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

Development of foundational technology for reliability assessment of next-generation integrated systems to overcome cosmic ray-induced malfunctions

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Project Information	Project Number : 24H00073　Project Period (FY) : 2024-2028 Keywords : integrated systems, semiconductor, cosmic rays, soft error, superconducting circuits

Purpose and Background of the Research

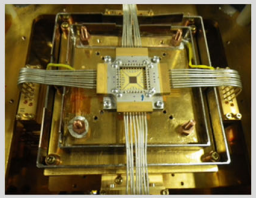
●Outline of the Research

The advancement of AI and autonomous driving technologies is accelerating, yet within computer systems, temporary malfunctions caused by radiation from space affect reliability. While research has addressed soft errors, new computer chip designs, including three-dimensional structures and superconducting circuits, pose potential unknown error risks. This study aims to investigate radiation effects through experimentation and simulation, establishing foundational reliability assessment technologies for next-gen computers (Fig. 1).

Complexifying system
Transistor count significantly exceeds the world's population

High-density 3D transistors
Particles passing through multiple transistors

Superconducting chips
Sensitive to particles



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Establishment of foundational reliability assessment technologies for future computing systems

Error propagation analysis and mitigation methods for complex systems
Simulation methods for errors in three-dimensional transistors
Evaluation of the impact of particles on superconducting circuits

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Prevent unforeseen reliability degradation and contribute to a highly reliable information society

Figure 1. Research Overview

●Research Purpose

The research aims to establish foundational technologies for evaluating the reliability of future computer systems across the following three areas (Fig. 2):

System: Develop methodologies for analyzing how soft errors occurring in memory propagate to system failures in complex systems consisting of multiple processors and dedicated processing circuits, transcending hardware and software boundaries.

Devices: Establish frameworks for accurately and rapidly simulating soft errors occurring in transistors at the limits of miniaturization.

Physics: Identify radiation that disrupts the operation of superconducting circuits and quantum bits.

●Research Purpose

This research will contribute to preventing unforeseen reliability degradation in future generations of computer systems, thereby fostering the realization of a highly reliable information society.

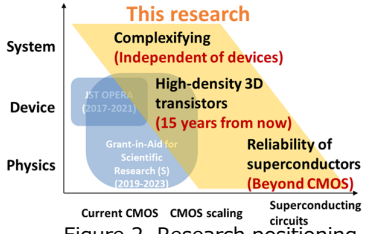

Figure 2. Research positioning

Expected Research Achievements

● Research Approach

This research addresses reliability issues in future computer systems caused by radiation through experimental and simulation studies. It aims to develop evaluation frameworks to enhance global computer reliability technologies. The interdisciplinary research team covers physics, circuits, systems, and information science. By combining experimentation and simulation, it pioneers the comprehensive evaluation of cosmic ray impacts on future computer systems. The error propagation evaluation technique will be a core technology across all computer device configurations. The study's academic strength lies in its accurate physics-based simulation system and innovative approach to identifying radiation energy affecting superconducting circuits.

● Specific Challenges

Challenge 1: Modeling and Mitigating System Error Propagation
(Task 1-1) involves developing an error propagation model. Then, error mitigation strategies are implemented in (Task 1-2). The effectiveness of these measures is verified through radiation experiments in (Task 1-3).

Challenge 2: Soft Error Analysis for High-Density Three-Dimensional Transistors
(Task 2-1) focuses on constructing models for simulating high-density three-dimensional transistors. Using these models, (Task 2-2) develops upset error models, while (Task 2-3) measures ultra-low-temperature characteristics. Subsequently, (Task 2-4) predicts the reliability of cutting-edge transistors (Fig. 3).

Challenge 3: Evaluation of Radiation Effects on Superconducting Circuits
(Task 3-1) involves measuring radiation in terrestrial environments. In (Task 3-2), techniques for simulating radiation effects on superconducting components are developed. Radiation irradiation experiments are conducted in (Task 3-3) (Fig. 4), and reliability predictions are made in (Task 3-4).

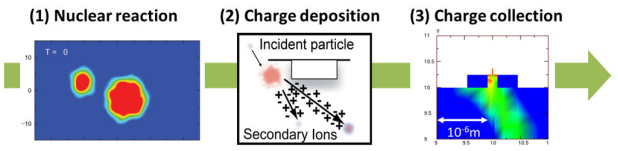

Figure 3. Soft error simulation process

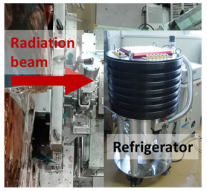

Figure 4. Experimental imagery

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