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Microwave SQUID multiplexer for readout of optical TES array

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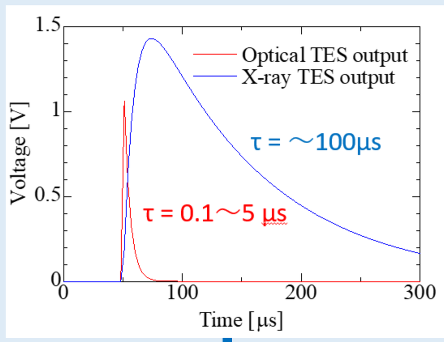
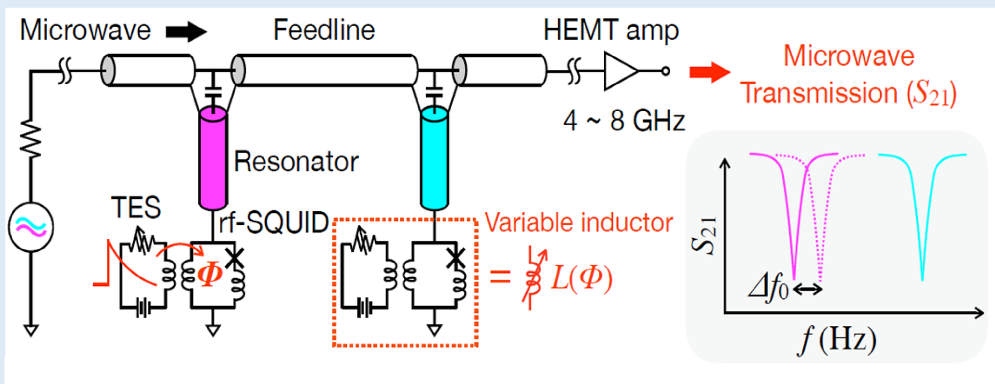
Introduction

- ✓ Development of photon counting device with optical transition edge sensor (TES) for biological imaging.
- ✓ Reduce imaging time
  - → Increase the number of TESs
    - → Multiplex readout

Optical TES is faster than X-ray TES.



- ✓ Multiplexing method
  1. Time Division Multiplexing (TDM)
  2. Code Division Multiplexing (CDM)
     - Slow Switching (160ns)
  3. Frequency Division Multiplexing (FDM)
     - Low modulation frequency (5 MHz)
  4. Microwave SQUID Multiplexer (MW-Mux)
- ✓ MW-Mux has a FDM carrier wave of gigahertz. It can increase the bandwidth

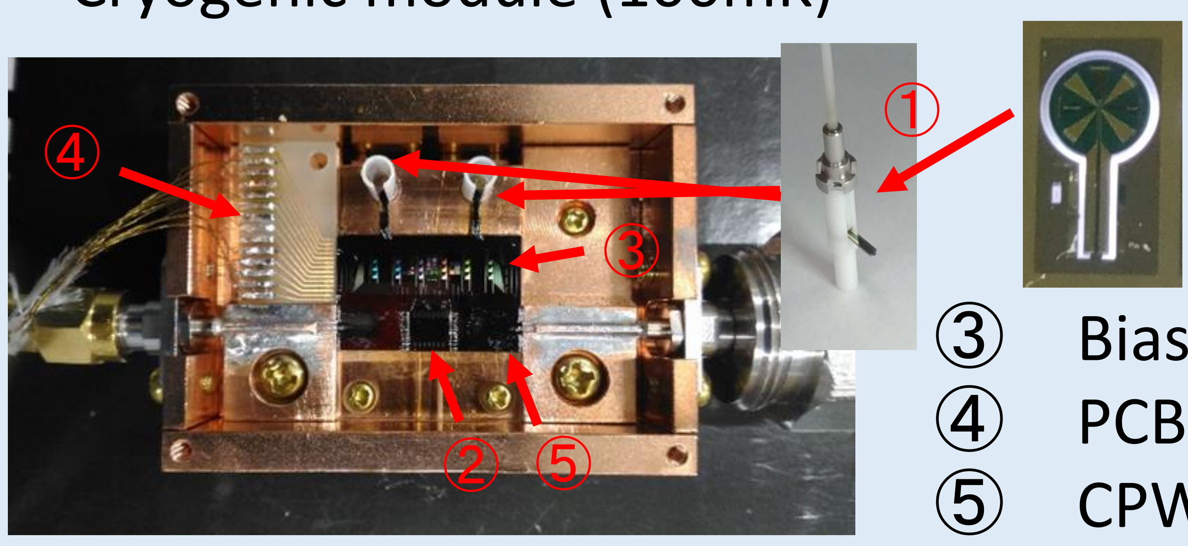


Readout TES signal as a shift of resonance frequency.

Principle of MW-Mux.

Setup

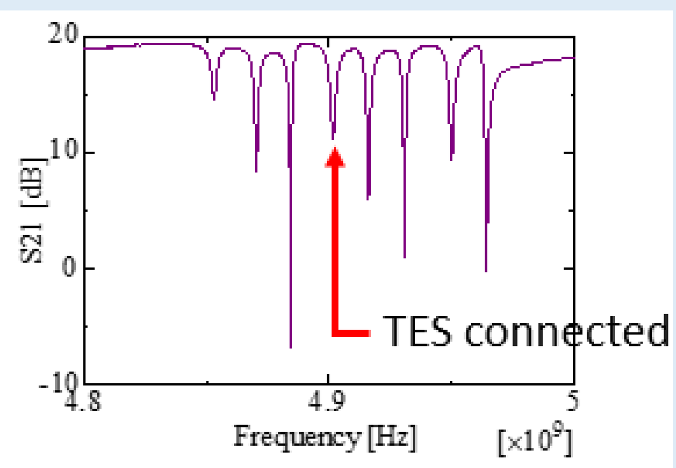
- ✓ Cryogenic module (100mK)



③ Bias chip
④ PCB
⑤ CPW wave-guide

① Optical TES
- Ti/Au (20/10 nm) bilayer TES
- Tc = 0.3 K
- Self-aligning fiber-to-detector coupling (used only right TES)

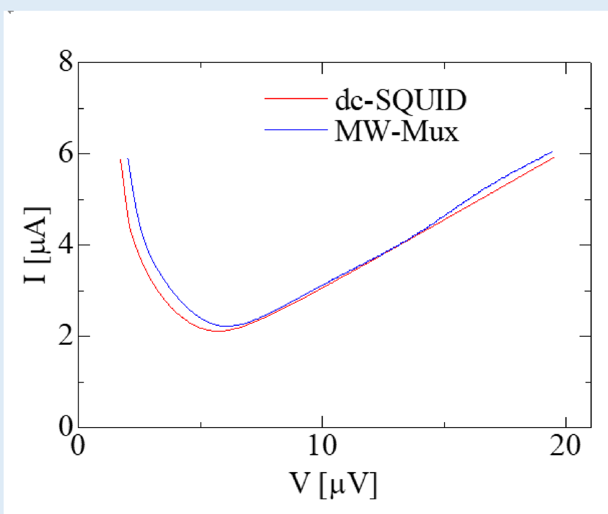
② MW-Mux chip
- 8 resonators
- fr: 4.901620 GHz
- Bandwidth: 2 MHz
- Q: 2400



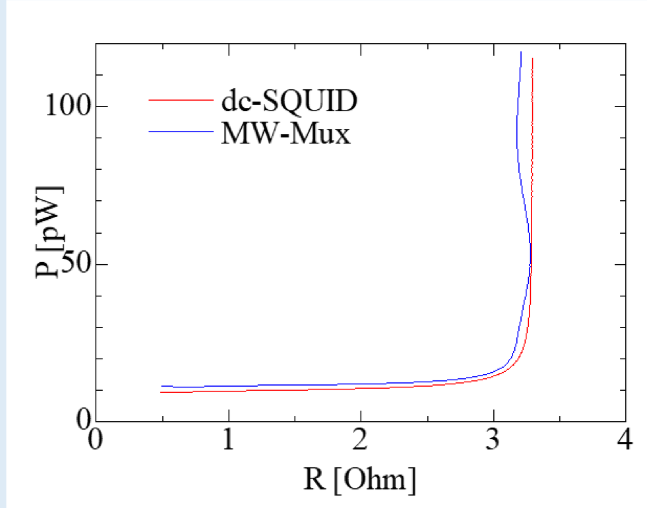
- ✓ Pulse laser
  - Repetition frequency: 10 kHz
  - Energy: 0.8 eV / photon (wavelength: 1550 nm)

Result & Discussion

- ✓ Voltage-Current characteristics measured by MW-Mux reproduced that of dc-SQUID.



I: output current
V: bias voltage

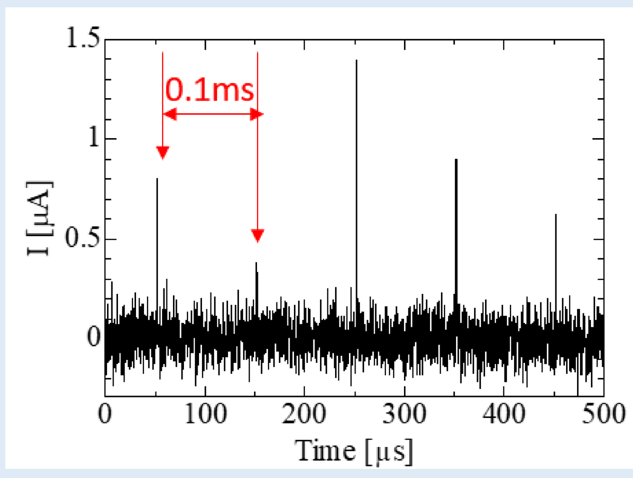


R: resistance of TES
P: Joule heat generated by TES

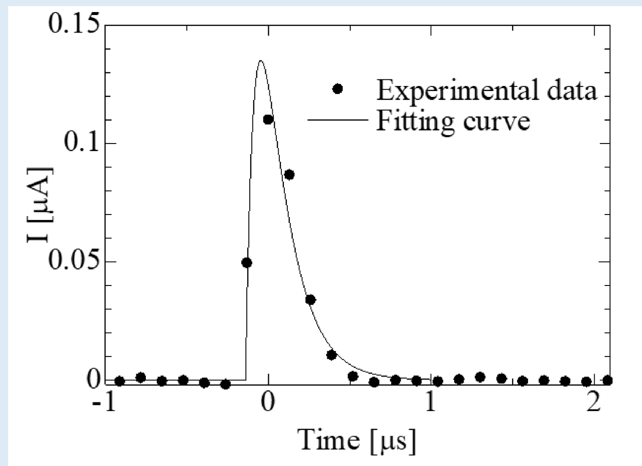
- ✓ We successfully measured a pulse from an optical TES and resolve number of photons.

- Responses of the TES to photons

(a)



(b)

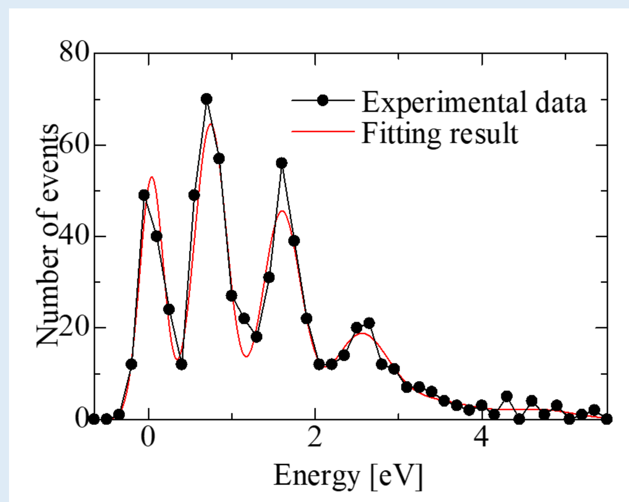


(a) Output signal from optical TES. Pulses were measured according to repetition frequency of pulse laser.
(b) Average pulse.
Rise time constant: 100 ns. Fall time constant: 156 ns.

- Energy Resolution
  - Experiment: 0.42 eV
  - Calculation: 0.35 eV

$$= \sqrt{\Delta E_I{}^2 + \Delta E_R{}^2 + \Delta E_S{}^2}$$

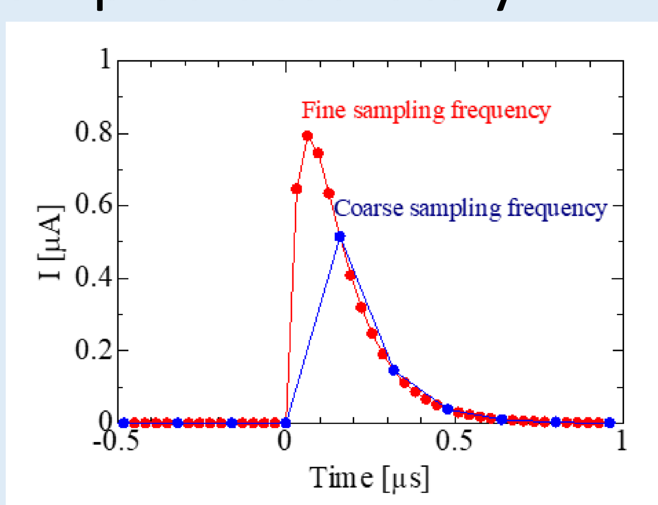
$$= \sqrt{0.27^2 + 0.07^2 + 0.21^2}$$

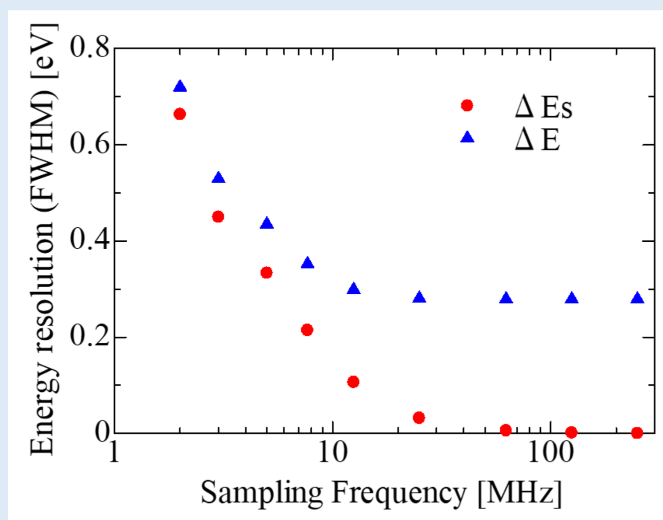


Energy spectrum from a pulsed laser at 1550 nm

ΔE_I: Intrinsic energy resolution
ΔE_R: Readout noise = 10 pA/√Hz
ΔE_S: Coarse sampling effect

- What's the coarse sampling effect
  - Sampling time >> Rise/Fall time constant → sparse sampling
  - the pulse height cannot be sampled accurately.





Calculated result of ΔE_S