Development of Superconducting Tunnel Junction Detector using Hafnium for COBAND experiment

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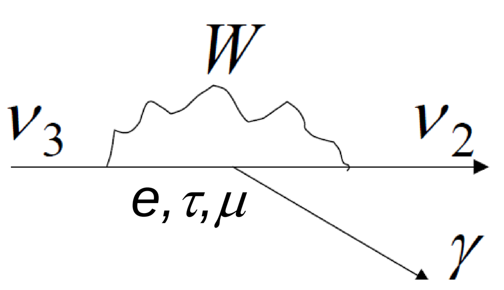
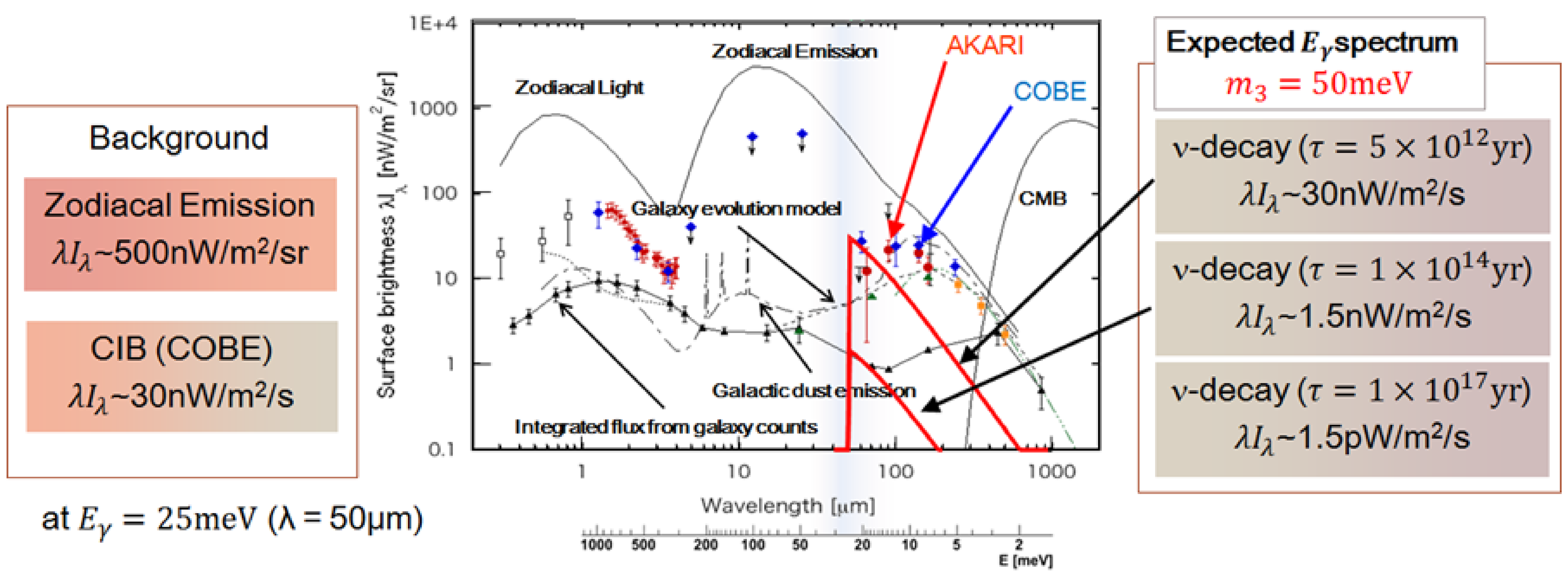
1. COBAND experiment

- **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.**
- **COBAND(Cosmic BAckground Neutrino Decay search) experiment aims at measuring the neutrino mass by observing the neutrino decay of the cosmic background neutrinos (CBN).**
- **In the COBAND experiment, we measure the cosmic infrared photon energy spectrum continuously to find the energy cutoff from the CBN decay against the zodiacal emission which is the dominant background.**



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

	Telescope diameter	Viewing angle	Detector; Numbers of pixels	DAQ period	Refrigerator
Rocket experiment	15cm	0.006° x 0.05°	Nb/Al-STJ 50x8	200sec	^{3}He sorption refrigerator 0.4K
Satellite experiment	20cm	0.1°	Hf-STJ 20x20	100days	ADR 0.1K

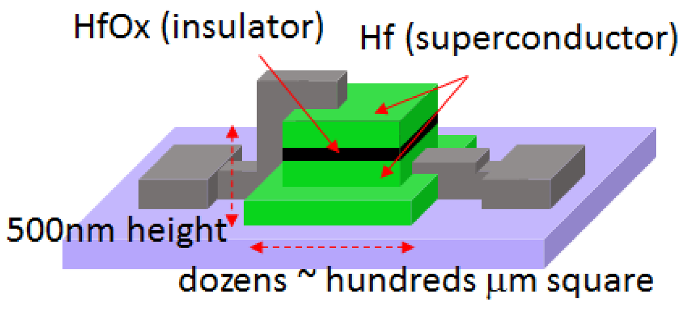


at E_γ = 25meV (λ = 50μm)

- **Detector requirements for the 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 Eγ ~ 25meV to identify the sharp edge in the spectrum.**

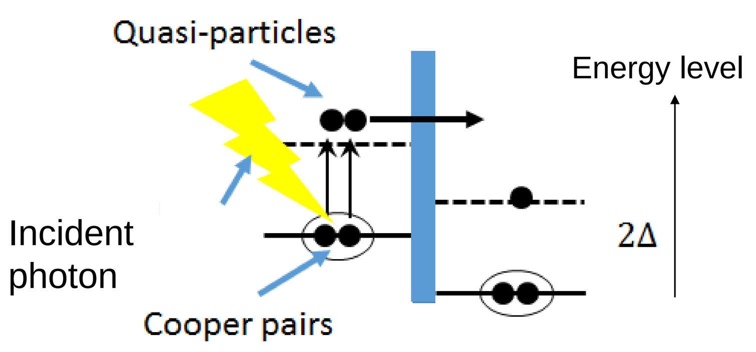
→ We adopted Hf-STJ as a detector for the COBAND satellite experiment.

2. STJ detector

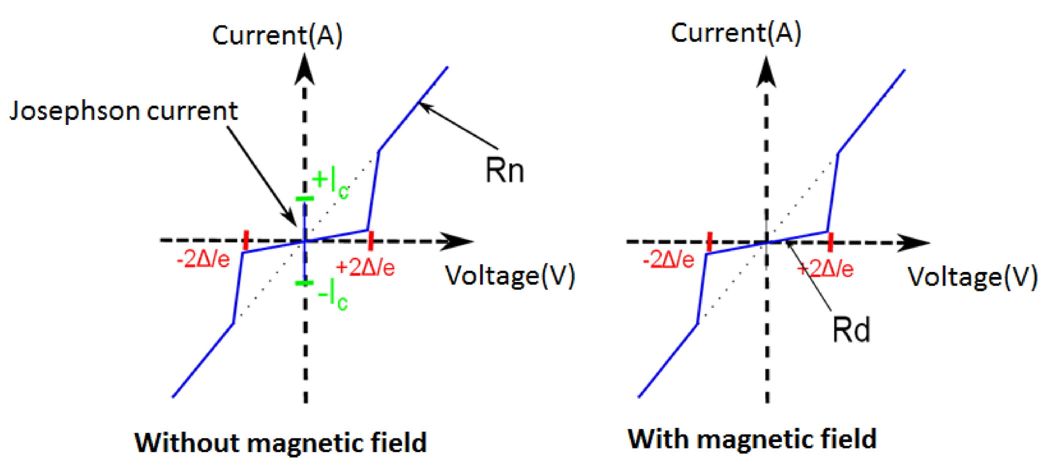


STJ overhead view

- **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 operated at low temperature for best performance. (T < 0.1 × Tc)**



Working principle



IV characteristics 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. we can measure the energy of incident photon by measuring the tunnel current.

Energy resolution

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

Δ: Superconducting gap energy
F: Fano factor
E: Photon energy
T_c: Critical temperature

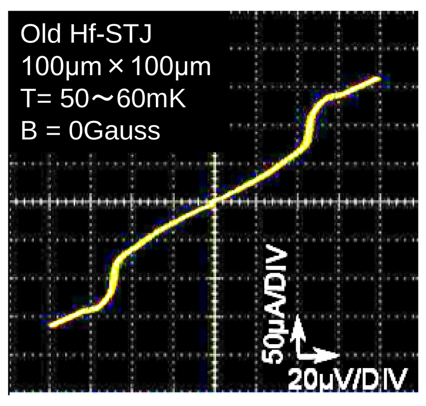
Material	Tc(K)	Δ(meV)
Niobium	9.20	1.550
Aluminum	1.14	0.172
Hafnium	0.13	0.021

Hf-STJ energy resolution

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

3. Hf-STJ development

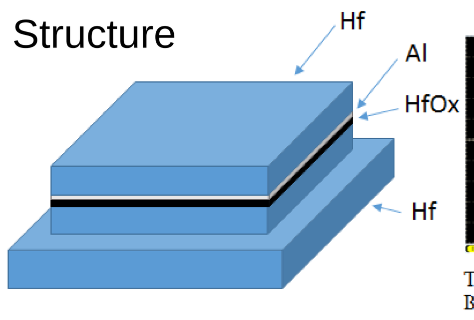
- Our old Hf-STJ has large leakage current.
  - 20μA@20μV, 50mK.
- We newly made two types of Hf-STJ.
  - Hf-STJ w/ thin Al layer
  - Hf-STJ using smooth Hf film
- These two samples work as STJ detector and leakage current improved.



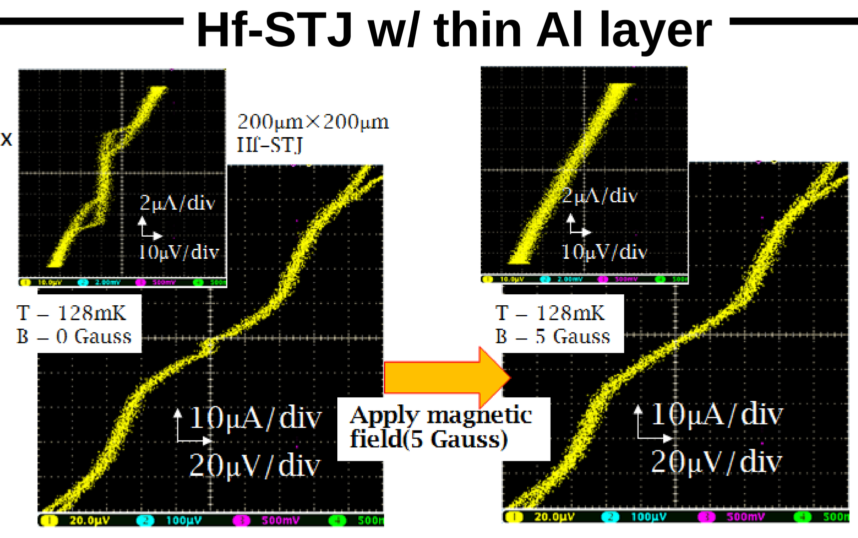
IV characteristics of old Hf-STJ

Hf-STJ w/ thin Al layer

Structure

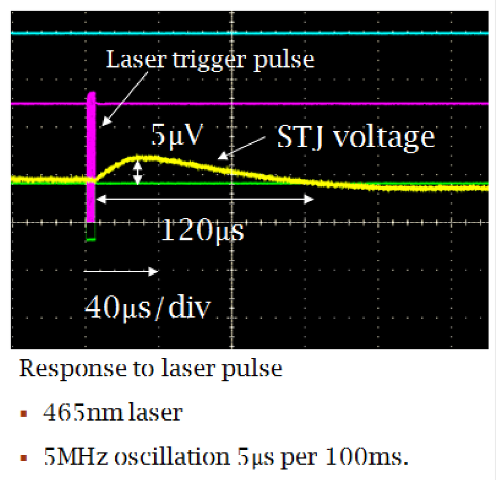


material	thickness
Hf	250 nm
Al	10 nm
HfOx	1~2nm
Hf	400nm



IV characteristics

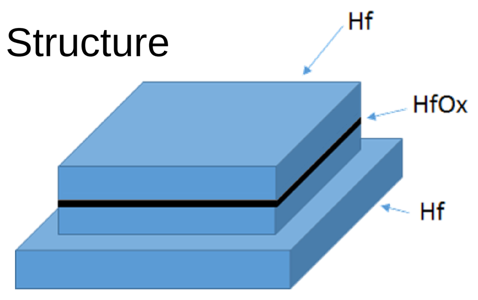
Leakage current: 6μA@20μV, 128mK



Response to laser pulse
- 465nm laser
- 5MHz oscillation 5μs per 100ms.

Hf-STJ using smooth Hf film

Structure



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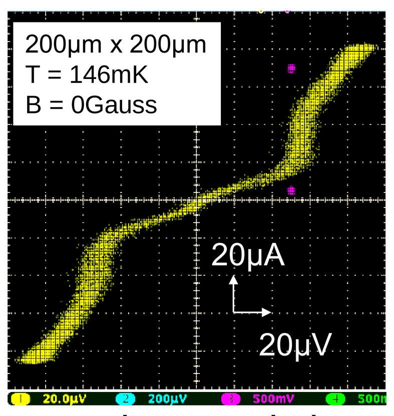
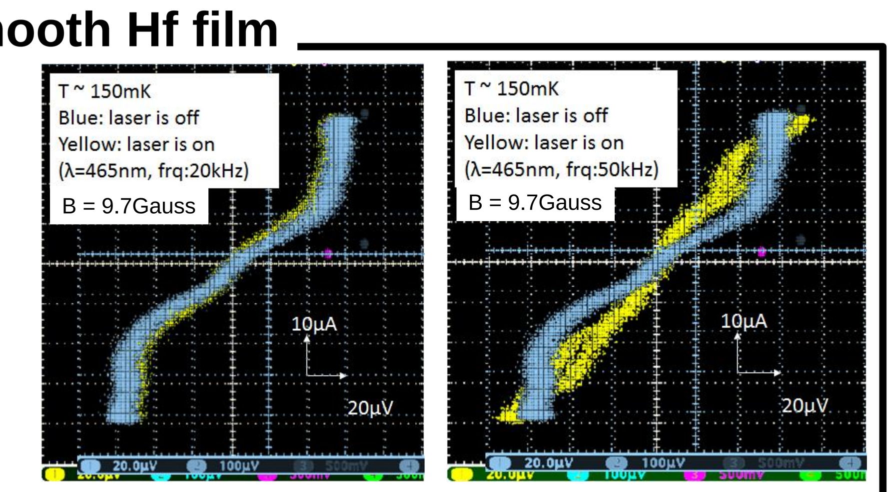


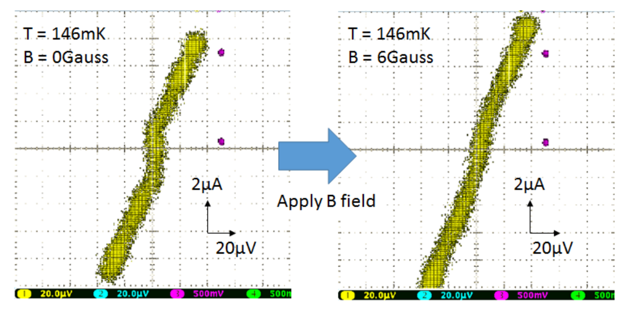
IV characteristic

Leakage current: 7μA@20μV,146mK



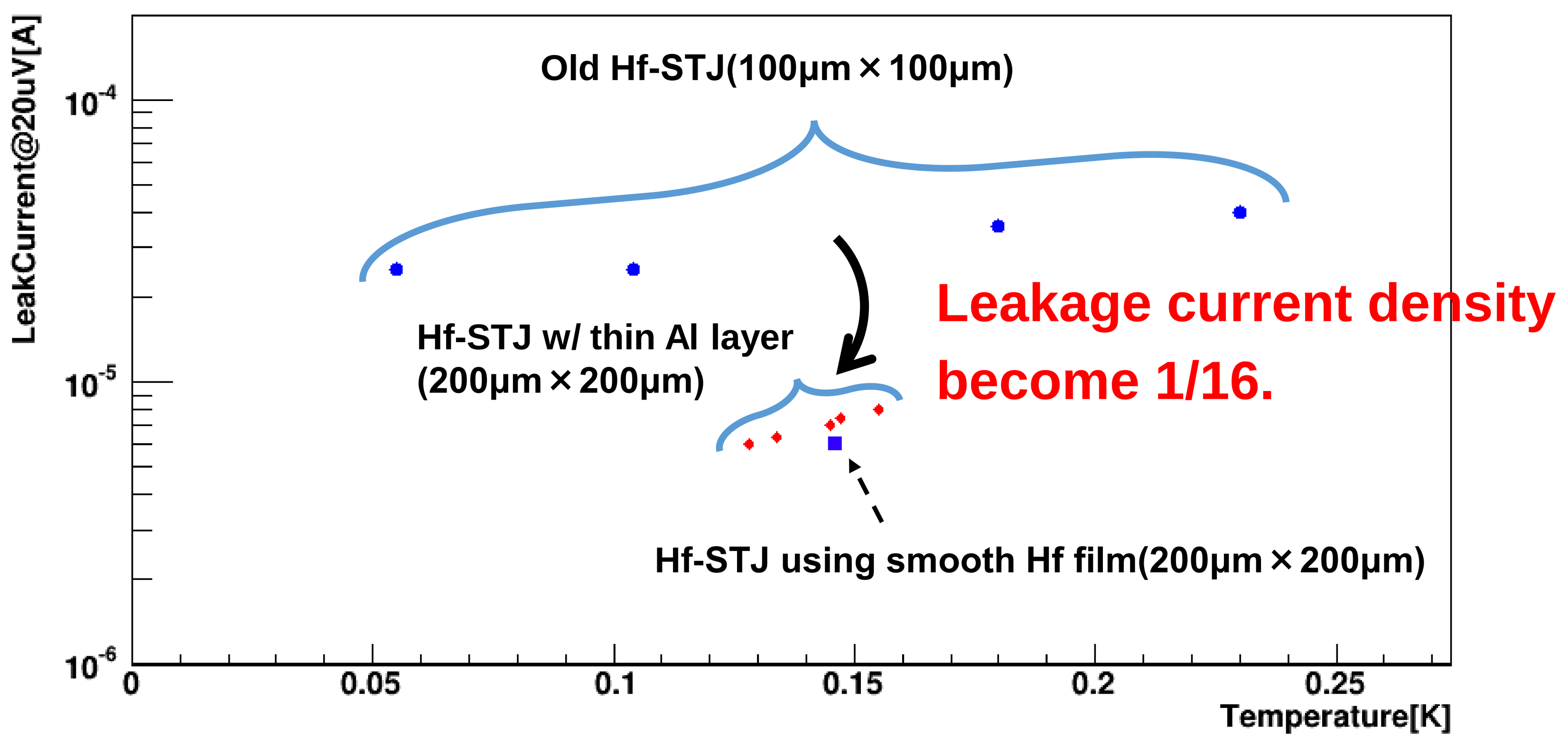
Response to DC-like laser light
465nm, 20kHz: 2μA increase@20μV
465nm, 50kHz: 7μA increase@20μV

Smoothen Hf film by sputtering parameter tuning.
DC magnetron sputter,
Ar 2.0Pa,50sccm,70W,T/S=60mm.



Josephson current

Leakage current temperature dependence



Leakage current improved. However, leakage current is still large.
Goal: leakage current < 0.4nA@20μV,140mK

Ideas to reduce leakage current

- produce HfOx by plasma oxidation
- downsizing(200μmX200μm→10μmX10μm)
- smoothen Hf film by dry etching

4. Summary

- **COBAND experiment aims at measuring the neutrino mass by observing the CBN decay.**
- **We are developing Hf-STJ for the COBAND satellite experiment.**
- **The leakage current density of new type of Hf-STJ became 16 times smaller than old Hf-STJ.**
- **Also, Hf-STJ response to the visible laser light pulse was observed.**
- **However, our Hf-STJ sample has large leakage current of 6μA@20μV and need more improvement to function as a far-infrared photon detector.**