Fujitsu Develops Diamond-Spin Quantum Computer Prototype

New diamond-spin quantum computer prototype incorporating tin-vacancy (SnV) centers into photonic integrated circuits marks significant step toward quantum computing scalability

September 8, 2026

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Fujitsu's Strategy for Quantum Computing

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- Cover all the technology layers with the world's leading research institutions
- Put emphasis on software technologies, while working on several types of hardware
- Develop applications with end users by using Hybrid Quantum Computing Platform

Quantum Application	Research with end-user input **Materials** | **Drug discovery** | **Finance**		**FUJIFILM, Tokyo Electron,** etc.	**TU Delft**
Quantum Software	Algorithm	**UC Berkeley** Quantum Error Correction	**U of Osaka** Quantum Error Correction	
Quantum Platform	Compiler Middleware	**U of Edinburgh** Hybrid Computing	Cloud Technology	
Quantum State Control Quantum Device & Integration	**RIKEN** Superconducting Qubit	**TU Delft** Diamond Spin Qubit	Exploring other possibilities, Neural Atom etc.	

Approaches to Quantum Computer Hardware

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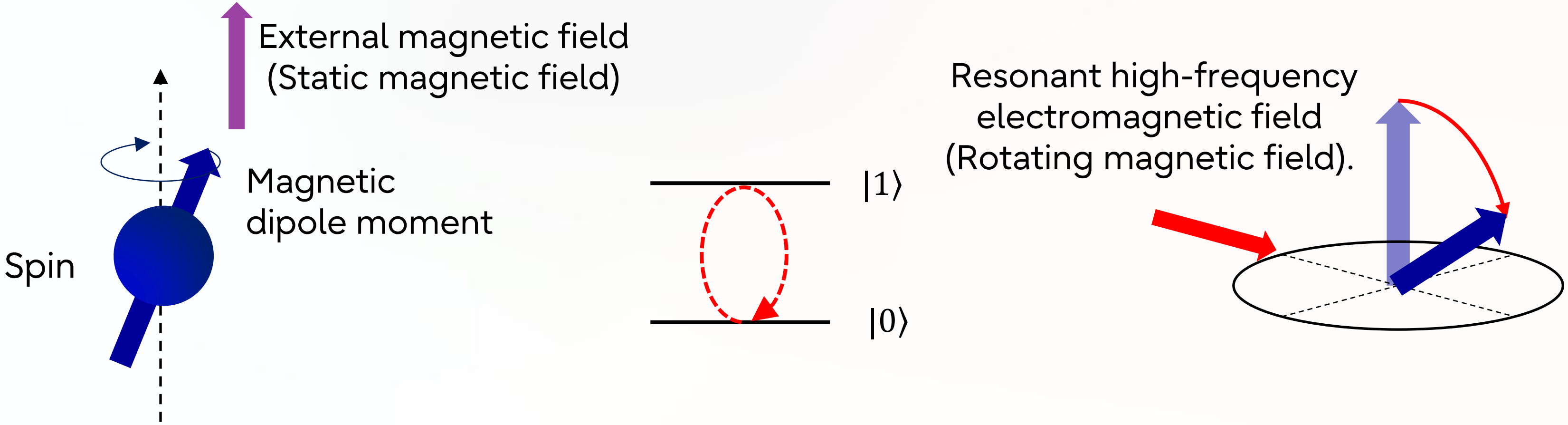
Developing the diamond-spin as the 6th approach, leveraging the advantages of light and spins in solids.

Quantum Computers

Superconducting	Diamond	Silicon	Trapped Ion	Neutral Atom	Light
Superconducting circuits	Electron spins + Nuclear spins	Spins in quantum dots	Electronic states of ions	Electronic states of neutral atoms	Amplitude and phase of light

What is a Spin Qubit?

- Spins possess a magnetic dipole moment and behave like tiny magnets.
- A two-level system formed by an external magnetic field can be used as a qubit.
- The state of the qubit can be controlled by applying a resonant high-frequency electromagnetic field (rotating magnetic field).



Formation of a two-level system in spin within an external magnetic field and spin qubit control using resonant high-frequency fields.

Diamond-Spin Qubits

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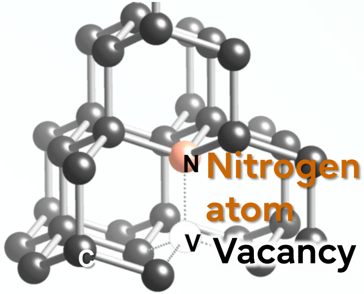
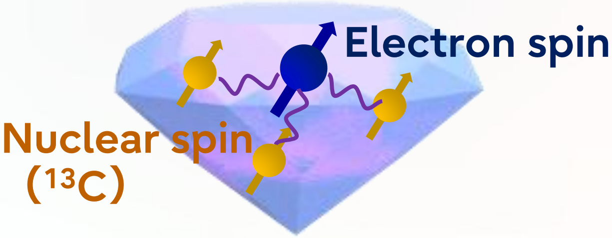
- Diamond-spin qubits use high-purity artificial diamond crystals, which are excellent quantum host materials, and defects (color centers) formed within them.
- A quantum module is constructed using the electron spin of a single color center in the diamond and nuclear spin coupled to it as qubits.
- **With a long coherence time, it is possible to achieve inherently high fidelity.**
- The state of the electron spin qubit can be read out using entangled photons.

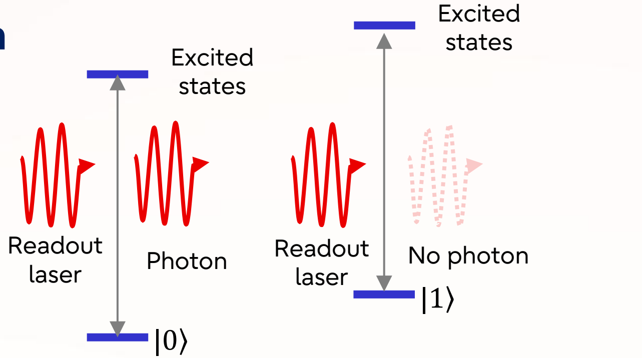


NV center



Diamond-spin quantum module

	Coherence time (T_2)
Electron spin (NV)	> 1 sec.
Nuclear spin (^{13}C)	> 1 min.



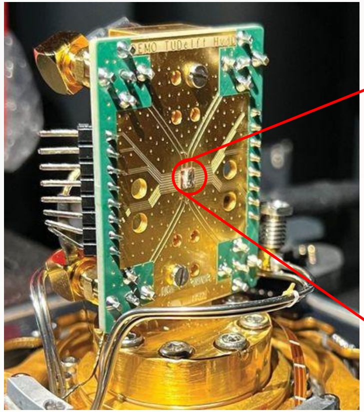
$|0\rangle$: Photon emission $|1\rangle$: No-photon emission

Optical readout of diamond-spin qubits

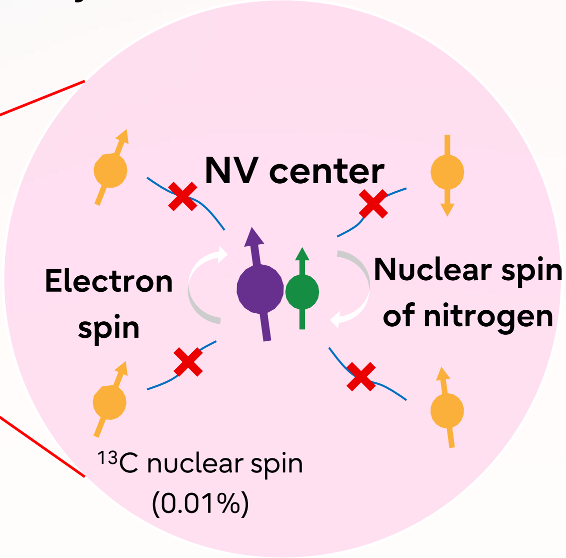
Example of High-Fidelity Quantum Gate Operation (NV Center)

Demonstrated quantum gate operations with an error probability of less than 0.1%.

- 2-Qubit Gate Fidelity: > 99.9%
- 1-Qubit Gate Fidelity
  - Electron Spin: > 99.99%
  - Nuclear Spin : > 99.999%



Evaluation setup



Press released in March 2025.

H.P. Bartling *et al.*,
Phys. Rev. Applied **23**, 034052 (2025).

https://info.archives.global.fujitsu/global/about/resources/news/press-releases/2025/0324-02.html

Highly Scalable Modular Architecture Based on the Diamond-Spin Approach

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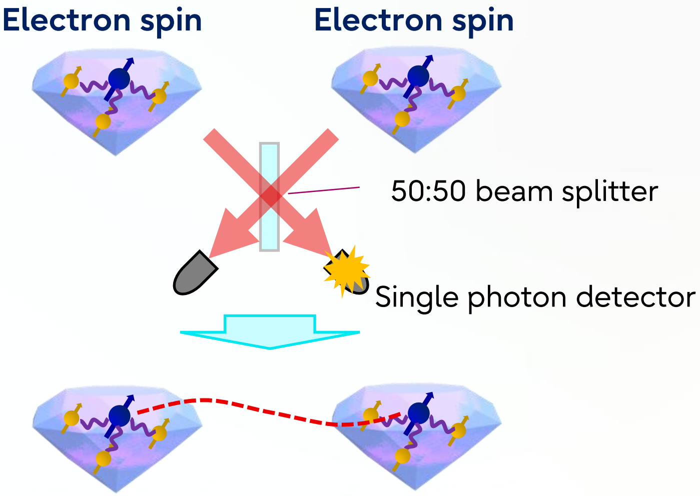
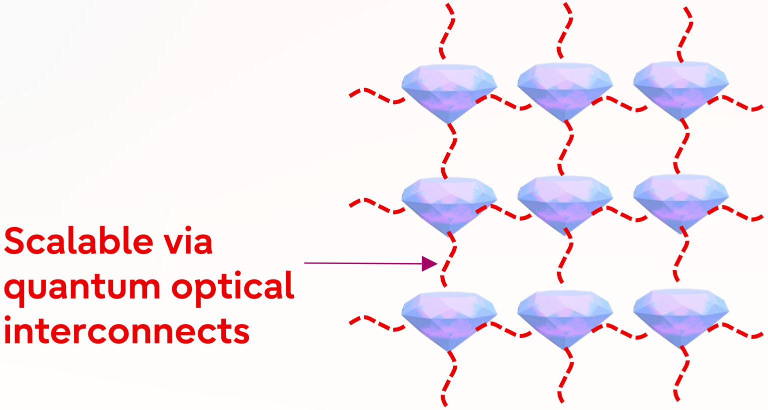
- **Operating Temperature:** Higher temperatures (>1 K) compared to superconducting systems.
- **Modular Quantum Computer:** Connects quantum modules via optical interconnects that can transfer quantum states, enabling quantum computing as a single integrated system.



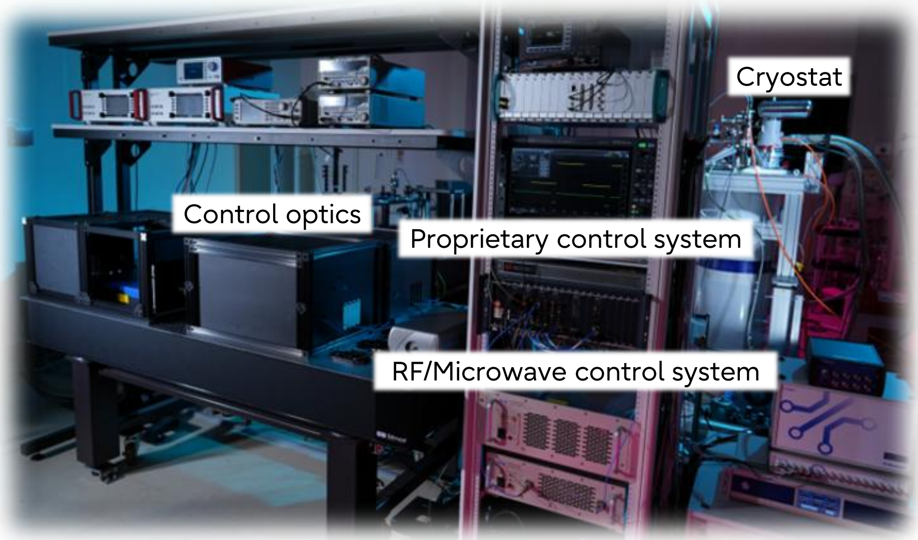
Conceptual diagram of quantum optical interconnects
(Remote entanglement of electron spin qubits via light)

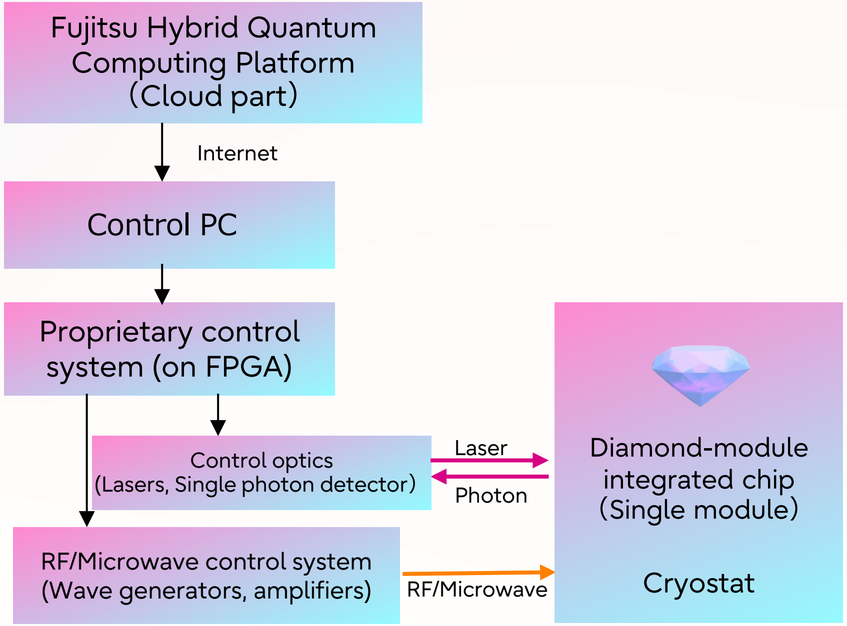


Modular architecture

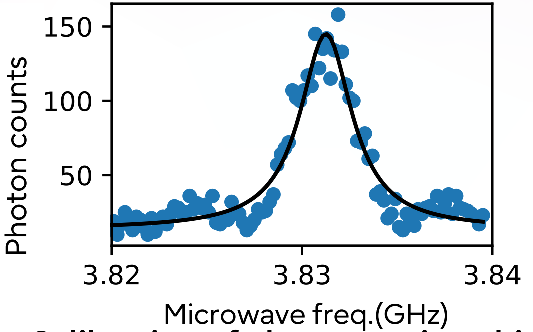
Overview of the Developed Prototype

- The world's first quantum gate-operable system with chip-integrated Tin-Vacancy (SnV) center qubits in diamond, suitable for scaling through optical interconnects

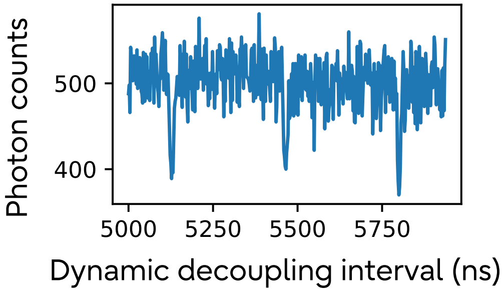




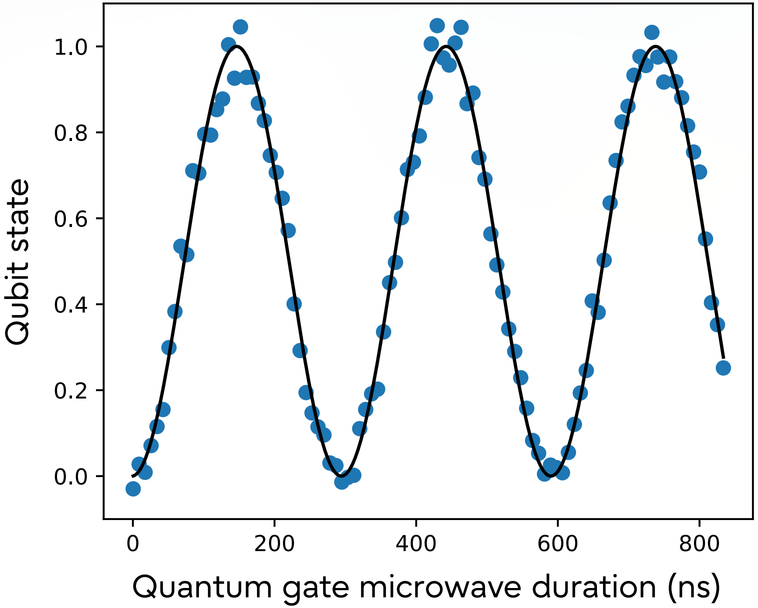
Example of Diamond-Spin Qubit Operation



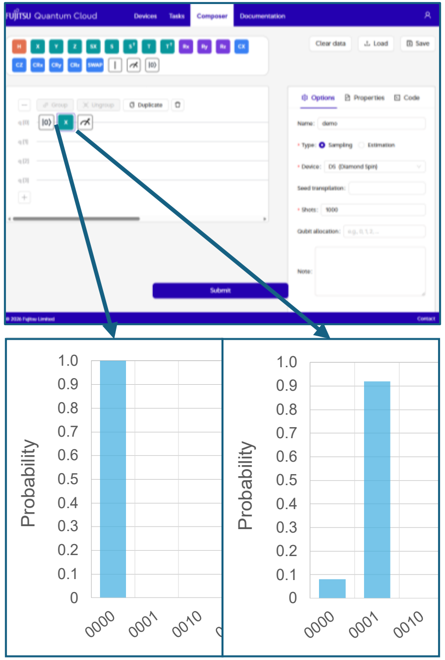
Calibration of electron spin qubit frequencies



Calibration of nuclear spin qubit frequencies



Electron spin qubit operation (Rabi oscillation)



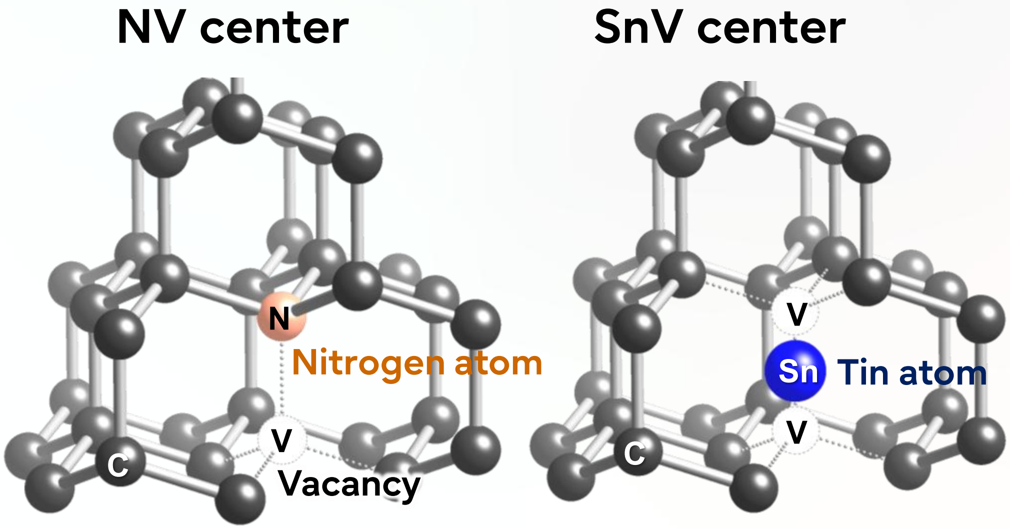
Cloud system access (Conceptual image)

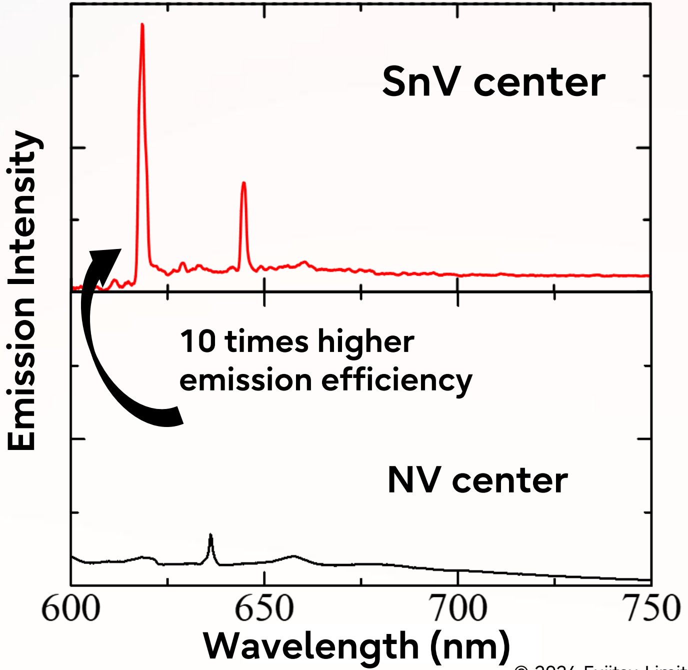
Video Message from Joint Research Institutions

- Tim Taminiau, Group Leader, QuTech, Delft University of Technology

Novel Material: Tin-Vacancy (SnV) Center

- Structural symmetry enables charge-noise robustness for scalable nanofabrication.
- 10x higher photon emission efficiency than NV centers enables highly efficient optical interconnects.





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Need for Photonic Chip Integration

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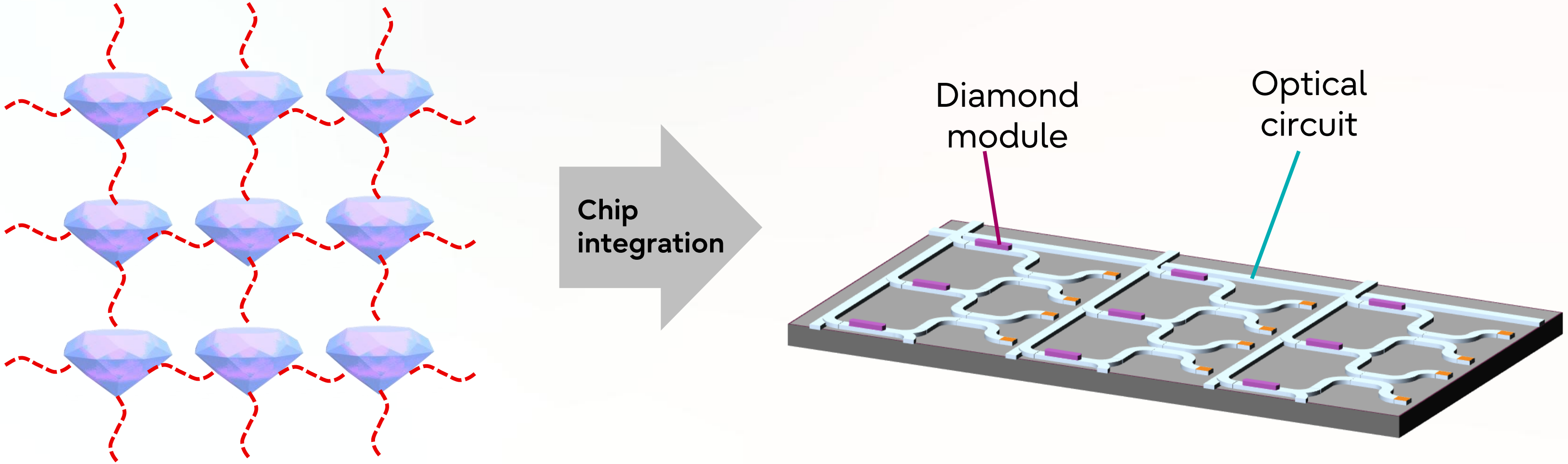
- Chip integration is necessary to fit more diamond modules in a limited space.
- We developed optical integrated chips based on heterogeneous material bonding technology, combining small, high-quality diamond crystals with an optical circuit platform.



Photonic Integrated Circuit Technology for Diamond Spin

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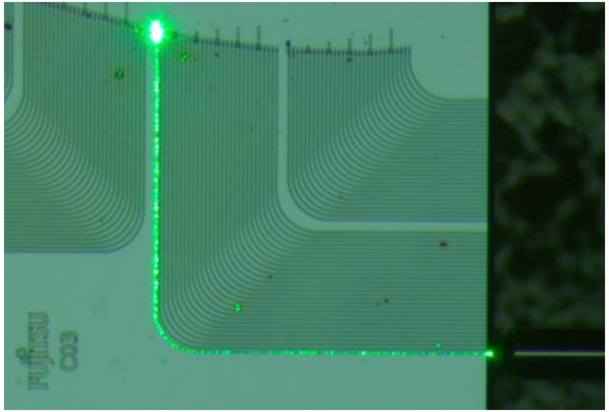
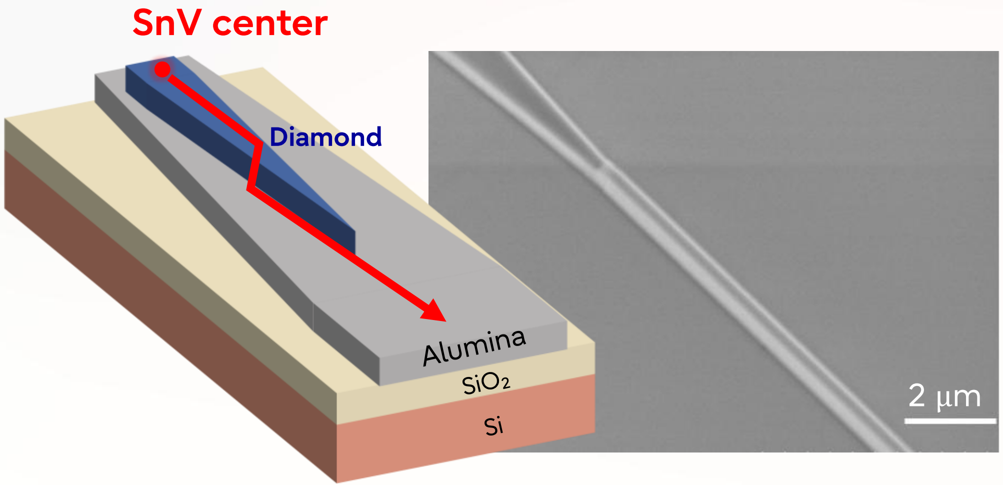
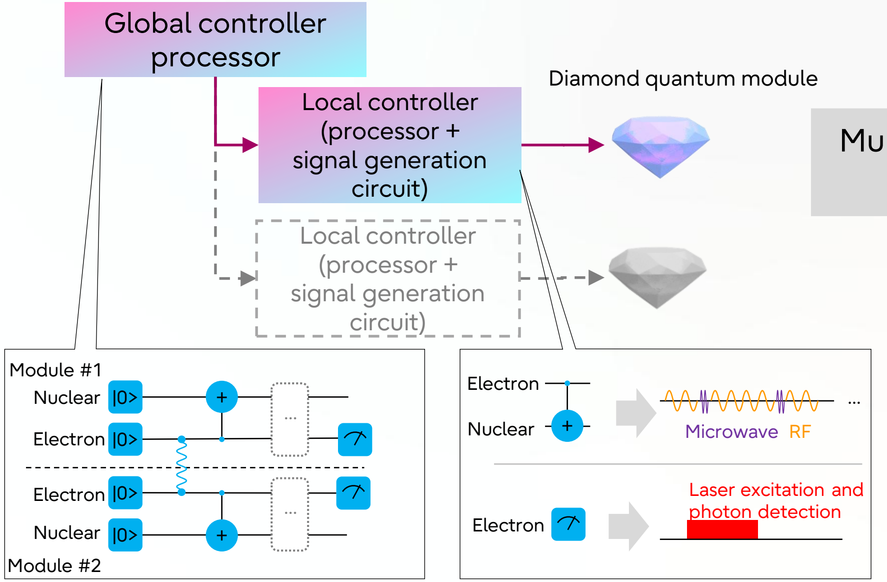
- Adopted alumina optical waveguide circuits, which exhibit low optical loss in the visible wavelength band used for SnV center control light and signal light.
- Optimized the waveguide shape and fabrication conditions to obtain favourable optical coupling between the bonded diamond module and the alumina optical waveguide.





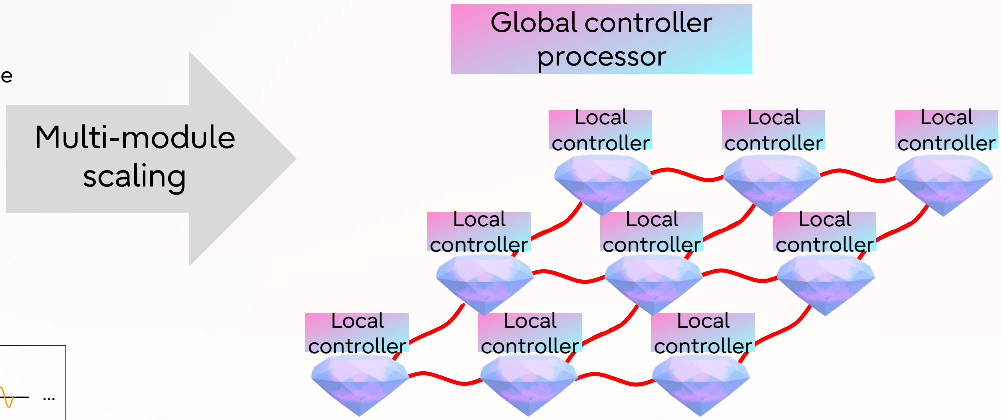
Proprietary Control System for Multi-Module Architecture

- The control system adopts a modular architecture, enabling straightforward scalability to future large-scale systems.
- Processors are deployed at both global and local control levels, enabling flexible intra- and inter-module control through software-defined real-time control.



Orchestrates local controllers to perform a sequence of quantum operations.

Controls physical-layer operations of a single diamond quantum module



Asynchronous handling of identical commands with variable execution times reduces processing time in multi-module systems.

Future Outlook

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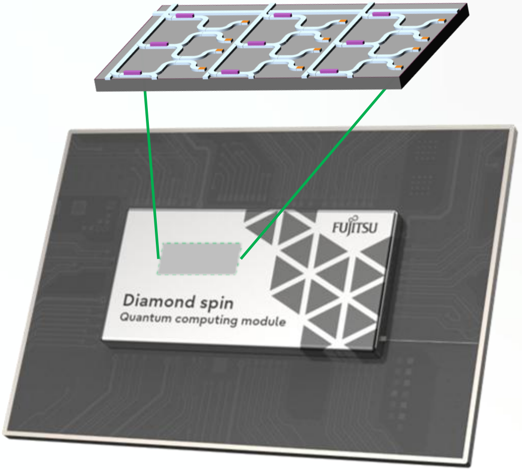
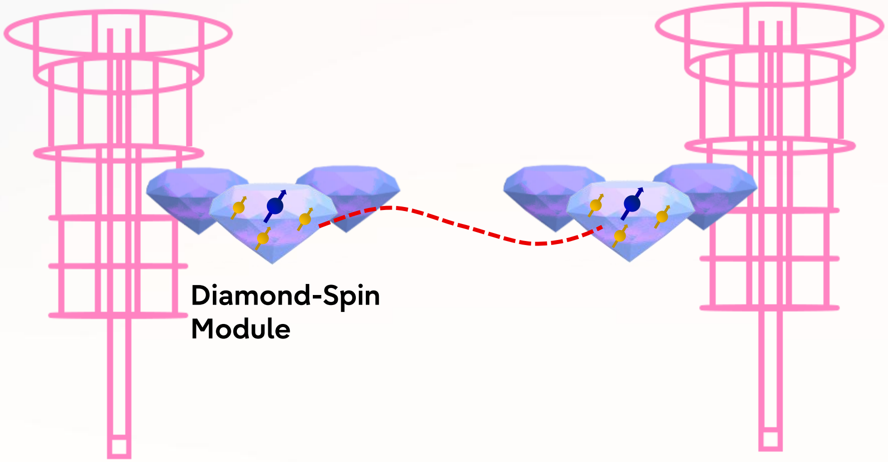
- Develop a multi-module architecture and interconnection technologies with superconducting quantum systems, aiming for fault-tolerant quantum computing by combining both approaches.



Concept of multi-module diamond-spin quantum chip



Concept of scaling up superconducting quantum computers

Thank you

Demonstrated Prototype Operation via the Cloud

- Successfully connected the developed prototype to the Fujitsu Hybrid Quantum Computing Platform and demonstrated qubit operations.