Development of Superconducting Tunnel Junction Detector using Hafnium (Hf-STJ)

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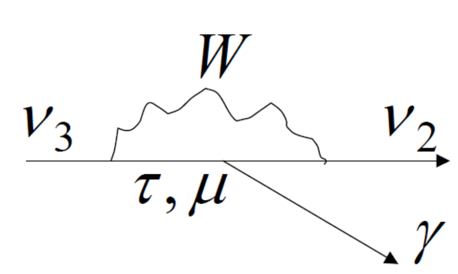
1. Introduction

- **Difference between mass-square of different generation neutrino has been measured by various experiments of neutrino oscillation.**
- **However, neutrino mass itself has not been measured.**
- **Detection of neutrino decay enable us to measure an independent quantity of the difference between squares of neutrino mass.**
- **→ We can obtain neutrino mass itself from these two independent measurements.**
- **To observe neutrino decay, we need measure the energy spectrum of the cosmic infrared photon background with energy resolution better than 2%.**
- **We adopted the Hf-STJ detector as such a detector and are developing it.**

2. Neutrino Decay

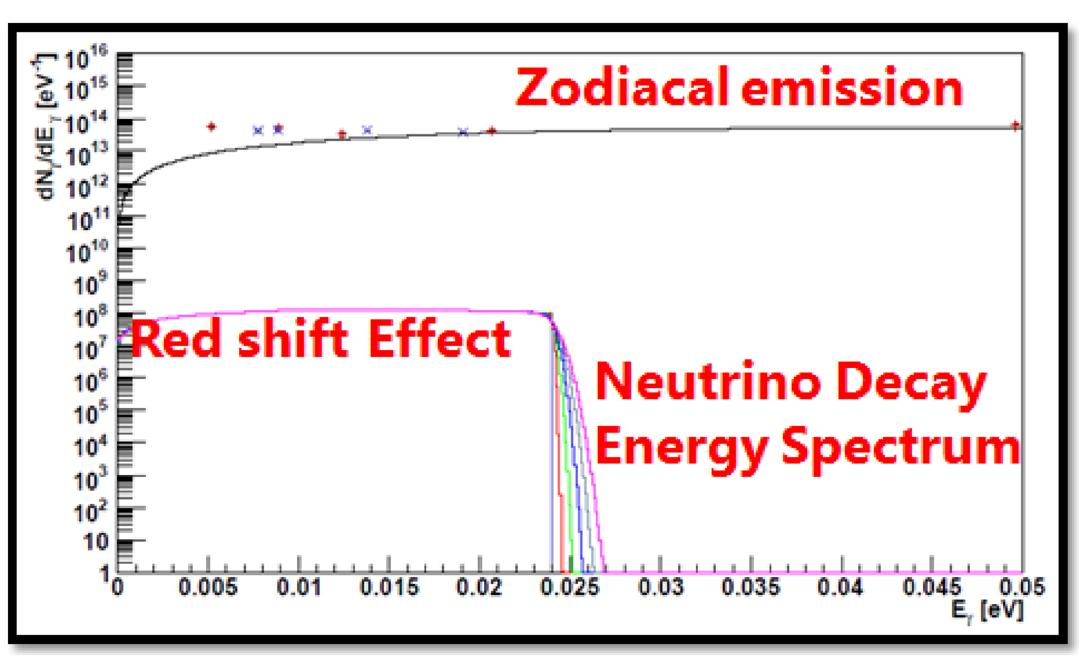
- **In neutrino decay process, a lighter neutrino(ν_2) and a photon(γ) are emitted from a heavier neutrino(ν_3).**

- $\nu_3 \rightarrow \nu_2 + \gamma$
- $E\gamma = \frac{\Delta m_{32}^2}{m_3}$



Feynman diagram of neutrino decay

- **Neutrino lifetime is very long (10^{43}year in the standard model, 1.5×10^{17}year in Left-Right symmetric model).**
- **To observe neutrino decay, we need an immense quantity of neutrino.**
- **Most promising method is to observe the decay of the cosmic background neutrino(CBN).**
  - **CBN has a particle density ρ of 110 cm^{-3} per generation**



← Expected energy spectrum of CBN decay and background (Zodiacal emission)

- m_3 = 50meV is assumed
- $E\gamma$ at neutrino restframe = 25meV
- **Energy spectrum of the photon from CBN has a cutoff at 25meV and low energy tail due to red shift effect.**

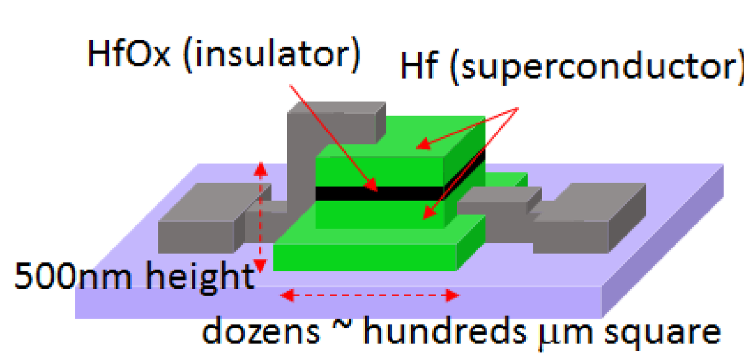
• Detector requirements for CBN decay observation

- **Continuous spectrum of photon energy around E_γ~25meV (λ = 50μm, far infrared photon).**
- **Energy measurement for single photon with better than 2% resolution for $E\gamma$ ~ 25meV to identify the shape edge in the spectrum.**

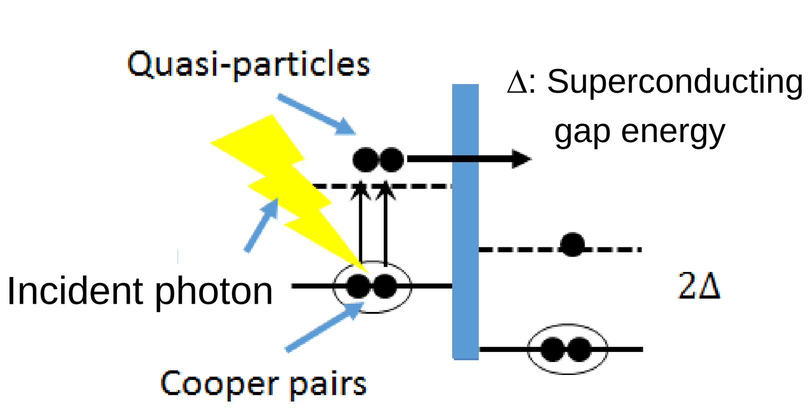
→ We adopted Hf-STJ as a detector for neutrino decay.

3. STJ detector

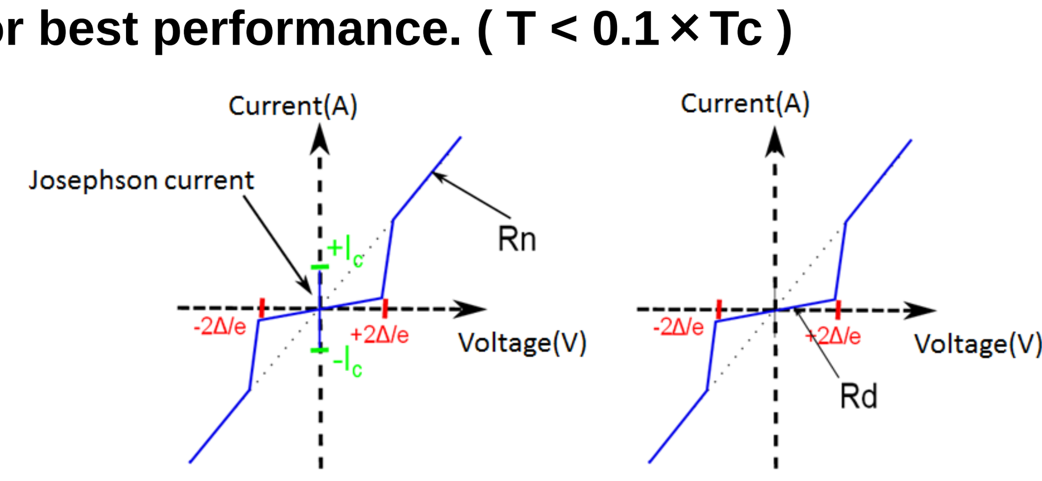
- **STJ = Superconductor / Insulator / Superconductor.**
- **Characteristics:**
  - Single photon counting
  - Broad response from the ultraviolet to the far infrared
  - Arrival time information to ~1μs
  - High energy resolution
- **Must be operate at low temperature for best performance. (T < 0.1 × Tc)**



STJ overhead view



Working principle



IV curve of STJ

Working principle

1. Incident photon is absorbed in the superconductor and excites cooper pairs.
2. Exited cooper pairs become quasi-particles.
3. Quasi-particles go through tunnel barrier by tunnel effect.
4. Number of quasi-particle is determined by energy of incident particle.
5. Thus, we can measure the energy of incident particle by measuring the tunnel current.

4. Energy resolution of STJ detector

- **Statistical fluctuation in number of quasi-particle determines STJ energy resolution.**
- **Smaller superconducting gap energy Δ yields better energy resolution.**

$$\sigma_E = \sqrt{(1.7\Delta)FE}$$

Material	Tc(K)	Δ(meV)
Niobium	9.20	1.550
Aluminum	1.14	0.172
Hafnium	0.13	0.021

Δ: Superconducting gap energy
F: fano factor
E: Photon energy

Tc : Superconducting critical temperature
Need ~1/10Tc for practical operation

Hf-STJ energy resolution

- **$N_{quasi\text{-}particle}$ = 25meV/1.7Δ = 735**
- **2% energy resolution @25meV is achievable if fano factor <0.3**

→ Hf-STJ can archive requirements for CBN decay observation.

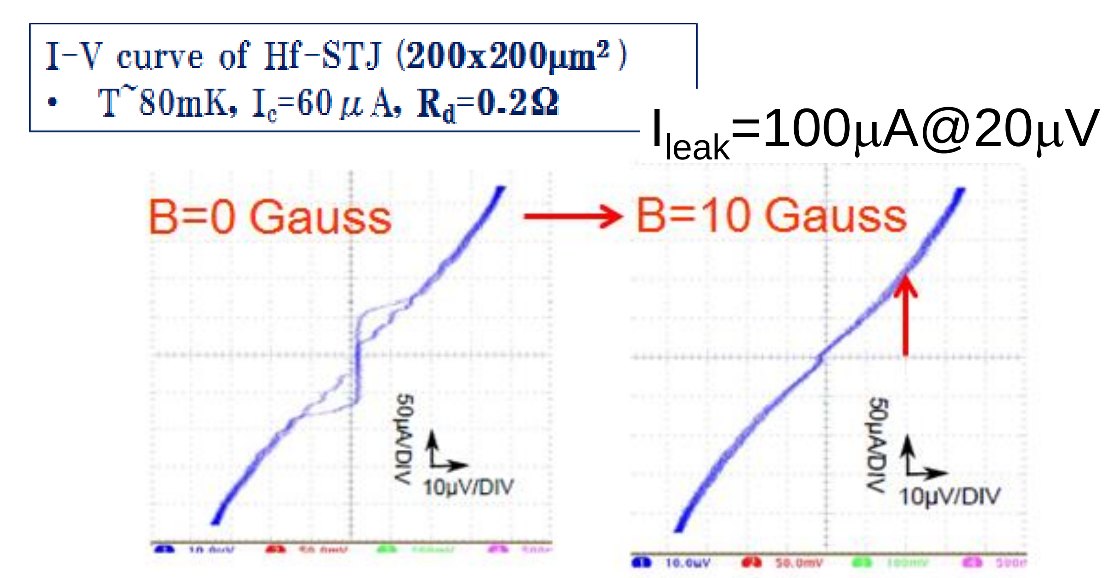
5. Current status of development

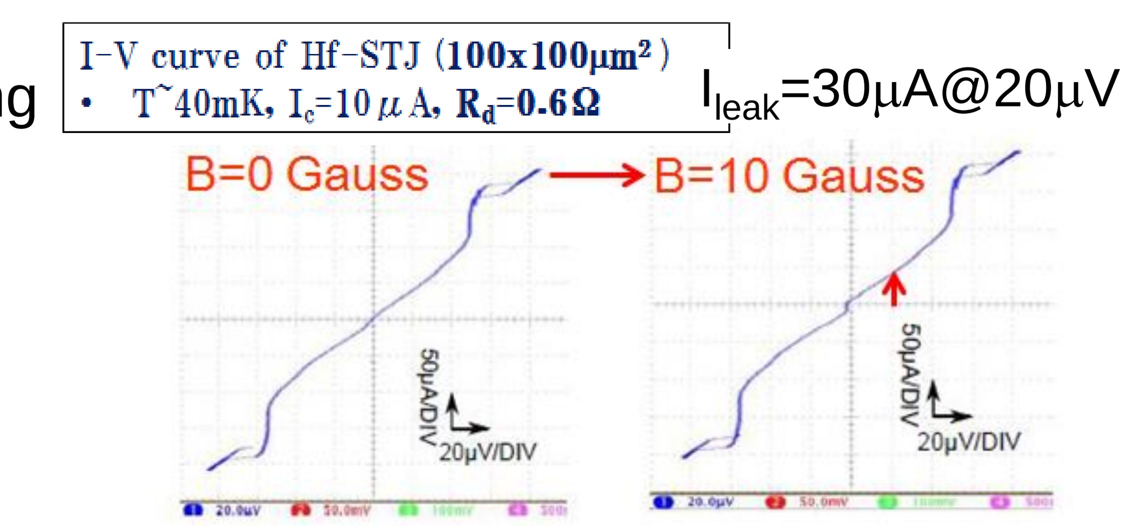
- **We observed Josephson current by Hf-HfOx-Hf barrier layer.**
- **So, we succeeded in producing Hf-STJ detector which works as STJ for the first time in the world.**

Optimizations

- **As our Hf-STJ sample has large leakage current, optimization is underway.**

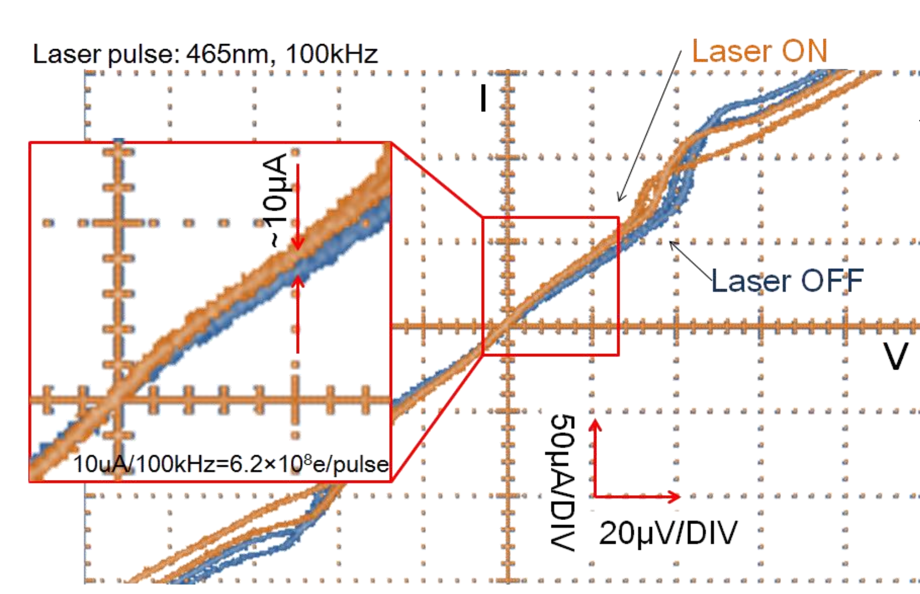
1. Downsizing
   Hf-STJ(100 × 100μm^2) shows smaller leakage current than Hf-STJ(200 × 200μm^2).
2. Optimize condition for making the insulator.
3. Oxidation on side surface.





Response to DC light

- **We observed the response of Hf-STJ to DC-like laser light at wave length of 465nm and frequency of 100kHz.**
- **The signal current was measured to be 10μA at 20μV.**



← IV curve of Hf-STJ with and without 100kHz laser light(465nm)

Sample information:
100 × 100μm^2
R_d= 0.6Ω
T = 139~153mK

6. Summary

- **To observe neutrino decay, we are developing Hf-STJ.**
- **We succeeded in producing Hf-STJ detectors which work as STJ for the first time in the world.**
- **Also, Hf-STJ response to the visible light was observed.**
- **However, our Hf-STJ sample has large leakage current of 30μA@20μV and need more improvement to function as a far-infrared photon detector.**