【Grant-in-Aid for Scientific Research (S)】

Broad Section C

Title of Project：Creation of extremely energy-efficient integrated circuit technology beyond the thermodynamic limit based on reversible quantum flux circuits

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【Purpose and Background of the Research】

To reduce the recent explosive increase in power consumption of information systems, fundamental power reduction based on the new device operating principle is essential. On the other hand, it is expected that calculation with infinitesimal energy can be achieved by using a reversible computation, where bi-directional calculation from input to output or from output to input is performed.

This study investigates the reversible logic circuits using adiabatic quantum parametron (AQFP) circuits characterized by low energy operation and realizes ultimate low energy integrated circuits beyond the thermodynamic energy limit. As a result, the energy consumption of logic circuits can be reduced by more than six orders of magnitude compared with current semiconductor logic circuits, which brings about sufficient advantage even in consideration of the cooling power. In this research, we utilize the reversible AQFP as a core technology, and research new processor architecture, a phase shift AQFP using magnetic material, a 3D high-density integrated circuit technology to establish basic technologies for extremely energy-efficient integrated circuits. The goal of the project is to realize a low-power reversible AQFP processor.

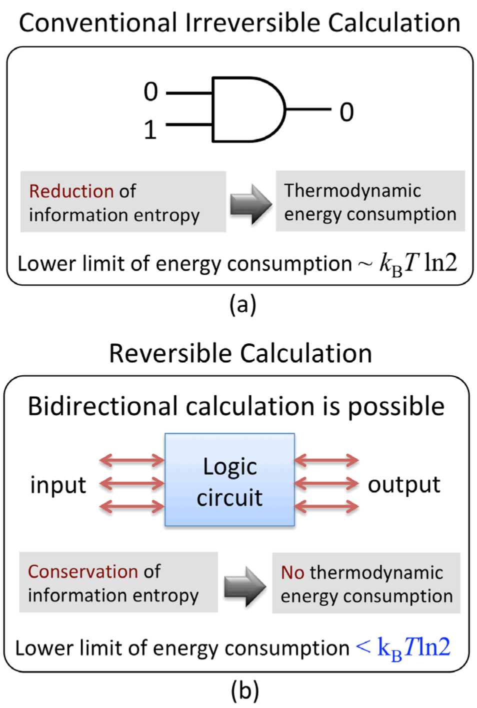

Figure 1　(a) Irreversible and (b) reversible circuits.

【Research Methods】

Conventional logic circuits such as semiconductor CMOS circuits perform the irreversible operation as shown in Figure 1(a), where the entropy of information (the complexity of information) decreases after the logic operation. According to Landauer's prediction, thermodynamic energy is consumed at this logic operation, which is considered to limit the lower energy limit in computation. On the other hand, in the reversible logic circuit shown in Figure 1 (b), bi-directional calculation from input to output or from output to input is possible. Since the entropy of information is conserved in this case, the energy consumption in calculation can be made infinitesimal. In this research, a reversible logic gate is proposed using a superconducting logic gate called adiabatic quantum flux parametron (AQFP), by which extremely energy efficient logic circuits are realized. In addition to clarifying the lower limit of energy consumption in the reversible logic circuit, we will establish an integrated circuit technology based on the proposed reversible circuit.

【Expected Research Achievements and Scientific Significance】

In this research, we aim to create integrated circuit technology that operates with energy consumption more than six orders of magnitude lower than current semiconductor circuits. As a result, significant power reduction of high-performance information processing systems such as data centers and supercomputers can be achieved. Moreover, application to control circuits for quantum computers is also expected.

【Publications Relevant to the Project】

・N. Takeuchi, Y. Yamanashi, N. Yoshikawa, "Reversible logic gate using adiabatic superconducting devices," Scientific Reports, 4, 6354 (2014).
・T. Yamae, N. Takeuchi, N. Yoshikawa, "A reversible full adder using adiabatic superconductor logic," Supercond. Sci., Technol., 32, 035005 (2019).

【Term of Project】 FY2019-2023

【Budget Allocation】 153,500 Thousand Yen

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