1st International Workshop on Quantum Information Engineering (QIE2023)

Seaside House, Okinawa Institute of Science and Technology (OIST), Okinawa, Japan
11th – 13th October 2023

Program and Abstracts

Program at a glance

	11th October (Wed.)	12th October (Thu)	13th October (Fri.)
9:00-9:20		Session T1 Li (imec, Invited)	Session F1 Perumangatt (Toshiba, Research Europe, Invited)
9:20-9:40			
9:40-10:00		Kodera (Tokyo Tech. Invited)	Baeuml (IFCO)
10:00-10:20			Casapao (OIST)
10:20-10:40	10:30 Opening	Fujita (Osaka)	Maity (OIST)
10:40-11:00	Session W1 Lu (USTC, Invited, Online)	Coffee break	Coffee break
11:00-11:20		Session T2 Hodgson (U. Leeds)	Session F2 Ishi-Hayase (Keio, Invited)
11:20-11:40	Kochi (Keio)	Kondo (Kinki U)	
11:40-12:00	Kobayashi (U Tokyo)	Mishra (Banaras Hindu U)	Tian (OIST)
12:00-14:00	Lunch	Lunch	Lunch
14:00-14:20	Session W2 Trupke (Austrian Academy of Sciences, IQOQI-Vienna, Invited)	Session T3 Koshino (TMDU, Invited)	Session F3 Ishihara (QuTech, TU Delft, Invited)
14:20-14:40			
14:40-15:00	Reyes (YNU)	Azuma (NII)	Yamamoto (YNU)
15:00-15:20	Soeda (NII)	Backes (RIKEN)	Jennings (RIKEN)
15:20-15:40	Coffee break	Coffee break	Closing(-15:30)
15:40-16:00	Poster session	Session T4 Yamamoto (NEC, Invited)	
16:00-16:20			
16:20-16:40		Hays (MIT, Invited)	
16:40-17:00			
17:00-18:00	Free discussion	Free discussion	
18:00-20:00	Dinner	Banquet	
20:00-	Free discussion	Free discussion	

Overview

We are excited to have the 1st International Workshop on Quantum Information Engineering (QIE2023) organized by JSAP's Quantum Information Engineering Research Group and the Okinawa Institute of Science and Technology. This event will bring together fifty world-class scientists & engineering, researchers and students working in the field of quantum information engineering. They will present their latest research as well as engage in active discussions about the current state of the field and its future prospects. This workshop is co-organized by Okinawa Institute of Science and Technology (OIST) and Quantum Information Research Center, Yokohama National University and is supported by JSAP and JST.

Scope

Quantum computing,
Quantum networks,
Quantum algorithms,
Quantum simulations,
Quantum sensing,
Middleware,
Novel quantum systems for quantum devices.

Organizing committee

Chair: Akira Oiwa (Osaka University)
Shinichiro Fujii (Yokohama National University)
Masao Hirokawa (Kyushu University)
Satoshi Iwamoto (University of Tokyo)
Kenichi Kawaguchi (Fujitsu)
Hideo Kosaka (Yokohama National University)
Yuimaru Kubo (OIST)
Kae Nemoto (OIST & NII)
Nobuyuki Matsuda (Tohoku University)
Shiro Saito (NTT)
Shintaro Sato (Fujitsu)
Takashi Yamamoto (Osaka University)
Makoto Yamashita (Osaka University)

Invited speakers

Junko Hayase (Keio University)
"Quantum physics and sensing application of electron spin multi-resonance in diamond"
Max Hays (MIT)
"Bosonic error correction using a bit-flip-protected control qubit"

Ryoichi Ishihara (Qutech, TU Delft)

"Large-scale Integration of Modular Quantum Computer based on Diamond Spin Qubits"

Tetsuo Kodera (Tokyo Tech)

"Trends and prospects of silicon qubit research"

Kazuki Koshino (Tokyo Medial and Dental University)

"Swapping between superconducting and microwave-photon qubits by single reflection"

Ruoyu Li (imec)

"Solid state qubits with industrial CMOS technology"

Chao-Yang Lu (University of Science and Technology of China)

“Recent progress in optical quantum computing”

Chithrabhanu Perumangatt (Toshiba Research Europe Ltd)

"Enabling Real-time, high-rate quantum key distribution from satellite to ground"

Michael Trupke (Austrian Academy of Sciences, IQOQI-Vienna)

"Sensing and quantum photonics with spin centres in crystals"

Tsuyoshi Yamamoto (NEC)

"Quantum annealer based on Kerr parametric oscillators"

Presentations:

Invited talks: 40 min. including 5 min. discussion

Contributed talks: 20 min. including 5 min. discussion

Poster: The poster board size is W900 x H1200mm, equivalent to A0 size.

Meals

Breakfast: Provided on 12th and 13th October.

Lunch: Provided for all three days of the event.

Dinner: Provided on 11th October.

For attendees staying at the Seaside Hotel from 10th October, please note that you will need to make your own arrangements for dinner on the 10th and breakfast on the 11th October.

Baquet

The banquet will be held on the evening of October 12th, starting at 18:00. Attendees who have indicated their participation in the banquet on the registration form and have paid the banquet participation fee are eligible to join. Please make your banquet payment via the "イベントペイ" (EventPay) website before the workshop begins.

Taxi to between hotels and Seaside House

For those who stay at the hotels (Kafuu Resort Hotel and PERIDOT Smart Hotel), we have booked taxies for the transportation between the hotels and Seaside House. In the morning, the taxies leave Kafuu hotel at 10:00 on 11th Oct. and at 8:30 for the other days. The taxies will leave Seaside house at 20:30 to Kafuu Hotel.

Bus transportation to Naha Airport (13 Oct.)

After finishing the workshop, the bus transportation to Naha Airport will be available for free without reservation. The capacity of the bus is 50 persons, enough for almost all participants. The bus will leave Seaside House at 16:00 and will go to Naha Airport.

Homepage

https://groups.oist.jp/qist/1st-international-workshop-quantum-information-engineering-qie2023

Contact

In case of questions please contact: QIE2023@sanken.osaka-u.ac.jp

Program

	Day 1: 11th October (Wed.)
10:30	Opening address
	Session W1: Optical Quantum Computer
10:40-11:20	W1-1 (Invited) :“Recent progress in optical quantum computing” Chao-Yang Lu (University of Science and Technology of China), Online
11:20-11:40	W1-2: “Femtosecond photon echo measurements from broadband InAs quantum dot ensemble using frequency up-conversion single-photon detector” Yuta Kochi (Keio Universit), Yutaro Kinoshita (Keio University), Sunao Kurimura (NIMS), Kouichi Akahane (NICT), Junko Ishi-Hayase (Keio University)
11:40-12:00	W1-3: “Quantum reservoir probing as a witness for information scrambling” Kaito Kobayashi, Yukitoshi Motome (The University of Tokyo)
12:00-14:00	Lunch (Chura Hall)
	Session W2: Solid State Quantum Photonics
14:00-14:40	W2-1(Invited): “Sensing and quantum photonics with spin centres in crystals” Michael Trupke (Austrian Academy of Sciences, IQOQI-Vienna)
14:40-15:00	W2-2 “Quantum frequency conversion of entangled photons from NV center in diamond towards constructing long distances quantum repeater network” Raustin Reyes (Graduate School of Engineering Science, Yokohama National University), Shunsuke Mouri (Graduate School of Engineering Science, Yokohama National University), Ayumu Kobayashi (Yokohama National University), Akira Kamimaki (Quantum Information Research Center, Institute of Advanced Science, Yokohama National University), Yuhei Sekiguchi (Quantum Information Research Center, Institute of Advanced Science, Yokohama National University), Hiromitsu Kato (Quantum Information Research Center, Institute of Advanced Science, Yokohama National University, Advanced Power Electronics Research Center, AIST), Toshiharu Makino (Quantum Information Research Center, Institute of Advanced Science, Yokohama National University, Advanced Power Electronics Research Center,AIST), Fumihiro China - Advanced ICT Research Institute, NICT), Shigehito Miki (Quantum Information Research Center, Institute of Advanced Science, Yokohama National University, Advanced ICT Research Institute, NICT), Yu Mimura (Quantum Information Research Center, Institute of Advanced Science, Yokohama National University, Advanced Technologies R&D Laboratories, Furukawa Electric), Hideo Kosaka (Graduate School of Engineering Science, Yokohama National University, Quantum Information Research Center, Institute of Advanced Science, Yokohama National University)

15:00-15:20	W2-3 "Succinct assessment of 1-link-1-node system as a quantum-computer network component" Akihito Soeda (National Institute of Informatics)
15:20-15:40	Coffee break
15:40-17:00	**Poster session**
17:00-18:00	Free discussion
18:00-20:00	Dinner
20:00-	Free discussion

Day 2: 12th October (Thu.)

Session T1: Semiconductor Quantum Computing

9:00-9:40	T1-1 (Invited): "Solid state qubits with industrial CMOS technology" Ruoyu Li (imec)
9:40-10:20	T1-2 (Invited): "Trends and prospects of silicon qubit research" Tetsuo Kodera (Tokyo Tech.)
10:20-10:40	T1-3: "Speed-up of adiabatic quantum state transition in single-spin inversion" Xiao-Fei Liu (SANKEN, Osaka University), Takafumi Fujita (SANKEN, Osaka University), Yuta Matsumoto (SANKEN, Osaka University), Arne Ludwig (Ruhr U. Bochum), Andread D Wieck (Ruhr U. Bochum), Akira Oiwa (SANKEN, Osaka University)
10:40-11:00	Coffee break

Session T2: Novel Quantum Systems and Methodology

11:00-11:20	T2-1: "Modelling light with local photons" Daniel Hodgson (University of Leeds), Almut Beige (University of Leeds), Rob Purdy (University of Leeds), Mohammed Basil Altaie (Yarmouk University), Christopher Burgess (University of St Andrews)
11:20-11:40	T2-2: "Model Open System realized with Molecules in Solvent" Yasushi Kondo (Kindai University), Haruki Kiya (Kindai University), Shingo Kukita (National Defense Academy)
11:40-12:00	T2-3: "Quantum-enhanced super-sensitivity of Mach-Zehnder interferometer using squeezed Kerr state" Dhiraj Yadav, Gaurav Shukla, Priyanka Sharma, Devendra Kumar Mishra, (Banaras Hindu University, India)
12:00-14:00	Lunch (Chura Hall)

Session T3: Quantum Control, Measurement and Simulation

14:00-14:40	T3-1 (Invited): "Swapping between superconducting and microwave-photon qubits by single reflection" Kazuki Koshino (Tokyo Medical and Dental University)

14:40-15:00	T3-2: "The Leggett-Garg inequality with a deformed Pegg-Barnett phase operator for a dissipative boson system" Hiroo Azuma (National Institute of Informatics), William J. Munro (National Institute of Informatics), Kae Nemoto (Okinawa Institute of Science and Technology Graduate University)
15:00-15:20	T3-3: "Dynamical mean-field theory for the Hubbard-Holstein model on a quantum device" Steffen Backes (RIKEN), Yuta Murakami (RIKEN), Shiro Sakai (RIKEN), Ryotaro Arita (Tokyo University & RIKEN)
15:20-15:40	Coffee break
	Session T4: Superconducting Quantum Computing
15:40-16:20	T4-1 (Invited): "Quantum annealer based on Kerr parametric oscillators" Tsuyoshi Yamamoto (NEC, AIST)
16:20-17:00	T4-2 (Invited): "Bosonic error correction using a bit-flip-protected control qubit" Max Hays (MIT)
17:00-18:00	Free discussion
18:00-	Banquet (Chura Hall)
	Day 3: 13th October (Fri.)
	Session F1: Quantum Communication
9:00-9:40	F1-1 (Invited): "Enabling Real-time, high-rate quantum key distribution from satellite to ground" Chithrabhanu Perumangatt (Toshiba Research Europe Ltd.)
9:40-10:00	F1-2: "Security of discrete-modulated continuous-variable quantum key distribution" Stefan Baeuml, Carlos Pascual, Rotem Liss, Antonio Acin (ICFO, Spain)
10:00-10:20	F1-3: Noise estimation in an entanglement distillation protocol Ananda G. Maity (OIST), Joshua C. A. Casapao (OIST), Naphan Benchasattabuse (Keio University SFC), Michal Hajdušek (Keio University SFC), Rodney Van Meter (Keio University SFC), David Elkouss (OIST)
10:20-10:40	F1-4: Noise is resource contextual in quantum communication Aditya Nema (RWTH, Germany), Ananda G Maity (OIST, Japan), Sergii Strelchuk (University of Cambridge, UK), David Elkouss (OIST, Japan)
10:40-11:00	Coffee break
	Session F2: Quantum Sensing
11:00-11:40	F2-1 (Invited): "Quantum physics and sensing application of electron spin multi-resonance in diamond" Junko Ishi-Hayase (Keio University)
11:40-12:00	F2-2: Feedback cooling of magnetically-levitated cm-size resonators

	James E. Downes (Macquarie University), Glemarie C. Hermosa (Yuan Ze University), Alexander H. Hodges (OIST), Krishna Jadeja (OIST), Daehee Kim (OIST), Ruvindha Lecamwasam (OIST), Camila P. C. Padilla (OIST), Shiu Tian (OIST), Jason Twamley (OIST)
12:00-14:00	Lunch (Chura Hall)
	Session F3: Novel Quantum Computing Systems
14:00-14:40	F3-1 (Invited): "Large-scale Integration of Modular Quantum Computer based on Diamond Spin Qubits" Ryoichi Ishihara (QuTech, Dep. Quantum and Computer Engineering, Delft University of Technology)
14:40-15:00	F3-2: "Research on diamond mechanical wave resonators for quantum interfaces" Moyuki Yamamoto (Grad. Sch. Eng., Yokohama Natl. Univ.), Hodaka Kurokawa (IAS, Yokohama Natl. Univ.), Hideo Kosaka (Grad. Sch. Eng., Yokohama Natl. Univ.,IAS, Yokohama Natl. Univ.)
15:00-15:20	F3-3: "Blueprint for quantum computing using electrons on helium" Asher Jennings (RIKEN), Ivan Grytsenko (RIKEN), Oleksiy Rybalko (RIKEN), Yiran Tian (RIKEN), Rajesh Mohan (RIKEN), Erika Kawakami (RIKEN)
15:20-15:30	Closing

Posters

P1: “Evanescent field mediated Rydberg interactions via an Optical nanofiber”
Aswathy Raj – OIST; Alexey Vylegzhanin - OIST; Dylan Brown -OIST; Danil F. Kornovan - Center for Complex Quantum Systems, Department of Physics and Astronomy, Aarhus University, Ny Munkegade 120, DK-8000 Aarhus C, Denmark; Jesse L. Everett - OIST; Etienne Brion - Laboratoire Collisions Agr´egats R´eactivit´e, UMR5589, Universit´e Toulouse III Paul Sabatier, CNRS, F-31062 Toulouse Cedex 09, France; Jacques Robert - Universit´e Paris-Saclay, CNRS, Laboratoire de Physique des Gaz et des Plasmas, 91405 Orsay, France; Sile Nic Chormaic - OIST.

P2: “Emergent topological properties in Kronig -Penney type models”
Sarika Sasidharan Nair, Giedrius Zlabys, Wen-bin He, Thomas Fogarty, and Thomas Busch- OIST.

P3: “Resource reduction in an error correction code using quantum multiplexing”
Nicolo Lo Piparo – OIQT, Shin Nishio - Quantum Information Science and Technology Unit, OIST, Department of Informatics, School of Multidisciplinary Sciences, SOKENDAI (The Graduate University for Advanced Studies), National Institute of Informatics, William J. Munro - Quantum Information Science and Technology Unit, OIST, Kae Nemoto - Quantum Information Science and Technology Unit, OIST, Department of Informatics, School of Multidisciplinary Sciences, SOKENDAI (The Graduate University for Advanced Studies), National Institute of Informatics.

P4: “Resonant image charge detection for e-@He qubit”
Mikhail Belianchikov - Okinawa Institute of Science and Technology, Natalia Morais - Okinawa Institute of Science and Technology, Denis Konstantinov - Okinawa Institute of Science and Technology.

P5: “An RFSoC-based Arbitrary Waveform Generator for Coherent Control of Atomic Qubits”
R. Ohira - QuEL, Inc., T. Miyoshi - QuEL, Inc., e-trees.Japan, Inc., QIQB, K. Maetani - Osaka University, T. Oshio - Osaka University, K. Koike - e-trees.Japan, Inc., S. Morisaka - QuEL, Inc., QIQB, K. Miyanishi - QIQB, Osaka University, T. Kobayashi - QIQB, Osaka University, K. Hayasaka - NICT, U. Tanaka - QIQB, Osaka University, K. Toyoda - QIQB, M. Negoro - QuEL, Inc., QIQB

P6: “Massive quantum superpositions using superconducting magneto-mechanics”
Sarath Raman Nair - Macquarie University; Shiu Tian - OIST; Gavin K. Brennen - Macquarie University; Sougato Bose - University College London; Jason Twamley – OIST

P7: “Structured nanofiber-based application”
Zohreh Shahrabifarahani -OIST Graduate University, Maki Maeda- OIST Graduate University

P8: “Fabrication and optical characterization of air-bridged diamond photonic crystal cavities”

Koudai Iijima - RCAST U-Tokyo; Satomi Ishida - RCAST U-Tokyo; Hidetsugu Matsukiyo - IIS U-Tokyo; Sangmin Ji - IIS U-Tokyo; Hideo Otsuki - RCAST U-Tokyo; Masao Nishioka - IIS U-Tokyo; Toshiharu Makino - AIST; Hiromitsu Kato - AIST; Satoshi Iwamoto - RCAST U-Tokyo, IIS U-Tokyo

P9: "Detecting and Controlling Weakly Coupled Nuclear Spins of NV Center under a Zero Magnetic Field: A Theoretical Study"
Naoya Egawa - Tohoku University, Shiro Tamiya - Tokyo University, Kansei Watanabe - Yokohama National University, Joji Nasu - Tohoku University, Hideo Kosaka - Yokohama National University

P10: "Tailoring light-atom interaction using optical waveguides"
Wenfang Li-OIST; Jinjin Du-OIST; Chris Wilson-Waterloo University; Michal Bajcsy-Waterloo University; Sile Nic Chormaic-OIST

P11: "The influence of light irradiation the transport properties of SiGe/Ge heterostructure devices"
Gabriel Gulak Maia - Osaka University

P12: "The effect of storage and readout resonator coupling on the tomography of a bosonic qubit"
Kosuke Mizuno - NTT Basic Research Laboratories; Takaaki Takenaka - NTT Basic Research Laboratories; Imran Mahboob - NTT Basic Research Laboratories; Shiro Saito - NTT Basic Research Laboratories

P13: "Two-dimensional photonic crystal nanocavity with quantum dots integrated on a glass-clad Si waveguide using transfer printing"
Akinari Fujita – Keio University; Natthajuks Pholsen – RCAST, Tokyo University; Ryusei Kawata – Keio University; Sangmin Ji – RCAST, Tokyo University; Toshihiro Kamei – AIST; Makoto Okano – AIST; Satoshi Iwamoto – RCAST, Tokyo University; Yasutomo Ota – Keio University

P14: "Wide-field imaging of complex amplitude of AC magnetic field utilizing RF-dressed states of electron spins in diamond"
Fuki Otsubo - Keio University; Takumi Mikawa - Keio University; Yuichiro Matsuzaki - AIST; Norio Tokuda - Kanazawa University; Norikazu Mizuochi - Kyoto University; Junko Ishi-Hayase

Abstracts

Session W1: Session W1 Optical Quantum Computer (10:40-12:00, Wednesday, 11th October)

W1-1 (Invited): “Recent progress in optical quantum computing”

Chao-Yang Lu, University of Science and Technology of China,

Since the early 1980s, the field of quantum computing has witnessed significant progress, from the conceptual foundations proposed by Benioff, Feynman, and others to the establishment of universal quantum Turing machines by Deutsch, as well as the development of key algorithms like Shor's factorization and quantum error correction. A primary challenge in this field has been the quest for a reliable physical system capable of scalable and high-precision manipulation of quantum bits (qubits), ultimately leading to the realization of a quantum computer surpassing classical capabilities.

Our research in the semiconductor system has introduced techniques such as pulsed resonant excitation technology (He Nature Nanotechnology 2013), enabling deterministic and highly indistinguishable single-photon emission. Additionally, we achieved microcavity coupling technology with high Purcell factors (Ding PRL 2016), asymmetrically cavity-coupled quantum dots (Wang Nature Photonics 2019), and dual-color resonant coherent excitation schemes (He Nature Physics 2019). These enabled successful development of deterministic single-photon sources characterized by high purity, indistinguishability, polarization control, and efficiency, all simultaneously.

Leveraging these achievements, we created a quantum computing prototype named "Jiuzhang," consisting of 76 photons, and demonstrated "quantum computational advantage" using photons (Zhong Science 2020). Furthermore, we proposed stimulated photon amplification schemes and constructed Jiuzhang 2.0 with 113 photons and Jiuzhang 3.0 with 255 photons, introducing phase programming capabilities (Zhong PRL 2021). Building upon the foundation of "Jiuzhang," we successfully solved practical graph theory problems such as dense subgraph and Max-Haf (Deng PRL 2023).

These advancements pave the way for further stages in the evolution of optical quantum computing, including the realization of specialized quantum simulators and the ultimate goal of programmable universal quantum computers with the ability to manipulate millions of qubits.

W1-2: “Femtosecond photon echo measurements from broadband InAs quantum dot ensemble using frequency up-conversion single-photon detector”

Yuta Kochi (Keio Universit), Yutaro Kinoshita (Keio University), Sunao Kurimura (NIMS), Kouichi Akahane (NICT), Junko Ishi-Hayase (Keio University)

Recently, quantum communications and quantum computing using single-photon have gathered much attention. For increase a temporal density of qubits, it is necessary to implement broadband quantum memory. Photon echo in an inhomogeneous two-level system provides a powerful tool to realize broadband quantum memory. However, conventional photon-echo-based quantum memories, such as those using rare-earth ions, have inhomogeneous broadening of approximately MHz, and the pulse width of the signal photons that can be stored is suppressed to the microsecond order. In addition, in conventional electronic single photon detectors such as Si APD and SNSPD, the dead time and the temporal resolution were limited to ~10 ns and ~50 ps, respectively. These specifications limited the pulse interval of measurable qubits to nanosecond order. To solve these problems, we have demonstrated a photon-echo-based quantum memory using a self-assembled InAs quantum dot ensemble and a single-photon detector using a frequency up-conversion technique. Our quantum memory has a bandwidth of 7.2 THz owing to the large inhomogeneous broadening of quantum dots and enables femtosecond pulse storage. In addition, our pulse-pumped Up-Conversion Single-Photon Detector (UCSPD) enables us to achieve the femtosecond scale temporal resolution and dead-time-free measurement. To combine these devices, we successfully demonstrated femtosecond time-bin pulse transfer and evaluated the relative phase of time-bin photon echo signals.

W1-2: “Quantum reservoir probing as a witness for information scrambling”

Kaito Kobayashi - the University of Tokyo; Yukitoshi Motome - the University of Tokyo

Quantum information scrambling refers to the dynamical phenomenon of initially localized quantum information spreading throughout a system [1]. Recently, scrambling has been quantified using out-of-time-order correlators and tripartite mutual information; however, these measures only indicate the presence or absence of scrambling and provide limited insight into how information is scrambled in the Hilbert space and time. In this study, by extending the idea of quantum reservoir computing, we propose a new framework, quantum reservoir probing (QRP), that allows for direct tracing of the dynamics of information propagation in quantum systems [2]. By scanning the read-out operators employed in the QRP, we can estimate the dynamical distribution of information across multiple degrees of freedom, probing relevant information propagation channels. Indeed, in the quantum Ising chain with transverse and longitudinal magnetic fields, the QRP has deduced two distinct types of information propagation: quasiparticle-mediated propagation in an integrable free fermion system and correlation-mediated scrambling in a quantum chaotic system. Our study provides an efficient approach for further exploration of the dynamics of quantum information in a plethora of exotic quantum many-body systems.

[1] P. Hayden et al., J. High Energy Phys. 09 (2017) 120.
[2] K. Kobayashi et al., arXiv:2308.00898.

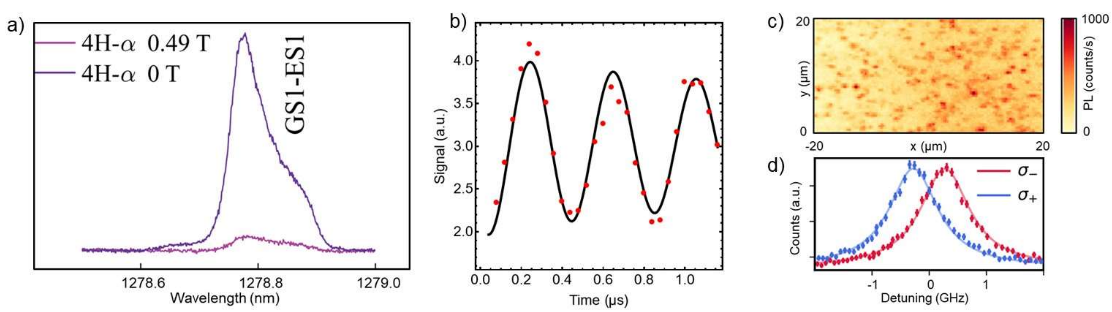
Session W2: Solid State Quantum Photonics (14:00-15:20, Wednesday, 11th October))

W2-1(Invited): "Sensing and quantum photonics with spin centres in crystals"

Michael Trupke (Austrian Academy of Sciences, IQOQI-Vienna, Boltzmanngasse 3, 1090 Vienna, Austria)

Spin centres in crystals, particularly in diamond and silicon carbide (SiC), have emerged as a key platform for the development of quantum technology. The nitrogen-vacancy (NV) centre in diamond has spearheaded this development, chiefly towards devices for quantum sensing. Their sensitivity is in part limited by the spin contrast and by the collection of photoluminescence. I will present a method to improve the spin contrast by tailoring the optical initialization to the NV's ionization cycle[1]. I will also describe progress on electrical readout, which allows to circumvent optical collection, with a view to enhanced state readout[2].

For quantum photonics, other systems are being explored in search of better optical properties. In many cases, their performance is significantly reduced by wavelength conversion from the telecom range to the optical transition frequency of the atoms or defects[3]. Vanadium in SiC has emerged as a strong candidate for these applications[4–9]: It has a strong optical transition at 1.3 μm, compatible with optical fiber networks, a long-lived electron spin, and is hosted in a material that is available with high quality at an industrial scale. Our investigations have resulted in significant advances in our understanding of this remarkable system, the control of its electron spin, and the development of photonic interfaces for quantum networks10. Furthermore, we have shown that vanadium can be used as an extremely sensitive probe for the crystalline structure and electronic properties of the silicon carbide host.



a) Spectrum of an ensemble of neutral vanadium (V^{4+}) α in 4H SiC at 100 mK[7]. b) Ensemble Rabi oscillations at 0.4 K (unpublished). c) Photoluminescence map of V^{4+} α defects in 4H SiC[9]. d) Spin-dependent optical excitation of a single V^{4+} spin centre[9].

References

1. D. WIRTITSCH et al., "Exploiting ionization dynamics in the nitrogen vacancy center for rapid, high-contrast spin, and charge state initialization," Phys. Rev. Research 5 1, 013014 (2023); https://doi.org/10.1103/PhysRevResearch.5.013014.
2. M. GULKA et al., "Room-temperature control and electrical readout of individual nitrogen-vacancy nuclear spins," Nat Commun 12 1, 4421 (2021); https://doi.org/10.1038/s41467-021-24494-x.
3. S. WEI et al., "Towards Real-World Quantum Networks: A Review," Laser & Photonics Reviews 16 3, 2100219 (2022); https://doi.org/10.1002/lpor.202100219.
4. L. SPINDLBERGER et al., "Optical Properties of Vanadium in 4 H Silicon Carbide for Quantum Technology," Phys. Rev. Applied 12 1, 014015 (2019); https://doi.org/10.1103/PhysRevApplied.12.014015.
5. C. M. GILARDONI et al., "Hyperfine-mediated transitions between electronic spin-1/2 levels of transition metal defects in SiC," New J. Phys. 23 8, 083010 (2021); https://doi.org/10.1088/1367-2630/ac1641.
6. B. TISSOT et al., "Nuclear spin quantum memory in silicon carbide," Phys. Rev. Research 4 3, 033107 (2022); https://doi.org/10.1103/PhysRevResearch.4.033107.

7. T. ASTNER et al., "Vanadium in Silicon Carbide: Telecom-ready spin centres with long relaxation lifetimes and hyperfine-resolved optical transitions," arXiv (2022); https://doi.org/10.48550/ARXIV.2206.06240.
8. J. HENDRIKS et al., "Coherent spin dynamics of hyperfine-coupled vanadium impurities in silicon carbide," arXiv (2022); https://doi.org/10.48550/ARXIV.2210.09942.
9. P. CILIBRIZZI et al., "Ultra-narrow inhomogeneous spectral distribution of telecom-wavelength vanadium centres in isotopically-enriched silicon carbide," arXiv (2023); https://doi.org/10.48550/ARXIV.2305.01757.
10. J. FAIT et al., "High finesse microcavities in the optical telecom O-band," Appl. Phys. Lett. 119 22, 221112 (2021); https://doi.org/10.1063/5.0066620.

W2-2: "Quantum frequency conversion of entangled photons from NV center in diamond towards constructing long distances quantum repeater network"

Raustin Reyes (Graduate School of Engineering Science, Yokohama National University), Shunsuke Mouri (Graduate School of Engineering Science, Yokohama National University), Ayumu Kobayashi (Yokohama National University), Akira Kamimaki (Quantum Information Research Center, Institute of Advanced Science, Yokohama National University), Yuhei Sekiguchi (Quantum Information Research Center, Institute of Advanced Science, Yokohama National University), Hiromitsu Kato (Quantum Information Research Center, Institute of Advanced Science, Yokohama National University, Advanced Power Electronics Research Center, AIST), Toshiharu Makino (Quantum Information Research Center, Institute of Advanced Science, Yokohama National University, Advanced Power Electronics Research Center,AIST), Fumihiro China - Advanced ICT Research Institute, NICT), Shigehito Miki (Quantum Information Research Center, Institute of Advanced Science, Yokohama National University, Advanced ICT Research Institute, NICT), Yu Mimura (Quantum Information Research Center, Institute of Advanced Science, Yokohama National University, Advanced Technologies R&D Laboratories, Furukawa Electric), Hideo Kosaka (Graduate School of Engineering Science, Yokohama National University, Quantum Information Research Center, Institute of Advanced Science, Yokohama National University)

Quantum communication is being researched and developed worldwide. Quantum key distribution (QKD) has recently been demonstrated over distances exceeding 600 km[1]. The nitrogen-vacancy (NV) center in diamond is a candidate that can realize quantum repeater. It is necessary to perform quantum frequency conversion of entangled photons to the telecommunication wavelength band (C-band) to extend the communication distance. In this study, we have performed quantum frequency conversion of entangled photons to C-band. The entangled photons were input into the periodically-poled LiNbO3 waveguide and were converted to 1550 nm photons. The wavelength-converted photons were then input into a 10 km C-band fiber, and the signals were detected by the superconducting single-photon detector.

This work is supported by a Japan Science and Technology Agency (JST) Moonshot R&D grant (JPMJMS2062) and by a JST CREST grant (JPMJCR1773). We also acknowledge the Ministry of Internal Affairs and Communications (MIC) for funding, research and development for construction of a global quantum cryptography network (JPMI00316) and the Japan Society for the Promotion of Science (JSPS) Grants-in-Aid for Scientific Research (20H05661, 20K20441).

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W2-3: "Succinct assessment of 1-link-1-node system as a quantum-computer network component"

Akihito Soeda- National Institute of Informatics

Global operations between network nodes are crucial to achieve any benefit of quantum computation. We have to design the individual network components appropriately so that they function as a single large quantum system when connected together. How to assess quantumness of a single device when composed to form a large network? How to do so with as little experimental resources as possible? We explore the case of remote CNOT gate utilizing one Bell state and discuss how we can reduce the assessment complexity with respect to full quantum tomography.

Session T1: Semiconductor Quantum Computing (9:00-10:40, Thursday, 12th October)

T1-1 (Invited): "Solid state qubits with industrial CMOS technology"

Ruoyu Li (Imec)

Useful quantum computing applications require a physical qubit number beyond a million scale. Large qubit arrays need improvements in material quality and the fabrication process for good and uniform qubits, as well as layout optimization for an efficient analog control interface and qubit interconnect. Towards this end, we leverage the know-how of CMOS technology for scaling and integrate superconducting qubits and silicon spin qubits with advanced manufacturing technology. The advanced process control in a 300 mm fab can result in an ultra-clean interface and uniform performance, providing new insight into material properties, controlling circuits, and upscaling possibilities. We will discuss the potential and constraints for qubit manufacturing with an industrial fab line and take a deep dive into the spin qubit platform. Through full gate stack optimization, we achieve ultra-low charge noise environments and develop a microscopic model for the noise mechanism as well as future optimization directions. In addition to qubit fabrication, we utilize CMOS device and circuit technologies to gain a deeper understanding of the qubit device and develop novel cryogenic control protocols.

T1-2 (Invited): "Trends and prospects of silicon qubit research"

Tetsuo Kodera (Tokyo Tech)

Spins in silicon quantum dots are one of the promising candidates for implementing quantum bits (qubits) for quantum computers because of their long coherence times and compatibility with mature silicon technology. In this talk, I will first provide an overview of the basic knowledge of silicon qubits. Then I will introduce global research and development trends related to high fidelity, qubit integration, and various peripheral technologies. I will also discuss silicon qubit devices we have fabricated so far, as well as our research results in charge detection, spin blockade, spin manipulation, RF reflectometry, and so on[1-15].

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T1-3: “Speed-up of adiabatic quantum state transition in single-spin inversion”

Xiao-Fei Liu (SANKEN, Osaka University), Takafumi Fujita (SANKEN, Osaka University), Yuta Matsumoto (SANKEN, Osaka University), Arne Ludwig (Ruhr U. Bochum), Andread D Wieck (Ruhr U. Bochum), Akira Oiwa (SANKEN, Osaka University)

Switching quantum states from one eigenstate to the other has become a basic preparation procedure for qubit inversion, or spatially transferring charge or spin states at a distance. In such procedures, adiabatic operation, or transition-less condition, makes the quantum state resilient to noise compared to coherent operations by having the state vector follow the intermediate eigenstates during the state switching. A straightforward technique to achieve adiabaticity is to tilt the interaction vector in the Block sphere from pointing the initial state and to the final state sufficiently slow compared to the interaction strength. Here, we experiment on the speed-up of adiabatic passage for the inversion of spin qubit. The time dependence of the required interaction vector trajectory can be theoretically calculated, which acts as the counter-diabatic driving. We applied this counter-diabatic driving for the single electron spin resonance by controlling the interaction vector in two axes using the in-phase and quadrature components of the microwave. As a result, the speed-up of the transition was observed as more than twice, depending on the aimed fidelity. In addition, we found that the counter-diabatic driving can be manually modified to mitigate the resonance broadening due to the random nuclear spins in GaAs quantum dots, which resulted in inversion fidelities as high as 97.8 %. These speed-up and findings will be useful to implement together in future qubit operations.

Session T2: Novel Quantum Systems and Methodology (11:00-12:00, Thursday, 12th October)

T2-1: “Modelling light with local photons”

Daniel Hodgson (University of Leeds), Almut Beige (University of Leeds), Rob Purdy (University of Leeds), Mohammed Basil Altaie (Yarmouk University), Christopher Burgess (University of St Andrews)

Single-photon wave packets are the fundamental building blocks of the electromagnetic field, and are an important resource in an extensive array of quantum technologies. Despite their particle-like nature, photons can be systematically generated with a large amount of control over both their spatial and time-like properties. In order to fully characterise these states, quantum physicists routinely make use of a variety of representations to describe single photons. Whilst normally defined in a basis of monochromatic energy eigenstates, due to the local nature of many interacting systems there is also need to introduce a formalism for localised single-photon wave packets. The aim of my current research has been to construct a localised basis for single-photon wave packets thereby overcoming a long history of difficulties concerning photon localisation. This theory goes beyond standard approaches by extending the usual photon Hilbert space and differentiating between localised photons and localised field observables. In this talk I shall present a description of localised photons in one dimension and discuss how localised photons in a cavity leads to an alternative picture of the Casimir effect.

T2-2: "Model Open System realized with Molecules in Solvent"

Yasushi Kondo (Kindai University), Haruki Kiya (Kindai University), Shingo Kukita (National Defense Academy)

An open quantum system is now attracting much attention because devices such as quantum computers and quantum sensors are emerging. These devices cannot be perfect closed systems and thus it is important to understand their nature as open systems for developing them. However, most of the studies are theoretical, and experimental ones have only recently emerged. These experiments employed well-isolated systems, such as ultra-cold atoms. Here, we introduce another system, or molecules in isotropic liquids, in order to study open systems.

An interaction between molecule spins (System) and isotropic solvents (the environment) is often weak: spins' T1s are often more than 10 s. Therefore, these spins are approximately isolated. Further, the spins in the molecule may be divided into two Systems I and II. System II works as an environment of System I and thus we can prepare various virtual environments. We may add magnetic impurities into the solvent and can introduce another controlled environment, too. We experimentally studied spin dynamics in various environments and the dynamics of an entangled sensor in noisy environments. These dynamics were also analyzed by using the GKSL equation. We are now studying spin dynamics in more realistic environments realized by only System II.

T2-3: "Quantum-enhanced super-sensitivity of Mach-Zehnder interferometer using squeezed Kerr state"

Dhiraj Yadav, Gaurav Shukla, Priyanka Sharma, Devendra Kumar Mishra, (Banaras Hindu University, India)

We study the phase super-sensitivity of a Mach-Zehnder interferometer (MZI) with the squeezed Kerr and coherent states as the inputs. We discuss the lower bound in phase sensitivity by considering the quantum Fisher information (QFI) and corresponding quantum Cramer-Rao bound (QCRB). With the help of single intensity detection (SID), intensity difference detection (IDD) and homodyne detection (HD) schemes, we find that our scheme gives better sensitivity in both the lossless as well as in lossy conditions as compared to the combination of well-known results of inputs as coherent plus vacuum, coherent plus squeezed vacuum and double coherent state as the inputs. Because of the possibility of generation of squeezed Kerr state (SKS) with the present available quantum optical techniques, we expect that SKS may be an alternative nonclassical resource for the improvement in the phase super-sensitivity of the MZI under realistic scenario. This work is published in arXiv:2309.04731 [quant-ph].

Session T3: Quantum Control, Measurement and Simulation (14:00-15:20, Thursday, 12th October)

T3-1 (Invited): "Swapping between superconducting and microwave-photon qubits by single reflection"

Kazuki Koshino (Tokyo Medical and Dental University)

The number of superconducting qubits contained in a single quantum processor is increasing steadily. However, to realize a truly useful quantum computer, it is inevitable to increase the number of qubits much further by distributing quantum information among distant processors using flying qubits. One of the key element towards this goal is a SWAP gate between the superconducting-atom and microwave-photon qubits. Here, we demonstrate the swapping between the atom and photon qubits by confirming the bidirectional quantum-state transfer between them. The working principle of this gate is the single-photon Raman interaction, which results from strong interference in waveguide QED setups and enables a high gate fidelity insensitively to the pulse shape of the photon qubit, by simply bouncing the photon qubit at a cavity attached to the atom qubit. The averaged fidelity of the photon-to-atom (atom-to-photon) state transfer reaches 0.829 (0.801), limited mainly by the energy relaxation time of the atom qubit. The present atom-photon gate, equipped with an in situ tunability of the gate type, would enable various applications in distributed quantum computation using superconducting qubits and microwave photons.

T3-2: "The Leggett-Garg inequality with a deformed Pegg-Barnett phase operator for a dissipative boson system"

Hiroo Azuma (National Institute of Informatics), William J. Munro (National Institute of Informatics), Kae Nemoto (Okinawa Institute of Science and Technology Graduate University)

We study the Leggett-Garg inequality for a boson system whose observable is given by deforming the Pegg-Barnett phase operator and show that the quantum Fourier transform is useful for the required measurement. The Leggett-Garg inequality (LGI) is the temporal analogue of Bell's inequality. The LGI was proposed to determine how well the following two assumptions work: (1) macroscopic realism and (2) non-invasive measurability. Because the LGI is obtained from correlations of the system observed at different times, it must be obtained using quantum non-demolition (QND) measurements. In this work, we explore the LGI for a boson system weakly coupled to a zero-temperature environment with various decay rates and a specific frequency of the boson system. To compute the LGIs, we assume that the initial states of the system are given by coherent states. Introducing dissipation to the boson system, we show that the violation of the LGI decreases rapidly as the time difference between the measurements increases. We also estimate errors and imperfections in the measurement of the deformed Pegg-Barnett phase operator with a circuit of the quantum Fourier transform.

T3-3: "Dynamical mean-field theory for the Hubbard-Holstein model on a quantum device"

Steffen Backes (RIKEN), Yuta Murakami (RIKEN), Shiro Sakai (RIKEN), Ryotaro Arita (Tokyo University & RIKEN)

Recent developments in quantum hardware and quantum algorithms have made it possible to utilize the capabilities of current noisy intermediate-scale quantum devices for addressing problems in quantum chemistry and condensed-matter physics. Here we report a demonstration of solving the dynamical mean-field theory (DMFT) impurity problem for the Hubbard-Holstein model on the IBM Quantum Processor Kawasaki, including self-consistency of the DMFT equations. This opens up the possibility to investigate strongly correlated electron systems coupled to bosonic degrees of freedom and impurity problems with frequency-dependent interactions. The problem involves both fermionic and bosonic degrees of freedom to be encoded on the quantum device, which we solve using a recently proposed Krylov variational quantum algorithm to obtain the impurity Green's function. We find the resulting spectral function to be in good agreement with the exact result, exhibiting both correlation and plasmonic satellites and significantly surpassing the accuracy of standard Trotter-expansion approaches. Our results provide an essential building block to study electronic correlations and plasmonic excitations on future quantum computers with modern ab initio techniques.

Session T4: Superconducting Quantum Computing (15:40-17:00, Thursday, 12th October)

T4-1 (Invited): "Quantum annealer based on Kerr parametric oscillators"

Tsuyoshi Yamamoto, Secure System Platform Research Laboratories, NEC Corporation, [2]NEC-AIST Quantum Technology Cooperative Research Laboratory, National Institute of Advanced Industrial Science and Technology (AIST)

Josephson parametric oscillator is a superconducting driven oscillator, in which the resonance frequency is modulated at twice of it with a modulation amplitude larger than a threshold. The oscillation states of a JPO composed of two different states with the same amplitude but opposite phase (0π or 1π) can be used as two basis states of a qubit [1, 2]. In this talk, I will show our study on the basic physical properties of a JPO toward the realization of a quantum annealing machine, which includes the realization of JPO in a single-photon Kerr regime, called Kerr parametric oscillator [3], observation of correlated parametric oscillation in coupled KPOs [4], and spectroscopy of KPO under two-photon drive [5].

This work is based on results obtained from a Project, Project No. JPNP16007, commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

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T4-2 (Invited): "Bosonic error correction using a bit-flip-protected control qubit”

Max Hays (MIT)

Bosonic quantum error correction (QEC) involves encoding information in the phase space of a quantum harmonic oscillator, and offers a hardware-efficient path towards fault-tolerant quantum information processing. In superconducting circuits, bosonic QEC has been achieved using 3D cavity resonators controlled via fixed-frequency transmon qubits [1-4]. However, all previous demonstrations have been limited by bit-flips in the transmon control qubit (with typical T_1 lifetimes on the order of 100 microseconds), resulting in logical lifetimes that are upper-bounded by approximately ~10T_1. We propose replacing the transmon with a heavy fluxonium qubit, which has been shown to possess T_1 lifetimes in excess of 1 millisecond [5-7]. In this talk, I will discuss two ongoing experiments: the first aims to embed a fluxonium qubit within a 3D superconducting cavity, while the second seeks to perform error correction of an on-chip superconducting resonator using an accelerated error correction technique.

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Session F1: Quantum Communication (9:00-10:40, Friday, 13th October))

F1-1 (Invited): “Enabling Real-time, high-rate quantum key distribution from satellite to ground”

Chithrabhanu Perumangatt (Toshiba Research Europe Ltd)

Global quantum networks are essential to ensure the security of current and future communications. Toshiba has been developing industry leading commercial quantum key distribution systems which are already installed in terrestrial telecommunication networks. Although such fibre links can distribute secret keys between nodes separated by hundreds of kilometres, satellite links are necessary to ensure global connectivity. In this talk, I will give an overview of our approach towards satellite-based quantum communication. We have developed a quantum transmitter that can generate polarization-encoded weak coherent state for decoy state BB84 protocol at a clock rate of 1GHz. This transmitter, along with a quantum receiver, is used to demonstrate real-time generation of quantum keys over an emulated satellite pass. The post-processing of QKD is done instantly via two-way classical communication using telecom lasers that co propagate with the quantum channel. To simulate a realistic satellite to ground link, random misalignments are introduced at the transmitter and receiver. In order to rectify the random misalignment, we implement a fine pointing and tracking system, which includes a beacon laser, a fast-steering mirror, and a camera, to minimize errors. We have achieved a secret key generation of >4.5 Mbits during an emulated satellite pass considering moderate telescope apertures. We anticipate our system to set the stage for practical implementations of intercontinental quantum secure communications and integration to the growing fibre-based terrestrial quantum network.

F1-2: “Security of discrete-modulated continuous-variable quantum key distribution”

Stefan Baeuml, Carlos Pascual, Rotem Liss, Antonio Acin (ICFO, Spain)

Continuous variable quantum key distribution with discrete modulation has the potential to provide quantum physical security using commercial optical elements and existing telecom infrastructure, while allowing for the use of well studied error correction protocols. However, proving finite-key security against coherent attacks poses a challenge. In this work we apply the generalised entropy accumulation theorem, a tool that has previously been used in the setting of discrete variables, to prove security against coherent attacks in the finite regime for a discretely modulated QKD protocol involving heterodyne detection and four coherent states whose infinite-dimensional representation does not rely on a dimensional cutoff for a numerical description.

F1-3: Noise estimation in an entanglement distillation protocol

Ananda G. Maity (OIST), Joshua C. A. Casapao (OIST), Naphan Benchasattabuse (Keio University SFC), Michal Hajdušek (Keio University SFC), Rodney Van Meter (Keio University SFC), David Elkouss (OIST)

Estimating noise processes is an essential step for practical quantum information processing. Standard estimation tools require consuming valuable quantum resources. Here we ask the question of whether the noise affecting entangled states can be learned solely from the measurement statistics obtained during a distillation protocol. As a first step, we consider states of the Werner form and find that the Werner parameter can be estimated efficiently from the measurement statistics of an idealized distillation protocol. Our proposed estimation method can find application in scenarios where distillation is an unavoidable step.

F1-4: Noise is resource contextual in quantum communication

Aditya Nema (RWTH, Germany), Ananda G Maity (OIST, Japan), Sergii Strelchuk (University of Cambridge, UK), David Elkouss (OIST, Japan)

Estimating the information transmission capability of a quantum channel remains one of the fundamental problems in quantum information processing. In contrast to classical channels, the information-carrying capability of quantum channels is contextual. One of the most significant manifestations of this is the superadditivity of the channel capacity: the capacity of two quantum channels used together can be larger than the sum of the individual capacities. Here, we present a one-parameter family of channels for which as the parameter increases its one-way quantum and private capacities increase while its two-way capacities decrease. We also exhibit a one-parameter family of states with analogous behavior with respect to the one- and two-way distillable entanglement and secret key. Our constructions demonstrate that noise is context dependent in quantum communication.

Session F2: Quantum Sensing (11:00-12:00, Friday 13th October)

F2-1 (Invited): "Quantum physics and sensing application of electron spin multi-resonance in diamond"

Junko Ishi-Hayase (School of Fundamental Science and Technology, Keio University, Center for Spintronics Research Network, Keio University)

Electron spin of nitrogen-vacancy (NV) centers in diamond are promising candidates for future quantum technologies, including quantum computation, communication, and sensing. It is because that spin-triplet electron states of NV centers can be coherently manipulated using microwave field (Electron Spin Resonance) and optically initialized/readout with long coherence time at room temperature. In this study, we propose and demonstrate quantum sensing scheme for measuring AC magnetic field and/or temperature based on electron spin double- or triple-resonance of NV centers in diamond observed under the simultaneous excitation of microwave and radio-frequency fields[1-5]. Moreover, we succeeded in analyzing the electron spin double-resonance spectra under the strong driving fields using Floquet theory[6] and Lindblad master equation.

This work was done in collaboration with Dr. Matsuzaki (Chuo Univ.), Prof. Tokuda (Kanazawa Univ.), Dr. Ikeda (RIKEN), Dr. Watanabe (AIST), Prof. Mizuochi (Kyoto Univ.), Prof. Kobayashi, Dr. Sasaki (Univ. Tokyo), and Hayase Laboratory members (Keio Univ.). This work was partly supported by MEXT Q-LEAP (No. JPMXS0118067395), JSPS KAKENHI (No. JP20H05661, JP21K13852, and JP22H01558), , JST PRESTO (Grant Nos. JPMJPR1919 and JPMJPR2112), JST Moonshot R&D (Grant No. JPMJMS226C), Kanazawa University CHOZEN Project 2022, and Keio University CSRN.

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F2-2: Feedback cooling of magnetically-levitated cm-size resonators

James E. Downes (Macquarie University), Glemarie C. Hermosa (Yuan Ze University), Alexander H. Hodges (OIST), Krishna Jadeja (OIST), Daehee Kim (OIST), Ruvindha Lecamwasam (OIST), Camila P. C. Padilla (OIST), Shiu Tian (OIST), Jason Twamley (OIST)

Cooling a macroscopic resonator near its ground state is crucially important for many applications, ranging from ultrahigh precision measurements to the exploration of funda- mental macroscopic quantum physics. Measurement-based feedback cooling is one of the most-used methods to control the motions, where a properly delayed dissipative force is fed back to reduce the thermal motion energy. We use the velocity feedback to cool the center-of-mass motion of our homemade high Q resonators, with excellent agreement between experiment and theory.

Diamagnetic levitation is a good platform, with no energy input, low noise, and the capacity to trap massive objects. However, conductive pyrolytic graphite, one of the strongest room-temperature diamagnetic materials, suffers severe eddy damping and leads to a very low Q factor. To overcome this, we make insulating composites by blending the chemically treated graphite powders with vacuum-compatible wax. The cm-sized composite resonators achieve motional Q factor at the scale of 10^5 − 10^6.

We use the velocity feedback to cool the vertical motion mode of the high Q resonator. In principle, the velocity feedback can cool all the motion modes. However, different motion modes have different frequencies and distinct sensitivities and reflections on our interferometric measurement. To avoid crosstalk, in the experiment, only the vertical mode is filtered out and delayed using FPGA for feedback cooling. The feedback force is applied by magnetic actuation through nearby coils. The experimentally observed coolings at different phase delays conform to the theory and simulation results. With the proper delay, the effective center-of-mass temperature of the vertical mode can be remarkably cooled. The strong feedback cooling of massive resonators paves the way for us to make macroscopic quantum states for ultrasensitive quantum sensors.

Session F3: Novel Quantum Computing Systems (14:00-15:20, Friday, 13th October)

F3-1 (Invited): "Large-scale Integration of Modular Quantum Computer based on Diamond Spin Qubits"

Ryoichi Ishihara (QuTech, Dep. Quantum and Computer Engineering, Delft University of Technology)

Quantum computer chip based on spin qubits in diamond uses modules that are entangled with on-chip optical links. This enables an increased connectivity and a negligible crosstalk and error-rate when the number of qubits increases on-chip. Here, 3D heterogeneous integration is the key enabling technology for a large-scale integration of the diamond spin qubits to meet the needs of increased electronic and photonic interconnect for routing, control and readout of the qubits [1]. In this talk, after addressing the engineering challenges for the integration, recent results on development of diamond-on-insulator platform, pick-and-place assembly of diamond device on photonic circuit and flip-chip bonding with superconducting microbumps will be presented. At the end, the outlook of the integration technology for realization of a scalable quantum computer based on diamond spin qubits will be discussed.

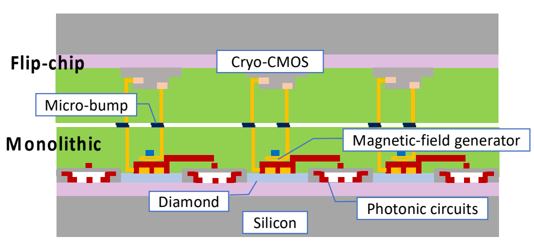

Figure 1. 3D heterogeneous integration of modular quantum computer chip with spins in diamond

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F3-2: "Research on diamond mechanical wave resonators for quantum interfaces"

Moyuki Yamamoto (Grad. Sch. Eng., Yokohama Natl. Univ.), Hodaka Kurokawa (IAS, Yokohama Natl. Univ.), Hideo Kosaka (Grad. Sch. Eng., Yokohama Natl. Univ.,IAS, Yokohama Natl. Univ.)

The scale of quantum computers based on superconducting qubits can be expanded by converting microwave (MW) photons, which can directly interact with qubits, into optical photons to transmit at room temperature and performing quantum communication between refrigerators. Therefore, a quantum interface, which transduces microwave photons to optical photons, is required [1].
We consider the use of color centers in diamond, which can strongly couple to optical photons, as components of quantum interfaces. To enhance the interaction between MW photons and color centers, we consider a method using mechanical wave mediated interactions. The wavelength of mechanical wave is 4 orders of magnitude shorter than that of MW. As a result, the energy of the MW can be confined in a smaller resonator, allowing strong interaction with the color center.
In this presentation, we will discuss the progress and future prospects of experiments aimed at verifying conversion efficiency and phase transfer to evaluate the operation of our method as a quantum interface.
This work is supported by a Japan Science and Technology Agency (JST) Moonshot R&D grant (JPMJMS2062) and by a JST CREST grant (JPMJCR1773). We also acknowledge the Ministry of Internal Affairs and Communications (MIC) for funding, research and development for construction of a global quantum cryptography network (JPMI00316) and the Japan Society for the Promotion of Science (JSPS) Grants-in-Aid for Scientific Research (20H05661, 20K20441).
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F3-3: "Blueprint for quantum computing using electrons on helium"

<u>Asher Jennings</u> (RIKEN), Ivan Grytsenko (RIKEN), Oleksiy Rybalko (RIKEN), Yiran Tian (RIKEN), Rajesh Mohan (RIKEN), Erika Kawakami (RIKEN)

Surface electrons (SEs) on liquid helium present a promising candidate for scalable quantum computing, with the spin-state decoherence time on the order of seconds. We propose to use a hybrid qubit by coupling the spin state of the SE to the hydrogen-like Rydberg state. A SE can be trapped above the surface using a nanofabricated device beneath the surface of a thin superfluid helium film. A gradient magnetic field can then be created by a micro-magnet placed nearby to couple the Rydberg and spin state of the trapped SE. Two SEs can be placed nearby each other, and a two-qubit gate can be performed by Coulomb interaction.

In order to perform the readout of the qubit state, we must be able to detect the Rydberg state of a single SE. To this end, the image-charge detection technique was developed and has been successfully applied to many electrons. To increase the sensitivity of this method down to a single electron, we propose to integrate a high Q-factor LC circuit with the image-charge technique. We have since performed measurements using an LC circuit and RF reflectometry with many SEs trapped on liquid helium.

Here, we present our proposal for the hybrid electron-on-helium qubit, and our progress on developing the readout of the qubit state.

Poster session (15:40-17:00, Wednesday, 11th October)

P1: “Evanescent field mediated Rydberg interactions via an Optical nanofiber”
Aswathy Raj – OIST; Alexey Vylegzhanin - OIST; Dylan Brown -OIST; Danil F. Kornovan - Center for Complex Quantum Systems, Department of Physics and Astronomy, Aarhus University, Ny Munkegade 120, DK-8000 Aarhus C, Denmark; Jesse L. Everett - OIST; Etienne Brion - Laboratoire Collisions Agr´egats R´eactivit´e, UMR5589, Universit´e Toulouse III Paul Sabatier, CNRS, F-31062 Toulouse Cedex 09, France; Jacques Robert - Universit´e Paris-Saclay, CNRS, Laboratoire de Physique des Gaz et des Plasmas, 91405 Orsay, France; Sile Nic Chormaic - OIST.

Rydberg atoms are considered as one of the most promising candidates for quantum technologies. We have realized Rydberg atom excitation using light guided by an optical nanofiber (ONF). The large evanescent field resulting from the strong confinement of light in the ONF is a good platform for atom-light interactions. Our experiment consists of an ONF overlapped with a cloud of Rubidium-87 atoms cooled and confined by a magneto-optical trap (MOT). The atoms from the MOT are excited to the Rydberg state via a two-photon process, with one photon from the cooling beams and the other guided through the ONF. Atoms excited to the Rydberg state are lost from the MOT, leading to a reduction in the fluorescence measured, which we use as an indirect measurement of the excitation rate. We have achieved the Rydberg excitations for various n levels from n = 24 to n = 68 for S and D states; however, we observed a different n level (principal quantum number) threshold for stoppage of Rydberg excitation for S states compared to D states and also observe a shift in the resonant frequency of S states compared to D states. We discuss the possible reasons for the differences and also compare our experimental results with the theoretical model.

P2: “Emergent topological properties in Kronig - Penney type models”
Sarika Sasidharan Nair, Giedrius Zlabys, Wen-bin He, Thomas Fogarty, and Thomas Busch

Ultracold systems offer a clean testbed for realizing different quantum models, which are challenging to implement with condensed matter systems. Experimental advancement in cold atom physics allows the creation of subwavelength nanoscale potentials where atoms can strongly interact. This potential allows us to realize the Kronig –Penney model and its variations. Introducing a lattice shift in this potential resulted in nontrivial topology and topologically protected edge states. Developing control strategies for such systems is of fundamental interest in quantum technologies that relies on the robustness of states. In this work, we analyze the topological properties of 1d potential, which resembles the Kronig Penney model, which support topological edge states. We have studied the many body quench between trivial and nontrivial regimes and see the deviations in expected orthogonality catastrophe. To better understand the effect of the edge states in the quench dynamics, we also examine the work probability distribution.

P3: “Resource reduction in an error correction code using quantum multiplexing”
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Quantum error correction (QEC) is a fundamental tool for the implementation of quantum computation and quantum communication systems. Due to losses, high-dimensional QEC codes are necessary to guarantee the successful transmission of information between users separated by large distances. However, such codes require an enormous number of two-qubit gates (CNOT) for their initial encoding, making their realization quite unpractical. Here, we apply the technique of quantum multiplexing to the encoding of high dimension Quantum Reed-Solomon (QRS) codes. We show that we can drastically reduce the number of CNOT gates required for creating the initial codewords of a QRS code.

P4: “Resonant image charge detection for e-@He qubit”
Mikhail Belianchikov - Okinawa Institute of Science and Technology;

Natalia Morais - Okinawa Institute of Science and Technology;
Denis Konstantinov - Okinawa Institute of Science and Technology.

Fundamental limitations of superconducting qubits forced the search for new alternative quantum systems for qubit realization. Coherence time of spin state on the order of seconds and mobile qubit architecture favor electrons on the superfluid film of helium among other candidates for realization of scalable quantum computer [1]. At the current early stage of development, the realization of e-@He qubit requires a reliable readout of Rydberg states, which will pave the way to spin state readout via artificial spin-orbit coupling.
In this presented work we aim at image charge detection of electron's Rydberg transitions using a microchannel device with superfluid helium film to trap and control electrons. A high-quality LC tank circuit is used for electron's image charge detection. We can resonantly accumulate electron's image charge current by driving electron's Rydberg transition with a pulse-modulated microwave radiation set to the resonant frequency of the tank circuit. Finally, the voltage across the LC tank is detected using a cryogenic low noise amplifier [2].
Presently, with CryoHEMT based cryogenic amplifier and superconducting tank circuit we managed to achieve 7.46 nV/√Hz noise level in detection system with quality factor 985 and resonance frequency 835 kHz. With an expected single electron image charge current of 3.9 fA in a microchannel device, we estimate 0.2 s measurement time for the spin state of a single electron.

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P5: "An RFSoC-based Arbitrary Waveform Generator for Coherent Control of Atomic Qubits"
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In this study, we explore the potential of utilizing a system-on-chip (SoC) for the coherent control of atomic qubits. In quantum computing experiments involving atomic qubits, RF systems play a crucial role in executing qubit operations, such as modulating laser pulses or directly driving qubits using microwaves. As we move toward the development of a large-scale quantum processor based on atomic qubits, a scalable RF system becomes indispensable. To address this need, we introduce the Xilinx RFSoC (ZCU111) as an arbitrary waveform generator (AWG). Our primary focus is to examine the benefits that an RFSoC-based AWG provides for the coherent manipulation of atomic qubits. Through a series of experiments, we offer concrete examples of how RFSoC can be effectively applied in quantum computing with atomic qubits. These experiments include the coherent manipulation of an atomic ion qubit, ion shuttling, and the generation of a tailored RF signal for an acousto-optic deflector. Our results underscore that RFSoC technology holds considerable promise as a scalable RF system for the coherent control of atomic qubits, a factor that is crucial for the advancement of large-scale quantum computers.

P6: "Massive quantum superpositions using superconducting magneto-mechanics"
Sarath Raman Nair - Macquarie University; Shiu Tian - OIST; Gavin K. Brennen - Macquarie University; Sougato Bose - University College London; Jason Twamley – OIST

Trapping, cooling and driving a large massive object towards novel quantum motional states, or Schrodinger cats, is a highly challenging but much sought after goal and is useful for quantum sensing, testing quantum mechanics at large scales and exploring the role of gravity in quantum systems. The goal is to achieve macroscopic quantum superpositions, where the spatial separation between the individual cats: Δx, is much larger than their zero point motion xzpm. To achieve this one requires systems which possess ultra-low decoherence, and some way to provide a coherent superposition of forces to displace the object into an ultra-large spatial superposition. In this work we examine two methods to produce ultra-large spatial superposition of massive nanometer to micron-sized objects where the ratio can reach values χ ≡ Δx/xzpm ~ 10^6. In the first method we consider the levitation of an insulating ferromagnetic spherical particle of radius R ~ 50 nm, held in a low frequency trap and we use nearby superconducting circuits that produce quantum magnetic forces to create a spatial superposition and find we can achieve extremely high χ which is independent of the size, with motional Q ~ 10^6 − 10^9. In the second method we propose the magnetic levitation of an entire superconducting quantum circuit. We note that certain types of superconducting circuits can be driven via induced couplings and do not require a direct galvanic contact with the driving circuit. This permits entire superconducting circuits to be levitated and driven inductively. We consider supercon- ducting circuits on spatial scales of 100-300 microns and show under what conditions they can be levitated and compute, both analytically and numerically (via Comsol), their mo- tional trap frequencies. We find that by driving these circuits inductively we can achieve extremely large values for $\chi \sim 10^6$, again with ultra-high motional Q values.

P7: "Structured nanofiber-based application
Zohreh Shahrabifarahani" -OIST Graduate University
Maki Maeda- OIST Graduate University

Different structured optical nanofiber-based waveguides are promising platforms for trapping few numbers of atoms. In this study the transmission of light is calculated for different shapes of the structured nanofibers. Moreover, 2-color dipole trapping potential for best configuration well be presented.

P8: "Fabrication and optical characterization of air-bridged diamond photonic crystal cavities"
Koudai Iijima - RCAST U-Tokyo; Satomi Ishida - RCAST U-Tokyo; Hidetsugu Matsukiyo - IIS U-Tokyo; Sangmin Ji - IIS U-Tokyo; Hideo Otsuki - RCAST U-Tokyo; Masao Nishioka - IIS U-Tokyo; Toshiharu Makino - AIST; Hiromitsu Kato - AIST; Satoshi Iwamoto - RCAST U-Tokyo, IIS U-Tokyo

Diamond has garnered attention as a platform for quantum nano-photonics [1]. In particular, single photon sources and quantum interfaces using color centers in diamonds are important since they are fundamental building blocks for quantum networks. Optical nanocavities, enabling significant enhancement of the interaction between the color centers and photons, play an essential role in improving the performance of these devices. Diamond-based photonic crystal (PC) nanocavities have been realized in many groups. However, in Japan, the fabrication technology remained immature. In this study, we realized air-suspended diamond PC nanobeam cavities, to our knowledge, for the first time in Japan. Diamond PC nanobeam cavities were fabricated by using anisotropic and quasi-isotropic ICP dry etching with oxygen plasma [2]. In micro-photoluminescence measurement at room temperature, we observed an emission peak originating from a cavity mode at around 670 nm. The peak wavelength shifts reasonably when the width/thickness of the PC nanobeam cavity changes. We will also present the successful realization of air-bridged diamond 2D PC nanocavities.
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P9: "Detecting and Controlling Weakly Coupled Nuclear Spins of NV Center under a Zero Magnetic Field: A Theoretical Study"
Naoya Egawa - Tohoku University, Shiro Tamiya - Tokyo University, Kansei Watanabe - Yokohama National University, Joji Nasu - Tohoku University, Hideo Kosaka - Yokohama National University

A hybrid spin system of an electron spin and nuclear spins in a diamond is a key platform for quantum information processing. A central challenge in realizing quantum technologies with the hybrid spin register is to selectively control as many spins with different coupling strengths as possible while maintaining coherence. However, Conventional methods for achieving scalable registers have some operational constraints in detecting and controlling nuclear spins due to the application of a magnetic field [1, 2]. To overcome these challenges, we propose a new method for extending hybrid spins as a scalable register under a zero magnetic field. We theoretically determine radio frequency phase and π-pulse intervals for zero-field registers, assuming perfect π-pulses. Our findings show that this protocol removes various constraints intrinsic to the conventional method.
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P10: "Tailoring light-atom interaction using optical waveguides"
Wenfang Li-OIST; Jinjin Du-OIST; Chris Wilson-Waterloo University; Michal Bajcsy-Waterloo University; Sile Nic Chormaic-OIST

Controlling light-matter interactions at the quantum level is crucial for applications like precision measurement and quantum information processing. Recent advances in nanofabrication enable the use of Micro- or Nanophotonic devices to customize photon-atom interactions. Optical waveguides with tightly confined transverse light fields exemplify such devices, offering a strong and efficient light-matter interface. We present two examples: an on-chip fiber-based quantum transducer for converting microwave photons to optical telecommunication band photons, and a nanofiber-based cavity to enhance photon emission and coupling efficiency from single quantum emitters. These studies hold promise for all-fiber-integrated quantum devices in quantum information processing and quantum computing.

P11: "The influence of light irradiation the transport properties of SiGe/Ge heterostructure devices"
Gabriel Gulak Maia - Osaka University

Germanium quantum well heterostructures have emerged in recent years as an interesting candidate for quantum repeater technologies, a fundamental aspect in the development of quantum networks, due to its mobility characteristics and the relatively easy integration with the existing telecommunications technology infrastructure. One of the main aspects of this integration is the bandgap of Germanium lying within the waveband currently employed in telecommunications. Inherent to the information transmission process is the introduction of environmental noise, the cumulative effect which can, given long enough transmission distances, negatively impact the reliability of the transmitted data. To address this issue repeater stations are introduced in communication networks to amplify and retransmit the noisy signal. Quantum networks, however, require quantum repeaters in order to preserve the quantum nature of the data being transmitted. With this goal in mind, it is important to understand the influence of light on the transport properties of Germanium devices, and to investigate the presence of persistent photoconductivity phenomenon. In this work we present the results of light irradiated Hall and Shubnikov-de Haas measurements.

P12: "The effect of storage and readout resonator coupling on the tomography of a bosonic qubit"

Kosuke Mizuno - NTT Basic Research Laboratories; Takaaki Takenaka - NTT Basic Research Laboratories; Imran Mahboob - NTT Basic Research Laboratories; Shiro Saito - NTT Basic Research Laboratories

Bosonic qubits, which store quantum information in superconducting cavities, are a hardware-efficient approach to quantum computation [1]. A bosonic qubit comprises a superconducting (storage) cavity, a transmon ancilla qubit, and a readout resonator for the transmon. Dispersive coupling amongst these elements enables universal control and tomography of the system. In this study, we report that the outcomes of a dispersive readout, which quantify the ancilla population, depend on the storage state. Therefore, converting measurement outcomes reliably to an ancilla population becomes difficult when the storage state is unknown. This phenomenon stems from the dispersive coupling between the storage and readout resonators via the ancilla. Consequently, readout pulses should be made as weak as possible for bosonic qubits, in order to make tomography reliable. Moreover single-shot readout by parametric amplifiers, Purcell filers [2], and multi-tone readout [3] could further mitigate this problem.

This work was supported by JST Moonshot R&D, Grant Number JPMJMS2067.

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P13: "Two-dimensional photonic crystal nanocavity with quantum dots integrated on a glass-clad Si waveguide using transfer printing"

Akinari Fujita – Keio University; Natthajuks Pholsen – RCAST, Tokyo University; Ryusei Kawata – Keio University; Sangmin Ji – RCAST, Tokyo University; Toshihiro Kamei – AIST; Makoto Okano – AIST; Satoshi Iwamoto – RCAST, Tokyo University; Yasutomo Ota – Keio University

Photonics integrated circuits (PICs) are a promising platform of photonic quantum information processing (QIP). In particular, silicon photonics utilizes CMOS process technologies and offers large-scale circuitry with various functionalities useful for the manipulation of quantum states of light. However, silicon PICs in general lack deterministic single photon sources (SPSs) required for QIP based on discrete variables. Previously, we demonstrated hybrid integration of quantum dot SPSs on Si using transfer printing. The SPS is based on a 1D nanobeam photonic crystal (PhC) cavity that facilitates efficient coupling of generated single photons into the Si circuits. To achieve higher coupling efficiency, the use of 2D PhC nanocavities is advantageous because they can suppress unwanted spontaneous emission into free space by their photonic bandgap effect. However, it was difficult for 2D PhC nanocavities to achieve high Q factors on glass due to TE-TM mode coupling and resulting optical loss. Here, we demonstrate the integration of high Q factor 2D PhC nanocavities on glass and their efficient coupling into an a-Si:H waveguide underneath. We repeated transfer printing and covered the nanocavity by a glass thin film to suppress the TE-TM mode conversion, leading to high Q factor resonances on glass. With the glass-covered structure, the radiation from the cavity can mostly be funneled into the a-Si:H waveguide that is phase matched with the cavity mode and enables low loss propagation at the operation wavelength of about 900 nm. The demonstrated cavity structure will be a key to achieve near ideal SPS on Si PICs.

P14: "Wide-field imaging of complex amplitude of AC magnetic field utilizing RF-dressed states of electron spins in diamond"

Fuki Otsubo - Keio University; Takumi Mikawa - Keio University; Yuichiro Matsuzaki - AIST; Norio Tokuda - Kanazawa University; Norikazu Mizuochi - Kyoto University; Junko Ishi-Hayase

Nitrogen-vacancy (NV) center in diamond has been expected as a highly sensitive magnetic field quantum sensor with high spatial resolution even at room temperature and is applicable to wide-field imaging with a CCD/cMOS camera. For high-frequency AC magnetic field sensing, schemes using pulse sequences[1] of microwaves and laser beams have been used in general. However, these techniques could be a problem when it comes to wide-field imaging because they are incompatible with CCD/cMOS cameras, which are used for wide-field imaging, due to the difficulties in controlling the pulse synchronization and spatial non-uniformity of pulses.

Therefore, our group proposed MHz-range AC magnetic field sensing using a continuous-wave optically detected magnetic resonance (CW-ODMR), which does not require pulse sequences, by utilizing RF-dressed states[2] of electron spins of NV centers under transverse magnetic field.

In the presentation, we show the demonstration of the wide-field imaging of the amplitude and phase of MHz AC magnetic field of μT-order generated by a micro-circuit with the spatial resolution better than 2 μm using CW-ODMR.

This work was supported by MEXT KAKENHI (20H05661, 22H01558), MEXT Q-LEAP (No.JPMXS0118067395), CSRN, Keio University Leading Initiative for Excellent Young Researchers MEXT JAPAN, JST presto (Grant No.JPMJPR1919) Japan, Kanazawa University CHOZEN Project 2022.

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