Development of Superconducting Tunnel Junction photon detector using Niobium and Aluminum(Nb/Al-STJ)

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Koya Moriuchi （University of Tsukuba)
For Neutrino Decay Collaboration*

1. Introduction

We are developing Nb/Al-STJ as a far-infrared single photon detector to search for the radiative decay of cosmic background neutrino(CBν). We aim at the direct detection of CBν and the measurement of neutrino mass. The energy of photon from neutrino decay is about 25meV(50um in wavelength) if it is assumed that mass v_3 is 50 meV. Nb/Al-STJ is capable of detecting single photon in the region. However ,we still have not measured a single far-infrared photon because the output of Nb/Al-STJ is too small (about 100 electrons for a single far-infrared photon) and the noise from readout system is too large. We need to improve the measurement system to reduce a leak current and Develop ultra-low noise readout system for STJs.

2. Search for Radiative Decay of Cosmic Background Neutrino

The difference between the mass-squares of different-generation neutrinos has been measured by various neutrino oscillation experiments, and we will measure $E_\gamma = \frac{m_3^2 - m_2^2}{2m_3}$. From these two independent experiments, we can determine the neutrino mass itself. And we also aim at sensitivity to the lifetime τ_{v3} (10^{17}years) .

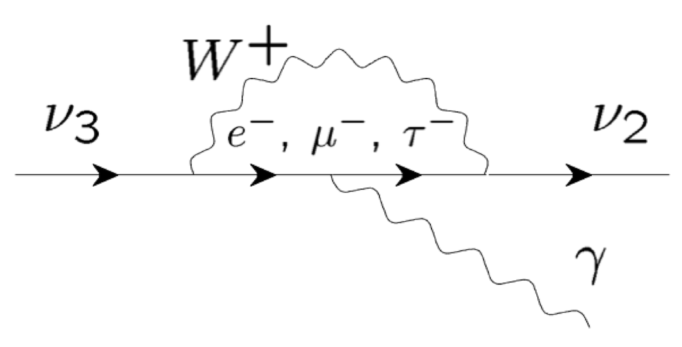

Fig.1 $\nu_3 \rightarrow \nu_2 + \gamma$ Feynman diagram

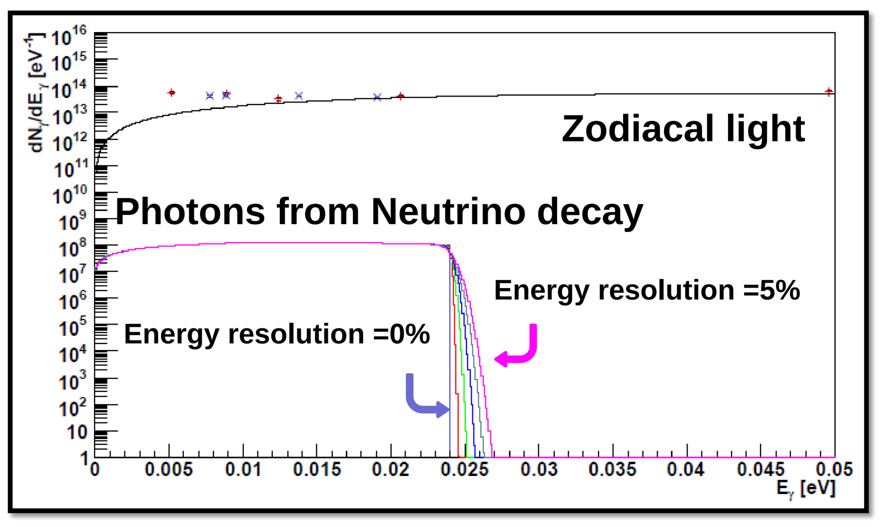

Fig.2 Energy spectrum of photons from neutrino radiative decay. We will measure the edge in Zodiacal light from neutrino decay photon. The sharpness of this edged depends on energy resolution of detector

We plan a rocket experiment to search for photons from the radiative decay of the cosmic background neutrinos. we need to measure the energy spectrum of cosmic far-infrared background in 2% energy resolution at 25meV to detect neutrino radiative decay.

We will use the system that consisted of a grating(separate the energy) and photon detector array (photon counting). The requirement for detector is to detect single 25meV photon.
The candidate device to detect the far infrared photons is Nb/Al based superconducting tunnel junction(Nb/Al-STJ) detector array.

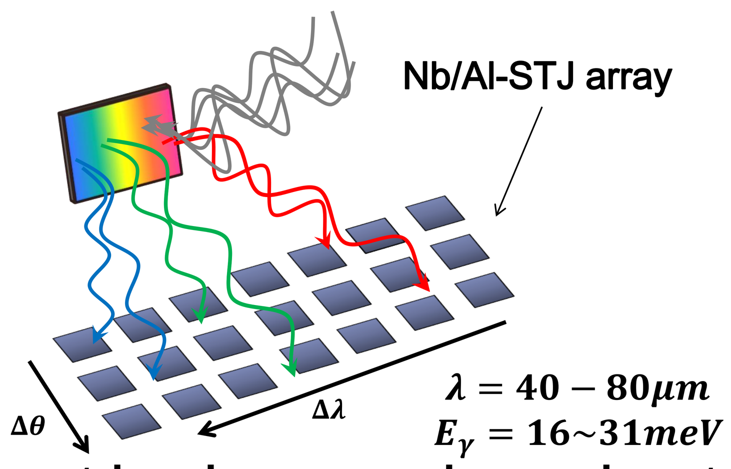

Fig.3 The schematic of neutrino decay search experiment

3. Nb/Al Superconducting Tunnel Junction Detector (Nb/Al-STJ)

STJ(Superconducting Tunneling Junction) is a superconducting photoelectric detector which has a sandwich structure of superconductor and insulator (Fig.4) .

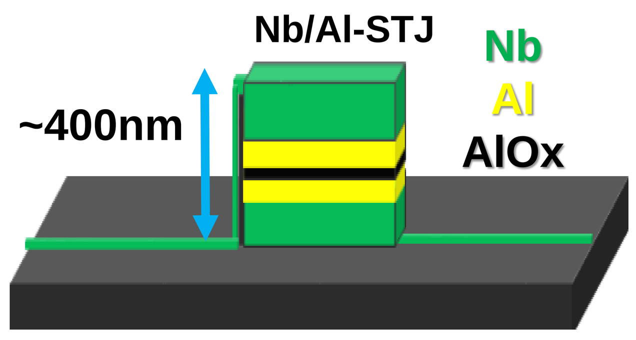

Fig.4 The schematic of Nb/Al-STJ

Operation principle

When photons break up cooper pairs in STJ. the electrons from the broken cooper pairs tunnel through the insulating layer as a tunnel current. As energy required to break up cooper pairs, called band gap, is as low asenergy resolution ~meV, the of STJ can be much better than semiconductor detector.

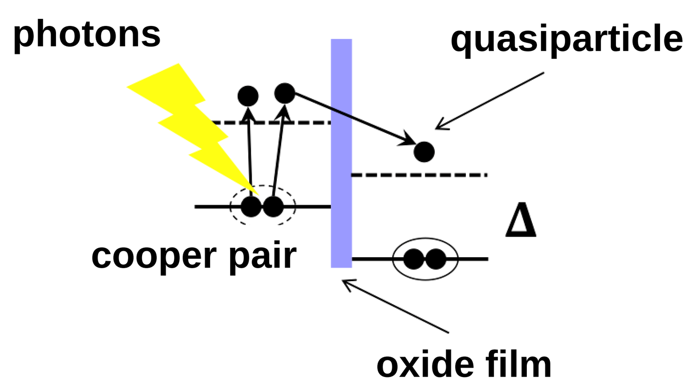

Fig.5 Operation principle of STJ. First, photons break up cooper pairs, then the quasiparticles tunnel through the oxide film and are collected as a current.

	Si	Nb	Al	Hf
Tc [K]		9.23	1.20	0.165
Δ [meV]	1100	1.550	0.172	0.020

TABLE.1 A list of energy gap.

$$q = G_{Al} \frac{E_p}{1.7\Delta} \quad (1)$$

G_{Al} trapping gain of Al (~10)
E_p Energy of photon (eV)
Δ Gap energy of superconductor (eV)

Equation.1 The charge caused by photon in STJ.

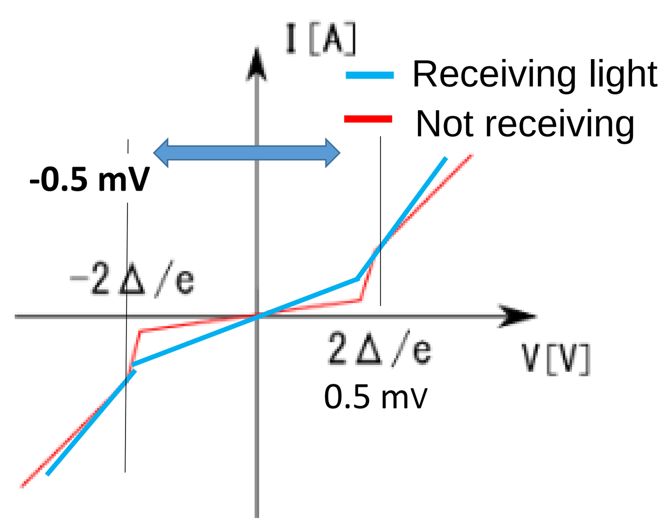

Fig.6 The typical I-V curve of STJ

4. Measurement system

The main noise source is leakage current of Nb/Al-STJ and electric noise from measurement system.

According to Fig.7, the proper operating temperature is below 0.4K and the energy gap is expected about 57meV.

The charge caused by 25meV single photon is about 200 electrons. We need to improve the measurement system to reduce a leak current.

Reduce the leakage current below 100pA

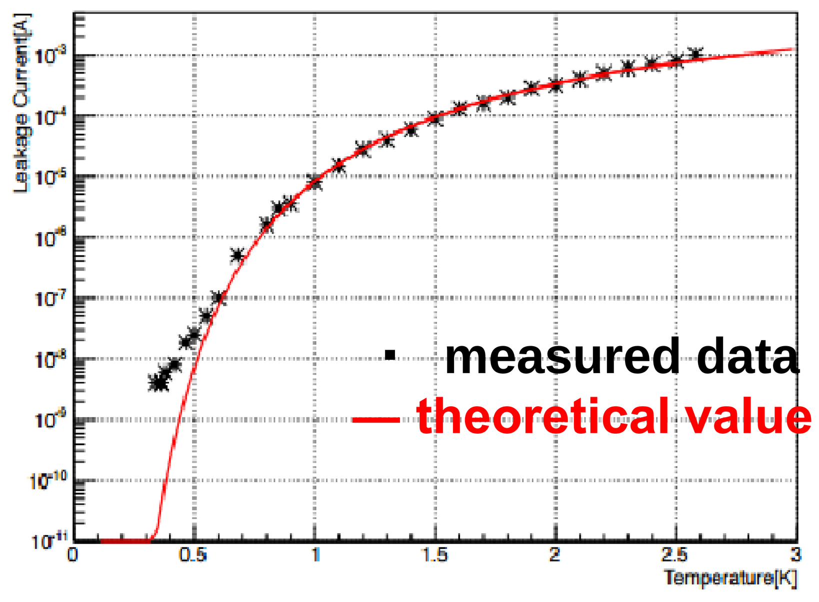

Fig.7 The temperature dependence of leakage current of Nb/Al-STJ.

Leakage current caused by
- **Magnetic field across the insulator**
  - **no magnetic material near the STJ**
- **Pinhole(constant) across the insulator**
  - **can expect to reduce it by using smaller one.**
- **Thermal excitation($\propto \sqrt{T}\exp(-\frac{\Delta}{k_B T})$)**
  - **need to make cooler to 0.4K.**

We improved measurement system
- **Some stainless steel screw (it may be magnetic) →titanium screw (not magnetic)**
- **Set a magnetic shield**
- **Remove the ground loop**

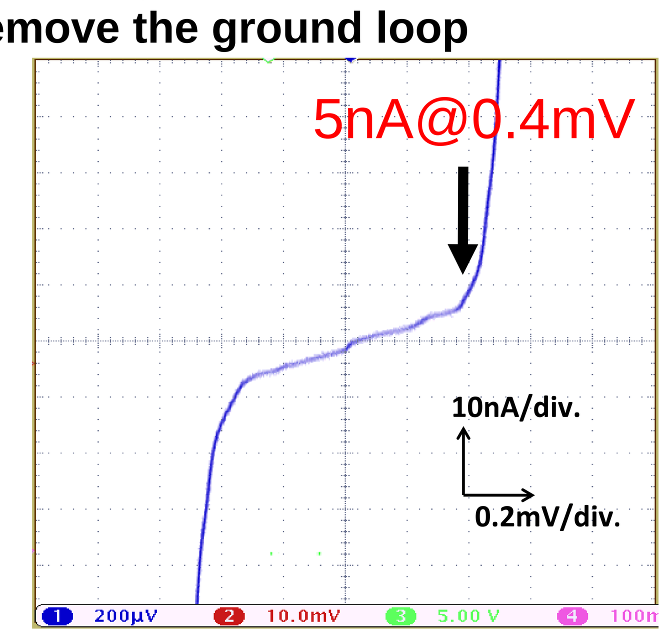

Fig.8 I-V curve(0.4K) of Nb/Al-STJ(100umx 100um) with improved measurement system

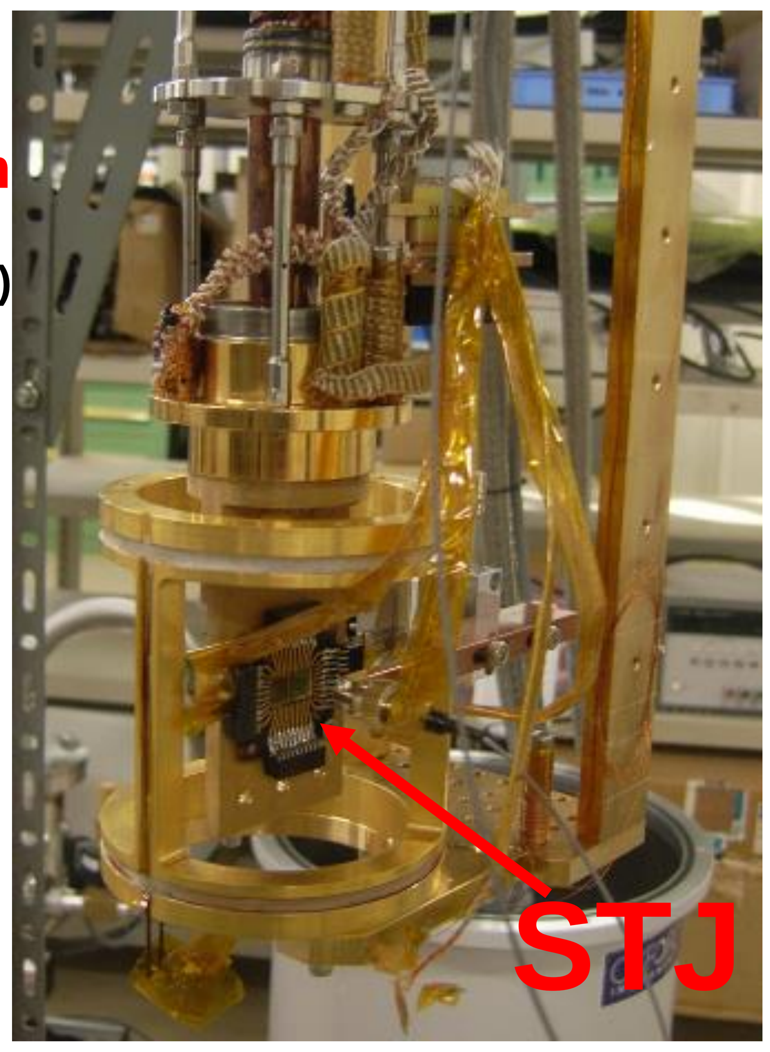

Fig.9 The measurement system near the STJs

We now aim at further improvement.

5. Light response of Nb/Al-STJ

Figure 10 shows a STJ signal to 10 photons with a wavelength of 465nm, which was read out with a charge amplifier and a shaper amplifier.
- **Response time of Nb/Al-STJ T_{stj} ~ 1μs**

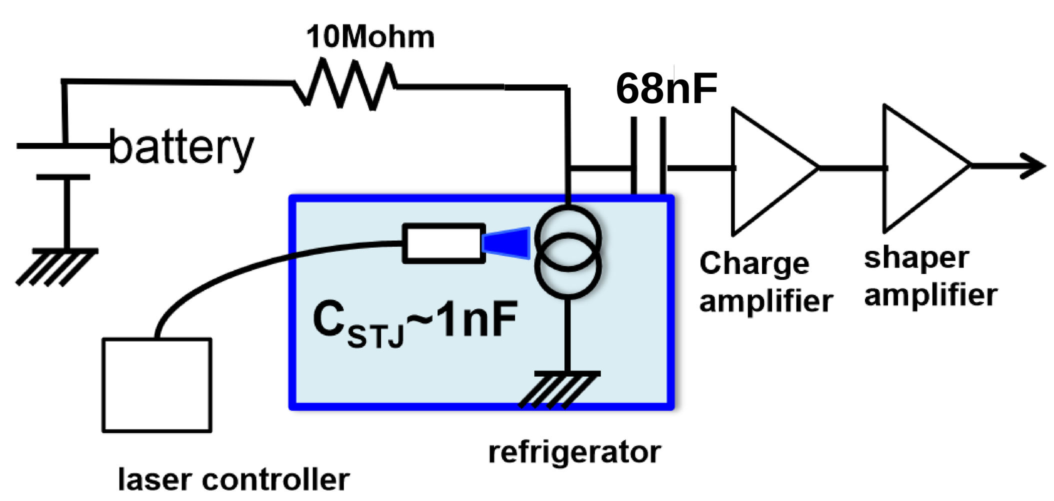

Fig.10 the schematic of measurement system

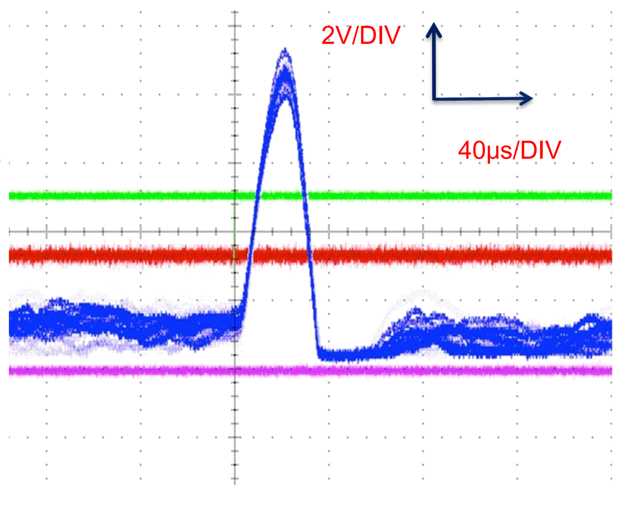

Fig.11 STJ signal to blue photons (wavelength =465nm)

We aim at detecting far-infrared single photon with Nb/Al-STJ.
- **Improving the measurement system to reduce a leak current.**
- **Developing ultra-low noise readout system for STJs.**
- **Improve Signal to Noise ratio by using cold amplifier.**
  - **SOI-STJ SOI preamplifier works in very low temperature (0.3K).**

6. Summary

We aim at detecting a far-infrared single photon with Nb/Al-STJ.
-Improving the measurement system to reduce a leak current.
Leak current 5nA(100um x 100um Nb/Al-STJ)
-Developing ultra-low noise readout system for STJs
Remove the circuit ground loop
We are developing SOI preamplifier for STJs

7. Acknowledgement

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