Development of superconducting tunnel junction detector with cryogenic amplifier for COBAND experiment.

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For COBAND collaboration

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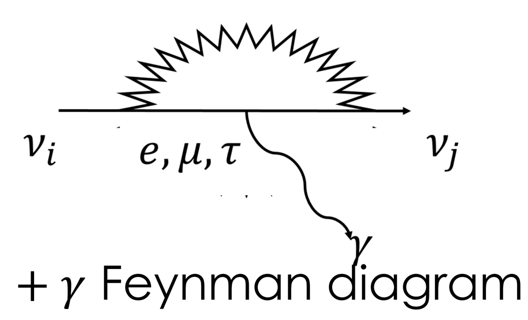
1. COBAND experiment

- **COsmic Background Neutrino Decay search experiment**
- The purpose of COBAND experiment is to determine neutrino mass by measuring the energy of neutrino decay photon.
- Neutrino lifetime is very long(T>O(10^{12} years):COBE+AKARI experiment), so we use cosmic neutrino background which is the highest intensity neutrino source in the universe.
- From the diagram, neutrino mass is

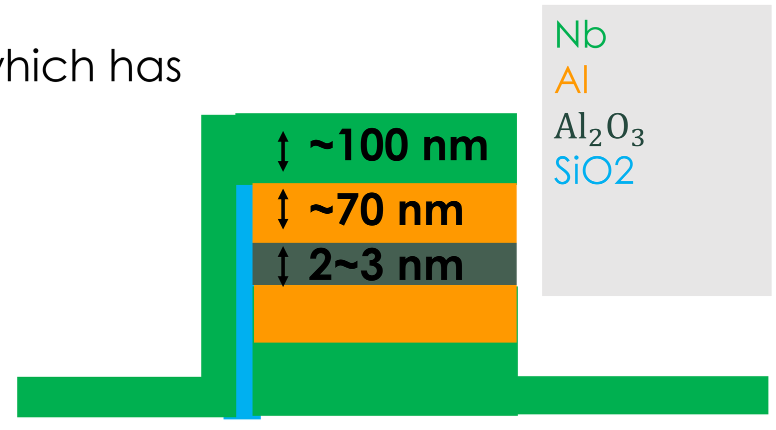
$$m_i = \frac{|m_i^2 - m_j^2|}{2E_\gamma}$$

where E_γ is neutrino decay photon energy and $|m_i^2 - m_j^2|$ have already been obtained by neutrino oscillation experiment.



$\nu_i \to \nu_j + \gamma$ Feynman diagram

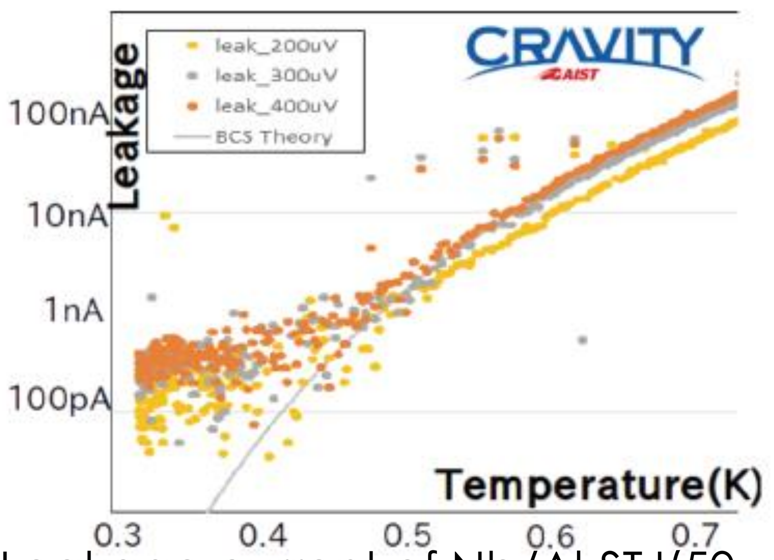
- Expected neutrino decay photon energy is too small(E_γ~25 meV), so we will use STJ(Superconducting Tunnel Junction) detector which has sufficiently small energy gap.
- **Nb/Al-STJ**
- It consists of Nb/Al/AlOx/Al/Nb.
- A constant bias voltage is applied.
- Photons break Coper pairs into quasi-particles which tunnel through the insulator layer as a current.



Nb/Al-STJ section

2. Cryogenic SOI Amplifier

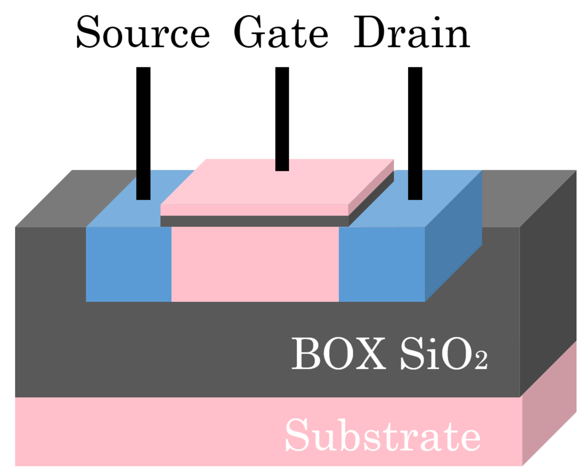
- **Issue**
- The requirement for Nb/Al-STJ that leakage current is smaller than 100 pA is already achieved.
- As a large amount of noise from refrigerator readout line prevents the detection of the far-infrared single photon, so we need to amplify the STJ signal near the STJ.
- **Requirement for cryogenic amplifier**
- Operation at cryogenic temperature(<3K)
- Capable of amplifying STJ's fast signals(<10 μs)
- Low power consumption and low noise



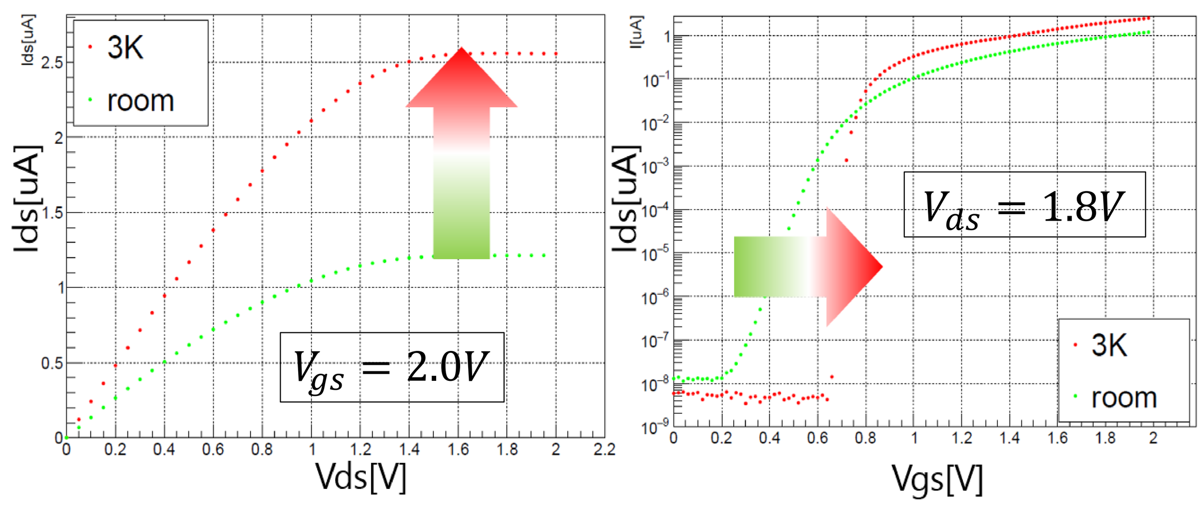
Leakage current of Nb/Al-STJ(50 µm sq.) temperature dependency

STJ Size [µm sq.]	Leakage Current [pA]
50	224±29
20	39±13
10	14±7

Leakage current of Nb/Al-STJ



schematic FD-SOI MOSFET

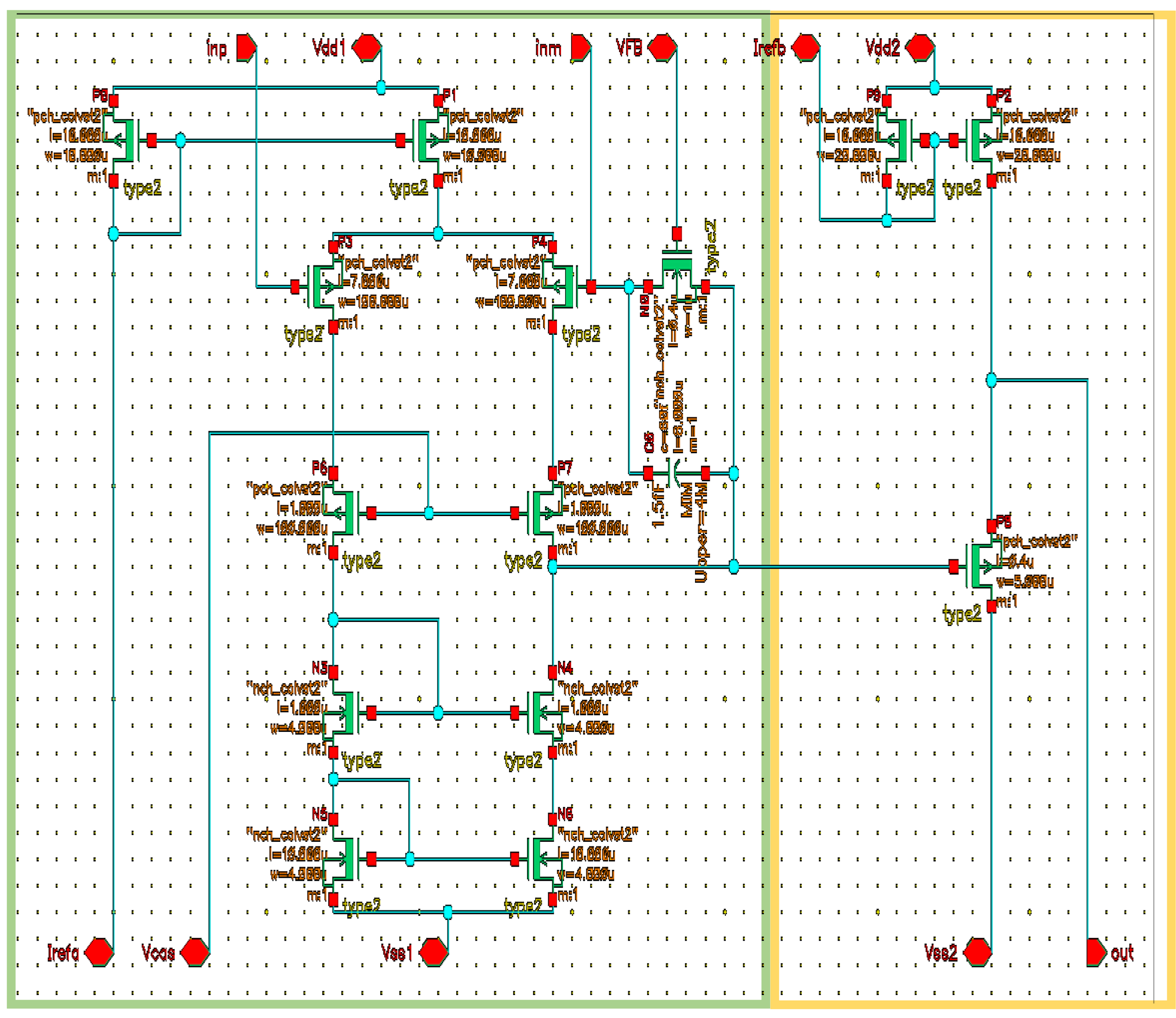


IV characteristic of FD-SOI MOSFET

- **FD-SOI MOSFET**
- FD-SOII(Fully Depleted-Silicon On Insulator) MOSFET
- It has very thin body(<50 nm)
- It is reported operation at 4 K by A group of JAXA/ISAS(T. Wada et al., J. Low. Temp. Phys. 167, (2012) 602).
- At 3 K, its threshold voltage shifts and Ids increase, but as far as we operate suitable voltage, it does not matter.
- **We develop cryogenic amplifier using FD-SOI MOSFET.**

3. Test of Amplification

- **SOI-STJ6**

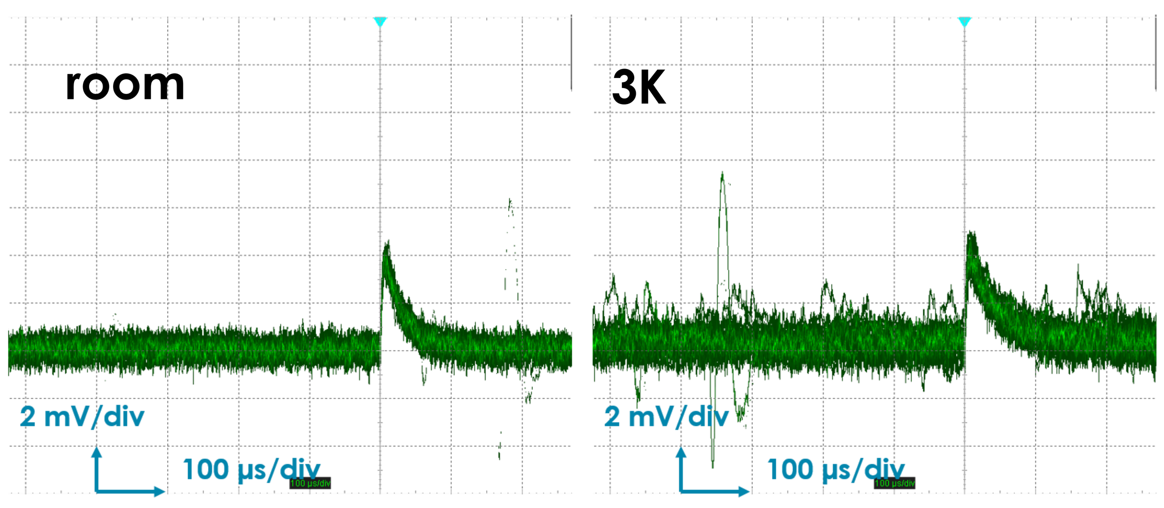


Circuit diagram of SOI-STJ6

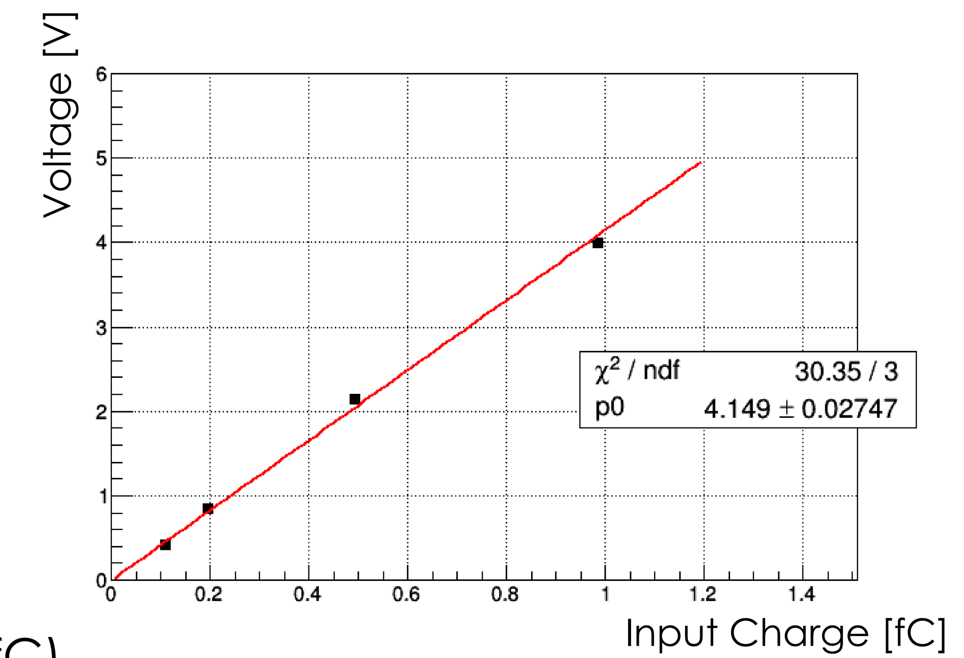
Amplification Stage
- ✓ Op-amp with negative feedback
- ✓ C_{FB} = 300 fF
- ✓ Using FD-SOI MOSFET as a R_{FB}

Buffer Stage
- ✓ Source Follower Circuit
- ✓ It improves frequency band and reduce output impedance.

- **Charge injection test**



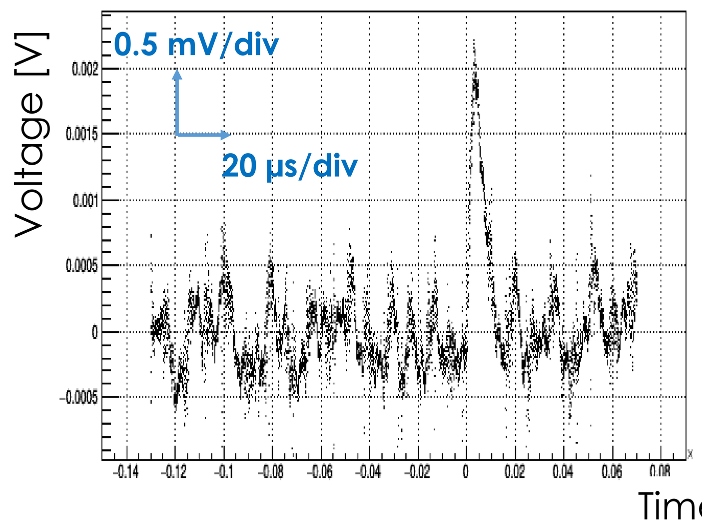
Output waveform test signal amplification(Qin=0.49 fC)



Input charge vs. signal height(3K)

- Test signal input through R=1 kΩ and C = 1 pF .
- Expected charge for single visible photon(λ = 465 nm) is 3.3 fC.
- Gain is 4.15±0.03 mV/fC
- ENC is 0.124±0.001 fC
- **We confirmed SOI-STJ6 normally operated at 3 K as well as room temperature.**
- **SOI-STJ6 has a sufficient performance to detect single visible photon.**

- **Result of STJ signal amplification**



Output waveform of STJ's signal amplification

- Amplifying STJ's signal illuminated by visible laser pulse(λ = 465 nm) were successfully achieved by SOI-STJ6.
- Because generated charge escape to stray capacitance on wires of four-terminal method circuit to measure STJ, output signal is smaller than its expectation value.
- **We need re-measurement without four-terminal method.**

4. Summary

- We are developing cryogenic amplifier to detect neutrino decay photon for COBAND experiment.
- We confirmed normal operation of SOI-STJ6 at 3 K.
- We succeeded in amplifying STJ signals for visible laser pulse with SOI-STJ6.
  - ✓ Output signal is smaller than our expectation, so we need re-measurement.
- We will attempt to detect infrared single photon.