Agency for
Science, Technology
and Research
SINGAPORE

A*STAR MINI SYMPOSIUM ON QUANTUM SCIENCE & TECHNOLOGY

EXPLORING THE QUANTUM FRONTIER: SCIENCE & TECHNOLOGY

DATE

March 7th 2023

VENUE

Innovis, Level 1
Multi-Purpose Hall (MPH)
2 Fusionopolis Way

Content

About the A*STAR Mini Symposium on Quantum Science & Technology

Quantum science and technology is the study of the behaviour of matter and energy at the atomic and subatomic levels. It has the potential to revolutionize fields such as computing, communications, precision measurement and sensing.

This symposium aims to bring together minds from the research community to share their efforts to address the wide range of issues pertaining to our theme of "Exploring the Quantum Frontier: Science and Technology". Our distinguished speakers from Australia and Singapore will share their Quantum Science and Technology achievements and endeavours. The symposium will also feature latest reports from A*STAR quantum projects, as well as panel discussions on a wide range of topics on quantum technologies, including:

- Building Advanced Quantum Computing Hardware
- Opportunities with Quantum Sensing Technologies
- Quantum Photonics for Information, Communication, and Technology
- Intercepting Current Computational Workflows

This event aims to be a platform for meaningful scientific exchange and to pave the way to mutually beneficial collaborations.

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A*STAR Mini Symposium on Quantum Science & Technology

"Exploring the Quantum Frontier: Science & Technology"

7th March 2023

08:00-08:30	Arrival and Registration
08:30-08:35	Introduction by Symposium Committee Chairperson, Chief Quantum Scientist, **Prof. Ping Koy Lam**
08:35-08:45	Opening Address by Deputy Chief Executive (Research), A*STAR, **Prof. Andy Hor**

Session 1: Building Advanced Quantum Computing Hardware

Moderator: Dr. Calvin Wong

08:45-09:15	Keynote Lecture by **Prof. Igor Aharonovich, University of Technology Sydney**
09:15-09:55	**Dr. Aaron Lau, IMRE, A*STAR** *A 2D Semiconductor Quantum Dot* **Dr. Yan Yan Zhou, IME, A*STAR** *Photonic Integration for Ion Trap Quantum Processor* **Dr. Ding Huang, IMRE, A*STAR** *Advantages of van der Waals Materials on Superconducting Quantum Circuits* **Dr. Cleaven Chia, IMRE, A*STAR** *Harnessing Quantum Vibrations for Quantum Devices*
09:55-10:15	**Block Q&A**
10:15-10:45	*Tea Break & Networking*

Session 2: Opportunities with Quantum Sensing Technologies

Moderator: Dr. Tao Wang

10:45-11:55	**Dr. Renzhe Bi, IBB, A*STAR** *Challenges and Opportunities of Quantum Sensing and Imaging Technologies in Healthcare* **Dr. Anna Paterova, IMRE, A*STAR** *Infrared Metrology with Visible Light* **Dr. Victor Leong, IMRE, A*STAR** *Towards Detecting Single Visible Photons with Integrated Silicon Photonics* **Dr. Jun Yi Lee, IMRE, A*STAR** *Applications of Atomic Vapor Technologies* **Dr. Lu Ding, IMRE, A*STAR** *Cavity Optomechanics and Its Applications*
11:55-12:15	**Block Q&A**
12:15-14:00	*Lunch & Networking*

A*STAR Mini Symposium on Quantum Science & Technology

"Exploring the Quantum Frontier: Science & Technology"

7th March 2023

Session 3: Quantum Photonics for Information, Communication, and Technology

Moderator: Dr. Jason Png

14:00-15:10	**Prof. Dawn Tan, SUTD & IME, A*STAR** *Advances in Nonlinear CMOS Photonics* **Dr. Di Zhu, IMRE, A*STAR** *Integrated Quantum Photonics on Thin-Film Lithium Niobate* **Dr. Doris Ng, IME, A*STAR** *Exploring AlN Material Platform for Quantum Photonics* **Dr. Wang Qian, IMRE, A*STAR** *Nanofocusing In-Plane Hyperbolic Phonon Polaritons in TMD/MoO3 Heterostructures* **Dr. Jiabin You, IHPC, A*STAR** *Simulations for Quantum Optical Systems*
15:10-15:30	**Block Q&A**
15:30-16:00	*Tea Break & Networking*

Session 4: Intercepting Current Computational Workflows

Moderator: Dr. Jun Ye

16:00-17:10	**Dr. Patrick Rebentrost, CQT NUS** *Quantum Finance: Pricing of Classical and Quantum Assets* **Dr. Zhiguang Cao, I²R, A*STAR** *Learning to Solve Combinatorial Optimization Problems* **Dr. Yaw Sing Tan, BII, A*STAR** *A Quantum Leap for Biomolecular Modelling?* **Dr. Dax Enshan Koh, IHPC, A*STAR** *An Expressive Ansatz for Low-Depth Quantum Optimisation* **Dr. Siong Thye Goh, IHPC, A*STAR** *Exploring Quantum Computing for The Traveling Salesman*
17:10-17:30	**Block Q&A**
17:30-17:45	Closing Address by **Prof. Ping Koy Lam**

BII: Bioinformatics Institute
CQT: Centre for Quantum Technologies
I²R: Institute for Infocomm Research
IBB: Institute of Bioengineering & Bioimaging
IHPC: Institute of High Performance Computing
IME: Institute of Microelectronics
IMRE: Institute of Materials Research and Engineering
NUS: National University of Singapore
SUTD: Singapore University of Technology & Design

Session 1

Building Advanced Quantum Computing Hardware

Prof. Igor Aharonovich
Professor
University of Technology Sydney
Chief Investigator
UTS Node Director
ARC Centre of Excellence for
Transformative Meta-Optical
Systems

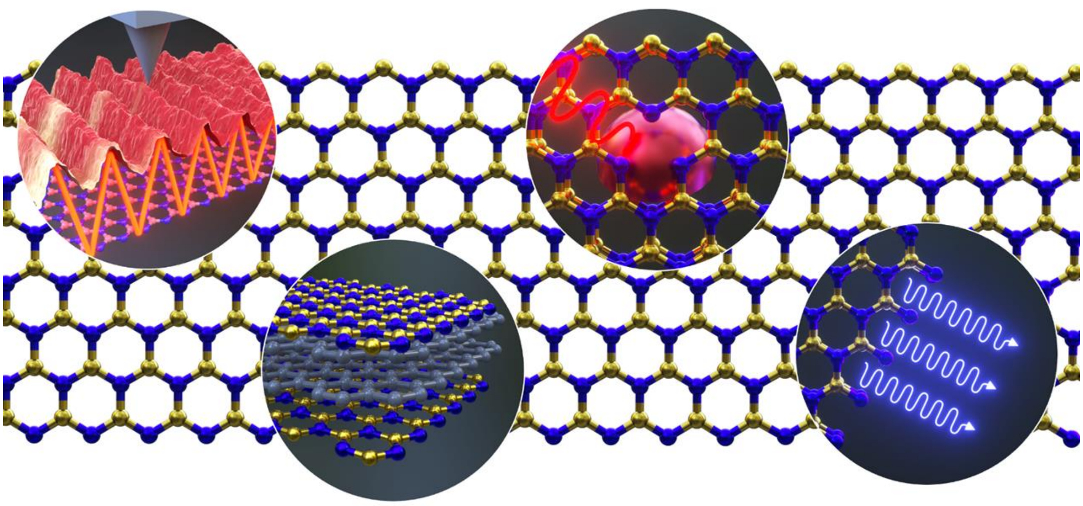
Igor Aharonovich is an award-winning scientist working on cutting-edge research into quantum sources that are able to generate, encode and distribute quantum information. A Professor in the School of Mathematical and Physical Sciences at UTS, Igor investigates optically active defects in solids, with the aim of identifying a new generation of ultra-bright solid state quantum emitters. His contributions to the field include the discovery of new colour centers in diamond and hexagonal boron nitride, and the development of new methodologies to engineer nanophotonic devices from these materials. He is a chief investigator at the ARC Centre of Excellence for Transformative Meta-Optical Materials (TMOS) and leads an international collaboration investigating the chemical structure of crystal imperfections, or defects, in the nanomaterial hexagonal boron nitride (hBN). In 2013, he established the nanophotonics research group at UTS, was promoted to Associate Professor in 2015, and to a full Professor in 2018. His research group explores new quantum emitters in wide bandgap materials, with the aim of fabricating quantum nanophotonic devices on a single chip for the next generation of quantum computing, cryptography and bio-sensing. In 2016, Igor and his team discovered the first quantum emitters in 2D materials that operate at room temperature based on defects in hBN. He has co-authored more than 200 peer-reviewed publications, including one of the most cited reviews on diamond photonics. He has also written a road map for solid state single-photon sources. In 2019, Igor co-founded the inaugural online photonics conference, Photonics Online Meetup, which attracted more than 1100 attendees from around the world, and which was highlighted by top science outlets. The conference now runs twice a year. Igor received his B.Sc. (2005) and M.Sc. (2007) in Materials Engineering from the Technion – Israel Institute of Technology, under the supervision of Prof Yeshayahu Lifshitz. He then undertook his PhD studies at the University of Melbourne under the supervision of Prof Steven Prawer, where he developed experimental techniques to engineer novel, ultra bright single photon emitters in diamond. Igor has received several international awards including the Pawsey Medal (2017), the IEEE Photonics Young Investigator Award (2016). In 2021, he became a Fellow of the Optical Society (OSA), the prime global society in optics and photonics, and recipient of the 2020 Kavli Foundation Early Career Lectureship in Materials Science from Materials Research Society.

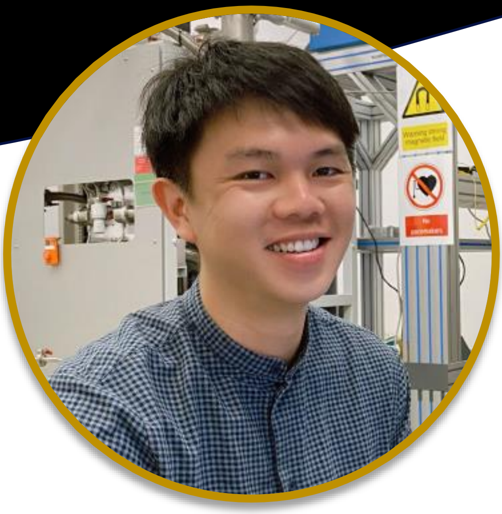
Quantum Nanophotonics with Hexagonal Boron Nitride

Engineering robust solid-state quantum systems is amongst the most pressing challenges to realize scalable quantum photonic circuitry. While several 3D systems (such as diamond or gallium arsenid) have been thoroughly studied, solid state emitters in two dimensional (2D) materials are still in their infancy.

In this presentation I will discuss the appeal of an emerging van der Waals crystal – hexagonal boron nitride (hBN). This unique system possesses a large bandgap of ~ 6 eV and can host single defects that can act as ultra-bright quantum light sources. In addition, some of these defects exhibit spin dependent fluorescence that can be initialised and coherently manipulated. In this presentation I will discuss in details various methodologies to engineer these defects and show their peculiar properties. Furthermore, I will discuss how hBN crystals can be carefully sculpted into nanoscale photonic resonators to confine and guide light at the nanoscale. Taking advantage of the unique 2D nature of hBN, I will also show promising avenues to integrate hBN emitters with silicon nitride photonic crystal cavities.

All in all, hBN possesses all the vital constituents to become the leading platform for integrated quantum photonics. To this extent, I will highlight the challenges and opportunities in engineering hBN quantum photonic devices and will frame it more broadly in the growing interest with 2D materials nanophotonics.





Dr. Aaron Lau
Scientist III
Institute of Materials Research and Engineering (IMRE)
A*STAR

Aaron Lau is an experimental quantum scientist who engineers and studies next-generation materials and devices to understand the physics of low-dimensional systems. He graduated from the National University of Singapore in 2012 with a Bachelor of Science (Physics), first class honours, before receiving the A*STAR Graduate Scholarship to pursue his PhD at the University of Oxford. There, he frequented the Department of Materials and the Royal Oak Pub where he worked on quantum transport through single-molecule electronics. He successfully defended his thesis and returned to A*STAR IMRE in 2017, where he now works on atomically thin materials for quantum applications.

A 2D Semiconductor Quantum Dot

2D semiconductors have potential for many applications including quantum but progress is severely hindered by contact and dielectric engineering. I will discuss our group's efforts to establish high-quality contacts at cryogenic temperatures where we revealed new insights into the nature of metal/2D semiconductor interface. Next, I will discuss our work on the influence of dielectrics and interface roughness on carrier transport and present our measurements on the first gate-defined chemical vapour deposition grown bilayer WS2 quantum dot. Finally, we will share some of our latest work on integrating ultrathin metal oxides printed from liquid metals with 2D materials, and how they can potentially address crucial device engineering challenges in 2D materials.

C.S. Lau, J.Y. Chee et al., 'Quantum Transport in Two-Dimensional WS2 with High-Efficiency Carrier Injection through Indium Alloy Contacts', ACS Nano, 14 (10), 13700-13708 (2020)

C.S. Lau, J.Y. Chee et al., 'Gate-Defined Quantum Confinement in CVD 2D WS2, Advanced Materials, 2103907 (2021)

Yan Yan Zhou received her Ph.D. (2015) and B.Eng. (2010) in Electrical and Electronic Engineering from Nanyang Technological University. She joined the Institute of Microelectronics, A*STAR as a research scientist in 2019. Her current research includes metasurface, nano-lasers and photonics designs.

Dr. Yan Yan Zhou

Scientist I
Institute of Microelectronics (IME)
A*STAR

Photonic Integration for Ion Trap Quantum Processor

In this talk, we present our progress on using photonics integrated circuit (PIC) for controlling and manipulating trapped ions in an ion trap. We designed and fabricated various components of the PIC, including waveguides and couplers, and tested their performance in a series of experiments. We will discuss the challenges we encountered during the research process, including the need for high-quality optics and precise control of the light, and how we overcame them. Our work has significant implications for the field of quantum technology research, as ion traps with integrated PIC can provide a more compact, robust, efficient, and scalable platform for quantum computing and simulation. We believe our findings will contribute to the ongoing efforts to develop practical quantum technologies for real-world applications.

Dr. Ding Huang
Scientist I
Institute of Materials Research and Engineering (IMRE)
A*STAR

Ding Huang is an experimental physicist interested in quantum science and engineering. His research aims at understanding and controlling the properties of quantum systems at small length scale. He joined IMRE A*STAR in 2021, where he is now exploring quantum devices based on 2D materials. Ding received his PhD from Princeton University in 2021. His PhD work focuses on the spectroscopy of atomic defects in diamond and coupling them to nanophotonic cavities for quantum network applications. Prior to that, he received his master and bachelor's degrees from Imperial College London in 2014, where he graduated with First Class Honours. In his spare time, he likes to hike, ski and play video games.

Advantages of van der Waals Materials on Superconducting Quantum Circuits

Superconducting quantum circuit is an attractive platform to build quantum computers capable of solving problems beyond the reach of existing technologies. Recently, there have been significant developments in enhancing the performance of superconducting qubits using two-dimensional van der Waals (vdW) materials. Replacing the planar capacitor of a superconducting qubit using vdW heterostructures drastically reduces the size of superconducting qubit by at least 250 times. This provides a viable pathway for high-density qubit integrations and suppressed crosstalk for large-scale qubit operations. However, the material losses and the limiting mechanisms for coherence times of such superconducting qubits remain elusive. Here, we present our on-going efforts to systematically characterize the losses of vdW materials in the context of superconducting qubit technology.

Dr. Cleaven Chia
Scientist I
Institute of Materials Research
and Engineering (IMRE)
A*STAR

Cleaven Chia graduated with a BSc in Physics with Theoretical Physics from Imperial College London in 2014, and a PhD in Applied Physics from Harvard University in 2021. During his PhD, he worked with Prof. Marko Lončar to integrate diamond optomechanical crystals and silicon vacancy centre spins, in order to couple photons and phonons to spins. He also has experience with numerical simulations of photonic and phononic crystals, nanofabrication on diamond, and fibre optical characterization. Cleaven's current research interests lie in developing hybrid quantum systems that interface photons, phonons, and spins.

Harnessing Quantum Vibrations for Quantum Devices

Phonons, which are quantum mechanical vibrations, couple intrinsically to various modalities such as photons and spins. Hence, phonons can serve as versatile transducers to send quantum information between different qubit platforms that store quantum information. However, phonons are double-edged swords because thermal phonons can also act as a source of noise, causing qubits to lose their coherence. As such, engineering of phonon modes are required to maximise coherent coupling between qubits and desired phonon modes, and to minimise the interactions with thermal phonons.

In my talk, I will give an overview of how phonon modes can be engineered in quantum devices for coupling to qubits. Specifically, I will introduce diamond as a candidate material for coherent qubit-phonon coupling in the solid state, between silicon vacancy centre spins and localised modes in phononic crystals. Finally, I will provide an outlook for how engineered phonon modes can be used to interface with other qubit platforms, such as 2D materials.

Session 2

Opportunities with Quantum Sensing Technologies

Dr. Renzhe Bi
Senior Scientist I
Institute of Bioengineering and Bioimaging (IBB)
A*STAR

Renzhe Bi is a senior scientist in Institute of Bioengineering and Bioimaging (IBB), A*STAR. In the past 12 years, his research focused on development of novel bio-photonics technologies and medical technology innovations. To date, he has 36 scientific publications, 3 granted patents and 11 patent applications. All his 3 patents have been assigned or licensed to Singapore-based MedTech companies. His inventions were translated into medical devices that can help the surgeons to monitor the foot blood flow during the lower limb surgery, help the hospitals to track the patients' breathing remotely, and help the dermatologists to evaluate skin eczema more precisely. Renzhe won the Young Scientist Award (YSA) in 2022 for his contributions in MedTech innovation.

Challenges and Opportunities of Quantum Sensing and Imaging Technologies in Healthcare

The rapid development of quantum technologies brings new opportunities for healthcare. This presentation will share some very recent developments in Biophotonics technologies and MedTech innovations. The successful clinical translation of these technology innovations will be introduced, in the fields of vascular diseases and skin care, etc. Then the current development of optically pumped magnetometers (OPMs), quantum ghost imaging and quantum 2-photon fluorescence microscopy will be briefly reviewed. These quantum technologies will enable various new opportunities in healthcare related applications. However, several challenges need to be solved before the quantum technologies can be used in clinical studies. The challenges and potential solutions will be discussed.

Dr. Anna Paterova
Scientist II
Institute of Materials Research and Engineering (IMRE)
A*STAR

Anna Paterova received her undergraduate degree in 2014 from Lomonosov Moscow State University. Later she moved to Singapore to start a PhD with the support from the SIPGA A*STAR and SINGA A*STAR scholarships. From 2014 to 2018, Anna was doing joint PhD research related to quantum optics and interferometry in Data Storage Institute A*STAR and Nanyang Technological University. She successfully defended her PhD degree in 2018 at Nanyang Technological University with the topic "IR metrology using visible light". Since receiving her PhD, Anna has been a research scientist in the Institute of Materials Research and Engineering at A*STAR. Currently, her research interests focus on the field of quantum interferometry and its applications. Beside her research she loves playing volleyball and reading books in her spare time.

Infrared Metrology with Visible Light

Infrared (IR) wavelengths is a range of big importance, since many molecules present their fingerprint absorption properties at this region. Thus, IR spectroscopy and IR imaging are important tools for measurement of chemical composition across different regions of a specimen. Conventional techniques of IR measurements are based on using quantum cascade lasers (QCLs) or synchrotron light sources and IR point detector arrays. However, such light sources have limited tunability range and high cost. Furthermore, IR photodetectors suffer from strong background noise and require cooling, which leads to high cost and limited sensitivity.

An alternative to the scheme with the direct detection of IR light is using a nonlinear interference of correlated photon pairs, which allows inferring the IR properties of the sample from the detection of visible light. Thus, this technique allows to probe IR fingerprints using a standard CMOS camera, which improves signal-to-noise ratio. In our group, we have realised this method for IR imaging, IR spectroscopy, IR optical coherence tomography and IR polarimetry. Furthermore, we would like to demonstrate the nonlinear interferometry method in medical diagnostics and chemical analysis.

Victor Leong obtained his PhD from CQT in 2016 with a cold atom project on single atom - single photon interactions. He has since been a research scientist at A*STAR, first at the Data Storage Institute (DSI), and now at the Institute of Materials Research and Engineering (IMRE). He research focus is on developing integrated photonics platforms for quantum technologies and has a keen interest in the fields of quantum optics, photonics, and sensing.

Dr. Victor Leong

Scientist III
Institute of Materials Research
and Engineering (IMRE)
A*STAR

Towards Detecting Single Visible Photons with Integrated Silicon Photonics

Integrated photodetectors are key building blocks of scalable photonics platforms. Focusing on visible-light operation, we have been developing CMOS-compatible integrated avalanche photodetectors (APDs) which are monolithically integrated with a silicon nitride photonics circuit via end-fire coupling. I will report our progress on the design, fabrication, and testing of our APDs, which exhibit competitive performance with up to 30GHz bandwidth. I will discuss our efforts to push the APD performance towards single-photon detection capability.

Dr. Jun Yi Lee
Scientist I
Institute of Materials Research and Engineering (IMRE)
A*STAR

Junyi Lee received his B.A. in physics from the University of Chicago and obtained his Ph.D. in physics at Princeton University under Professor Michael Romalis. During his time at Princeton, Junyi improved the best constraints of the axion's anomalous coupling to nucleons by an order of magnitude over two decades of axion mass. Since then, he has developed a frequency-domain analysis for correctly analyzing stochastic dark matter axion signals and has improved the constraints on feV-scale axions' coupling to the neutron spin by five orders of magnitude. Separately, he has also developed a non-variational algorithm for efficiently preparing states with low entanglement on quantum computers that can use an order of magnitude less gates than other state-of-the-art non-variational algorithms. He is currently interested in applying spin-squeezing techniques to improve the sensitivity per unit volume of scalar atomic magnetometers operating in geomagnetic fields and in achieving quantum memories with hours-long lifetimes.

Applications of Atomic Vapor Technologies

Vapor cells containing alkali and/or noble-gas atoms are at the heart of many quantum sensing and processing applications. For example, these vapor cells can be used in centimeter-scale, non-cryogenic ultra-sensitive magnetometers with sensitivity at the fT/sqrt(Hz) level operating at both DC and RF frequencies. The sensitivity of these magnetometers, which rival cryogenic superconducting quantum interference devices, can enable longer range magnetic anomaly and unexploded ordnance detection (MAD and UXO detection), neuroscientific and brain-computer interface research using magnetoencephalography (MEG), or even chemical-specific stand-off detection of explosives and narcotics through the measurement of nuclear quadrupole resonances in nitrogen. When filled with isotopically enriched noble-gas, these vapor cells can also be used in compact gyroscopes with bias stability far exceeding that of micro-electro-mechanical systems (MEMS) gyroscopes. Besides quantum sensing applications, vapor cells with alkali and noble-gas atoms can also be used in quantum information processing as a quantum memory for light with potential lifetimes on the scale of hours to days in a non-cryogenic cell. In this talk, I'll give a brief overview of how atomic vapor technologies can enable some of the above technologies and the work we have done here at QTE, IMRE in this field thus far.

Dr. Lu Ding
Scientist III
Institute of Materials Research
and Engineering (IMRE)
A*STAR

Lu Ding received her B.E. degree in Microelectronics from Jilin University, Jilin, China, in 2003, and her Ph.D. degree in Physics from the Hong Kong University of Science and Technology (HKUST) in 2007. After a period of postdoctoral work in the Materials and Quantum Phenomena (MPQ) laboratory at the Paris Diderot University, France, she joined Institute of Materials Research and Engineering (IMRE, A*STAR, Singapore) in 2011. She works on various photonic resonant cavities for on-chip and free space applications. Her expertise is on various optical characterizations, THz spectroscopy, s-SNOM, microscopic spectroscopy, etc. Her research interests include on-chip cavity optomechanics, nanophotonics, and semiconductor optoelectronics, etc.

Cavity Optomechanics and Its Applications

Cavity optomechanics systems are quantum hybrid systems coupling photons and phonons. They have important applications from quantum mechanics to ultraprecise photonic sensing. Ground-breaking experimental demonstrations since 2021 on quantum-mechanically entangled mechanical oscillators have signified a new era of optomechanics, where the coupling between optical, microwave, and mechanical resonators are exploited to push quantum phenomena to nanoscale and beyond. The scientific pursuit of photonic and hybrid implementations of optomechanics holds promises towards innovation in sensing, communications, metrology, condensed-matter physics, foundational quantum physics, and other areas. I would like to give a brief introduction on the key developments of this thriving field and look out for the prospects.

Session 3

Quantum Photonics for Information, Communication, and Technology

Prof. Dawn Tan
Associate Professor
Singapore University of Technology and Design (SUTD)
Principal Scientist
Institute of Microelectronics (IME)
A*STAR

Dawn Tan is an Associate Professor at the Singapore University of Technology and Design and Principal Investigator of the Photonics Devices and Systems Group. She holds a joint appointment with the A*STAR Institute of Microelectronics. Her group's research encompasses integrated optics, nonlinear optics and silicon photonics. Dawn received her doctorate in Electrical Engineering at the University of California San Diego where she was a Powell Fellow. She was previously a visiting professor at the Massachusetts Institute of Technology and part of the design team at Californian startup, Luxtera Inc. She is a National Research Foundation (NRF) Investigator, Class of 2023.

Advances in Nonlinear CMOS Photonics

We report recent progress on nonlinear photonic devices demonstrated on the ultra-silicon-rich nitride (USRN) platform. USRN's high Kerr nonlinearity (100X larger than in stoichiometric silicon nitride), absence of two-photon absorption at the telecommunications wavelength and compatibility with complementary metal-oxide semiconductor processing makes it an ideal vessel for the observation of low power parametric processes, nonlinear topological photonics and Bragg soliton phenomena including compression and fission, picosecond pulse generation and optical parametric Bragg amplification.

Dr. Di Zhu
Scientist II
Institute of Materials Research and Engineering (IMRE)
A*STAR

Di Zhu is a research scientist at the Institute of Materials Research and Engineering (IMRE), A*STAR, Singapore. Di received his Ph.D. (2019) and M.Sc. (2017) from Massachusetts Institute of Technology, and B.Eng. (2013) from Nanyang Technological University. From 2019 to 2021, he was a postdoctoral fellow at Harvard University. His Ph.D. thesis focused on superconducting nanowire single-photon detectors, and postdoc work centered around thin-film lithium niobate photonics. He was a recipient of the NRF Fellowship (Class of 2023), inaugural Harvard Quantum Initiative Postdoctoral Fellowship, A*STAR National Science Scholarship, and MIT Jin-Au Kong thesis award. His current research interests include integrated quantum photonics, applied superconductivity, and nanoscale electromagnetics.

Integrated Quantum Photonics on Thin-Film Lithium Niobate

Optical photons are ideal carriers of quantum information and have played central roles in numerous recent breakthroughs, from record-distance quantum secure communication to computational advantages. However, scaling today's photonic quantum technologies to realize complex systems for practical computation and simulation still faces critical challenges. Such systems often require thousands to millions of components, which are infeasible to implement using traditional bulk optics. Integrated photonics is likely the only solution.

In this talk, we will describe our research efforts on developing an integrated photonic platform for scalable quantum information processing. We will first introduce thin-film lithium niobate (TFLN) as an ideal material platform for this purpose. TFLN offers many attractive properties that are critically missing in existing leading platforms, such as large electro-optic and piezoelectric coefficients, strong second-order nonlinearity, and engineerable ferroelectric domains. We will describe how these properties enable key functionalities such as efficient quantum light generation, coherent spectral control, and ultra-fast switching. We will then introduce superconducting nanowires as an effective solution for on-chip single-photon detection. Combining both, we aim to realize a fully integrated quantum photonic processor that allows single-photon generation, control, and detection on a single chip.

Dr. Doris Ng
Senior Scientist II
Institute of Microelectronics (IME)
A*STAR

Doris Ng received her Ph.D. degree in Engineering from the National University of Singapore (NUS), Singapore in 2008. She joined A*STAR (Agency for Science, Technology and Research) since 2007 and worked on integrated photonics for more than 10 years from devices and platforms to applications for datacom, data storage, sensing, and instrumentation. She has been taking a major role in the development of integrated photonics infrastructure and innovative technologies towards photonic sub-system-on-chip. Her research interests include electronic-photonic integration, materials development for non-linear optics, photonics-based gas sensors, pyroelectric infrared detectors and study of novel piezoelectric materials. Her key achievements include high-efficiency heterogeneous Si/III-V integration with short optical vertical interconnect access, ultra-silicon-rich nitride for non-linear optics applications, a simple one-step direct deposition of ultra-smooth metal film deposition for nanoplasmonic applications and development of CMOS-compatible pyroelectric detectors for gas sensing applications.

Exploring AlN Material Platform for Quantum Photonics

As the development in quantum technologies and quantum computing progresses, it becomes imperative that a scalable and compact material platform is required. In recent years, aluminum nitride (AlN), with a large bandgap of 6.2 eV, has emerged as a new and promising material of interest in the regime of integrated quantum photonics. The attractiveness in AlN material is mainly due to its strong second order nonlinearity and wide band operation from ultra-violet to infrared wavelengths. On top of that, AlN quantum emitters have been demonstrated from AlN, making it potential host materials for high quality quantum emitters. From the material aspect, AlN film can be deposited on 8-inch substrate using physical vapor deposition with low thermal budget, making it complementary metal-oxide-semiconductor (CMOS) compatible and scalable, allowing the devices to be integrable with CMOS electronics, making monolithic integration possible.

Over the past 2 years, IME has been developing AlN material platform for integrated quantum photonics. Here, we present IME in-house fabricated AlN film over 8-inch wafer, its material properties, suitability for quantum photonics devices and how we address certain limitations in the material. This material is then processed to fabricate AlN photonics devices and the structural characteristics of the resulting devices will be presented. The outcome can allow for further optimization and provide a pathway for realization of integrated quantum photonics devices, making AlN a viable material platform for quantum technologies and quantum computing.

Dr. Qian Wang
Senior Scientist I / Deputy Head
Institute of Materials Research
and Engineering (IMRE)
A*STAR

Wang Qian obtained her PhD degree from Nanyang Technological University in 2012. During 2013-2014 she was an ASTAR international postdoctoral fellow in the Optoelectronics Research Centre at University of Southampton. Since 2015, she joined IMRE. She has published over 40 scientific papers on peer-reviewed journals including Nature Photonics, Science and Light. Sci. Appl. Her research interests span non-volatile phase change materials, near-field manipulation of plasmonics & phonon polariton, quantitative phase imaging and all-optical neuromorphic computing.

Nanofocusing In-Plane Hyperbolic Phonon Polaritons in TMD/MoO3 Heterostructures

Polaritons formed by hybridization of light with polarized charges can focus light into regions much smaller than its associated free-space wavelength. This property has raised a surge of interest of applications in nanophotonics, ranging from biological sensing to nonlinear and quantum optics. Hyperbolic phonon polariton sustained in polar van der Waals crystals, such as MoO3, exhibit high confinement of long-wave electromagnetic fields to the subwavelength scale. However, the nanofocusing control of the in-plane hyperbolic phonon polariton remain elusive. Here, we demonstrate a mechanism to further enhance light-matter interactions by manipulating PhP into deep focusing using semiconducting transition metal dichalcogenide (TMDCs)/MoO3 heterostructures. This allows development of efficient phonon polariton manipulation devices for planar nanophotonics applications.

Dr. Jiabin You
Scientist II
Institute of High Performance Computing (IHPC)
A*STAR

Jiabin You is a scientist in Institute of High Performance Computing, Agency for Science, Technology and Research (IHPC, A*STAR). He obtained his PhD degree in physics in National University of Singapore in 2015. He was a postdoctoral fellow in Hong Kong University during 2015-2017, then he joined in IHPC, A*STAR from 2017 to present. His current research interests are simulations of quantum optical systems, simulations of layered quantum dots, and quantum algorithms. He has published 30 more papers in peer-reviewed journals in Nano letters, Physical Review A/B/E, Optics Letters etc. He was awarded Career Development Award in 2020.

Simulations for Quantum Optical Systems

We aim to develop simulations for quantum optical systems. First of all, we introduce the Lindblad master equation formalism, which is a theoretical framework for simulating open quantum systems. We apply this approach to investigate a range of quantum phenomena in plasmonic systems, including photon blockade and single photon sources, optical spectrum, quantum switch, and quantum entanglement. To extend our simulations to quantum many-body systems, we use the variational matrix product state algorithm in conjunction with the Lindblad master equation formalism. This enables us to study the spectral hole burning effect in plasmonic systems and the generation of entanglement in 1D chiral spin chain models. These phenomena are of significant interest in the field of quantum optics, and our simulations can provide insights into their behavior and potential applications. Furthermore, we explore the hybridization of the finite element method and quantum solver to model and propose practical experimental setups. This approach allows us to combine the power of classical simulations with quantum simulations to study complex quantum systems. By using this hybrid approach, we can gain a more accurate understanding of the behavior of quantum systems and design more effective experimental setups. Our work may have applications in areas such as quantum communication, quantum computation, and quantum sensing, where the behavior of quantum systems plays a critical role in their performance.

Session 4

Intercepting Current Computational Workflows

Dr. Patrick Rebentrost
Principal Investigator
Centre for Quantum Technologies (CQT)
National University of Singapore (NUS)

Patrick Rebentrost's research interests are in quantum computing, quantum algorithms, quantum machine learning, learning theory, and mathematical finance. He currently leads a project on "Computer science approaches to quantum computing for finance" supported by Singapore's Quantum Engineering Programme. This project looks at how quantum computers can address computational challenges such as options pricing, portfolio optimisation and trading. He joined CQT in 2018 as a Senior Research Fellow, becoming a PI in 2022. His previous affiliations include Massachusetts Institute of Technology and Xanadu Quantum Technologies.

Quantum Finance: Pricing of Classical and Quantum Assets

Quantum computers have the potential to provide advantages for solving problems in finance. First, we briefly review the pricing of financial derivatives using quantum subroutines for Monte Carlo estimation. Second, we investigate new market scenarios and asset classes that could arise from the emergence of quantum technologies for computation and communication. We define the notion of quantum assets and develop an extended definition of arbitrage. We provide a quantum version of the first fundamental theorem of asset pricing, with application to new types of financial derivatives.

Dr. Zhiguang Cao
Scientist II
Institute for Infocomm Research (I^2R)
A*STAR

Zhiguang Cao is a scientist at the Institute for Infocomm Research (I^2R), A*STAR. Previously, he worked as a research assistant professor in the Department of Industrial Systems Engineering and Management, NUS, and a research fellow in the BMW Future Mobility Research Lab, NTU. Recently, his research interests focus on Learning to Optimize, where he exploited deep (reinforcement) learning to solve various combinatorial optimization problems. His works under this topic are published in NeurIPS (x6), ICLR, AAAI, IJCAI and IEEE Trans, and the papers & codes are available at: https://zhiguangcaosg.github.io/publications/

Learning to Solve Combinatorial Optimization Problems

Learning to Optimize (L2Opt) is an emerging topic in both AI and operations research (OR). It usually exploits neural heuristics based on deep (reinforcement) learning against conventional heuristics to solve combinatorial optimization problems (COPs) such as the vehicle routing problems (VRPs). In this presentation, I will first talk about the background for L2Opt, and then elaborate two types of neural heuristics for solving VRP. I hope the ideas there would be helpful for Quantum computing.

Yaw Sing Tan graduated with a B.Sc. (Hons) from the National University of Singapore in 2009, with a double major in Chemistry and Life Sciences. Funded by the A*STAR Graduate Scholarship, he proceeded to pursue his postgraduate studies at the University of Cambridge, where he obtained his PhD in Chemistry. He then joined the Bioinformatics Institute (BII) as a postdoctoral research fellow. He now leads his own group in BII after he was promoted to the position of Assistant Principal Investigator in 2021.

Dr. Yaw Sing Tan

Assistant Principal Investigator
Bioinformatics Institute (BII)
A*STAR

A Quantum Leap for Biomolecular Modelling?

The field of biomolecular modelling faces increasing challenges of scale and complexity. Longer time scales, modelling of larger and more complex systems, and the use of AI algorithms place huge demands on computing infrastructure. Quantum computing is a promising emerging technology that could address many of these challenges. In this talk, I discuss the potential for quantum computing to enable a dramatic advance in our understanding of complex biological phenomena through biomolecular modelling.

Dr. Dax Enshan Koh
Scientist I
Institute of High Performance Computing (IHPC)
A*STAR

Dax Enshan Koh is the Quantum Algorithms Lead at the Institute of High Performance Computing (IHPC), where he leads the Quantum Algorithms, Quantum Complexity, Quantum Error Mitigation and Benchmarking Domain of IHPC's Innovation Technology Area (ITA) for Quantum Computing. Dr Koh is a recipient and Principal Investigator of the A*STAR Science and Engineering Research Council (SERC) Central Research Fund (CRF) award for Use-Inspired Basic Research (UIBR). His research interests include quantum computation, quantum information theory, quantum foundations, and computational complexity theory. Previously, Dr Koh was a Z-Fellowship Postdoctoral Researcher at Zapata Computing, Inc. (Boston, MA, USA) and a recipient of A*STAR's National Science Scholarship (NSS BS-PhD). Dr Koh received the B.S. degree in Mathematics and Physics from Stanford University (Stanford, CA, USA); the M.Sc. degree in Physics from the University of Waterloo (Waterloo, ON, Canada) in conjunction with a Perimeter Scholars International certificate from the Perimeter Institute for Theoretical Physics (Waterloo, ON, Canada); and the Ph.D. degree in Mathematics from the Massachusetts Institute of Technology (Cambridge, MA, USA).

An Expressive Ansatz for Low-Depth Quantum Optimisation

The Quantum Approximate Optimisation Algorithm (QAOA) is a hybrid quantum-classical algorithm used to approximately solve combinatorial optimisation problems. It involves multiple iterations of a parameterised ansatz that consists of a problem and mixer Hamiltonian, with the parameters being classically optimised. While QAOA can be implemented on near-term quantum hardware, physical limitations such as gate noise, restricted qubit connectivity, and state-preparation-and-measurement (SPAM) errors can limit circuit depth and decrease performance. To address these limitations, this work introduces the eXpressive QAOA (XQAOA), a modified version of QAOA that assigns more classical parameters to the ansatz to improve the performance of low-depth quantum circuits. XQAOA includes an additional Pauli-Y component in the mixer Hamiltonian, thereby allowing the mixer to implement arbitrary unitary transformations on each qubit.

To benchmark the performance of the XQAOA ansatz at low depth, we derive its closed-form expression for the MaxCut problem and compare it to QAOA, Multi-Angle QAOA (MA-QAOA), a Classical-Relaxed (CR) algorithm, and the state-of-the-art Goemans-Williamson (GW) algorithm on a set of unweighted regular graphs with 128 and 256 nodes and degrees ranging from 3 to 10. Our results show that XQAOA performs better than QAOA, MA-QAOA, and the CR algorithm on all graphs and outperforms the GW algorithm on graphs with degrees greater than 4. Additionally, we find an infinite family of graphs for which XQAOA solves MaxCut exactly and show analytically that for some graphs in this family, special cases of XQAOA can achieve a larger approximation ratio than QAOA. Overall, XQAOA is a more viable choice for implementing quantum combinatorial optimisation on near-term quantum devices, as it can achieve better results with a single iteration, despite requiring additional classical resources. Based on: https://arxiv.org/abs/2302.04479.

Dr. Siong Thye Goh

Scientist I
Institute of High Performance Computing (IHPC)
A*STAR

Siong Thye Goh is a research scientist from the Institute of High Performance Computing (IHPC), a research institute under Singapore's Agency for Science, Technology and Research (A*STAR). Prior to joining IHPC, he was a research scientist with Singapore Management University's School of Computing and Information Systems. He works with QUBO solvers such as Digital Annealer and Alpha QUBO to solve optimization problems. Besides formulating problems into forms that are suitable to be solved by the mentioned solvers, he also studies how to enhance the quality of solvers and how to improve scalability. His current research interests include researching on complexity theory and studying the performance of variational models. His educational trajectory entails the conferment of a Ph.D. degree in Operations Research from the Massachusetts Institute of Technology. Additionally, he is trained in mathematics. He has received an M.Sc in Mathematics and a B.Sc in Applied Mathematics and Statistics from the National University of Singapore.

Exploring Quantum Computing for The Traveling Salesman

The search for an optimal sequence to optimize metric is a common problem in logistics. The well-known traveling Salesman Problem (TSP) exemplifies a combinatorial optimization problem. It is an NP-hard problem. Additionally, its application is prevalent in the field of logistics.

This talk commences with a scrutiny on various classical approaches associated with TSP. For instance, mixed integer programming formulations as well as state-of-the-arts approaches that have been utilized to solve problems. Subsequently, we will move on to annealing. Annealing is another approach that can be adopted to solve TSP. Specifically, we will be focusing on Quantum annealing. Next, technical difficulties that are usually omitted in literature will be addressed. Additionally, various techniques that can be applied to improve the quality of solutions will be shown. Besides the annealing approach, we will explore the possibility of using a gate-based approach to tackle TSP. Quantum Approximate Optimization Algorithm typifies gate-based approaches. Furthermore, a technique known as Quantum Alternating Operator will also be discussed. It is a handy technique that can be adopted to ensure feasibility. Lastly, different aspects to further optimize algorithms will be investigated before we summarise TSP's challenges and opportunities it engenders.

Poster Exhibition

Presenter	Title
Dr. Dasari Venkatakrishnarao (IMRE)	High K-Dielectric Metal Oxides for 2D Semiconductors Quantum Applications
Dr. Yvette Chow, Dr. Jiabin You (IHPC)	Design and Modelling of a TMDC Quantum Dot Qubit
Dr. Sarthak Das (IMRE)	Engineering Light-Matter Coupling in Superconducting Circuits with van der Waals Heterostructures
Dr. Zhiguang Cao (I^2R)	Learning to Solve Combinatorial Optimization Problems (COPs)
Dr. Cleaven Chia (IMRE)	Quantum Phononic Devices as Hybrid Interfaces with Spins and Light
Dr. Yaw Sing Tan (BII)	Potential of Quantum Computing for Computational Drug Discovery
Dr. Di Zhu (IMRE)	Integrated Quantum Photonics on Thin-Film Lithium Niobate
Dr. Amy Tong, Mr. Wing Wai Chung (IME)	Aluminium Nitride Integrated Photonics Platform for Quantum Applications
Dr. Thomas Vincent Produit (IMRE)	Infrared Microscopy with Visible Light
Dr. Dax Enshan Koh (IHPC)	An Expressive Ansatz for Low-Depth Quantum Optimisation
Mr. Muhammad Danial Afiq Bin Abdullah (IMRE)	Building a Non-Cryogenic Centimeter Scale Magnetometer with 10 fT/sqrt(Hz) Sensitivity in Earth's Field
Dr. Adrian Matthew Mak Weng Kin (IHPC)	Molecular Energies with Electron Correlation from Linear Depth Quantum Circuits
Dr. Aswin Alexander (IMRE), Dr. Yuriy Akimov (IHPC)	Loss Mechanisms in AlN Microring Resonators and Their Impact on Generation of Frequency Combs

Poster Exhibition

Presenter	Title
Dr. Thomas Ang, Dr. Ray Ng (IHPC)	Integrated Silicon Photodetector System: Design, Modeling and Simulation
Dr. Xuezhi Ma (IMRE)	Near-Field Seeing the Colorful Nano-World
Dr. Dmitry Kalashnikov (IMRE)	Interfacing of Carbon-Doped hBN Nanoflakes with Si3N4 Photonic Structures
Dr. Tao Wang (IMRE)	Next-Generation Quantum Sensors Based on Superconducting Levitated Ferromagnetic Particle
Dr. Yunlong Xiao (IHPC)	The Dynamical Uncertainty Principle Determines the Programmability of Quantum Processors
Dr. Aravind Padath Anthur (IMRE)	Demultiplexed Photon Pair Generation From a GaP Metasurface Enabled by Quasi-Bound States in the Continuum
Dr. Jun Young Khoo (IHPC)	Extraction of Hamiltonian Parameters from Quantum Ground States Using Variational Quantum Convolutional Neural Network
Dr. Fabio Bussolotti (IMRE)	Interlayer Hybridization in a van der Waals Quantum Spin-Hall Insulator/Superconductor Heterostructure
Dr. Kishor Bharti (IHPC)	Certifying Temporal Correlations
Dr. Calvin Wong Pei Yu (IMRE)	Towards Graphene Quantum Hall Resistance Standard
Dr. Huang Tian (IHPC)	When Quantum Annealing Meets Multitasking: Potentials, Challenges and Opportunities
Dr. Ivan Verzhbitskiy (IMRE)	Anisotropic 2D Semiconductors for Quantum Logic Devices
Dr. Bai Ping (IHPC)	Qubit Integrated Simulator (QBISim)

Poster Exhibition

Presenter	Title
Dr. Karthik Shreekumar (IMRE)	Integrated Avalanche Photodetectors for Visible-Light Photonics
Dr. Siong Thye Goh (IHPC)	Techniques to Enhance a QUBO Solver for Permutation-Based Combinatorial Optimization
Dr. Ewe Wei Bin, Dr. Fong Yew Leong (IHPC)	Variational Quantum Algorithms for Partial Differential Equations and Applications

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