Science and Technology Group Annual Report FY2021

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1 Introduction

Microwave quantum technologies have been recognized as one of the most promising research subjects for 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 fundamentally 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.

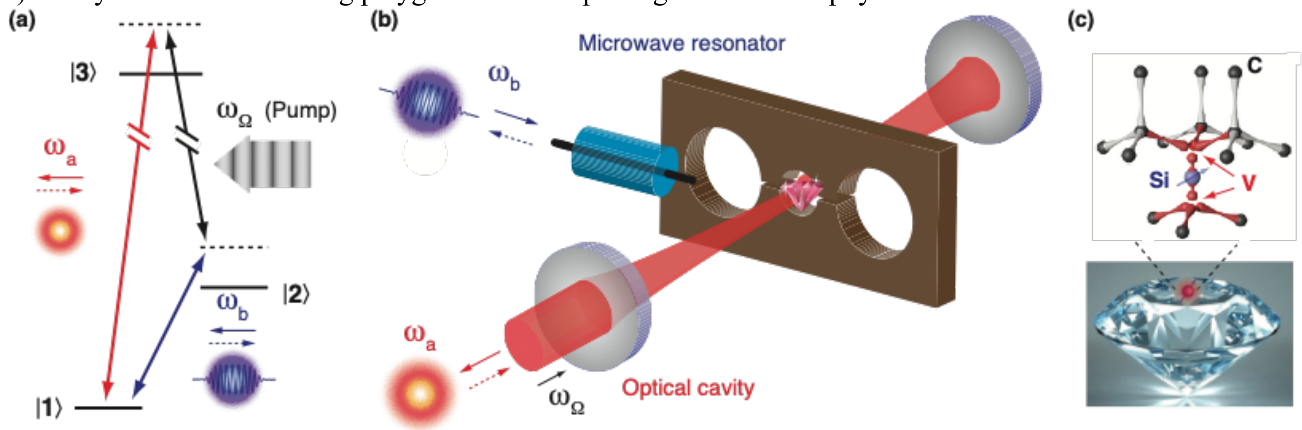

Figure 1: Spin-based quantum transducer. (a) operating principle. The three states ($|1\rangle$, $|2\rangle$, and $|3\rangle$), the pump tone (ω_Ω), the frequencies of the optical (ω_a) and the microwave photons (ω_b) are shown. Microwave photons (optical photons) are up(down)-converted via a pump laser.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

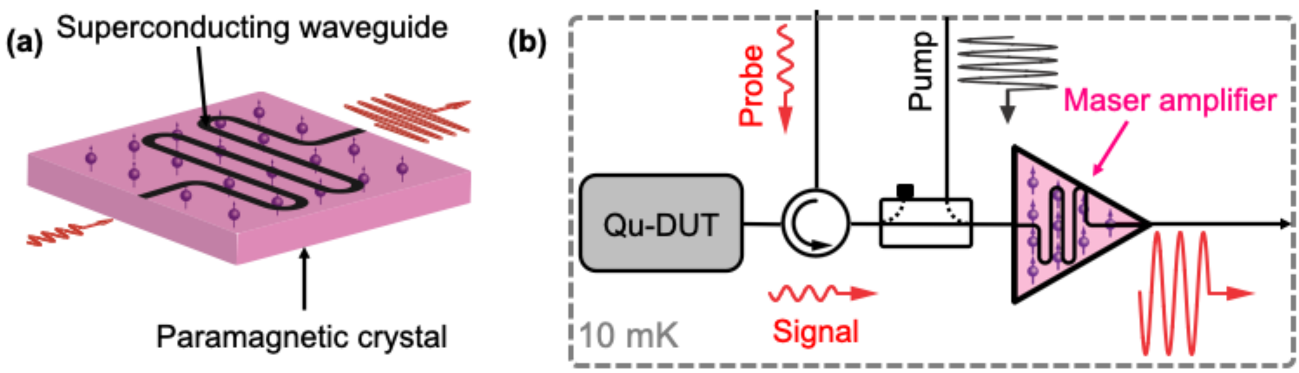

Figure 2: Spin-based quantum amplifier. (a) Cartoon of the proposed amplifier device. A superconducting waveguide is patterned on a paramagnetic crystal. (b) Conceived implementation of the maser amplifier in a quantum information experiment. Qu-DUT stands for quantum "device-under-test ." The maser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

2 Activities and Findings

Joining STG in May, I have been dedicated to start-up the lab, moving and re-installing experiments with the help of two Ph.D. students, Tatsuki Hamamoto and Morihiro Ohta, and a postdoc (Rupak Bhattacharya) throughout the fiscal year 2021. The key experimental equipment for our projects, a dilution refrigerator, has arrived and been installed in February 2022. Besides, we have advanced the device design and simulations, as shown in Figure 3.

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Unpublished results

Figure 3. FY2021 activities.

3 Collaborations

We started 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 with Prof. Yasunobu Nakamura at the University of Tokyo, who provided us with a couple of superconducting circuit devices. An MTA has been agreed upon and concluded. Moreover, another collaborative project with Profs. Masahiro Nomura and Takayuki Yamada at the University of Tokyo have been launched, and a joint research and development agreement has been concluded.

Besides, a JSPS bilateral project has also been running with the group of Prof. Michael Stern at Bar-Ilan University in Israel. Another collaboration project with Dr. Caglar Girit at College de France will also launch in FY2022, and an application to the JSPS Invitation Program has been awarded for this.

4 Publications and other output

[1] J. F. da Silva Barbosa, M. Lee, P. Campagne-Ibarcq, P. Jamonneau, Y. Kubo, S. Pezzagna, J. Meijer, T. Teraji, D. Vion, D. Esteve, R. W. Heeres, and P. Bertet, *Determining the Position of a Single Spin Relative to a Metallic Nanowire*, Journal of Applied Physics 129, 144301 (2021).

[2] Y. Kubo, *Hybrid Quantum Systems with Spins in Diamond Crystals and Superconducting Circuits*, in Hybrid Quantum Systems, edited by Y. Hirayama, K. Ishibashi, and K. Nemoto (Springer Singapore, Singapore, 2021), pp. 119–142.

[3] 久保結丸，書評「共振器量子電磁力学---量子コンピュータのハードウェア理論」，数理科学 2022 年 2 月号 p74

[4] Yuimaru Kubo," *Broadband Pulse Electron Spin Resonance Spectroscopy using a Superconducting Waveguide*," Invited talk at MRM2021 (Materials Research Meetings) Pacifico Yokohama, 2021/12/15

[5] Yuimaru Kubo, *A "masing" Spin Ensemble: Maser for Quantum Information Technologies*, Invited seminar series at Centre for Quantum Technology, University of Glasgow (Online) 2022/02/25