Successful Multi-photon Control of a Superconducting Flux Qubit Using Microwaves

NTT, in collaboration with the Japan Science and Technology Agency (JST), has successfully performed an experiment on flipping supercurrent flow (quantum state transition) by irradiating a superconducting flux quantum bit (qubit), a candidate element of next-generation quantum computers, with photons (microwaves). Qubit state transitions could be induced for energies corresponding to one, two, or three photons. This result confirmed that quantum mechanics, a theoretical system that describes behavior in the microscopic world composed of atoms and elementary particles, can also be applied to a qubit (in a macroscopic state composed of millions of Cooper pairs) about 6 µm in size (in this demonstration). The superconducting flux qubit, a superconducting loop consisting of three Josephson junctions of submicrometer dimensions, is therefore a promising device for constructing quantum computers.

In the experiment, we constructed the device using microfabrication technology and cooled it to 30 mK using a dilution refrigerator. We then operated the device under a magnetic field so that the magnetic flux through the loop was about half a superconducting flux quantum, thereby preparing a two-state quantum system (qubit). This qubit consisted of a ground state and an excited state corresponding to counterclockwise- and clockwise-flowing supercurrents. The energy difference between these two states could be precisely adjusted by slightly altering the magnetic flux through the loop. A quantum mechanical superposition state can result from a superposition of these two types of supercurrents. We next irradiated the device with photons (microwaves) resonating with the qubit's energy difference and detected absorption transitions of one to three photons between the ground state and excited state using a superconducting quantum interference device (SQUID) fabricated adjacent to the qubit. We also observed characteristic oscillation of the flux qubit in a Ramsey interference experiment using two resonant microwave pulses and successfully controlled the coherence operation, which is necessary for a practical quantum computer.

In future research, we will try to extend the coherence* time of this superconducting flux qubit to achieve a sufficiently long computational time for controlling multiple qubits.

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* Coherence: A property that measures the ability of the quantum states to interfere with each other