots (1QSS) for the RX and AEON. These results provide a potential route to the realization of high fidelity quantum computation.

T11.104 A stabilisation mechanism for many-body localisation in 2D

Darryl Foo*, Nyayabanta Swain, Gabriel Lemarie, Pinaki Sengupta, Shaffique Adam (CA2DM)

04:50pm – 05:05pm

We demonstrate that the assumption of exponentially localized single particle wavefunctions in disordered systems may be broken by simple application of an external confining potential, relevant for real experiments, and the resulting super-exponential (Gaussian) decay therefore challenges the conclusion that thermal avalanches always destroy MBL in $D > 1$. Furthermore, the receding of the mobility edge on strengthening of the confining potential is demonstrated. We therefore argue that the presence of such confining potentials in experimental studies, that till now have been ignored in theoretical considerations, bridges the divide between demonstrations of MBL in these systems and theoretical arguments that till now have claimed such demonstrations could not be conclusive.

T11.116 NISQ Algorithm for Semidefinite Programming

Kishor Bharti*, Tobias Haug, Vlatko Vedral, Leong-Chuan Kwek (CQT)
05:05pm – 05:20pm

Semidefinite Programming (SDP) is a class of convex optimization programs with vast applications in control theory, quantum information, combinatorial optimization and operational research. Noisy intermediate-scale quantum (NISQ) algorithms aim to make an efficient use of the current generation of quantum hardware. However, optimizing variational quantum algorithms is a challenge as it is an NP-hard problem that in general requires an exponential time to solve and can contain many far from optimal local minima. Here, we present a current term NISQ algorithm for SDP. The classical optimization program of our NISQ solver is another SDP over a smaller dimensional ansatz space. We harness the SDP based formulation of the Hamiltonian ground state problem to design a NISQ eigensolver. Unlike variational quantum eigensolvers, the classical optimization program of our eigensolver is convex, can be solved in polynomial time with the number of ansatz parameters and every local minimum is a global minimum. Further, we demonstrate the potential of our NISQ SDP solver by finding the largest eigenvalue of up to 2^{1000} dimensional matrices and solving graph problems related to quantum contextuality. We also discuss NISQ algorithms for rank constrained SDPs. Our work extends the application of NISQ computers onto one of the most successful algorithmic frameworks of the past few decades

T11.84 Quantum Dynamical Simulation of a Transversal Stern-Gerlach Interferometer

Mikolaj Paraniak*, Berge Englert* (CQT)
05:20pm – 05:35pm

Originally conceived as a thought experiment, an apparatus consisting of two Stern-Gerlach apparatuses joined in an inverted manner touched on the fundamental question of the reversibility of evolution in quantum mechanics. Theoretical analysis showed that uniting the two partial beams requires an extreme level of experimental control, making the proposal in its original form unrealizable in practice. In this work, we revisit the above question in a numerical study concerning the possibility of partial-beam recombination in a spin-coherent manner. Using the Suzuki-Trotter numerical method of wave propagation and a configurable, approximation-free magnetic field, a simulation of a transversal Stern-Gerlach interferometer under ideal conditions is performed. The result confirms what has long been hinted at by theoretical analyses: the transversal Stern-Gerlach interferometer quantum dynamics is fundamentally irreversible even when perfect control of the associated magnetic fields and beams is assumed.

T12: Quantum Engineering 3

Time: Thursday 30 Sept, 2:00pm; Venue: Grand Ballroom; Chair: TBD
Time allocated for invited talks is 20 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T12.56 (INVITED) Quantum engineering with composite laser-pulses: new trends from optical clocks to matter-wave interferometry

Thomas Zanon* (Sorbonne University)
2:00pm – 02:20pm

More than 70 years ago, In 1949, N. Ramsey had proposed a new method for probing atomic systems with separated oscillating fields. Such a technique has leading to a quantum revolution in modern time and frequency metrology using microwaves. In the 1980s, by labeling internal states with momentum quantization, C.J. Bordé has extended the Ramsey spectroscopy from microwave to optical transitions realizing laser beam splitters and mirrors for quantum sensors based on atomic matter-wave manipulation.

During the talk, I will present composite laser-pulses spectroscopy, developed in the time-domain for hyper-clocks, to spatial-domain atomic interferometry. Various laser-pulse sequences will be discussed such as Hyper-Ramsey (HR), Generalized Hyper-Ramsey (GHR) and hyper Hahn-Ramsey (GHHR) protocols also with hybrid schemes as generalized auto-balanced Ramsey spectroscopy (GABRS). Some of these techniques have been already demonstrated with a single optical 171+Yb ion clock at PTB to provide excellent protection at the 10^{-18} level of relative accuracy against probe induced light-shift perturbations coupled to laser intensity variation. We will also present specific protocols based on "magic" $\pi/4$ and $3\pi/4$ phase-steps that are eliminating imperfect correction of probe-induced frequency-shifts even in presence of dissipative processes such as decoherence.

Advancing atomic and molecular coherent matter-wave manipulation with the latest composite pulse techniques would bring quantum sensors to robust real-world application from portable optical clocks to mobile gravimeters as well as boosting performances of actual devices with a minimal experimental effort.

Reference: [1] T. Zanon-Willette, R. Lefevre, R. Metzdor, N. Sillitoe, S. Almonacil, M. Minissale, E. de Clercq, A.V. Taichenachev, V. I. Yudin and E. Arimondo, Composite laser-pulses spectroscopy for high-accuracy optical clocks: a review of recent progress and perspectives. Rep. Prog. Physics (2018). https://doi.org/10.1088/1361-6633/aac9e9 [2] T. Zanon-Willette, D. Wilchowski, A.V. Taichenachev and V.I. Yudin. arXiv:2012.03877v5 [physics.atom-ph] (2020).

T12.63 Resonant radio-frequency loss of ion trap chip as a function of temperature

Ranjita C Sapam*, Anirudh Ajith, Jasper Phua Sing Cheng, Xu Baochang, Joven Kwek, Manas Mukherjee (CQT, NUS)
02:20pm – 02:35pm

Micro-fabricated chip technology for trapped ion is advancing in various aspect like performance, robustness and versatility. Remarkable progress along this enable demonstration of prototype chip functionality in quantum metrology, communications, quantum information science and fundamental studies of quantum dynamics. Design of such traps architectures and methodology is completely driven by the research aims and universally desirable properties for the advancement of quantum technology, which lead to the development of chip foundries. Here, we present a study of loss characteristics at resonant radio-frequency ($\approx 17\,\mathrm{MHz}$) of our currently in-house develop chip as a function of temperature, particularly suited for quantum simulations and dynamics of multi-ions.

T12.90 A Transportable High-Precision Absolute Atomic Gravimeter

Fong En Oon*, Rainer Dumke* (Nanyang Technological University)
02:35pm – 02:50pm

Gravimeters based on atom interferometry offer high stability in measuring local gravitational acceleration by referencing the acceleration of free-falling atomic test masses with the frequency standard. Atomic gravimeters are promising in realizing reference-free inertial navigation system, mobile subterranean minerals prospecting and long term gravitational field monitoring. A Raman light-pulse atomic gravimeter based on ultracold Rubidium-87 with a single seed laser has been designed and realized on a transportable platform. The gravimeter is made with high degree of computer control which is capable of running the measurements from a remote location. A compact vibration stabilization system based on active feedback cancellation has also been realized on the retro-reflecting mirror of the Raman lasers, achieving vibration noise at the level of $10^{-9}\,\mathrm{g}/\sqrt{\mathrm{Hz}}$ in the frequency range of 0.1 Hz to 10 Hz. The tilt angles of the retro-reflecting mirror in the two horizontal axes have also been stabilized to within 0.1 millidegree. We achieved resolution of approximate 9.4 μGal with 2.5 minutes of integration time in measuring local gravitational acceleration.

T12.66 Boson Sculpting with Quasi-deterministic Subtraction of Trapped-ion Phonons

Lin Htoo Zaw*, Collaboration Between Groups Of Valerio And Dzmitry And Dagomir (Centre for Quantum Technologies)
02:50pm – 03:05pm

In bosonic many-body systems, quantum correlations can be generated by subtracting particles from the system in a certain manner. States with desired quantum correlations - like the Bell or GHZ states - can be prepared by performing a sequence of subtractions from a larger system in a separable state (easier-to-prepare). This process is known as boson sculpting. Recently, quasi-deterministic subtraction of phonons has been experimentally demonstrated with ion trap settings. This form of subtraction is a realisation of the Susskind-Glogower phase operators, which has properties that are different from the type of subtraction previously studied for the purpose of generating quantum correlations. In this work, we extend boson sculpting to quasi-deterministic subtraction, and propose experimental techniques suitable for ion trap computers to generate specific quantum correlations between individual ions. Also, we show that this can be done solely via collective-mode operations.

T12.20 Road map to scaling up to a 10 qubit quantum system

Long Nguyen*, Yuanzheng Paul Tan*, Rangga Perdana Budoyo, Yung Szen Yap, Kun Hee Park, Christoph Hufnagel, Rainer Helmut Dumke (Nanyang Technological University - School of Physical and Mathematical Sciences)
03:05pm – 03:20pm

In the Noisy Intermediate - Scale Quantum era, superconducting qubits have gained significant amount of popularity due to their great flexibility in design, fabrication and control. However, scaling up from one-qubit chip to many-qubits chip is a challenge due to an increase the wiring density, frequency crowding and crosstalk. In this project, we are aiming to scale up our system from two single-qubit chips to a 10 – qubit chip. From our single-qubit chips, we were able to measure our qubit's lifetime of 8μs and decoherence time of 6μs. We also conducted Gauss Sum prime number factorization using one qubit and Bell inequality measurement using two qubits. We also built our software protocol for control of our quantum system remotely. The technology and experience is then applied to fabricate and measure the 10 – qubit chip.

T13: Quantum Engineering - QEP 1.0 Symposium 1

Time: Friday 1 Oct, 11:00am; Venue: Grand Ballroom; Chair: Alex Ling
Time allocated for invited talks is 20 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T13.131 Superconducting single photon detectors for quantum photonics

Miloš Petrović, Lijiong Shen, Shuyu Dong, Filippo Martinelli, Anton Vetlugin, Harish Krishnamoorthy*, Christian Kurtsiefer*, Cesare Soci* (Centre for Disruptive Photonic Technologies, SPMS, TPI, Nanyang Technological University)
11:00am – 11:15am

Evolution of modern photonic technologies along with the ever-increasing demands placed on bandwidth and computational speeds, as well as data security, has made it necessary to look for alternative technologies such as those that work in the quantum regime. Quantum technologies offer substantial advantages for computation, communication and sensing in terms of enhanced speed and bandwidth as well as security and accuracy. One of the main challenges in implementing optical quantum networks and sensors is the detection of single photons at the receiving end. Superconducting nanowire single photon detectors (SNSPDs) have shown higher sensitivity to single photons, better signal-to-noise ratio and broader operational bandwidth than conventional semiconductor-based detectors and seem to be the best candidates for single photon detection at telecom wavelengths. In this talk, we give an overview of the QEP project on superconducting single photon detectors.

In this project, we aim to establish key expertise to produce superconducting single photon detectors, which is currently lacking in Singapore. We will also tackle a broad range of technological challenges to improve photodetector efficiency, spectral bandwidth, and ease integration into practical quantum photonic platforms.

At the current stage, we have successfully fabricated and tested two types of superconducting detectors operating in the telecom range – the first based on meandering superconducting nanowires and the second, based on superconducting microstrips. In particular, by biasing the latter close to the critical current, we obtained readout signal which is an order of magnitude higher than that of typical nanowire detectors. We observed an excellent signal-to-noise ratio of the readout signal with a room temperature amplifier wherein the corresponding jitter contributed by electrical noise is less than 10 ps. In addition, we are also working on strategies to increase operational efficiency as well as enable nanophotonic integration by using optical cavities and waveguides.

Our approach brings together facile fabrication of fast detectors with efficient current redistribution mechanism and nanophotonic integration, enabling prospective applications in quantum photonics which necessitates efficient, accurate estimation of photon arrival events.

T13.67 Cost-effective and fast multi-user quantum key distribution network with an untrusted centralized quantum server

Chao Wang*, Ignatius William Primaatmaja, Gong Zhang, Wen Yu Kon, Charles Ci Wen Lim*
(National University of Singapore)
11:15am – 11:30am

In the IPS meeting, we will be presenting our recent theoretical and experimental research on Measurement-Device-Independent (MDI) QKD. First of all, we proposed a general security analysis method for any discretely modulated MDI QKD [1]. The method is able to provide an almost-tight security bound given the encoding states are pure and their inner products are known. Besides, we show three application examples of the proposed security analysis method: (1) Original decoy-state MDI QKD with Trojan horse attacks (2) Phase-coding coherent state MDI QKD and (3) Phase-matching QKD with finite number of test states. Since the MDI QKD protocol is immune to all kinds of detector-side-channel attacks, one can imagine the eavesdroppers may shift their attention to the source (quantum state preparation) side. To this end, we proposed the idea of optical power limiter, a passive device that limits the amount of light energy be transmitted through [2], which can reliably upper bound the information leakage (Trojan horse attack) of the quantum transmitter. Based on thermo-optical defocusing effect, the proposed device shows a reliable power limiting threshold by both simulation and experiments. Besides, the power limiting threshold is shown to be readily adjustable to suit different application scenarios, and robust against a wide variety of signal variations against malicious attacks. In addition, we show the versatility of the device as a countermeasure against bright illumination attack, and potentially enhance the implementation security of plug-and-play QKD systems. In addition to improving the QKD analysis and implementation for secure communications, we are also extending its quantum advantage to other cryptography applications. For example, we first time present the use of QKD keys to tackle the secret key distribution issue in Symmetric Private Information Retrieval (SPIR) for database query applications, and present the full security analysis and its performance simulations [3]. In this way, provable security can be achieved to ensure both the user privacy, i.e., the user's choice is unknown to the server, as well as the database security, i.e., the user won't access to more than what is necessary. To demonstrate the feasibility of the proposed scheme, we set up a fibre-based time-bin phase coding MDI QKD system with a working frequency of 125MHz and a fibre transmission distance of 50km. With the full implementation of the error correction and privacy amplification, the secure keys from the MDI QKD are used to faithfully implement the proposed SPIR protocol, where the fingerprint minutiae data is successfully transferred.

References: [1]. Primaatmaja, I. W., Lavie, E., Goh, K. T., Wang, C. & Lim, C. C. W. Versatile security analysis of measurement-device-independent quantum key distribution. Phys. Rev. A 99, 062332 (2019). [2]. Zhang, G. et al. Securing Practical Quantum Communication Systems with Optical Power Limiters. PRX Quantum 2, 030304 (2021). [3]. Kon, W. Y. & Lim, C. C. W. Provably Secure Symmetric Private Information Retrieval with Quantum Cryptography. Entropy 23, 54 (2021).

T13.58 III-V material based single-photon avalanche diode

Jishen Zhang, Haibo Wang, Yue Chen, Gong Zhang, Xiao Gong* (National University of Singapore)

11:30am – 11:45am

Single-photon avalanche diode (SPAD) working in near-infrared wavelength is one of the key enabling technologies for the current development of quantum key distribution (QKD), lidar and bio-imaging. In this presentation, we present our recent progress on InGaAs/InAlAs based SPAD development. We designed and successfully demonstrated a SPAD using a novel triple-mesa structure. High photon detection efficiency of 36% and a normalized dark count rate of 19 MHz are achieved, which is one of the best results of this material platform. The device is further heterogeneously integrated with mature silicon photonic chips using low-temperature die-to-die bonding technology. Decent performance can be achieved. Such an integration bypasses the difficulties of III-V on Si growth and opens new possibilities for large scale photonic circuits with weak light detection capability. We also showed the possibility of making an array with such a device, which is critical in applications like high-speed QKD and flash lidar. All the results show exciting potential for our novel SPAD design.

T13.71 Hollow-core fiber based atomic vapor cells

Ximeng Zheng*, Charu Goel*, Yoo Seongwoo*, Dzmitry Matsukevich*, Wonkeun Chang*, Shau-Yu Lan* (Nanyang Technological University)

11:45am – 12:00pm

Isolated atomic vapour systems are ideal platforms for modern quantum technologies, such as quantum computing, quantum communications, and quantum sensors. While proof-of-principle demonstrations of quantum experiments with atoms have stimulated the academic researches in both developing experimental tools and understanding theoretical frameworks, strategies of bringing table-top experiments into miniaturised devices for industrial or real-world applications remain open questions. Here, I will present our recent progress and discuss challenges in the development of atomic vapour in sealed hollow-core optical fibres with built-in optical cavities to enhance the atom-light interaction and the capability to be integrated into photonic waveguide systems. Such fibre-based atomic vapour can be used for quantum networks, atomic clocks, accelerometers, and optical magnetometers.

T13.130 A CMOS ion trap for integrated optical ion clocks

Murray Barrett* (CQT)

12:00pm – 12:15pm

CMOS fabrication is a promising technology for scalable ion-trap systems. We will discuss their potential application to ion-based optical clocks, with particular reference to the lutetium ion system developed at CQT.

T13.75 Resolving starlight: a quantum perspective

Mankei Tsang* (National University of Singapore)

12:15pm – 12:30pm

The wave-particle duality of light introduces two fundamental problems to imaging, namely, the diffraction limit and the photon shot noise. Quantum information theory can tackle them both in one holistic formalism: model the light as a quantum object, consider any quantum measurement, and pick the one that gives the best statistics. While Helstrom pioneered the theory half a century ago and first applied it to incoherent imaging, it was not until recently that the approach offered a genuine surprise on the age-old topic by predicting a new class of superior imaging methods. For the resolution of two sub-Rayleigh sources, the new methods have been shown theoretically and experimentally to outperform direct imaging and approach the true quantum limits. Recent efforts to generalise the theory for an arbitrary number of sources suggest that, despite the existence of harsh quantum limits, the quantum-inspired methods can still offer significant improvements over direct imaging for subdiffraction objects, potentially benefiting many applications in astronomy as well as fluorescence microscopy.

T14: General Physics 1

Time: Friday 1 Oct, 11:00am; Venue: Sky Ballrom I; Chair: TBD
Time allocated for invited talks is 20 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T14.74 (INVITED) Radiation damage and transmutation in tungsten-alloys for nuclear fusion applications

Matthew Lloyd*, David Armstrong, Duc Nguyen-Manh, Enrique Martinez, Paul Bagot, Michael Moody (Singapore University of Technology and Design)
11:00am – 11:20am

Nuclear power is a vital part of global efforts to reduce fossil fuel dependency and decarbonise electricity production. Fusion energy is a novel nuclear technology which has been under development for many years. It has a near limitless source of fuel and drastically reduces the quantity of long-lived nuclear waste when compared to conventional fission reactors. The realisation of fusion energy is dependant on the development of materials which can withstand the extreme environment of the reactor core. Understanding how the properties of candidate materials change under very high operating temperatures and under high levels of neutron radiation is a key part of this engineering challenge. In this study, we investigate how the combined effects of nuclear transmutation reactions and radiation damage under neutron radiation, act to degrade the properties of tungsten; the leading candidate material for the plasma facing components of a fusion power station. Single crystal and polycrystalline W samples were neutron irradiated at the High Flux Reactor (HFR) to a dose of 1.67 displacements per atom (dpa) at a temperature of 1173K. The microstructure of the samples was analysed post-irradiation using a combination of Scanning Transmission Electron Microscopy (STEM) and Atom Probe Tomography (APT). Analysis showed the formation of nanoscale Re and Os rich precipitates induced by radiation damage, as well as decorated voids, grain boundaries and dislocation loops. Our experimental work was supported by atomistic Monte Carlo simulations, which showed a strong binding between vacancies and Re/Os atoms and the formation of Re/Os decorated voids.

T14.95 (INVITED) Theoretical investigation of impact sensitivity of nitrogen rich energetic salts

Gayani Pallewela*, Ryan Bettens (National University of Singapore)
11:20am – 11:40am

Energetic materials such as propellants, explosives, pyrotechnics, and rocket fuels have become quite significant in both military and civil purposes. However, the higher impact sensitivity diminishes its wide range of applications. The impact sensitivity determines the safety and reliability of an energetic material. Usually, salt formation enhances the stability of the molecules towards impact. Herein quantum mechanically derived criteria: HOMO-LUMO energy gap, the ratio of the bond dissociation energy to molecular total energy, the electrostatic potential at bond mid-point, bond topological have been utilized to predict the impact sensitivity trends for the series of nitrogen rich energetic salts: 3-Amino-1,2,4(4H)- oxadiazol-5-one (AOD) and 4-Nitramino-1,2,4-Triazole (NRTZ). The accuracy of predictions is assessed against experimental

BAM fall hammer test results. The results demonstrated an excellent qualitative prediction of the impact sensitivity by using CAMB3LYP/6-31G(d)/IEFPCM = water level of theory. Hence, quantum mechanical predictions are an ideal preliminary approach to design advanced energetic salts based on AOD and NRTZ with enhanced stability before the synthesis, which facilitates reducing the great cost and risk to safety.

T14.99 Molecular Dynamics Unravel New Insights Into Antibiotic Permeation Across The Escherichia coli Outer Membrane

Javad Deylami*, Shu Sin Chng, Ee Hou Yong* (Nanyang Technological University)
11:40am – 11:55am

Permeation of antibiotics through the Gram-negative bacterial cell envelope is a complex process. Specifically, the outer membrane serves as an effective permeability barrier. To shed light on the energetics of antibiotic permeation across the outer membrane, we employed a molecular dynamics (MD) simulation approach to calculate the free energy profiles as various clinically important antibiotics were pulled across an Escherichia coli outer membrane model. Here, we deliver the first reported free energy estimates of erythromycin, gentamicin, novobiocin, rifampicin, and tetracycline as they cross the asymmetric outer membrane along with permeation rates of these antibiotics. While all antibiotics free energy curves have similar trends, the relative free energy barriers could be significantly different when each antibiotic permeates the outer membrane. We provide a complementary analysis of hydrogen bonds drug forms during permeation, revealing the relationship between the number of hydrogen bonds formed by the drugs and their permeation rates. Our results allow ranking of the outer membrane permeability of various antibiotics based on their free energy and diffusion coefficient values along with different segments of the asymmetric outer membrane. These detailed findings of drug/membrane interactions provide critical insights for understanding drug permeation and efficacy against Gram-negative bacteria such as E. coli.

T14.124 Certification of Random Number Generators using Machine Learning

Hong Jie Ng*, Raymond Ho*, Syed Assad, Ping Koy Lam, Omid Kavehei, Chao Wang, Nhan Duy Truong, Jing Yan Haw* (National University of Singapore)
11:55am – 12:10pm

Two coveted qualities for a random number generator (RNG) are uniformity and unpredictability. Pseudo-random number generators (PRNGs) are used to provide uniformly distributed numbers efficiently. A PRNG typically produces a uniform output, but it is predictable when one has knowledge of the algorithm and the state of the PRNG, which is detrimental for privacy sensitive applications. A quantum-RNG (QRNG) uses the indeterminacy of measurement result on an observable of a quantum state, therefore providing a strong assurance on the randomness of the generated numbers. However, a QRNG, being a hardware-based RNG, is not immune to implementation failures, side-channel attacks, and environmental influences. Conventionally, given a string of output from an RNG, one is able to analyse its quality by using statistical test suites such as NIST test, Diehardер test, and TestU01. These test suites contain several randomness tests, and an RNG is declared as non-random if the output fails more than a set number of tests. Recently, machine learning (ML) techniques and other predictive models have shown the potential to be an alternative test of randomness. Instead of a recipe-based technique that pick only certain characteristics in the dataset under scrutiny, an ML-based approach uses artificial intelligence predictive power to inquest whether the randomness has weaknesses. In this work, we propose a randomness testing framework using any ML model and analyse the performance of this randomness test with a particular ML model. We implement our approach to test some PRNGs and we also use the same approach to analyse the implementation of a QRNG based on homodyne detection of vacuum fluctuations.

T14.86 Energy cost study for controlling complex social networks with conformity behavior

Hong Chen*, Ee Hou Yong* (Nanyang Technological University)
12:10pm – 12:25pm

To understand controlling a complex system, an estimation of the required effort needed to achieve control is vital. Previous works have addressed this issue by studying the scaling laws of energy cost in a general way with continuous-time linear dynamics. However, continuous-time linear dynamics is unable to capture conformity behavior, which is common in many complex social systems. Therefore, to understand controlling social systems with conformity, discrete-time modeling is used and the energy cost scaling laws are derived. The results are validated numerically with model and real networks. In addition, the energy costs needed for controlling systems with and without conformity are compared, and it was found that controlling networked systems with conformity features always requires less control energy. Finally, it is shown through simulations that heterogeneous scale-free networks are less controllable, requiring a higher number of minimum drivers. Since the conformity-based model relates to various complex systems, such as flocking, or evolutionary games, the results of this paper represent a step forward toward developing realistic control of complex social systems.

T15: Atomic, Molecular, and Optical Physics

Time: Thursday 30 Sept, 11:00am; Venue: Sky Ballrom II; Chair: TBD
Time allocated for invited talks is 20 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T15.6 (INVITED) An ultrastable superradiant laser based on a hot atomic beam

Travis Nicholson*, Haonan Liu, Simon Jager, Xianquan Yu, Steven Touzard, Athreya Shankar, Murray Holland (Centre for Quantum Technologies)
11:00am – 11:20am

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 are extremely challenging. 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 system large, expensive, and unsuitable for many applications. With the aim of creating superradiant lasers that are more accessible and useful, 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 with 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 less sensitive to vibrations, making it more applicable in field applications than existing ultrastable lasers.

T15.101 (INVITED) Large array of Schrödinger cat states facilitated by an optical waveguide

Wui Seng Leong*, Mingjie Xin, Zilong Chen, Shau-Yu Lan (Nanyang Technological University)

11:20am – 11:40am

Quantum engineering using photonic structures offer new capabilities for atom-photon interactions for quantum optics and atomic physics, which could eventually lead to integrated quantum devices. Despite the rapid progress in the variety of structures, coherent excitation of the motional states of atoms in a photonic waveguide using guided modes has yet to be demonstrated. Here, we use the waveguide mode of a hollow-core photonic crystal fiber to manipulate the mechanical Fock states of single atoms in a harmonic potential inside the fiber. We create a large array of Schrödinger cat states, a quintessential feature of quantum physics and a key element in quantum information processing and metrology, of approximately 15000 atoms along the fiber by entangling the electronic state with the coherent harmonic oscillator state of each individual atom. Our results provide a useful step for quantum information and simulation with a wide range of photonic waveguide systems.

T15.45 LiK B$^1\Pi$ potential: combining short and long range data

Sofia Botsi*, Anbang Yang, Sambit B. Pal, Mark M. Lam, Sunil Kumar, Markus Debatin, Kai Dieckmann (Centre for Quantum Technologies, National University of Singapore)

11:40am – 11:55am

We report on high-resolution spectroscopic measurements of the long-range states of the ^{6}Li^{40}K molecule near the ^{6}Li($2\,^2S_{1/2}$)+^{40}K($4\,^2P_{3/2}$) dissociation threshold, which in combination with existing data in the short-range lead to the complete characterization of the B$^1\Pi$ potential. Starting from weakly bound ultracold Feshbach molecules, we perform one-photon loss spectroscopy of the high-lying states of the B$^1\Pi$ and record the transition frequencies to twenty-five vibrational levels. Level assignment to the spin-orbit coupled potentials is facilitated by existing data in the long-range [Ridinger et al., EPL, 2011, 96, 33001] and by examining the Zeeman effect for the Hund's case (c) coupling scheme. The C_6 coefficients are deduced by fitting our vibrational energies together with the long-range levels to the LeRoy-Bernstein formula. We present a complete set of data for the $\Omega = 1$up state, by combining the long-range measurements with data from the short-range states of the B$^1\Pi$ potential obtained for the ^{7}Li^{39}K isotopologue [Pashov et al., Chem. Phys. Lett., 1998, 292, 615-620]. Using mass-scaling, we model the short- and the long-range states simultaneously and produce an improved Rydberg-Klein-Rees curve for the complete potential.

T15.37 Zitterbewegung dynamics of UltraCold Sr atoms in an artificial gauge field

Ketan Rathod* (National University of SIngapore)

11:55am – 12:10pm

In this presentation, I shall discuss the first experimental realization of Zitterbewegung "jittery motion" in 2D of an UltraCold atomic wavepacket. First I shall discuss the technique used to create the artificial gauge field followed by a brief overview of preparing the Sr atomic wavepacket below the recoil limit. I shall also discuss the anisotropic nature of Zitterbewegung in the presence of non-Abelian gauge field.

T15.55 Towards the Ultracold Dipolar Quantum Gas of ^{6}Li^{40}K

Anbang Yang, Sofia Botsi, Sunil Kumar, Avalos Pinilos Victor Andre*, Canming He*, Kai Dieckmann* (Centre for Quantum Technologies; Department of Physics, National University of Singapore)

12:10pm – 12:25pm

We demonstrate a two-photon pathway to the X1Σ+ rovibrational ground state of ^{6}Li^{40}K molecules that involves only singlet-to-singlet transitions. We start from a Feshbach state which contains a significant singlet character of 52%. With the only contributing singlet state to the molecular state being fully stretched and with control over the polarization of the laser we address a sole hyperfine component of the A1Σ+ potential without resolving its hyperfine structure. The dark resonance spectroscopy is performed with two narrow-linewidth lasers to precisely determine the two-photon resonance for STIRAP transfer to the v" = 0 of X1Σ+ground state. The strong dipolar nature of ground state ^{6}Li^{40}K is revealed by Stark spectroscopy. A high finesse cavity is built to simultaneously stabilize the two STIRAP lasers using the PDH lock to ensure relative phase coherence between the lasers. Apart from the narrow linewidth, the phase noise of lasers is also crucial for coherent population control. We characterize the phase noise of the STIRAP laser system and estimate the loss during the population transfer. Several improvements have been made to suppress the excessive phase noise. The estimation based on the new noise characterization suggests a low loss STIRAP transfer to the ground state.

T16: Quantum Engineering - QEP 1.0 Symposium 2

Time: Friday 1 Oct, 2:00pm; Venue: Grand Ballroom; Chair: Alex Ling
Time allocated for invited talks is 20 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T16.70 Co-development of quantum devices under the Quantum Foundry

Rangga Perdana Budoyo*, Manas Mukherjee*, Rainer Dumke* (Centre for Quantum Technologies, NUS)
2:00pm – 02:15pm

Quantum technologies have made a tremendous progress over the last decade. Along with it, the quantum machines also became more and more complex requiring engagement of experts from diverse fields. One of the crucial expertise in developing quantum computers require microfabrication. In particular, two most advance platforms namely superconducting circuits and ion traps rely on developing reliable and repeatable chips to operate the quantum computers. The Quantum Foundry project funded by the Quantum Engineering Program 1.0 is currently operating to fill this gap by developing the chips for the above two platforms by co-developing strategies, processes and design engineering with Singapore based clean-room facilities. Within the last one and half years, the project has been able to deliver some of the early devices for this purpose. We will provide an overview of the challenges, achievements and the path forward to a more inclusive national level foundry based on the current experiences.

T16.141 (INVITED) IBMQ and cloud quantum computing in the QEP

Dimitris Angelakis* (Centre for Quantum Technologies, NUS)
02:15pm – 02:35pm

An update on the usage of IBMQ by the Singapore community will be provided. In addition, plans for wider access to overseas NISQ machines will be shared.

T16.57 A Comparison of Quantum and Classical Leaderless Consensus

Paul Griffin*, Dimple Mevada (Singapore Management University)
02:35pm – 02:50pm

Quantum computing is coming of age and being explored in many business areas for either solving difficult problems or improving business processes. Distributed ledger technology (DLT) is now embedded in many businesses and continues to mature. Consensus, at the heart of DLTs, has practical scaling issues and, as we move into needing bigger datasets, bigger networks and more security, the problem is ever increasing. Consensus agreement is a non-deterministic problem which should match to quantum computers due to the probabilistic nature of quantum phenomena. In this paper we show that three quantum nodes entangled in a variety of network topologies perform similarly to classical consensus executed on quantum simulators and real quantum computers with and without noise mitigation. There is no difference in the average time for the network to agree but there is a higher variation in agreement times compared to classical systems. The implication is that, with continued improvement in quantum technology, the scale and advantages of quantum processing can be exploited to provide for bigger and more sophisticated consensus. Furthermore, exploring the variation in agreement time could potentially lead to shorter times.

T16.4 Enhancing quantum models of stochastic processes with error mitigation

Matthew Ho*, Ryuji Takagi, Mile Gu (Nanyang Technological University, School of Physical and Mathematical Sciences)

02:50pm – 03:05pm

Error mitigation has been one of the recently sought after methods to reduce the effects of noise when computation is performed on a noisy near-term quantum computer. Interest in simulating stochastic processes with quantum models gained popularity after being proven to require less memory than their classical counterparts. With previous work on quantum models focusing primarily on further compressing memory, this work branches out into the experimental scene; we aim to bridge the gap between theoretical quantum models and practical use with the inclusion of error mitigation methods. It is observed that error mitigation is successful in improving the resultant expectation values. While our results indicate that error mitigation work, we show that its methodology is ultimately constrained by hardware limitations in these quantum computers.

T16.142 (Special session) QEP National Platforms Panel Discussion

Alexander Ling* (Quantum Engineering Programme)

03:05pm – 03:35pm

QEP is supporting 3 nation-wide collaborative platforms to promote collaboration and coordination in the areas of computing, device fabrication and communications. The lead PIs for these 3 platforms will be on stage to share the goals, and to answer queries and seek feedback from the community. Panellists are: Jose-Ignatio Latorre (Computing Hub), Manas Mukherjee (Foundry) and Charles Lim (Quantum-Safe Network).

T17: General Physics 2

Time: Friday 1 Oct, 2:00pm; Venue: Sky Ballrom I; Chair: TBD
Time allocated for invited talks is 20 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T17.47 (INVITED) Statistics and Topology of Fluctuating Ribbons

Ee Hou Yong*, Farisan Dary*, Luca Giomi, Lakshminarayanan Mahadevan (Nanyang Technological University)
2:00pm – 02:20pm

Ribbons are slender structures all three of whose dimensions are widely separated from each other. This geometric scale separation leads to unusual mechanical properties: ribbons can be bent without being twisted, but not twisted without being bent. Here we study the consequences of this geometric constraint on the statistical mechanics of a fluctuating ribbonlike biopolymers loaded by forces and torques. Starting with a discrete version of an asymptotic model for an inextensible elastic ribbon - the Sadowsky ribbon, we show that it exhibits a range of topologically and geometrically complex morphologies. We use computational topology to track the link, twist, and writhe of the ribbon conformations and show that there are three distinct morphological phases - twist-dominated helical phase (HT), a writhe-dominated helical phase (HW), and an entangled phase that arise as the applied torque is varied. The transition from HW to HT phases is characterized by the spontaneous breaking of chiral symmetry and the disappearance of perversions that characterize chirality reversals, commonly seen in plant tendrils and telephone cords. We further describe a universal response curve of a topological quantity, the link, as a function of the applied torque that is similar to magnetization curves in 2nd order phase transitions, and provide a phase diagram for the different morphologies. Our study has a set of clear experimental predictions and are applicable to many ribbonlike objects in polymer physics and nano-science that cannot be described by the classical wormlike chain model.

T17.79 Single Ion Counting via Fluorescence Imaging of Scintillator for Deterministic Ion Implantation

Chengyuan Yang*, Kuan Huei James Lee, Zhaohong Mi, Andrew Bettiol* (Physics department, National University of Singapore)
02:20pm – 02:35pm

Deterministic ion implantation has shown a great promise for fabricating entangled single-photon sources for quantum technologies. To achieve an error-free fabrication process, it is critical to precisely count the ions implanted at a target at single-ion precision. In this work, we demonstrate a method for single ion counting by capturing the ion-induced fluorescence of a scintillator with a high-sensitivity EMCCD camera. We use MeV protons as an example to show that our method not only counts ions but also offers their lateral spatial distribution, both of which are important for investigating ion-matter interactions. We also develop an algorithm for analyzing the fluorescence images to automatically count ions in each image and measure their lateral positions. Furthermore, we show that the spatial information offered by our method enables detection of multiple ions that arrive simultaneously or within a short time interval, of-

fering a unique advantage compared to conventional ion-counting methods using Si detectors. Therefore, our method offers significance for achieving deterministic ion implantation and efficient fabrication of single-photon sources.

T17.80 Single-particle-exact density functionals

Berge Englert*, Martin-Isbjoern Trappe*, Jun Hao Hue*, Mikolaj Paraniak*, Jonah Huang* (Dept of Physics, NUS)
02:35pm – 02:50pm

We introduce a novel kind of density functionals for interacting many-fermion systems, where all single-particle contributions to the energy are represented by exact functionals, and only the functional for the interaction energy requires an approximation. We discuss a scheme for constructing systematic approximations and report the results of benchmarking exercises.

T17.113 Two dimensional water flow: confinement effects

Alexandra Carvalho*, Maxim Trushin*, Suchit Negi, Antonio Castro Neto (National University of Singapore)
02:50pm – 03:05pm

Interfacial water and confined water have long been known to form ordered states, often known as '2D ice'. However, due to the interest in the use of graphene and derived materials for water filtering applications, the flow of monolayer or few-layer confined water has attracted increased attention.

We used molecular dynamics simulations to clarify the state of 2D water confined by graphene or boron nitride sheets, showing that it remains structured even during stationary flow. The flow of 2D water between reservoirs with a pressure difference shows clear non-linear dependence on pressure. From a comparison with a continuum model derived from the Navier Stokes equation, it becomes apparent that the ability of the two-dimensional water to flow through the confined space is intrinsically linked to its ability to contract and expand, and in particular to its bulk viscosity. We thus show that 2D water can display, in the same state, properties characteristic of a solid and of a liquid. We also show how these can be influenced by the confining substrate as a consequence of structural changes in the water layer.

T17.126 Monovalent-ion induced inter-DNA interactions at high ionic strengths

Ishita Agrawal*, Rajesh Sharma, Liang Dai, Patrick Doyle, Slaven Garaj (National University of Singapore)
03:05pm – 03:20pm

The compaction of negatively charged DNA in the cell nucleus is driven by crowding neutral polymers, while monovalent ions purportedly only act to screen inter-DNA repulsion. On the other hand, multivalent ions mediate strong electrostatic inter-DNA attraction, leading to DNA condensation [1]. In the past, tantalizing hints that even monovalent ions could also induce DNA attraction [2] were never proven due to the lack of instrumental techniques that could quantify moderate interactions.

Here we demonstrate that even monovalent ions could mediate attraction between DNA strands at high molar concentrations. We employ a new nanopore-based technique to precisely quantify the knotting probability of long DNA chains [3], which is a very sensitive measure to inter-DNA interactions. Modeling effective DNA width from the knotting data, we demonstrate that the DNA-DNA interaction evolves from repulsive to attractive with increasing salt concentration, with the onset of attraction at the critical ionic concentration ranging between c_{att}=1.5M - 2M. The c_{att} corresponds to the mean ionic distance approaching the hydration ion radius. It scales well with the hydration radius of different salts (Li+, Na+, K+) indicating ion-induced correlations as the driving force for attraction.

Understanding DNA interaction at high molar concentrations informs our understanding of DNA in the physiological environment. As we strive to employ synthetic biological machinery in different environments, unshackled from physiology, understanding inter-DNA interaction at high molarity becomes even more so biotechnologically important.

T17.44 Surpassing supernova constraints for halo-bound axions with table-top precision measurements

Junyi Lee*, Matthew Moschella, William Terrano, Mariangela Lisanti, Mike Romalis (Institute of Materials Research and Engineering)
03:20pm – 03:35pm

Multiple astrophysical observations suggest that dark matter make up approximately a quarter of the universe's total mass-energy content, and is roughly five times more abundant than the visible matter which we are familiar with. However, their exact nature remains mysterious and there has to date been no confirmed detection of them in laboratory experiments. QCD-axions and other generic axion-like particles that arise generically from spontaneous symmetry breaking in theories beyond the Standard Model are well-motivated dark matter candidates. If these light particles are gravitationally bound to our galaxy, we expect them to have a distinctive stochastic experimental signature. In this talk, I highlight how table-top alkali-noble gas co-magnetometers can be used to search for such axions, and present two complementary theoretical frameworks for correctly accounting for the stochastic nature of the axion's gradient that previous analysis has failed to account for. Applying this analysis to old data from a K-3He co-magnetometer, I present upper limits on the axion's coupling to nucleons that surpasses astrophysical constraints from SN1987A.

T18: Whitespace / post-deadline session

Time: Friday 1 Oct, 2:00pm; Venue: Sky Ballrom II; Chair: TBD
Time allocated for invited talks is 20 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T18.133 Dynamic control of spontaneous emission rate using active hyperbolic metamaterials

Li Lu, Harish Krishnamoorthy*, Mengfei Wu, Ramon Paniagua-Dominguez, Cesare Soci*, Robert E. Simpson* (Singapore University of Technology and Design (SUTD))
2:00pm – 02:15pm

We present a nanophotonic system based on a phase change material (PCM) which enables dynamic control over the spontaneous emission rates of quantum emitters. PCMs have been widely studied for tuneable photonics applications 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 switch can be very fast, on a sub-ns scale [2] and is non-volatile and reversible. We have introduced a wide bandgap, low-loss phase change material called antimony trisulphide (Sb_2S_3). 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 whilst the optical absorption is low in the visible and NIR spectrum. Thus, Sb_2S_3 is a promising material for reprogrammable visible and N-IR photonics. Hyperbolic metamaterials (HMMs) exhibit a broadband enhancement in the photon density of states (PDOS), and are, therefore, promising for various applications such as imaging, biosensing and spontaneous emission enhancement. They are usually composed of stacked nanometer-scale dielectric and metallic films. In this talk, an active HMM composed of Sb_2S_3 dielectric and Ag layers with a Si_3N_4 as diffusion barrier between the bilayers will be introduced. The larger PDOS in the HMM results in an enhancement in the rate of spontaneous emission of quantum dots placed on top. In particular, by changing the structural phase of Sb_2S_3, spectral region of hyperbolic dispersion is altered which in turn changes the concomitant rate of quantum dot spontaneous emission. The results suggest that tuneable HMMs using PCMs can be potentially employed to realize single photon sources with tuneable emission rates. We acknowledge support from the Nano Spatial Light Modulator (NSLM) A-Star Programmatic grant (A18A7b0058). Li Lu is grateful for his scholarship from Singapore Ministry of Education (MOE).

T18.135 Photocurrent nanoimaging on topological insulators at optical frequencies

Alexander M. Dubrovkin*, Giorgio Adamo, Qi Jie Wang, Nikolay I. Zheludev, Cesare Soci (Nanyang Technological University)
02:15pm – 02:30pm

A raise of nanoscale 2D materials dramatically increased variety of light detection devices. Nano-optoelectronic phenomena arising in such materials has stimulated number of applications, ranging from peculiar photocurrents in atomically-thin devices to extraordinary light detection in topologically non-trivial medium, to name a few. Number of experimental demonstrations to map photocurrents at the nanoscale has been demonstrated based on scattering-type scanning near-field optical technic combined with optoelectronic imaging, particularly in graphene devices at mid-IR and THz frequencies, however application of such method to resolve deeply nanoscale optoelectronic phenomena in the optical range is yet to be explored. In this work, we report the first demonstration of such approach to photocurrent mapping on topological insulator materials in the near-infrared and visible part of the spectrum. Nanoimaging of local photocurrents in nanostructured photodetectors is demonstrated as well as the impact of light polarization is discussed. The experimental realization of photocurrent nanoimaging is based on correlative optoelectronic mapping using scattering-type scanning near-field optical microscope platform. This approach enables simultaneous photocurrent and optical field mapping (amplitude and phase) upon topographic imaging of the sample via tapping-mode atomic-force microscope (AFM). The deeply nanoscale resolution of the photocurrent signal is achieved by higher harmonic demodulation at the AFM tip tapping frequency. The photodetector devices were fabricated from topological insulators of $\mathrm{Bi}_x\mathrm{Sb}_{1-x}\mathrm{Te}_y\mathrm{Se}_{1-y}$ family using electron beam lithography and focused ion beam milling techniques. We revealed fringe patterns in the photocurrent amplitude distributions, which are accompanied with photocurrent phase (sign) modulations. We further show that photocurrent maps on the topological devices may be tuned by nanopatterning, changing the configuration of the electrodes, or the polarization of the incident light. Our results provide insights into deeply nano-scale optoelectronic phenomena at the topological insulators and contribute for their use in the optical part of the spectrum.

T18.136 Perovskite Metasurfaces with Giant Chirality

Giorgio Adamo*, Jingyi Tian, Guankui Long, Hailong Liu, Maciej Klein, Harish N. S. Krishnamoorthy, Hebin Wang, Hong Liu, Cesare Soci (Centre for Disruptive Photonic Technologies, TPI, SPMS, Nanyang Technological University, 21 Nanyang Link, Singapore)
02:30pm – 02:45pm

Thanks to their remarkable optoelectronic properties, high refractive index, and simple processability, halide perovskites are becoming a prominent material platform for all-dielectric integrated nano-optics. Following the first demonstration of direct nanostructuring of dielectric perovskite metasurfaces, a number of passive and active flat optical metadevices have already been realized. One important functionality of perovskite metasurfaces which has yet to be demonstrated is optical chirality. While hybrid perovskites with chiral optical response have been recently synthesised, their inherent chirality is very weak. We adopt two metasurfaces designs, the first comprising of metamolecules with broken in-plane inversion and the second comprising of chiral metamolecules and demonstrate two all-dielectric perovskite chiral metasurfaces concepts which allow us to obtain: i) enhanced directional chiral photoluminescence emission with record-high 40% Degree of Circular Polarization (DOP) at room; ii) circular dichroism as high as 16% and 10-fold increase of g factor compared to the inherent chirality of perovskites engineered by synthetic methods. The combination of chemical and structural engineering of both perovskite matrix and metasurface design allows extending this paradigm to the entire visible and near infrared spectrum. Combining strong optical activity, unique light emission properties and simple fabrication, hybrid perovskites can pave the way for a new class of chiroptoelectronic and chiro-spintronic devices.

(notes)

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