JAIST International Symposium

on Quantum Research

Date : November 28(Fri) and 29(Sat) , 2025

Venue: Kanazawa Chamber of Commerce and Industry Hall

ABSTRACT

JAIST
JAPAN
ADVANCED INSTITUTE OF
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1990

Greeting

This year, JAIST launched the "transition arena for quantum materials and information sciences (taQumi)". This organization is unique in that it aims to integrate fields that tend to be highly specialized in the field of quantum research. It seeks to integrate materials science—including quantum materials, quantum devices, and quantum sensors—information science—such as quantum communication, quantum computing, and quantum cryptography—and knowledge science, which seeks to connect the outcomes of quantum science to human prosperity.
This international symposium marks the kickoff of taQumi, and we have selected "quantum information" as the theme. We look forward to diverse discussions centered on quantum information.

Professor Yoshifumi Oshima
Chair of the Organizing Committee
Director, Nanomaterials and Devices Research Area
Japan Advanced Institute of Science and Technology

Time Schedule

28th, November, 2025

12:30 Reception (desk) open

13:00 "Opening ceremony of taQumi Research Center" Prof. Oshima

13:10 **Prof. O'Brien** (Univ. Oxford) (Keynote lecture)
"The UK Quantum Computing Hubs: Achievements and Future Directions"
(60 min.)

14:10 **Dr. Kato** (NICT) (invited talk)
"Securing the Future: Real-World Efforts Toward Quantum Key Distribution"
(40 min.)

14:50 Break

15:10 **Prof. Rodney** (Keio Univ.) (invited talk) "Quantum Multicomputers" (40 min.)

15:50 **Prof. Lim** (JAIST) (invited talk)
"Optimizing Fidelity and Latency in Quantum Routing: From QEC-Enhanced Algorithms to Adaptive Metrics" (40 min.)

16:30 Break

17:00 Poster session (about 2 hours)

18:00 Light meal

19:00- Banquet

21:00 Night cross taking (Facilitator: Prof. Oshima)

29th, November, 2025

10:00 Young researchers Award

10:20 **Dr. Toyoshima** (NICT) (invited talk)
"Trends of Space Laser Communications and Satellite QKD" (40 min.)

11:00 **Lecturer Cuiwei**, He (JAIST) (invited talk)
"Fluorescent Antennas and Photonic Reservoir Computing for Next-Generation Optical Wireless Communications"
(40 min.)

11:40 Closing marks

Introduction of Presenter

Keynote Lecture

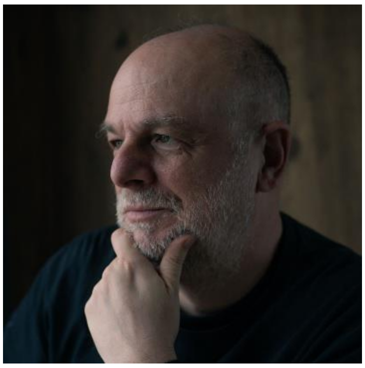
Prof. Dominic O'Brien
Director of QCi3, University of Oxford
（オックスフォード大学　量子拠点長）
https://qci3.org/our-team

Lecture Title
"The UK Quantum Computing Hubs: Achievements and Future Directions"

Invited speakers

NICT Dr. Go, KATO
Director, Quantum ICT Laboratory
https://www.nict.go.jp/quantum/

Title
"Securing the Future: Real-World Efforts Toward Quantum Key Distribution"



Keio Univ. Prof. Rodney Van Meter
https://aqua.sfc.wide.ad.jp/members

Title
"Quantum Multicomputers"

NICT Dr. Toyoshima Morio
Director General, Wireless Networks Research Center
https://www2.nict.go.jp/wireless/en/toyoshima.html

Title
"Trends of Space Laser Communications and Satellite QKD"

JAIST Prof. Yuto LIM
https://www.jaist.ac.jp/is/labs/lim-lab/

Title
"Optimizing Fidelity and Latency in Quantum Routing: From QEC-Enhanced Algorithms to Adaptive Metrics"

JAIST Lecturer Cuiwei, He

Title
"Fluorescent Antennas and Photonic Reservoir Computing for Next-Generation Optical Wireless Communications"

Requests for poster presenters

(1) The maximum poster size is **A0 (Vertically long)**.

(2) Prepare a PowerPoint presentation to introduce your presentation in oral (1 minute).

(3) The room will open at 12:00 on November 28.

(4) We would like to receive the file of your PowerPoint presentation at the registration desk. This file will be erased after the symposium.

(5) We will provide "studs" to display your poster. Please post your poster at your poster number.

(6) Please take down your posters on the morning of November 29.

Venue Information

(1) Coffee, tea, green tea, water, and hot water are available.

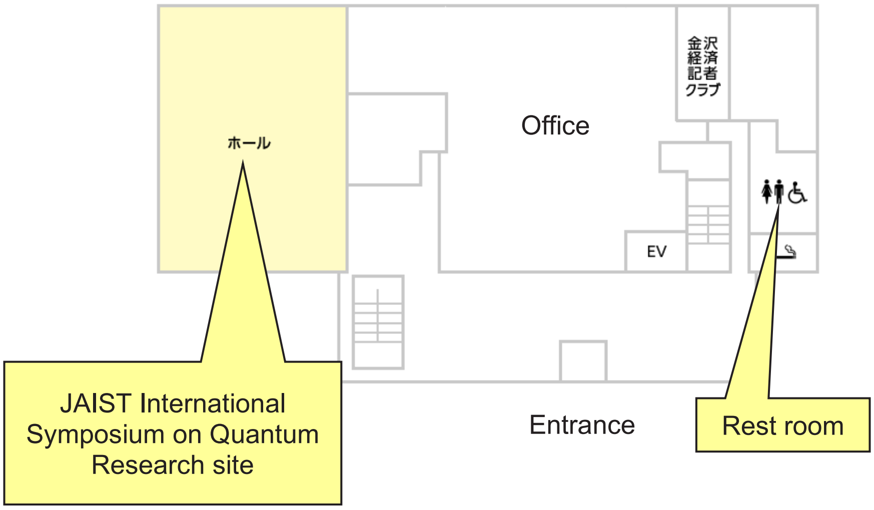
(2) WIFI is available at the venue free of charge.

SSID: Kanazawa_cci_a or Kanazawa_cci_g

Pass: 0762631151

(3) The venue website is as follows.

https://www.kanazawa-cci.or.jp/rooms/access.html



Poster Presentation

Category
A: Quantum Information · Quantum Networks · Quantum Computing
B: Quantum and Spintronics-Related Materials/Devices, Quantum Sensing, Spin Measurement
C: Machine Learning, AI, and Data-Driven Science

A-01: **SANINO DA SILVA, Marina Heloysa** (OIST and UNESP) "Single-site diagonal quantities capture off-diagonal long-range order"
A-02: **CONNOLLY, Nicholas Smith** (Okinawa Institute of Science and Technology) "Exploring Graph State Local Equivalence Classes with DH Split Decompositions"
A-03: **ZHAO, Feiyang** (JAIST) "Extending QFide: Toward Scalable and Realism Quantum Teleportation"
A-04: **ZIMING, Qin** (JAIST) "QFI-Aware Quantum Routing: Using Quantum Fisher Information for Reliable Entanglement Distribution"
A-05: **NGUYEN, Trang Thu** (JAIST) "QFiLa: Entanglement-Assured Routing Metric Design in Long Distance Quantum Networks"
A-06: **SUN, Jianwen** (JAIST) "Reinforcement Learning-Based Entanglement Resource Management and Optimal Control in Quantum Networks"
A-07: **MUHAMMAD, Sadiq** (JAIST) "EAQ: Cross-Layer Energy-Aware Quantum Computation Framework"
A-08: **NAGOSHI, Ryuichi** (JAIST) "Improving Reliability of Measurement-based Quantum Computation by Formal Verification"
A-09: **Yi, LIU** (JAIST) "From Linear to Log: Modular Any-Distance Remote CNOT over Linear Quantum Chains"
B-01: **SINGH, Saurabh** (Okinawa Institute of Science and Technology) "Electron-on-Helium Quantum Sensing: From Corbino Devices to Integrated RF Reflectometry"
B-02: **MD, Foyshal** (JAIST) "Electrical characterization of $Co_{0.8}Fe_{0.2}/In_{1-x}Ga_xAs$ on GaAs (001) with varying composition"
B-03: **YU, Jiaqin** (JAIST) "Photocurrent Characteristics of bulk-layer MoS_2 Photodetectors"

B-04: **MURAYAMA, Taiyo** (JAIST) "Preparation for the establishment of DEER measurements for detecting electron spins on the sample side using a scanning NV probe microscope"

B-05: **PRANANTO, Dwi** (JAIST) "Towards nanoscale MRI with unpaired electron spins on the tip of a scanning diamond NV probe"

B-06: **BIZEN, Takumi** (JAIST) "Spin-Flip Transition Phenomena of Guests in the van der Waals Gaps of Magnetic Intercalation Compounds"

B-07: **KOMATSU, Soh** (Japan Advanced Institute of Science and Technology) "Effect of channel materials on performance in one dimensional Zeeman-type spin-polarizers"

B-08: **SHIIBA, Shodai** (JAIST) "Fabrication and Characterization of An FET Using An InAs Nanowire Grown on HSQ Masked GaAs"

B-09: **UESUGI, Shunsuke** (JAIST) "Towards magnetic noise imaging from Fe_3O_4 superparamagnetic particles using a scanning NV probe microscope"

C-01: **PRADO BUCARO, Noel Francisco** (Kanazawa University) "Programmable Photonic Extreme Learning Machine Using Multiport Directional Couplers"

C-02: **SUN, Yijia** (QuWi Lab JAIST) "Quantum-Enhanced U-Net for Signal Waveform Separation"

C-03: **HA, Minh Quyet** (JAIST) "Multi-Source Evidence Integration for Uncertainty-Aware Decision-Making in Materials Discovery"

C-04: **DAO, Duc-Anh** (JAIST) "Material Dynamics Analysis with Deep Generative Model"

C-05: **LE, Khiet Dinh** (JAIST) "From Data to Knowledge: LLM-Guided Interpretable Rule Mining for Materials Discovery"

C-06: **VU, Tien Sinh** (JAIST) "Reconstructing Nanoscale Structures from Sparse Experimental Data: A Generative Modeling Framework Toward Quantum Material Characterization"

C-07: **ITO, Yuito** (Kanazawa University) "Physical Reservoir Sensing for Capturing high-Speed Dynamics"

Abstract

Keynote Lecture

Biography of Prof. Dominic O'Brien

Dominic has two decades of experience in photonic systems integration, including system design, integration process development, and control system development, resulting in world-leading optical wireless system performance. He has worked extensively with international academic and industrial partners, with more than 200 publications in this area and eight patents granted or in progress. He was previously Co-Director for Systems Engineering in the Networked Quantum Information Technologies Hub (NQIT) as well as the Director of the QCS Hub, the two Hubs preceding QCi3.

The UK Quantum Computing Hubs: Achievements and Future Directions

Prof. Dominic O'Brien
Director of QCi3, University of Oxford

The UK National Quantum Technologies Programme was initiated in 2014, with research hubs in different areas of quantum technology playing a key role. A Hub in quantum computing has existed over the past decade and led to a substantial set of achievements across the broad topic of quantum computing.

This presentation will introduce the programme, then focus on the topic of quantum computing. A brief introduction to the field will be given; I will then focus on the past, present and future work of the hubs and the wider UK programme.

Abstract

Invited Talk

Biography of Dr. Go Kato

Dr. Go Kato is a Director at the National Institute of Information and Communications Technology (NICT), Japan. He received his B.S., M.S., and Ph.D. degrees in Science from The University of Tokyo, Tokyo, Japan, in 1999, 2001, and 2004, respectively. In 2004, he joined the NTT Communication Science Laboratories, where he engaged in theoretical studies on quantum information. In 2022, he moved to NICT. His research interests lie in the mathematical aspects of quantum information. As examples of this interest, he has derived inequalities concerning random variables that are useful for security proofs in quantum key distribution, and classified the spatial structures naturally endowed on Hilbert spaces in the context of indirect quantum system control. He is a member of the Physical Society of Japan.

Securing the Future: Real-World Efforts Toward Quantum Key Distribution

Go Kato
Quantum ICT Laboratory, Advanced ICT Research Institute, NICT
4-2-1 Nukui-Kitamachi, Koganei, Tokyo, 184-8795 Japan

Quantum information and communication technologies (QICT) apply the principles of quantum mechanics to achieve unprecedented levels of security and information processing capabilities. As a leading institute in this field, the National Institute of Information and Communications Technology (NICT) conducts a broad range of research from fundamental science to practical implementation. This presentation provides an overview of NICT's major initiatives, illustrating how these technologies are progressing toward real-world deployment.

One of the most mature applications of QICT is Quantum Key Distribution (QKD), which allows the secure exchange of secret keys using quantum states of light. NICT has built a metropolitan QKD network in the Tokyo area, carrying out long-term field trials and integration with existing optical communication systems [1]. These efforts aim to advance the practical use of quantum-secure communications in real environments.

To extend the reach of quantum communication, NICT is also developing satellite-based QKD. Satellite links can overcome the distance limitations of optical fibers, enabling secure quantum communication on a global scale. Through dedicated satellite experiments, NICT seeks to establish reliable quantum optical communication technologies in space.

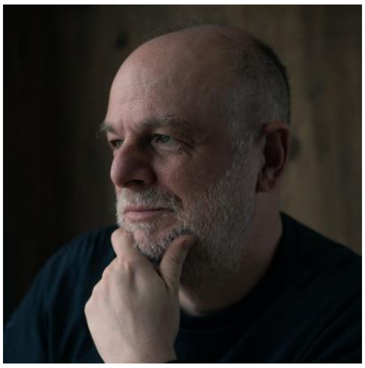
Further expansion of quantum networks will rely on quantum repeater technologies, which enable the faithful transmission of quantum information over long distances. NICT is conducting foundational studies on quantum memories and entanglement distribution as essential elements for realizing a future quantum internet.

As QKD systems have matured, ensuring their reliability and interoperability has become increasingly important. NICT is developing certification and evaluation frameworks that define quality and security standards [2], supporting the safe interconnection of quantum devices within existing communication infrastructures.

By bridging basic quantum physics and practical engineering, NICT aims to accelerate the transition of quantum information technologies from laboratory research to trusted societal infrastructure.

[1] M. Sasaki, M. Fujiwara, et. al., "Field test of quantum key distribution in the Tokyo QKD Network," Opt. Express 19, 10387-10409 (2011).
[2] Technical documents on evaluation and certification of QKD modules https://qforum.org/en/documents

Biography of Prof. Rodney Van Meter



Rodney Van Meter received a B.S. in engineering and applied science from the California Institute of Technology in 1986, an M.S. in computer engineering from the University of Southern California in 1991, and a Ph.D. in computer science from Keio University in 2006. His current research centers on quantum computer architecture, quantum networking and quantum education. He is the author of the boo _Quantum Networking_. Other research interests include storage systems, networking, and post-Moore's Law computer architecture. He is now a Professor of Environment and Information Studies at Keio University's Shonan Fujisawa Campus. He is the Vice Center Chair of Keio's Quantum Computing Center, co-chair of the Quantum Internet Research Group, a leader of the Quantum Internet Task Force, and a board member of the WIDE Project. Dr. Van Meter is a member of AAAS, ACM, APS, and IEEE. He is currently Editor in Chief of IEEE Transactions on Quantum Engineering, but this talk is 100% personal opinions.

Quantum Multicomputers

Rodney Van Meter
Keio University

Quantum multicomputers -- modular systems built from smaller quantum nodes coupled together using an interconnection network -- were first proposed as a route to scalable quantum computation two decades ago. Key ideas were studied in the 2005-2015 time frame, then a lull ensued as researchers and developers focused on near-term, single-device NISQ systems. Commercial roadmaps now point toward reaching fault-tolerant, single-device limits within this decade. Activity in multicomputers has blossomed over the last three years, mostly centered on mechanisms for making high-fidelity inter-node entanglement. Our own work began in the early 2000s with top-down designs, focusing on workloads, network topologies, error correction and techniques for distributed computation. Today, our ideas are being realized in the Q-Fly experimental network. I will review that recent progress and address the open issues in extending from single links to networks.

Biography of Dr. Toyoshima, Morio

Morio Toyoshima is Director General of the Wireless Networks Research Center in NICT. He received his Ph.D. in electronic engineering from the University of Tokyo in 2003. He joined the Communications Research Laboratory (CRL, Ministry of Posts and Telecommunications) in 1994 and shortly after was engaged in research for the Engineering Test Satellite VI (ETS-VI) optical communication experiment. He joined the Japan Aerospace Exploration Agency (JAXA; formerly, NASDA) to assist in the development of the Optical Inter-orbit Communications Engineering Test Satellite (OICETS) from 1999 to 2003. He spent one year as a guest scientist at Vienna University of Technology, Austria in 2004. In April 2006, he returned to NICT, where he performed ground-to-OICETS laser communication experiments in 2006. He was involved in the development of the Small Optical TrAnsponder (SOTA) for 50-kg-class satellites and conducted the satellite-to-ground quantum communication experiments. He was also involved in the development of the communication payloads for the Engineering Test Satellite 9 (ETS-9).

Trends of Space Laser Communications and Satellite QKD

Morio Toyoshima[1]*
1. Wireless Networks Research Center, National Institute of Information and Communications Technology (NICT), 4-2-1, Nukuikita, Koganei, Tokyo 184-8795, Japan
(* corresponding author e-mail: morio@nict.go.jp)

Abstract

The fifth-generation mobile communication system (5G) was introduced in earnest in 2020, and the research and development for Beyond 5G (B5G) and sixth-generation mobile communication system (6G) are active in many countries around the world. Satellite communications have become more sophisticated and active worldwide with, for example, the digitization of communications satellites and the launch of many small satellites in satellite constellations. The research and development of Non-Terrestrial Networks (NTN) is expected, and it is necessary to create a three-dimensional seamless network required for a safe and secure smart society in the 2030s. NTN's features include the scalability and wideness of its coverage area, with seamless connection and communication services to digitally divided areas such as sea, mountainous areas, and the sky that cannot be covered by terrestrial systems. In areas that will be expanded by NTN, various uses are expected, such as communication to space, the moon, and underwater, backhaul links to remote base stations and portable base stations, air mobility such as drones and flying cars, communication to connected cars, high-capacity communication to aircraft and ships, and Internet of Things such as fleet management. Among these technologies, space laser communication technology using satellites is highly resistant to interference, has features suitable for miniaturization and mass reduction, and is attracting attention as a means of high-speed, large-capacity communication that cannot be achieved with radio waves (RF). It is expected to help bring about an innovative leap forward in global telecommunications [1–3]. In addition, the quantum key distribution (QKD) on the ground has the limited transmissible distance because of the loss of the optical fibers; however, the QKD using satellites will be able to enhance the security aspect in the global communication networks through the free-space transmission. In this paper, the trends and future prospects of space laser communications and satellite QKD for the B5G/6G era are introduced.

Reference

[1] V. W. S. Chan, Journal of Lightwave Technology, 21(11), pp. 2811–2827 (2003)
[2] M. Toyoshima, Journal of Lightwave Technology, 39(3), pp. 693–699 (2021)
[3] V. W. S. Chan, Journal of Optical Communications and Networking, 16(1), pp. A53–A67 (2024)

Biography of Prof. Lim, Yuto

Yuto Lim received the B.Eng. (Hons) and M.Inf. Tech. degrees from Universiti Malaysia Sarawak (UNIMAS), Malaysia, in 1998 and 2000, respectively. He received the Ph.D. degree in communications and computer engineering from Kyoto University in 2005. In November 2005, he joined the National Institute of Information and Communications Technology (NICT), Japan, as an expert researcher, where he worked until September 2009. Since October 2009, he has been with the Japan Advanced Institute of Science and Technology (JAIST), where he served as an associate professor. In April 2025, he was appointed as a full professor at JAIST. His research interests include quantum networks, future wireless communication and networks, wireless network coding, smart homes, smart cities, cyber-physical systems, the Internet of Things (IoT), and smart energy distribution. He is a member of the IEEE, IEICE, and IPSJ.

Optimizing Fidelity and Latency in Quantum Routing: From QEC-Enhanced Algorithms to Adaptive Metrics

Yuto Lim[1]
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Japan Advanced Institute of Science and Technology, Nomi, Ishikawa 923-1292, Japan
ylim@jaist.ac.jp

Abstract

The realization of large-scale quantum networks requires reliable distribution of high-fidelity entangled states across long distances, while simultaneously addressing the challenge of communication latency. This talk explores advances in quantum routing algorithms with a particular focus on quantum error correction (QEC) and fidelity–latency optimization. We first examine Q-LEAP, a previously proposed routing algorithm that reduces computational complexity through a purification decision method, and introduce Q-FIND, a novel routing scheme designed to further minimize network latency. Our study applies QEC to evaluate these algorithms under noisy channel conditions, with simulations implemented in Qiskit revealing that the integration of QEC significantly improves network performance. Building on this foundation, we propose QFiLa (Quantum Fidelity–Latency), a new quantum link metric specifically engineered to balance the trade-off between fidelity and latency in entanglement routing. By integrating QFiLa into the Q-LEAP framework, we enable adaptive routing strategies that dynamically prioritize either minimal latency—for time-sensitive applications such as real-time QKD and quantum sensing—or maximal fidelity—for high-precision tasks including quantum teleportation and distributed fault-tolerant computing. Together, these contributions highlight how QEC-enhanced algorithms and fidelity–latency-aware metrics pave the way for efficient, scalable, and application-oriented quantum communication infrastructures.

Biography of Dr. Cuiwei He

Cuiwei He received his Ph.D. degree on the topic of optical wireless communication from Monash University, Melbourne, Australia, in 2017. From 2017 to 2020, he worked as a Research Fellow at Monash University. From 2020 to 2021, he was a Postdoctoral Research Assistant (PDRA) with the Department of Engineering Science, University of Oxford, U.K. He is currently a Senior Lecturer with the School of Information Science, Japan Advanced Institute of Science and Technology (JAIST). His research interests include visible light communications and optical wireless communications. He has served as a Guest Editor for *IEEE Photonics Technology Letters* and *Photonics*, and is currently a member of *IEEE Photonics Society*.

Fluorescent Antennas and Photonic Reservoir Computing for Next-Generation Optical Wireless Communications

Cuiwei He[1]*, Hideyuki Murata[2], and Satoshi Sunada[3]

1 School of Information Science, Japan Advanced Institute of Science and Technology, Nomi, Ishikawa 923-1292, Japan

2 School of Materials Science, Japan Advanced Institute of Science and Technology, Nomi, Ishikawa 923-1292, Japan

3 Institute of Science and Engineering, Faculty of Mechanical Engineering, Kanazawa University, Kanazawa, Ishikawa 920-1192, Japan

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Abstract

Optical wireless communication (OWC) is expected to play an important role in future generations of wireless networks, offering high-speed and secure links across diverse application scenarios, from long-distance satellite communications and medium-range underwater links to short-range indoor applications.

One promising approach to advancing OWC technology is the development of new optical devices. In the first part of this talk, we present our recent work on using organic fluorescent materials to fabricate an emerging type of optical device known as fluorescent antennas. These antennas can simultaneously achieve light concentration and optical filtering. More importantly, they provide a wide field of view (FOV) without being constrained by étendue, which is highly desirable for indoor mobile communications. Using multiple types of commercially available fluorescent fibers doped with different fluorophores, we further demonstrate the feasibility of these antennas for supporting wavelength-division multiplexing (WDM) to increase the overall data rate. Our recent studies also apply Förster resonance energy transfer (FRET) mechanism to enhance both the bandwidth and concentration gain of the antennas, which has been shown to significantly improve OWC transmission [1].

While many OWC systems support much higher transmission rates than their radio frequency (RF) counterparts, this advantage also leads to more severe inter-symbol interference (ISI), particularly at data rates at or above gigabit-per-second (Gbps) levels. This makes signal equalization a very important step in OWC. Conventional electrical-domain digital signal processing (DSP) equalizers, however, require costly high-bandwidth processors and consume significant power. In the second part of this talk, we introduce a new device based on a microcavity structure fabricated on a silicon chip, which enables optical domain signal equalization using reservoir computing principles. By performing equalization directly in the optical domain, without optical-to-electrical conversion, this approach achieves high bandwidth, low latency, and high energy efficiency. Our recent results demonstrate that this reservoir computing chip can effectively equalize signals and support data rates up to 10 Gbps [2].

This work was supported by the Japan Society for the Promotion of Science (JSPS) KAKENHI under Grants JP 23K13332, JP 23KK0257, JP 22H05198 and by JST/CREST under Grant JPMJCR24R2.

Reference

[1] C. He, S. Collins, H. Murata, Opt. Express 32, 17152 (2024).

[2] C. He, S. Motooka, S. Sunada, IEEE Photon. Technol. Lett., (2025).

Abstract

Poster Presentation

Single-site diagonal quantities capture off-diagonal long-range order

M. Sanino[1], I. D'Amico[2], V. V. França[1] and I. M. Carvalho[1]

[1]*Institute of Chemistry, São Paulo State University, 14800-090, Araraquara, São Paulo, Brazil.*

[2]*School of Physics, Engineering and Technology, University of York, York YO10 5DD, United Kingdom.*

Quantum phase transitions are typically marked by changes in quantum correlations across various spatial scales within the system. A key challenge lies in the fact that experimental probes are generally restricted to diagonal quantities at the single-site scale, which are widely believed to be insufficient for detecting phases with off-diagonal long-range order, such as superconducting states. In a striking departure from conventional expectations, we show that single-site diagonal descriptors — charge and spin fluctuations, occupation probabilities, and entanglement — can capture the emergence of off-diagonal long-range order in the one-dimensional extended Hubbard model at halffilling. These single-site quantities display clear critical signatures of the superconducting transition, preceded by a continuous breaking of particle-hole symmetry, consistent with a second-order phase transition. While this symmetry breaking has a negligible effect on single-site descriptors, it allows a direct connection between local fluctuations and nonlocal correlations.

Exploring Graph State Local Equivalence Classes with DH Split Decompositions

Nicholas Connolly[1] and Kae Nemoto[1,2]

[1] Okinawa Institute of Science and Technology, Japan

[2] National Institute of Informatics, Japan

Graph states are a type of quantum state important for measurement-based quantum computation [1]. The preparation of a graph state is represented by a graph, wherein vertices denote qubits and edges denote entanglement through a CZ gate (FIG 1). Graph states can be transformed using single qubit Clifford operations, which change the state while preserving the entanglement structure. Mathematically, these transformations correspond to a combination of *local complement* (LC) operations on the corresponding graph [2]. Applying local complement to a graph modifies the neighborhood of a chosen vertex by complementing the edge set (FIG 2). The equivalence class of graphs related by local complements is in bijection with graph states related by local Clifford operations. Graphs related in this way are called *LC equivalent* and the entire equivalence class is referred to as the *LC orbit* of the graph.

Recent research into graph states has focused on understanding and enumerating the mathematical structure of LC equivalent graphs and their orbits [3]. Since graph states from the same LC orbit exhibit equivalent entanglement, one practical advantage of this technique is the ability to identify a graph which is optimal with respect to some physical parameter, such as the amount of preparation resources [4]. However, finding an explicit transformation of a given graph state to a preferred LC equivalent state requires knowledge about the equivalence class. The goal of this research is the exploration of the LC orbit for certain families of *distance hereditary* graphs with a particularly rich and useful structure.

A graph is said to be *distance hereditary* (DH) if all connected induced subgraphs preserve distance between vertices [5]. Many graphs which play a significant role in network communications theory are distance hereditary, such as complete *k*-partite graphs and repeater graphs. In connection with LC orbits, the distance hereditary property is preserved under local complements [6]. There is a wealth of mathematical literature exploring families of LC equivalent graphs, much of which relies on a technique known as the *split decomposition* of a graph [7], which divides a graph into simple *split components* whose connectivity is described by a *split tree* (FIG 3). LC equivalent graphs have the same split tree and LC equivalent split components. In the case of DH graphs, the split components are trivial (either star or complete) and hence simple to enumerate. By fixing a split tree, we explore families of LC equivalent DH graphs through an exhaustive enumeration of the symmetries of LC equivalent split components. Whereas previous studies into LC equivalent graph states have relied on brute force searches of the LC orbit [3], our technique yields a general formula for the size of the LC equivalence class for certain families of DH graphs based on their splits along with explicit transformations to obtain any representative of the orbit.

References:

[1] H. J. Briegel and R. Raussendorf, *Physical Review Letters*, 86(5): 910 (2001).

[2] M. Van den Nest, J. Dehaene, and B. De Moor, *Physical Review A*, 69(2): 022316 (2004).

[3] J. C. Adcock, S. Morley-Short, A. Dahlberg, and J. W. Silverstone, *Quantum*, 4: 305 (2020).

[4] A. Cabello, L. E. Danielsen, A. J. López-Tarrida, J. R. Portillo, *Physical Review A*, 83(4): 042314 (2011).

[5] E. Howorka, *The Quarterly Journal of Mathematics*, 28(4): 417-420 (1977).

[6] A. Bouchet, *Journal of Graph Theory*, 12(2): 195-207 (1988).

[7] W. H. Cunningham, *SIAM Journal on Algebraic Discrete Methods*, 3(2): 214-228 (1982).

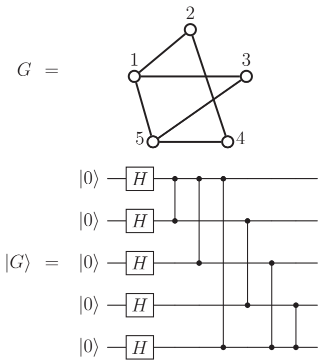

FIG 1: Graph State Preparation

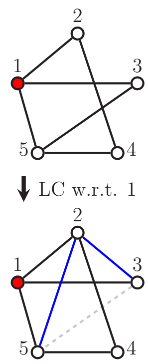

FIG 2: LC Equivalent Graphs

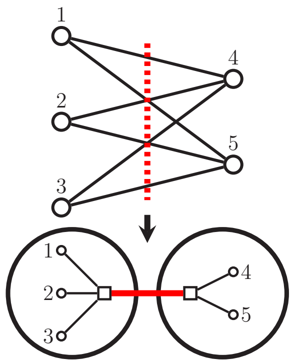

FIG 3: DH Graph Split Decomposition

Extending QFide: Toward Scalable and Realism Quantum Teleportation

Zhao Feiyang, Muhammad Sadiq, and Lim Yuto,
Japan Advanced Institute of Science and Technology, JAPAN

QFide [1] is a quantum teleportation fidelity simulator designed to analyze how various noise processes and photon-loss mechanisms affect the reliability of quantum communication. While it provides detailed physical-level modeling using Qiskit's quantum channels–such as depolarizing noise, amplitude damping, and amplitude damping channel (ADC)-based loss, in which it is currently limited to static, single-link scenarios and lacks temporal dynamics, multi-node structures, and network-level behaviors.

To enable realism and scalable quantum-network studies, this work proposes a set of architecture-level extensions to QFide. First, link-level realism will be introduced by modeling fiber-length-dependent attenuation, decoherence, and classical-channel delay. Second, the simulator will be expanded to support multi-node repeater chains with automatically generated circuits. Third, a finite-coherence-time quantum-memory model will be implemented to reflect storage-induced decoherence. Fourth, an event-scheduling mechanism inspired by SeQUeNCe [2] will be incorporated to represent time-ordered operations and asynchronous processes. Future extensions include multi-user and multi-request scenarios to explore resource contention, along with additional performance metrics such as success probability, throughput, and end-to-end latency.

In summary, these enhancements aim to transform QFide from a single-link teleportation tool into a more realistic and scalable quantum-network simulator capable of bridging physical-layer fidelity analysis and network-level communication research.

References:

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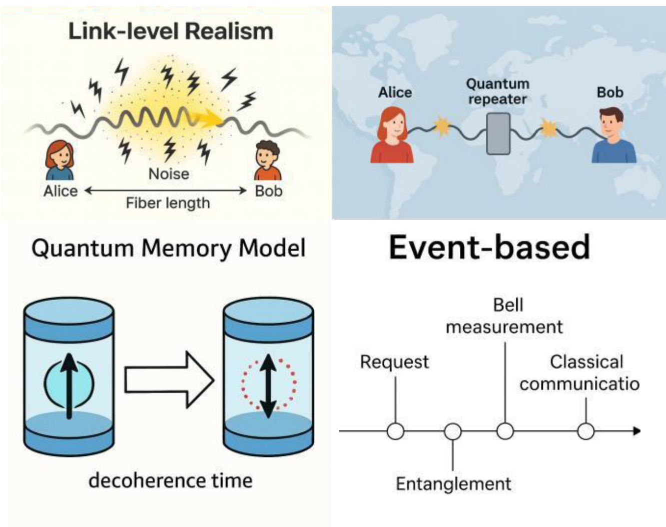

Figure 1: Overview of QFide extension features. Illustration of the planned QFide extensions, including link-level realism, multi-node repeaters, quantum-memory decoherence modeling, and an event-based scheduling mechanism

QFI-Aware Quantum Routing:
Using Quantum Fisher Information for Reliable Entanglement Distribution

Ziming QIN, Thu Trang NGUYEN, Yuto LIM
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The quantum internet distributes entanglement between distant nodes using repeaters and noisy optical links [1]. In quantum metrology, the Quantum Fisher Information (QFI) sets the fundamental limit of parameter-estimation precision and is a standard measure of a state's metrological usefulness [2].

The objective of this work is to propose a quantum routing strategy that uses QFI as a physically grounded measure of link availability and reliability. Instead of routing only by hop count or estimated success probability, this work constructs a QFI-weighted quantum network and select paths that maximize the bottleneck QFI, aiming at more robust long-distance entanglement [3].

Each edge represents a physical quantum channel capable of distributing an EPR pair, and its color encodes the link-level QFI, which characterizes the metrological quality of the distributed entanglement as shown in Fig. 1. QFI guides routing to choose the end-to-end path whose weakest link best preserves phase information [4,5]. We combine fidelity and QFI because a high-quality quantum link must be both strongly entangled and operationally useful for parameter estimation Fig. 1(b) and Fig. 1(c).

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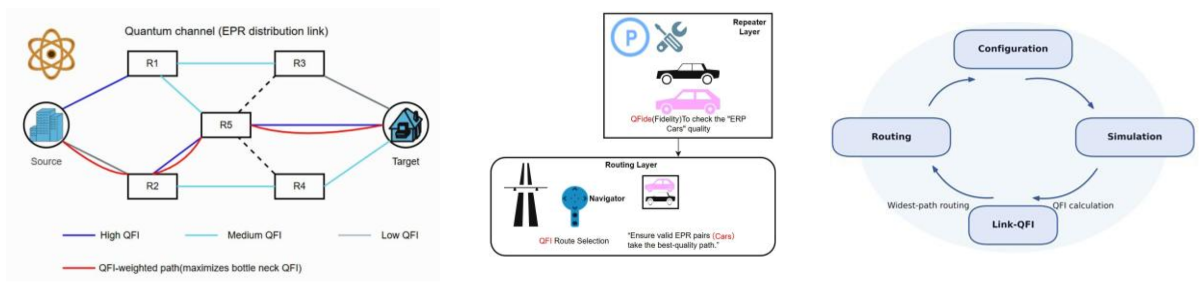

(a) (b) (c)

Fig. : (a) QFI-weighted links and the selected widest-QFI path, where edge colors encode link-level QFI and the red route maximizes the bottleneck QFI between source and target; (b) Two-layer QFI–fidelity framework, in which the repeater layer uses fidelity checks to filter valid EPR pairs and the routing layer applies QFI-based route selection to choose the best-quality end-to-end path; and (c) QFI-aware routing workflow, where configuration and simulation generate Link-QFI metrics that drive widest-path routing for robust long-distance entanglement distribution.

QFiLa: Entanglement-Assured Routing Metric Design in Long Distance Quantum Networks

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Efficient entanglement routing protocols are a cornerstone for the development of the Quantum Networks. However, these protocols face a fundamental trade-off between maximizing quality of an entangled quantum state and minimizing latency. Existing state-of-the-art methods, such as Q-LEAP [1], provide a potential mechanism for guaranteeing end-to-end fidelity but do not inherently include latency optimization in their path-selection logic. This omission can lead to high-latency routes, creating a bottleneck for time-sensitive quantum applications [2].

To address this critical gap, we introduce Q_{FiLa} (Quantum Fidelity-Latency), a novel and tunable composite link metric designed to extend the Q-LEAP framework. By integrating both fidelity and latency into a single, weighted metric, Q_{FiLa} transforms the routing algorithm into a multi-objective solution capable of balancing these metrics too satisfy the base on the needs various applications and networks conditions.

We validated our approach through extensive simulations on two distinct topology types: the realistic JPNM topology (48 nodes) and generality random topologies (50 nodes). The results demonstrate a significant improvement in network efficiency. Compared to the original fidelity-focused Q-LEAP, a balanced Q_{FiLa} configuration reduces average end-to-end latency by up to 15% and slashes path computation time by up to 34.5% in networks. Crucially, these gains are achieved with no discernible impact on network throughput (Fig. 1).

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Figures and figure captions

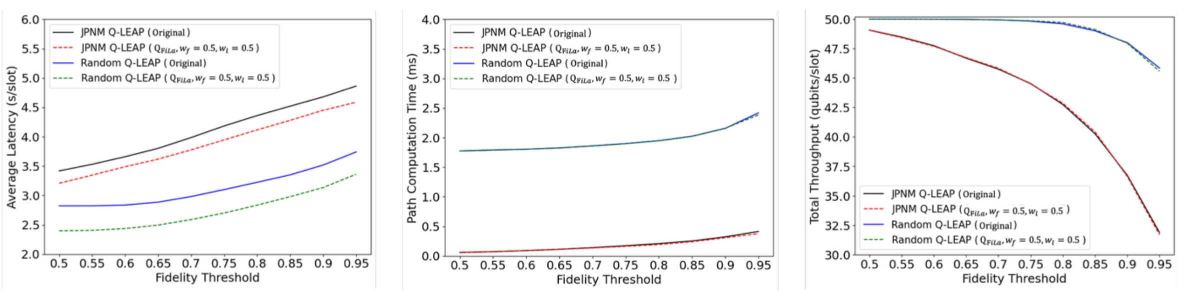

Fig 1. Performance comparison of the original Q-LEAP (Fidelity) and the balanced Q_{FiLa} metric ($w_f = 0.5$ and $w_l = 0.5$) across the JPNM and 50node random topologies. Q_{FiLa} consistently reduces (a) average latency and (b) path computation time, while maintaining (c) almost the same total throughput.

A-06

Reinforcement Learning-Based Entanglement Resource Management and Optimal Control in Quantum Networks

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Efficient long-distance entanglement distribution is a fundamental requirement for the realization of scalable quantum networks. Future large-scale quantum internets are expected to support distributed quantum computing and high-fidelity communication, yet their performance is fundamentally constrained by probabilistic entanglement generation, channel loss, and rapid memory decoherence. Conventional repeater-based strategies rely predominantly on static routing and predetermined control rules, limiting their responsiveness to highly dynamic network conditions. Recent theoretical studies on quantum internet architectures[1] highlight the necessity of adaptive, state-aware control to ensure high-quality end-to-end connectivity.

In this work, we investigate reinforcement learning (RL) as an integrated decision-making framework for dynamic entanglement management. We address three central challenges: (i) adaptive path selection under fluctuating channel transmissivity, (ii) real-time optimization of entanglement swapping in the presence of decohering quantum memories, and (iii) autonomously controlled purification to maintain fidelity under time-varying noise. Building on recent advances in learning-based entanglement routing[2], we develop an RL-driven control architecture that jointly optimizes routing, swapping, and purification through explicit modeling of delay, decoherence, and resource cost. The proposed framework achieves improved distribution success probability, reduced latency, and enhanced fidelity, offering a topology-agnostic and load-robust optimization strategy for future programmable quantum networks.

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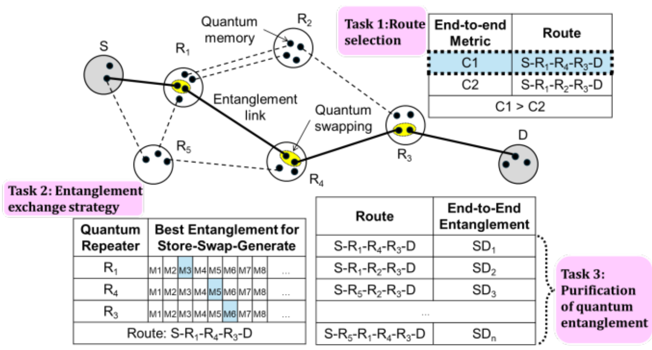

Fig 1. Three Tasks in Research on Quantum Entanglement Resource Management

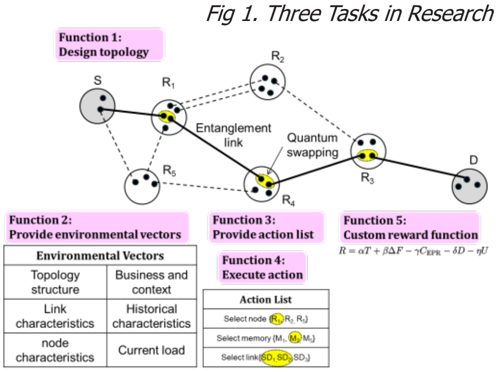

Fig 2. Functional Diagram of Quantum Network Gym.

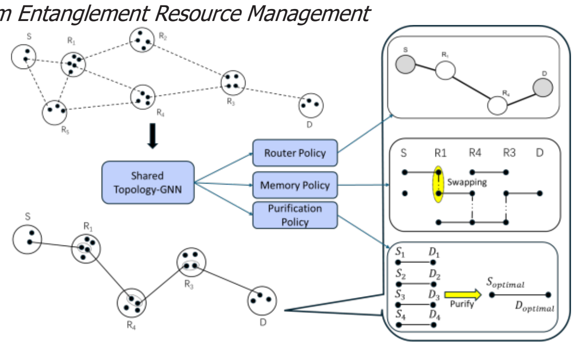

Fig 3. Proposed Multi-Round HAQR with Conditional Adapters

A-07

EAQ: Cross-Layer Energy-Aware Quantum Computation Framework

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Quantum computing promises speedups for solving complex problems, but energy consumption is emerging as a fundamental bottleneck in the scalability of quantum computation, where cooling systems, control electronics, and quantum error correction (QEC) dominate power demands. Existing research primarily targets performance improvements, such as higher fidelity, faster gates, and reduced error rates while offering limited insight into how quantum systems can be engineered for energy efficiency. This proposal introduces an Energy-Aware Quantum Computation (EAQ) framework that optimizes energy use across the quantum stack, from hardware control to algorithm design. EAQ models total energy per logical gate and per algorithm run, identifies energy bottlenecks across different quantum architectures, and formulates adaptive strategies that reduce cooling load, pulse-generation overhead, and error-correction cost. By integrating cross-layer energy-aware optimization, EAQ aims to enable sustainable, scalable, and practical quantum computing systems.

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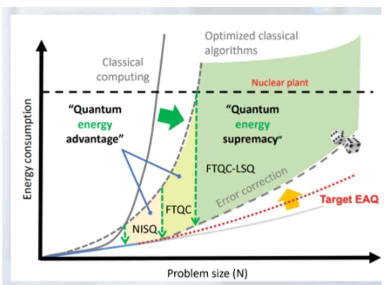

Fig 1: Energy Consumption in Quantum Computation

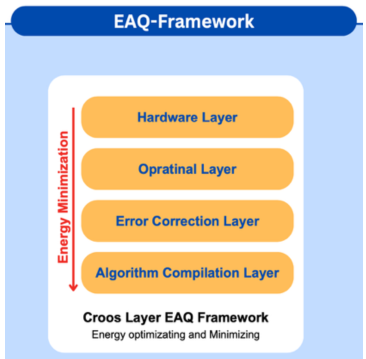

Fig 2: Energy-Aware Quantum Computation Framework

Improving Reliability of Measurement-based Quantum Computation by Formal Verification

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Measurement-based quantum computation (MBQC) [1] is a model of quantum computation in which a highly entangled resource state is prepared in advance and the computation is driven by a sequence of adaptive single-qubit measurements. It is promising for various physical architectures and for applications such as blind or delegated quantum computation. However, ensuring the correctness of MBQC protocols remains challenging. Because quantum computation is grounded in the principles of quantum mechanics, debugging and verification techniques developed for classical computation cannot be directly applied. Moreover, formal verification studies targeting MBQC are still limited, and the methodological foundation for guaranteeing the correctness of MBQC protocols is not yet well established. These issues underscore the critical need for mathematically rigorous formal verification methods tailored to MBQC.

In this work, we propose a framework for exhaustively and automatically verifying the correctness of MBQC protocols (patterns) using Maude, an executable algebraic specification language based on rewriting logic. The framework is built on three key approaches. First, we represent quantum states and operations not as numerical matrices but as symbolic terms in Dirac notation and realize quantum execution as symbolic reduction using Maude rewriting rules. Second, based on the Measurement Calculus [2] we formalize MBQC operations such as initialization, entanglement generation, measurement, and outcome dependent Pauli corrections as rewrite rules, and execute a pattern given as a command list by rewriting. This enables us to enumerate all branches induced by probabilistic measurement outcomes and to extract the corresponding output states. Third, we evaluate the final states using fidelity. Specifically, we normalize the output of each branch and compute its fidelity against a desired state. Since fidelity is invariant under global phase differences, it provides a robust criterion for confirming equivalence.

We have conducted case studies on seven MBQC patterns, including Hadamard, quantum teleportation, X- and Z- rotations, CNOT, general rotation, and GHZ state preparation, using our Maude-based verifier. For every branch induced by probabilistic measurement outcomes, the normalized output state was confirmed to be equivalent to the desired state. Moreover, by measuring the number of qubits in the pattern computation space, the number of branches, the number of rewrite steps, and the verification time for each pattern, we demonstrated that exhaustive verification can be carried out with practical computational cost (Table. 1).

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Table 1. Experimental Result

Pattern	Qubits	Branches	Rewrite Steps	Times
Hadamard	2	2	671	1 ms
Quantum Teleportation	3	4	3,426	4 ms
X-rotation	3	4	4,461	4 ms
Z-rotation	3	4	5,114	4 ms
CNOT	4	4	3,072	4 ms
General rotation	5	16	30,225	36 ms
GHZ	5	4	14,535	20 ms

From Linear to Log: Modular Any-Distance Remote CNOT over Linear Quantum Chains

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Remote two-qubit control is a central bottleneck for near-term quantum architectures built as linear chains of nearest-neighbor qubits. Existing schemes realize long-distance CNOTs by serial SWAP or entanglement-swapping patterns, inevitably incurring circuit depth linear in the chain length. This work proposes a modular any-distance remote CNOT protocol that simultaneously targets scalability, analyzability, and optimality. We factor the protocol into three reusable modules and introduce a parallel entanglement-swapping module whose depth scales only as $\Theta(\log(N+1))$ over a chain of N links. On top of this design, we develop an entanglement-contraction–based analysis that yields matching lower and upper bounds on the number of rounds, proving that our protocol attains the fundamental log-depth limit under standard 1D nearest-neighbor assumptions and fixed communication resources. The full construction and all complexity claims are machine-checked in a rewriting-logic–based formal framework.

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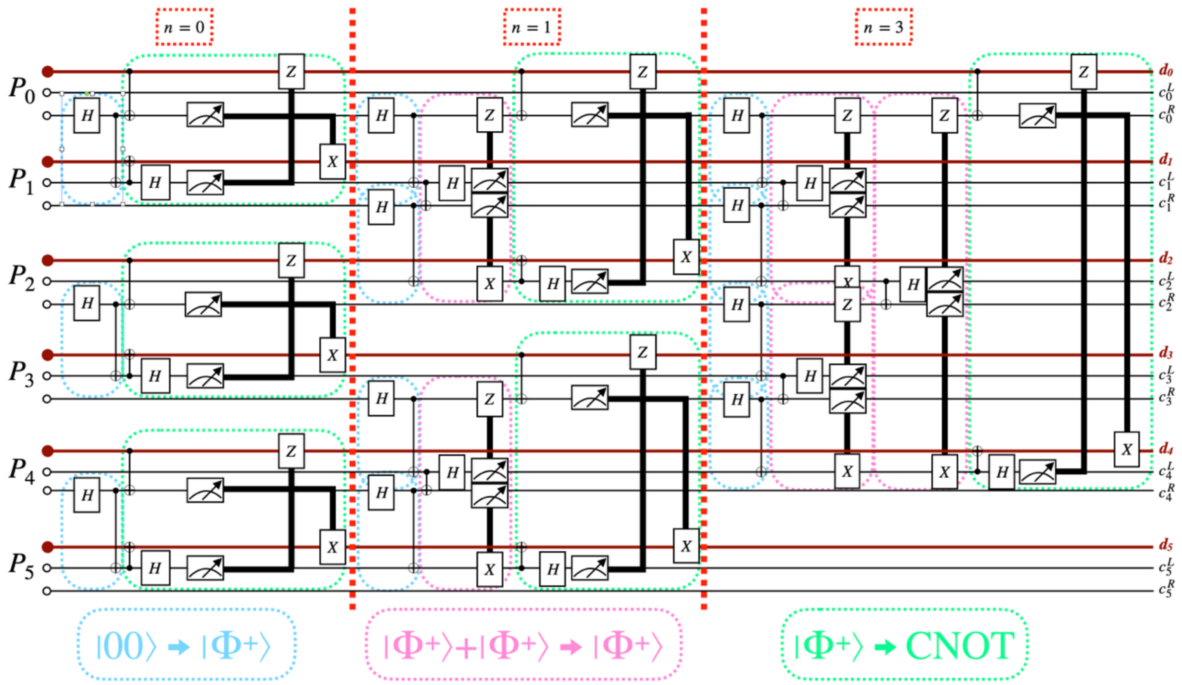

Electron-on-Helium Quantum Sensing: From Corbino Devices to Integrated RF Reflectometry

Saurabh Singh[1], Jui Yin Lin[1], Natalia Morais[1], and Denis Konstantinov[1]

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Both high sensitivity and fast readout are prerequisites for building high-performance quantum computing technologies. In this study, we developed an experimental technique to sense the quantum states of electrons on condensed helium, which offers a pristine, low-noise platform for quantum-state detection. In the previous work, we successfully established an experimental technique using a superconducting tank circuit suitable for quantum-states detection based on radio frequency (RF) reflectometry [1]. High capacitance sensitivity (0.13 aF/√(Hz) at 10-Hz bandwidth) was achieved using a Corbino device (FIG 1 a), facilitating the detection of Rydberg transitions in many-electron systems on the surface of bulk liquid 4He. Although RF reflectometry has the potential for fast readout with extremely high sensitivity, the large surface area (~mm^2) of the Corbino devices typically confines many electrons (~ 10^7 electrons) in a real experimental condition. This poses a challenge to work with few- or single-electron systems. Therefore, improvement in the geometry of devices suitable for the fast readout of single or fewer electrons with higher sensitivity is desirable. As a possible solution, we have integrated the device architecture consisting of microchannels with confined areas (~ μm^2 scale) allows working with a reduced number of electrons ($10^2 - 10^3$). This approach is beneficial for fast qubit-state readout, high sensitivity and large measurement bandwidths (few MHz).

Overall, our approach of exploiting RF reflectometry with an integrated microchannel device (FIG 1 b,c) paves the way for further significant advancement towards quantum computing. This allows high-bandwidth (MHz-range) detection of quantum states (including Rydberg transitions) in low-electron-number regimes. Ongoing work aims to establish this method as a scalable, high-sensitivity platform for electron-on-helium qubit technologies.

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a) b) c)

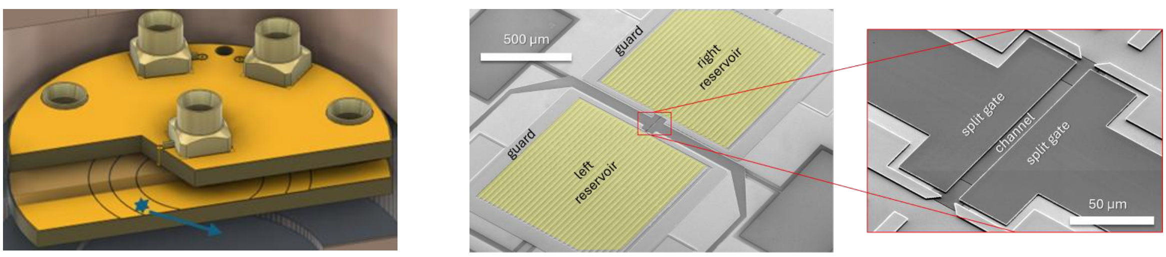

FIG. 1. a) Schematic representation of Corbino device; b) FET-like microchannel device for trapping electrons above helium surface. Two reservoirs (left and right) of electrons (source and drain) are connected by a microchannel; c) micrograph of linear microtrap inside the channel consists of trap, door and split gate (SG) electrodes.

Electrical characterization of $Co_{0.8}Fe_{0.2}$/$In_{1-x}Ga_xAs$ on GaAs(001) with varying composition

Md Foyshal[1,] *****, Yufeng Lu[1], Md Faysal Kabir[1], Soh Komatsu[1], Masashi Akabori[1]
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The realization of semiconductor-based spin devices requires a ferromagnetic (FM) material to generate spin-polarized carriers and a semiconductor (SC) channel capable of preserving spin coherence during transport [1]. Among III–V SCs, indium gallium arsenide ($In_{1-x}Ga_xAs$) is particularly promising due to its high electron mobility, tunable bandgap, and strong spin–orbit coupling, all of which are favorable for spin transport and manipulation. Among FMs, $Co_{0.8}Fe_{0.2}$ provides higher spin polarization compared to a popular FM like permalloy ($Ni_{0.8}Fe_{0.2}$). In fact, $Co_{0.8}Fe_{0.2}$/$In_{0.75}Ga_{0.25}As$ has been reported as an important FM/SC system to show significant spin injection efficiency [2]. However, to our knowledge, there was no systematic work on $Co_{0.8}Fe_{0.2}$/$In_{1-x}Ga_xAs$ with varying composition.

In this study, four $In_{1-x}Ga_xAs$ samples (x = 0.1, 0.2, 0.3, and 0.4) were grown on GaAs(001) by molecular beam epitaxy (MBE). The composition and the thickness were confirmed by triple-axis X-ray diffraction (Fig. 1) and by cross-sectional scanning electron microscopy, respectively. Hall measurements revealed that, as Ga composition x increased, the electron mobility decreased from 2.6×10^3 to 3.6×10^2 $cm^2/V\cdot s$, while the sheet resistance increased from 3.6×10^2 to 2.3×10^4 Ω/sq. This behavior results from bandgap widening, increased effective mass, and enhanced alloy scattering with increasing Ga composition x.

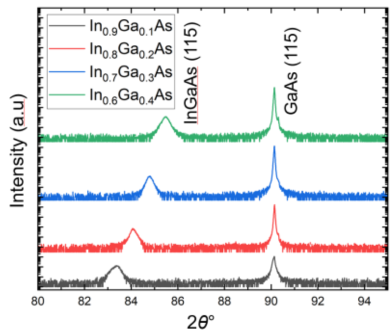

Fig.1. XRD curves.

For device fabrication, photolithography was employed to define electrode patterns. First, Ti (30 nm)/Au (60 nm) electrodes were deposited by electron-beam evaporation and lift-off to form non-magnetic Ohmic contacts. Subsequently, $Co_{0.8}Fe_{0.2}$ (50 nm) electrodes were deposited by electron cyclotron resonance sputtering and lift-off to form FM contacts. The diameter of the CoFe circular electrode was 200 μm (Fig.2).

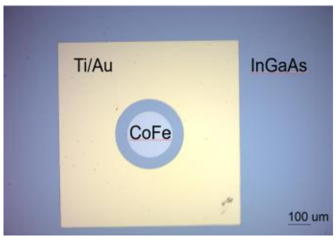

Fig.2. Optical microscope image.

I-V measurements at room temperature were performed by a semiconductor device analyzer (Fig. 3). Voltage for $Co_{0.8}Fe_{0.2}$ contacts were swept, and Ti/Au contacts were grounded. The measurements revealed not Schottky but Ohmic behavior in all devices. The resistance increased with increasing Ga composition x (6.0×10^1, 1.5×10^2, 4.0×10^2, and 1.8×10^3 Ω for x = 0.1, 0.2, 0.3 and 0.4). The trend looks almost same as that in Hall measurements. Thus, in this study, $Co_{0.8}Fe_{0.2}$ contacts look almost independent of Ga composition x of $In_{1-x}Ga_xAs$. This systematic understanding provides valuable design insights for future semiconductor-based spin devices.

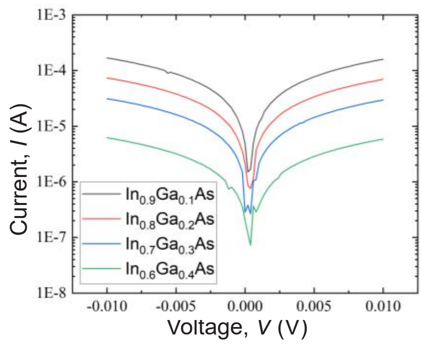

Fig.3. *I-V* curves.

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Photocurrent Characteristics of bulk-layer MoS_2 Photodetectors

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Two-dimensional (2D) materials, owing to their reduced dimensionality, exhibit pronounced quantum confinement effects and are therefore widely regarded as quantum materials. These materials are only a few atoms thick, and the atomically thin layers are bonded together by van der Waals interactions. Molybdenum disulfide (MoS_2) is a typical 2D quantum material composed of three atoms, with molybdenum sandwiched between two sulfur atoms.[1] Compared with traditional materials, MoS_2 shows good physical flexibility, high light absorption efficiency, and a tunable bandgap. The bandgap of MoS_2 changes from about 1.2 eV in the bulk layer (indirect) to about 1.8 eV in the monolayer (direct), reflecting its strong quantum confinement and enabling versatile control over its electronic properties. It is widely used in the field of photodetectors. Photodetectors are sensor devices that convert light signals into electrical signals. Materials absorb photons to generate electron–hole pairs, which are separated by an external electric field to produce a photocurrent. In recent years, most studies have focused on monolayer MoS_2. However, in this study, the main focus is on bulk layer MoS_2 to investigate its photoconductive properties and evaluate its potential for photodetector applications.

MoS_2 was mechanically transferred onto a SiO_2/Si substrate. The flake thickness was preliminarily estimated under a microscope, and suitable flakes were selected as the targets. Lithography was then used for patterning. The Ti/Au electrodes were fabricated using electron beam evaporation. The device was designed with an electrode width of about 3 μm and a channel length of approximately 2 μm. Electrical characterization was performed using a B1500A semiconductor parameter analyzer. The measurements were carried out both in the dark and under illumination with a green laser (523 nm). Finally, Raman spectroscopy was used to accurately determine the number of MoS_2 layers.

From the Raman spectrum, the calculated peak separation between the two characteristic modes was approximately 25.32 cm^{-1}, which corresponds to bulk-like MoS_2 layers according to previous reports. The *I*–*V* characteristics show nonlinear behavior, indicating Schottky-like contacts rather than ideal Ohmic ones. Under illumination, the current increases compared to the dark state, and the difference becomes larger with higher bias voltage, suggesting efficient carrier collection. The photocurrent ($I_{ph} = I_{illumination} - I_{dark}$) also increases with bias voltage, as shown in Fig.2. The photocurrent level is on the order of 10^{-6}–10^{-7} A at a 1 V bias, which is slightly higher but comparable to values reported[2] for monolayer MoS_2 photodetectors.

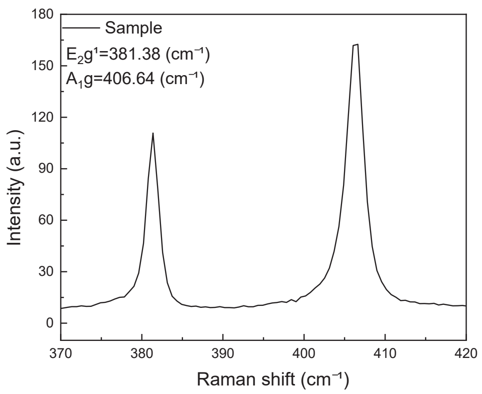

Fig.1 Raman spectrum of MoS_2

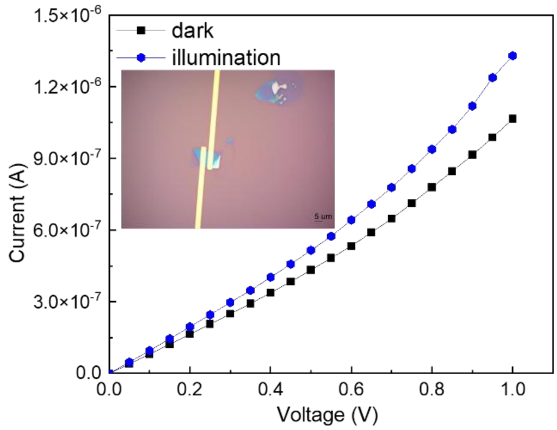

Fig.2 I–V characteristics of MoS_2

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Preparation for the establishment of DEER measurements for detecting electron spins on the sample side using a scanning NV probe microscope

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The nitrogen–vacancy (NV) center in diamond is a solid-state defect possessing a stable spin-triplet electronic ground state at room temperature, whose quantum state can be optically read out through optically detected magnetic resonance (ODMR) [1]. Quantum sensing and quantum imaging techniques utilizing its spin properties have attracted considerable attention in recent years [2]. In particular, the double electron–electron resonance (DEER) method, which employs dipolar interactions between spins in combination with magnetic resonance techniques, has been used as an effective approach for spin detection via the NV center [3]. In this study, we aim to establish DEER measurements for detecting electron spins not in a probe but on the sample side using a scanning NV probe (Fig. 1). Recently, DEER measurements detecting electron spins located within or on the surface of scanning NV probes have been reported [4]; however, DEER measurements targeting electron spins inside or on the surface of samples have not yet been realized. As a preparatory step toward realizing DEER measurements for detecting electron spins on the sample side using a scanning NV probe, we first perform DEER spectroscopy and DEER-Rabi oscillation measurements via NV center to detect nitrogen electron spins (P1 centers) existing within a diamond fragment, using NV centers embedded in the same diamond fragment as a probe (Fig. 2).

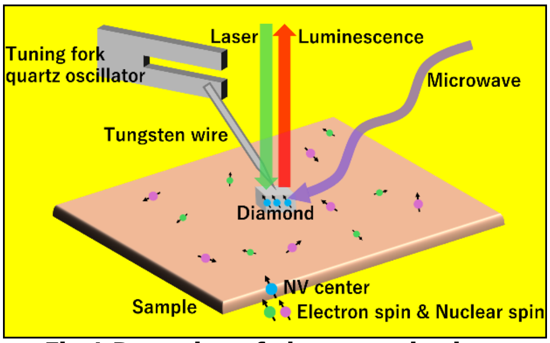

Fig.1 Detection of electron spins in a sample using a scanning NV probe.

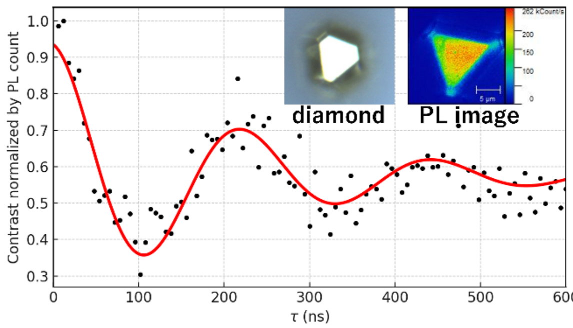

Fig.2 A DEER Rabi oscillation of P1 electron spins in the diamond fragment sample.

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Towards nanoscale MRI with unpaired electron spins on the tip of a scanning diamond NV probe

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Magnetic resonance imaging (MRI) has played a significant role in understanding physical, chemical, and biological processes by non-invasively imaging the internal structure of materials in three dimensions. Conventional MRI relies on inductive coils to detect weak nuclear spin signals, limiting its resolution to about 1 μm [1]. Recent advancements in scanning diamond nitrogen-vacancy (NV) probe microscopy (SNVM) have enabled imaging of electron spins or magnetization with a practical maximum resolution of around 10 nm, constrained by the distance between the NV spin and the sample [2]. The presence of noise-inducing unpaired electron spins on the surface of a diamond NV probe, originating from dangling bonds, and so on, has been the limiting factor in bringing the NV centers closer to the diamond surface. Here, we propose utilizing the coherent controlled unpaired electron spins on the surface of an SNVM tip as a quantum reporter [3, 4] to mediate the detection of nuclear spins by an NV center, overcoming the distance barrier that limits SNVM resolution. As a first step toward implementing the proposed method, we present measurements and control of unpaired electron spins on the SNVM tip using the double electron-electron spin resonance (DEER) protocol. DEER spectroscopy confirms the presence of unpaired electron spins through a magnetic resonance spectrum with a Landé g-factor of 2. The DEER Rabi oscillation demonstrates coherent control of unpaired electron spins, which is essential for detecting nearby nuclear spin species in the proposed nanoscale MRI.

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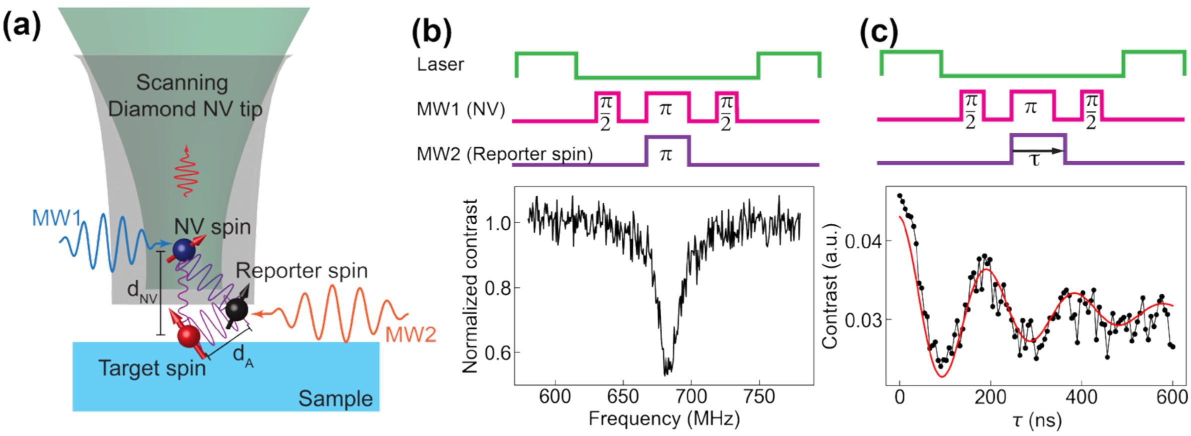

Fig. 1. (a) Schematic of the proposed nano MRI method, where an unpaired electron spin on the surface of an SNVM tip serves as a quantum reporter mediating the interaction between the target spin and the NV spin, therefore overcoming the distance barrier limiting the resolution of an SNVM. (b) DEER spectroscopy pulse sequence (top) and DEER spectrum (bottom) of electron spins on the surface and an SNVM tip. (c) DEER Rabi sequence (top) and Rabi oscillation of the electron spin on the surface of an SNVM tip.

B-06

Spin-Flip Transition Phenomena of Guests in the van der Waals Gaps of Magnetic Intercalation Compounds

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Transition-metal dichalcogenides (TMDC) TX_2 are layered X-T-X frameworks stacked by van der Waals (vdW) forces; some guest atoms can be intercalated into the vdW gap. The TMDC is currently attracting attention, owing to their strong spin–orbit coupling and the quantum-geometric Berry curvature that governs a variety of transport phenomena.

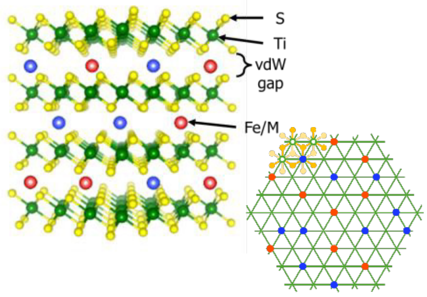

Fig.1 Structure of $(Fe_yM_{1-y})_{0.33}TiS_2$.

We investigate magnetic intercalation compounds M_xTiS_2 (M = Mn, Fe, Co and Ni; $0 \leq x \leq 0.50$), in which $3d$ magnetic atoms are intercalated into the vdW gaps of the 1T -TiS_2 host lattice (Fig.1). In order to elucidate the effect of guest-guest interactions, we synthesized and characterized cointercalation compounds $(Fe_yM_{1-y})_{0.33}TiS_2$ with two different atoms.

The single crystals were grown by chemical vapor transport using Iodine as a transport agent. The magnetization M measurements were performed on stacked single crystals with the magnetic field applied parallel to the c-axis using MPMS-XL (Quantum Design Inc.). The magnetoresistance (MR) and Hall resistivity were measured by rectangular shape (approx.1 mm ×3 mm), terminals were attached, a magnetic field was applied along the c-axis, and Hall resistance was measured using PPMS.

Figure 2 shows the magnetic field dependence of M and MR for $Fe_{0.25}TiS_2$. The magnetization exhibits a typical hysteresis curve, indicating that the magnetic moments of Fe atoms display ferromagnetic ordering in the vdW gap. In Fig. 2(a), as the applied field increases from –5 T to 5 T, the magnetization abruptly switches from –100 emu/cc to 100 emu/cc at the coercive field H_C, corresponding to a spin-flip transition from up-spin to down-spin.

Figure 2(b) shows the MR associated with the M process in Fig. 2(a). The magnetoresistance displays a distinctive "butterfly pattern", which is characteristically observed in Tunnel MR and Giant MR (GMR) devices used in magnetic read-head applications. The $\Delta\rho\ \rho_0^{-1}$ increases continuously and drops sharply at H_C due to the spin-flip transition, then decreases symmetrically.

We also observed MR changes associated with magnetic-field dependent spin flipping in magnetic intercalation compounds, similar to those in GMR devices.

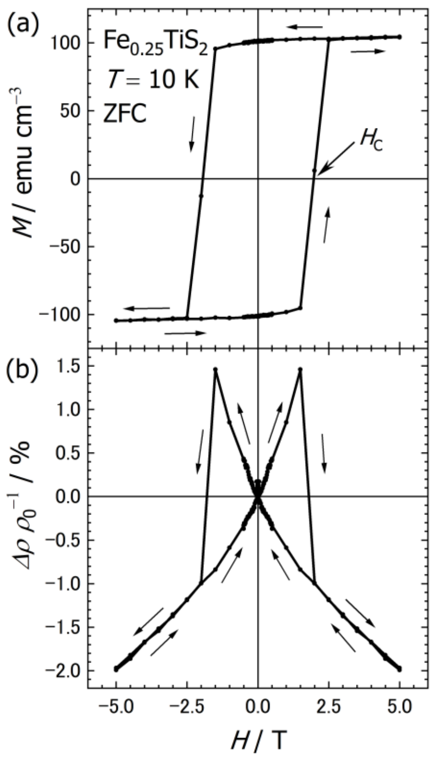

Fig. 2 Field-dependence of (a) magnetization and (b) magnetoresistance for $Fe_{0.25}TiS_2$.

We are ongoing the measurement for other intercalation compounds M_xTiS_2 (M =Mn, Fe, Co, and Ni), and cointercalation compounds. The presentation will focus on these quantum-transport characteristics.

B-07

Effect of channel materials on performance in one dimensional Zeeman-type spin -polarizers

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Zeeman-type spin-polarizer is a device designed to generate spin-polarized current using quantum effects and it is attracting attention for spintronic device applications [1-4]. Figure 1 shows a schematic illustration of the spin-polarizer. It consists of a ferromagnetic (FM) nanomagnet and a nanoscale gate electrode on a semiconductor channel, separated by an insulating layer. The electron current flows from left to right, and the magnetization of the FM nanomagnet is perpendicular to the current flow. One of the major challenges for the spin-polarizer is its operating temperature; the device cannot operate at 5.0 K or higher [1, 3]. Recently, we theoretically demonstrated the potential to enhance thermal stability by decreasing the channel dimension and applying voltage to the FM nanomagnet [4]. However, for operating in higher temperatures, these improvements are insufficient. In this study, we investigate the effect of channel materials on performance in one-dimensional spin-polarizers using theoretical calculations.

We focused on InAs and InSb nanowires (NWs) as one-dimensional electron gas channels, using CoFe as the FM nanomagnet material. In the device performance calculation, we applied a spin-dependent two-current model that incorporates the tunneling process. This model accounts for the Zeeman effect induced by the magnetic field and vector potential from the FM nanomagnet, as well as the field effect by the electrostatic potential from Gate 1 (FM nanomagnet) and Gate 2 (nanoscale gate electrode). Spin-polarization P was calculated by $P = (\sigma\uparrow - \sigma\downarrow) / (\sigma\uparrow + \sigma\downarrow)$, where $\sigma\uparrow$ and $\sigma\downarrow$ are the conductance components of up- and down-spin, respectively. Figure 2 shows spin-polarization as a function of Gate 2 voltage for (a) InAs NW and (b) InSb NW channels at V_{Gate1} = -35.0 mV. Spin polarization is oscillating by changing the Gate 2 voltage. The spin-polarization in the InSb NW channel can be modulated from -60% to +40% at 5.0 K, which is higher than that in the InAs NW channel. This large spin polarization is attributed to the stronger Zeeman effect in InSb, resulting from its larger effective g-factor and smaller electron effective mass. These results suggest superior performance compared to that in the previous work. Consequently, selecting a channel material to enhance the Zeeman effect is a promising approach to improve the thermal stability of Zeeman-type spin-polarizers.

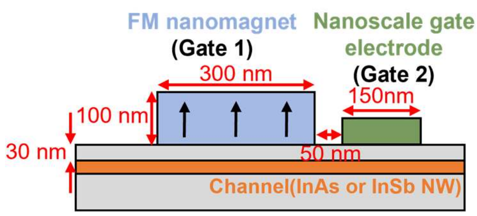

Fig. 1 Schematic illustration of the spin-polarizer.

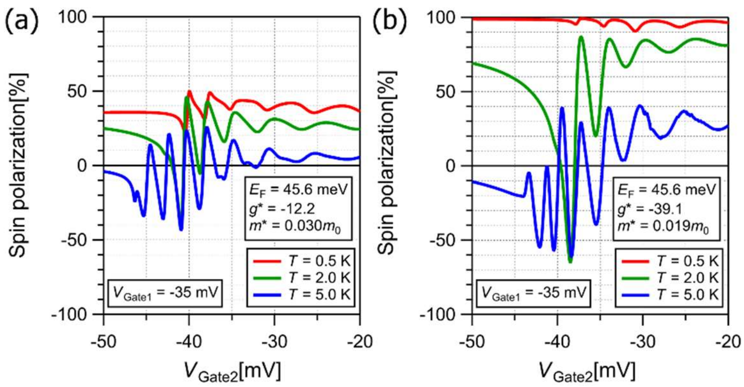

Fig. 2 spin-polarization as a function of Gate 2 voltage for (a) InAs NW and (b) InSb NW

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B-08

Fabrication and Characterization of An FET Using An InAs Nanowire Grown on HSQ Masked GaAs

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InAs nanowires (NWs) are attracting significant interest as a promising channel material for quantum devices [1], such as spin field-effect transistors (FETs). This is attributed to the combination of the outstanding physical properties of InAs, such as high electron mobility, large spin-orbit coupling, etc., and the advantages of the one-dimensional NW structures. In this presentation, we focus on the selective area growth of InAs NWs using hydrogen silsesquioxane (HSQ) masks. As published literature on InAs NW growth utilizing HSQ masks is limited, we report on the fabrication and characterization of InAs NWs grown using this technique. Figure 1 shows a schematic illustration of an InAs NW FET fabricated in this study. The InAs NWs were grown on HSQ masked GaAs(001) using molecular beam epitaxy, as shown in Figure 2. The growth conditions were a III/V ratio of 400, a growth temperature of 400°C, and a growth time of 4 hours. The grown NWs, with a diameter of approximately 110 nm, were suspended into isopropyl alcohol and subsequently dispersed onto an Si/SiO_2 substrate, which was pre-patterned with Ti/Au position markers. The relative positions of the dispersed NWs and the markers were measured by scanning electron microscopy (SEM). Electrode patterns were subsequently formed using electron beam lithography. Ti/Au electrodes were deposited using electron cyclotron resonance sputtering. Figure 3 shows an SEM image of the fabricated InAs NW FET. The field-effect mobility was calculated from the obtained transfer characteristics and the capacitance. It was calculated from the analytical expression corresponding to the capacitance of a cylindrical wire on a planar substrate. As shown in Figure 4, the field effect mobility was 10100 cm^2/Vs. This value is remarkably high[1][3]. We believe this exceptional mobility is expected to pave the way for the development of next-generation, ultra-fast electronic devices and spintronic devices.

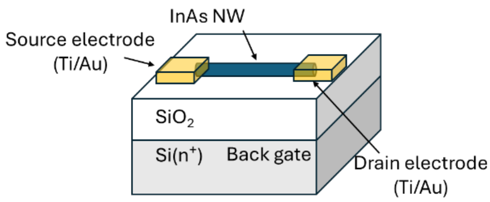

Fig. 1 Schematic illustration of the InAs NW FET.

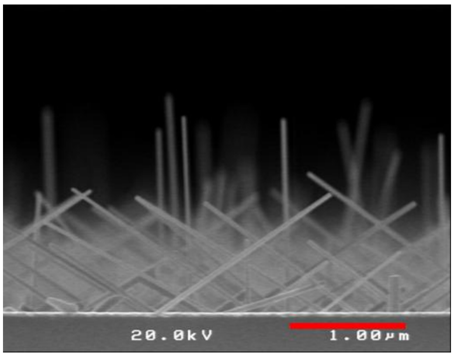

Fig. 2 SEM image of InAs NWs. The scale bar colored by red is 1 μm.

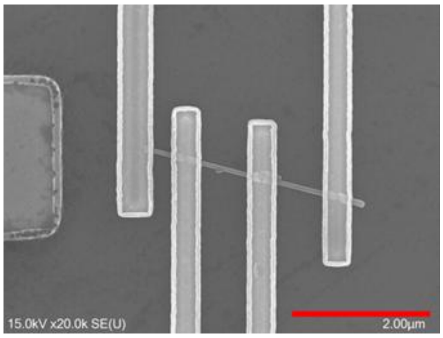

Fig. 3 SEM image of the InAs NW FET. The scale bar colored by red is 2 μm.

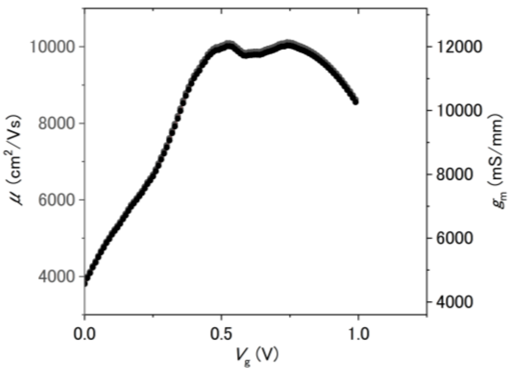

Fig. 4 The field effect mobility of the InAs NW FET.

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Towards magnetic noise imaging from Fe_3O_4 superparamagnetic particles using a scanning NV probe microscope

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Quantum sensing is attracting attention as a technology that enables high-sensitivity measurements inaccessible by conventional classical sensors. Nitrogen-vacancy centers, lattice defects consisting of nitrogen and its neighboring vacancies in a diamond lattice, have a long coherence time at room temperature and can be coherently manipulated by microwave pulses, enabling optical initialization and readout of spin states. Thus, NV centers have been extensively studied as quantum sensors that can operate at room temperature.

NV centers can be used for optical readout of spin states and magnetic measurements using confocal microscopy. We have developed a scanning NV probe microscope by combining a probe with an ensemble of NV centers attached to the tip apex of a tungsten needle and an atomic force microscope based on a quartz oscillator (Fig.,1,2) [1]. The scanning NV probe enables magnetic imaging with nanoscale spatial resolution without being affected by the diffraction limit of the irradiating laser, using ultimately a single NV center [2].

First, we tested a measurement of the magnetic noise from superparamagnetic core-shell particles of Fe_3O_4 through T_1 measurement with ensemble NV centers in bulk diamond (Fig.3) [3]. Next, we try to measure magnetic noise from a superparamagnetic particle of Fe_3O_4 in the shell part by using a scanning NV probe. We will report on the results obtained in more detail.

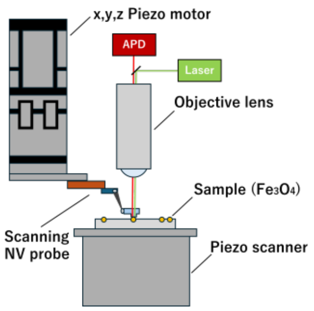

Fig.1 Experiment setup for scanning NV probe microscopy

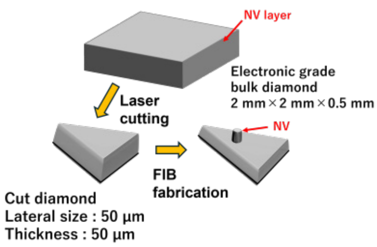

Fig.2 Fabrication process of diamond

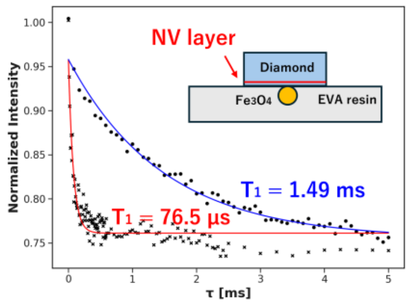

Fig.3 Effect of superparamagnetic particles on NV layer. A bulk diamond with NV layer was placed on a superparamagnetic particle, and T1 of NV layer proximal to the particle was compared with NV's T1 value far away from the particle.

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Programmable Photonic Extreme Learning Machine Using Multiport Directional Couplers

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Programmable silicon photonic circuits provide an energy efficient platform for hardware machine learning accelerators. In this work, we present a programmable photonic extreme learning machine (ELM) implemented using multiport directional couplers with thermo-optic phase shifters. The circuit realizes a wavelength dependent linear transformation of the optical fields propagating inside the circuit, with the inputs encoded through phase shifters, while the required nonlinear activation is supplied by the square-law response of the photodetectors, which convert coherent field interference inside the mesh into nonlinear optical to electrical outputs.

To expand the dimensionality of the ELM feature space, we explore a multiwavelength strategy, in which each optical wavelength experiences a distinct transfer matrix within the programmable mesh. Because the interferometric circuit is inherently wavelength dependent, probing the same input pattern at multiple wavelengths naturally produces several decorrelated optical transformations without requiring any additional photonic hardware. We experimentally demonstrate the full operation of the system, including spatial optical encoding, multiwavelength photonic transformation, detection at the photodiode, and linear readout. We evaluate the separability of Fashion-MNIST features obtained from the device. Our measurements show that using multiple wavelengths increases feature diversity and enhances linear separability, demonstrating the potential of programmable photonic meshes for optical machine learning.

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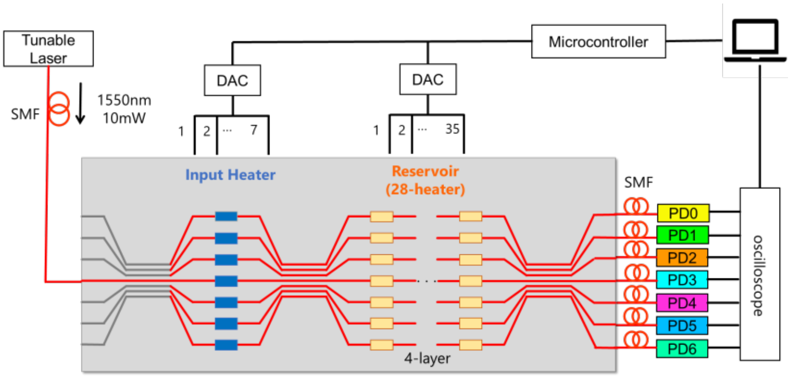
Figures and figure captions



Experimental Setup.

Quantum-Enhanced U-Net for Signal Waveform Separation

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Japan Advanced Institute of Science and Technology, Japan.

High-fidelity audio source separation is a cornerstone for next-generation signal processing and acoustic analysis. However, classical deep learning protocols face a fundamental trade-off between minimizing model complexity and maximizing the capture of global spectral correlations. Existing state-of-the-art Quantum Machine Learning (QML) methods, such as Quantum Denoising Diffusion Models [1][3], provide robust generative capabilities but do not inherently optimize for inference speed, often suffering from sampling noise. This limitation can create a bottleneck for real-time or high-precision audio applications.

To address this critical gap, we propose the Quantum-Enhanced U-Net, a novel and hybrid architecture designed to extend the classical CNN framework. By integrating a Variational Quantum Circuit (VQC) into the bottleneck layer, our model is designed to transform the feature extraction process into a high-dimensional Hilbert space mapping. Theoretically, this approach allows for balancing parameter efficiency with precise vocal isolation [2]. In this work, we present the detailed architectural design and the forward pass mechanism of the hybrid network. We anticipate that this quantum-classical synergy will significantly reduce parameter complexity compared to standard U-Nets while maintaining high Signal-to-Distortion Ratio (SDR) and preserving phase information. This research lays the groundwork for scalable quantum neural networks in audio signal processing.

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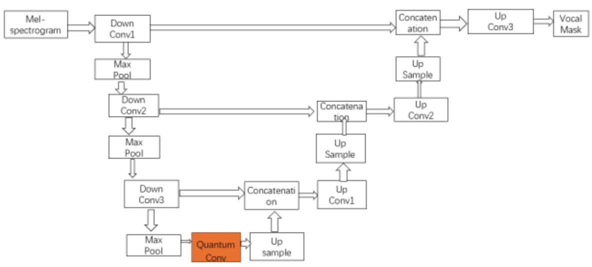

*Fig 1. Overview of the proposed **Quantum-Enhanced U-Net architecture**, integrating a Variational Quantum Circuit (VQC) as the bottleneck layer within a classical U-Net framework.*

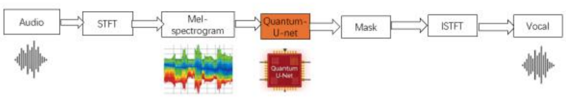

Fig 2. The end-to-end signal processing pipeline, illustrating the transformation from raw audio to Mel-spectrograms, quantum processing, and waveform reconstruction via Inverse STFT.

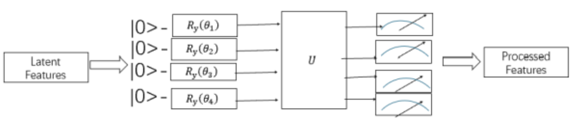

Fig 3. Schematic of the Variational Quantum Circuit (VQC) used in the bottleneck layer, featuring angle embedding (R_y) and entanglement operations for feature mapping.

Multi-Source Evidence Integration for Uncertainty-Aware Decision-Making in Materials Discovery

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Uncertainty quantification represents a fundamental challenge across materials science, manifesting in diverse contexts from compositional design to structural characterization. In materials discovery, researchers must navigate vast design spaces with limited experimental data while making rational decisions about candidate selection under resource constraints [1]. In materials characterization, incomplete or ambiguous measurements introduce uncertainties that complicate structural determination. These challenges share a common requirement: systematic frameworks for quantifying uncertainty and integrating evidence from multiple sources to support reliable decision-making [2].

We present a materials informatics framework that explicitly models uncertainty and systematically integrates evidence from heterogeneous knowledge sources to enhance prediction reliability beyond traditional interpolation limits. The framework distinguishes between aleatoric uncertainty—arising from inherent randomness and measurement variability—and epistemic uncertainty—stemming from incomplete knowledge that can be reduced through additional information [3]. Dempster-Shafer theory provides the mathematical foundation for rigorous uncertainty quantification and evidence fusion, enabling predictions that extend beyond conventional data boundaries while maintaining interpretable reasoning [4].

The methodology integrates multiple complementary knowledge sources including data-driven predictions with explicit uncertainty bounds, domain expertise from scientific literature, and physics-based principles governing material stability. This multi-source integration approach enables extrapolation to novel compositional or structural regions while providing quantified confidence estimates for each prediction. We examine the proposed framework across multiple material domains including solvent systems, high-entropy alloys, and magnetic material structures. The results demonstrate that multi-source models exhibit superior performance compared to conventional single-source approaches in both exploitation tasks—maximizing performance based on existing knowledge—and extrapolation tasks—predicting properties in novel compositional regions beyond the training data distribution. The framework provides interpretable insights, and quantified uncertainty estimates that support rational decision-making in materials design.

This uncertainty-aware methodology addresses fundamental challenges common across materials research where prediction reliability under incomplete information critically impacts experimental resource allocation. Beyond compositional design applications, the framework's systematic approach to uncertainty quantification and evidence integration offers a generalizable strategy for diverse materials challenges. The methodology is applicable to problems where measurement ambiguities or data limitations introduce similar decision-making requirements. These include advanced characterization techniques for complex material structures at multiple length scales and compositional design challenges in emerging functional materials such as quantum materials where data scarcity and uncertainty management are critical.

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Material Dynamics Analysis with Deep Generative Model

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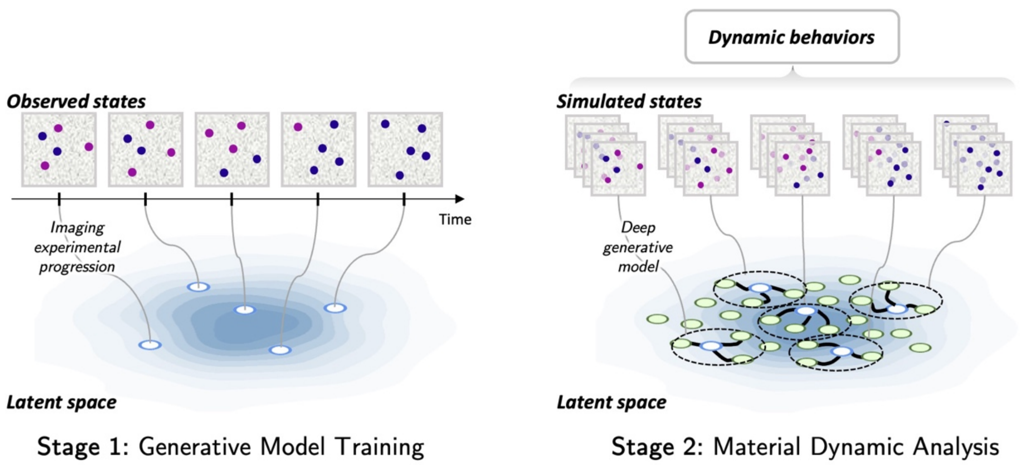
Understanding nanoscale material evolution—including phase transitions, structural deformations, and chemical reactions—under dynamic conditions remains a fundamental challenge in materials science. While advanced imaging techniques enable visualization of transformation processes, they typically capture only discrete temporal observations at specific time intervals. Consequently, intermediate stages and alternative pathways between captured images often remain unresolved, introducing ambiguity in analyzing material dynamics and transformation mechanisms. To address these limitations, we present a two-stage framework using deep generative models to probabilistically reconstruct intermediate transformations. Our framework is based on the hypothesis that generative models trained to reproduce experimental images inherently capture the dynamical processes that generated those observations. By integrating these trained generative models into Monte Carlo simulations, we generate plausible transformation pathways that interpolate unobserved intermediate stages. This approach enables the extraction of meaningful insights and the statistical analysis of material dynamics. This study also evaluates the framework's applicability across three phenomena: tantalum test chart translation, gold nanoparticle diffusion in polyvinyl alcohol solution, and copper sulfidation in heterogeneous rubber/brass composites. The generated transformations closely replicate experimental observations while revealing previously unrecognized dynamic behaviors for future experimental validation. These findings suggest that learned generative models encode physically meaningful continuity, enabling statistical interpolation of unobserved intermediate states and classification of transformation modes under sparse observational constraints



Conceptual framework for material dynamics analysis

From Data to Knowledge: LLM-Guided Interpretable Rule Mining for Materials Discovery

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Abstract:

High-throughput computational screening has generated extensive structural databases spanning millions of candidate materials [1]. However, a fundamental challenge persists: while predictive models can identify promising candidates, they rarely elucidate the underlying design principles governing structure-property relationships. This opacity hinders knowledge accumulation and limits researchers' ability to generalize insights across materials families [2]. The central challenge is not merely prediction accuracy but rather the systematic transformation of numerical structural data into human-interpretable design principles that advance scientific understanding and enable rational design strategies.

We address this challenge through a systematic framework that leverages large language models for interpretable rule extraction from structural databases [3]. The methodology comprises three stages: (1) automated identification of local atomic motifs through geometric analysis across candidate structures, (2) correlation analysis linking these motifs to target properties, and (3) LLM-mediated articulation of identified correlations as natural language design rules. This approach bridges numerical pattern recognition with symbolic knowledge representation, producing explicit rules that encode structure-property relationships in forms accessible to domain experts. Critically, the framework generates falsifiable hypotheses that researchers can validate experimentally and refine iteratively.

We demonstrate the framework on rare-earth permanent magnets, a materials class where magnetic properties depend sensitively on local coordination environments. Analysis of candidate structures reveals quantitative design rules relating coordination polyhedra to magnetic anisotropy. For instance, extracted rules specify how rare-earth site symmetry and nearest-neighbor distances influence uniaxial anisotropy—providing actionable criteria for composition optimization. These rules successfully rationalize known high-performance compositions and suggest previously unexplored design directions. The interpretable nature of extracted rules enables domain experts to assess their validity, incorporate additional physical constraints, and guide targeted synthesis efforts.

This work demonstrates a paradigm for integrating materials science, information science, and knowledge science through systematic knowledge extraction from data. The LLM functions not as a replacement for domain expertise but as an analytical tool that systematically identifies and articulates patterns exceeding human cognitive capacity to detect manually in high-dimensional databases. The framework is generalizable across materials discovery domains requiring interpretable structure-property relationships. Applications extend beyond magnetic materials to diverse functional materials classes, including those for quantum technologies where limited experimental data necessitates efficient extraction of design principles to guide resource-intensive characterization and synthesis efforts.

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Reconstructing Nanoscale Structures from Sparse Experimental Data: A Generative Modeling Framework Toward Quantum Material Characterization

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Advancing quantum technologies—from superconducting qubits to quantum sensors and nanoscale devices—demands precise characterization of material structures, defect configurations, and interface properties across multiple length scales. However, experimental datasets in quantum material research are often sparse, noisy, and challenging to interpret, limiting our ability to understand phenomena critical to quantum coherence and device performance [1]. Here, we present a generative AI framework designed to reconstruct and simulate micro- and nanoscale structures from incomplete or noisy experimental observations. The hybrid architecture leverages variational encoding for robust latent feature extraction and adversarial training for high-fidelity simulation, enabling the model to learn physically meaningful representations of complex material structures. We demonstrate the framework's versatility across diverse material systems: reconstructing and simulating Cu clump states from 3D spectroimaging of copper sulfidation in heterogeneous rubber/brass composites [2], and generating realistic gold nanocontact structures from 2D TEM images [3]. These applications—spanning bulk heterogeneous materials to nanoscale metallic junctions—highlight the framework's flexibility and its potential for broader quantum material characterization, including defect analysis in quantum devices and interface engineering in superconducting systems. This generative approach offers a scalable computational tool for quantum science applications—enabling researchers to extract meaningful information from limited experimental data, explore latent representations of material states, and accelerate the design and optimization of quantum materials, devices, and sensors.

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C-07

Physical Reservoir Sensing for Capturing high-Speed Dynamics

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1.Introduction

In modern science and technology, the ability to measure high-speed and high-frequency signals is required in a wide range of fields, including communications, radar, quantum metrology, biosensing, materials characterization, and astronomy. However, as the signal frequency increases, sensors cannot follow components outside their limited bandwidth, causing high-frequency information to be lost. This inability to capture out-of-band signal content has become a major bottleneck in many scientific fields.[1,2]

Conventional high-speed sensors face a fundamental trade-off between bandwidth and sensitivity: widening the bandwidth typically reduces sensitivity and SNR.[3] Higher bandwidth also demands more complex and costly supporting electronics. Moreover, existing high-frequency measurement techniques—such as equivalent-time sampling and compressed sensing—often require assumptions about the signal (e.g., periodicity or sparsity) or specialized hardware, limiting their practical applicability.

In this study, we propose a reservoir-computing–based framework[4] that enables high-speed signal measurement using multiple low-bandwidth sensors. The proposed method offers four major advantages:

- **Effective bandwidth extension:**
  Low-bandwidth, inexpensive sensors can measure frequency components far beyond their intrinsic limits, while wide-bandwidth sensors can further expand their measurable range.
- **High scalability:**
  In theory, the achievable bandwidth expansion scales linearly with the number of sensors, meaning that adding more sensing channels increases the measurable frequency range in direct proportion.
- **Low implementation cost:**
  High-speed measurement can be achieved using inexpensive low-bandwidth sensors, whose cost decreases rapidly with narrower bandwidth. In addition, reservoirs can be easily realized in many physical platforms, offering flexible and low-cost implementation.
- **Minimal assumptions on signal structure:**
  Unlike conventional techniques that require periodicity, sparsity, or other structural constraints, the method can capture single-shot events and complex, non-repetitive waveforms.

Taken together, this method overcomes long-standing physical and economic constraints of existing technologies and provides a new framework for bandwidth expansion, enabling low-cost and high-accuracy measurement of diverse high-speed phenomena.

2.Method

In the proposed method, a high-speed signal is first injected into a reservoir—a dynamical system that produces diverse temporal responses through its internal interactions. As illustrated in Fig. 1, the reservoir spreads the input across multiple response channels, and each resulting output is measured using a set of narrow-bandwidth sensors. In this setting, the sensor bandwidth B_{sensor} is much smaller than the bandwidth of the target signal B_{sig}. Although each sensor individually detects only a low-bandwidth, distorted version of the signal, the original high-speed waveform can be reconstructed by applying linear regression to the collection of reservoir outputs.

Next, we describe the training and testing procedures. In the training phase, a set of broadband random signals is prepared as training data, where each signal is independently generated. The system reconstructs these signals, and the readout weight www is optimized so that the reconstructed outputs closely match the original inputs. In the test phase, we evaluate the generalization capability of the system using either new random signals or various types of waveforms that were not included in the training dataset.

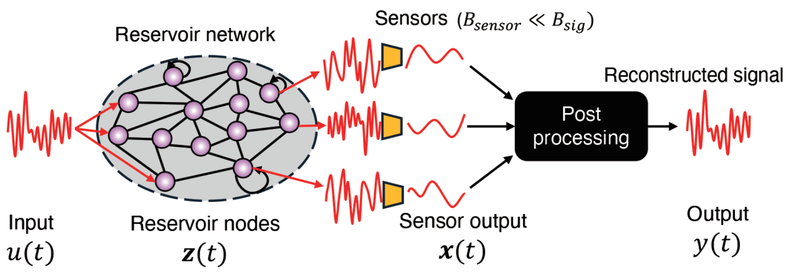

Fig.1 Proposed method diagram.

To demonstrate the effectiveness of this general framework, we implemented the reservoir using an optical cavity structure and conducted experiments with the setup shown in Fig. 2. In this optical implementation, a 10 GHz optical signal was fed into a photonic reservoir chip, and the resulting distributed outputs were measured by 1 GHz-bandwidth photodetectors. This configuration allows us to evaluate whether a set of low-bandwidth photodetectors can accurately reconstruct a 10 GHz signal using the proposed method.

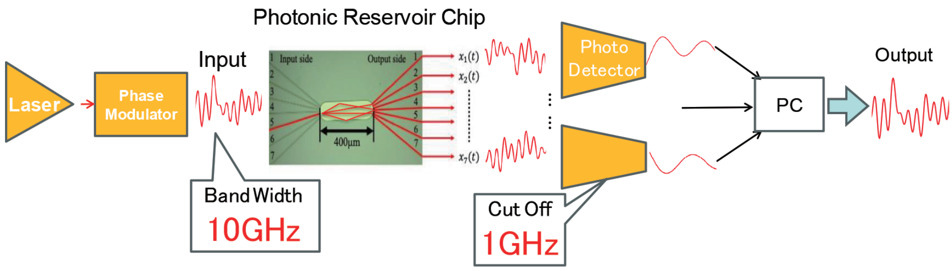

Fig.2 Experimental setup

3.Result

Figure 3 shows the experimental results, where (a) presents the signals in the time domain and (b) shows their spectra in the frequency domain.

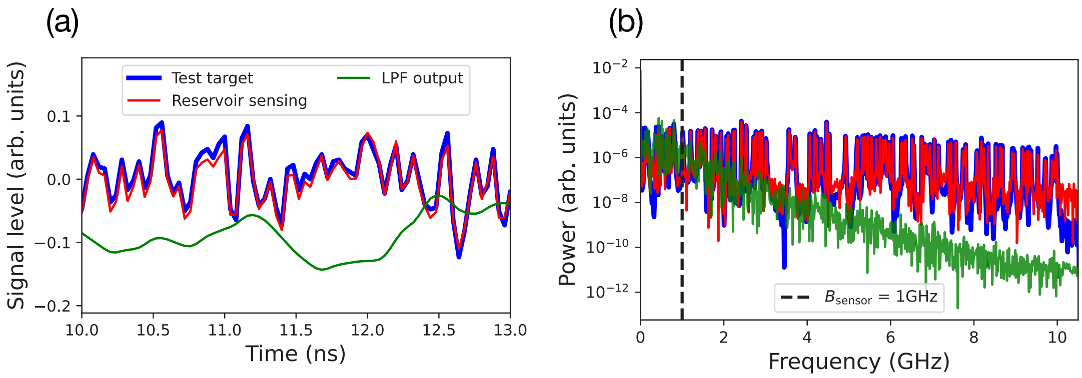

Fig.3 Experimental results: (a) Time-domain waveforms, (b) Frequency-domain spectrum.

The blue line represents the input signal $u(t)$, which is the target waveform. The green line shows the signal measured using a 1-GHz photodetector, clearly exhibiting distortion due to the detector's limited bandwidth. The red line indicates the reconstructed waveform, which closely matches the target signal in contrast to the distorted measurement. In the frequency domain, the attenuated high-frequency components are successfully recovered. These results demonstrate that the proposed method effectively expands the sensor bandwidth by a factor of ten.

Furthermore, as shown in Fig. 4, the measurement accuracy—evaluated using the normalized mean squared error (NMSE)—improves as the number of sensors increases. In other words, employing more sensing channels enables a broader effective bandwidth. Under ideal conditions, the measurable bandwidth scales linearly with the number of sensors N, allowing an N-fold expansion.

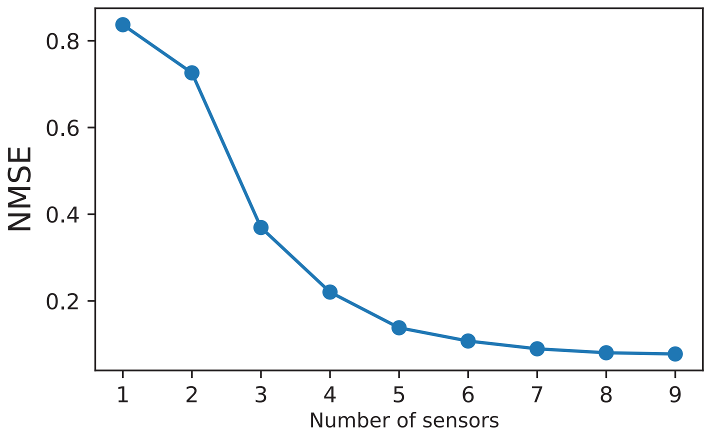

Fig. 4. Improvement in measurement accuracy with increasing sensor count.

Moreover, the proposed method exhibits strong generalization capability. During training, the system is calibrated using broadband random signals. Despite being trained solely on random inputs, the method is able to accurately reconstruct a wide variety of waveforms—as illustrated in Fig. 5 including laser chaos, Santa Fe chaos, pulses, and chirped signals.

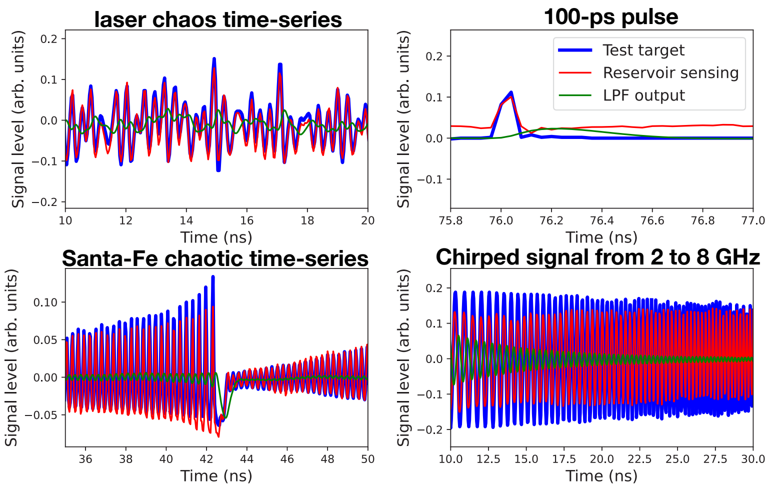

Fig. 5. Generalization capability of the proposed method.

This result indicates that the proposed approach does not require prior knowledge of the target waveform. Once trained with broadband random signals, the system can reconstruct arbitrary signal shapes, even when the signals to be measured are completely unknown in advance.

4. Conclusion

The results demonstrate that the proposed method can successfully reconstruct high-frequency information that would be lost using conventional method, thus overcoming the inherent bandwidth limitations of the optical sensor. Specifically, we have succeeded in reconstructing a high-frequency signal within the 10 GHz band using an optical sensor with a cutoff frequency of only 1 GHz. This achievement represents an effective tenfold expansion of the measurement bandwidth.

This approach has potential to provide a low-cost, high-precision measurement solution for numerous fields that necessitate the measurement of high-speed signals. It is anticipated that the proposed method will play a pivotal role in driving future technological advancements in these areas.

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