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Investigation of the superconducting flux qubit for quantum annealing utilizing multi-layered Nb/AlOx/Nb Josephson junction technology

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A machine learning based on quantum computing is expected to be superior to the conventional machine learning in terms of high accuracy and learning time [1]. To build a superconducting quantum annealing computer suitable for the machine learning application, we have been investigated superconducting flux quantum bits (qubits) composed of the tunable rf-SQUID [2], which can be easily coupled to other qubits via magnetic coupling.
We evaluated a device consisting of the flux qubit and a dc-SQUID, Josephson junctions of which are resistively shunted, for read-out of the qubit state. The device was fabricated utilizing multi-layered Nb/AlOx/Nb Josephson junction technology, the AIST 2.5 kA/cm^2 Nb standard 2 process [3]. The critical currents of the Josephson junction were estimated to be 50 μA for the readout dc-SQUID and 50μA and 125μA for the qubit respectively. All measurements were carried out at 4.2 K. Figure 1 (a) shows a schematic of a circuit consisting of the flux qubit and the readout dc-SQUID. Since the qubit and the dc-SQUID are magnetically coupled by overlapping the qubit loop and the SQUID loop, the SQUID can read out the internal state of the qubit by applying appropriate bias current (I_{bias}) and flux (I_{flux}). To determine the appropriate bias condition for the readout dc-SQUID, the voltage response of the dc-SQUID was investigated. Figure 1 (b) shows dependences of the measured voltage on the I_{flux} when the I_{bias} of 0.7 mA and 1.2 mA were supplied. A periodic response, corresponding to applying the flux quantum Φ_o, was observed when I_{bias} of 1.2 mA was supplied. The voltage response of the readout dc-SQUID to magnetic flux applied to the qubit was measured by fixing the I_{bias} to be 0.04 mA (I_1). Figure 1(c) shows the measured voltage response as the function of magnetic flux applied to the qubit. We found the voltage response was digitalized. This indicates that the readout identifies the flux direction in the qubit.

Reference:
[1] S. Adachi and M. Henderson, arXiv :1510.06356, 2015.
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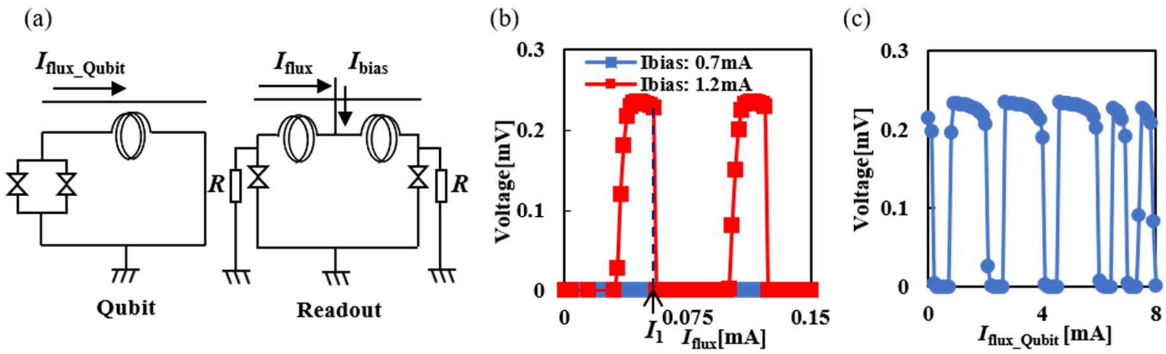

Fig.1 (a) Schematic circuit of readout having shunt resistances and qubit. (b) The readout voltage vs. applied I_{flux} at 4.2K measurement. (c) I_{flux_Qubit} dependence of the readout voltage.

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