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R&D of Hf-STJ for COBAND experiment

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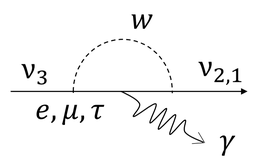
1. Motivation

COBAND experiment searches for the **Cosmic Background Neutrino** which is predicted to exist uniformly in the universe.

By the observation of the neutrino oscillation, the neutrino masses were found to be non-zero.



The squared mass difference between neutrino generations (m_1, m_2, m_3) has been already established, i.e.

$$|\Delta m_{12}^2| = m_2^2 - m_1^2 \sim 7.37\times10^{-5}\ \mathrm{eV}^2$$

$$|\Delta m_{23}^2| = m_3^2 - m_2^2 \sim 2.46\times10^{-3}\ \mathrm{eV}^2$$

If we assume $m_1^2 \ll m_2^2$, we obtain

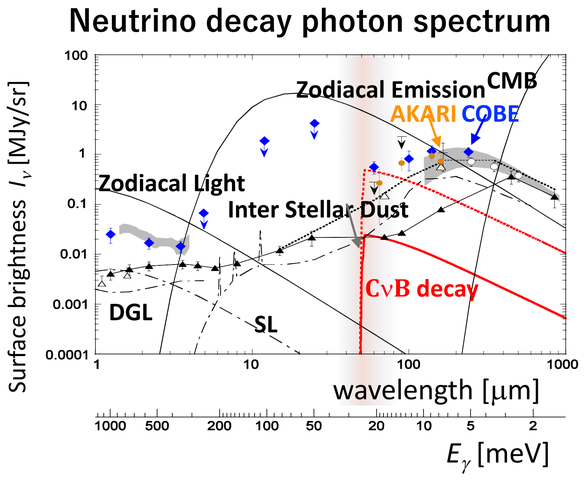
$$m_2 \sim 8.6\ \mathrm{meV}, \text{ and } m_3 \sim 50.3\ \mathrm{meV}$$

A heavier neutrino can decay into a lighter neutrino with a photon.

$$\nu_3 \rightarrow \nu_2 + \gamma, \qquad E_\gamma\ (\text{at } \nu_3 \text{ rest frame}) = \frac{m_3^2 - m_2^2}{2m_3}$$

If we assume $m_3 = 50\mathrm{meV}$, E_γ at ν_3 rest frame would be 25meV, which corresponds to $\lambda_\gamma = 50\mu\mathrm{m}$. Therefore, by measuring the energy of this photon, we can determine the heavy neutrino mass.

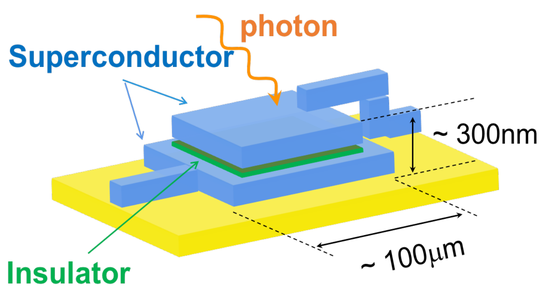
Neutrino decay photon spectrum

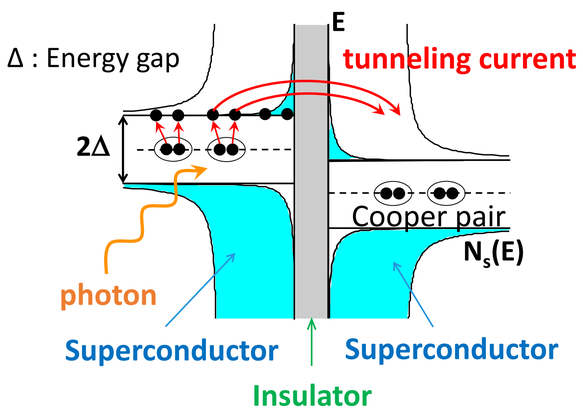


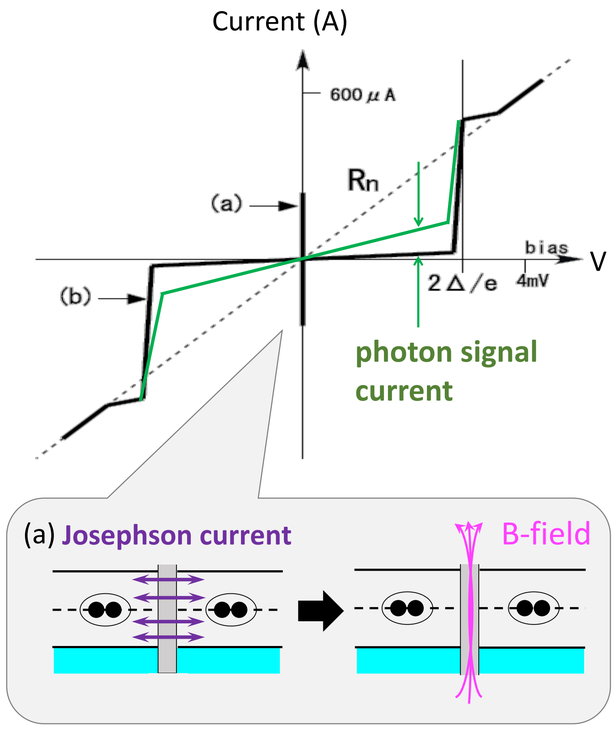
The neutrino lifetime is so long, Left-Right symmetric model predict it larger than 10^{17}years, and 10^{12} years or less from COBE and AKARI observation. Thus we search for the photon emission from the decay of the Cosmic Background Neutrino (CνB) in the far infrared region of photon energy spectrum.

Neutrino decay photon spectrum has unique cut-off and tail by red shift.

2. STJ detector







STJ schematic

Superconducting Tunnel Junction (STJ) is composed of superconductors and insulator.

Principle of operation

1. A constant bias voltage (|V|<2Δ/e) is applied between the two superconductors.
2. Incident photon into superconductor breaks Cooper pairs and they become the quasi-particles.
3. Quasi-particles tunnel through the insulator, which become tunneling current that is proportional to the incident photon energy.

I-V characteristics of STJ

Tunnel current of Cooper pairs (Josephson current) is suppressed by applying B-field.

Energy resolution

Signal : Number of quasi-particles,

$$N_{q.p.} = G\frac{E_\gamma}{1.7\Delta}$$

Resolution: Statistical fluctuation in number of quasi-particles,

$$\sigma_E/E = \sqrt{(1.7\Delta)F/E}$$

→ Smaller superconducting gap energy Δ yields better energy resolution

When E=25meV, Energy resolution is below.

Material	Energy gap Δ(meV)	transition temp. (K)	Energy resolution (%)
Nb	1.55	9.23	14.5
Al	0.172	1.19	4.8
Hf	0.021	0.165	1.7

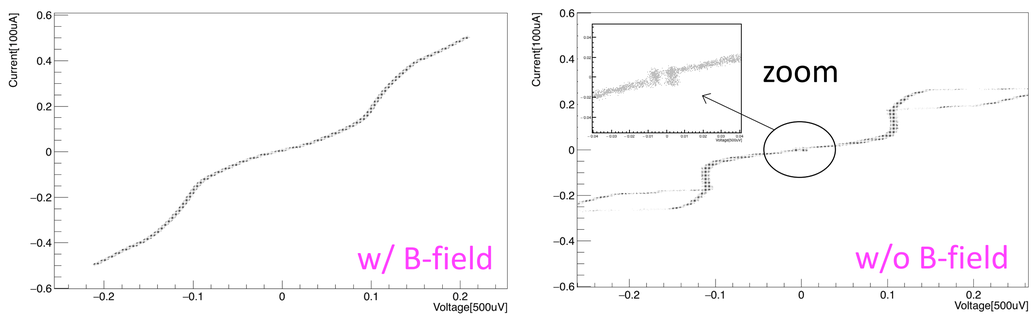
F: Fano factor (~0.2), G: Back-tunneling gain

3. Hf-STJ development

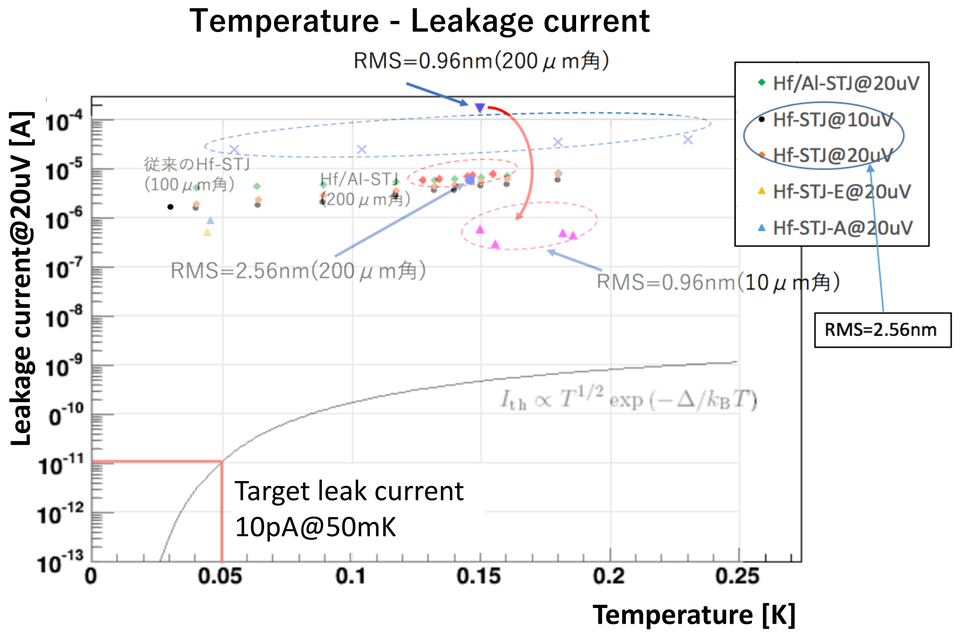
Leakage current improvement

- We newly made two types of Hf-STJ.
  - Hf-STJ junction size is changed from 200um sq. to 10um sq.
  - Roughness of Hf layer surface was changed from 0.96nm to 2.56nm in RMS by changing sputtering condition.
- The leakage current improved by 1 order by each change.

IV curve of 200um sq. Hf-STJ @32mK

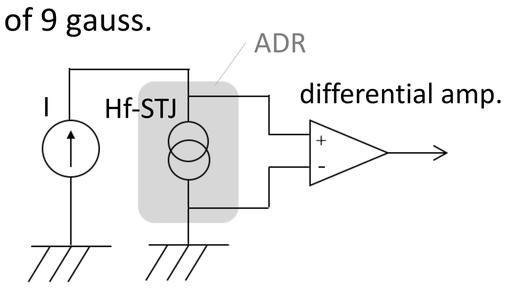


Temperature - Leakage current

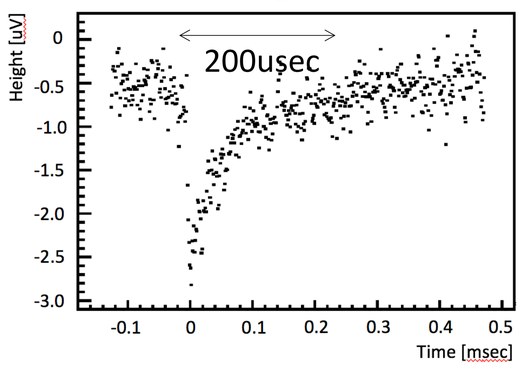


6 keV X-ray signal detection

- We detected 6 keV x-ray signals of Hf-STJ in an adiabatic demagnetization refrigerator (ADR) at IBS-CUP.
- We made a superconducting coil with a persistent current switch (PCS) to suppress Josephson current by the B-field of 9 gauss.
- We amplify Hf-STJ signal by differential amplifier for SQUID. (#XXF-1, Gain:1100~2000, Bandwidth:0.2~50MHz)

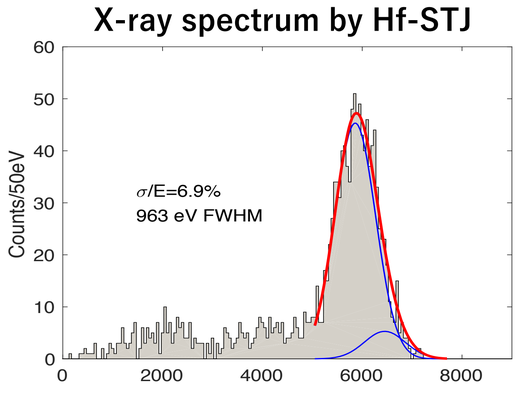


1 event signal shape



- We detected 6 keV x-ray response of Hf-STJ in the ADR at 33mK.
- The X-ray source is Fe55.
- We applied the B-field of 9 gauss in parallel to the insulator plane of Hf-STJ by the superconducting coil with the PCS.
- Signal time constant is around 200us.

X-ray spectrum by Hf-STJ



- We applied optimal filtering method to find the amplitude of the measured traces.
- Two blue curves corresponds to Kα and Kβ X-rays, respectively.
- σ/E was fond to be 6.9 %.

4. Summary

- The leakage current of Hf-STJ was improved, by using small size junction and changing the smoothness of Hf layar surface.
- We detected 6 keV X-ray response of Hf-STJ in ADR, and succeeded in observing the X-ray signal spectra by Hf-STJ for the first time.
- Next we are going to see X-ray signal by 10um sq. Hf-STJ to improve σ/E.