R&D Theme Name

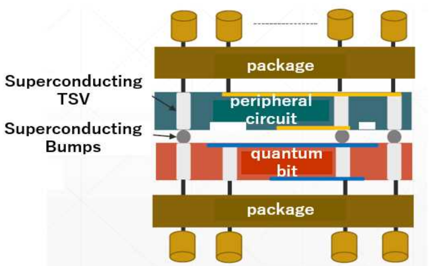
Research and development of qubit-integrated hardware systems

Progress by FY2022

1. Overview

In the typical setup of today's superconducting qubit circuits, qubit chips placed at cryogenic temperatures and microwave electronics operating at room temperature are wired together by one or more coaxial cables per qubit. However, this method cannot scale up to tens of thousands of qubits or more due to the limitations of space and cooling capacity of the cryocooler. To solve this problem, this R&D theme aims to develop hardware technologies around quantum chips, such as a high-capacity dilution refrigerator with high cooling capacity and connector-less high-density wiring, to break through the wiring bottleneck for integration.

The key to this development is how to control and process signals in the vicinity of the qubits and reduce wiring between different temperature stages. For this purpose, we are developing a "vertically integrated" qubit module, in which a qubit chip is hybrid-integrated with a signal processing circuit that controls and reads out the qubits. For the dilution refrigerator, we are optimizing the entire refrigerator system, including not only the 10mK stage where the qubit chips are placed, but also the high temperature stage where the cryoelectronics may be placed.

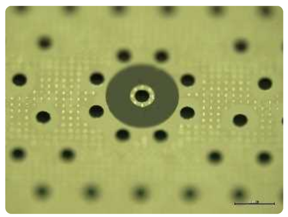


Structure image

2. Results by FY2022

1) Development of Transparent Mounting Structure

Design, prototyping, and evaluation experiments are underway to realize a vertical transmission-type mounting module structure as an electrical connection for vertically stacked structures. Specifically, we are working on technology to create an intra-board coaxial structure using through-substrate vias (TSVs), technology to create micro indium solder bumps for inter-board connection, and technology to create superconducting electrodes as the connection technology between the top and bottom surfaces of the boards. First, we developed a prototype chip for evaluation of stacked chips, and then developed a flip chip bonding technology for stacking three chips with six layers (assuming a qubit substrate, readout substrate, and upper wiring substrate). We continued with the design and fabrication of a vertical input/output package to house the vertically transparent mounting module with such stacked chips, as well as the fabrication of a magnetic shielding. In addition, to evaluate low-temperature electrical characteristics, we installed a refrigerator and electrical characteristics measurement equipment.


Test chip for vertical transmission module


Package of module mounted on a refrigerator

(2) Design of high-power dilution refrigerator

In order to scale up quantum computers, increasing the refrigeration power is needed in the millikelvin [Supplement 1] range of dilution chillers. In FY2022, based on the results of the previous year, we have worked to improve the efficiency of the heat exchanger, which is a key component, in order to achieve higher output, and have obtained results that are expected to improve the refrigeration capacity.


Dilution refrigerator under prototype

[Supplement 1] A Kelvin is a unit of temperature that is zero at absolute zero (-273.15°C). mK (millikelvin) is 1/1000 of Kelvin. mK (millikelvin) is 1/1000 of mK. Since superconducting qubits require a cryogenic temperature of about 10 mK (-273.14°C) to operate, dilution refrigerators are used.

3. Future Developments

Regarding the transmission-type mounting structure, we will prepare an evaluation environment for the prototype vertical transmission-type mounting module and proceed with high-frequency electrical characteristics evaluation experiments, such as transmission loss and resonator characteristics.

With regard to the dilution refrigerator, the challenges to realize an error-tolerant general-purpose quantum computer are to further increase the cooling power and to optimize the cooling power at each temperature stage. We will conduct research and development to further increase the cooling power to 1.3 mW from the 0.97 mW at 100 mK achieved so far.

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