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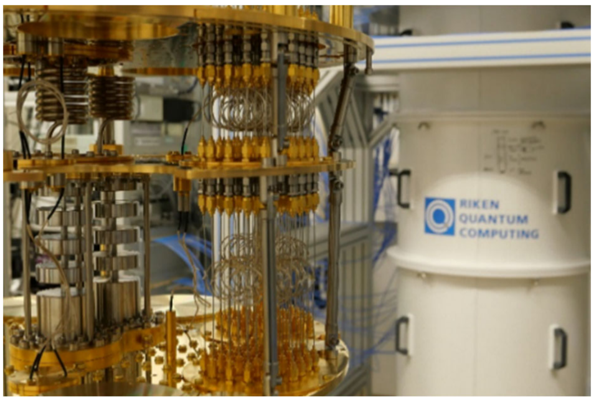
Japanese joint research group launches quantum computing cloud service

Opening access to Japan's first superconducting quantum computer

Tokyo, March 24, 2023 – A consortium of joint research partners including RIKEN, the National Institute of Advanced Industrial Science and Technology (AIST), the National Institute of Information and Communications Technology (NICT), Osaka University, Fujitsu Limited (Fujitsu) and Nippon Telegraph and Telephone Corporation (NTT) announced the successful development of Japan's first superconducting(1) quantum computer(2). Starting March 27, 2023, the partners will provide the newly developed technology to users in Japan as a cloud service for non-commercial use under a joint research agreement with RIKEN.

The new technology represents a significant step toward the wider use of quantum computing in Japan.

The joint research group is comprised of: Dr. Yasunobu Nakamura, Director of the RIKEN Center for Quantum Computing (RQC), Dr. Katsuya Kikuchi, Group Leader of the 3D Integration System Group of the Device Technology Research Institute at AIST, Dr. Hirotaka Terai, Director of the Superconductive ICT Device Laboratory at the Kobe Frontier Research Center of the Advanced ICT Research Institute of NICT, Dr. Masahiro Kitagawa, Director of the Center for Quantum Information and Quantum Biology at Osaka University, Dr. Shintaro Sato, Head of the Quantum Laboratory at Fujitsu Research of Fujitsu, and Dr. Yuuki Tokunaga, Distinguished Researcher at NTT Computer & Data Science Laboratories.



Superconducting quantum computer developed at RIKEN

Dawn of the Quantum Age: a new frontier in computing technology
Since the early twentieth century, quantum mechanics has been attracting attention as a fundamental theory of physics, laying the foundation for the development of various scientific fields. In particular, phenomena including quantum superposition and quantum entanglement(3) have contributed significantly to the development of today's science and technology. From the perspective of quantum information science, however, the potential of quantum mechanics has not yet been fully exploited. Thus, R&D to apply the fundamental principles of quantum mechanics to the technological fields of computation, communications, and measurement have been gaining momentum worldwide.

To further promote research in quantum information science, RIKEN established the Macroscopic Quantum Coherence Research Team under the lead of Dr. Jaw-Shen Tsai(4) in 2001, and the RIKEN Center for Quantum Computing under the lead of Dr. Yasunobu Nakamura in 2021, focusing on R&D in quantum computing. The Center for Quantum Computing conducts R&D not only on superconducting quantum computer hardware, but also on various physical systems including photonics research (led by Dr. Akira Furusawa)(5), semiconductor methods (led by Dr. Seigo Tarucha)(6), and methods using atoms in a vacuum. RIKEN is further promoting R&D in quantum software including quantum computing theory, quantum algorithms and quantum architecture, thus covering the entire spectrum of R&D in quantum computing.

In 2021, RIKEN and Fujitsu established the "RIKEN RQC-Fujitsu Collaboration Center" within the RQC. Research results were also utilized within the newly developed superconducting quantum computer cloud service.

RIKEN and Fujitsu will further leverage their expertise in computing technologies and applied quantum technology to provide a superconducting quantum computer for industrial use by the end of FY 2023.

Research Methods and Results
The newly developed superconducting quantum computer uses integrated circuits with 64 qubits(7) with two special features: two-dimensional integrated circuits and perpendicular wiring packages.

In the two-dimensional integrated circuits, four qubits are arrayed in a square, with each connected to its neighbors by inter-qubit connections (upper right of Fig. 1). In addition, readout resonators and filter circuits for multiple readout are arranged in the square. This basic unit consisting of four qubits can be arranged in two dimensions to form a qubit integrated circuit. The 64 qubit integrated circuit consists of 16 of these basic units formed on a two centimeter square silicon chip. (Fig. 1)

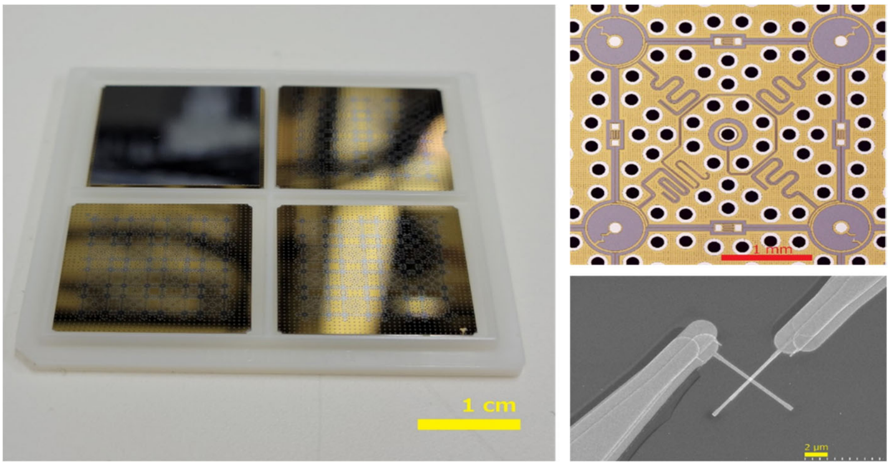


Figure 1: 64 qubit integrated circuit chip

Left: 64 qubit two-dimensional integrated circuit chip performs quantum computation. The design has 16 basic units, each comprised of 4 qubits. The titanium nitride film, which is a superconductor, gives off a gold shine.

Upper right: schematic diagram of a basic unit of 4 qubits. Qubits are arranged at the four corners of a square, and a readout circuit designed in the middle.

Lower right: electron micrograph of a Josephson junction forming a qubit.

Furthermore, if the wiring is on the same planar surface as the qubits in the system, the space of the wiring to the outside is insufficient for the number of qubits arrayed in the chip, so it is necessary to devise methods to control individual qubits and wiring for readout. Therefore, the joint research group adopted a design based on perpendicular wiring packages, in which the wiring to the chip for the qubits arrayed on a two-dimensional planar surface is perpendicularly connected. The research team is further developing a wiring package that enables the wiring to the qubit integrated circuit chip at once (Fig. 2).

Taking advantage of the features of the two-dimensional integrated circuits and perpendicular wiring packages, a highly scalable system is formed in which the number of qubits can be easily increased. This enables the large-scale of the newly developed system without altering the basic design.

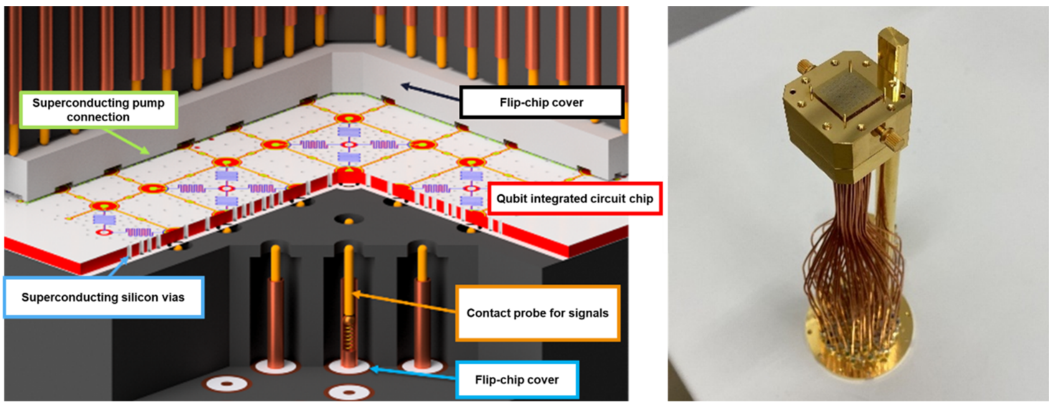


Figure 2: Perpendicular wiring packages

Left: schematic diagram of perpendicular wiring. The control and readout wiring for the qubits is perpendicularly connected to the chip via a contact probe for signals. Microwave signals are transmitted and received through the wiring.
Right: wiring package for the qubit integrated circuit chip.

The signals controlling the qubits use voltage pulses that oscillate at microwave frequencies (8-9 GHz). However, as each qubit requires a different microwave frequency, the joint research group developed a controller that can generate stable microwave phases with high precision (Fig. 3). The team also developed software for the controller that controls the qubits.

Figure 3: Qubit controller

Qubit controller consisting of an oscillator and receiver for microwave signals. The new 64 qubit quantum computer uses 96 input wires and 16 output wires for control and readouts to perform quantum calculations.

Starting March 27, 2023, RIKEN is providing the newly developed superconducting quantum computing technology as a “quantum computing cloud service” (Fig. 4) for non-commercial use to researchers and engineers in Japan under joint research agreements. Users will be able to access the new superconducting quantum computer for jobs within the scope of the joint research agreement and can send data/receive results via the cloud.

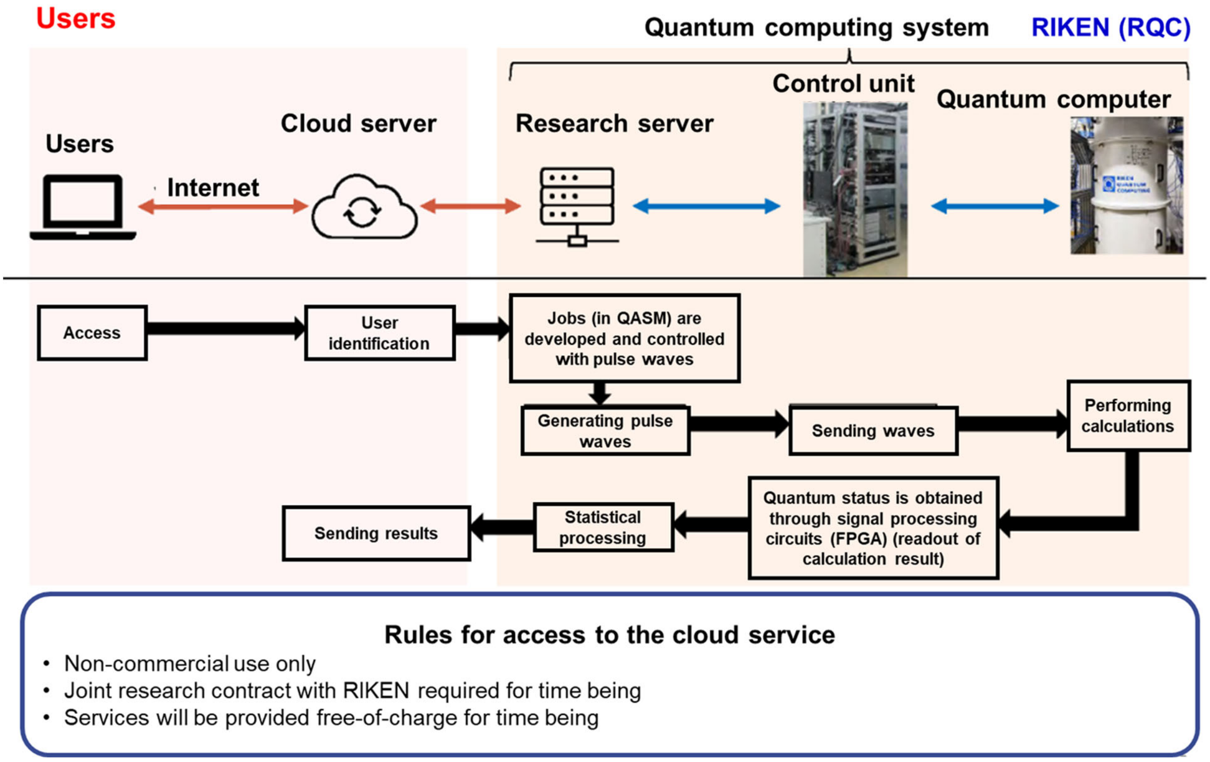


Figure 4: Image of user access to superconducting quantum computer

Authentication of registered users and job transmission/reception on a web interface.

Moving forward, the joint research group will further enhance the new system to enable quantum computing operations with a higher number of qubits and increase the density of wiring inside the dilution refrigerator (Fig. 5). The research team will further provide access to the superconducting quantum computer as a testbed for noisy intermediate-scale quantum (NISQ) computers [8].

Based on the newly developed services, the research partners will further accelerate R&D in quantum computing through deeper collaboration with quantum software developers, quantum computing researchers, and corporate developers.

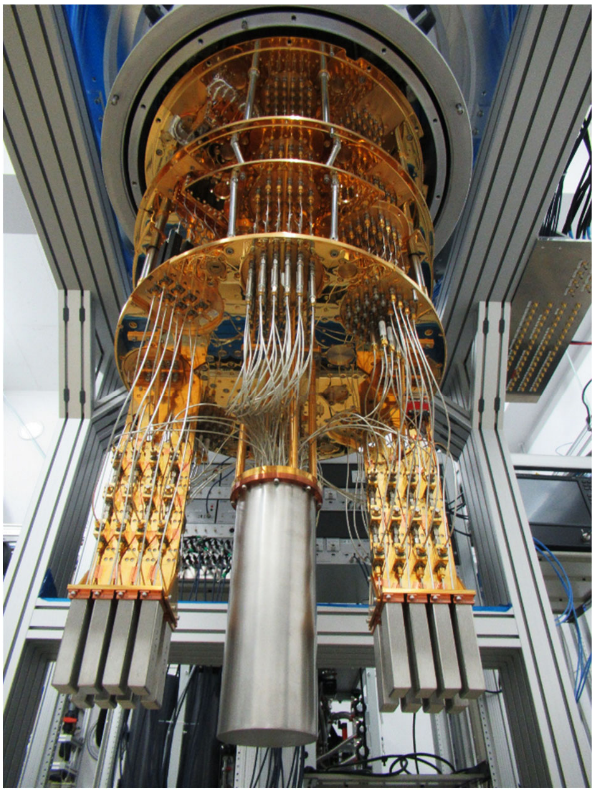


Figure 5: Wiring inside the dilution refrigerator of the 64 qubit superconducting quantum computer

A 64 qubit integrated circuit chip is placed in a central cylindrical magnetic shield to connect control and readout wiring. In operations, it is necessary to cool the periphery of the chip to about 10 mK (about -273 °C), so the entire chip is placed in a vacuum insulated container and cooled by a dilution refrigerator.

Future plans

Using the highly scalable integrated circuit (Fig. 6) as a core technology, the joint research team will continue to work toward the realization of quantum computers with 100 and 1,000 qubits, and promote further R&D toward the integration of 1 million qubits and the realization of fault-tolerant quantum computing (9) for real world application.

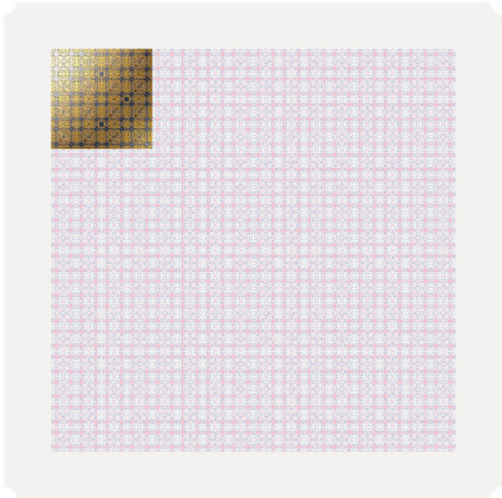


Figure 6: Future image of qubit integrated circuits
By periodically arranging basic units composed of four qubits on a planar surface, the number of integrated qubits can be increased. The figure above shows the future image of 1,024 qubits by periodically arranging 64 qubits in a 4 x 4 array.

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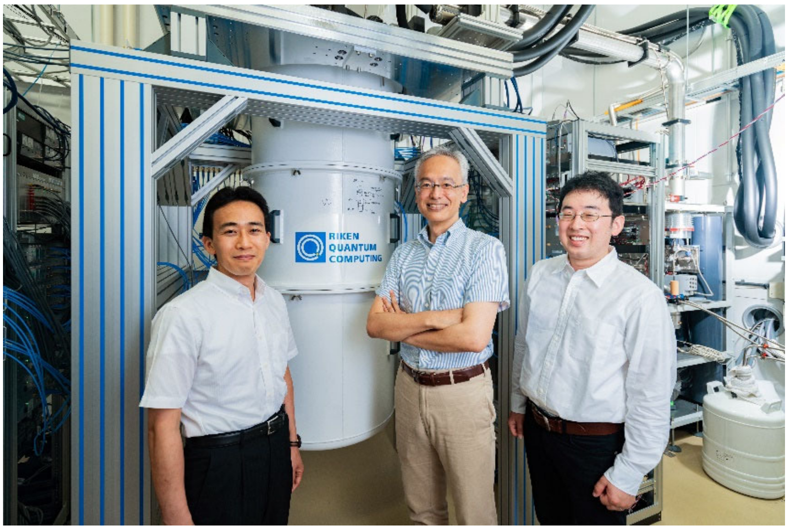

(From left): Eisuke Abe, Yasunobu Nakamura, and Yutaka Tabuchi

Notes

1. **Superconducting method:**
   A quantum computer system that uses a Josephson junction, a tunnel junction element, to realize quantum bits on an electronic circuit using a superconducting material. Because of the small scale of the energy difference of the 0 or 1 qubit state, it is necessary to cool the qubits to extremely low temperatures (to about -273°C) in a dilution refrigerator.

2. **Quantum computers:**
   Computers performing calculation based on the principles of quantum physics. By using quantum superposition and quantum entanglement that are not possible with conventional computers, quantum computers are expected to solve a variety of problems at high speed, including prime factorization or efficient simulations of quantum-like behavior such as the electronic state in molecules.

3. **Quantum superposition and quantum entanglement:**
   A phenomenon where multiple states exist at the same time, which is incompatible with how humans experience the world. Quantum entanglement is a unique correlation in quantum physics that occurs in combination with quantum superposition.

4. **Dr. Jaw-Shen Tsai:**
   Currently Team Leader of the Superconducting Quantum Simulation Research Team at the RIKEN Center for Quantum Computing

5. **Dr. Akira Furusawa:**
   Deputy Director of the Center for Quantum Computing and Team Leader of the Optical Quantum Computing Research Team

6. **Dr. Seigo Tarucha:**
   Team Leader, Semiconductor Quantum Information Device Research Team

7. **Qubits:**
   The smallest unit of quantum information. In a regular digital circuit, a bit can be in one of two states, either 0 or 1, but a qubit can be in a superposition state of 0 and 1. It can superimpose 0 and 1 for any complex numbers, and the state of a qubit schematically can be shown by an arrow displaying an arbitrary point from the center of a sphere to the surface of the sphere.

8. **Noisy intermediate-scale quantum (NISQ) computer:**
   Small or medium-sized quantum computers in which computing errors generated by noise cannot be corrected. Applications such as variational quantum algorithms are expected for practical use in the near future.

9. **Fault-tolerant quantum computing:**
   Conventional computers also cause errors, but they have the ability to correct errors in the middle of calculations. In the case of quantum computers, likewise, calculations can be conducted while correcting quantum errors. By generating quantum entanglement between multiple qubits, the information of one qubit is expressed, and by detecting the turbulence between entangled qubits, errors can be corrected without disturbing the quantum information. Fault-tolerant quantum computation means quantum computation that reduces the probability of errors occurring in the control and readout of quantum bits throughout a quantum computer, and has the ability to perform large-scale calculations while correcting errors occurring in the process of computation without accumulating the effects of errors. It is estimated that 1 to 100 million qubits are necessary for fault-tolerant quantum computing.

About RIKEN
RIKEN is Japan's largest comprehensive research institution renowned for high-quality research in a diverse range of scientific disciplines. Founded in 1917 as a private research foundation in Tokyo, RIKEN has grown rapidly in size and scope, today encompassing a network of world-class research centers and institutes across Japan.
https://www.riken.jp/en/about/

About National Institute of Advanced Industrial Science and Technology (AIST)
AIST is one of the largest public research organizations in Japan and has a history of more than 140 years. AIST focuses on the creation and practical realization of technologies useful in Japanese industry and society, working to bridge gaps between innovative technological seeds and commercialization. As a pioneer and still core player in Japan’s national innovation system, AIST manages some 2,300 specialists engaged in research and development at 11 research bases across the country.
https://www.aist.go.jp/index_en.html

About National Institute of Information and Communications Technology (NICT)
As Japan's sole National Research and Development Agency specializing in the field of information and communications technology, NICT is charged with promoting ICT sector as well as research and development in ICT, which drives economic growth and creates an affluent, safe and secure society.
For more information, please visit https://www.nict.go.jp/en/.

About Osaka University
Osaka University was founded in 1931 as one of the seven imperial universities of Japan and is now one of Japan's leading comprehensive universities with a broad disciplinary spectrum. This strength is coupled with a singular drive for innovation that extends throughout the scientific process, from fundamental research to the creation of applied technology with positive economic impacts. Its commitment to innovation has been recognized in Japan and around the world, being named Japan's most innovative university in 2015 (Reuters 2015 Top 100) and one of the most innovative institutions in the world in 2017 (Innovative Universities and the Nature Index Innovation 2017). Now, Osaka University is leveraging its role as a Designated National University Corporation selected by the Ministry of Education, Culture, Sports, Science and Technology to contribute to innovation for human welfare, sustainable development of society, and social transformation.
Website: https://resou.osaka-u.ac.jp/en

About Fujitsu
Fujitsu's purpose is to make the world more sustainable by building trust in society through innovation. As the digital transformation partner of choice for customers in over 100 countries, our 124,000 employees work to resolve some of the greatest challenges facing humanity. Our range of services and solutions draw on five key technologies: Computing, Networks, AI, Data & Security, and Converging Technologies, which we bring together to deliver sustainability transformation. Fujitsu Limited (TSE:6702) reported consolidated revenues of 3.6 trillion yen (US$32 billion) for the fiscal year ended March 31, 2022 and remains the top digital services company in Japan by market share. Find out more: www.fujitsu.com/

About Nippon Telegraph and Telephone Corporation (NTT)
NTT believes in resolving societal issues through our business operations by applying technology for good. We help clients accelerate growth and innovate for current and new business models. Our services include digital business consulting, technology and managed services for cybersecurity, applications, workplace, cloud, datacenter and networks all supported by our deep industry expertise and innovation. As a top 5 global technology and business solutions provider, our diverse teams operate in 80+ countries and regions and deliver services to over 190 of them. We serve over 80% of Fortune Global 100 companies and thousands of other clients and communities around the world. For more information on NTT, visit www.global.ntt/.

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