IPS Meeting 2015
4 - 6 March

Institute of Physics Singapore

Conference Program

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1 Foreword

Dear fellow Physicists,

this year we are back again to the School of Physical and Mathematical Sciences on the campus of Nanyang Technological University for our annual gathering of physicists active in research. For some of our colleagues, who come from their new campus of the Singapore University of Technology and Design (SUTD), this is probably as far as it gets - at least in Singapore.

Some time ago, when the IPS council got together, we realized that the UNESCO had declared 2015 as the international year of light. As physicists, this is something many of us use in their daily work, so here was the theme for this year's meeting.

We felt that a focus session on precision measurements and Spectroscopy does fit very well this theme - and a lot of work is done on this topic in Singapore as well! This emphasis is also highlighted by plenary talks discussing exciting new developments in various realizations of precision measurements.

It turned out that even one of our colleagues who works – among other topics – on black holes got noted widely for his work describing light paths around these objects - something that made it into a major Hollywood movie. So convinced Edward Teo to open the meeting with a plenary talk, explaining to us the exotic physics hidden in the movie.

We got quite a number of international experts coming to our shores this year as plenary speakers, as they either happened to be in the area, or had planned to collaborate with our colleagues. Jorge Treddice will tell us something about the more scary aspects of extreme events emerging from a crisis, but if you check the abstract you will realize that we still stay with light on this journey. Precision measurements many times involves light, and John Close from the Australian National University, and Harald Weinfurter from the university of Munich will share with us their ideas to put atoms and single quanta of light to use to push the limits what you can measure. With Peter Hänggi we from Augsburg University (and a regular visitor at NUS) we will have a black belt in theoretical statistical physics telling us about ways to learn something about the environment of qubits, and we return to optical phenomena and precision measurements with Philippe Bouyer from Nice in France.

This is an unusual IPS meeting in the sense that we have a lot of international speakers - also for the more technical sessions, as you will see in the program. Nevertheless, this meeting is still a platform to showcase the local research work done in this year in the various quarters – and we are getting stronger and stronger: this year is a record for the number of contributions! We have not only 6 plenaries, but also 95 oral presentations and over 70 posters, mostly featuring local work. Still, we belive that we could cover more areas, so if you have a colleague who is maybe a bit shy in showcasing what research they do, encourage them to take part in this annual event, and get connected again with the next generation of researchers!

As usual, we tried to find a balance between bringing people together with similar interest, and encourage exchange between different fields with the composition of the 17 different technical sessions. The location ensures that you are never far away from the other session if you want to sneak into something completely different.

Posters are always a very relaxing and scientifically stimulating way of communication. The poster pitch competition seemed to work well, so we have it again, where poster presenters can give a 3-minute advertiser to their work. Again, there is ample of time to hang around posters, and to catch up with the exhibitors who not only provide you with research equipment and services, but have often research experience as well. Since discussing exciting science drains a lot of energy, the long poster session on Thursday evening comes with food again. Just hang around and see what is going on, and take the opportunity to ask your colleagues questions in a relaxed atmosphere.

Again, the organization of this meeting had strong support from NTU, NUS, and IHPC - and new, SUTD. Big thanks to our logistics support from Won Lai Chun, Rebecca and Liang Jiaxing for NTU (local support), and Lim Kim Yong at NUS for settling the finances, as well as many physics students at NTU.

We are also happy again to acknowledge our institutional supporters, the Department of Physics at NUS and the School of Physics and Applied Physics at NTU, as well as the Centre for Quantum Technologies. Last but not least, let's thank our exhibitors, who again help with their generous sponsorship to make this conference possible.

With this, we hope this conference enlightens you with a lot of new ideas, new contacts, new collaborations for a successful new year of research in physical sciences ahead!

Your organizing team of the IPS meeting 2015

Contents

2 Schedule

Wednesday, 4 March

8.45 AM	Registration			
9.30 AM 9.45 AM	Opening Address (venue LT1) Plenary talk 1: Edward Teo (venue LT1)			
10.30 AM	Coffee/Tea Break + Exhibition + Poster mounting			
11.00 AM	Plenary talk 2: Jorge Tredicce (venue LT1)			
11.45 AM	Exhibition + Poster mounting			
12.30 PM	Lunch + Poster mounting + Exhibition			
1.30 PM	Technical Sessions			
	T1 (MAS1) Adcanced dynamics	T2 (LT4) Graphene and 2D materials	T3 (LT5) Photonics, plasmonics, metamaterials	T4 (MAS2) Quantum Information 1
3.10 PM	Coffee/Tea Break + Exhibition			
3.40 PM	Technical Sessions			
	T5 (MAS1) Atomic Physics	T6 (LT4) Emerging 2D materials	T7 (LT5) Photonics and plasmonics	
5.20 PM	End of Wednesday sessions			

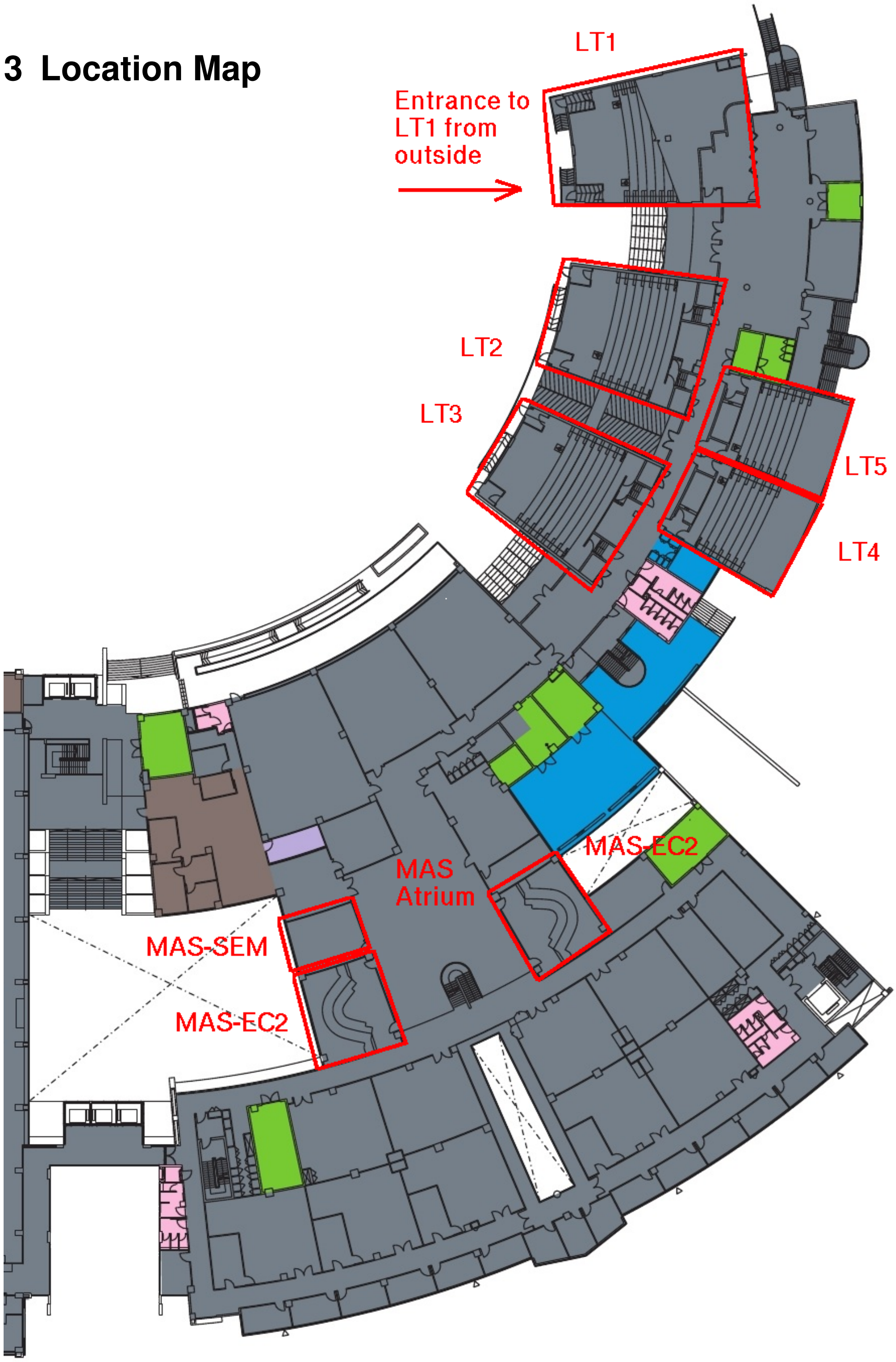
Thursday, 5 March

9.00 PM	Registration		
9.30 AM	Plenary talk 3: John Close (venue LT1)		
10.15 AM	Plenary talk 4: Harald Weinfurter (venue LT1)		
11.00 AM	Coffee/Tea Break + Exhibition + Poster mounting		
11.30 AM	PO1: Rapid Fire poster Pitch session(venue: LT1)		
12.30 PM	Lunch + Posters + Exhibition		
1.30 PM	Technical Sessions		
	T8 (MAS1) Topological Systems	T9 (LT4) Statistics 1	T10 (LT5) Precision measurements 1
3.10 PM	Coffee/Tea Break + Exhibition		
3.40 PM	Technical Sessions		
	T11 (MAS1) Solid state physics	T12 (LT4) Statistics 2	T13 (LT5) Precision measurements 2
5.20 PM	PO2: Pizza + Poster + Exhibition		
6.37 PM ($+\epsilon$)	Poster awards		
7.00 PM ($+\epsilon'$)	End of Thursday sessions		

Friday, 6 March

9.00 AM	Plenary talk 5: Peter Hänggi (venue LT1)			
9.45 AM	Plenary talk 6: Phillipe Bouyer (venue LT1)			
10.30 AM	Coffee/Tea Break + Exhibition			
11.00 AM	Technical Sessions			
	T14 (MAS1) Sound and cavitation	T15 (LT4) Materials for energy	T16 (LT5) Quantum information 2	T17 (MAS2) Bio- and Plasmaphyscis
12.40 PM	End of Friday sessions			

3 Location Map



4 Plenary sessions

We will have six distinguished plenary speakers from near and far this year – the topics are loosely related to the international Year-of-light, very diverse, but also accessible for every Physics researcher. So take the opportunity to learn something about areas you may be totally unfamiliar with!

P1: Black holes, wormholes, the fifth dimension, and Interstellar

Assoc. Prof. Edward TEO, Physics Department, National University of Singapore

Wednesday, 4 March, 9:45am, Venue: LT1

Abstract

The subject of black holes, wormholes, and the fifth dimension has been receiving some serious publicity recently due to the movie Interstellar. Indeed, there is so much science packed in this movie that 2 hours and 49 minutes is barely enough time to absorb it all. In this talk, I will give a general overview of some of the essential physics used in the movie. Topics to be covered include: basic properties of black holes, creating the image of the black hole Gargantua, the possibility of extreme time dilation on Miller's planet; the possibility of traversable wormholes, creating the image of a traversable wormhole; the concept of a fifth dimension or "bulk", and the concept of our universe as a brane in an AdS bulk. Although the main emphasis of this talk will be on established scientific ideas, I will end with a brief description of The Tesseract that appears at the climax of the movie. Much of this talk will be based on Kip Thorne's book, "The Science of Interstellar".

About the Speaker

Edward Teo obtained my Ph.D. in theoretical physics from the University of Cambridge in 1994. In 1997, he joined the Department of Physics at the National University of Singapore, where holds a position of an Associate Professor. His research lies in the areas of General Relativity and Gravitation. Prof. Teo is very interested in exact solutions of general relativity, particularly those describing black holes. More recently, he has been focusing on black holes and black rings in higher dimensions. His work that helped understanding to the surprising light trajectories shown in the movie was published in 2003 (E. Teo: "Spherical photon orbits around a Kerr black hole," General Relativity and Gravitation **35**, 1909-1926). He also has a nice web site at `http://www.physics.nus.edu.sg/~phyteoe/kerr/` explaining the physics for the not-so-specialized.

P2: Extreme events: a consequence of a crisis

Prof. Jorge Tredicce, Nonlinear Institute of Nice, CNRS & University of Nice, France

Wednesday, 4 March, 11:00am, Venue: LT1

Abstract

Rogue waves, earthquakes of high magnitude, financial crises, tsunamis, epileptic seizures have they any common feature other than their catastrophic and undesirable character? Yes! they are extreme events. Extreme events are often called disasters as they correspond to significant and abrupt changes (damages) of our environmental and socio-economic conditions. Nowadays the growing toll of damages from extreme events around the world leads to unprecedented economic losses and then presents a high challenge for public policy and scientific research. One of the main objectives of studying extreme events is to provide knowledge and tools that can contribute to the reduction of vulnerability. Greater attention is now paid to their causes and their study includes observation, statistics and prediction, in particular due to the rising societal exposure. It is then important to identify laboratory systems producing such "catastrophic events" in some controllable way.

Here we propose to study the nonlinear dynamics of a class-B laser with loss modulation, described by very simple equations and try to identify the appearance of optical rogue waves. The laser can be modeled by

$$\frac{dS}{dt} = -S(1 + m\cos(\omega t) - N) \quad (1)$$

$$\frac{dN}{dt} = -\Gamma(N - A + SN)\,, \quad (2)$$

where the time is in units of the photon lifetime, S and N are the photon and population inversion respectively, Γ is the ratio of the population to the photons lifetimes, A is the pump parameter, and m and ω are the amplitude and frequency of the modulation,respectively.

Through analysis of bifurcation diagrams of the maxima of intensity, S_{max}, as a function of a parameter m, we show that after reaching chaos, chaotic attractors expand abruptly in phase space. Furthermore, just before reaching a fully developed chaos, it is possible to observe the coexistence of a chaotic and periodic attractors at low m values. We noticed that the trajectory in phase space spends most of time in a dense region of the strange attractor, only occasionally performing a long excursion, resulting in a high pulse. Then such high intensity pulses are extreme events in the chaotic behaviour and their appearance generates a long tail in the probability distribution of the maxima of intensity. We determine that such extreme events appear only after a collision of the chaotic attractor with an unstable orbit. The collision is a bifurcation of the chaos called external crisis. Then the extreme events are direct consequence of a crisis as indicated in the title of this presentation.

The theoretical results are compared to experimental data obtained from a solid state laser with electro-optically modulated losses. The comparison shows a good qualitative agreement between numerical and experimental results.

About the Speaker

Born in Buenos Aires, Argentina, in 1953, Jorge Tredicce obtained his Laurea diploma in Physics at the University of Florence, Italy. From 1978 to 1985 he was a Researcher at the Institute of Optics in Florence. In 1985 he joined the Drexel University, Philadelphia, USA as a Professor. In 1992 he moved to the University of Nice – Sophia Antipolis, where he is currently the Chair Professor (Professeur Classe Exceptionnelle) of Physics, jointly with the University of New Caledonia, France. From 2001 until 2011 he was the Director of the Institut Non-Lineaire de Nice (INLN) (Nonlinear Institute of Nice), a joint unit of the French CNRS and the University of Nice. During his research career, Jorge worked on a variety of Photonics subjects, including laser physics, nonlinear dynamics, chaos, spatio-temporal dynamics in optics, solitons and, more recently, extreme events in optical systems.

P3: Precision measurements of gravity using Bose condensed atoms and atom lasers

Prof. John CLOSE, Australian National University

Thursday, 5 March, 9:30am, Venue: LT1

Abstract

In this talk, I will discuss our work comparing atom lasers and thermal atoms as sources for precision inertial measurements particularly precision measurements of gravity. I will discuss our work on high momentum transfer beam splitting, our thoughts on atomic squeezing and its prospects for making a practical enhancement in the sensitivity of an advanced atom interferometer and our recent results on the first realisation of a bright solitonic atom laser.

About the Speaker

Prof. John Close completed his PhD in physics at the University of California at Berkeley in 1991. He then was a postdoctoral fellow at the University of Washington in Seattle from 1991 to 1994, and an Alexander von Humboldt Fellow at the Max Planck Institute from 1994 to 1998. He returned to Australia taking up a Queen Elizabeth II Fellowship in 2000. He has been a Professor in the Research School of Physics and Engineering since 1998, and Deputy Director of the School with a focus on education since 2012. Prof. Close is a Senior Fellow of the Higher Education Academy, and has broad interests in experimental and theoretical physics, biology, chemistry and engineering and pursue questions that he finds interesting.

His current research activities gravitate around light beams in curved space-time, and some even more fundamental questions what is left to be found out about gravity, but he got his hands dirty with a lot of precision measurement physics involving atom interferometry and laser spectroscopy techniques.

P4: Quantum Metrology with entangled photons - Precision below the shot noise limit

Prof. Harald WEINFURTER, Ludwig-Maximilains-Universität München & Max-Planck Institute for Quantum Optics Garching, Germany

Thursday, 5 March, 10:15am, Venue: LT1

Abstract

Joint work of D. Schlenk, C. Schwemmer[1], N. Kiesel[2], and H. Weinfurter.

Quantum entanglement is the most important resource for the many new applications of quantum information science, such as secure communcation or quantum teleportation, but it also plays a vital role in quantum-enhanced measurement schemes where it can be used to improve the precission of measurements. We give an overview of the multitude of new possibilities and demonstrate this effect in detail using entangled multi-photon states to go beyond the shot noise limit in interferometric sensing or to break the diffraction limit for microscopy.

About the Speaker

Prof. Harald Weinfurter's research concerns the fundamental aspects of quantum physics. His areas of interest include experimental quantum interferometry with correlated photons, quantum correlations and entangled states and quantum communication and information and their application in quantum cryptography and quantum metrology, and has pioneered much of the experimental work in this area.

Harald Weinfurter received his doctorate in Vienna, then worked at the Atominstitut there and at the Hahn-Meitner Institute in Berlin on neutron physics, before he he moved on to Innsbruck to enter the field of quantum optics together with Prof. A. Zeilinger. Since 1999 he holds a professorship for experimental quantum optics at the Ludwig-Maximilians-Universität Munich, where he served as a vice-dean of the Physics Faculty from 2008 to 2012. He has received numerous awards for his work, including the Descartes Prize from the European Union in 2004, and the Copernicus Award 2014 issued jointly by the German Research Foundation and the Foundation for Polish Science. He has also been a Max Planck Fellow at the Max-Planck-Institute of Quantum Optics in Garching since 2010.

[1] University of Munich and Max Planck Institute for Quantum Optics, Germany
[2] University of Vienna, Austria

P5: Sweep a qubit to entangle states and to gauge its environment

Prof. Peter Hänggi, Universität Augsburg, Germany, and National University of Singapore

Friday, 6 March, 9:00am, Venue: LT1

Abstract

Joint work of P. Hänggi[3], M. Wubs[4], K. Saito[5], S. Kohler[6], Y. Kayanuma[7], D. Zueco[8], and G.M. Reuther[9].

Here, we shall demonstrate that the sweep of a Qubit which is coupled to external quantum degrees of freedom (such as quantum oscillator degrees of freedom) is extremely beneficial for entanglement creation and the gauging of quantum dissipation. Recently, we succeeded in the derivation of the *excact zero-temperature transition probability for the dissipative Landau-Zener problem* [1]. The standard, i.e. the non-dissipative Landau-Zener problem, is an exactly solvable textbook example in time-dependent quantum mechanics, having found its way into many applications in physics and chemistry. Our exact result [1] constitutes an prominent generalization: It describes how the coupling of the Qubit to other quantum degrees of freed (such as oscillators) impacts the transition probability. A first application is the realization of a *"photon pump on demand"*. Moreover, the measurement of this transition probability allows for a precise gauging of the quantum-dissipation at work. We find that the final quantum state exhibits a peculiar entanglement between the Qubit and the coupled quantum oscillator degrees [2]. It is thus possible to selectively perform a multi-partite entanglement among different oscillator degrees of freedom [3], – including an entanglement with a whole bath [1, 4]. A large class of realistic types of coupling is considered. Surprisingly, the final transition probability is not affected at all by environments that only cause pure dephasing. In general, we find that Landau-Zener sweeps provide a robust tool for characterizing the environment of a tunable Qubit. Promising applications include superconducting Qubits, especially in circuit-QED [2-6].

References:

[1] M. Wubs, K. Saito, S. Kohler, P. Hänggi, and Y. Kayanuma:
Gauging a quantum heat bath with dissipative Landau-Zener transitions, Phys. Rev. Lett **97**, 200404 (2006).

[2] K. Saito, M. Wubs, S. Kohler, P. Hänggi, and Y. Kayanuma:
Quantum state preparation in circuit QED via Landau-Zener tunneling, Europhys. Lett. **76**, 2228 (2006).

[3] M. Wubs, S. Kohler, and P. Hänggi:
Entanglement creation in circuit QED via Landau-Zener sweeps, Physica E **40**, 187197 (2007).

[3]University of Augsburg, and NUS
[4]The Niels Bohr Institute, Copenhagen
[5]Keio University, Yokohama, Japan
[6]Instituto de Ciencia de Materiales de Madrid (CSIC), Spain
[7]Osaka Prefecture University, Japan
[8]CSIC-Universidad de Zaragoza, Spain
[9]also University Augsburg, Germany

[4] K. Saito, M. Wubs, S. Kohler, Y. Kayanuma, and P. Hänggi:
Dissipative Landau-Zener transitions of a qubit: Bath-specific and universal behavior, Phys. Rev. B **75**, 214308 (2007).

[5] D. Zueco, G. M. Reuther, P. Hänggi, and S. Kohler:
Entanglement and disentanglement in circuit QED architectures, Physica E **42**, 363–368 (2010).

[6] D. Zueco, P. Hänggi, and S. Kohler:
Landau-Zener tunnelling in dissipative circuit QED, New J. Phys. **10**, 115012 (2008).

About the Speaker

Prof. Peter Hänggi received his PhD from the University of Basel, Switzerland in 1977, after which he had postdoc stints at the University of Illinois, Urbana-Champaign, University of California, San Diego and a visiting professorship in Stuttgart, Germany. In 1980, he became Assistant Prof and later Associate Professor at the Polytechnic Institute of New York, New York, from where he moved to the University of Augsburg, Germany to take on a his current Full Professor position in 1986. He received countless awards and honours, among the more recent ones the Distinguished Scientist Award and Medal,of the Ben-Gurion University in 2014, the Lars Onsager Medal 2011, and the RIKEN Eminent Scientist Award in 2003 . He held and does hold many visiting positions, and an amazing number of honorary PhD from all over the world. He is member of a vast number of professional societies (among them the European Academy of Sciences, the Academia Europaea, and the American Association for the Advancement of Science - AAAS), and editorial board member or editor of over 15 journals, among them the New Journal of Physics, Europhysics Letters or the European Physical Journal.

His main research area is Theoretical Statistical Mechanics, with specific interest in the Brownian motors, dissipative quantum physics and tunneling, quantum control, stochastical resoance and transport theory. Prof. Hänggi's findings have an impact e.g. on biophysics, nonlinear dynamics, quantum information, microfluidics and even elementary particle physics, and he is well-known everywhere for his active discussion culture in interacting with fellow scientists.

P6: Advanced concepts in atom interferomertry

Prof. Philippe BOUYER, LP2N, Laboratoire de Photonique Numérique and Nanosciences, Institut d'Optique Graduate School IOA, France

Friday, 6 March, 9:45am, Venue: LT1

Abstract

The remarkable success of atom coherent manipulation techniques has motivated competitive research and development in precision metrology. Matter-wave inertial sensors – accelerometers, gyrometers, gravimeters – based on these techniques are all at the forefront of their respective measurement classes. Atom inertial sensors provide nowadays about the best accelerometers and gravimeters and allow, for instance, to make the most precise monitoring of gravity or to device precise tests of the weak equivalence principle (WEP). We present here some recent advances in theses fields.

I will present the recent progress in compact and transportable atom interferometer. The outstanding developments of laser-cooling techniques and related technologies allows nowadays to develop reliable instruments that can be used outside the laboratory. For instance, this lead to the demonstration of an airborne matter-wave interferometer, which operated in the micro-gravity environment created during the parabolic flights of the Novespace Zero-g aircraft [1]. In addition to the potential commercial applications, such instruments can be used for exploring the frontiers of fundamental physics [2]. Using two atomic species (for instance ^{39}K and ^{87}Rb) can allow to verify that two massive bodies will undergo the same gravitational acceleration regardless of their mass or composition. An atom-interferometric test of the WEP can thus be performed on ground or even in space.

I will also introduce the new concepts of matter-wave interferometry that will be used to study sub Hertz variations of the strain tensor of space-time and gravitation. For instance, the MIGA instrument which is currently built in France, will allow the monitoring of the evolution of the gravitational field at unprecedented sensitivity, which will be exploited both for geophysical studies and for Gravitational Waves (GWs) detection.

[1] R. Geiger, et al., Detecting inertial effects with airborne matter-wave interferometry, Nature comm. **2**, 474 (2011).

[2] B. Barrett, et al., Mobile and remote inertial sensing with atom interferometers, arXiv:1311.7033 / Proceedings of the International School of Physics "Enrico Fermi" on Atom Interferometry (2014).

[3] B. Canuel, et al., The matter-wave laser interferometer gravitation antenna (MIGA): New perspectives for fundamental physics and geosciences, E3S Web of Conferences **4**, 01004 (2014).

About the Speaker

Prof. Philippe Bouyer is Director of Laboratoire Photonique, Numérique et Nanosciences, Bordeaux, France. He also holds a position as a Research Director at CNRS.

5 Poster Sessions

PO1: Rapid fire poster pitch student competition

As in the last two years, we have a full session (Thursday before lunch) with no parallel technical sessions where all IPS participants get your audience for a supershort (3 minutes) presentation on a poster if the authors want to participate. In order to encourage authors to participate, we will choose the Best Poster Award this year form those submissions where there was short presentation in this session.

For this, we just project your poster on the screen in the lecture hall (please provide us with a PDF file for that purpose). You can email this to us via postersipsmeeting.org, or leave it with the reception desk.

IPS Best Poster Award

During the conference the program committee will select the three best poster presentations for the IPS Best Poster Award. The award will be handed over to the winners at the Poster & Pizza session PO2 on Thursday evening, probably around 6pm-7pm at (Venue: Atrium).

PO2: General poster presentation

Timing

Posters are presented during the whole conference; perhaps you can make sure that the posters are up as soon as you can. We encourage everyone to browse around during coffe breaks and lunchtime (catered lunch is nearby). We would recommend that the best time for the poster presenters to be around at the poster is the Thursday evening session that comes together with some food and drinks as well. Please take down the posters by latest at the end of the conference, i.e., on Friday noon latest.

Location

The poster area will be in the foyer. Each poster is assigned a panel which corresponds to the easychair number. We will provide Velcro strips to mount the posters on the wall, please see the reception desk for this.

Format

The poster walls fit a A1 sized poster (portrait orientation).

Abstracts

Below, we show a list of abstracts submitted by the authors. You can locate the poster of your interest via the easychair number from the poster submission, they are sorted and labelled by these numbers.

PO2.4 Linear and nonlinear two-photon bunching on an atomic beam splitter

Alexandre Roulet*, Huy Nguyen Le, Valerio Scarani (Centre for Quantum Technologies, National University of Singapore)

Optical emitters strongly coupled to photons propagating in one-dimensional waveguides are a promising platform for optical quantum information processing. Here, we present a theoretical study of the scattering of two indistinguishable photons on a single two-level atom in a Hong-Ou-Mandel set-up. By computing the dynamics, we can describe the system at any time of the scattering event. This allows us to highlight the one-to-one correspondence between the saturation of the atom and the effective interaction induced between the photons. Furthermore, we discuss potential applications for on-chip quantum computing.

PO2.5 Optoelectronic properties of graphene and other two dimensional materials

Xuechao Yu*, Qijie Wang (School of Electrical & Electronic Engineering, Nanyang Technological University)

Graphene and other 2D materials have attracted tremendous attention thanks to their extraordinary electronic and optical properties, accommodating a large potential in modern optoelectronic applications such as photodetection. Graphene is considered as a suitable candidate for ultrafast and broadband photodetector, however, suffering from low light absorption and photoresponsivity. In our group, nanostructured graphene (graphene quantum dots and nanoribbons) were employed to enhance the photoresponsivity of graphene based photodetector. The low detectivity of graphene photodetector based on photoconductive mode operation remains big challenges in further applications. Here, we demonstrated the photovoltaic mode operation in graphene p-n junctions fabricated by a simple but effective electron irradiation method that induces n-type doping in the intrinsic p-type graphene and exhibit a high detectivity of 3×1010 Jones. On the other hand, metal dichalcogenides and black phosphorene with strong in-plane and weak out-of-plane interactions open up new opportunities for 2D materials for optoelectronic applications. Single crystal 1T phase Tin Diselenide (SnSe2) was synthesized and exfoliated into single and few layers. Atomically layered SnSe2 field-effect transistors displayed a high responsivity (0.5 A/W) and response time (2 ms) in the visible range. Few layer black phosphorene p-n junction formed by chemical doping was also demonstrated as a promising material for IR photodetector and filled the gap between graphene and metal dichalcogenides.

PO2.7 Conductive Shell Protected Vanadium Oxide Flexible Electrodes to Boost the Electrochemical Performance of Li and Na Ion Batteries

Dongliang Chao*, Changrong Zhu, Hong Jin Fan, Ze Xiang Shen* (NTU)

In order to pursue high-performance lithium and sodium ion batteries (LIB, SIB) with both high energy and power densities, in this work, we design and construct light bind-free integrated positive electrodes by combing VO_2@(GQD, graphene quantum dots) nanoarrays and self-supported ultralight graphene foam (GF). This multivariate integrated electrode combines the strategies of nanoporous design and conductive composite design. Such an integrated electrode not only possesses merits of nanostructures with short ion/electron diffusion path, but also shows improved structural stability and omni-bearing charge transfer modification for VO_2 by the GQDs and GF. As positive electrodes for LIBs and SIBs, the as-prepared GF-VO_2@GQD nanoarray exhibits superior Li and Na ion storage properties with high specific capacity, high-rate capability and high-rate cycling stability. Impressively, it delivers a noticeable Na storage capacity of 300 mAh g^{-1} at 0.5 C as well as a capacity of 110 mAh g^{-1} at 60 C after 1500 cycles. It is prospected that such integrated electrode design strategy can also be extended to fabricate other advanced electrode materials for applications in supercapacitors, full cells and catalysis.

PO2.8 Enhanced Lithium Storage Performance of CuO Nanowires by Coatings of Graphene Quantum Dots

Changrong Zhu*, Dongliang Chao, Hongjin Fan* (NTU-SPMS-PAP)

A new type of CuO/Cu/graphene quantum dots (GQDs) triaxial nanowires (referred as CCG) has been designed and successfully fabricated using a two-step electrochemical process followed by annealing. The synergistic combination of high-capacity metal oxide CuO and conductive layers of Cu and GQDs exerts an enhanced electrochemical performance for Li ion storage. The triaxial nanowire CCG electrode shows an improved reversible capacity (ca. 760 mAh g^{-1} cycled at 1/3 C) and rate capability (60 % capacity retention cycled at 10 C) compared with nanowires without GQDs coating. A relatively high initial coulombic efficiency (87 %) is obtained for the CCG anode as a result of the Cu and GQDs double layers. Meanwhile, the CCG anode showed high capacity retention in long cycles reached up to 1000 cycles. This ultrastability can be ascribed to the GQDs shell which provides an elastic protection for the nanowires and conductive path for electrons. Our results demonstrate the effectiveness of GQDs coating in improving the electrochemical performance and stability of nanostructured electrodes for Li ion batteries and possibly also for other electrochemical devices.

PO2.9 Interlayer Coupling and Electronic Structure of Trilayer MoS_2

Juan Xia, Jiaxu Yan, Xingli Wang, Zheng Liu, Zexiang Shen* (Nanyang Technological University)

Two dimensional transition metal dichalcogenide (2D-TMD) materials, such as MoS_2, $MoSe_2$, WSe_2, WTe_2, are among the hottest materials in research today due their many outstanding properties. They often show very strong layer-dependent properties, where interlayer coupling plays a key role in determining the optical and electronic properties. The layer-layer interaction and stacking sequence provide additional means for tuning the properties of two-dimensional materials. In this study, we demonstrate that MoS_2 trilayer samples grown by chemical vapour deposition with four different stacking configurations (AAB, ABB, ABA, AAA) exhibit distinct coupling phenomena in photoluminescence and Raman spectra. By means of ultralow-frequency Raman spectroscopy, the evolution of interlayer interaction for stacking order shows strong correlation with layer-breathing mode (LBM). Our ab initio calculations reveal that such interaction arises from competition between spin-orbit coupling and interlayer coupling in different structural configurations. Such insights will provide useful guidance to future spintronic device fabrication utilizing differently stacked few-layer MoS_2.

PO2.13 Complete achromatic optical switching between two waveguides with a sign flip of the phase mismatch

Wei Huang*, Andon Rangelov*, Elica Kyoseva* (Singapore University of Technology and Design)

We present a two-waveguide coupler which, realizes complete achromatic all-optical switching. The coupling of the waveguides has a hyperbolic-secant shape while the phase mismatch has a sign flip at the maximum of the coupling. We derive an analytic solution for the electric field propagation using coupled mode theory and show that the light switching is robust again small-to-moderate variations in the coupling and phase mismatch. Thus, we realize an achromatic light switching between the two waveguides. We further consider the extended case of three coupled waveguides in an array and pay special attention to the case of equal achromatic light beam splitting.

PO2.20 Driven standard optomechanical system

Christian Ventura-Velázquez*, Blas Manuel Rodríguez-Lara*, Héctor Manuel Moya-Cessa (Instituto Nacional de Astrofísica, Óptica y Electrónica)

By using sets of unitary transformations, we study the behavior of the driven standerd optomechanical system and show that, under the Lamd-Dicke regime, the composite system has a behavior similar to a driven trapped ion, so in the red-detuned sideband it is posible to cool de mechanical oscillator.

PO2.25 Spectrometry with Michelson Interferometer

Bianca Lee*, Shao Xuan Seah, Erkan Polatdemir*, Peng Kian Tan* (Centre for Quantum Technologies / Physics Department, National University of Singapore)

Conventional spectrometers have their resolution limited by their diffraction grating's slit separation and their detector, typically a charge-coupled device. We aim to build a spectrometer with photon level resolution, using a Michelson interferometer and an avalanche photon detector in conjunction with Fourier transformation techniques. This has possible applications in astronomy due to the low intensities of the relevant light sources.

PO2.27 Classifying 50 years of Bell inequalities

Denis Rosset*, Jean-Daniel Bancal*, Nicolas Gisin* (GAP-Optique, Université de Genève)

Since John S. Bell demonstrated the interest of studying linear combinations of probabilities in relation with the EPR paradox in 1964, Bell inequalities have lead to numerous developments. Unfortunately, the description of Bell inequalities is subject to several degeneracies, which make any exchange of information about them unnecessarily hard. Here, we analyze these degeneracies and propose a decomposition for Bell-like inequalities based on a set of reference expressions which is not affected by them. These reference expressions set a common ground for comparing Bell inequalities. We provide algorithms based on finite group theory to compute this decomposition. Implementing these algorithms allows us to set up a compendium of reference Bell-like inequalities, available online at www.faacets.com . This website constitutes a platform where registered Bell-like inequalities can be explored, new inequalities can be compared to previously-known ones and relevant information on Bell inequalities can be added in a collaborative manner.

PO2.28 Mechanically unfolding ribosomal frameshift-inducing RNA pseudoknots in Simian Retrovirus type 1 using optical tweezers

Zhensheng Zhong, Lixia Yang, Jiahao Shi, Jeya Vandana, Gang Chen* (Nanyang Technological University)

Minus-one Ribosomal frameshifting is an alternative translational mechanism widely utilized by RNA viruses to generate accurate ratios of structural and catalytic proteins. However the detailed mechanism of -1 ribosomal frameshifting is still unknown. An RNA pseudoknot structure located in the overlapping region of gag and pol genes of Simian Retrovirus type 1 (SRV-1) stimulates frameshifting. Using optical tweezers, we studied the single-molecule mechanical unfolding of a series of pseudoknots derived from the wildtype SRV-1 frameshifting pseudoknot. Our studies show that the mechanical stability of the pseudoknots, which is modulated by the base-triple formation and loop size, determines the -1 frameshifting efficiency.

PO2.29 Anharmonicity in Quantum Thermodynamic Cycles

Yuanjian Zheng*, Dario Poletti* (Singapore University of Technology & Design)

We study the performance of quantum Otto cycles driven by anharmonic trapping potentials under scale invariant driving. We show that while both mean work and efficiency of two cycles in different trapping potentials can be made equal, the work probability distribution for a single particle is still strongly affected by the difference in structure of the energy levels. This strong dependence on trap geometry is accentuated by the exchange symmetries of particles. Most notably, we prove that the work distribution for a system consisting of bosons is identical to that of fermions in a harmonic well, which we explain as a direct consequence of the regularity in its spectrum. Lastly, we demonstrate the nature of work statistics under the influence of exchange symmetries in potentials with qualitatively different spectrums. This paves the way for control of a quantum engine through design of the trap geometry.

PO2.30 Energy tranport in ion chain: relaxation, steady state and interaction

Chu Guo*, Manas Mukherjee, Dario Poletti* (Singapore University of Technology and Design)

Characterizing and controlling energy transport in nanostructure can provide tremendous implications for future technologies. Fundamental studies both on the theoretical and experimental side are required. A promising prototype to study the energy transport is the ultra cold ions, which provides a clean, well controlled and highly tunable experimental set up. Each ion can vibrate around its equilibrium position, and these vibrons can tunnel between different ions due to the Coulomb interaction between the ions. Moreover, with site-resolved side-band cooling, it is possible to impose a probability distribution of the different vibrational modes for any ion in the lattice. Moreover, in this set up it is possible to measure, both locally and globally, the vibrational modes excited. In this work, we study the energy transport in a chain of driven ultra cold ions. We use the quantum master equation to analyse both the dynamics and the steady state of the ion chain, and focus on several different configurations. Numerically, we use both the exact diagonalization and time-evolving Matrix Product State (tMPS) method. First, for the two sites case, we adiabatically eliminate the ion with laser and get a master equation for the vibrons on the other site, with this master equation, we can analytically study the interplay between the interaction and the dissipation. Second, for a chain with laser side-band cooling only one of the ions, we find that depending on whether the the laser acts on the even or odd number of site, the ion cain will likely have a unique steady state or not. For the former case, we also find that each ion with the same distribution fixed by the laser is a steady state of the system and it is likely to be unique. Third, we study the configuration with two boundary driving, which can form a energy and particle current through the chain, previous results have shown that without interaction the transport will be ballistic. And we find that with interaction on the middle site, the current will decrease, as well as the steady state average vibron occupation on the middle site. Also in the case with only three ions, we find an analytic solution which converges well with the numerical solutions.

PO2.37 Linearized dynamics of gas bubbles in gelatin under ultrasound forcing

Keita Ando*, Fumiya Hamaguchi (Keio University)

Acoustically forced oscillation of a spherical gas bubble in a viscoelastic medium is studied through comparisons between experiments and linear theory. An experimental setup is designed to observe dynamics of a spherical gas bubble in viscoelastic materials. A gas bubble was created by focusing an infrared laser pulse into gelatin. Observations of the spherical bubble oscillation driven by ultrasound were demonstrated to examine effects of viscoelasticity on its dynamics around resonance. The observations showed that the frequency response was shifted to the high frequency side and its peak was suppressed as the gelatin concentration increases. The measurements were compared to the linearized Rayleigh-Plesset equation closed with the Voigt model for linear viscoelastic solids. The fitting yields reasonable agreement by tuning unknown values of viscosity and rigidity of the gelatin of 3 and 6 w% concentration.

PO2.38 Translation of a microbubble interacting with megasonic waves in viscoelastic media

Keita Ando*, Eriko Shirota, Fumiya Hamaguchi (Keio University)

We report on experiments on the translation of a microbubble in a viscoelastic material under the forcing of megasonic waves whose frequency is much larger than natural frequencies of the bubble. An optical system using a high-speed camera is designed to observe bubble translation as well as deformation in gelatin induced by acoustic radiation force that originates from acoustic impedance mismatching at the bubble interface. Physical properties of the gelatin we use are inferred from comparisons between measured evolution of the bubble translation and the theory for bubbles in a (linear) Voigt viscoelastic solid. The relevance of bubble deformation to the translational motion is also discussed.

PO2.39 Cavitation resulting from shock-bubble interaction in viscoelastic media

Keita Ando*, Ryota Oguri, Takahiro Oda (Keio University)

We experimentally demonstrate that cavitation can arise from shock-bubble interaction in viscoelastic media. A gas bubble whose lifetime is on the order of minutes is produced by focusing an infrared laser pulse into gelatin. A spherical shock is created, through rapid expansion of plasma that results from the laser focusing, in the vicinity of the bubble. The shock-bubble interaction is captured by a CCD camera with flash illumination of a nanosecond green laser pulse. The observation captures cavitation inception in the gelatin under tension that results from acoustic impedance mismatching at the bubble interface. Namely, the shock reflects at the bubble interface as a tension wave, which induces the nucleation of cavitation bubbles as a result of rupturing the gelatin.

PO2.42 Half-skyrmion and meron pair in spinor condensates

Yuxin Hu, Benoit Gremaud*, Christian Miniatura (CQT,)

We propose a simple experimental scheme to generate spin textures in the ground state of interacting ultracold bosonic atoms loaded in a two-dimensional harmonic trap. Our scheme is based on two co-propagating Laguerre-Gauss laser beams illuminating the atoms and coupling two of their internal ground state Zeeman sublevels. Using a Gross-Pitaevskii description, we show that the ground state of the atomic system has different topological properties depending on the interaction strength and the laser beam intensity. A half-skyrmion state develops at low interactions while a meron pair develops at large interactions.

PO2.43 Fast Quantum Random Number Generator

Yicheng Shi*, Mei Yuen Chng, Christian Kurtsiefer (center for quantum technologies)

Various quantum and classical communication schemes require a large number of good random numbers. We build and characterize a miniature setup performing a homodyne measurement on the vacuum fluctuations(photon number fluctuations of a coherent beam) and use the output as the source signal of a quantum random number generator(QRNG). The device can be run off USB power and consists of a simple laser diode and a polarizing beam splitter, 2 photodetectors and associated electronics to convert the signal into digital bits in a small portable housing. Accompanied with a fast and compact post-processing extraction algorithm, we can now generate secure random numbers at a rate of 60Mbyte/s.

PO2.44 Optimal error intervals for quantum parameter estimation

Xikun Li*, Jiangwei Shang, Hui Khoon Ng, Berthold-Georg Englert (CQT, NUS)

To directly estimate certain properties of an unknown quantum state without going through full state reconstruction has attracted a lot of attention recently. As a generalization of the concept of optimal error regions for quantum state estimation [see New J. Phys. 15, 123026 (2013)], we propose a systematic method to construct error intervals for quantum parameters directly from experimental data without relying on complete state reconstruction. Surprisingly, the optimal choice of error intervals can be characterized simply by finding the constant likelihood values conditional on the parameter. For illustration, we identify the optimal error intervals for fidelity (with respect to certain target states) and purity of single-qubit states, as well as the CHSH quantity for two-qubit states.

PO2.46 Low temperature photoresponse of monolayer tungsten disulphide

Bingchen Cao, Ting Yu*, Mustafa Eginligil* (Nanyang Technological University)

Photo-induced effects in monolayers of semiconducting transition metal dichalcogenides (TMDs) are of great interest since the band gap of these materials corresponds to visible range of spectrum. Although high photo-response can be achieved in TMDs, the response time is inconveniently limited by defects. Here we report our low temperature photo-response studies of tungsten disulphide (WS_2), a TMD with less defects, based field effect transistor (FET) prepared by both mechanical exfoliation and a recent chemical vapor deposition (CVD) method. The FET fabricated from mechanical exfoliation exhibits n-type behavior while the other one fabricated from a triangular flake grown by CVD exhibits intrinsic behavior. Upon illumination by 532 nm laser, the CVD device, which is in OFF state at dark, can be turned ON. But the current values are about two orders of magnitude smaller compared to the exfoliated sample which can be ON at 3V gate voltage, even at dark. For -40V gate voltages, there is a clear monotonic dependence of the drain current on illumination power, for the CVD sample. The temporal measurements of photo-responsivity at -40V gate voltage and highest applied drain voltage showed that light on/off ratio is about four times larger in the CVD sample. More strikingly, the CVD based FET's photo-response decay and rise times are on the order of 0.1 second (limited by the setup), while the exfoliated one has few seconds. These findings can be understood in terms of trap states in the exfoliated sample and localization in the CVD sample.

PO2.47 Active feedback control of magnetic field for cold strontium experiments

Chang Chi Kwong*, Kanhaiya Pandey, Mysore Srinivas Pramod, Frédéric Leroux, Vladimir Akimov, David Wilkowski* (Nanyang Technological University; Centre for Quantum Technologies, National University of Singapore; Majulab, CNRS-UNS-NUS-NTU International Joint Research Unit UMI 3654)

We implement an active feedback loop on the magnetic field for cold atomic experiments. The system consists of a network of 8 three-axis magnetic field sensors that extrapolate the components of the magnetic field at the position of the atom. Three pairs of compensation coils, in Helmholtz configuration, are used to set the DC magnetic field, with an accuracy in the milligauss range. Additionally, we are able to suppress the 50 Hz AC magnetic field, maintaining a constant magnetic field at submilligauss precision. We carry out magneto-optical experiments that involves Faraday rotation in the coherent forward transmission of light, to perform an absolute calibration of the sensors and to improve substantially the accuracy. Properly calibrated, this system paves the way for future experiments targeting the intercombination line of strontium, where the transition linewidth corresponds to a Zeeman shift of 3.6 mG.

PO2.48 Superflashes of coherently transmitted light through a cloud of cold atoms

Chang Chi Kwong*, Tao Yang, Mysore Srinivas Pramod, Kanhaiya Pandey, Dominique Delande, Romain Pierrat, David Wilkowski* (Nanyang Technological University; Centre for Quantum Technologies, National University of Singapore; MajuLab, CNRS-UNS-NUS-NTU International Joint Research Unit UMI 3654)

We study transient phenomena in the coherent transmission of light through an optically thick cold strontium gas. We observe coherent superflashes of light, in the forward transmission, immediately after an abrupt extinction of the probe. For the optical thickness that is within the reach of our experimental setup, we observe a peak intensity of the flash which is more than 3 times the incident intensity. We further show that similar flashes of high peak intensities can be generated by abrupt change in the phase of the incident field. We give a simple explanation of the occurrence of these superflashes. It also allows us to provide theoretical bounds on the maximum peak intensity of the flashes. The time scale of these flashes are much shorter than the transition lifetime of the atom. We make use of this property of the flashes to experimentally generate high repetition rate pulse trains. In the optimal setting, spontaneous emission of the atoms can be suppressed, while maintaining a high contrast of the pulses.

PO2.49 Quantum State Estimation of a Self-calibrating Experiment

Jun Yan Sim*, Jiangwei Shang, Hui Khoon Ng, Berthold-Georg Englert (Centre for Quantum Technologies)

Self-calibrating quantum state estimation is the procedure of reconstructing the quantum state and certain properties of the measurement devices from the same data. We apply self-calibration to the double-crosshair POM of the BB84 scenario for reconstructing the state and detector efficiencies simultaneously. When we perform maximum likelihood estimation, we observe multiple maxima in the likelihood function even when the state parameters and detector efficiencies are uniquely determined by detection probabilities. This problem disappears when prior knowledge of the ratios of detector efficiencies is taken into account.

PO2.53 Ultra-fast Mode Switching on Ge-Sb-Te Cored Optical Fibers

Duc Minh Nguyen*, Behrad Gholipour, Long Cui, Cesare Soci* (Centre for Disruptive Photonic Technologies, NTU)

Data-carrying capacity in optical communication system has been increasing rapidly for several decades and is now approaching the limit on single-mode-fiber-based transmission systems. This barrier can be overcome by the use of space-division multiplexing (SDM) on multi-core fibers or few-mode-fibers, thus the development of electro-optic or all optical devices on SDM network systems has drawn a great deal of interest. Here we report a spatial mode modulator based on phase change material (PCM) cored step index optical fibers that can modulate actively spatial modes in a few-mode-fiber on nanosecond and sub-nanosecond time scale. Because of a large shift of refractive index of PCMs (for example, a refractive index shift of 2.5 for germanium antimony telluride (GST) at 1.5 um in this case) when changing between amorphous states and crystalline states in mid-infrared regime, the PCMs cored fibers will become a monomode/multimode switching platform and the number of mode can be selected, if the core diameter is designed around the cut-off condition at the amorphous state. In our work, the core diameter of 400 nm is designed at the amorphous cut-off condition, and optical pulses are illuminated from the fiber side to induce phase change within the nano-core to switch the fiber between different modal states. Because the refractive index n of amorphous GST is around 2 at 1.5 um, only a small shift of n (0.1) is required to switch the fiber to multimode operation. The reversible phase change of GST can occur at subnanosecond time scale and thus allow an ultrafast modulation of the core refractive index and the excited optical modes. The modulator has limitation of coupling due to the sub-micron size of the core, but it can be improved by using microstructure photonic crystal fibers.

PO2.55 Hamiltonian Monte Carlo sampling for the quantum state space

Yi-Lin Seah*, Boyu Wang, Jiangwei Shang, Hui Khoon Ng, David John Nott, Berthold-Georg Englert (CQT)

Hamiltonian Monte Carlo (HMC) is an efficient method for sampling the quantum state space as it gives a high acceptance rate, while producing sample points that are not strongly correlated, as in the case of typical Markov Chain Monte Carlo (MCMC) random walks. However, HMC requires a suitable parameterization of the state space to work. Even with such a parameterization, the implementation can be very involved. In this work, we discuss some of our approaches to these challenges.

PO2.59 Quantum State Tomopgraphy with Additional Unknown Parameters

Jibo Dai*, Yink Loong Len*, Yong Siah Teo*, Hui Khoon Ng*, Berthold-Georg Englert* (CQT, NUS)

We look at cases in quantum state tomography where some additional parameters other than the states to be reconstructed are also unknown. Following a recent publication to reconstruct optimal error regions based on bounded-likelihood region, we estimate both the state and additional parameters with optimal regions. The optimal error regions constructed is a joint property of the state parameters and the other parameters as a whole. The experimenter may want to separate the different estimators from their joint optimal regions, and attaching error regions (intervals) to them separately. We show that this can be achieved systematically by marginalizing over the nuisance parameters to obtain a marginal likelihood which only depends on the parameter of interest. We illustrate the method and technique with several examples, some of which displaying unusual features in the likelihood function.

PO2.64 Shaping single photons for efficient absorption

Mathias Seidler*, Victor Javier Huarcaya Azanon, Alessandro Cerè, Victor Leong, Mathias Steiner, Christian Kurtsiefer (CQT)

We obtain heralded single photons from a pair source based on a four-wave mixing process in a cold atomic ensemble of 87Rb [1]. These photons are resonant to the 87Rb ground state transition and their temporal shape is a decaying exponential. Previous experiments showed that an exponentially rising light pulse is ideal for efficient absorption in a single atom [2]. We can reverse the temporal profile of our photons with the help of a cavity with matching bandwidth [3]. A single 87Rb atom, trapped in a far detuned dipole trap, is ready for interaction in our lab [4]. We plan to measure the absorption probability of our heralded single photon as a function of its time envelope.

References [1] Bharath Srivathsan et al., Phys. Rev. Lett. 111, 123602 (2013) [2] Syed Abdullah Aljunid et al., Phys. Rev. Lett. 111, 103001 (2013) [3] Bharath Srivathsan et al., Phys. Rev. Lett. 113, 163601 (2014) [4] Syed Abdullah Aljunid et al., Journal of Modern Optics 58, 299-305 (2011)

PO2.66 Inhomogeneous Photoluminescence of Hexagonal Monolayer WS_2 by Chemical Vapor Deposition Method

Shoujun Zheng, Linfeng Sun, Hong Jin Fan* (Nanyang Technological University)

We fabricated hexagonal shape WS_2 from monolayer to 7 layers by CVD method at 1100°C high temperature. Photoluminescence (PL) of hexagonal WS_2 monolayer presents inhomogeneous intensity with different positions which is supposed to result from the inhomogeneous composition in the growth process. Photoluminescence from hexagonal monolayer to hexagonal multilayer shows the transition of 2-D WS_2 from direct band gap to indirect band gap.

PO2.68 Epitaxy-Enabled Growth of Planar and Vertical ITO Nanowires with Controlled Orientations

Youde Shen*, Stuart Turner, Ping Yang, Gustaaf Tendeloo, Oleg Lebedev, Tom Wu* (University of Science and Technology (KAUST))

Controlling nanowire morphology in bottom-up synthesis and assembling them on planar substrates is of tremendous importance for device applications in electronics, photonics, sensing and energy conversion. To date, however, there has been only limited success in reliably achieving these goals, hindering both the fundamental understanding of the growth mechanism and the integration of nanowires in real-world technologies. Here we report that growth of planar, vertical and randomly oriented tin-doped indium oxide (ITO) nanowires can be realized on yttria-stabilized zirconia (YSZ) substrates via the epitaxy-assisted vapor-liquid-solid (VLS) mechanism, by simply regulating the growth conditions, in particular the growth temperature. Our (scanning) transmission electron microscopy and reciprocal space mapping experiments reveal the indispensable role of substrate-nanowire epitaxy in the growth of oriented planar and vertical nanowires at high temperatures, whereas randomly oriented nanowires without epitaxy grow at lower temperature. Further control of the orientation, symmetry and shape of the nanowires can be achieved by using YSZ substrates with (110) and (111), in addition to (100) surfaces. Based on these insights, we succeed in growing regular arrays of planar ITO nanowires from patterned catalyst nanoparticles. Overall, our discovery of unprecedented orientation control in ITO nanowires advances the general VLS synthesis, providing a robust epitaxy-based approach towards rational synthesis of nanowires.

PO2.69 Optical Conductivity Studies on Bi_2Te_3&single-layer-graphene in Terahertz Range

Huanxin Xia, Meng Zhao, Chan La-O-Vorakiat, Xingquan Zou, Kian Ping Loh, Elbert Chia* (Nanyang Technological University)

The real part of the optical conductivity of the topological insulator Bi_2Te_3, single-layer-graphene (SLG), and Bi_2Te_3/SLG composite, all grown on p-doped Si substrate, were obtained using terahertz time-domain spectroscopy (THz-TDS), in the temperature range 10 – 300 K and frequency range 0.3 - 3 THz. Besides, gating experiments were performed on pure graphene and graphene with Bi_2Te_3 nanoparticles. Both the Drude responses, and three Raman-infrared-active optical phonon modes, were observed in Bi_2Te_3 and Bi_2Te_3/SLG composite. The Drude contribution from SLG in the Bi_2Te_3/SLG composite was surprisingly suppressed above 80 K, whose origin was ascribed to electron injection from Bi_2Te_3 to Graphene.

PO2.71 Scalable quantum memory in the ultrastrong coupling regime

Thi Ha Kyaw*, Simone Felicetti, Guillermo Romero, Enrique Solano, Leong Chuan Kwek (Centre for Quantum Technologies, National University of Singapore)

Circuit quantum electrodynamics, consisting of superconducting artificial atoms coupled to on-chip resonators, represents a prime candidate to implement the scalable quantum computing architecture because of the presence of good tunability and controllability. Furthermore, recent advances have pushed the technology towards the ultrastrong coupling regime of light-matter interaction, where the qubit-resonator coupling strength reaches a considerable fraction of the resonator frequency. Here, we propose a qubit-resonator system operating in that regime, as a quantum memory device and study the storage and retrieval of quantum information in and from the Z_2 parity-protected quantum memory, within experimentally feasible schemes. We are also convinced that our proposal might pave a way to realize a scalable quantum random-access memory due to its fast storage and readout performances.

PO2.72 Density Functional for One-Dimensional Fermion-Boson-Mixtures in Thomas-Fermi Approximation

Jun Hao Hue*, Yilun Guan*, Martin-Isbjörn Trappe, Berthold-Georg Englert (Center for Quantum Technologies, NUS)

Ultracold fermions and ultracold bosons are known to behave differently in the zero-temperature limit. In a system where two fermions can combine to a boson, this difference in behaviors will result in an interesting distribution of the two species. This study aims to explore this type of system in 1D using a density functional approach - a method that has been used extensively to study ultracold boson and fermion gases. An explicit form of the energy functional which underlies the conversion process is proposed, and numerical results of the distributions are obtained for various parameter regimes.

PO2.75 Probing Quantum-Classical Boundary With Compression Software

Pawel Kurzynski, Dagomir Kaszlikowski, Hou Shun Poh*, Siddarth Koduru Joshi, Alessandro Cerè, Christian Kurtsiefer (CQT / NUS)

We demonstrate that with a pair of deterministic universal Turing machines, it is impossible to replicate the observed quantum bipartite correlations from a spontaneous parametric down-conversion (SPDC) experiment. Using the concept of Kolmogorov complexity K [1] and a Normalised Compression Distance (NCD) [2] which allows for a comparison of two pieces of data without detailed knowledge about their characteristics, we derive an inequality [3] S(A, B) = NCD(A0, B1) - NCD(A0, B0) - NCD(A1, B0) - NCD(A1, B1) $\leq$ 0, that must be obeyed by data generated by two local deterministic universal Turing machines with correlated inputs. With the correlations generated by a maximally entangled polarisation state of two photons, we experimentally probe the dependence of S on the experimental settings. With the accumulated statistics from repeated measurements at the optimsed setting, we violate this inequality with a value of S = 0.0494 $\pm$ 0.0076. The evaluation of the inequality is done by estimating K with conventional lossless compression programs which are routinely used on common computing platforms. We also briefly discuss philosophical and information-theoretical implications of our results.

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PO2.78 Weak Measurement and Quantum Measurement Reversal in Complementarity Principle

Chang Jian Kwong*, Leong Chuan Kwek (Centre for Quantum Technologies)

Decoherence caused by coupling of the system with environment often results in the degradation of quantum coherence which is essentially in implementation of quantum gates and quantum computational. It has been shown that weak measurement and quantum measurement reversal can be used to protect entanglement from decoherence. Here, we study the ability of weak measurement and quantum measurement reversal in protecting quantum coherence from decoherence in interferometric system. By studying the complementarity relation, we observe that the presence of weak measurement and quantum measurement reversal in a single path does not protect against decoherence. Instead, it serve to accelerates the degradation of quantum coherence in the interferometric system, i.e. visibility drops with increasing strength of weak measurement. On the other hand, the presence of the weak measurement and quantum measurement reversal in both paths allows protection against decoherence in the interferometer.

PO2.82 Phonon down-conversion in a linear ion trap

Gleb Maslennikov*, Shiqian Ding, Roland Hablutzel, Huanqian Loh, Dzmitry Matsukevich* (Centre for Quantum technologies)

Ions confined in a Paul trap are well isolated from environment and their motion in the trap is usually well approximated by a set of normal modes. However, Coulomb interaction between trapped ions is nonlinear and can introduce coupling between the normal modes of motion. We report our experimental work on coherent coupling between axial and radial modes of motion in the ion crystal formed by two Yb ions and show that under the resonant conditions one phonon in the axial motional mode of the ion crystal can be down-converted into two phonons in the radial mode of motion.

PO2.83 Supercritical Coulomb Impurity in Graphene under Magnetic Field

Sihao Wang*, Vitor Pereira* (National University of Singapore)

The phenomenon of supercritical collapse in graphene under a magnetic field is analyzed both perturbatively and numerically. An exact analytical solution of the perturbation calculation is obtained. A numerical study over both sub- and supercritical regions reveals a new class of states, the intrinsic supercritical states, which is responsible for the strong features near the origin in the density of states plots. The boundaries of classes of states are identified and mapped for different angular momentum channels. This study obtains the exact eigen-energies and eigenfunctions, which allow a complete understanding of supercritical collapse under a magnetic field, and a direct comparison with recent STM experiments that probe the local density of states in these systems.

PO2.87 Magneto-transverse scattering of light in an atomic beam

Musawwadah Mukhtar*, Pramod Mysore Srinivas, David Wilkowski (Centre for Quantum Technologies, NUS)

We predict magneto-transverse scattering of light in an atomic beam due to corrections of the Lorentz transformation. The scattering of light is due to electric dipolar interaction between high-speed atoms and incident laser beam. The spatial symmetry of light scattering is broken when the atomic velocity is taken into account. As a trivial consequence, the scattering rate is affected by the well-known-Doppler effect. However, this effect alone will not give a magneto-transverse effect. In this work, we show that in the presence of an external magnetic field, transverse scattering imbalance may result along direction of $\vec{v} \times \vec{B}$. It is done by full relativistic treatment of electromagnetic fields of incident and scattered light. We will also present how this small effect can be observed experimentally with strontium atomic beam from an oven at 550 °C.

PO2.88 Efficiently field-free orientation of CO molecules by a femtosecond pulse and a THz pulse train

Yin Huang*, Ting Xie, Shu-Lin Cong (Nanyang Technological University,SPMS/Division of Chemistry & Biological Chemistry)

We theoretically study the field-free orientation dynamics of CO molecules in three cases, with the orientation steered (I) by a single-cycle THz pulse, (II) by a single-cycle THz pulse train L1, and (III) by the combination of an off-resonant femtosecond pulse L0 with L1. In case (I), the strong intensity of the single-cycle THz pulse is required to realize efficient molecular orientation. In case (II), by using a pulse train L1 with experimentally accessible intensity 1 MV/cm, the maximum orientation degree 0.906 is achieved when pulse number N = 25. In case (III), by introducing the Raman excitations of L0, the pulse train L1 with only N = 3 can realize a high degree of orientation 0.896. Moreover, we investigate the dependence of the thermally averaged orientation on the initial rotational temperature in cases (II) and (III). The maximum orientation degree decreases with the increase of rotational temperature in the two cases. However, case (II) is more robust against the rotational temperature.

PO2.96 Replica Exchange Molecular Dynamics Simulation of Cross-Fibrillation of IAPP and PrP106-126

Khi Pin Chua, Lock Yue Chew, Yuguang Mu* (Nanyang Technological University)

Aggregation of proteins into amyloid fibrils has been the central hallmark of a number of protein diseases. Most studies had been done to investigate aggregation between proteins of similar species. However, there have been observations that some patients with certain protein disease can easily acquire another unrelated protein disease (patients with Type II diabetes are associated with elevated risk of dementia for example). Thus studies have been inspired to explore aggregation between proteins of different species, although usually the aggregation can be attributed to similarity between the amino acid sequences. In this paper we were motivated by an experimental study of aggregation between amylin (Islet Amyloid Polypeptide, IAPP) and Prion 106-126 (PrP106-126, residues 106-126) fragment, both of which are not homologous to each other, yet may aggregate quickly to form fibrils in the presence of lipid bilayer. We attempted to elucidate the molecular mechanism of the early fibrillation stage of dimerization of these two peptides through extensive replica exchange molecular dynamics (REMD) simulations. Stable conformations consisting of various degrees of beta-sheets structures, both intra-chain and inter-chain, were found in the simulations. The simulation implied that in the correct condition, both proteins can form an extensive fibrillar structure. The difficulty of forming this structure however, may be the reason why membrane was crucial in the fibrillation process as found from experiment. The mechanism of the fibrillation process was also elucidated by analyzing the continuous trajectory. Very interestingly, a transient alpha-helix structure was found to form before a stable beta-sheet secondary structure emerged. Our study sheds insight into the exciting research of protein cross-fibrillation.

PO2.97 Dimer-induced heavy-fermion superconductivity in the Shastry-Sutherland Kondo lattice model

Lei Su*, Pinaki Sengupta* (Nanyang Technological University)

We study the Kondo lattice model on the geometrically frustrated Shastry-Sutherland lattice focusing on the quantum phase transition between the valence bond solid and the heavy fermion liquid phases. By explicitly including spinon pairing of local moments at the mean-field level, we establish the emergence of a unique heavy fermion superconducting phase induced by dimer ordering of the local moments coexisting with Kondo hybridization. Furthermore, we demonstrate that for suitable choices of parameters, a partial Kondo-screening phase, where some of the valence bonds are broken, precedes the aforementioned dimer-induced superconducting phase. Our results have important implications in understanding the experimental observations in the heavy fermion Shasstry-Sutherland compounds.

PO2.98 Determination of Thermal Conductivity of Suspended Mono- and Bilayer WS_2 using Raman Spectroscopy

Namphung Peimyoo*, Jingzhi Shang, Weihuang Yang, Chunxiao Cong, Yanlong Wang, Ting Yu (Nanyang Technological University)

Atomically thin two-dimensional tungsten disulfide (WS_2) has emerged as an attracting material for electronic and optoelectronic applications due to its striking photoluminescence emission and unique electronic properties. Here, we report the temperature- and power-dependent Raman spectra of monolayer (1L) and bilayer (2L) WS_2 fabricated by using chemical vapor deposition (CVD) technique. In order to avoid the substrate effects, both supported and the suspended samples have been investigated. In the temperature dependent Raman study, the first-order temperature coefficients for the E12g and A1g modes from 1L and 2L WS_2 are obtained. For 1L-WS_2, Raman frequency shift of the A1g mode is greater than that of the E12g mode, which is thought to be due to stronger electron-phonon coupling for the A1g mode than that for the other mode. By integrating the obtained data with the results from the power-dependent Raman modes, the thermal conductivities at room temperature of 1L- and 2L-WS_2 can be estimated to be 32 and 53 W/mK, respectively. Our results enable the fundamental understanding of the thermal property of WS_2, and are of great importance for developing thermal management in electronic and optoelectronic devices based on thin WS_2 layers.

PO2.99 Magnetodielectric Effect and Magnetoresistance in $Eu_{0.4}Ba_{0.6}TiO_3$

Km Rubi*, R Mahendiran* (NUS)

In recent years, there has been an upsurge interest in magnetic insulators, which show interaction between magnetic and dielectric properties. This interaction is manifested as an anomaly in the temperature dependence of dielectric constant at magnetic phase transition temperature in the absence of an external magnetic field and magnetically tunable capacitance around and below the magnetic ordering temperature. Bulk $EuTiO_3$, which is paraelectric and antiferro-

magnetic in zero field, shows a rapid drop in dielectric constant just below its Neel temperature (TN = 5.5 K) in zero field and the anomaly was eliminated under a high magnetic field. $EuTiO_3$ thin film under tensile stress shows ferroelectricity and ferromagnetism. Similar effect can be expected in $Eu_{1-x}Ba_xTiO_3$ as the bigger size cation Ba2+ induces a tensile strain in the lattice. We report magnetodielectric effect (MDE) and magnetoresistance (MR) in the insulating pervoskite $Eu_{0.4}Ba_{0.6}TiO_3$, which shows no long range magnetic ordering down to 2.5 K. An applied magnetic field of 7 T at T = 10 K leads to a positive MDE (Δε/ε(0) = +7.6%) and a negative MR (Δρ/ρ(0) = -13.5%), where ε(0) and ρ(0) are the dielectric constant and resistivity in zero magnetic field. It is seen that MDE $\propto$ M2 for smaller field mu_0H (< 1 T), but MDE $\propto$ M for higher field values, where M is the magnetization. So, the MDE could be possibly due to suppression of spin fluctuations at low fields but other mechanisms play role at higher field. It is found that isothermal MDE is linearly proportional to MR for different frequencies.

PO2.101 Strain-induced Tunable Light Emission and Lattice Vibration in Monolayer WS_2

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In-situ strain Photoluminescence (PL) and Raman spectroscopy has been employed to exploit evolutions of electronic band structure and lattice vibrational responses of chemical vapour deposition (CVD) grown monolayer tungsten disulphide (WS_2) under uniaxial tensile strain. It is found that a sudden broadening and appearing of an extra small feature at the longer wavelength side shoulder of the PL peak occur under the strain strength of 2.5%. Such evolution of the PL profile could be an indicator of the transition from direct to indirect bandgap. As strain further increases, the spectral weight of the indirect transition becomes larger gradually. Cross the entire strain range, with the increase of strain, the light emissions corresponding to each optical transition such as direct band gap transition (K-K) and indirect band gap transition (Γ-K, $\geq$2.5%) show monotonous linear red-shift. In addition, larger binding energy of the indirect transition compared to the direct one is deduced and slight lowering of trion dissociation energy with increasing strain is observed. Not only the electronic band structure could be tuned by the strain, the lattice vibrations could also be modulated by strain. Our in-situ strain Raman spectroscopy study reveals the softening and splitting of in-plane E' mode and inertness of out-of-plane A_1' mode subject to the uniaxial tensile strain. The polarization dependent Raman spectroscopy under uniaxial tensile strain confirms the observed zigzag-oriented edge of CVD grown WS_2 in previous studies. These findings indeed enrich our understanding of strained states of monolayer transition metal dichalcogenide (TMD) materials and further lay a foundation for developing applications such as strain detection and light emission modulation of such emerging two-dimensional TMDs based on their strain dependent optical properties.

PO2.102 Ultrafast Dynamics of Bi1.5Sb0.5Te1.8Se1.2 Topological Insulator

Liang Cheng, Chi-Sin Tang, Saritha Krishnankutty Nair, Bin Xia, Lan Wang, Jian-Xin Zhu, Elbert Chia* (Nanyang Technological University)

Bi1.5Sb0.5Te1.8Se1.2 (BSTS) is a type of topological insulator, which is an insulator in bulk but surface states are gapless. In this work, we took optical pump-probe data on BSTS crystal to analyze the dynamics of phonons and charge carriers. The ultrafast dynamics were obtained as a function of temperature ranging from 10K to 300K, as well as fluence ranging from 1 J/cm2 to 10 J/cm2. In additional to the coherent optical phonon mode found in other topological insulators, acoustic phonon mode was observed in our experiment. We also observed phonon softening and the temperature dependence of carrier lifetime in BSTS.

PO2.104 Terahertz Conductivity of Aluminium Zinc Oxide Films

Yi Ming Ng*, Huanxin Xia*, Jung-Kun Lee, Elbert E.M. Chia (Nanyang Technological University)

Aluminium doped zinc oxide (AZO), which is a transparent conducting oxide (TCO), has potential applications in devices such as solar cells and flat panel displays. The optical conductivities of the $Zn_{0.97}Al_{0.03}O$ (AZO) film and $Zn_{0.97}Al_{0.03}O$ films with different ratios of Ag nanoparticles (e.g. 0wt%, 1wt%) were investigated using terahertz (THz)time-domain spectroscopy at different temperatures (10K-300K). The results were then analysed by fitting the extracted data theoretically.

PO2.107 Towards production of Fermionic 6Li quantum gas using narrow-line cooling

Christian Gross*, Huat Chai Jaren Gan, Saptarishi Chaudhuri, Jiayu Li, Jimmy Sebastian, Ke Li, Wenhui Li, Kai Dieckmann (Centre for Quantum Technologies)

We present our experimental results leading to the realization of a fermionic Lithium quantum gas in optical potentials. Lithium offers a broad Feshbach resonance that allows the tuning of the two-body interaction strength, enabling the experimental investigation of quantum many-body physics. This offers an ideal starting point to experimentally study and address open questions in quantum many-body physics that are also encountered elsewhere, particularly in condensed-matter physics As part of our approach of an all-optical experimental sequence, we report on a study of peak and phase-space density of a two-stage magneto-optical trap (MOT) [1]. Following trapping and cooling of the atomic cloud on the D2 transition at 671 nm, the atoms are then further cooled and compressed on the narrower 2S1/2- 3P3/2 ultra-violet (UV) transition at 323 nm. Optimized experimental parameters yield high phase-space densities of up to 3×10^{-4}, which are two orders of magnitude higher as compared to the conventional MOT on the D2 transition. This facilitates direct loading into an optical dipole trap and subsequent evaporative cooling of the atomic sample to quantum degeneracy.

References: 1. J. Sebastian et al., PRA 90, 033417 (2014)

PO2.109 Geometric quantum computation with a four-level tripod system in a cloud of Strontium

Frederic Leroux*, Kanhaiya Pandey, Pramod Mysore Srinivas, David Wilkowski (CQT)

In a fermionic ultracold Strontium atoms cloud, a four-level tripod system between two hyperfine states 1S0 and 3P1, subject to a bias magnetic field, is driven continuously by three resonant lasers. We aim to perform operations of quantum computation on a single geometrical qubit composed of the two dark states generated from this light-matter interaction. We present some experimental results showing the different steps to prepare the cold sample. In particular a magneto-optical trap on the strontium intercombination and the transfer of the gas in an optical dipole trap followed by optical pump and further Doppler cooling. We also present internal states manipulation using stimulated Raman Adiabatic Passage.

PO2.110 Modification of ZnO nanowires using a focused laser beam

Kim Yong Lim, Wan Xin Loh, Matthew Wei Jie Lee, Minrui Zheng, Chorng Haur Sow* (Department of Physics, National University of Singapore)

ZnO nanowires (NWs) are transparent to light of visible wavelengths and are hence resistant to visible wavelength laser modification. However, by depositing rhodamine B on ZnO NWs, a focused laser beam of wavelength 533nm can be used to modify the ZnO NWs. Fluorescence microscopy, scanning electron microscopy (SEM) and Photoluminescence (PL) spectroscopy has been used to characterize the optical changes when the ZnO NWs are systematically modified by different powers of laser irradiation. The modification is also capable of producing nanometer-scale roughened surface of the nanowires, suspected to be a reason behind the optical variations in the ZnO NWs.

PO2.112 Photon Polarization Dependence of Photocurrent in Monolayer Molybdenum Disulphide

Mustafa Eginligil*, Zilong Wang, Bingchen Cao, Cesare Soci, Ting Yu* (Nanyang Tech Univ)

The class of two-dimensional (2D) materials led by graphene is a new chapter in the condensed matter physics offering many technological advantages as well as interesting physical mechanisms. It is well known that in monolayer molybdenum disulphide (MoS_2), there is strong excitonic transitions due to the direct band gap in K valleys. The inherit broken inversion symmetry in monolayer MoS_2 leads to a large spin-orbit interaction which splits the valence band (VB) by 160 meV, which corresponds to an on-resonance exciton energy with 1.96 eV laser excitation. The same broken inversion symmetry together with time reversal symmetry leads to spin-valley coupling in MoS_2. On the other hand, growth of TMDCs by unique chemical vapor deposition without lack of quality compared to the exfoliated counterparts has attracted a lot of attention of the community for its potential optoelectronic applications. Photocurrent (PC) of 2D materials provides a useful framework to study light-matter interactions, since their band gap is in the visible range of spectrum. Here, we present our recent on photon polarization dependent PC of spin-valley coupled MoS_2 and provide a discussion on the origin of our results

PO2.113 Metal-insulator phase transition in a novel VO_2(B) polymorph observed with terahertz spectroscopy

James Lourembam*, Amar Srivastava, Chan La-O-Vorakiat, Helene Rotella, Thirumalai Venkatesan, Elbert Chia (Nanyang Technological University, Singapore)

A remarkable feature of vanadium dioxide is that it can be synthesized in a number of polymorphs. The conductivity mechanism in the metastable layered polymorph VO_2(B) thin films has been investigated by terahertz time domain spectroscopy (THzTDS). In VO_2(B), a critical temperature of 240 K marks the appearance of a nonzero Drude term in the observed complex conductivity, indicating the evolution from a pure insulating state towards a metallic state. In contrast, the THz conductivity of the well-known VO_2(M) is well fitted only by a modification of the Drude model to include backscattering. The electronic phase diagram is constructed, revealing that the width and onset of the metal-insulator transition in the B phase develop differently from the M phase.

PO2.119 The Photonic Ant Colony: Plasticity in a Stigmergic Photonic Network

Wenchao Hu*, Kan Wu, Ping Shum, Nikolay Zheludev*, Cesare Soci* (NTU)

We implement an all-optical stigmergic fiber network to realize the famous ant colony optimization algorithm. This demonstrates the potential of "cognitive photonic networks" to mimic learning and plasticity of the brain.

PO2.121 Hierarchical Assembly of MoS_2-CNT-rGO Hybrid Nanomaterial en-route to potential applications

Jia Xin Peng*, Hung Ping Lee*, Elizabeth Chin*, Sharon Lim, Chorng Haur Sow (Dunman High School)

Molybdenum disulphide-carbon nanotube (MoS_2-CNT) hybrids show promising performance when used as electrode material in supercapacitors because the weak van de Waals interactions between MoS_2 layers allow ion diffusion to occur readily and because CNT has high charge carrier mobility and chemical and physical stability. However, MoS_2-CNT devices cannot achieve greater energy densities because of their lack of surface area. MoS_2-CNT is also generally insoluble in common solvents, presenting a bottleneck in wet processing routes. As such, our group proposes the integration of graphene oxide (GO) into MoS_2-CNT hybrids to achieve greater energy densities and make the resultant MoS_2-CNT-rGO hybrid solvent-dispersible. In the present study, we successfully synthesized MoS_2-CNT-rGO hybrids using three different methods. Under Scanning Electron Microscopy and Raman Spectroscopy, MoS_2, rGO and CNT were identified and found to be successfully assembled in a hierarchical structure for the hybrids, while X-ray Diffraction confirmed the presence of rhombohedral crystalline MoS_2 in the hybrids. From Transmission Electron Microscopy, it was found that 3-5 MoS_2 layers coated the MWCNTs in 2 of the 3 hybrids. Cyclic Voltammetry tests have also shown good capacitance of the hybrid materials, the best being S2 with a specific capacitance of $20.1\,Fg^{-1}$), closely followed by S3 at $18.3\,Fg^{-1}$. The hybrid nanomaterial is promising as its capacitance can still be improved through varying the amount of GO added. Moreover, it has also shown to be dispersible in water which shows promise for wet-processing routes.

PO2.127 Towards ultracold 6Li40K ground-state molecules

Markus Debatin, Sambit Pal, Mark Lam, Kai Dieckmann* (CQT-NUS)

With the creation of dipolar molecules in their ro-vibrational ground state, a long-standing scientific goal has been achieved [1-2]. Heteronuclear molecules like 6Li40K in its absolute ground state possess a relatively large electric dipole moment. In a high phase-space density, ultracold heteronuclear molecular samples are promising tools for quantum simulation of a large class of many-body effects as well as for quantum computation due to their long-range anisotropic dipolar interactions. In our group, work towards ground-state transfer of the previously presented bosonic 6Li40K Feshbach molecules [3] has been started.

On the poster we present spectroscopic measurements of electronically excited states that would open a route to two-photon ground-state transfer. In one initial search we target high-lying levels of the 1Π potential. Close to the asymptote, spin-orbit coupling strongly mixes the potentials yielding states that have mixed singlet and triplet character as well as a rich hyperfine structure. While we have discovered a broad variety of new lines, assignment of the lines and detailed characterization is still work in progress. We also investigate lower levels of the 1 Σ potential, which would provide an alternate route for ground-state transfer.

Furthermore we give details about our laser system, which uses a GPS-referenced frequency comb for long-term stability and an optical resonator for short-term stability.

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PO2.128 Circuit QED design and development

Alessandro Landra* (Centre for Quantum Technologies)

In atomic-solid state Hybrid Quantum System the transfer of quantum states can be mediated by a coplanar waveguide resonator acting like a bus system.

Several designs have been simulated, from Low-Q copper resonators to High-Q superconducting resonators, studying the basic laws of transmission lines and the coupling with external lines. We plan in the near future a realization of a fast tunable superconducting resonator.

PO2.130 Towards realization of a 2D MOT as a high flux atom source

Francesca Tosto* (Centre for Quantum Technologies)

A high flux of low velocity atomic beam is essential for most ultra cold atom experiments. There exist several technical realizations to generate a atom source. The system we are realizing is based on a 2D MOT where a collimated slow beam of cold atoms is realized by two dimensional cooling of an atomic ensemble. The system must be compact and stable. We redesigned the laser setup with special effort in miniaturization towards the goal of a solely fiber based optical setup.

PO2.131 Cu_2S-coated Cu_2O nanostructures by ion exchange reaction and photoelectrochemical properties

Marc Courte*, Ignacio Minguez-Bacho, Denis Fichou*, Hongjin Fan* (NTU - NANYANG TECHNOLOGICAL UNIVERSITY)

Cuprous oxide Cu_2O is a promising p-type semiconductor for photoelectrochemical (PEC) solar hydrogen generation because it has a suitable bandgap (Eg=2.0-2.2 eV) and a band alignment adapted to water reduction. However, Cu_2O is unstable under light irradiation in solution and it reduces into metallic copper. Therefore, our recent efforts focused on the growth of a protective overlayer on top of Cu_2O in order to stabilize Cu_2O when used as a photocathode in an aqueous electrolyte. Among potential protective materials cuprous sulphide Cu_2S is another p-type semiconductor with a 1.2eV bandgap and an appropriate energy level alignment with Cu_2O that would allow electrons flowing to the interface. We present here an original and simple method to coat a Cu_2S overlayer on top of different nanomorphologies (compact layer and nanowires) based on Ion exchange reaction. The Cu_2S coating improves the stability and PEC performances of the Cu_2O photocathodes.

PO2.132 Towards Hybrid Quantum Systems of Atoms and Superconductors

Chin Chean Lim*, Naveinah Chandrasekaran, Chee Howe Ew, Christoph Hufnagel*, Rainer Dumke (Centre for Quantum Technologies)

Hybrid quantum sytems, i.e. the interfacing of two distinct quantum systems to form combined entities, are a promising candidate for emerging quantum technologies. Crossing the boarder between well established quantum systems will have a variety applications, ranging from quantum information processing to fundamental measurements. In this poster we review the recent progress we made toward experiments with hybrid quantum systems consisting of ultracold atoms and superconducting structures. In particular we will discuss the building blocks of our setup, including a cold atom part with magnetic transport and a dilution refrigerator, which we installed recently. As an outlook we will discuss different hybrid systems we will be able to realize with our setup.

PO2.134 Metamaterial Coherent Plasmonic Absorption With a Single Photon

Charles Altuzarra*, Stefano Vezzoli, Thomas Roger, Eliot Bolduc*, Joao Valente*, Julius Heitz*, John Jeffers*, Jonathan Leach*, Christophe Couteau*, Cesare Soci*, Nikolay Zheludev*, Daniele Faccio* (Institute for Photonics and Quantum Sciences, HWU)

With a plasmonic metamaterial absorber of sub-wavelength thickness we demonstrated that coherent absorption can be observed even with a single photon that could be coupled with nearly 100% probability into a localized plasmon.

PO2.137 Precision measurement of branching ratio in Ba+ ions: Testing many body theories

Riadh Rebhi*, Debashis De Munshi, Swarup Das, Tarun Dutta, Manas Mukherjee* (Centre for Quantum Technologies)

The branching fraction from the excited state 6P(1/2) of singly charged Barium ion has been measured with a precision of 0.05% in an ion trap experiment. This measurement allowed the determination of the dipole matrix elements for the transitions P-S and P-D to below one percent level. Therefore, for the first time it is now possible to compare the many body calculations of these matrix elements at level which is of significance to any parity non-conservation experiment on barium ion.

PO2.139 Tailored Optical Potentials

Koon Siang Gan*, Nghia Tin Nguyen* (Nanyang Technological University)

Bose-Einstein Condensate (BECs) in a ring structure is a simple configuration which contains a rich amount of physics, especially in the field of atomtronics. Various methods have been applied successfully to create ring-like structures to simulate devices like a Superconducting Quantum Interference Device (SQUID). Here we work towards a versatile method of producing different structures, specifically a ring lattice with a weak link, utilising a Spatial Light Modulator (SLM). A stable flux qubit can be created by inducing a flow in a BEC ring lattice. Coupling 2 stacks of BEC in a ring lattice produces a 2-ring qubit. Different complex structures can be also simulated and investigated using this method.

PO2.141 Cathodoluminescence from fluorescent organic dyes and proteins

Daniel Floyd*, Paul Matsudaira*, Utukur Utkur Mirsaidov (NUS)

Cathodoluminescence is the emission of a photon through excitation by an incident electron. We report that common fluorescent dyes and proteins such as fluorescein, rhodamine, organic LEDs, and eGFP are cathodoluminescent. When these molecules are irradiated with a scanning electron beam in the SEM or STEM equipped with a cathodoluminescence detector, a luminescence spectrum (250-850nm) identical to the fluorescence emission spectrum is collected. Because the incident electron energy ranges between 1-200 keV and the fluorescence excitation energy is typically 2-3 eV, the mode of excitation must be through secondary electrons produced by inelastic scatter. SEM imaging of bacteria expressing soluble eGFP, shows that an EM and cathodoluminescence image are collected simultaneously. Resolution is determined by the e-beam diameter (typically 1-20 nm) convoluted by the secondary electrons originating from the interaction volume of the material surrounding the luminescent source. This Correlative CathodoLuminescence Electron Microscopy (CCLEM) method simplifies the mapping of tagged proteins, membranes, and nucleic acids to their structure.

PO2.144 Interaction between atoms and cryogenic surface

Nhung Nguyen* (Quantum Technology Lab)

For interfacing atomic systems with solid state systems the atom surface interaction plays an important role. For certain systems the interaction depends strongly on the temperature and atoms can be trapped on cryogenic surfaces by forming atom surface bound states. In this project we investigate these bound states between Rb and a sapphire surface with evanescent wave spectroscopy. The spectrum can be used to determine the trapping potential.

PO2.147 The influence of PTAS seeding on the device performance of atomically thin $MoSe_2$ from CVD synthesis

M. Iqbal Bakti Utama, Xin Lu, Yanwen Yuan, Qihua Xiong* (Nanyang Technological University)

Catalyst seeds, particularly perylene-3,4,9,10-tetracarboxylic acid tetrapotassium salt (PTAS), have been used to promote the growth of atomically thin layered materials in chemical vapor deposition (CVD) synthesis. Nevertheless, the consequences from the use of such catalyst is not known. Here we discuss the influence of PTAS seeding on the performance of field-effect transistor devices from few-layered CVD-grown molybdenum diselenide ($MoSe_2$) flakes [*]. As expected, better repeatability and relatively higher yield can be obtained when PTAS seed is used during the synthesis. However, the devices from PTAS-seeded $MoSe_2$ flakes consistently displayed poorer field-effect mobility, current on-off ratio, and subthreshold swing as compared to unseeded flakes. We attributed such deleterious effect to the impurity introduced by the seeding process.

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PO2.148 Rapid and nondestructive identification of polytypism and stacking fault in few-layer $MoSe_2$ by Raman spectroscopy

Xin Lu, M. Iqbal Bakti Utama, Xin Luo, Su Ying Quek, Qihua Xiong* (Nanyang Technological University)

We have found that $MoSe_2$ few-layers, which are grown by chemical vapor deposition (CVD), have new features on Raman spectroscopy. Firstly, at least one Raman-inactive mode in 2H structure becomes active on >70% of CVD-$MoSe_2$ flakes. Secondly, multiple combinations of interlayer shear modes emerge in CVD-$MoSe_2$ flakes with the same thickness. As corroborated by density functional theory calculations and bond polarizability model, we have assigned the different mode combinations to the variation of interlayer stacking. Thus, CVD-$MoSe_2$ are identified to be consisted of flakes with pristine phases (2H and 3R), stacking fault (e.g. ABCB in 4 layer), or polytypic structure (e.g. mixture of 2H and 3R). Scanning transmission electron microscopy has further confirmed the existence of phase mixture and stacking fault on the flakes. Therefore, our work manifests a reliable, rapid, and nondestructive method in the identification of stacking in few-layer transition metal dichalcogenide crystals by Raman scattering.

PO2.149 Finite Classical Information

Ray Fellix Ganardi*, Tomasz Paterek (SPMS, NTU)

Computer simulations are getting more and more common in physics. Here we examine the underlying assumption that nature can be simulated with classical bits. We postulate that nature can be encoded into a number of classical bits [1]. We allow the bits to have an unknown but fixed probability distribution. We also postulate that measurements are deterministic functions on these bits. We show that we can model exponentially many measurements with n bits. We also derive the minimum precision that we need in order to disprove this model. [1] J.D. Bekenstein, PRD 7, 2333 (1973)

PO2.150 Manipulation and measurement of ultracold atomic assembles with nano-SQUIDs

Phyo Baw Swe* (Nanyang Technological University)

Hybrid quantum system, combination of advantages from both solid state devices and atomic system has drawn huge interest in advancement of quantum technology. Superconducting Quantum Interference Devices (SQUIDs) are very sensitive magnetometer and offer non-destructive way to measure the magnetic moment. Ultracold atomic assembles have very long coherence time and permit precise measurement with low noise. In our experiment, we are incorporating nano-SQUIDs to manipulate and measure magnetic moment of ultracold atomic assembles with high accuracy. This hybrid system might be the successful candidate for quantum memory devices and quantum information processing.

PO2.151 Superconducting Fano resonances in THz metamaterials

Yogesh Kumar Srivastava*, Ranjan Singh* (School of Physical and Mathematical Sciences, Nanyang Technological University)

Superconducting metamaterials possess many unique features like low loss, compact dimensions, switching and highly tunable behavior. Large tunability is due to the superconducting properties and the kinetic inductance in high temperature superconductors. In this work we compare the superconductor's performance with the metallic Fano resonances and compare their quality factors. Strongly tunable Fano resonance is observed when electric field is applied perpendicular to TASR gap respectively. Fano resonance behavior is only achieved below the superconducting phase transition temperature, Tc. Electric field response in the TASR gaps explain the evolution and the tunability of the Fano resonance phenomena in the superconducting and the metallic meta-atoms.

PO2.153 Measuring a Topological Edge Invariant in a Microwave Network

Wenchao Hu*, Jason Pillay, Kan Wu, Michael Pasek, Yidong Chong* (NTU)

We map the famous "thought" experiment into a microwave network and successfully measure a topological edge invariant for the first time.

PO2.154 Manipulating Optical Properties of ZnO-Ga:ZnO Core-Shell Nanorods via Spatially Tailoring Electronic Band Gap

Xin Zhao, Yuan Gao, Yue Wang, Shijie Wang, Hilmi Demir, Handong Sun* (Nanyang Technological University & Centre for Disruptive Photonic Technologies)

High surface-to-volume ratio induced surface depletion and exciton dissociation have long been considered as a major obstacle in the way of realizing high-performance nano-optoelectronics. To address these problems, we report a facile and scalable method, which involves hydrothermal growth of ZnO templates and epitaxial growth of Ga doped ZnO shell via pulsed laser deposition, to form vertical-aligned ZnO-Ga:ZnO core-shell nanorod arrays (NRAs). The core-shell NRAs relieve the surface depletion and prevent excitons from being trapped and dissociated. The modified optical property is revealed by the enhanced near-band-edge emission and alternation in spectral line shape of the deep-level emission. Further, by correlating the photoluminescence and X-ray photoelectron spectroscopy results, we propose an integrated band diagram of the core-shell structure showing that the energy dip induced by carrier concentration difference accounts for the optical property enhancement. Thus, this study proposes a novel growth scheme and achieves optical property enhancement through doping, which is rarely reported before. By correlating the conjugating factors such as carrier concentration, electronic band structure and surface depletion, this work provides significant physical insight for designing high-performance optoelectronic nano-devices with optimized optical and electrical properties.

PO2.156 Entangling two separated systems via a third system

I Wayan Gede Tanjung Krisnanda*, Margherita Zuppardo, Tomasz Paterek (Nanyang Technological University)

Entanglement is an important quantum correlation between systems that enables crucial quantum information processing such as quantum cryptography and quantum computing. Therefore it is important to distribute entanglement between two systems, A and B, in separate laboratories. In this paper, we investigated a scenario where a third system, C, was used and allowed to interact continuously with A and B. We prove that entanglement in the partition A-B cannot increase when the state of the whole system is pure and the state of C is separable from AB. If the state of the whole system is mixed and the state of C does not change and stay separable as in the Born approximation, entanglement also cannot grow. Our results also show that entanglement inequality E(A-BC)-E(B-AC)$\leq$E(C-AB) holds for some entanglement measures when the state is pure. This work provides a way towards proving that non-classical correlations (in the partition AB-C) are needed to distribute entanglement (in the partition A-B). Also, the entanglement inequality can be used to find the bound on distributed entanglement between A-B which in turn can be used to minimise the requirements and so the cost for distributing entanglement.

PO2.162 Updating the Small Photon Entangling Quantum System (SPEQS)

Hung Do*, Septriani Brigitta*, Durak Kadir*, Ling Alexander* (Center for Quantum Technologies)

The SPEQS-1 device is a compact (under 10 cm x 10 cm x 3 cm) entangled photon system designed to work on multi-mission nanosatellites. SPEQS-1 is a pathfinder for brighter space-capable sources in the future. The SPEQS-1 devices are already at a high technology readiness level [1]. We are now working on the next generation devices called SPEQS-2. SPEQS-2 is planned to fly on dedicated nanosatellites, and this relaxes the size requirements, enabling the use of lenses and optimal path geometry to maximize the generation of useful photon pairs. For optimum efficiency in the production of photon pairs, it is important to define the modes of the pump beam and collection beam [2]. The optical pump is provided by a free-running laser diode (405 nm). Spatial-mode filtering will be performed on the optical pump using a suite of pinholes and lenses. By overfilling one of the pinholes, it is possible to generate a pump spatial mode that is close to Gaussian-beam parameters. To optimize photon-pair collection, we vary the pump beam and collection modes until a high pair-to-singles ratio is achieved at a high brightness level. It is shown that the efficiency of the signal and idler photon collection follows a theoretical model that we have recently devised. In this poster, we will present detailed studies of the BBO source settings as well as the physics of spatial-mode filtering using pinholes.

[1] Z. K. Tang Scientific Reports, Vol. 4, 6366 [2] A. Ling Physical Review A, Vol. 77, 043834

PO2.167 Towards atom interferometry with guided matter waves in optical fibers

Mingjie Xin*, Wui Seng Leong, Wei Sheng Chan, Arpan Roy, Shau-Yu Lan* (Nanyang Technological University)

Precision measurement with light-pulse grating atom interferometry in free space have been used in the study of fundamental physics, such as measuring fine structure constant, testing general relativity, and building a clock referenced the mass of a single particle. It also finds its applications in gravimetry, gradiometry, and rotation sensing. However, due to the diffraction nature of light, this approach requires large-diameter laser beams to maximize its sensitivity while minimizing systematic effect and therefore complex the experimental setup. Recent development of photonic bandgap fibers allows light for travelling in hollow region while preserving its fundamental Gaussian mode. Optically guided matter waves inside a hollow-core photonic bandgap fiber can mitigate this diffraction limit problem and has the potential to bring research in the field of atomic sensing and precision measurement to the next level of compactness and accuracy. Here, we will show our experimental progress towards an atom interferometer in optical fibers.

PO2.168 Time to failure parameterization of silver nanowire under thermal stress

Garen Kwan, Cheng Hon Alfred Huan* (Institute of High Performance Computing, Agency for Science, Technology and Research)

It is known that heating silver nanowires (AgNW) initially increases the conductivity of the wire but this falls due to degradation upon extended heating. This degradation is due to Rayleigh instability induced spheroidization and a framework to predict the time to failure (TTF) of these AgNWs is described. It is experimentally shown that the TTF is reduced when the AgNWs are heated in the presence of oxygen and as a result of this, a unit-less τ value is needed to parameterize this degradation. The τ value takes into account factors such as the dimensions of and material used in the nanowires and gaseous environment and temperature of operation and it was found that a value 1.5 represented the onset of Rayleigh instability induced failure in nanowires. Following this, we found that the presence of a graphene oxide over layer had the ability of increasing the TTF of the nanowires and discuss the reasons for this lifetime improvement.

PO2.169 Carrier multiplication in low dimensional PbSe nanostructures

Manoj Kumar, Annalisa Bruno*, Apoorva Chaturvedi, Paola Lova, Ziling Wang, Gagik Gurzadyan, Cesare Soci* (Division of Physics and applied Physics SPMS NTU Singapore)

In conventional solar cell, most of the absorbed energy is wasted in the form of heat and so theoretical power conversion efficiency (PCE) of single p-n junction solar cell is around 33%. Solar cell PCE may be considerably increased using the lost energy to create another exciton. This is possible in principles by exploiting the efficient carrier multiplication (CM) in low-dimensionality nanostructures. Until now despite the demonstration of high CM efficiency in PbSe quantum dots (QDs), PbSe QDs solar cells PCE remains low, relative to inorganic solar cells. One of the limitations for low efficiency is that In QDs after CM, excitons may recombine either radiatively or via Auger processes, reducing photocurrent generation yield and charge extraction in tightly confined nanostructures. So far charge extraction has hindered CM benefits in QDs solar cells. One and two dimensional semiconductors simultaneously show quantum confinement and efficient charge transport properties due to their anisotropic shape. These exceptional properties of nanowires and nanosheets generated significant interest for CM studies. In this work we investigate CM phenomena in PbSe QDs as function of photon energy by using a combination of steady state and transient absorption pump and probe spectroscopy. Probe energy was chosen according to energy gap of QDs (from absorption spectra) which is 1.13 eV (1100 nm) in PbSe QDs. Pump energy dependent (1.55 eV, 3.1 eV and 4.64 eV) measurements have been performed to investigate CM and we observed three excitons per absorbed photon at 4.64 eV (267 nm) pump energy in PbSe QDs. Nanowires (NWs 1D) and nanosheets (NSs 2D) have been synthetized in our lab. Diameter of NWs is $\sim$ 5 nm and length $\sim$ 30 μm on the other hand NSs have typical diameter of 80 nm and height in the range of 6-8 nm. Quantum confinement effect in nanowires and nanosheets has been observed. Energy gap of PbSe NWs and NSs is shifted from 0.27 eV (bulk) to 0.54 eV and 0.64 eV respectively.

PO2.171 Nanobubbles in graphene liquid cells: shape and stability

Meera Kanakamma Mohan*, Utkur Mirsaidov, Manish Arora, Claus-Dieter Ohl* (SPMS, NTU)

The imaging of graphene liquid cell with transmission electron microscope is a good platform to understand various dynamics of liquids under very high vacuum conditions. The transparency of the liquid cell along with its geometry provides a promising technique for liquid imaging. In our experiments, we already observed various bubble dynamics and stable nanobubbles inside the liquid cells during electron beam interaction with the liquid. The nanobubbles inside the graphene cells are unstable during imaging, but they are amazingly stable in the absence of the beam. Recently, we reached in a new hypothesis about the shape of the bubble that can explain the stability of these nanobubbles. In this paper we are presenting our recent developments to figure out the above said mysterious stability.

PO2.175 Neutron Yield Measurement using Beryllium and Zirconium Activation Detectors for the NX3 Plasma Focus Device

M.N. Nasrabadi*, S.V. Springham, Rajdeep Singh Rawat, Paul Lee, Maung Soe Nyunt Zaw
(University of Isfahan)

Neutron yield measurement is of crucial importance using compact intense sources of pulsed fast neutrons such as plasma focus or Z-pinch devices when operated with deuterium gas. In this research a neutron yield diagnostic has been used with the NX3 plasma focus which is based on a combination of zirconium and beryllium activation detectors and their relative responses of the activation cross-section. Zirconium and beryllium were activated simultaneously with fast neutrons from the NX3 plasma focus device at deuterium gas pressures in the range from 1.5 mbar to 10 mbar and secondary radiations are measured with a BGO detector and xenon-filled proportional counters respectively. The ratio of zirconium activation counts to beryllium activation counts at different pressures of deuterium gas is obtained and the neutron yield derived using MCNP5. Meanwhile the neutron energy at angles 0° and 90° with respect to the plasma focus axis were found for a series of 90 NX3 plasma focus shots in the range of mentioned pressures. It is found that neutron yield is higher at 0 ° to the PF axis than at 90 ° . This indicates neutron anisotropy distribution which decline with increasing D2 pressure.

PO2.176 Local Density of Plasmon States signature in photoluminescence of metallic nanostructures

Tingting Yin, Zhaogang Dong, Lei Zhang, Liyong Jiang, Joel Kwang Wei Yang, Zexiang Shen*
(Division of Physics and Applied Physics, School of Physical and Mathematical Sciences, Nanyang Technological University)

Photoluminescence (PL) and absorption (scattering) are complementary in nature ranging from the semiconductors to metals. PL of semiconductors is always red-shifted compared to absorption (scattering) in wavelength, while blue-shifted PL is investigated in metallic nanostructures. Here, we perform both the PL and dark-field scattering spectra in dolmen-type nanostructures with plasmonic Fano-like resonance in visible range, which involves energy transfer between plasmonic dipolar modes (radiative) and quadrupolar modes (nonradiative) via near-field coupling. Through observations of Lorentz-like lineshape PL with blue-shifted peak and Fano-like lineshape PL without blue-shifted dip both compared to the scattering spectra can successfully probe apparent traces of density of plasmon states (DoPS) in electrons excitation and decay processes for PL generation. And such PL displays strong sensitivty on excitation-collection polarizations, indicating varied plasmon modes have different DoPS. On the other hand, PL from semiconductors results from the direct recombination between excited electrons in the bottom of conduction bands after relaxing with holes on the top of valence bands, which are generated by aborption process at first. So the electrons excitation and decay processes will not suffer from the DoPS modulation due to no surface plasmon resonance in semiconductors. Our work presents two distinct physical mechanism for red-shift PL in semiconductor and blue-shift PL in metallic nanostructures compared to their corresponding absorption (scattering) spectra and demonstrates DoPS is the key.

PO2.177 Structural and energy storage studies of Copper Oxide

Shiyuan Mei, Reddy Mv* (Department of Physics, Solid State Ionics/Advanced Batteries Lab, National University of Singapore)

Since year 2000, a group of Taeascon publicized preliminary structural and energy storage studies of Copper Oxide (CuO), increasing attention has been paid to researches on CuO. CuO is less expensive and less harmful in comparison with other compounds such as CoO, VO, etc. CuO has a theatrical capacity of 670 mAh/g^{-1}, while many research papers have reported an experimental capacity of 300-450 mAh/g^{-1}. This is probably due to various preparation methods and conditions such as different temperatures and different reactants. We aim to explore how preparation temperature and annealing affect morphology and electrochemical properties of CuO. The samples were prepared by Molten Salt Method (MSM) at different temperatures and reheated it to the same temperature, 750 oC. Another sample was prepared by using different reactant and heated it directly to 750 oC (MSM). They were then tested via X-ray diffraction, Scanning electron microscopy and density and BET surface area methods. Their electrochemical properties were studied by Cyclical Voltammetry and Galvanostatic Cycling.

PO2.178 MOLTEN SALT METHOD OF PREPARATION AND OPTIMIZATION OF TiO2 PHASES

Aloysius Chan*, M V Venkatashamy Reddy* (National University of Singapore)

This project revolves around the effectiveness of using TiO2 nanoparticles as intercalation/deintercalation reaction anodes for Lithium-Ion batteries. Amorphous and Anatase TiO2 salts were synthesized using one-pot Molten Salt Method (MSM) and Solid State Method. This was done using TiOSO4xH2SO4, as the Ti-source, with molten salts in the ratio of 0.375M LiNO3 : 0.180M NaNO3: 0.445M KNO3. Various samples were made by heating the mixture at 145°C, 280°C, 380°C and 480°C for 2h in air respectively. Reheating the amorphous sample was to 850°C surprisingly didn't yield Rutile TiO2. Morphology, crystal structure, surface area were then examined through X-Ray Powder Diffraction (XRD) and Scanning Electron Microscopy (SEM). Thereafter, electrochemical properties were studied using Galvanostatic Cycling (GC), Cyclic Voltammetry (CV) at a current density of 33 mA/g and a scan rate of 0.058 mV/sec respectively, in the voltage range 1.0 - 2.8V vs. Li. Further analysis was then done through Electrochemical Impedance Spectroscopy (EIS). TiO2 produced at 280°C showed the best results with the lowest capacity fading in the Galvanostatic Cycling test and a very low electrochemical impedance.

PO2.179 Essential oil precursor based novel green approach for synthesis of vertical graphene/MnO2/carbon sandwich structure for enhanced super-capacitor performance

Bo Ouyang*, Yizhong Huang, Ting Yu, Rajdeep Singh Rawat (NIE, Nanyang Technological University)

In this work, we used a simple and cost-effective approach to directly synthesize vertical graphene on porous nickel foam in RF powered plasma assisted chemical vapor deposition (RF-PECVD) system at 500 W, 13.56 MHz RF power and at reactor chamber temperature of 800 °C. Instead of hazardous and costly hydrocarbon gases, we use low-cost, non-toxic and environmentally-friendly natural organic material, M. alternifolia essential oil (containing hydrocarbon monomer), as precursor in our RF-PECVD system. The PECVD grown vertical graphene was then covered by MnO2 layer using hydrothermal method. Finally, the same essential oil was used again to grow the amorphous carbon thin film on top of MnO2 layer to produce sandwich structure of vertical graphene/manganese oxide/carbon thin film. The individual layer and the sandwich structure was characterized using different methods. Such structure can bring about enhanced capacitance and excellent cycle stability of electrodes because of the protection of hydrocarbon thin film and the conductive substrate of vertical graphene.

PO2.181 Preparation of Mg, Cu, Zn doped Fe2O3 anodes for Li-ion Batteries

Bryan Kong, Chu Yao Quan*, Zack Choa, M V Reddy* (National University of Singapore)

Mg, Cu, Zn doped Fe2O3 were synthesized in varying concentrations of Mg and Zn by simplest, most versatile, and cost-effective molten salt approach. The materials were charactrized by X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM) and Brunauer-Emmett-Teller (BET) surface area. Cyclic voltammetry (CV), galvanostatic cycling and electrochemical impendance spectroscopy (EIS) studies were used to investigate the electrochemical properties of the varying concentrations of Mg and Zn in our compounds. All synthesize compounds are of nano-phase, in the range of 160-170nm, and exhibit a characteristic lattice parameter of corundum structure and have density to surface area ratios. High reversible capacities, in the range of of 660-750 mAh/g at a current rate of 60mA/g after 50 charge-discharge cycles, with low capacity fading values of 15-18% were observed for all compounds. This is a huge improvement over a different production methods. Thus, these compounds are suitable as alternatives to anode materials for Li-ion batteries.

6 Technical Sessions

T1: Advanced dynamics

Time: Wednesday 4 Mar, 1:30pm; Venue: MAS1; Chair: Dario Poletti
Time allocated for invited talks is 15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T1.21 A General Quantum Carnot Engine: Maximum Effiency and its Conditions

Xiao Gaoyang*, Gong Jiangbin* (NUS)
1:30pm – 01:45pm

In this work, a quantum analogue of the classical Carnot engine is proposed and discussed. By directly exploiting second law, we show that the maximum efficiency of such quantum heat engine is generally lower than Carnot efficiency, and can only reach $1 - T_C/T_H$ for scaling invariant systems. Then an equality reveals the condition for such quantum heat engine to reach its maximum efficiency is derived. This equality, suitable for both scalable and non scalable systems, indicates the fact that the maximum effciency of a non scalable heat engine is working substance dependent, and relied on the temperature T_H and T_C of two reservoirs alone rather than just their ratio $T_C = T_H$. Numerical calculations of a special model support our statements and show some interesting properties of such non scalable quantum heat engine.

T1.22 Interband Coherence Induced Correction to Adiabatic Pumping in Periodically Driven Systems

Hailong Wang, Longwen Zhou, Jiangbin Gong* (Physics Department, NUS)
01:45pm – 02:00pm

Periodic driving can create topological phases of matter absent in static systems. In terms of the displacement of the position expectation value of a time-evolving wavepacket in a closed system, a type of adiabatic dynamics in periodically driven systems is studied for general initial states possessing coherence between different Floquet bands. Under one symmetry assumption, the displacement of the wavepacket center over one adiabatic cycle is found to be comprised by two components independent of the time scale of the adiabatic cycle: a weighted integral of the Berry curvature summed over all Floquet bands, plus an interband coherence induced correction. The found correction is beyond a naive application of the quantum adiabatic theorem but survives in the adiabatic limit due to interband coherence. Our theoretical results are hence of general interest towards an improved understanding of the quantum adiabatic theorem. Our theory is checked using a periodically driven superlattice model with nontrivial topological phases. In addition to probing topological phase transitions, the adiabatic dynamics studied in this work is now also anticipated to be useful in manifesting coherence and decoherence effects in the representation of Floquet bands.

T1.58 (INVITED) What is the joint initial state of the system and the bath?

Jibo Dai*, Yink Loong Len*, Hui Khoon Ng* (CQT, Yale-Nus)
02:00pm – 02:20pm

The initial state of a system-bath composite is needed as the input for predictions from any quantum evolution equation, which describes the effects of noise on the system from joint evolution of the system-bath interaction dynamics. The conventional wisdom is to simply write down an uncorrelated state as if the system and bath were prepared in the absence of each other; or one pleads ignorance and writes down a symbolic system-bath state, allowing for possible arbitrary correlations—quantum or classical—between the system and the bath. Here, we show how one uses ideas from quantum tomography or state estimation to deduce a reasonable and consistent initial system-bath state. In typical situations, such a state turns out to always be uncorrelated or almost uncorrelated between the system and the bath. This has implications, in particular, on the subject of subsequent non-Markovian or non-completely-positive dynamics of the system, where the non-complete-positivity stems from initial nontrivial correlations between the system and the bath.

T1.73 Localization and adiabatic pumping in a generalized Aubry-André-Harper model

Fangli Liu*, Somnath Ghosh, Yidong Chong (SPMS, Nanyang Technological University)
02:20pm – 02:35pm

A generalization of the Aubry-Andre-Harper (AAH) model is developed, containing a tunable phase shift between on-site and off-diagonal modulations. A localization transition can be induced by varying just this phase, keeping all other model parameters constant. The complete localization phase diagram is obtained. Unlike the original AAH model, the generalized model can exhibit a transition between topologically trivial bandstructures and topologically non-trivial bandstructures containing protected boundary states. These boundary states can be pumped across the system by adiabatic variations in the phase shift parameter. The model can also be used to demonstrate the phenomenon of adiabatic pumping breakdown due to localization.

T1.89 Numerical Simulation of Electron Diffusive Process in an Electron-Spin Interaction System

Ruofan Chen* (Department of Physics, NUS)
02:35pm – 02:50pm

We numerically simulated the dynamic process of an electron-spin system. In this system the model of lattice spin is the usual Heisenberg model and electron interact with lattice spin via exchange effect between lattice spin and electron spin, thus electron would get scattered with lattice spin while hopping. Trotter–Suzuki method is used to simulate such a system. By simulate such a system we can directly get the diffusion constant of the electron, and thus get the mobility of the electron which is useful to determine the conductance of materials.

T1.106 (INVITED) Many-Body Dynamics by Propagation of Basis-Projected Heisenberg Equations of Motion

Ulf Bissbort*, Dario Poletti* (SUTD)
02:50pm – 03:10pm

We present a new method to compute non-equilibrium, real-time dynamics in many-body quantum systems. It is based on the time propagation of the fundamental ladder operators and applies to a variety of systems, such as interacting bosons, fermions and distinguishable spins. Well-known approximations, such as Gross-Pitaevskii, Bogoliubov and BCS mean-field theories naturally drop out as lowest order truncations in our approach. In contrast to most other numerical approaches, the truncation is not performed of states in the Hilbert space, but rather in the order of the correlations. This also allows to directly treat dynamics of mixed states at finite temperature. Specifically, we discuss the dynamics of strongly interacting bosons in optical lattices beyond mean-field theory.

T2: Graphene and 2D materials

Time: Wednesday 4 Mar, 1:30pm; Venue: LT4; Chair: Jens Martin
Time allocated for invited talks is 15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T2.161 (INVITED) Local gate tunable electrical transport in encapsulated Bilayer Graphene

Sujit Kumar Barik*, Muneer Ahmad, Xu Wentao*, Jens Martin* (NATIONAL UNIVERSITY OF SINGAPORE)
1:30pm – 01:50pm

Valleytronics offer a new way to process information in digital electronics using the valley degrees of freedom, where the information is stored in the valley, in analogy with the carrier spin in Spintronics. Two-dimensional crystals with hexagonal lattice structure and broken inversion symmetry are good candidates. Monolayers of transition metal dichalcogenides (TMDC) have intrinsic broken inversion symmetry and a direct band gap at the K point. Recently, the optical generation of valley polarization was achieved using the valley dependent circular dichroism in TMDC such as WSe_2 and MoS_2. Here, light of σ+ (σ-) circular polarization excites electron-hole pair exclusively in the + K (- K) valley leading to valley polarization. , In addition, direct electrical measurement and control of valley current is also very important for realization of practical devices. The direct measurement of valley current has been measured recently in encapsulated bilayer graphene by Shan et al. The broken inversion symmetry and band gap in bilayer graphene are achieved by an external electric field. More importantly, the bilayer graphene offers unique advantages over TMDC in the flexibility with which broken inversion symmetry and formation of chiral edge states can be achieved by manipulating local electric fields. We are attempting to built a valley polarizer-analyzer using an encapsulated bilayer graphene with 2D hexagonal Boron Nitride (h-BN) as the dielectric between bilayer graphene and the local top and bottom gates. We have so far managed to build local bottom gates, encapsulated bilayer graphene, and top gates successfully. The local bottom and top gates are fabricated via electron beam lithography (Jeol). The encapsulation of bilayer graphene process was performed using a dry transfer process, where BN and graphene flakes were first exfoliated on a PDMS polymer and then transferred to the Si/SiO2 substrate. This process has been optimized to minimize residues and bubbles formation between the layers. The electrical characterization will follow soon, where we aim to demonstrate the formation of chiral edge states and measure significant valley polarised current.

T2.19 Kelvin angle and caustics of plasmonic ship-wake on graphene

Xihang Shi, Baile Zhang* (NTU-SPMS-PAP)
01:50pm – 02:05pm

Kelvin predicted that the semi-angle of the V-shaped wedge behind a ship moving in deep water region is 19.5°, independent of the ship's velocity. But the predication has been recently challenged by the measurement that the semi-angle makes a transition from Kelvin angle to Mach angle as the ship's velocity increases [PRL 110, 214503 (2013)]. We demonstrate that similar phenomena happen on graphene plasmons excited by a swift charged particle. At relatively small velocity (0.1c), the wake has a caustic boundary with the semi-angle almost equals to 19.5°. The field intensity has a slight enhancement near the caustic boundary. At large particle's velocity, however, there is no caustic boundary, and the effective semi-angle of the wake decreases as particle's velocity increases.

T2.62 Phonon-mediated interfacial thermal transport between monolayer graphene and hexagonal boron nitride

Zhun Yong Ong*, Gang Zhang (Institute of High Performance Computing)
02:05pm – 02:20pm

Single sheets of laterally connected monolayer graphene and hexagonal boron nitride (h-BN) have been recently proposed for the development of atomically thin circuitry [1]. However, thermal transport at interfaces in such lateral heterostructures remains poorly understood. We apply our recently extended version of the atomistic Green's function method [2] to study phonon-mediated thermal transport at the armchair-oriented lateral interface between monolayer graphene and hexagonal boron nitride (h-BN). At 300 K, the thermal conductance of the interface is computed to be 3.5 nW/nm^2 or equivalent to about 200 nm of BN. We also find that the application of a strain, parallel or normal to the interface, also reduces the interfacial thermal resistance. We do a modal decomposition of the phonon transmission spectrum and identify the phonon scattering channels responsible for heat transfer at the interface. We show that at low frequencies, interfacial heat transfer is dominated by the longitudinal, transverse and flexural acoustic phonons. At higher frequencies, it is mostly by longitudinal acoustic phonons because of the severe misalignment of the transverse and flexural acoustic phonon bands between graphene and h-BN. Our work sheds light on the mechanism of phonon-phonon conversion at the interface of 2D lateral heterostructures.

References: 1. M. P. Levendorf, C.-J. Kim, L. Brown, P. Y. Huang, R. W. Havener, D. A. Muller, and J. Park, Nature (London) 488, 627 (2012). 2. Z.-Y. Ong and G. Zhang, in submission.

T2.11 Phononic and Electronic Properties of Phosphorene, a First-principles Study

Yongqing Cai* (Institute of High Performance Computing)
02:20pm – 02:35pm

Phosphorene, another elemental two-dimensional (2D) material besides graphene, has recently attracted increasing attentions owing to its finite bandgap, high mobility and intriguing anisotropy in electronic properties. Here we explore the phonons, another important collective excitation determining carriers scattering and thermal conductivity of phosphorene, by a detailed theoretical study. Through sampling the whole 2D Brillouin zone, we uncover several "hidden" directions, different from the widely explored armchair and zigzag directions, along which small-momemtum phonons are found to be frozen with strain and thus having the smallest degree of anharmonicity. Rigid-layer vibrations are investigated for multilayer phosphorene, and an unique orientational dependent interlayer coupling is obtained. We suggests that phosphorene is distinctive with strong anisotropic vibrational properties together with a large structural flexibility, and promising for fabricating conceptually new acoustic and thermal devices, such as acoustic and thermal cloaking and other phononic devices, where anisotropy of vibrations is a prerequiste. For electronic properties, the anisotropic character and work function shows a strong thickness dependence. We also explore the effects of external molecules on the electronic properties.

T2.32 Spin-Orbit Coupling and Quantum Spin Hall Effect in Graphene under a Strong Magnetic Field

Chunli Huang*, Miguel Cazalilla (NTU)
02:35pm – 02:50pm

A recent experiment [1] has observed the quantum spin Hall effect (QSHE) in graphene under a strong (tilted) magnetic field. Under such condition, the bulk is an insulator but the edge has two surface states with (roughly) opposite spin propagate in opposite directions. We describe a simple model that explains the origin of the lack of quantization of conductance at the edge. We show that spin-orbit coupling plays a minor role in suppressing the conductance quantization, unlike it was initially suggested [1]. In particular, the leading-order Rasbha potential induces no backscattering. It is the lack of perfect anti-alignment of the electron spins in the counter-propagating channels that becomes the major source for backscattering in the presence of impurities. The situation encountered here is therefore very different from the QSHE in semiconductor quantum wells, where the presence of a disorder spin-orbit potential of the Rashba type can induce backscattering [2].

[1] A. F. Young, et.al. Tunable symmetry breaking and helical edge transport in a graphene quantum spin hall state. Nature, 505(7484):528–532, 2014

[2] Anders Ström, Henrik Johannesson, and G. I. Japaridze. Edge dynamics in a quantum spin hall state: Effects from rashba spin-orbit interaction. Phys. Rev. Lett., 104:256804, 2010

T3: Photonics, plasmonics, metamaterials

Time: Wednesday 4 Mar, 1:30pm; Venue: LT5; Chair: Zhang Baile
Time allocated for invited talks is 15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T3.124 (INVITED) Terahertz meta-sensors: From high Q Fano resonant metasurfaces to perfect meta-absorbers

Ranjan Singh* (NTU)
1:30pm – 01:50pm

Resonant sensing is limited by the quality factor of the resonance phenomena that occurs in any resonator system. We excite high quality factor Fano resonances via symmetry breaking in planar terahertz metasurfaces for ultrasensitive sensing. However, we recently discovered that three layered metamaterial absorbers show significantly higher sensitivity than planar metasurfaces. In this talk I would discuss and compare the performance and physics of Lorentzian and Fano metasurfaces with that of metamaterial absorber based sensors.

T3.163 (INVITED) Tunable hyperbolic metamaterials utilizing phase change heterostructures

Harish N. S. Krishnamoorthy*, You Zhou, Shriram Ramanathan, Evgenii Narimanov, Vinod Menon (Dept. of Physics, The City University of New York, USA; Center for Disruptive Photonic Technologies, Nanyang Technological University, Singapore (current affiliation))
01:50pm – 02:10pm

We report our work on a tunable anisotropic metamaterial where the topology of the optical iso-frequency surface is tuned from elliptical to hyperbolic geometry by utilizing the phase transition in the correlated material vanadium dioxide [1]. By carrying out ellipsometry measurements on vanadium dioxide (VO_2)-titanium dioxide (TiO_2) heterostructures, we demonstrate the transition in the effective dielectric constant parallel to the layers to undergo a sign change from positive to negative as the VO_2 layers undergo the phase transition. The ability to tune the optical iso-frequency surface in real time using external perturbations such as temperature, voltage, or optical pulses creates new avenues for controlling light-matter interaction.

[1] "Tunable hyperbolic metamaterials using phase change heterostructures", H. N. S. Krishnamoorthy, Y. Zhou, S. Ramanathan, E. Narimanov, V. M. Menon, Appl. Phys. Lett. 104, 121101 (2014)

T3.135 100 THz bandwidth plasmonic metamaterial switch

Venkatram Nalla*, João Valente, Stefano Vezzoli, Cesare Soci, Sun Handong, Nikolay Zheludev (Nanyang Technological University)
02:10pm – 02:25pm

The development of coherent optical networks and processing are catalysing increasing attention as solutions to accelerate the data transfer speed and data processing. Conventional technology in coherent optical networks can perform at the maximum speed of 100 Gb/s. Here we evaluate the effect of plasmonic finite response time on the coherent perfect absorption process for a plasmonic metamaterial absorber, to achieve 100 Tb/s.

All-optical modulation means control of the phase or intensity of one light beam by another. In the coherent perfect absorption scenario, the interference of two counter-propagating coherent beams on a highly absorbing material of sub- wavelength thickness can either lead to nearly total transmission or to nearly total absorption of the incident light, depending on their mutual intensity and phase.

We study the coherent modulation of the total energy as a function of the pulse duration, from few hundreds fs down to 6 fs. Our measurements allow us to assess the maximal bandwidth for all-optical control of femtosecond pulses, which is about 100 THz. All optical switching also eliminate the disadvantages of optical–electrical–optical conversion thus opening a road to advances in terabits per second communications for high-performance communications and computing.

Our device based on coherent absorption has the advantage of being compact, intrinsically low power (as low as single photons), while demonstrating large modulations (modulation bandwidth $\approx$7:1) and speed exceeding 100 THz has been observed. Finally we also evaluate the effect of nonlinearities on coherent modulation and its spectral dependence.

T3.125 Polarization control in terahertz metasurfaces with the lowest order rotational symmetry

Longqing Cong, Ningning Xu, Weili Zhang, Ranjan Singh* (Nanyang Technological University)

02:25pm – 02:40pm

Polarization of an electromagnetic wave is a fundamental property since the transverse nature of light and the concept of interference itself was established due to the polarization of light. When an individual molecule emits light, it is always completely polarized unlike natural light. Metamolecules have recently played prominent role in tailoring the linear and circular polarization of light. However, the three dimensional and the high-order rotationally symmetric designs limit the operation region of the polarimetric metadevices. Here, we demonstrate a planar metamolecule design with two-fold rotational symmetry that shows giant cross polarization transmission which leads to strong optical activity and asymmetric transmission of circularly polarized light. We also demonstrate a bidirectional circular polarizer functionality of the metamolecules. Such planar metasurfaces would be used to design active polarization control devices for real applications in optical and terahertz systems.

T3.36 Reversing The Temporal Envelope Of A Heralded Single Photon Using A Cavity

Bharath Srivathsan*, Gurpreet Kaur Gulati, Brenda Chng, Alessandro Cerè, Christian Kurtsiefer* (Centre for Quantum Technologies)

02:40pm – 02:55pm

We demonstrate a way to prepare single photons with a temporal envelope that resembles the time reversal of photons from the spontaneous decay process. We use the photon pairs generated from a time-ordered atomic cascade decay as a starting point: the detection of the first photon of the cascade is used as a herald [1,2]. We show how coupling the heralding photon into an asymmetric Fabry-Perot cavity reverses the temporal shape of the heralded photon from a decaying to a rising exponential envelope. A single photon with such an exponentially rising temporal envelope would be ideal for interacting with two level systems. Using the analogy between an atom and a cavity [3] we demonstrate a proof-of-principle experiment on how these photons can be used for strong interaction with a single atom [4].

References: [1] B. Srivathsan et al, Phys.Rev. Lett. 111, 123602 (2013). [2] G. Kaur Gulati et al, Phys Rev A. 90, 033819 (2014). [3] M. Bader, S. Heugel, A. L. Chekhov, M. Sondermann, and G. Leuchs, New J Phys 15, 123008 (2013). [4] B. Srivathsan, G. Kaur Gulati, A. Cer'e, B. Chng, and C. Kurtsiefer, Phys. Rev. Lett. 113, 163601 (2014).

T3.170 Super-oscillation of single photon beyond the diffraction limit

Guanghui Yuan*, Stefano Vezzoli, Charles Altuzarra, Edward Rogers, Christophe Couteau, Cesare Soci*, Zexiang Shen, Nikolay Zheludev (Centre for Disruptive Photonic Technologies, NTU)

02:55pm – 03:10pm

We report the first experimental demonstration of super-oscillatory behaviors in single photon regime, where the quantum wave-function of a single photon can be localized into length scale much smaller than the smallest wave length contained in its Fourier spectrum.

Super-oscillations are phenomena that a band-limited function can oscillate much faster than its highest Fourier component over arbitrarily large intervals [1]. As a result of delicate near-destructive interference, superoscillations feature particularly intriguing characteristics that they occur in relatively low-intensity regions accompanying with rapid phase variations. The super-oscillation idea is surprising and counterintuitive since it gives the illusion that the Fourier component is 'super-shifted' to be outside the spectrum of the function.

Super-oscillations are of particular interest in quantum physics. The original insights which eventually led to super-oscillations started with the observation by Aharonov that the usual measurement procedure for preselected and postselected ensembles of quantum systems can give unusual results [2]. As a result of the uncertainty principle, the initial boundary condition of a quantum mechanical system can be selected independently of the final boundary conditions. Interestingly, the weak measurement of quantum system can have values much higher than the spectrum of the operator. Although quantum weak-measurement of single photon and super-oscillations of classical fields have been verified in previous works, direct evidence on subwavelength localization of single photon due to super-oscillation has not been provided thus far.

Both classical and quantum measurements are carried out, where we use either a continuous laser or a single photon source from a pair of correlated photons generated by spontaneous parametric down-conversion in nonlinear crystal. We direct one channel onto a specially designed one-dimensional meta-lens consisting of multiple parallel slits, which serves as a binary mask to diffract the incoming light causing it to interfere behind the mask. In the focal plane of the lens, a hot-spot with FWHM of $\approx 0.4\lambda$ was achieved in the super-oscillation region, undoubtedly revealing sub-wavelength localization of quantum wavefunctions of single photon.

References

[1] M. V. Berry and S. Popescu, ”Evolution of quantum super-oscillations and optical superresolution without evanescent waves,” J. Phys. A **39**, 6965-6977 (2006).
[2] Y. Aharonov, D. Z. Albert, and L. Vaidman, ”How the result of a measurement of a component of the spin of a spin-1/2 particle can turn out to be 100,” Phys. Rev. Lett. **60**, 1351-1354 (1988).

T4: Quantum information 1

Time: Wednesday 4 Mar, 1:30pm; Venue: MAS2; Chair: Valerio Scarani
Time allocated for invited talks is 15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T4.61 (INVITED) What can we know about the past of a photon?

Berge Englert*, Hui Khoon Ng, Jibo Dai, Yink Loong Len, Leonid Krivitsky, Kelvin Horia (Centre for Quantum Technologies (CQT))
1:30pm – 01:50pm

When a photon is sent through an interferometer and eventually detected after emerging from one of the output ports, what can we say about the photon's whereabouts at intermediate times? There is a debate about this matter, in particular in the context of the "two-state formalism" advocated by Yakir Aharonov, Lev Vaidman, and others, where one may conclude that the photon reaches parts of the interferometer without passing through connecting links. We explain why this mystery is only apparent. A related experiment is in progress.

T4.60 Towards a loophole-free violation of Bell's Inequality

Jianwei Lee*, Alessandro Cere, Christian Kurtsiefer, Brenda Chng (Center for Quantum Technologies and Department of Physics, National University of Singapore)
01:50pm – 02:05pm

Until now, there has not been yet a conclusive, loophole-free experimental violation of the Bell inequality [1]. This leaves room for interpretation based on local deterministic hidden-variable (LHV) theories [2]. We plan to use polarisation entangled photon pairs to progressively close all loopholes in two stages.

First, we will prove that we can close the detection loophole as previously demonstrated by Giustina et al. [3] and McCusker et al. [4]. We do this by using transition-edge sensors (TES) and a spontaneous parametric down-conversion (SPDC) source to generate nonmaximally entangled states as proposed by Eberhard [5].

Secondly, we develop fast polarisation switches to perform a change of basis in tens of nanoseconds and use quantum random number generators to determine the choices to close the freedom-of-choice loophole. The basis choice, implementation and detection events will be sufficiently space-like seperated to ensure that the locality loophole is closed. Finally, all three loopholes will be closed simultaneously.

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[5] P. H. Eberhard, Background level and counter efficiencies required for a loophole-free Einstein-Podolsky-Rosen experiment, Phys. Rev. A 47, R747 (1993).

T4.26 Randomness of post-selected data

Phuc Thinh Le*, Gonzalo de La Torre Carazo*, Jean-Daniel Bancal*, Nicolas Brunner*, Valerio Scarani* (National University of Singapore)
02:05pm – 02:20pm

When a Bell inequality is violated, the outcomes of the experiment are partially random and private: they can be used (after hashing) for many cryptographic applications. However, in a practical Bell experiment, because of the inefficiencies of the source and the detectors, the recorded data will mostly be populated with the no detection events $\emptyset$. From physics, we know that these no-detection events carry little or no randomness: for instance, they may be associated to the source not having emitted any pair in a given time. However, in a device-independent certification, one cannot simply ignore those events, because this opens the detection loophole. Here we provide a method to quantify the randomness present in a subset of events (for instance, double detections) which takes into account the whole observed statistics (including the no-detection events) and thus does not open the detection loophole. A priori, there are two natural scenario we can consider, depending on whether we reveal to Eve the runs that have been kept or discarded. For simplicity, in this work we focus only on the scenario where Eve is allowed to learn the runs we have kept, and we assume i.i.d.. For several physically-motivated models of the observed statistics, we show that one can indeed vindicate the idea that most of the randomness is present in the double-detection events. In other words, the current analysis allows us to extract more randomness from the outcomes of Bell tests than a previous analysis, and also permit hashing the post-selected subset of the original data thereby reducing the needed seed length, and also the time required to compute the final output.

T4.100 Random correlations detect and characterise quantum entanglement

Minh Tran*, Borivoje Dakic, Francois Arnault, Wieslaw Laskowski, Tomasz Paterek (NTU)
02:20pm – 02:35pm

We show that expectation value of squared correlations measured along random local directions is a quantifier of quantum entanglement in pure states which can be directly experimentally assessed by a measurement on two copies of the state. Entanglement can therefore be measured by parties who do not share a common reference frame and do not even possess a well-defined local reference frame. We show that already a single-qubit-per-party reference and rotationally invariant measurements are sufficient to quantify entanglement and violate a Bell inequality. We also provide an entanglement witness solely in terms of random correlations, capable of detecting entanglement in mixed states, and emphasise how data gathered for a single measurement setting reliably detects entanglement.

T4.24 State complexity and quantum computation

Yu Cai*, Huy Nguyen Le*, Valerio Scarani* (National University of Singapore)
02:35pm – 02:50pm

It is well known that the classical description of a generic quantum state requires exponentially many parameters in the number of parties. For instance, a generic state of n qubits,

$$|\Psi >= \sum_{i=1}^{2^n} c_i |i >,$$

requires 2^n complex coefficient a priori. Not all states possess this exponential complexity: product states, for instance, can be described with at most 2n complex numbers; and the class of matrix product states, which approximate well the ground state of a large class of many-body Hamiltonians, requires only polynomially-many parameters. But complex states are definitely important, and not only because there are overwhelmingly many of them if one were to draw states randomly from a uniform distribution. It is notably believed that complex states are a necessary resource for quantum computers to overpower classical ones; this intuition has been validated by rigorous proofs for some models of computation and quantification of complexity [1–3].

Tree size (TS) is a measure that captures the complexity of a multiqubit state in the above sense: It can be understood as the minimal number of parameters required for describing a given state with bra-ket representation. TS is an interesting measure because not only is it in principle computable, but one can also obtain nontrivial lower bounds for it [4,5]. In this way, it has been possible to identify explicit families of complex states whose TS scales superpolynomially in the number of qubits [4,5]: including the resource state for universal measurement-based quantum computation, the 2D cluster state [6].

However, the problem of how one can test that a pure quantum state has indeed superpolynomial TS remains to be addressed. Quantum state tomography is not feasible as it requires an exponential number of measurements. We show that the superpolynomial tree size of the complex subgroups states and the 2D cluster state can be verified efficiently. The verification is based on measuring a stabilizer witness, which requires only a polynomial number of elementary operations [6].

Tree-size complexity is also relevant to the ”speed up” quantum computation offers over its classical counterpart. It is likely that this speed up is achieved only when the state has superpolynomial TS at some step during the computation. With a number-theoretic conjecture, Aaronson showed that the state in Shor’s algorithm has superpolynomial TS [4]. We find that the same holds for the states in Deutsch-Jozsa’s algorithm [6]. Moreover, we show that measurement-based quantum computation can be simulated efficiently with classical computers if the TS of the resource state is only a polynomial in the number of qubits [6].

References: [1] G. Vidal, Phys. Rev. Lett. 91, 147902 (2003). [2] M. Van den Nest, W. Duer, G. Vidal, and H.J. Briegel,Rev. A 75, 012337 (2007). [3] H.N. Le, Y. Cai, X.Y. Wu, and V. Scarani, Phys. Rev. A 88, 012321 (2013). [4] S. Aaronson, STOC ’04 Proceedings of the 36th Annual ACM Symposium on Theory of Computing, (ACM, New York, 2004), pp. 118-127; arXiv:0311039. [5] H.N. Le, Y. Cai, X.Y. Wu, R. Rabelo and V. Scarani, Phys. Rev. A 89, 062333 (2014). [6] Y. Cai, H.N. Le, V. Scarani, in preparation (2015)

T4.57 Experimental Detection of Entanglement with Optimal-Witness Families

Jibo Dai*, Yink Loong Len*, Yong Siah Teo*, Berge Englert*, Leonid Krivitsky* (Data Storage Institute)

02:50pm – 03:05pm

We report an experiment in which one determines, with least tomographic effort, whether an unknown two-photon polarization state is entangled or separable. The method measures whole families of optimal entanglement witnesses. We introduce adaptive measurement schemes that greatly speed up the entanglement detection. The experiments are performed on states of different ranks, and we find good agreement with results from computer simulations.

T5: Atomic Physics

Time: Wednesday 4 Mar, 3:40pm; Venue: MAS1; Chair: Alessandro Cerè
Time allocated for invited talks is 15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T5.15 Hong-Ou-Mandel Interference Between Triggered And Heralded Single Photons From Separate Atomic Systems

Victor Xu Heng Leong*, Alessandro Cerè, Gurpreet Kaur Gulati, Bharath Srivathsan, Sandoko Kosen, Christian Kurtsiefer (CQT, NUS)
3:40pm – 03:55pm

The realization of quantum networks and long distance quantum communication rely on the capability of generating entanglement between separated nodes. This can be achieved if the separated nodes generate indistinguishable photons, independently of the physical processes on which they are based [1,2]. We demonstrate the compatibility of two different sources of single photons: a single atom and four-wave mixing in a cold cloud of atoms. The four-wave mixing process in a cloud of cold 87 Rb generates photon pairs. The cascade level scheme used ensures the generation of heralded single photons with exponentially decaying temporal envelope [3]. The temporal shape of the heralding photons matches the shape of photons emitted by spontaneous decay but for the coherence time, shortened because of the collective effects in the atomic cloud [4].

A single 87 Rb atom is trapped in an far-off-resonance optical dipole trap and can be excited with high probability using a short ($\approx$3 ns) intense pulse of resonant light. emitting a single photon by spontaneous decay. A large numerical aperture lens collects $\approx$4% of the total fluorescence [5].

The heralded and the triggered photons are launched into a Houng-Ou-Mandel interferometer: a symmetrical beam-splitter with outputs connected to single photon detectors. The rate of coincidence events at the two outputs varies depending on the relative delay time between the detection of the heralding photon and the optical excitation pulse, and on the relative polarization of the input modes. Controlling these parameters, we observe a maximum visibility of 70$\pm$4%.

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T5.51 Narrowband photon pairs from a cold atomic vapour for interfacing with a single atom

Gurpreet Kaur Gulati, Bharath Srivathsan, Victor Leong, Brenda Chng, Alessandro Cerè, Christian Kurtsiefer* (Center for Quantum Technologies)
03:55pm – 04:10pm

Recent advances to build quantum networks and quantum repeaters using atomic ensembles benefit from photon pair sources that not only generate nonclassical light but also resonant, narrowband light [1]. We present a narrowband, bright source of time correlated near infrared photon pairs based on a cold cloud of 87Rb atoms via a non-degenerate fourwave mixing process [2,3]. The bandwidth of the generated photons can be tuned from 10 MHz–30MHz by changing the optical density of the atomic cloud. We observe an instantaneous rate of 20,000 pairs per second using silicon avalanche photodetectors and an efficiency indicated by a pair-to-single ratio of 23%. The rates and efficiency reported are uncorrected for losses due to non-unit detector efficiency, filtering efficiency and fiber coupling efficiency. The violation of the Cauchy-Schwarz inequality by a factor of $50 * 10^6$ indicates a strong non-classical correlation between the generated fields. We further present an estimation of the polarization entangled state of the generated photon pairs by performing quantum state tomography. The bandwidth and wavelength of the generated photons is suitable to interface with 87Rb atoms, a common workhorse for quantum memories. As a first step towards interfacing, we have performed Hong-Ou-Mandel interference experiment between a single photon from a single 87Rb atom and a heralded single photon from our source [4]. The experiment demonstrates indistinguishability of single photons generated from two different physical systems which is an important step towards realizing quantum networks.

References [1] L.-M. Duan et al, "Long-distance quantum communication with atomic ensembles and linear optics," Nature 414 413 (2001). [2] B. Srivathsan et al, "Narrow Band Source of Transform-Limited Photon Pairs via Four-Wave Mixing in a Cold Atomic Ensemble," Phys.Rev. Lett. 111, 123602 (2013). [3] G. Kaur Gulati et al, "Generation Of An Exponentially Rising Single-photon Field From Parametric Conversion In Atoms," Phys Rev A 90, 033819 (2014) [4] C. K Hong et al, "Measurement of subpicosecond time intervals between two photons by interference," Phys.Rev. Lett. 59, 2044 (1987).

T5.79 Microwave Control of Trapped-Ion Motion Assisted by a Running Optical Lattice

Shiqian Ding*, Gleb Maslennikov, Huanqian Loh, Roland Hablutzel, Dzmitry Matsukevich* (Centre for Quantum technologies)
04:10pm – 04:25pm

Control of atomic and molecular motion in the quantum regime is crucial for quantum information processing, quantum simulation, and metrology. Traditionally, the motion of the ions is coupled to their internal states by the laser light only. We show that motional and internal states of a trapped ion can be coupled also by microwave radiation if the ion is placed in a state-dependent potential generated by a running optical lattice. Both the optical lattice depth and the running lattice frequency provide tunability of the spin-motion coupling strength. The spin-motion coupling is exploited to experimentally demonstrate sideband cooling of a 171Yb ion to the ground state of motion.

T5.81 Controlling atoms with plasmons: a novel 2D metamaterial interface

Eng Aik Chan*, Syed Abdullah Aljunid*, Giorgio Adamo*, Martial Ducloy, David Wilkowski, Nikolay Zheludev (CDPT/NTU)
04:25pm – 04:40pm

We report on a new type of two-dimensional material system of sub-wavelength thickness, a plasmonic metasurface in atomic gas. Such plasmono-atomic metamaterial has unique properties underpinned by the interactions in the nearfield layer of the nanostructure.

Using sub-Doppler reflective spectroscopy with a tunable diode laser and a hole-burning frequency reference we show that the spectra of Caesium atoms are strongly affected by the Fano-like resonant coupling between atomic and plasmonic excitations. Moreover, the Caesium spectra modifications depend on the detuning between the D2 line of Caesium ($6^2S_{1/2}$–$6^2P_{3/2}$) and the dipole plasmonic absorption resonance of the nanostructure.

We extract, via a precise analysis of resonant profiles, the atomic transition frequency shift induced in the nearfield of the metasurface. Our work provide clear experimental evidence that narrow lines of the atomic gas, that are only about 10MHz in width, are extremely sensitive to dispersion due to plasmonic resonances that are typically a million times wider.

T5.85 Triangular and Honeycomb Lattices of Cold Atoms in Optical Cavities

Shabnam Safaei*, Christian Miniatura, Benoît Grémaud (Centre for Quantum Technologies)
04:40pm – 04:55pm

In a system consisting of two optical cavities and a cloud of non-interacting cold Bosons pumped by a laser field in dispersive regime, we examine the possibility of formation of triangular and honeycomb lattices of cold atoms as a result of superradiance and self-organization. We consider a two-dimensional homogenous ensemble of cold atoms inside two optical cavities in a layout where the axes of the cavities and atomic system are on the xy-plane and cavities make $\pi/6$ and $5\pi/6$ angles with positive direction of x-axis. The laser field, which is far-detuned from the atomic transition and slightly-detuned from the cavity modes, pumps the atomic system in y direction. For laser strengths larger than a critical value, the atoms will collectively scatter the laser field into the cavity modes resulting in a sudden increase in the average number of photons inside the cavities. In return, superposition of the standing waves of the laser and the cavity fields will create an effective potential for the atoms to self-organize themselves. By deriving the dynamical equations of the system we show how the effective potential can change from a triangular to honeycomb structure depending on the phase of the cavity fields with respect to the laser. We also address instability of the initial system and obtain an estimation of the critical laser intensity for superradiance by studying the linear response of the system to perturbation. Finally, the dynamics of the system is monitored by numerical simulation of the dynamical equations indicating occurrence of superradiance and self-organization of cold atoms in either triangular or honeycomb lattices with equal consecutive or alternative sites, depending on the phase of the cavity fields. The long-time dynamics proves the stability of triangular lattice as well as honeycomb lattice with equal consecutive sites. It is also shown that, in most of the cases, it is possible to drive the system between different lattice structures by dynamically changing the phase of the cavity fields with respect to the laser.

T5.94 Molecular spectroscopy of electronically excited states of 6Li-40K: Towards STIRAP transfer to absolute ground state.

Sambit Bikas Pal*, Markus Debatin*, Mark Lam*, Kai Dieckmann* (Centre for Quantum Technologies, NUS)
04:55pm – 05:10pm

6Li-40K molecules in its absolute ground state have a large dipole moment of 3.6 debye, which makes them a suitable candidate for investigating long range dipole-dipole interactions. Starting from 6Li-40K Feshbach molecules [1] we plan to transfer them to the ground state using stimulated Raman adiabatic passage (STIRAP). Achieving this, demands spectroscopic investigations of the precise transition frequencies and transition strengths between the states relevant for the STIRAP transfer. In this talk we present our latest single-photon spectroscopic measurements of the ro-vibrational states in the electronically excited 1Π potential of 6Li-40K molecules.

[1] A.-C. Voigt, M. Taglieber, L. Costa, T. Aoki, W. Wieser, T. W. Hänsch, and K. Dieckmann, Phys. Rev. Lett. 102, 020405 (2009)

T5.180 Electromagnetic induced transparency with Rydberg atoms

Thibault Vogt*, Jingshan Han, Ruixiang Guo, Wenhui Li* (centre for quantum technologies)
05:10pm – 05:25pm

Rydberg atoms constitute a paradigmatic system for the study of quantum many-body physics. Very large dipole-dipole interaction between Rydberg atoms leads to the dipole blockade, at the heart of promising proposals for quantum simulation or studies of strongly correlated systems [1-2]. Dipole blockade has already been used to excite spatially organized structures of Rydberg atoms [3], realize single photon sources [4] or implement quantum gates [5]. In this talk, I will present the recent developments of our experimental setup for achieving highly coherent Rydberg excitation. I will present preliminary spectroscopic measurements obtained for the excitation of 87Rb Rydberg atoms in an ultra-cold gas. I will also discuss our progress towards the detection of Rydberg atoms based on the interaction enhanced absorption imaging technique [6].

[1] Weimer, H., et al. Nature Physics 6:382-388 (2010). [2] Pupillo, G., et al. PRL 104 223002 (2010). [3] Schausz, P., et al. Nature 491 87-91 (2012). [4] Peyronel et al. Nature 488 58-60 (2012). [5] Isenhower et al. PRL 104 010503 (2010). [6] Günter et al. Science 342, 954-956 (2013).

T6: Emerging 2D materials

Time: Wednesday 4 Mar, 3:40pm; Venue: LT4; Chair: Shen Zexiang
Time allocated for invited talks is 15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T6.10 (INVITED) Optical study of Interlayer coupling and layer-dependent electronic structure in MoS_2

Zexiang Shen*, Jiaxu Yan, Juan Xia (Nanyang Technological University)
3:40pm – 04:00pm

The optical and electronic structures of two dimensional transition metal dichalcogenide (2DTMD) materials often show very strong layer-dependent properties. Detailed understanding of the inter-layer interaction will help greatly in tailoring the properties of 2D TMD materials for applications. Raman/Photoluminescence (PL) spectroscopy and imaging have been extensively used in the study of nano-materials and nano-devices. They provide critical information for the characterization of the materials such as electronic structure, optical property, phonon structure, defects, doping and stacking sequence. In this talk, we use Raman and PL techniques to study few-layer MoS_2 samples. The Raman and PL spectra show clear correlation with layer-thickness and stacking sequence. Our ab initio calculations reveal that difference in the electronic structures mainly arises from competition between spin-orbit coupling and interlayer coupling in different structural configurations.

T6.52 Micro-Dressing of CNTs Array with MoS_2 Gauze

Sharon Xiaodai Lim, Chornghaur Sow* (Department of Physics NUS)
04:00pm – 04:15pm

In this work, 3D hybrid material comprising of few-layered MoS_2 gauze assembled onto vertically aligned CNTs array has been created. Using a focused laser beam with different wavelengths, site selective patterning of either the MoS_2 film or the supporting CNTs array is achieved. This paved the way for applications and investigations into the fundamental properties of the hybrid MoS_2/CNTs material. Through Raman mapping, straining and electron doping of MoS_2 film as a result of interaction with the supporting CNTs array are detected. Role of the CNTs is further emphasized, with higher density CNTs (hence providing more electrical contact points with the MoS_2 film) resulting in a more significant shift in the G peak of the Raman spectrum. Photo-response measurements are successful in detecting optoelectronic behavior of the hybrid material. At 0V, 3.49nA of current is measured upon illuminating the sample with a broad beam 532nm laser. With it responding well to external irradiation of different wavelength, and changes to the power of the excitation source, the hybrid material has shown potential for applications in light harnessing devices.

T6.142 Information processing with topologically protected vortex memories in exciton-polariton condensates

Helgi Sigurdsson*, Oleg Egorov, Xuekai Ma, Ivan Shelykh, Timothy C. H. Liew (Division of Physics and Applied Physics, Nanyang Technological University)
04:15pm – 04:30pm

We show theoretically that in a non-equilibrium system of an exciton-polariton condensate, where polaritons are generated from incoherent pumping, a ring-shaped pump allows for stationary vortex memory elements of singular topological charge. Using simple potential guides we can choose whether to copy the same charge or invert it onto another spatially separate ring pump. Such manipulation of binary information opens the possibility of a new type of processing using vortices as topologically protected memory components.

T6.63 (INVITED) Improved Photoelectrical Properties of 2D TMDC Films after Laser Modification

Chornghaur Sow* (Department of Physics NUS)
04:30pm – 04:50pm

Direct patterning of ultrathin 2D TMDC films with well-defined structures and controllable thickness is appealing since the properties of TMDC sheets are sensitive to the number of layer and surface properties. In this work, we employed a facial, effective and well-controlled technique to achieve micropatterning of TMDC films with a focused laser beam. We demonstrated that a direct focused laser beam irradiation was able to achieve localized modification and thinning of as-synthesized TMDC films. With a scanning laser beam, micro-domains with well-defined structures and controllable thickness were created on the same film. We found that laser modification altered the photoelectrical property of the TMDC films and subsequently photodetectors with improved performance have been fabricated and demonstrated using laser modified films.

T6.145 High-yield synthesis, optical properties, and photocatalytic performance of g-C_3N_4

Yanwen Yuan, Lulu Zhang, Jun Xing, M. Iqbal Bakti Utama, Xin Lu, Yongmei Li, Xiao Hu, Shijie Wang, Jordi Arbiol, Qihua Xiong* (Nanyang Technological University)
04:50pm – 05:05pm

Graphitic carbon nitride (g-C_3N_4) has gained great attention as a fascinating semiconductor material with a graphene-like 2D–structure. Owing to a band gap of 2.7 eV, g-C_3N_4 shows excellent performance in photocatalytic reactions. g-C_3N_4 is also a promising inexpensive metal-free visible-light photocatalyst with high thermal and chemical stability. Therefore, it is important to obtain high quality g-C_3N_4 and study its optical properties. The main synthesis method of g-C_3N_4 is direct annealing of reagent such as cyanamide, dicyandiamide, or melamine in air; however, such air heating method suffers from very low yield because polymerization temperature is higher than the sublimation point of reagent and the reagent may escape before reaction occurs. Herein, we report the high-yield synthesis of g-C_3N_4 via the encapsulated high temperature synthesis. By sealing the reagent in a vacuum ampoule, the average yield of g-C_3N_4

products could be improved to as high as 62% under the optimal synthesis temperature. We also obtain the samples under a variety of temperatures (from 450°C to 650°C) to further understand the synthesis mechanism of g-C_3N_4. With comprehensive characterizations by thermal gravity analysis (TGA), X-Ray diffraction (XRD) and X-ray photoelectron spectroscopy (XPS), we study the components and chemical structure of the g-C_3N_4 product. Meanwhile, optical spectroscopy investigations including photoluminescence, infrared and Raman spectroscopy shed light on the growth mechanism and their optical properties. Finally, we demonstrate the photocatalytic performance of the g-C_3N_4 product by the photocatalytic degradation experiment.

T7: Photonics and plasmonics

Time: Wednesday 4 Mar, 3:40pm; Venue: LT5; Chair: Ranjan Singh
Time allocated for invited talks is 15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T7.40 (INVITED) Light in Magnetic Recording

S.N. Piramanayagam* (Nanyang Technological University)
3:40pm – 04:00pm

Magnetic recording has come a long way from drums, to tapes and eventually to tiny drives. Human beings have benefited from magnetic recording, almost as much as from semiconductor technology. Facebook, Youtube and other such applications would be unimaginable without the progress in the hard disk drives. Physicists Albert Fert and Peter Grunberg won their Nobel prizes due to the application of their invention which revolutionized hard disk drives.

Lay persons have difficulty in distinguishing CDs from hard disk drives. While CDs and DVDs use light, hard disk drives use magnetic principles. The technology faced certain difficulties, such as thermal instability of magnetization which could cause erasure of information. And then there was light. The emerging technology in magnetic recording, which is called heat-assisted magnetic recording, uses tiny beam of light. The light helps to raise the temperature of recording medium to its Curie temperature, thus enabling writing on a medium which would not allow writing without light.

The talk will be of a tutorial nature, without equations, and would describe the physics behind the use of light in magneto-optic recording and hard disk drives.

T7.12 (INVITED) Optimal shell thickness of metal-in-insulator nanoparticles for net enhancement of photogenerated polarons in organic absorber films

Wei Peng Goh, Zi En Ooi*, Evan Laurence Williams, Ren Bin Yang, Wee Shing Koh (Institute of Materials Research and Engineering, Agency for Science, Technology and Research (A*STAR))

04:00pm – 04:20pm

Embedding metal nanoparticles in the active layer of organic solar cells has been explored as a route to improving charge carrier generation, with localized field enhancement as a proposed mechanism. However, embedded metal nanoparticles can also act as charge recombination sites. To suppress such recombination, the metal nanoparticles are commonly coated with a thin insulating shell. At the same time, this insulating shell also limits the extent that the localized enhanced electric field influences charge generation in the organic medium. It is presumed that there is an optimal thickness which maximizes field enhancement effects while suppressing recombination. To find this optimum, Atomic Layer Deposition (ALD) was used to deposit Al_2O_3 layers of different thicknesses onto silver nanoparticles in a thin film of P3HT. Photoinduced absorption (PIA) spectroscopy was used to study the dependence of the photogenerated P3HT+ polaron population on the Al_2O_3 thickness. The optimal thickness was found to be 3-5 nm. This knowledge can be further applied in the design of metal nanoparticle-enhanced solar cells.

T7.115 Coupling of polarons in conjugated polymers to resonant IR nanoantennas

Zilong Wang, Jun Zhao, Bettina Frank, Qiandong Ran, Giorgio Adamo, Harald Giessen, Cesare Soci* (Nanyang Technological University)

04:20pm – 04:35pm

Local electric field enhancement in the vicinity of plasmonic metal nanostructures are regarded not only as an effective light trapping technique but also methods to modify the photophysics of the material at nanoscale. In organic semiconductors, hybridization of plasmonic modes in metal nanostructures with excitonic states of organic semiconductors has been extensively exploited to alter their optical absorption and emission properties. Here we propose and demonstrate a novel coupling mechanism between plasmons and photoinduced polaronic transitions in conjugated polymer P3HT in the mid-infrared.

Upon visible photoexcitation, polarons are generated in semiconducting polymer, giving to characteristic optical transitions in near-IR (NIR, 1.24 - 1.9 eV) and mid-IR (MIR, 0.1 - 0.6 eV) spectral regions. We designed split-ring metamaterials resonating in the MIR region to exactly match one of these polaronic transitions. Experimentally, large area nanoantenna samples were fabricated by hole-mask colloidal nanolithography using a tilted-angle-rotation evaporation technique covered by a thin P3HT film. Polarized steady-state photoinduced absorption measurements of the hybrid polymer-nanoantenna system clearly indicate near-field interaction between charged polarons in the polymer and localized particle-plasmons. This new mechanism yields a modification of photophysics in polymer exciton dissociation and polaron formation, and may be used to enhance power conversion efficiency of conventional polymer photovoltaic cells by recovering thermal photon energy.

T7.84 Structure, optical function and self-assembly of amorphous photonic nanostructures from avian feather barbs: a comparative small angle X-ray scattering (SAXS) analysis of 230 bird species

Vinodkumar Saranathan*, Richard O. Prum (PAP, SPMS, NTU)

04:35pm – 04:50pm

Non-iridescent structural colours of feathers are a diverse and an important part of the phenotype of many birds. These colours are generally produced by three-dimensional, amorphous (or quasi-ordered) spongy beta-keratin and air nanostructures found in the medullary cells of feather barbs. Two main classes of three-dimensional barb nanostructures are known, characterized by a tortuous network of air channels or a close packing of spheroidal air cavities. Using synchrotron small angle X-ray scattering (SAXS) and optical spectrophotometry, we characterized the nanostructure and optical function of nearly 300 distinctly coloured feathers from 230 species belonging to 52 avian families. The SAXS data provided quantitative diagnoses of the channel- and sphere-type nanostructures, and confirmed the presence of a predominant, isotropic length scale of variation in refractive index that produces strong reinforcement of a narrow band of scattered wavelengths. The SAXS structural data identified a new class of rudimentary or weakly nanostructured feathers responsible for slate-grey, and blue-grey structural colours in addition to a previously identified instance of 2D quasi-ordered bundles of keratin nanofibres in the medullary barb cells of Blue Penguin (Eudyptula minor, Spheniscidae). SAXS structural data provided good predictions of the single-scattering peak of the optical reflectance of the feathers. The SAXS structural measurements of channel- and sphere-type nanostructures are also similar to experimental scattering data from synthetic polymers that self-assemble by phase separation processes. These results support the hypothesis that numerous lineages of birds (at least 52) have independently evolved self-assembled, quasi-ordered, colour-producing nanostructures in feather barbs that develop via arrested phase separation of polymerizing beta-keratin from the cytoplasm of medullary cells. Such self-assembled avian amorphous photonic nanostructures with isotropic optical properties may provide biomimetic inspiration for next-generation photonic technology.

T7.123 Polymer Photonic Crystals Vapor Sensors

Paola Lova*, Giovanni Manfredi, Annalisa Bruno, Davide Comoretto, Cesare Soci (Energy Rersearch Institute at NTU, Nanyang Technological University)
04:50pm – 05:05pm

In these work we present a new strategy to increase Distributed Bragg Reflectors (DBR) responsivity to gases and vapors.

In the last few years, polymers become predominant DBR building blocks thank their mechanical flexibility, low cost and simple preparation methods athough for mutually processable polymers the low dielectric contrast achievable represents a limitation in reaching high reflectivity. In addition, for photonic crystal sensors, high porosity structures, which are unconceivable with amorphous polymers, are needed to allow analytes permeation within the dielectric lattice.

Our strategy is based on loading surface-modified ZnO nanoparticles into polystyrene to increase its refractive index and permeability. The new nanocomposites have been used to fabricate DBR with photonic band-gap tunable from the visible to near-infrared regions and with a diffraction pattern up to the fifth order. The new structures show a 10 times enhancement of optical responsivity to organic vapor increased respect to multilayers grown with un-doped polymers. Moreover very high sensitivity (lower than 10 ppm of toluene) and fast response time ($\sim$15 s) have been proved.

T8: Topological systems

Time: Thursday 5 Mar, 1:30pm; Venue: MAS1; Chair: Chong Yidong
Time allocated for invited talks is 15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T8.2 (INVITED) Geometric Valley Physics and Valley-related Novel Topological Phases

Shengyuan Yang* (Singapore University of Technology and Design)
1:30pm – 01:50pm

In this talk, I will talk about several of our works related to valley physics in condensed matter systems. In the first part, the emphasis will be put on the geometric aspects, which are associated with the Berry curvature and the orbital magnetic moment of the Bloch electrons. For valleys related by time reversal symmetry, these quantities have opposite signs for different valleys, leading to a great possibility for the valley control and manipulation. In particular, we investigated the magnetic field effects, magnetic control of valley polarization, valley transport through p-n junctions in the quantum Hall regime, and anomalous contribution to the Hall effect. In the second part, I will talk about several valley-related new topological phases. In 2D systems, we discovered the topological metallic states, disorder-induced perfect valley-polarized quantum anomalous Hall phase, and we proposed a perfect valley filter in a topological domain wall. We also attempted to push the valley physics to 3D and proposed the Dirac and Weyl 3D superconductors.

T8.14 (INVITED) Topological Phononic Crystal

Zhaoju Yang*, Baile Zhang* (NTU)
01:50pm – 02:10pm

The concept of topologically nontrivial bandstructures, which originally arose in the study of the quantum Hall effect and topological insulator materials, has recently led to the emergence of the field of ”topological photonics”. Here, we further extend the concept to acoustics by designing a phononic crystal which maps theoretically onto the integer quantum Hall effect. Time-reversal symmetry is broken by a circulating fluid flow in each unit cell, which corresponds to nonzero periodic effective magnetic flux density. We derive the bandstructure, and show the existence of topologically nontrivial bands possessing nonzero Chern numbers. Numerical simulations reveal the existence of unidirectional acoustic modes at the boundaries of the phononic crystal, which are topologically protected against backscattering from disorder. Such topological phononic crystals may have novel applications in acoustics.

T8.108 Distinctive Features of Transport in Topological Insulators

Vincent Sacksteder*, Quansheng Wu, Kristin Arnardottir, Ivan Shelykh, Tomi Ohtsuki, Koji Kobayashi (Nanyang Technological University)
02:10pm – 02:25pm

We predict a new signature of the topological state in 3-D topological insulators: at low temperatures the magnetoconductivity is sensitive to the TI sidewalls and deviates strongly from the Hikami-Larkin-Nagaoka (HLN) formula. This regime is dominated by scattering processes which wrap around the TI sample, and temperature dependence is lost. This new topological signature should be visible in the same samples and temperatures where the Altshuler-Aronov-Spivak (AAS) effect has already been observed.

We also present numerical calculations of TI transport, including both the bulk and the surfaces. The bulk reduces the effects of surface disorder. It also causes the magnitude of the magnetoconductivity to depend systematically on sample details such as doping and disorder strength, unlike the HLN result where this magnitude is a numerical constant.

Lastly we present a practical means of systematically controlling topological transport on the surface of a three dimensional topological insulator, by introducing strong disorder in a layer of depth d extending inward from the surface of the topological insulator. The dependence on d of the density of states, conductance, scattering time, scattering length, diffusion constant, and mean Fermi velocity are investigated. The proposed control via disorder depth d requires that the disorder strength be large eneough to drive the TI into the non-topological phase. If d is patterned using masks, gates, ion implantation, etc., then integrated circuits may be fabricated.

T8.114 Plasmonic Properties of Topological Insulator Crystals by First Principle Studies

Jun Yin, Zilong Wang, Weiping Wu, Giorgio Adamo, Nikolay I. Zheludev, Cesare Soci* (Nanyang Technological University)
02:25pm – 02:40pm

Topological insulator (TI) crystals, as $\mathrm{Bi}_{2-x}\mathrm{Sb}_x\mathrm{Te}_{3-y}\mathrm{Se}_y$ (BSTS), show superior properties of large bulk resistance and surface-dominated transport, as well as negative permittivity and low-loss plasmonic resonances in the visible part of the spectrum. Here we present first-principle studies on the electronic band structures and dielectric functions of various topological insulator materials based on many-body perturbation theory. The optical response of BSTS crystals were described by using both random phase approximation and Bethe-Salpeter equation methods. The bulk band structures show an inversion between the conduction band and valence band at Γ point due to band splitting. Through increasing the strength of spin-orbital coupling, the direct bandgap becomes indirect, allowing strong optical transitions around the Z region. The cross bulk plasma wavelength can be tuned in the visible and near-infrared regime by adjusting the composition of BSTS. Interestingly, the lager dielectric constant can be achieved by increasing the ratio of Te, a valuable design parameter for the synthesis of new TI compounds. Our results elucidate origin and composition dependence of bulk plasma wavelength in the visible and near-infrared parts of the spectrum and provide a solid framework to screen out BSTS and other TI compounds to design optical and plasmonic properties on demand.

T8.155 (INVITED) Preparation of 1-Bilayer Bi(111) and Investigation of its Electronic States

Xuesen Wang* (National University of Singapore)
02:40pm – 03:00pm

Theoretical and computational studies predicted that 1-bilayer (1-BL) Bi(111) is a 2D topological insulator (TI) [1]. The realization of 1-BL Bi(111) and verification of its topological nature, however, have been an experimental challenge. We explored a few procedures to prepare 1-BL Bi(111) samples and then characterized them with in situ scanning tunneling microscopy/spectroscopy (STM/STS). We get the 1-BL Bi(111) by freezing a Bi film on Si(111) during its transition from (110) to (111) orientation. Edge states have been observed which exhibit certain characteristics consistent with a 2D TI. Recently, DFT-based calculations predicted that 1-BL Bi(111) hydride is a 2D TI with extraordinarily large bulk gaps of 1eV, which would make it an excellent 2D TI for device applications at room temperature [2]. In order to get 1-BL Bi(111) hydride, we carried out hydrogenation of ultrathin Bi(111) films grown on Si(111), and observed buckling with some change in surface lattice constant induced by hydrogenation. The buckling exhibits a height difference of 0.3 nm, and the dI/dV spectra revealed different electronic structures in the higher and lower regions of the buckled surface. But so far we have not found any region with a surface-state gap ¿ 0.3 eV. By depositing Bi on a hydrogenated Bi film, however, we get 1-BL and 2-BL Bi(111) that show some predicted characters of 2D TI, indicating certain degree of isolation from the substrate. Contributors: PAN Feng, WU Ke, YAO Guanggeng, XU Wento, and LUO Ziyu [1] S. Murakami, Quantum spin Hall effect and enhanced magnetic response by spin-orbit coupling, Phys. Rev. Lett. 97, 236805 (2006); M. Wada, S. Murakami, F. Freimuth, G. Bihlmayer, Localized edge states in two-dimensional topological insulators: ultrathin Bi films, Phys. Rev. B 83, 121310 (2011). [2] Z. Song et al., Quantum spin Hall (QSH) insulators of BiX/SbX (X = H, F, Cl, and Br) monolayers with a record bulk band gap, arXiv:1402.2399 (2014).

T9: Statistics 1

Time: Thursday 5 Mar, 1:30pm; Venue: LT4
Time allocated for invited talks is 15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T9.80 (INVITED) Mechanism for Wide-scattering of Congested Traffic States

Wei Liang Quek*, Lock-Yue Chew* (Nanyang Technological University)
1:30pm – 01:50pm

Based on current traffic flow theories, there are contradictory views on the nature and formation of traffic congestions. One of these contradictions is the occurrence of wide scattering of flow-density states in congested traffic. In this study, we investigated possible conditions which lead to wide-scattering by applying a modification of traffic bottlenecks to the Nagel-Schreckenberg(NaSch) Cellular Automata (CA) model. By studying the microscopic dynamics of the model, we hypothesised that wide-scattering could be a result of the heterogeneity of cluster formation in congested traffic flow. We presented a numerical analysis using the macroscopic quantities of the simulation with varying bottleneck strength. The correspondence of the simulation results to real traffic data is also studied by applying a similar analysis on measured traffic flow data obtained from a highway segment in Singapore.

T9.56 (INVITED) Spatial and Temporal Dynamics of Markets Far From Equilibrium

Darrell Tay*, Chung-I Chou, Tee Shang You, Cheong Siew Ann, Li Sai Ping (Nanyang Technological University)
01:50pm – 02:10pm

The sub-prime housing crisis in USA led to the global financial crisis in 2008. The scale of the crash was unprecedented, with many banks and financial institutions going bankrupt. We compare the Dow Jones Industrial Average (DJIA), and the Housing Price Index (HPI) of the United States. The former is a benchmark of the stock markets and the latter is a benchmark for the Housing markets. It is evident that while the DJIA has returned to it pre-crash levels, the HPI has yet to recover. Unlike a non-liquid market, liquid markets have the ability to return to equilibrium faster, as it operates at much faster time scales. In our studies, we discover and review new and existing equilibrium models in housing markets. We identify out of equilibrium features by comparing these model with real data. We analyze transaction level data to identify out of equilibrium features in these data. Next, we build agent based models to understand the possible mechanisms for such features. A suitable model can then be used to test for the effects of intervention in such markets. We also develop tools that measure the effectiveness of existing policies applied to housing markets. These models and tools will enable us to do evidence based testing on the effects of housing policies.

T9.31 Cluster Fusion-Fission Dynamics in the Singapore Stock Exchange.

Boon Kin Teh*, Siew Ann Cheong (Nanyang Technological University)

02:10pm – 02:25pm

In this paper, we investigate how the cross correlations between stocks in the Singapore Stock Exchange (SGX) evolve over 2008 and 2009 within overlapping one-month time windows. In particular, we examine how these cross correlations change before, during, and after the Sep-Oct 2008 Lehman Brother Crisis. To do this, we extend the complete-linkage hierarchical clustering algorithm, to obtain robust clusters of stocks with stronger intracluster correlations, and weaker intercluster correlations. After we identify the robust clusters in all time windows, we visualize how these change in the form of a fusion-fission diagram. Such a diagram depicts graphically how the cluster sizes evolve, the exchange of stocks between clusters, as well as how strongly the clusters mix. From the fusion-fission diagram, we see a giant cluster growing and disintegrating in the SGX, up till the Lehman Brothers Crisis in September 2008 and the market crashes of October 2008. After the financial crisis, clusters in the SGX remain small for few months before giant clusters emerge once again. In the aftermath of the crisis, we also find that strong mixing of component stocks between clusters. As a result, the correlation between an initially stronglycorrelated pair of stocks decay exponentially with average life time of about a month. These observations impact strongly how portfolios and trading strategies should be formulated.

T9.34 The Brain at the Edge of Chaos: A Theory of How The Brain Computes

Teck Liang Tan* (Nanyang Technological University)

02:25pm – 02:40pm

Till today, people still do not how the brain function as a computer. We lack specific understanding of how the brain represent or transform information nor recognize logical operations used. In the early 2000s, Kauffman suggested that the brain operates at the Edge of Chaos. We intend to investigate the implications of this idea. We consider complex networks of nonlinear neuronal equations after determining the parameter region with high density of qualitatively distinct states. We believe such a parameter region is the Edge of Chaos. The neuron equation will then be coupled parametrically so that each neuron transits between parameter regions as a result of the dynamics of involving its neighbors. We aim to demonstrate that information can be encoded and transform in this manner, and in addition to that, understand the development of the human brain from infant to adult. Ultimately, a theory of how the brain computes will allow us to (1) seek novel cures and remedies to neurological disorders like epilepsy, dementia, autism, and attention deficiency disorder; (2) provide neuroscience basis to education and pedagogy, to open the doors for science-based curriculum planning; and (3) design brain-mimetic supercomputers that are radically different from modern digital computers.

T9.93 Diffusion issues in InGaAs

Liu Wenyuan, Cheong Siew Ann* (Nanyang Technological University)

02:40pm – 02:55pm

Indium gallium arsenide is widely regarded as promising candidate for future microelectronic devices due to its excellent electron mobility, consequently, the understanding of dopants diffusion in InGaAs is necessary. However, compare with Si and GaAs, the investigations on dopants diffusion mechanisms in InGaAs are still limited. We review diffusion issues in InGaAs in theory and experiment with the focus on the diffusion mechanisms in this paper. We present the basic properties of defects firstly, including formation energies, since the dopants diffusion in III-V semiconductor mediate mainly by point defects (vacancies and interstitials). Based on these important parameters, some efforts trying explain experimental diffusion profiles under different experimental condition (dopant species, temperature, diffuse time, and doping level) within the framework of a set of physical models are retrospected. Inadequacies in existing formulations are also identified to suggest the remained problems and further researcher direction. The goal of this paper is to explain available experimental data within a reasonable physical models that can be used in simulation to predict diffusion processes in InGaAs.

T9.33 Mean Square Displacement from a jumper model

Antonio Piscitelli*, Massimo Pica Ciamarra (Nanyang Technological University)
02:55pm – 03:10pm

The motion of a particle in a supercooled liquids is characterized by long caging periods, during which the particle is confined by its neighbors, interrupted by fast local rearrangements, known as jumps. This intermittent dynamics is conveniently described within the continuous time random walk approach, that allows to relate the long time diffusion coefficient to the average time particles wait in their cages before performing a jump and to the average squared jump length. Here we show that it is possible to describe the whole time dependence of the mean square displacement of supercooled liquids by integrating the continuous time random walk approach and a model for the short time particle motion. We have validated this model against numerical simulations of different models, also trying to determine the model parameters relation with structural properties of the system.

T10: Precision measurements 1

Time: Thursday 5 Mar, 1:30pm; Venue: LT5; Chair: Manas Mukherjee
Time allocated for invited talks is 15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T10.17 (INVITED) Quantum Tests of the Universality of Free Fall

Dennis Schlippert*, Henning Albers, Christian Meiners, Logan L. Richardson, Etienne Wodey, Hendrik Heine, Dipankar Nath, Christian Schubert, Wolfgang Ertmer, Ernst M. Rasel (Institut fuer Quantenoptik, Leibniz Universitaet Hannover)
1:30pm – 01:50pm

Searches for violations of the Universality of Free Fall (UFF) mark an important approach in reconciling quantum mechanics and general relativity. In this respect, matter wave interferometers resemble a novel test method that differs fundamentally from experiments employing macroscopic test masses. We report on a quantum test of the UFF at the 100 ppb level using two different chemical elements, K-39 and Rb-87. We show recent improvements of the experiment aiming towards a ppb test, focusing on both, the stability, and the systematic uncertainty aided by the use of a common optical dipole trap. We furthermore present future strategies for tests of the UFF aiming for accuracies of parts in 10^{13} and beyond in large scale apparatuses on ground and in space.

T10.165 (INVITED) Precision Metrology for Future Space Missions using Femtosecond Light Pulses

Young Jin Kim* (Nanyang Technological University (NTU))
01:50pm – 02:10pm

Femtosecond pulse lasers offer breakthroughs in precision metrology particularly in the fields of time, distance and spectroscopy. This advance attracts much attention to extend today's space missions by improving the precision of remote sensing and control capabilities. In this presentation, we introduce how femtosecond lasers are being investigated for space explorations in the near future.

T10.126 Atom interferometers using Bragg diffraction and Bloch oscillations

Pei Chen Kuan* (Nanyang Technological University)
02:10pm – 02:25pm

I will present a new scheme for atom interferometry based on both large-momentum transfer Bragg beam splitters and Bloch oscillations. This scheme can increase the signal and decrease a dominant systematic phase shift, which is predicted from the theoretical calculation and suppressed at least 60-fold using the new scheme. The resolution of the fine structure constant is 0.33ppb in six hours. With further study of systematic effects, this will lead to a new precision measurement of the fine structure constant.

T10.133 A Gravimeter using velocity-selective Ramsey-Interferometer

Fong En Oon*, Rainer Dumke (CQT)

02:25pm – 02:40pm

In this project we are constructing a portable atom interferometer which will find practical applications in various fields like geophysics, volcanology, mineral prospecting, etc. The system has reached an accuracy of 4×10^{-8}g in an integration time of 50 minutes in measuring gravitational g constant and is currently working toward active cancelling the mechanical vibration in the system.

T10.164 Light in a Highly Dispersive Moving Medium

Shau-Yu Lan* (Nanyang Technological University)

02:40pm – 02:55pm

The group velocity of electromagnetic waves travelling in the direction of a moving medium observed in the lab frame will increase with an amount smaller than the velocity of the moving medium. It is known as Fresnel-Fizeau effect or light dragging effect. An atomic medium under the condition of electromagnetically-induced transparency (EIT) could enhance this effect by reducing the group velocity of light in the moving medium. I will review this effect in an EIT system and discuss its potential applications in designing an inertial sensor.

T10.90 Quantum Refractometer

Anna Paterova, Dmitry Kalashnikov, Sergei Kulik, Leonid Krivitsky* (Data Storage Institute)

02:55pm – 03:10pm

We exploit interference of two Parametric Down Conversion (PDC) sources to observe infrared resonances of CO_2. Frequency correlations of PDC enable determination of the refractive index at IR wavelengths with visible range optics and photodetectors.

T11: Solid state physics

Time: Thursday 5 Mar, 3:40pm; Venue: MAS1
Time allocated for invited talks is 15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T11.6 (INVITED) Tunable room-temperature ferromagnet using an iron-oxide and graphene oxide nanocomposite

Aigu Lin, João Rodrigues*, Chenliang Su, Mirco Milletari, Loh Kian Ping, Tom Wu, Wei Chen, Antonio Castro Neto, Shaffique Adam, Andrew Wee (Graphene Research Centre and Department of Physics, National University of Singapore)
3:40pm – 04:00pm

Magnetic materials have found wide application ranging from electronics and memories to medicine. Essential to these advances is the control of the magnetic order. To date, most room-temperature applications have a fixed magnetic moment whose orientation is manipulated for functionality. Here we demonstrate an iron-oxide and graphene oxide nanocomposite based device that acts as a tunable ferromagnet at room temperature. Not only can we tune its transition temperature in a wide range of temperatures around room temperature, but the magnetization can also be tuned from zero to 0.011 A m^2/kg through an initialization process with two readiy accessible knobs (magnetic field and electric current), after which the system retains its magnetic properties semi-permanently until the next initialization process. We construct a theoretical model to illustrate that this tunability originates from an indirect exchange interaction mediated by spin-imbalanced electrons inside the nanocomposite.

T11.111 (INVITED) Reentrant Josephson coupling in a quasi-one-dimensional superconductor

Diane Ansermet*, Alexander Petrovic, Shikun He, Christos Panagopoulos (NTU-SPMS-PAP)
04:00pm – 04:20pm

Short coherence lengths are an intrinsic property of low dimensional superconductors, and a prerequisite for high critical fields or temperatures. Unfortunately, reducing the coherence length increases fluctuations in the phase of the superconducting order parameter. These fluctuations diverge as the temperature T, magnetic field H or current I rise, severely limiting practical applications. Here we show that inhomogeneous filamentary superconductors possess an inbuilt resilience to phase fluctuations at elevated (T, H, I). $Na_{2-\delta}Mo_6Se_6$ is a quasi-one-dimensional superconductor exhibiting Na vacancy disorder and hence a good example of such materials. Single crystals of $Na_{2-\delta}Mo_6Se_6$ behave as percolative networks of superconducting filaments, in which long-range superconducting order is established via transverse Josephson coupling. Electrical transport measurements demonstrate that upon raising (T, H, I), a region of reentrant phase coherence develops, coinciding with a peak in the calculated Josephson energy. $Na_{2-\delta}Mo_6Se_6$ can therefore be regarded as a blueprint for a new generation of filamentary superconductors. Such disordered Josephson-coupled arrays of superconducting nanofilaments or clusters show great promise as functional superconducting materials, due to their intrinsic suppression of phase fluctuations at high (T, H, I).

T11.129 From antiferromagnetic ordering to magnetic textures in the two-dimensional Fermi-Hubbard model with synthetic spin-orbit interactions

Benoît Grémaud*, Jiri Minar (Centre for Quantum Technologies)

04:20pm – 04:35pm

We study the interacting Fermi-Hubbard model in two spatial dimensions with synthetic gauge coupling of the spin-orbit Rashba type, at half-filling. Using real-space mean-field theory, we numerically determine the phase as a function of the interaction strength for different values of the gauge-field parameter. For a fixed value of the gauge field, we observe that when the strength of the repulsive interaction is increased, the system enters into an antiferromagnetic phase, then undergoes a first-order phase transition to a noncollinear magnetic phase. Depending on the gauge-field parameter, this phase further evolves to the one predicted from the effective Heisenberg model obtained in the limit of large interaction strength (spiral phase, skyrmion...). The presence of the antiferromagnetic phase at small interaction is explained by the divergence, at low temperatures, of the spin-spin susceptibility for the antiferromagnetic ordering.

T11.152 (INVITED) Magnetoresistance in 3D Weyl Semimetals

Navneeth Ramakrishnan*, Mirco Milletari, Shaffique Adam (National University of Singapore)

04:35pm – 04:55pm

We theoretically investigate the transport and magnetotransport properties of three-dimensional Weyl semimetals. Using the RPA-Boltzmann transport scattering theory for electrons scattering off randomly distributed charged impurities, together with an effective medium theory to average over the resulting spatially inhomogeneous carrier density, we smoothly connect our results for the minimum conductivity near the Weyl point with known results for the conductivity at high carrier density. In the presence of a non-quantizing magnetic field, we predict that for both high and low carrier densities, Weyl semimetals show a transition from quadratic magnetoresistance (MR) at low magnetic fields to linear MR at high magnetic fields, and that the magnitude of the MR$\gtrsim$10 for realistic parameters. Our results are in qualitative agreement with recent unexpected experimental observations on the mixed-chalcogenide compound TlBiSSe.

T11.160 (INVITED) Sideband Raman Cooling of Optical Phonons in Semiconductors

Jun Zhang*, Leong Chuan Kwek, Qihua Xiong* (Division of Physics and Applied Physics, School of Physical and Mathematical Sciences, Nanyang Technological University, 637371, Singapore.)

04:55pm – 05:15pm

Although the radiation pressure of lights has been widely used to laser cool the movements of trapped atoms and the mechanical vibration modes of cavity optomechanical systems, laser cooling of one specific lattice vibration in solids, saying phonons, has remained little studied. In 1980s, Dykman theoretically discussed the possibility of cooling, heating and amplification of specific phonon in solids by similar physics of laser cooling in atoms. Recently, by using electrostrictive forces of light acting on dielectrics, Bahl et al., experimentally demonstrated spontaneous Brillouin cooling and stimulated Brillouin excitation of whispering-gallery type acoustic mode, analogue of acoustic phonon in solids, in silica microsphere resonator. These works raise the question of whether it is possible to cool optical phonon modes in solid by means of a Raman process. For achieving Raman anti-Stokes cooling, the heating Stokes line needs to be filtered out. However, as high optical phonon frequencies have higher dissipation than acoustic phonon, eliminating the Stokes line against the anti-Stokes line is not easily available in solid materials. Here we experimentally demonstrate spontaneous Raman cooling and heating of longitudinal optical phonon with a 6.23 THz frequency in polar semiconductor zinc telluride nanobelts. We use the exciton to resonate and assist photo-elastic Raman scattering from LOPs due to the large exciton-LOP coupling. The cooling (heating) is mediated by detuning the laser pump to lower (higher) energy sideband, and spontaneous scattering photon resonates with exciton at anti-Stokes (Stokes) side, that beat and photo-elastically attenuate (enhance) the dipole oscillation of the optical phonon.

References: 1. F. Diedrich, J. C. Bergquist, W. M. Itano & D. J. Wineland, Laser cooling to the zero-point energy of motion. Phys. Rev. Lett. 1989, 62, 403-406. 2. A. Markus, J. K. Tobias & M. Florian, Cavity optomechanics. Arxiv, 2013, 1303.0733v1301. 3. J. Zhang, L. C. Kwek, Q. H. Xiong, Sideband Raman cooling of optical phonons in semiconductors, Bulletin of Am. Phys. Soc., 2014, 59-1, Y36.00010

T12: Statistics 2

Time: Thursday 5 Mar, 3:40pm; Venue: LT4
Time allocated for invited talks is 15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T12.166 (INVITED) The Effect of Community Structure on Multiple Stable States in Socio-Ecological System

Hendrik Santoso Sugiarto*, Lock Yue Chew, Ning Ning Chung, Choy Heng Lai (Nanyang Technological University)
3:40pm – 04:00pm

In most common pool resources, such as irrigation system, the maintenance of the ecological resources requires an effective cooperation among individuals who have equal access to the common resources. However, the collapse of cooperation is inevitable if everyone is rational since they will maximize their own profit by overusing the common resources. This collapse is also known as tragedy of the commons. The danger of sudden collapse in socio-ecological system poses a serious challenge to human society because it will lead to a depletion of resources which in turn destroys the economic viability of the whole system. Previously Tavoni et al, propose ostracism mechanism to restrain the exploitation of ecological resource and promote the social cooperation. This mechanism creates a complex non-linear coupling between social and ecological system, which is responsible for the existence of alternative stable states. Sometimes, the system may undergo a transition from one regime to another regime, which is also known as a regime shift. In this talk we will extent the previous model so that every individual players make discrete choice decision based on their social interaction within certain network topology. In real society, people tends to live in groups and cluster themselves within certain community structure. Since modularity is also closely related to the topology of a network, we therefore expect this property to affect the underlying structure of multiple regimes in this socio-ecological system. This investigation may provide us with useful insight to manage and design a sustainable system.

T12.122 (INVITED) High-order jamming crossovers and density anomalies

Massimo Pica Ciamarra*, Peter Sollich (NTU)
04:00pm – 04:20pm

Water and other network-forming liquids are characterized by density anomalies; these consist in the presence of a negative thermal expansion coefficient, and in a non-monotonic dependence of the diffusivity on the density. These features are commonly associated to anisotropic interaction potentials promoting the formation of tetrahedral structures. Here we show that these anomalies also occur in systems of particles interacting via simple radially symmetric repulsive potentials, as a consequence of ”high-order jamming crossovers”. The crossovers consist in the collapse of successive coordination shells on increasing the density. We rationalize the dependence of these crossovers on the interaction potential, and relate the jamming crossovers and the density anomalies in the framework of elastic models of liquid dynamics.

M. Pica Ciamarra and P. Sollich, Soft Matter 9, 9557, 2013; J. Chem. Phys. 138, 12A529, 2013; J. Non-Crys. Solids 407, 23, 2015

T12.41 Scaling and hyperscaling of sheared systems close to jamming

Roberto Arevalo*, Massimo Pica Ciamarra (Nanyang Technological University)

04:20pm – 04:35pm

The current microscopic picture of plasticity in amorphous materials assumes local failure events to produce displacement fields complying with linear elasticity. Indeed, the flow properties of nonaffine systems such as foams, emulsions and granular materials close to jamming, that produce a fluctuating displacement field when failing, are still controversial. Here we show, via a thorough numerical investigation of jammed materials, that nonaffinity induces a critical scaling of the flow properties dictated by the distance to the jamming point. We rationalize this critical behavior introducing a new universal jamming exponent and hyperscaling relations, and use these results to describe the volume fraction dependence of the friction coefficient.

T12.45 Complex Network Analysis of Teaching Practices

Woon Peng Goh*, Dennis Kwek, David Hogan, Siew Ann Cheong* (Physics and Applied Physics, SPMS, NTU)

04:35pm – 04:50pm

The application of functional analysis to infer networks in large datasets is potentially helpful to experimenters in various elds. In this paper, we developed a technique to construct networks of statistically signicant transitions between variable pairs from a high-dimensional and multi-scale dataset of Grade 5 and Grade 9 Mathematics teaching practices obtained by the National Institute of Education in Singapore. From the Minimum Spanning Trees (MST) and Planar Maximally Filtered Graphs (PMFG) of the transitions networks, we observed that teaching knowledge as truth and teacher-dominated talking serve as hubs for teaching practices in Singapore. These practices reflect a transmissionist model of teaching and learning. We also identied complex teacher-student-teacher-student interaction sequences of teaching practices that are over-represented in the data.

T12.50 Critical slowing down and the subprime crisis

James Tan*, Siew Ann Cheong* (Nanyang Technological University)

04:50pm – 05:05pm

Continuous phase transitions can be adequately described by Landau's theory when dimensions are greater than four. In a second order phase transition, critical slowing down occurs when the system is at the critical temperature. It is characterized by a slower inverse square root return to equilibrium when the system is perturbed. Outside physics, critical slowing down can be seen in a variety of complex systems on the verge of transitions between phases of distinct behaviors. In this talk, I will show how the power spectrum of housing permit time series can be used to infer the presence of critical slowing down in the U.S. housing market around the time period of the subprime crisis.

T12.95 Statistical Methods to Observe the Impact of Feminism in Novels

Neo Chee Yong*, Cheong Siew Ann (School of Physical and Mathematical Sciences)

05:05pm – 05:20pm

Books are a reflection of society, and hence an excellent source of information on social trends. However the amount of content produced far outpaces the rate we can read. Computers are able to go through large amounts of data in short spans of time, but lack the ability to extract knowledge from texts. In this study we extracted knowledge of how males are described in the form of 'keywords' by employing statistical techniques. A network centric approach was then taken to further study how keywords have changed with the introduction of feminism. This coupling of techniques allows us to extract information out of texts quickly, and enabling tracking of shifts in social trends.

T13: Precision measurements 2

Time: Thursday 5 Mar, 3:40pm; Venue: LT5; Chair: Shau Yu Lan
Time allocated for invited talks is 15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T13.173 (INVITED) Selective reflection spectroscopy: a high-resolution probe of atom-surface physics

Martial Ducloy* (Universite Paris 13 Nord / SPMS, NTU)
3:40pm – 04:00pm

The interaction between microscopic quantum systems (like atomic systems) and material nanobodies is a case study in quantum physics of hybrid systems, with many applications in cavity QED, engineering of atom-surface forces, matter-wave interferometry, surface metrology, quantum information. Among the various approaches to atom-surface physics, selective reflection spectroscopy at solid material/atomic vapour interfaces allows one to apply ultra-high resolution atomic physics to condensed matter physics and nanophysics. Interacting atoms in the surface potential provide original probes of nanosurfaces, nanostructures and nanofields. Recent advances about resonant coupling between atomic systems and surface plasmon/polariton modes cover influence of thermal surface excitations, fundamental symmetry breaking, influence of nanobody form and structure, surface allowing of forbidden transitions. Experimental works in progress concern Fano-like atomic/molecular coupling with metamaterials, chiral nanoparticles or graphene.

T13.172 (INVITED) Precision metrology and fundamental physics

Manas Mukherjee* (CQT, NUS)
04:00pm – 04:20pm

Trapped and laser cooled ion provides a clean tool to measure precisely atomic properties which in turn allows to probe physics at the basic level. The physics that we are interested in, is related to the understanding of the weak interaction and its manifestation in atomic physics. However, experimentally this requires measurements to be performed below one percent precision on heavy atoms. We will report on our recent measurements of the atomic wavefunctions to below one percent precision for barium ion. In addition we will discuss that our results have put different well established theoretical calculations under stringent test. In conclusion, a number of other experiments that we are presently performing will also be discussed.

T13.146 Lutetium+: A better optical clock candidate

Kyle Arnold*, Eduardo Paez, Elnur Haciyev, Arifin, Murray Barrett (NUS/CQT)
04:20pm – 04:35pm

With the extreme precision now reached by optical clocks it is reasonable to consider redefinition of the frequency standard. In doing so it is important to look beyond the current best-case efforts and have an eye on future possibilities. We will argue that singly ionized Lutetium is a strong candidate for the next generation of optical frequency standards. Lu+ has a particularly narrow optical transition in combination with several advantageous properties for managing systematic uncertainties compared to the other atomic species. We summarize these properties and our specific strategies for managing the uncertainties due to external perturbations. Finally, we present the status of our ongoing experiments with trapped Lu+, including the results of precision measurements of its atomic structure.

T13.23 Solid-state magnetometry with single nitrogen-vacancy centres

Yue Sum Chin*, Matthias Steiner, Christian Kurtsiefer (Centre for Quantum Technologies)
04:35pm – 04:50pm

We realize a solid-state scalar magnetic field sensor based on single nitrogen vacancy (NV) centres in diamond at room temperature. Specifically, we measure the shift of electron spin resonance (ESR) of the NV centre due to the Zeeman effect and extract the magnetic field along its orientation axis. The ESR is optically detected by relating the NV ground state population to the photoluminescence intensity. Under conventional continuous wave excitation, the magnetic sensitivity suffers a trade off between power broadening of the linewidth and contrast reduction of the ESR spectrum. We overcome this problem with coherent control of pulse excitation. With a simple ESR pulse scheme, we study the linewidth and the contrast of the ESR spectrum for different microwave powers. Further optimizing these parameters, a magnetic sensitivity of 1.6μT/sqrt(Hz) is achieved.

T13.138 Cavity enhanced Atomic Magnetometry

Ley Li Yuan*, Rainer Dumke, Herbert Crepaz (Centre for Quantum Technologies)
04:50pm – 05:05pm

Atom sensing based on Faraday rotation is an indispensable method for precision measurements. Here we demonstrate an all-optical magnetometer where the optical cell for Faraday rotation spectroscopy is augmented with a low finesse cavity. Cavity enhancement shows in an increase in optical polarization rotation and sensitivity compared to single-pass congurations.

T14: Sound and cavitation

Time: Friday 6 Mar, 11:00am; Venue: MAS1; Chair: Claus-Dieter Ohl
Time allocated for invited talks is 15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T14.35 (INVITED) Production of gas-supersaturated water by bubble aeration

Keita Ando*, Tatsuya Yamashita (Keio University)
11:00am – 11:20am

We report on the production of gas-supersaturated water by a commercial fine bubble generator of spiral flow type. Micron/submicron oxygen bubbles are continuously injected in the circulation system of tap water for the gas to dissolve into the liquid phase. A dissolved oxygen (DO) meter with a fluorometric sensor does show oxygen concentrations beyond the saturation limit in the water. This supersaturation state stays for a couple of days without significant bubble formation at the container surface. However, this metastable period is much shorter than predictions from Fick's law. To verify the measured values of DO concentrations, we examine diffusion-driven growth of millimeter-sized gas bubbles nucleated at a glass surface. The growth rate is found to agree with the (extended) theory of Epstein and Plesset that assumes quasistatic bubble growth, meaning that the water is indeed supersaturated and the measured DO concentrations are valid. We speculate that a large number of nanobubbles attached at the surface of floating particles may possibly exist in the supersaturated water.

T14.118 Poking nanobubbles: a simultaneous optical-atomic force microscopy study

Beng Hau Tan, Chon U Chan, Hongjie An, Claus-Dieter Ohl* (Nanyang Technological University)
11:20am – 11:35am

Surface attached nanobubbles are spherically capped gaseous domains that attach onto wetted surfaces. Nanobubbles are widely studied for their potential applicability in various industrial and medical applications at the microscale, and have also gathered fundamental interest, as they exhibit many unusual features that have yet to be fully explained.

One of the main impediments in studying the properties of nanobubbles experimentally is that it can be difficult to distinguish nanobubbles from contamination under atomic force microscopy (AFM). It is therefore critical to develop experimental techniques that can distinguish nanobubbles from liquid drops of contamination.

Here we performed a study of nanobubble dynamics using two modes of microscopy simultaneously. We used an AFM tip to poke on nanobubbles, while imaging them under total internal reflection fluorescence microscopy (TIRFM) to observe changes in real time. We demonstrate that we are able to distinguish between nanobubbles and contamination drops using this technique – upon poking, bubbles deflate, but drops of liquid don't.

Nanobubbles are stable against diffusion for up to weeks, defying the theoretical prediction of under 1 second. This remarkable stability is thought to be explained by the observation that the bubble's footprint is always pinned to the substrate ('contact line pinning'). However, when a bubble is poked with an AFM tip, it unpins from the substrate, shrinks and repins over a timescale of 1 second. These observations indicate to us that the stability of nanobubbles cannot solely be justified by the existence of contact line pinning.

T14.120 Bubble dynamics in laser lithotripsy

Milad Mohammadzadeh*, Claus-Dieter Ohl* (Nanyang Technological University)
11:35am – 11:50am

Laser lithotripsy is a common procedure for fragmentation of urinary stones. Using a fiber optic and a ureteroscope, the urologists aim and shoot the urinary clalculi with a laser, which is usually in the mid-infrared range (e.g. Holmium-YAG, λ=2.1 μm) with a comparatively long pulse duration (τ=200-500 μs). Since water in the urinary tract absorbs the mid-infrared laser, a bubble is necessarily formed before the stone is irradiated and fragmented due to a photothermal mechanism. A common challenge associated with laser lithotripsy is stone motion which is caused by the bubble activity in this procedure. In this work, we focus on the bubble dynamics during laser lithotripsy and provide a model which links the bubble shape with the temporal laser pulse profile. We model the bubble dynamics by solving the 2D Rayliegh-Plesset equation and reconstruct the pear-shaped elongated bubble layer by layer. Finally, we propose a novel laser design in order to reduce the stone motion by controlling the bubble dynamics, which is achieved by modification of the temporal laser pulse profile.

T14.136 High Frequency Stable Bubble Oscillations in a Superheated Liquid

Fenfang Li*, Silvestre Roberto Gonzalez Avila, Claus Dieter Ohl* (Nanyang Technological University)
11:50am – 12:05pm

We present an unexpected regime of resonant bubble oscillations on a continuously heated plate submerged in water. The plate coated with gold is illuminated with a focused CW laser with intensities of the order of 10^8 W/m^2. The oscillatory bubble dynamics reveals a remarkably stable frequency of several 100 kHz and is resolved from the side using video recordings at 1 million frames per second. The emitted sound is measured simultaneously and shows higher harmonics. Once the laser is switched on, the water in contact with the gold layer is superheated and an explosively expanding cavitation bubble is generated, similar to previous experiment using absorbing liquids [1]. However, after the collapse a microbubble (10 μm diameter) is nucleated from the bubble remains which displays long lasting oscillations. Generally, pinch-off from of the upper part of the microbubble is observed generating a continuous stream of small gas bubbles rising upwards. The cavitation expansion, collapse, and the jetting of gas bubbles are detected by the hydrophone and are correlated to the high speed video. Our findings indicate an unreported boiling regime with significant heat transfer through the vivid fluidic motion.

T14.140 (INVITED) Nanoscale Dynamics in Ultrathin Liquids visualized with TEM

Utkur Mirsaidov*, Jingyu Lu, Zainul Aabdin (National University of Singapore)
12:05pm – 12:25pm

Nanoscale imaging of frozen aqueous specimens and solid materials with transmission electron microscopes (TEM) has revolutionized our understanding in biological and material sciences. However, there is an ample number of important problems in life and physical sciences that occur only in liquid environments. Therefore, there is an incredible advantage of being able to image nanoscale processes directly in liquids[1-5]. I will describe our recent work on development of platform for imaging soft materials and biological samples in liquids using TEM[6-8]. We use this platform to study liquid properties at nanoscale. Here we show that the properties of fluid at nanoscale dominated by its interfacial interaction with the solid substrate surface and drastically differ from the expected bulk behavior. For example, the diffusive movement and rotation of nanocrystals within liquid nanodroplets are severely dampened when compared with macroscopic fluids. We will describe dynamic processes in nanoscale fluids such as condensation of nanodroplets and flow of nanodroplets. Imaging nanoscale fluids also enabled us to observe nanocrystal nucleation through nanocluster aggregation that differs from predictions of classical nucleation theory. We observe that crystals form amorphous aggregates. In addition, we will also describe our attempts at new all-graphene nanofluidic platforms that enable high contrast imaging of nanoscale dynamic processes in liquids[9]. Using these graphene nanochannels we have for the first time visualized the interface between water and graphene using TEM.[9]

References:

[1] H. Zheng, R. Smith, Y. Jun, C. Kisielowski, U. Dahmen, A. P. Alavisatos, Science 324 (2009), p. 1309. [2] M. J. Williamson, R. M. Tromp, P. M. Vereecken, R. Hull, F. M. Ross, Nature Materials 2 (2003), p. 532. [3] N. de Jonge, D. B. Peckys, G. J. Kremers, D.W. Piston, Proc. Natl Acad. Sci. USA 106 (2009), p. 2159. [4] Z. Aabdin, J. Lu, X. Zhu, U. Anand, D. Loh, H. Su, U. Mirsaidov, Nano Letters 14 (2014), p. 6639. [5] J. Lu, Z. Aabdin, D. Loh, D. Bhattacharya, U. Mirsaidov, Nano Letters 14 (2014), p. 2111. [6] U. Mirsaidov, H. Zheng, D. Bhattacharya, Y. Casana, P. Matsudaira, Proc. Natl. Acad. Sci. U.S.A. 109 (2012), p. 7187. [7] U. Mirsaidov, C. D. Ohl, P. Matsudaira, Soft Matter 8 (2012), p. 3108. [8] U. Mirsaidov, H. Zheng, Y. Casana, P. Matsudaira, Biophysical Journal 102 (2012), p. L15. [9] U Mirsaidov, V.R.S.S Mokapati, D. Bhattacharya, H. Anderson, B. Ozyilmaz, P. Matsudaira, LabChip 13 (2012), p. 2874. [10] This work was supported by the Singapore National Research Foundation's Competitive research program funding (NRF-CRP9-2011-04).

T14.143 (INVITED) The fragmentation process of droplets levitated in an acoustic field

S. Roberto Gonzalez-A*, Claus-Dieter Ohl (NTU)
12:25pm – 12:45pm

Early in the 1930's King1 described the theoretical framework for small objects to levitate in an acoustic field; however, only recently the trapping of small objects by standing waves has been used as a non-contact manipulation technique2-4 and in the study of fundamental fluid mechanics5 and material engineering6 problems. More recently, the fragmentation of small liquid droplets by a laser has been investigated due to its relevance in the development of extreme ultraviolet machines (EUV) in the near future7. Single droplets that can be trapped and held at a fixed location present an attractive alternative to study in the detail the initial stage of the fragmentation process. Here, we show that this rather commonly observed process, the atomization or fragmentation of millimeter or sub-millimiter droplets, is accompanied by very complex phenomena such as shock waves that cause tension at the liquid surface, and create secondary cavitation. We resolve this initial stage of the droplet fragmentation with ultra-fast flash photography (exposure time 6 ns) and high speed recordings.

T14.158 Novel Optoacoustic source for arbitrarily shaped acoustic wavefronts

Julian Mercado*, Weiwei Chan*, Claus Dieter Ohl*, Manish Arora, Qiushi Gu, Yuanxiang Yang
(Cavitation Group-SPMS NTU)
12:45pm – 01:00pm

The generation of high frequency pressure waves is of great interest due to its application in medical treatments (e.g. acoustic histotripsy). Moreover, a highly focused wavefront ensures an improved localized ablation zone which is desired in order to minimize the damage of the surroundings. High frequency acoustic waves can be generated by means of the optoacoustic effect: absorption of a pulsated light source and its immediate conversion into thermal energy enabling a rapid thermo-elastic expansion of a given material. A narrow focused region can be achieved by using a concave lens geometry.

In this on-going experimental work we present results of novel optoacoustic transmitters using ad-hoc shaped lens geometries and optimized materials. The body of the lenses are made of PDMS, which ensures a large thermal expansion leading to a strong pressure generation. A thin layer of carbon nanotubes is deposited on the surface of the PDMS lens, followed by a gold coating layer. This forms a light absorbing film that allows a rapid thermo-elastic expansion of the PDMS.

We are able to generate strong and fast pressure pulses with typical peak amplitudes of approximately 40 bar and a rise time as fast as 20 ns. We also show that a narrow focal zone (in the micrometer range) is possible when using spherical and more complex shaped lens geometries. The characterization of the pressure pulses is done with an optical hydrophone. Finally, we are also able to visualize the pressure wavefront by implementing Schlieren optics.

T15: Materials for energy

Time: Friday 6 Mar, 11:00am; Venue: LT4
Time allocated for invited talks is 15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T15.65 Lithium thio-phosphates Solid electrolytes for Lithium sulfur batteries

Rayavarapu Prasada Rao*, Adams Stefan (National University of Singapore)
11:00am – 11:15am

Rechargeable all-solid-state lithium- or Li-ion batteries are attractive power sources for small scale applications (‘smart’ credit cards, medical implants), but in the near future could also become relevant as bulk systems for a wider range of applications, as they improve safety and stability over conventional batteries with flammable liquid electrolytes. This requires electrochemically stable Li+ fast ion conductors (FIC) as the solid electrolyte. Finding such stable fast ion conductors is thus the key to building practical solid-state batteries. There have been numerous developments on materials such as lithium rich sulfide glasses as solid electrolyte. However, low current density remains a major obstacle in these electrolyte systems. Among the most promising compounds with high ionic conductivities are the thiophosphate-based solid electrolytes. Our studies showed that disorder in the immobile sublattice is a crucial factor for maximizing their conductivity. This is shown both for the argyrodite-type halide-doped thiophosphates Li_6PS_5X (where anion-ordered Li_6PS_5I exhibits the lowest ionic conductivity despite the lattice expansion by the large soft I-, while the S2-/X- disorder for X = Cl, Br opens up local paths for Li+ motion) as well as for Li_{10}(Ge,P)PS_{12}, where the local P/Ge disorder limits the packing density and leaves free volume for fast ion transport channels Li(1)-Li(3)-Li(3)-Li(1) along c and especially their interconnection to an anisotropic 3D pathway network via interstitial Li(4) sites. The nearly ideal hopping distance of 1.7 - 2.3 Å among partially occupied sites and the moderate energy required for interconnections between the 1D channels render this structure type particularly suited to combine fast ion transport with structural stability. The only fully occupied Li site, Li(2), does not participate in ion transport and its isomorphous replacement could further optimize the properties of this novel class of solid electrolytes. In situ neutron powder diffraction of ball milled precursors showed that a crystalline argyrodite phase, essentially Li7PS6, forms from extensively ball-milled precursors with the Li_6PS_5Cl stoichiometry at temperatures as low as 80°C, but it takes significantly higher annealing temperatures (¿ 430°C) and preferentially fast cooling to reach the composition Li_6PS_5Cl. This explains why samples crystallized at low temperatures such as 150 °C do not exhibit the same fast-ionic conductivity as those crystallized at higher temperatures. Lithium argyrodite-type Li_6PS_5X (X=Cl,Br) as well as $Li_{10}GeP_2S_{12}$ membranes as electrolytes exhibit an ionic conductivity of the order of 10^{-3} S/cm at 30°C. Here, we investigate the stability of these solid electrolytes in contact with catholytes consisting of polysulfide, Li_2S_8, dissolved in monoglyme.. XRD and SEM indicate that the crystal structure and morphology of the solid electrolyte was not altered by immersion into the catholyte. $Li_2S_8/Li_{10}GeP_2S_{12}$/Li semi-flow rechargeable battery exhibited an initial discharge specific capacity of 1544 mAh/g at 1C rate.

T15.86 (INVITED) Novel synthesis and reaction mechanisms of Li-ion battery electrode materials

M V Reddy* (Department of Physics, National University of Singapore)

11:15am – 11:35am

Lithium ion batteries (LIBs) are extensively used in the present-day portable electronic devices like, cell phones. For high-power applications like, electric/hybrid electric vehicles and back-up power supplies and, the LIBs need to satisfy several criteria, namely, cost-reduction, improvement in the energy density, safety-in-operation at high current charge/discharge rates and improvement in the low-temperature-operation. To satisfy the above criteria, researches are being carried out worldwide to find alternative novel nanostructured electrode materials and search for new reaction mechnaisms. In my my talk, I will discuss our group studies on novel electrode materials and efforts on understanding their reaction mechanisms. It includes preparation of simple and complex oxides by molten salt method, carbothermal/Grapehnenothermal reduction method, hydrothermal, sol-gel and ammonolysis methods etc. Materials were well characterized by Rietveld refinement X-ray diffraction, Neutron diffraction, X-ray absorption spectroscopy, Raman, X-ray photo electron spectroscopy (XPS), SEM, TEM, density and BET surface area methods. Electro analytical studies like cyclic voltammetry, galvanostatic cycling and electrochemical impedance spectroscopy techniques. Finally I will discuss the challenges and reaction mechanisms.

References [1] M.V. Reddy, G.V. Subba Rao, B.V. R. Chowdari ”Metal oxides and oxysalts as anode materials for lithium ion batteries” Chemical Reviews 113(2013)5364-5457 (I.F.: 45.66, citations: ¿380) [2] M .V. Reddy*, Lee Yu Tse, Wen Ke Zhen Bruce, B.V.R. Chowdari ”Low temperature molten salt preparation of Nano-SnO2 as Anode for Lithium-ion Batteries” Materials Letter 138(2015)231-234. [3] P.S.Vali, R. Naresh, M.V. Reddy*, V.V.S.S. Srikanth, B.V.R. Chowdari, MgO Decorated Few-Layered Graphene as Anode for Li Ion Batteries ACS Applied Materials & Interfaces 7(2015) 2301-2309 [4] M.V. Reddy*, C.Y. Quan, K. W. Teo, L.J. Ho, B.V.R. Chowdari Mixed Oxides, (Ni1-xZnx)Fe2O4 (x=0,0.25,0.5, 0.75, 1) : Molten Salt Synthesis, Characterization and its Li-Storage Performance for Li-Ion Batteries, Journal of Physical Chemistry C (2015) (DOI: 10.1021/jp5121178) [5] M.V. Reddy*, G. Prithivi, K.P.Loh, B.V.R. Chowdari ”Comparative Energy storage and Impedance spectroscopy studies on nanostructured Co3O4, CoO and CoN for Li-ion batteries” ACS Applied Materials and Interfaces 6(1) (2014)680-690

T15.92 MOLTEN SALT SYNTHESIS OF Mg, Cu, Zn DOPED Fe_2O_3 AS SUITABLE ANODE MATERIALS FOR Li-ION BATTERIES

M V Reddy*, Chu Yao Quan, Zack Choa Yu Zhe, Bryan Kong Shin Fai (National University of Singapore)

11:35am – 11:50am

Mg, Cu, Zn doped Fe_2O_3 were synthesized in varying concentrations of Mg and Zn by the molten salt method, which is one of the simplest, most versatile, and cost effective approaches for obtaining crystalline, chemically purified, single-phased powders at low production temperatures. X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM) and Brunauer-Emmett-Teller (BET) surface area studies were used to characterize the compounds. Cyclic Voltammetry

(CV), Galvanostatic Cycling (GC) and Electrochemical Impedance Spectroscopy (EIS) studies were used to investigate the electrochemical properties of the varying concentrations of Mg and Zn in our compounds. All synthesized compounds are of nano-phase, in the range of 160-170nm, and exhibit a characteristic lattice parameter of corundum structure and have density to surface area ratios. High reversible capacities, in the range of 660m-750mAh/g at a current rate of 60mA/g after 50 charge and discharge cycles, with low capacity fading values of 15-18 percent were observed for all compounds. This is a huge improvement over a different production methods. Thus, these compounds are suitable as alternative to anode materials for Li-ion batteries.

T15.116 (INVITED) Perovskite Light Emitting Field-Effect Transistor

Xin Yu Chin, Daniele Cortecchia, Jun Yin, Annalisa Bruno*, Cesare Soci* (Division of Physics and Applied Physics School of Physical and Mathematical Sciences Nanyang Technological University 21 Nanyang Link, Singapore 637371;)
11:50am – 12:10pm

Hybrid organic-inorganic perovskites have emerged as excellent solution-processable materials for photovoltaic applications. Recently, their light emission properties have also attracted considerable attention, opening up new opportunities for light-emitting device concepts.

Here we demonstrate hybrid organic-inorganic methylammonium lead iodide ($CH_3NH_3PbI_3$) light emitting field-effect transistor (LE-FET), a new device concept in perovskite-based optoelectronics. In LE-FET devices, ambipolar channels are formed simultaneously by proper source-drain and gate biasing. Under perfectly balanced conditions, holes and electrons injected from opposite electrodes recombine in the middle of the FET channel, thus defining a very narrow radiative emission zone. Improvement of both electron and hole field-effect mobility have been achieved through the elimination of screening effects, associated to ionic transport, by lowering the operating temperature. Under balanced carrier injection, gate-dependent electroluminescence has been observed from the transistor channel. Electroluminescence brightness and the spatial location of the emission zone can be controlled by tuning the biasing conditions. Electroluminescence emission is characterized by two distinct peaks appearing within specific temperature ranges, which stem from the known tetragonal to orthorhombic structural phase transition of $CH_3NH_3PbI_3$. This is in excellent agreement with the electronic structure of the two phases predicted by our first-principle calculations. This first demonstration of light emitting $CH_3NH_3PbI_3$ FETs proves the potential of perovskite materials for low cost optoelectronic emitting devices such as gated light emitting diodes and lasers operating at room temperature.

T15.117 Lead-Free Two-Dimensional Perovskite $(CH_3NH_3)_2CuCl_xBr_{4-x}$ for Solar Cells Applications

Daniele Cortecchia*, Annalisa Bruno, Herlina A. Dewi, Jun Yin, Shi Chen, Tom Baikie, Pablo P. Boix, Subodh Maisalkar, Cesare Soci, Nripan Mathews (Interdisciplinary Graduate School,

Energy Research Institute at NTU (ERI@N), Nanyang Technological University, Singapore 639798)
12:10pm – 12:25pm

Organolead-halide-perovskites have been applied as light harvesters in photovoltaic devices in the last few years combining simple fabrication and high performance, recently achieving the impressive NREL-certified power conversion efficiency of 20.1%. However, the best sensitizers (including methylammonium lead iodide $CH_3NH_3PbI_3$) are based on lead, which is toxic and harmful to the environment. This represent the main concern to their future commercialization, thus urging the need of a new class of environmentally friendly perovskites based on non-toxic and earth abundant constituents. In this regard, hybrid perovskites based on transition metals have great potential. In this work, novel two-dimensional (2D) hybrid perovskites with formula $(CH_3NH_3)_2CuCl_xBr_{4-x}$ were investigated. This series have been synthesized and the effects of Br/Cl ratio on their optoelectronic properties were studied. The band-gap associated to the main ligand-to-metal charge transfer transitions ($[\mathrm{Cl,Br}_p\pi \rightarrow \mathrm{Cu}_d]_{x^2-y^2}$) red-shifts across the visible range up to 1.8 eV when increasing the Br content, while d-d electronic transitions based on the copper further extend the absorption up to 900 nm. These experimental results have been also confirmed by first principle calculations based on density functional theory (DFT). Moreover, the processing methods of thin film deposition were optimized to achieve their integration in photovoltaic devices with different architectures (e.g. solar cells based on sensitized mesoporous TiO_2 or inverted structures with flat heterojunctions). The effect of fluorine doping on film morphology and stability and the optimization of the Cl- content to avoid Cu2+ reduction triggered by Br- and improve the photovoltaic performance will be discussed.

T15.67 Band Bending Induced Electron Transfer Blocking at $TiO_2/CH_3NH_3PbI_3$ Heterojunction

Guichuan Xing*, Tze Chien Sum* (Nanyang Technological University)
12:25pm – 12:40pm

The integration of TiO_2 with low temperature solution processed $CH_3NH_3PbI_3$ has recently demonstrated huge potential (PCE up to 19.3%) as a type-II light harvesting heterojunction. Meanwhile, conflicting reports on the efficiency of electron transfer from $CH_3NH_3PbI_3$ to TiO_2 and the presence of charge accumulation in $CH_3NH_3PbI_3$ raise a compelling case for more detailed studies into the interfacial charge transfer mechanisms at this heterojunction. By probing the photo-excited charge carrier dynamics in $CH_3NH_3PbI_3$/Quartz, $CH_3NH_3PbI_3/TiO_2$ (planar anatase) and $CH_3NH_3PbI_3$/PCBM in a comparative study, surface states induced electron transfer potential barrier between $CH_3NH_3PbI_3$ and TiO_2 is evidenced. This results in strong enhancement of photoluminescence intensity and lifetimes when $CH_3NH_3PbI_3$ is interfaced with compact TiO_2. Our results suggest that the existing high efficiency light harvesting based on $CH_3NH_3PbI_3/TiO_2$ heterojunction is initiated by hole extraction. There is an electron accumulation in the active layer to overcome the interface potential barrier, which is also responsible for the large hysteresis observed for devices with $CH_3NH_3PbI_3/TiO_2$ heterojunction. With careful surface engineering to reduce this potential barrier, substantially improved light conversion efficiency could be achieved.

T16: Quantum information 2

Time: Friday 6 Mar, 11:00am; Venue: LT5; Chair: Joe Fitzsimons
Time allocated for invited talks is 15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T16.77 (INVITED) Practical Homomorphic Encryption with Coherent States

Si-Hui Tan*, Yingkai Ouyang, Peter Rohde, Joseph Fitzsimons (SUTD)
11:00am – 11:20am

We present a scheme for implementing homomorphic encryption on coherent states encoded using phase-shift keys. The encryption operation requires only rotations in phase space and commutes with computations done via passive linear optics. We show that in the limit of small mean energies, we are able to hide any constant fraction of the number of accessible bits

T16.105 Skirting around the No-go Theorem in Measurement-Based Quantum Computation.

Leong Chuan Kwek*, Thi Ha Kyaw, Ying Li, Chang Jian Kwong (CQT)
11:20am – 11:35am

We introduce the paradigm of measurement-based quantum computing (MBQC) or one-way quantum computing. MBQC performs quantum processing by performing single particle measurement over a highly entangled resource state. To obtain this resource state, it is highly desirable to cool a many-body quantum correlated system to its ground state. However, it is known that it is not possible to get this resource state as the non-degenerate ground state of a two-body frustration free Hamiltonian. In this talk, we will discuss how we can overcome the no-go theorem using higher dimensional spins or adiabatic evolution.

T16.1 Discord Empowered Quantum Illumination

Christian Weedbrook, Stefano Pirandola, Jayne Thompson, Vlatko Vedral, Mile Gu* (Tsinghua University & Centre for Quantum Technologies, National University of Singapore)
11:35am – 11:50am

Quantum illumination employs entanglement to detect reflecting objects in environments so noisy that all entanglement is destroyed. This defies conventional intuition: the benefit of entanglement outlasts entanglement itself. Here, I outline how quantum discord - a more resilient form of quantum correlations - can underpin the resilience of quantum illumination.

I demonstrate a direct equality between the performance gain in quantum illumination and the amount of discord which is expended to resolve the target. This simultaneously explains how entanglement's benefits are preserved in entanglement-breaking noise, and highlights discord's practical relevance. The will also discuss the greater context of this connection - including its relation to recent insight into discord's operational significance [1], and related applications to entanglement-free certification of entangling gates [2].

[1] Gu, Mile, et al. "Observing the operational significance of discord consumption." Nature Physics 8.9, 671-675 (2012) [2] Almeida, M. P., et al. "Entanglement-free certification of entangling gates." Physical Review A 89.4, 042323 (2014)

T16.76 Excessive distribution of quantum entanglement

Margherita Zuppardo*, Tomasz Paterek, Som Bandyopadhyay (Nanyang Technological University Singapore)
11:50am – 12:05pm

Quantum entanglement is not only an essential concept of quantum mechanics, but also one of the most useful resources for realization of quantum technologies. Distributing entanglement between two distant laboratories is crucial for quantum information processing as exemplified by cryptography, dense coding or teleportation. Nonetheless the limits on entanglement distribution have only recently been studied and are yet not fully understood. Our direction is a systematic characterization of entanglement distribution protocols together with examples where they could (or could not) be useful.

We present two classifications of such protocols. The first one refers to the way entanglement has been created: if it was first established in one laboratory by directly interacting subsystems before displacing them, we call it a ”direct” distribution protocol. If, on the other hand, we start with the subsystems already apart and we use ancillary systems as communication channels between the laboratories, we call the protocol ”indirect”. The latter class includes among others the very intriguing protocols with separable ancillary carriers. The existence of these reveal that even if no entanglement is being communicated, a significant amount of entanglement can still be transmitted.

This motivates our second classification. There is, in fact, an entire, larger class of protocols where the entanglement gain exceeds the communicated entanglement. We call such protocols ”excessive”, and the remaining ones ”non-excessive”.

Intuition suggests that excessive protocols can be a resource if some noise is present in the channel between the laboratories, since the carrier is the only particle interacting with it. We show that entanglement distribution via separable carriers is not possible for entanglement breaking communication channels, even for indirect protocols. However, for weaker channels, indirect excessive protocols are in many cases the best and sometimes the only way of increasing previously established entanglement. We provide analytical and numerical examples of protocols that belong to each category.

We provide analytical and numerical examples of protocols that belong to each category as well as relations between them. Our study covers cases of both pure and mixed states in ideal conditions or in noisy environments.

T16.3 Replicating the benefits of closed timelike curves without breaking causality

Xiao Yuan, Syed Assad, Jayne Thompson*, Jing Yan Haw, Vlatko Vedral, Timothy Ralph, Ping Koy Lam, Christian Weedbrook, Mile Gu* (Center for Quantum Technologies, National University of Singapore)
12:05pm – 12:20pm

In general relativity, closed timelike curves can break causality with remarkable and unsettling consequences. At the classical level, they induce causal paradoxes disturbing enough to motivate conjectures that explicitly prevent their existence. At the quantum level, resolving such paradoxes induces radical benefits - from cloning unknown quantum states to solving problems intractable to quantum computers. Instinctively, one expects these benefits to vanish if causality is respected.

Here I will outline how in harnessing entanglement, we can efficiently solve NP-complete problems and clone arbitrary quantum states - even when all time-travelling systems are completely isolated from the past. Thus, the many defining benefits of closed timelike curves can still be harnessed, even when causality is preserved. The results presented in this talk highlight the subtle interplay between entanglement and general relativity, and significantly improve the potential of probing the radical effects that may exist at the interface between relativity and quantum theory.

T16.74 Permutation-invariant quantum codes

Yingkai Ouyang* (Singapore University of Technology and Design)
12:20pm – 12:35pm

A quantum code is a subspace of a Hilbert space of a physical system chosen to be correctable against a given class of errors, where information can be encoded. Ideally, the quantum code lies within the ground space of the physical system. When the physical model is the Heisenberg ferromagnet in the absence of an external magnetic field, the corresponding ground-space contains all permutation-invariant states. We use techniques from combinatorics and operator theory to construct families of permutation-invariant quantum codes. These codes have length proportional to t^2; one family of codes perfectly corrects arbitrary weight t errors, while the other family of codes approximately correct t spontaneous decay errors. The analysis of our codes' performance with respect to spontaneous decay errors utilizes elementary matrix analysis, where we revisit and extend the quantum error correction criterion of Knill and Laflamme, and Leung, Chuang, Nielsen and Yamamoto.

T17: Bio- and Plasmaphyscis

Time: Friday 6 Mar, 11:00am; Venue: MAS2; Chair: Massimo Pica Ciamarra
Time allocated for invited talks is 15 min speaking time, plus 5 min Q&A, and time allocated for contributed talks is 12 min speaking time plus 3 minutes Q&A.

T17.16 Electronic Properties of Guanine Assemblies in G-quadruplex Nucleic Acids

Christopher Lech*, Anh Tuan Phan, Maria-Elisabeth Michel-Beyerle, Alexander Voityuk (NTU - School of Physical and Mathematical Sciences - Division of Physics and Applied Physics)
11:00am – 11:15am

Four-stranded G-quadruplex DNAs are implicated in a host of biological functions and have potential use in an assortment of nanotechnology and material applications. These structures are built upon the cyclical arrangement of guanine bases termed a G-tetrad and stabilized by π-stacking between guanines. We present a series of investigations in which we employ Quantum Mechanical (QM) and Molecular Mechanic (MM) methods to examine the electronic properties of stacked G-tetrads. A systematic exploration into the ground-state stacking energy landscapes allows for an understanding of favorable G-tetrad arrangements. Electronic coupling and electron hole transfer rates are found to largely vary amongst different G-tetrad stacking geometries, providing useful understanding for the design of conductive molecular systems built upon the G-quadruplex architecture. Excited state calculations of these stacking geometries reveals the charge transfer nature of excitons and the role of structural fluctuations on exciton localization within stacked G-tetrads.

T17.18 Mechanics of Cellular uptake via membrane budding: A Physical insight

Sabyasachi Dasgupta*, Thorsten Auth, Gerhard Gompper (Mechanobiology Institute)
11:15am – 11:30am

We investigate mechanistic aspects of cellular entry via membrane wrapping for particles of various geometries. The membrane bending rigidity $\varkappa$, the membrane tension σ, and the adhesion strength w between the particle and the membrane characterizes such systems. Depending upon shape and orientation of the particle non wrapped, partially wrapped (with low and high wrapping fraction), and completely wrapped states are found. A continuous binding transition and discontinuous transitions either between two partially wrapped states or between a partially wrapped and the completely wrapped state are found. We predict stable partially wrapped states for nonspherical particles, such as ellipsoidal and rod-like nanoparticles [1,2]. Particles with flat sides show binding at very small adhesion strengths though the decisive factor for encapsulation is the ratio of the width to the length of the particles and the softness of their edges.

Two specific examples discussing role of membrane wrapping energy in biology are studied. The role of the different membrane elastic contributions for the invasion mechanism of the "egg-like" malarial merozoite into erythrocytes is investigated [3]. Furthermore, our calculations predict optimal shapes of 3D nanoelectrodes for efficient coupling to cells [4].

References

[1] S. Dasgupta, T. Auth, and G. Gompper, Soft Matter, 9, 5473-5483, (2013).

[2] S. Dasgupta, T. Auth, and G. Gompper, Nano Letters, 14, 687-693, (2014).
[3] S.Dasgupta, T.Auth, Nir.S.Gov, T.J.Satchwell, E.Hanssen, E.S.Zuccala, D.T.Riglar, A. M. Toye, T. Betz, J. Baum, and G. Gompper, Biophysical Journal, 107 (1), 43-54 (2014).
[4] F. Santoro, S. Dasgupta, J. Schnitker, T. Auth, E. Neumann, G. Panaitov, G. Gompper, and A. Offenhaeusser, ACS Nano 8(7), 6713-6723 (2014).

T17.103 Protein folding and transformations: insights from clustering techniques

Mikhail Filippov*, Siew Ann Cheong (Nanyang Technological University)
11:30am – 11:45am

In our work we applied combination of clustering techniques for pattern recognition within protein folding process. In the study of protein folding dynamics, a great number of dendrograms need to be classified in order to understand the underlying folding mechanism. While visual identification is still feasible when the number of den- drograms to be considered is still small, a more automatic approach is desirable to cluster a large number of dendrograms. In the first part of this paper, we undertake a systematic study of this problem of clustering the correlation matrices from which the dendrograms are derived. We explore both correlation-based distances and order-based distances in this study. Correlation- and order-based distances produce different classification results, which also differ from the visual classification. In the second part we are clustering descriptor matrices obtained from dendrograms analysis. Threshold descriptor and partition membership divergence are showing strong agreement to each other. Results obtained by using path descriptor are supporting correlation-based distances.

T17.157 Measurement of the underlying event activity using charged particle jets in proton-proton collisions at 2.76 TeV

Wei Yang Wang* (NUS)
11:45am – 12:00pm

A measurement of the underlying event (UE) activity in proton-proton collisions is performed using events with a leading charged particle jet produced at central pseudorapidity ($|\eta| < 2$) and of transverse momentum in the range of 1 to 100 GeV. The analysis uses 0.3 inverse nanobarns of integrated luminosity at the centre-of-mass energy of 2.76 TeV at the LHC by the CMS experiment. The UE activity is measured as a function of the jet transverse momentum in terms of the average multiplicity and scalar-pT sum of charged particles with $|\eta| < 2$ and $pT > 0.5$ GeV in the azimuthal region transverse to the leading jet direction. By dividing the transverse region into the minimum and maximum activity sides with respect to the leading jet, further information on the dynamics of the UE is obtained. The measurements are compared to previous results at 0.9 and 7 TeV and to predictions of several QCD-inspired models providing constraints of the parameters involved.

T17.174 Soft X-rays Optimization Studies and its Application in X-ray Lithography using Fast Miniature Plasma Focus Device

Selvi M. P Kalaiselvi*, Tuck Lee Tan, Alireza Talebitaher, Paul Lee, Rajdeep Rawat* (rajdeep.rawat@nie.edu.sg)

12:00pm – 12:15pm

X-ray lithography (XRL) can be a potential candidate for next generation lithography. The main objective of this study is to optimize the soft X-ray (SXR) emission from 200 J fast miniature plasma focus (FMPF) device and demonstrate XRL using it as the X-ray source. The advantage of using FMPF as X-ray source is the smaller X-ray spot size due to smaller electrode dimensions leading to higher resolution micro components. Through the extensive optimization studies conducted, an average yield of 1.8 J/shot was obtained using 2 cm tapered anode, which is the highest yield achieved from this device so far. Some of the major hurdles in the realization of XRL using FMPF device have been addressed in this investigation and FMPF based XRL is demonstrated for the first time. The dosage required for sufficient crosslinking in SU8 photoresist for fabrication of micro components is determined using Fourier transform infrared spectroscopy analysis.

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