Development of Superconducting Tunnel Junction Photon Detector with SOI Preamplifier board to Search for Radiative decays of Cosmic Background Neutrino

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STJ Detector

We are developing STJ photon detector for neutrino decay search (as Dr. Takeuchi slide) aiming at detecting single far infrared (50um) photon.

STJ (Superconducting Tunnel Junction) detector is superconducting photoelectric detector that composed of Superconductor / Insulator / Superconductor.

Incident photons break up cooper pairs in STJ, the electrons from the broken cooper pairs tunnel through the insulator layer.

<table>
<thead>
<tr>
<th></th>
<th>Si</th>
<th>Nb</th>
<th>Al</th>
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<tbody>
<tr>
<td>Tc [K]</td>
<td>9.23</td>
<td>1.20</td>
<td></td>
</tr>
<tr>
<td>Δ [meV]</td>
<td>1100</td>
<td>1.550</td>
<td>0.172</td>
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Since energy gap of Nb is ~1meV (Si:~1eV), the energy resolution of STJ can be much better than semiconductor detector.
Nb/Al-STJ

Nb/Al-STJ is one of the candidate detector for neutrino decay search.

The signal to infrared (1310nm) laser

Typical signal width is about 1us

Because of this signal width

Requirement for leakage current of Nb/Al-STJ to detect single far infrared photon is below 100pA.

But we haven’t achieved such leakage current yet…

To achieve leakage current below 100pA…

• use better quality STJ or smaller STJ

• operate STJ below 800mK

Temperature dependence of leakage current with Nb/Al-STJ (100 x 100um²)
STJ array prototype for Neutrino decay search

We processed STJ at AIST and KEK, and measured distribution of infrared (1310nm) laser with STJ array.

The distribution of laser from fiber is expected to be Gaussian.

The number of STJs: 10
The size of each STJ: 100um x 100um

![Diagram showing STJ array and laser fiber with Gaussian fit and output from each STJ]
**SOI-STJ**

We are also developing a new detector: SOI-STJ

**Silicon On Insulator (SOI)**
- Processing LSI on SiO₂ insulator
  - Low Power to be operated
  - High speed
  - Can operate at a few Kelvin
- SOI-FET is suitable for amplifier for STJ signal

**STJ**
- Has high energy resolution

**SOI-STJ**
- Processing STJ directly on a SOI preamplifier board to make the detector compact, low noise and easy to be multipixel detector.
- SOI-STJ can be new novel detector!

**Question**
- Is SOI caused any damage by processing STJ?
- Can Nb/Al-STJ be processed on SOI board?
We confirmed STJ processed on SOI board has no problem!
SOI-FET after processing STJ at Low Temperature

I-V curve of SOI-FETs after processing Nb/Al-STJ.

- Both of NMOS and PMOS can be operated below 800mK.
- Trans-conductance “gm” is not varied drastically for each temperature at operation voltage(0.2V).

SOI-FET with STJ processed has excellent performance below 800mK.

SOI-FET is suitable for cold preamplifier for STJ signal!
Summary

• We are developing STJ and SOI-STJ to detect single far infrared photon for neutrino decay search.
• We confirmed
  ✓ STJ processed on SOI board has sufficient quality.
  ✓ SOI-FET has no damage by processing STJ
  ✓ SOI-FET has excellent performance below 800mK.
BUCK UP
Temperature dependence of IV curve

Threshold voltage is changed. But the other properties are almost unchanged.
Requirement for leakage current

When far-infrared single photon incident to the Nb/Al-STJ, Number of created quasi-particle in STJ is around $100e$ (assuming $\text{Gal} = 10$). We want to separate between the signal and pedestal (3 sigma). so requirement for fluctuation of the leakage current of STJ is follow.

$$\delta N_{q\text{leak}} = 33 \text{ e}$$

If we assume that integration width is 1.5 uS, our requirement for the leakage current is...

$$N_{q\text{leak}} = 1089 \text{ e}$$

$$I_{\text{leak}} = \frac{1089 \times 1.6 \times 10^{-19}}{1.5 \times 10^{-6}} = 108[pA]$$
5 minutes DAQ at 200km height in 2016

- **Tertiary mirror**
- **Secondary mirror**
- **Main Mirror 15 cm, F=1 m**
- **Focal plane Instruments**
- **Grating**
- **Post-Preamplifier DAQ system**
- **Vibration Damper**
- **Star Sensor**
- **1.7K Cryostat >1W**
- **IR Light**
- **1.7K Cryostat**
- **50cm**
- **Weight 100kg**
- **Liq-He tank 1.7K >1W**
- **Preamplifiers (4K)**
- **Superconducting Tunnel Junction (STJ) Detector Array (50 x 8 channels)**

**5 minutes DAQ at 200 km height in 2016**

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Nb/Al-STJ on newly designed chip

Division 1
100um×100um STJ array

Division 2
STJs with dispersed junction

Division 3
STJ array with different sizes

Division 4
STJs with different under layer sizes
(Upper layer sizes are same)
To measure dispersion of quasi particle

Division 5
STJs with and without SiO₂
To measure transmittance of SiO₂

To measure transmittance of SiO₂