Science and Technology Group Annual Report FY2022

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1 Introduction

Quantum computing and related "peripheral" technologies attract significant attention as promising next-generation information processing and sensing applications. Superconducting quantum circuits, which have been remarkably developed in the past decade, are currently the top runner for a quantum computer among many quantum systems thanks to their scalability and versatility. On the other hand, however, microwave photons' low energy requires an ultra-low noise amplifier at millikelvin temperature. Moreover, it prevents us from transferring quantum information from one superconducting quantum computer to another.

To mitigate those challenging demands, I am developing spin-based quantum technology devices. The short-term objectives are a **spin-based quantum transducer** (Figure 1) and a **spin-maser quantum amplifier** (Figure 2). They will also be exciting playgrounds for exploring fundamental physics.

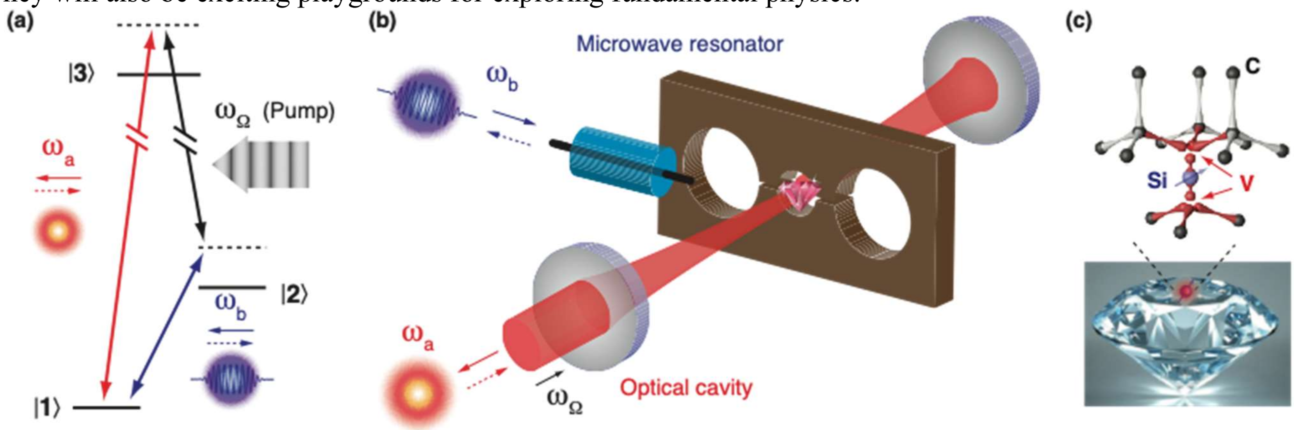

Figure 1: Spin-based quantum transducer. (a) operating principle. The three states ($|1\rangle$, $|2\rangle$, and $|3\rangle$), the pump tone (ω_Ω), the frequencies of the optical (ω_a) and the microwave photons (ω_b) are shown. Microwave photons (optical photons) are up(down)-converted via a pump laser. (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.

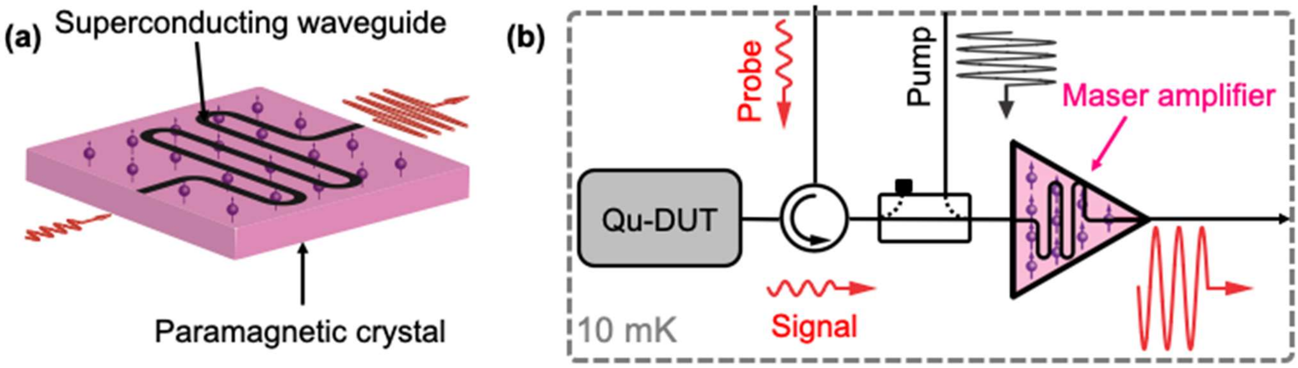

Figure 2: Spin-based quantum amplifier. (a) Cartoon of the proposed amplifier device. A superconducting waveguide is patterned on a paramagnetic crystal. (b) Conceived implementation of the maser amplifier in a quantum information experiment. Qu-DUT stands for quantum "device-under-test ." The maser amplifier first amplifies tiny microwave signals at 10 mK.

2 Activities and Findings

Same as last year, I have been dedicated to starting the lab, particularly installing another new lab room where a new dilution refrigerator was installed in February 2023. Two postdocs, Ching-Ping Lee and Amit Bhunia, joined my team. The team set up and performed electron spin resonance of impurity spins in diamond crystals at millikelvin temperature, developed the quantum transducer device design and simulations, and further developed the integrated spin-based quantum amplifier's device design, as shown in Figure 3.

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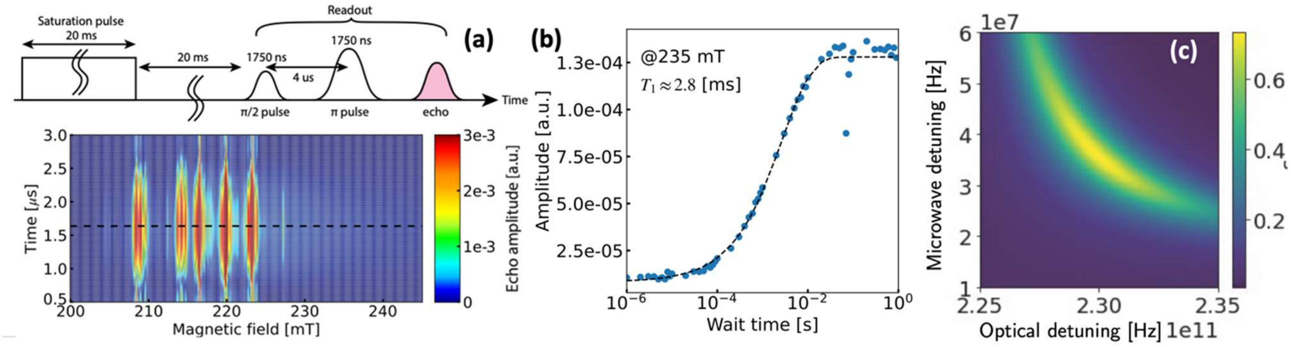

Figure 3: FY2022 activities summary. (a) Pulsed electron spin resonance spectroscopy. The pulse sequence (top) and data (bottom). Signals from impurity spins in diamonds appear. (b) Spin relaxation measurement at ten millikelvin [Lee, Ohta, Kubo, et al., in preparation]. (c) A simulation of quantum microwave-optical photon conversion. Efficiency is color-plotted as functions of microwave and optical frequency detunings [Hamamoto, Londdell, Kubo, in preparation].

3 Collaborations

We are preparing a collaborative theoretical paper with Prof. Jevon Longdell at the University of Otago, NZ. Figure 3 (c) shows one of the ongoing results. We also started a collaboration for the quantum amplifier project with a private company Orient Microwave Inc. (Shiga, Japan), with which we have contracted an NDA. They will design on-chip microwave circuits and provide us with prototype devices.

Besides, a JSPS bilateral project has been running with the group of Prof. Michael Stern at Bar-Ilan University in Israel. Another collaboration project was launched with Dr. Çağlar Girit at CEA-Saclay and CNRS France in March 2023. Dr. Girit arrived in March and will spend five months at OIST as a JSPS Invited Fellow.

4 Publications and other output

Author list, *Title*, Journal or other reference, volume information (year)

[1] Yuimaru Kubo, "Thermally Induced Negative Temperature in Diamond," OIST Center for Quantum Technologies Mini Symposium, OIST, 2022/11/9

[2] Yuimaru Kubo, "Towards Thermally Pumped Maser Oscillation in Diamond," Spins in London, University College London, 2022/11/24

[3] Yuimaru Kubo, "Towards Thermally Driven Maser Oscillation," Invited talk at NanoFrontier Materials Conference 2022 (NFM2022), NIMS Tsukuba, 2022/12/28

[4] OIST Center for Quantum Technologies Mini Symposium, OIST, 2022/11/9
Title: Electron spin resonance of vacancy clusters in diamond at millikelvin temperature
Authors: Morihiro Ohta, Jason R Ball, Tatsuki Hamamoto, Ching Ping Lee, Hitoshi Sumiya, Shinobu Onoda, Takeshi Ohsima, Junichi Isoya, Hiroki Takahashi and Yuimaru Kubo
Name of the conference: OIST Center for Quantum Technologies Mini Symposium

[5] Spins in London, 2022/11/24
Title: Electron spin resonance of unidentified spin objects in diamond at millikelvin temperature
Authors: Morihiro Ohta, Jason R Ball, Tatsuki Hamamoto, Ching Ping Lee, Hitoshi Sumiya, Shinobu Onoda, Takeshi Ohsima, Junichi Isoya, Hiroki Takahashi and Yuimaru Kubo

[6] Title: Towards Quantum Network with Color centers in Diamond
Authors: Tatsuki Hamamoto, Rupak Bhattacharya, Mathieu Couillard, Hiroki Takahashi, Yuimaru Kubo, Name of the conference: Spins in London, 2022/11/25

[7] Title: Spin Ensemble Quantum Memory for Superconducting Qubits
Authors: Mathieu Couillard, Tatsuki Hamamoto, Rupak Bhattacharya, Ching Ping Lee, Yuimaru Kubo, Name of the conference: Spins in London, 2022/11/25