The study of the response of the semiconductor quantum device to radiation

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Introduction

What is Semiconductor Quantum Devices?

- Semiconductor Devices which use some quantum effects (size : nm~mm)

Quantum Bit (Qubit) in Quantum Computer

・Some devices below can be used for qubit in quantum computers.

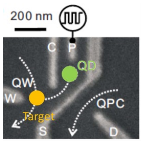
①Superconducting devices

- Most researched devices, but its coherence time (important for quantum computers) has not reached the theoretical expected value.

→ This is because of an effect of environmental radiation.

②Semiconductor quantum devices (Quantum Dot)

- These devices such as Quantum Dot is small, therefore, the exposure to radiation can be suppressed.



Quantum Dot

Motivation for This Research

If semiconductor quantum devices have…

・High resistance to radiation

→ Means that quantum dot is a good candidate of qubit.

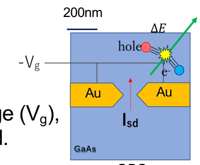
・High response to radiation

→ Show the possibility of use for a sensor to detect radiation with high energy resolution.

Methods

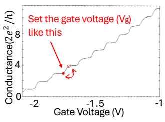
Quantum Point Contact (QPC)

- One of the semiconductor devices
- At a low temperature(~6K) and with the gate voltage (V_g), the conductance between the gates gets quantized.



QPC

→ We used QPC to measure a slight change of the electric field by electron-hole pairs from radiation.



Quantized Conductance

Measurement

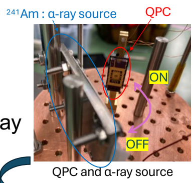
We took two measurements with α-ray and X-ray.
(at Aobayama, Tohoku University)
(for 2 days each measurement)

・α-ray source : ^{241}Am ・X-ray source : ^{55}Fe

① Put the source close to QPC, (~2.5mm) (irradiation "ON") and record 400 I_{sd} values.

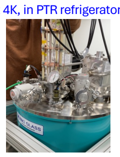
② Rotate mechanically and keep the source away from QPC, (~30mm) (irradiation "OFF") and record 400 I_{sd} values.

③ Repeat ① and ②.



QPC and α-ray source

At 4K, in PTR refrigerator

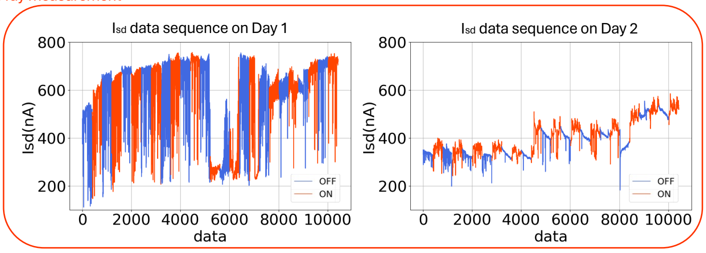


Recorded 400 I_{sd} values as 1 data file.

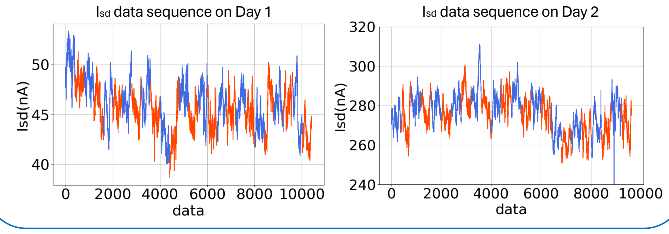
Due to the communication time between the computer and the current reader, it took about 1 second per 1 I_{sd} value recording.

Results and Analysis

α-ray measurement



X-ray measurement



→ How can we find the difference between these ON and OFF data?

→ We tried a machine learning. (model : SVM; good at binary classification)

Analysis with a Machine Learning

- Split dataset into ([for training] : [for test] = 4:1) ratio (Dataset means a specific group of data, e.g. by day)
- For 1000 ways to split data and to learn, calculate the average correct answer rate.

The correct answer rate

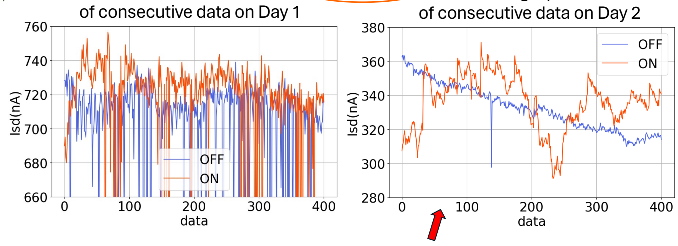
α-ray：Day 1 [179]	0.4916
α-ray：Day 2 [175]	**0.8186**
X-ray：Day 1 [175]	0.4647
X-ray：Day 2 [42]	0.4043

[N] is the number of data files.

By focusing on α-ray data, we tried to figure out what and how is the difference between ON and OFF.

Due to a bad accuracy, we gave up on more detailed analysis.

α-ray measurement



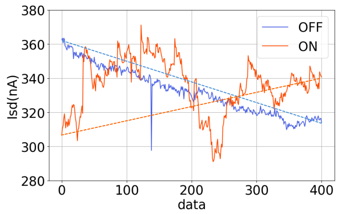
We can say about the difference in shape of data on Day 2 like this; (The part of a high correct answer rate)

ON → Baseline often goes up and down.

OFF → Baseline is almost stable and changes slowly.

We tried to quantify "this difference".

Comparing Variance with Baseline Modification



① Draw a baseline from start to end point
② Take the difference values between data and line
③ Calculate variance of the difference values for ON's and OFF's
④ Compare the ratio of data whose calculated variance is plus $\equiv r_+$

Comparison of r_+ (α-ray)

Day 1	0.371
Day 2	0.782

→ r_+ is a sort of quantification?

I_{sd} values and the correct answer rate of SVM

- Due to the reproducibility, we tried to find the I_{sd} range to get high correct answer rate (CAR).

I_{sd} and CAR of data on Day 2

I_{sd} range (nA)	267.8 ~ 444.6	444.6 ~ 494.1	494.1 ~ 572.0	572.0 ~ 600.9	600.9 ~ 631.8	631.8 ~ 713.0	713.0 ~ 747.4	747.4 ~ 772.0	772.0 ~ 794.6	794.6 ~ 862.0	862.0 ~ 918.9	918.9 ~ 1112
CAR	0.8208	**0.8918**	0.7063	**0.8602**	0.7608	0.5492	0.4933	0.6655	0.5874	0.5330	0.5742	0.4117

Each range has the same number of data.

→ Orange region may be good I_{sd} to detect α-rays.

Summary

- We could see the difference between ON and OFF data only in α-ray measurement on Day2.
- We found a way to quantify the difference, but there may be better ones.
- We should investigate the reproducibility, what the QPC condition depends on, and how the response is with use of other kinds of radiation.