

Science and Technology Group Annual Report FY2024

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1 Introduction

Quantum computing and related peripheral technologies are garnering significant attention as promising next-generation platforms for information processing and sensing. Among these, microwave quantum technologies have emerged as a powerful framework for quantum control, communication, and measurement. However, the inherently low energy of microwave photons and the stringent requirement for ultra-low-noise amplification at millikelvin temperatures continue to pose major challenges—particularly in measuring and interfacing quantum systems and enabling quantum information transfer.

In response to these challenges, our focus has been on developing spin-based quantum devices. This past fiscal year, we continued to try to realize a spin-based quantum transducer and a quantum-limited noise amplifier operating at millikelvin temperature based on spin-maser. These devices can not only be stepping stones towards next-generation information and communication technologies but also be platforms for fundamental sciences.

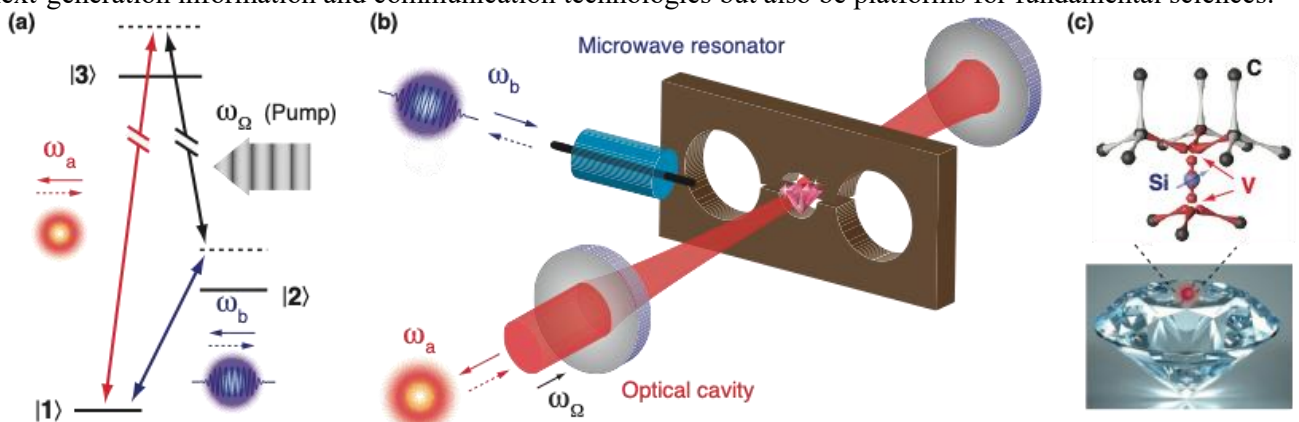


Figure 1: Spin-based quantum transducer. (a) operating principle. The three states ($|1\rangle$, $|2\rangle$, and $|3\rangle$), the pump tone (ω_Ω), the frequencies of the optical (ω_a) and the microwave photons (ω_b) are shown. It demonstrates the up-conversion of microwave photons and down-conversion of optical photons via a pump laser. (b) Cartoon of the proposed device. A diamond containing impurity spins is coupled with an optical cavity and a microwave resonator. (c) A silicon-vacancy (SiV) center in diamond, the impurity spin used in this project.

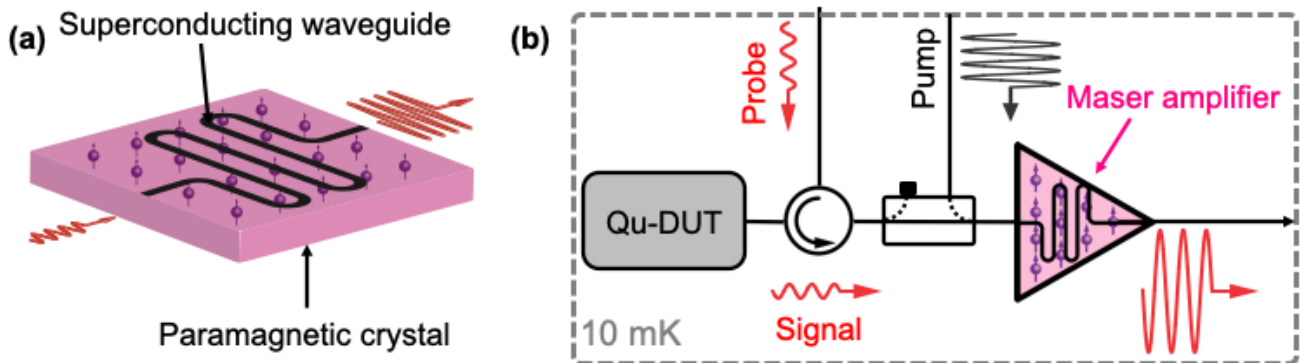


Figure 2: Spin-based quantum-limited amplifier. (a) Cartoon of the proposed amplifier device. A superconducting waveguide is patterned on a paramagnetic crystal. (b) Conceived implementation of the maser amplifier in a quantum information experiment. “Qu-DUT” refers to “quantum device-under-test.” The maser amplifier is designed to first amplify weak microwave signals at 10 mK.

2 Activities and Findings

To realize efficient microwave–optical quantum transduction using impurity spins in diamond, a key requirement is the integration and stabilization of an optical cavity at millikelvin temperatures. We successfully stabilized a Fabry–Pérot optical cavity containing a bulk diamond crystal inside a cryogen-free dilution refrigerator. This work was published in *Review of Scientific Instruments* and represents a crucial step toward quantum transduction using impurity spins in diamond. Furthermore, we have demonstrated, for the first time, the up-conversion of microwave signals to optical signals, although these results are not yet published.

We have also further advanced the maser-amplifier device developed during the previous Proof-of-Concept (Phase II) project, as shown in Figure 3. The device integrates a broadband coplanar waveguide with a microwave

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diplexer, enabling efficient handling of signals across different frequency ranges. The entire structure is fabricated from sputtered superconducting NbTiN film, patterned using electron-beam lithography and reactive ion etching (RIE) at NICT and OIST. The microwave circuit design has led to two patent applications.

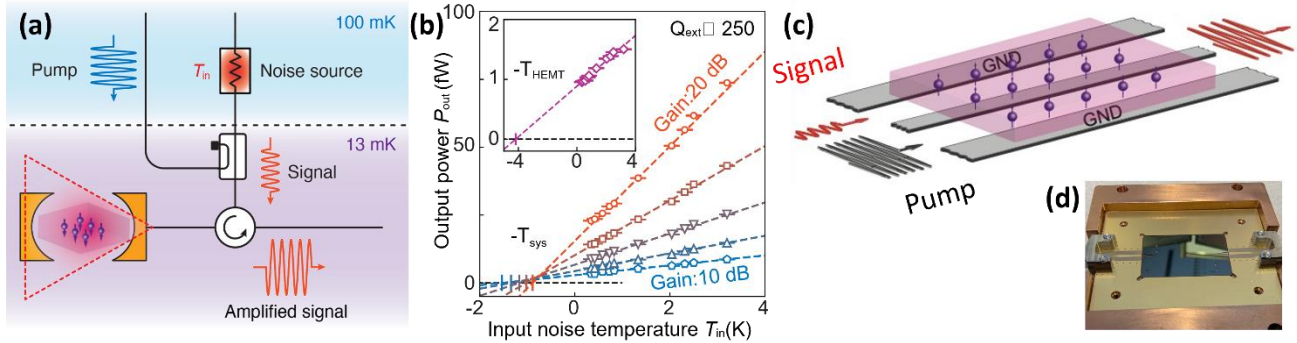


Figure 3: FY2025 activities summary. (a) Schematic of the maser amplifier device and setup at millikelvin temperatures in a dilution refrigerator. (b) maser noise measurement, demonstrating an ultra-low noise of 0.96 K. (c) Schematic of a broadband maser amplifier device and (d) a photograph of a test device.

3 Collaborations and Funding

We have embarked on a collaborative project with the University of Tokyo/RIKEN and NICT Kobe for hybrid quantum devices. I have started a collaborative research project “Magnetic-field resilient microwave cavity” with The University of Tokyo and KEK under support of KAKENHI Basic Research (B). The quantum transducer project has been supported by the JST Moonshot R&D project, and the diamond maser amplifier project has been supported by the OIST Proof-Of-Concept (PoC) program from OIST Innovation and the AGC Foundation.

4 Publications and other output

- [1] “A near-quantum-limited diamond maser amplifier operating at millikelvin temperatures” arXiv:2505.05705 (2025), under review in *Nature Communications*.
- [2] “Stabilizing an optical cavity containing a bulk diamond crystal at millikelvin temperatures in a cryogen-free dilution refrigerator”
T. Hamamoto, Amit Bhunia, Hiroki Takahashi, Yuimaru Kubo,
Review of Scientific Instruments 96, 085201 (2025)
- [3] Invited talk at the 3rd Workshop on Ultrafast Optoelectronics, Japan, Feb 2026
- [4] Invited talk at PQE Workshop, Snowbird (USA), Jan 2026
- [5] Invited talk at Autumn PIERS 2025, Makuhari, Nov 2025
- [6] Invited talk at the 86th JSAP Autumn Meeting, Sep 2025
- [7] Plenary talk at the JCK MEMS/NEMS 2025, OIST, July 2025