R&D Item

2. Development of middle-distance quantum link

Progress until FY2024

1. Outline of the project

To realize large-scale quantum processors in the future, it is essential to flexibly connect distant spin-based quantum bits (qubits) within semiconductor platforms. In this Theme, we focus on developing "middle-distance coupling" technologies, which allow the transfer of quantum information over micrometer-scale distances. This capability enables scalable qubit integration across an entire chip, which is important towards fault-tolerant quantum computing.

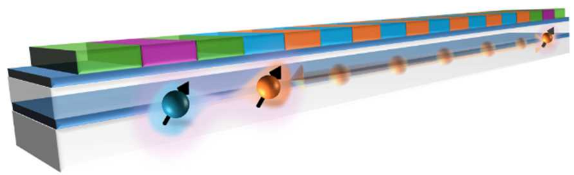

Figure 1: Conceptual illustration of two qubits coupled over a middle-distance.

2. Outcome so far

1. Exploring Various Qubit Transfer Methods

There are several ways to transfer qubits from one place to another: A "bucket brigade" method, where qubits are passed one-by-one by use of quantum tunneling. A "conveyor mode" method, where the potential landscape is shifted to carry the qubits smoothly. An exchange-interaction-based method that relays intermediate qubits to swap information.

We conducted small-scale simulations of the electromagnetic and quantum behavior of each method. Based on these studies, we identified the characteristics, challenges, and optimization approaches for each approach.

2. Testing Multi-Qubit Structures and Control Systems

To test the methods to couple qubits, we investigate quantum dots, tiny regions in a semiconductor that can hold single electrons, in a one-dimensional array serving as a “quantum link”.

Testing in-lab fabricated samples at low temperatures secured stable operation of electronic control systems that are essential for future quantum coupling demonstration.

Figure 2: Measurement setup at SANKEN.

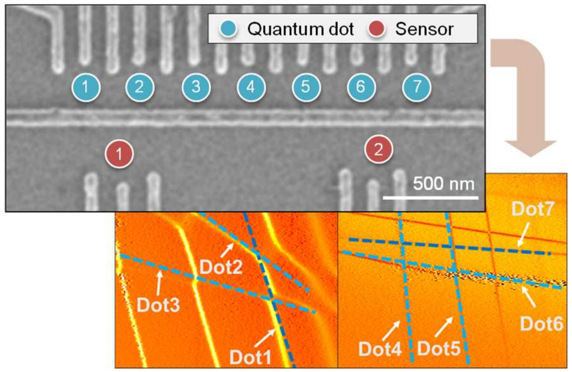

Figure 3: Electron microscope image of a multi-quantum-dot device measured at low temperatures, with the quantum dot array showing individually confined single electrons in each dot (indicated by dashed lines labeled Dot1 to Dot7).

3. Developing Devices for Conveyor Mode Method

Our analysis suggests that the conveyor mode method, using regularly spaced electrodes and periodic voltage signals, is a promising approach holding scalability and structural simplicity.

Challenges remain for us to ensure stable transfer of qubits over the quantum link without being excited. Solving them separates two qubits more distant required for realistic wiring technologies to facilitate operation of large-scale qubit processors.

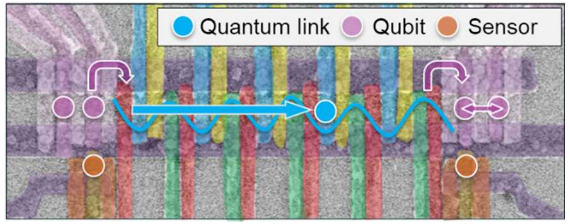

Figure 4: Example of a multi-quantum dot device under development (electron microscope image).

3. Future plans

The outcomes of this theme provides us the ground for building future quantum processors. Requirement has been grown for developing a method to connect middle-distant two qubits in a fast and accurate way, that we can implement by a structure manufactured with today’s industrial technologies of device integration.

By closely tracking the movement of qubits, we hope to establish a reliable and scalable method for quantum links, an essential step towards large-scale quantum computing.