R&D Theme

Hot silicon qubits

Progress until FY2022

1. Outline of the project

In this theme, we aim to achieve "high-temperature" operation of silicon qubits, referred to as “hot silicon qubits” (Fig. 1). This involves operating the qubits around 1 Kelvin (K), equivalent to around -272 degrees Celsius. This is higher than the typical operating temperature of solid-state qubits, which is a few tens of millikelvin (mK). By achieving hot silicon qubits, we can improve the permissible circuit power consumption (heat dissipation) and enable closer placement of cryogenic control circuitry. This contributes to the development of large-scale integrated silicon quantum computers. To achieve high-performance hot silicon qubits, we are exploring the "sweet spot" where quantum coherence time is maximized and comparing electron spin and hole spin systems.

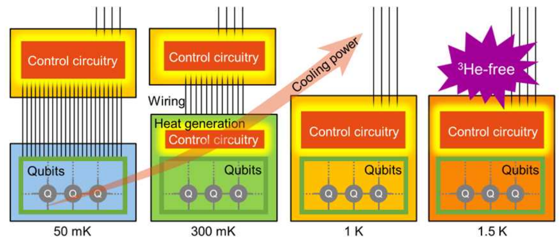

Figure 1: Implementation of cryogenic control systems through high-temperature operation of qubits.

2. Outcome so far

① **We verify the required characteristics for qubit operation in the developed silicon qubit structures.**

② **We overview the current status and challenges of essential technologies for silicon quantum computers.**

③ **We confirm that the increase in noise associated with temperature rise is suppressed in the hole spin system.**

①: We tested a part of silicon qubit array for qubit operations (Fig. 2). The qubit device showed the expected change in an energy level with magnetic fields, which will allow us to control its spin operation frequency. We also successfully detected single-electron tunneling events in real-time towards reading the spin state. These advancements bring us closer to realizing silicon qubits.

② : We summarized the current status and challenges in a silicon quantum computing. The summary includes discussions on the “quality” (indivisual qubit performance) and the “quantity” (approaches for large-scale integration). It is published to support researchers from various fields in the development of silicon quantum computers.

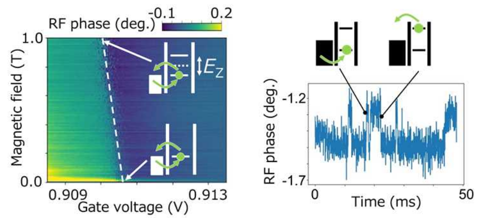

Figure 2: (left) Magnetic field dependence of an electron spin energy. (right) Real-time detection of single electron tunneling events.

③ : We investigated the temperature dependence of charge noise in the hole spin system (Fig. 3). The results reveal low noise levels up to 1 K, demonstrating promising performance at higher temperatures. Additionally, at 300 mK, the noise level was comparable to previous studies on electron spins in quantum dots measured at 50 mK or lower.

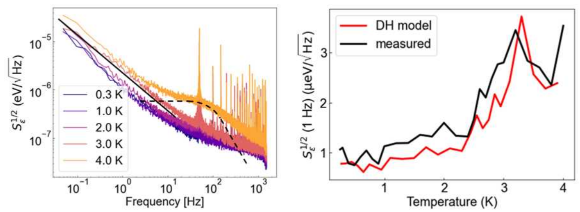

Figure 3: Noise increase with higher temperatures. (left) Noise spectrum density. (right) Noise magnitude at 1 Hz.

3. Future plans

Based on our accumulated knowledge on improving fidelity, our current focus is on demonstrating qubit operation. We aim to demonstrate the operation of silicon qubits at relatively high temperatures, such as 300 mK and even 1 K. This involves performing qubit initialization and readout under appropriate control voltage conditions and utilizing alternating magnetic or electric fields for state control.

国立研究開発法人 科学技術振興機構 JST Japan Science and Technology Agency