Structure optimization of TES microcalorimeter for 14.4 keV solar axion search by electro-thermal simulation

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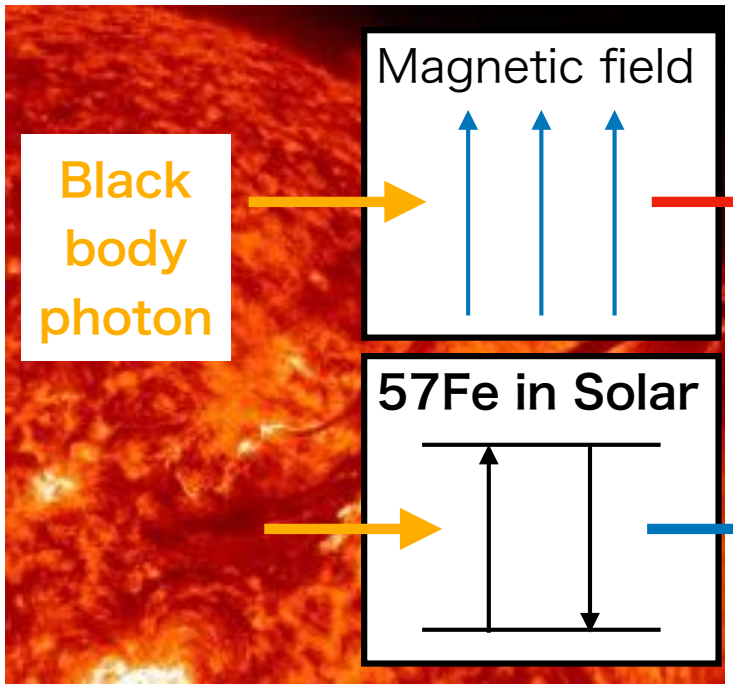
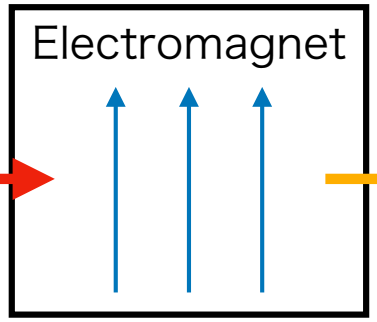
Solar Axion Search

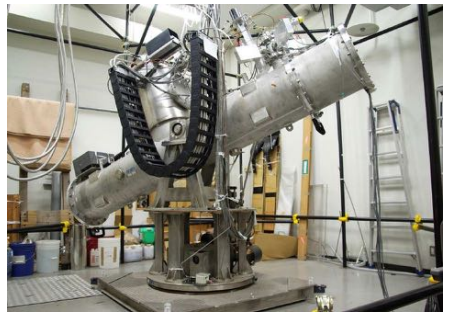


Continuum Axion

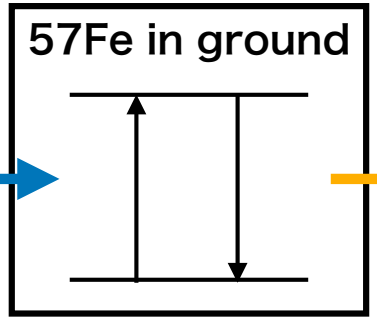


Continuumm photon

CAST, Sumico

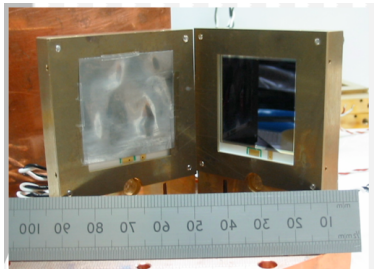


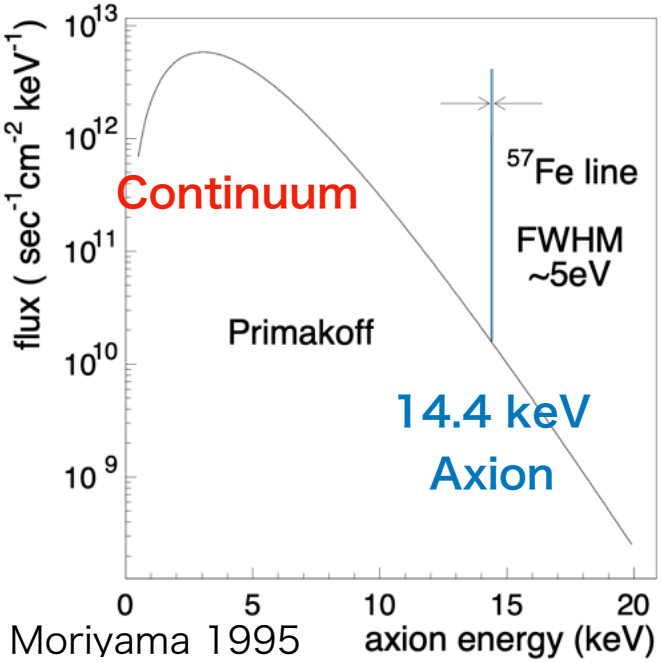
14.4 keV Axion



14.4 keV photon

Namba 2007

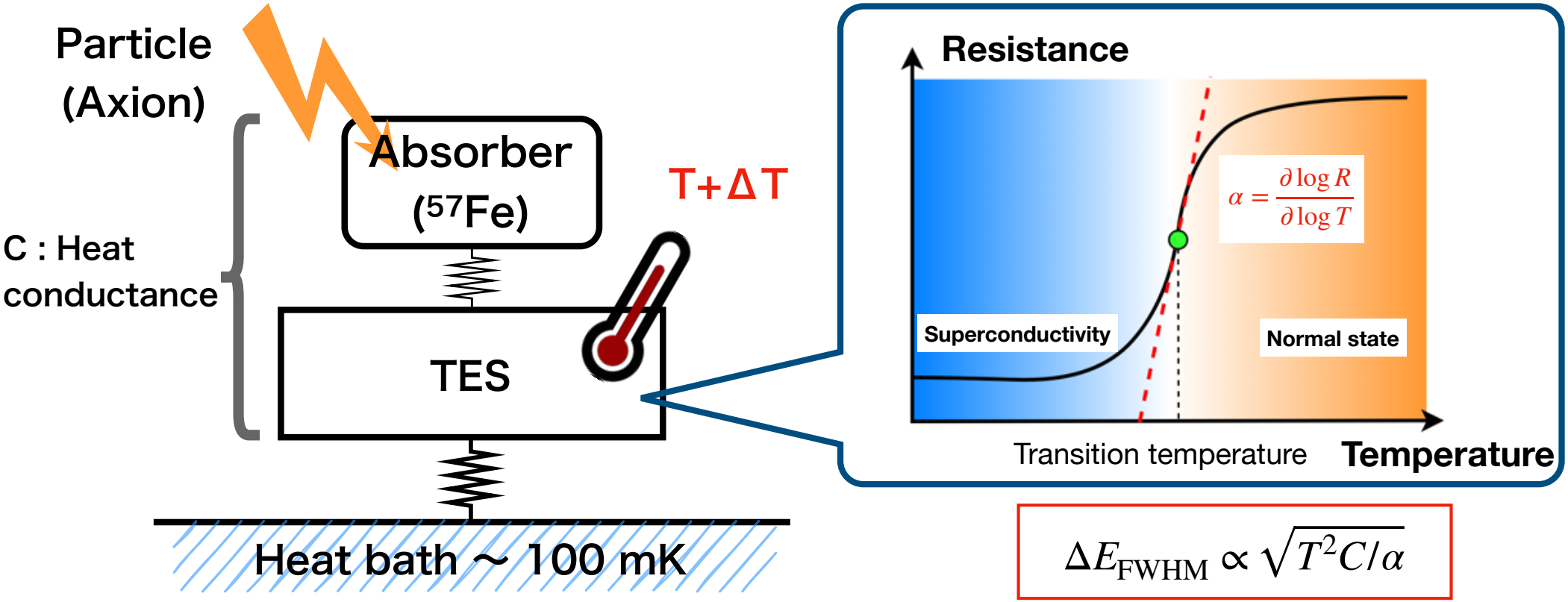




Moriyama 1995

- Solar axion converted to photons on the ground.
- We are developing TES microcalorimeter for 14.4 keV solar axion search.

Transition Edge Sensor(TES) microcalorimeters



- Measure particle energy as a temperature rise.
- Very high energy resolution ~ **2.8 eV@5.9 keV**(akamatsu+2009)

We are developing TES microcalorimeter using 57Fe as absorber.

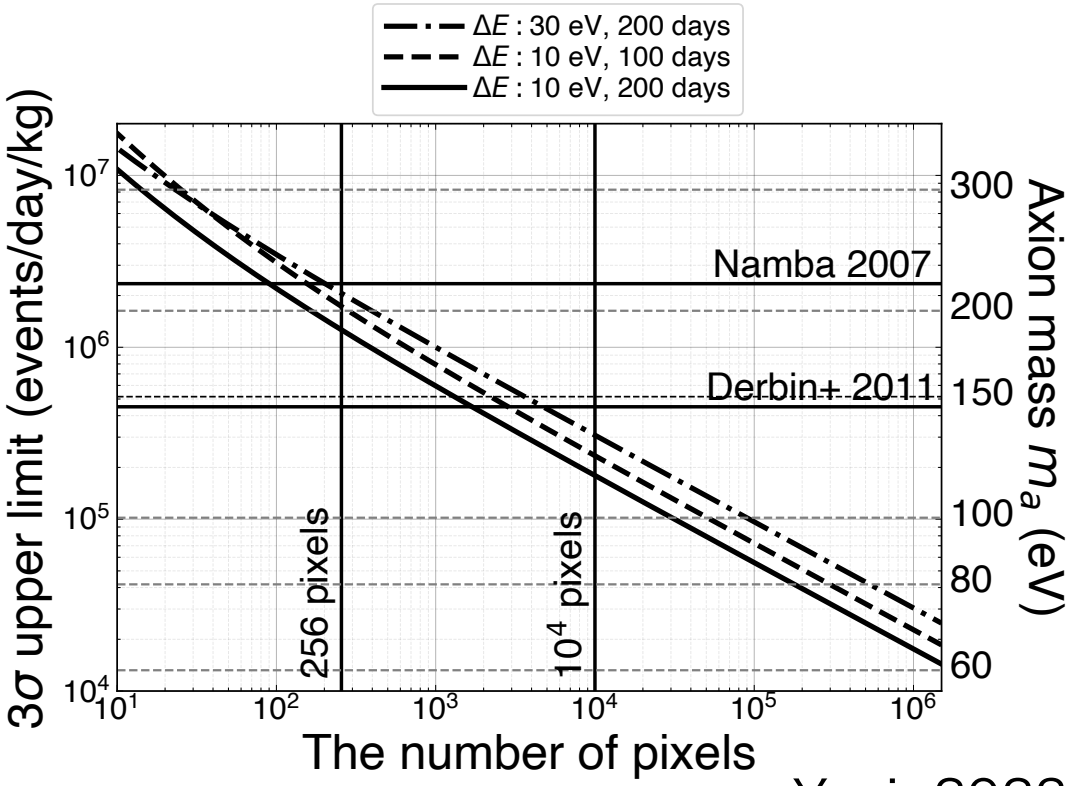
Sensitivity

TES strong point

High Absorption efficiency (∼70%@14.4 keV photon)

+

High energy resolution (10eV@14.4 keV)

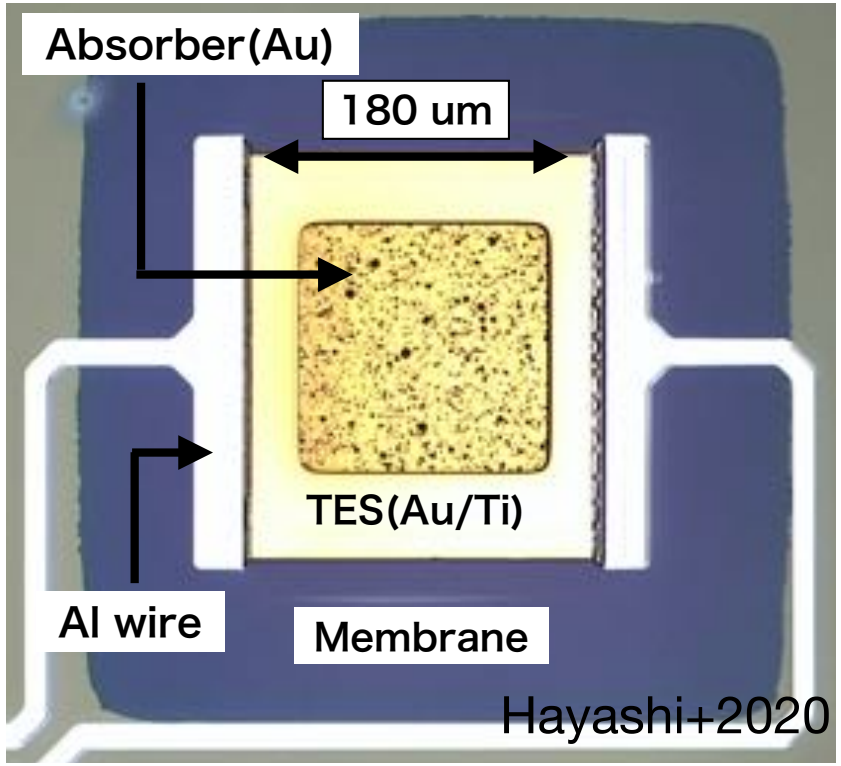


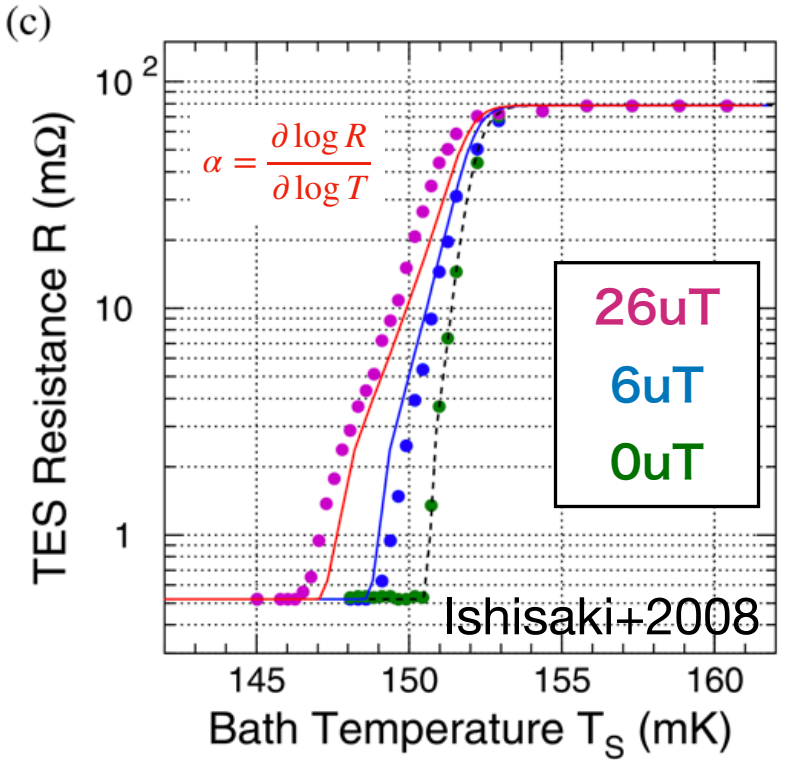
Yagi+2023a

- Efficiency depends on energy resolution, absorption efficiency, observation time, ^{57}Fe mass.
- Arraying 10k pixels gives unprecedented axion mass limitation.

Magnetic dependance of the TES resistance

X-ray TES microcalorimeter



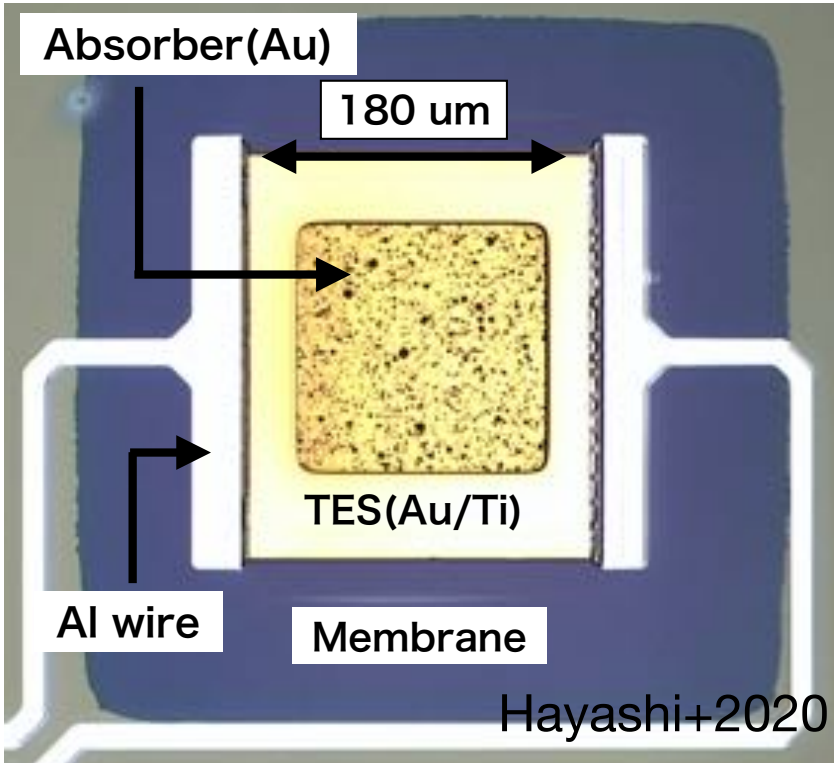


$$\Delta E_{\mathrm{FWHM}} \propto \sqrt{T^2 C/\alpha}$$

- TES energy resolution degrade by magnetic field.
- But 57Fe, solar axion converter is ferromagnetic substance

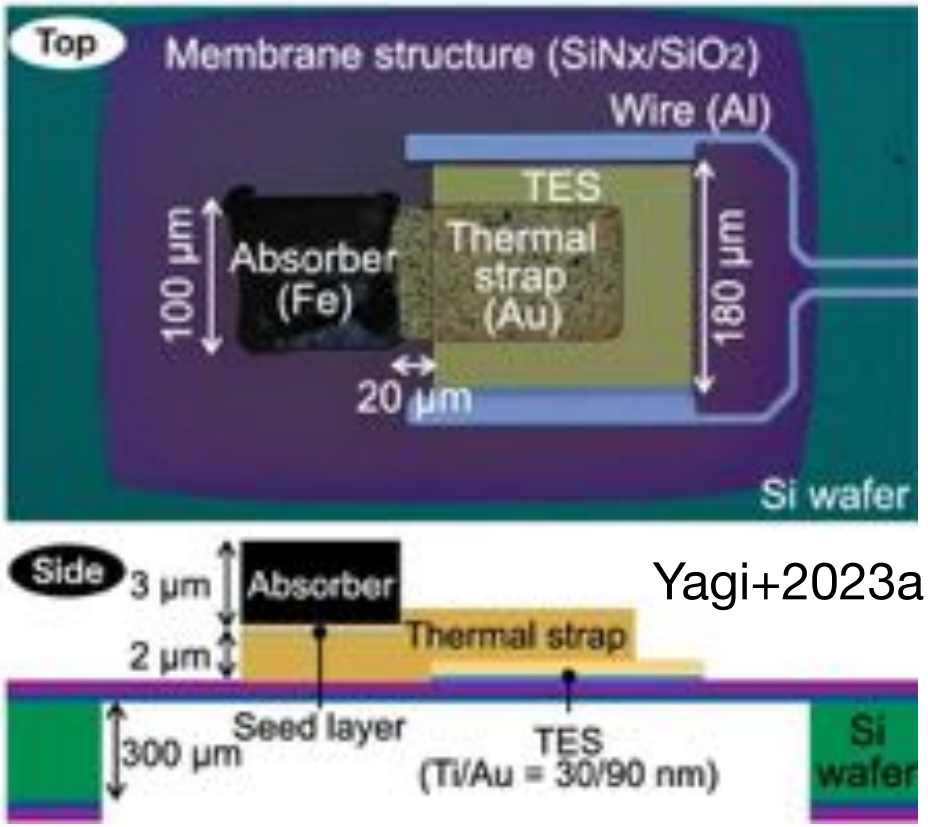
Structure of the axion TES microcalorimeter

X-ray TES microcalorimeter



Hayashi+2020

Axion TES microcalorimeter



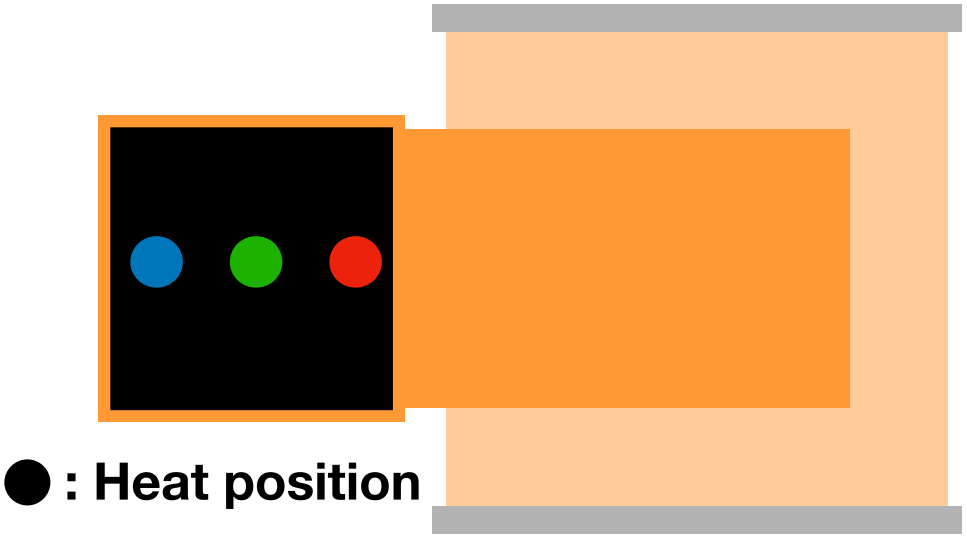
Yagi+2023a

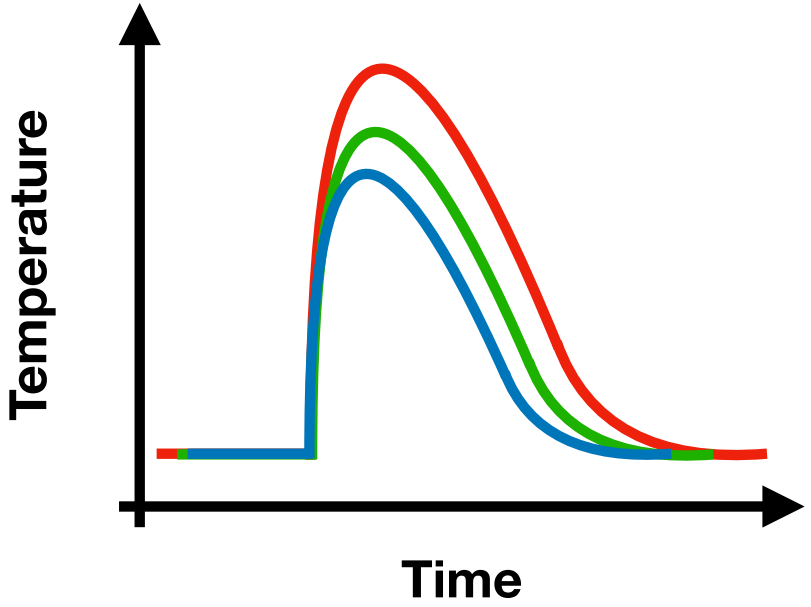
- Axion TES was fabricated with new structure.
- Fe absorber connected to the TES with Au strap.
- We have succeeded to make TES detector with such structure at ISAS supported by Waseda University.

Energy resolution and Au strap structure

1. Additional thermal structure may cause dependance of the waveform on the incident position.

2. Energy resolution of TES depends on heat conductance.

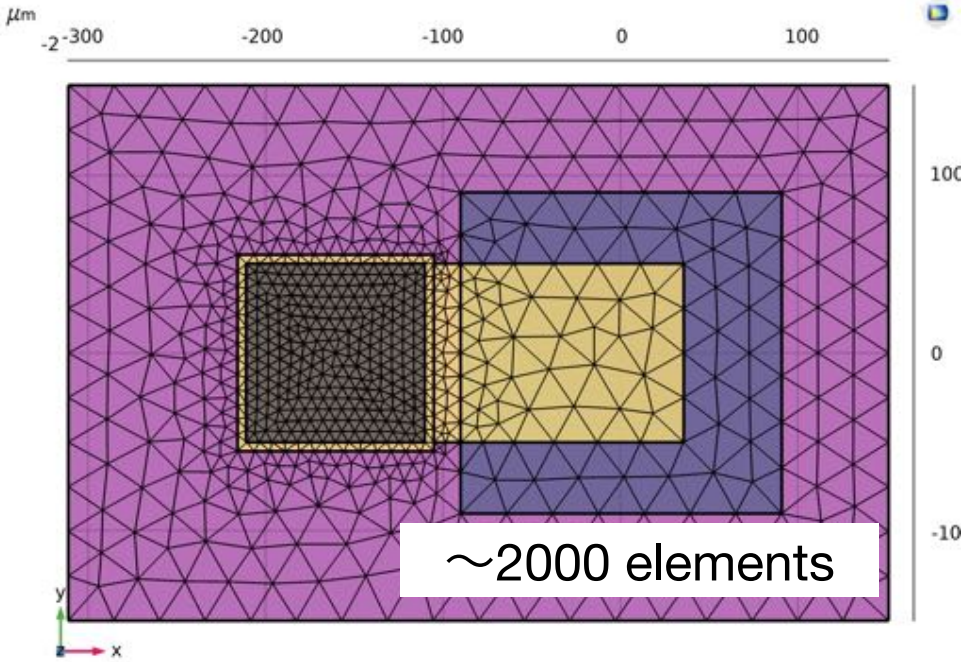


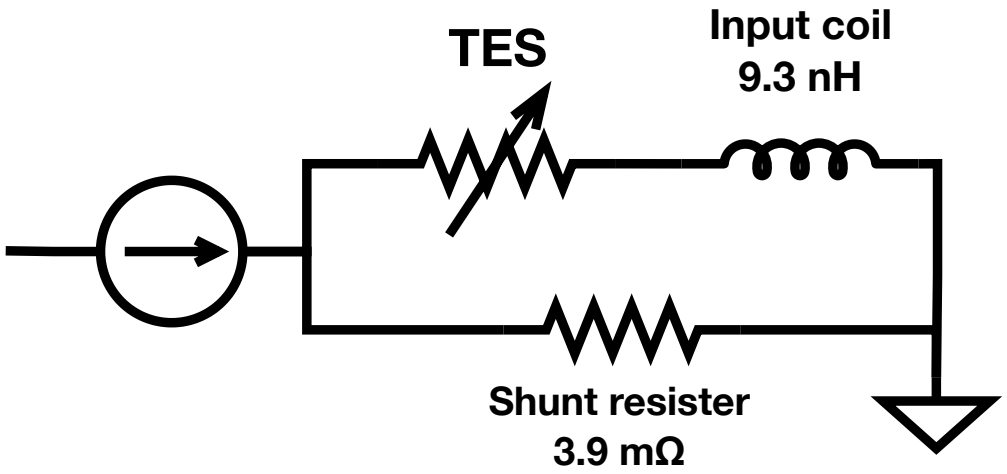


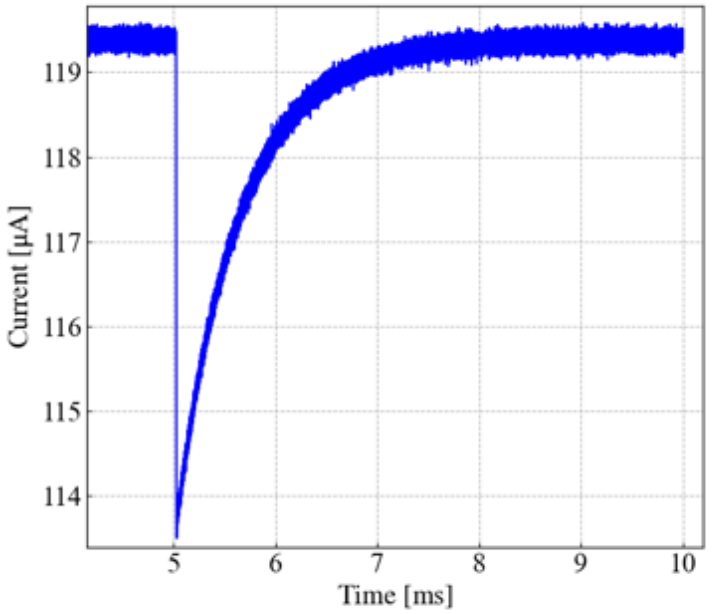
What kind of structure has the best energy resolution?

Electro-thermal simulation

- COMSOL Multiphysics : General physics simulator using finite element method.



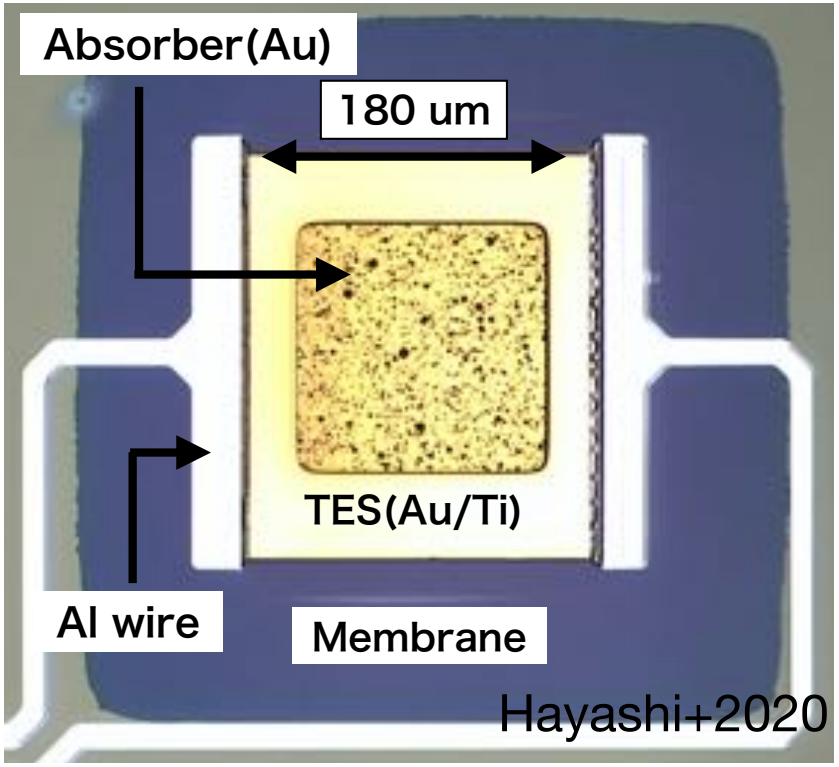


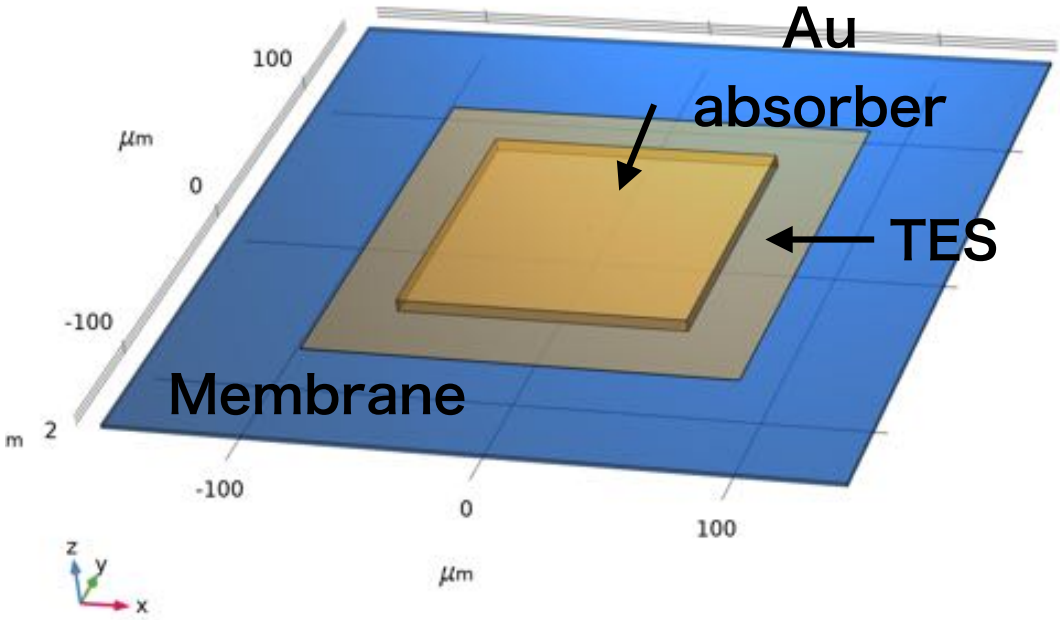


@210 mK	Fe absorber	Au strap	TES
Thermal conductivity [W/(m・K)]	0.25	4.83	0.693

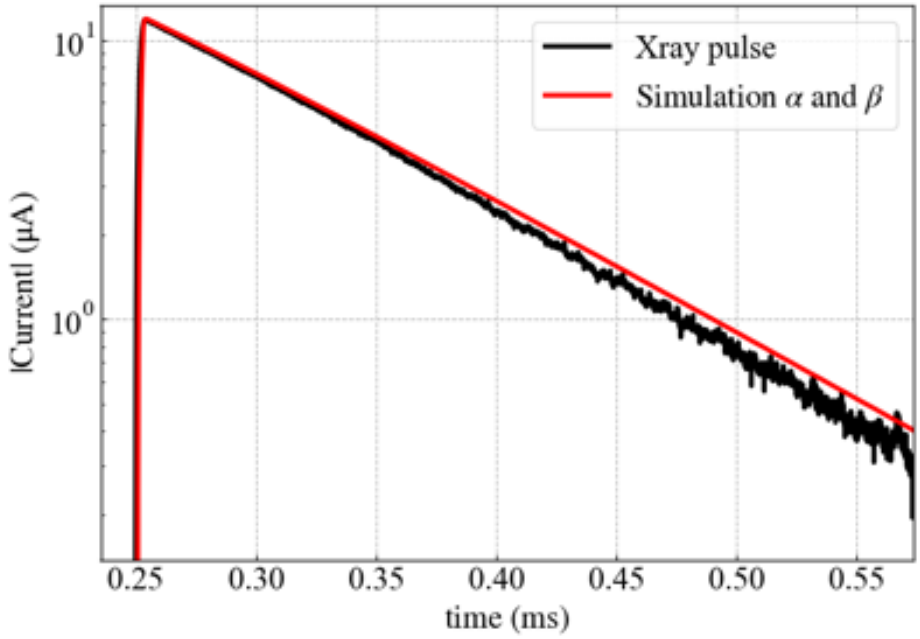
Reproduction of the measured waveform

X-ray TES microcalorimeter

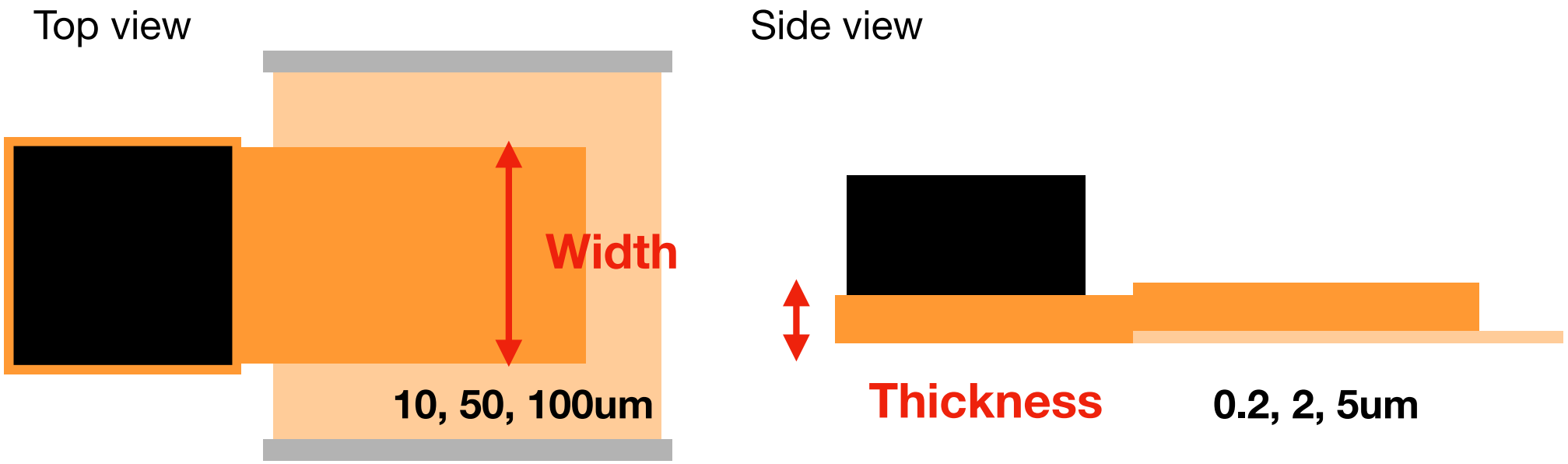




- I have reproduced to measured waveform.

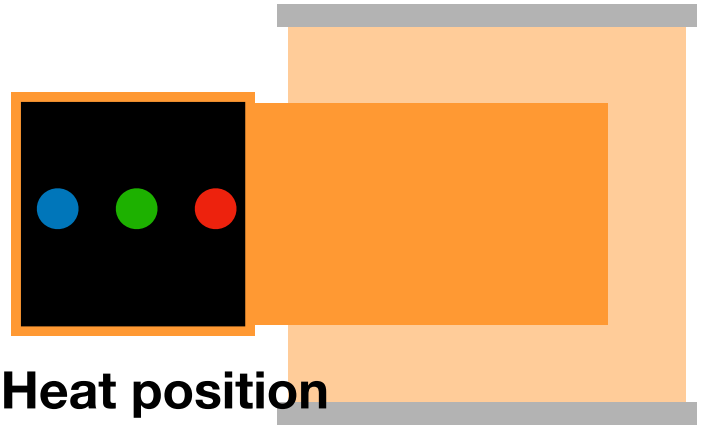


Au strap structure changes



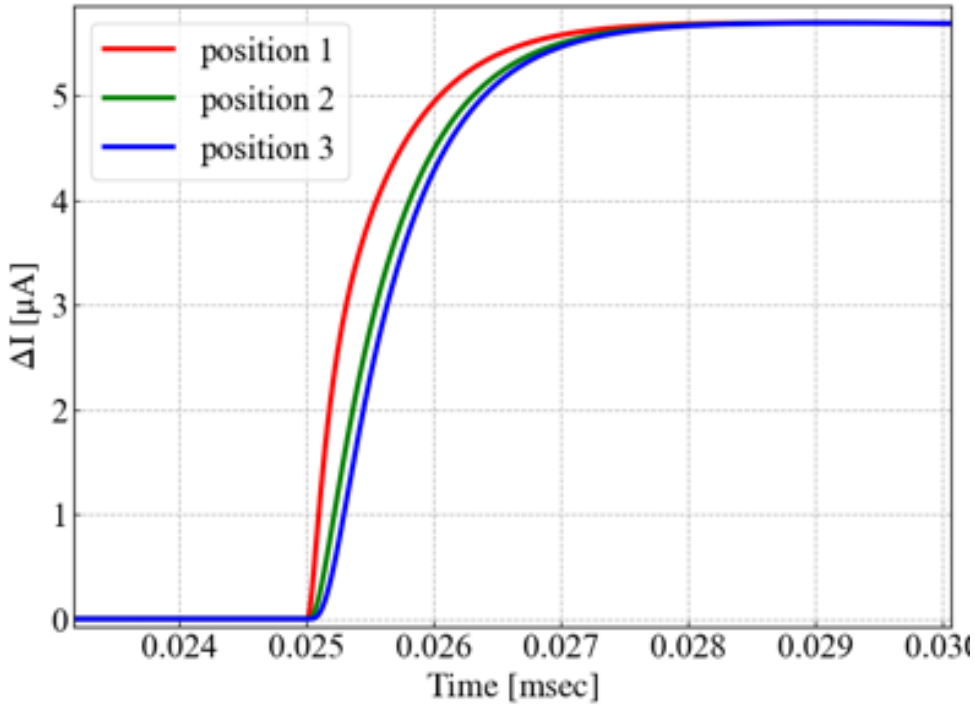
- I changed the width and thickness of the gold strap.
- As expected, the position dependence of the waveform and degradation of the apparent energy resolution are observed.

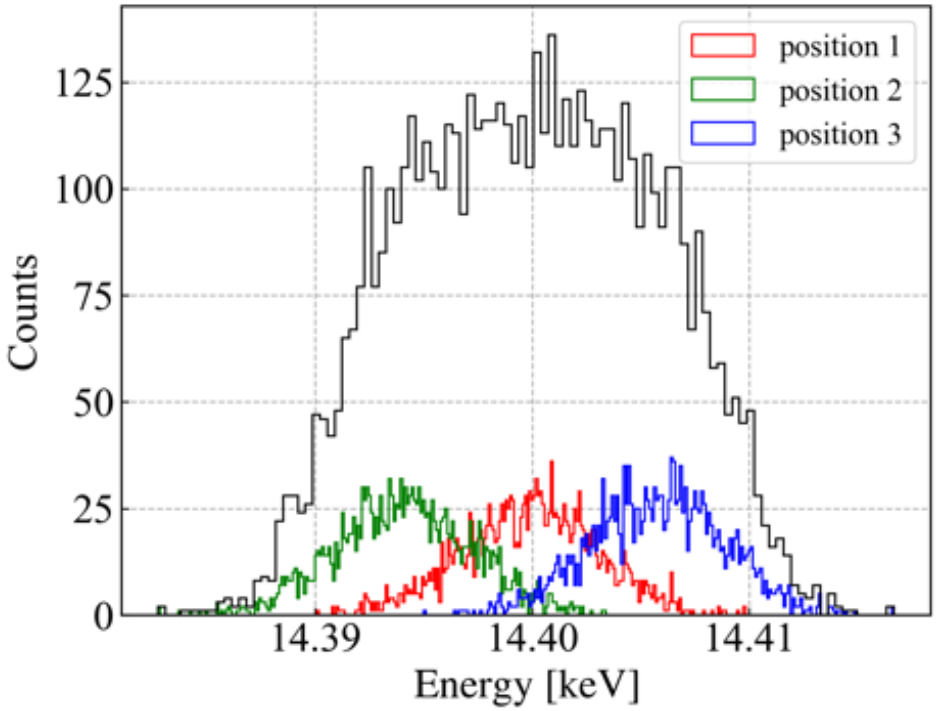
Position dependent in simulation



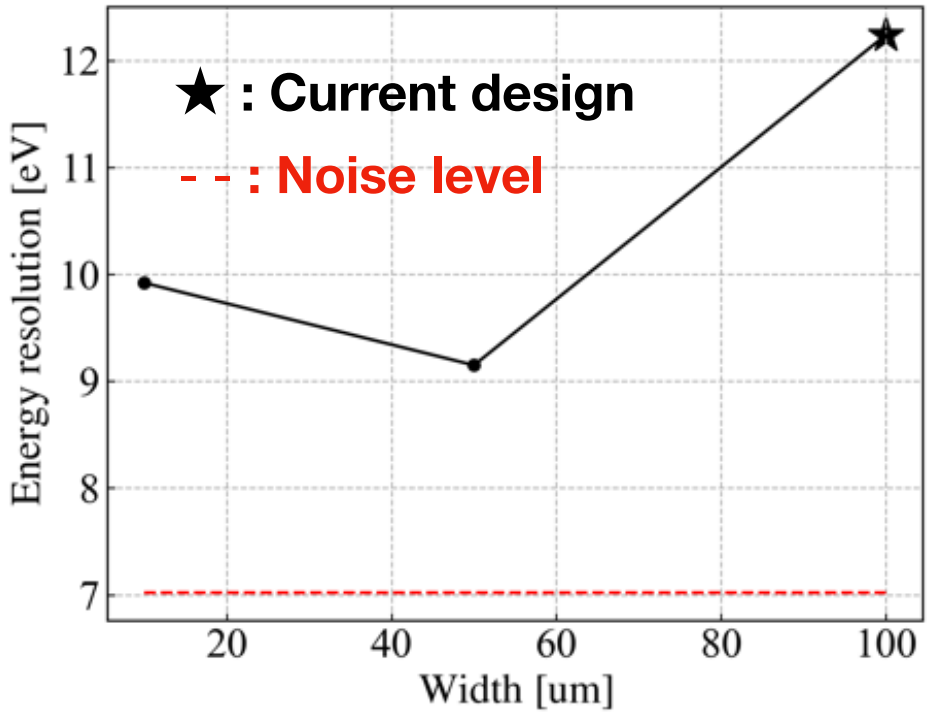
● : Heat position

- Position dependent was appeared in simulation.
- The energy resolution of summed spectrum become worse.

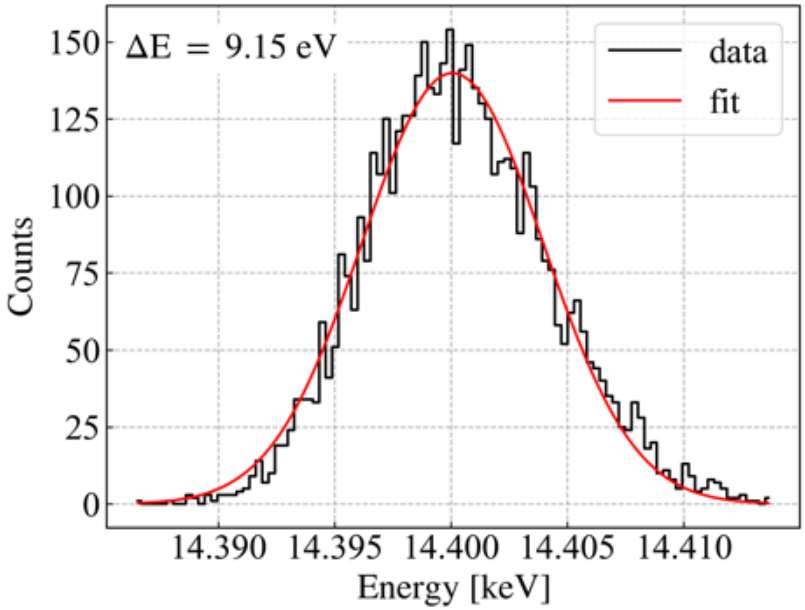




Result of changing Au strap width



Width = 50 um

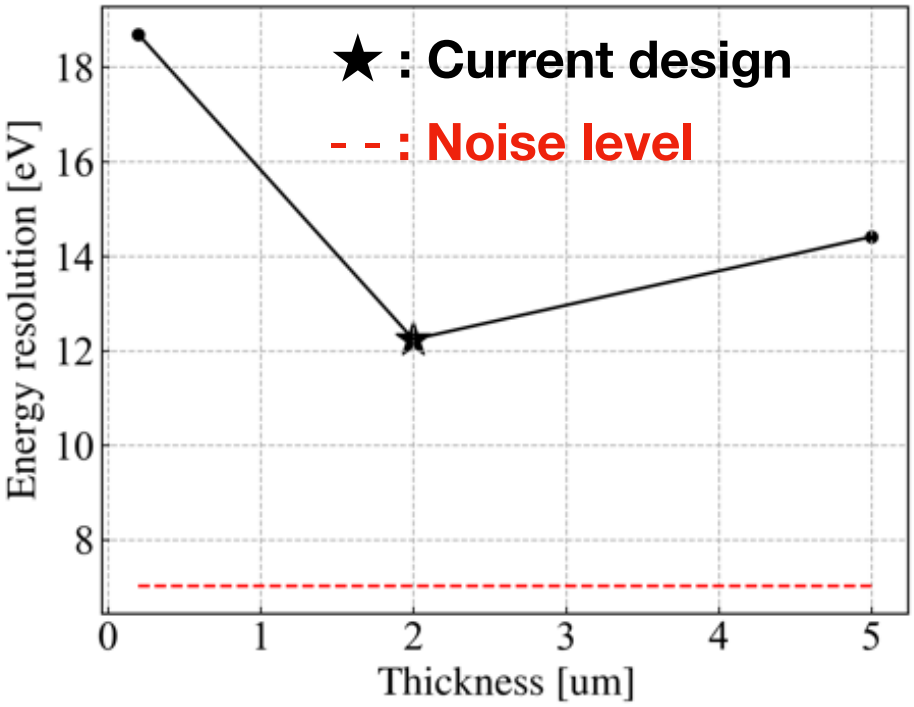


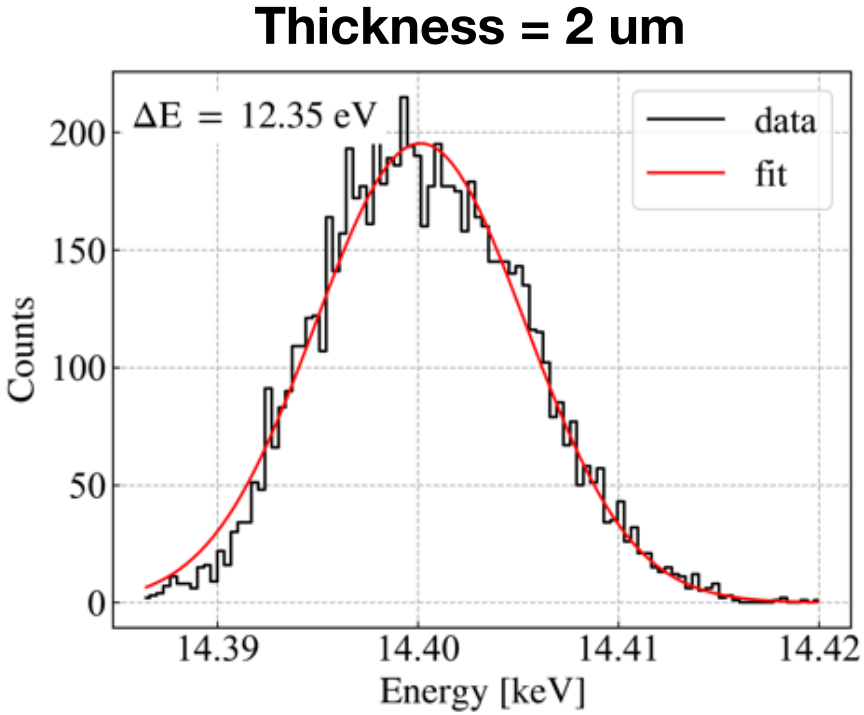
- Energy resolution is the best when gold strap width is 50um.
- This time, I used good thermal conductivity of Fe and Au.(Yagi+2023b, Miyagawa Master thesis)
- Differences in thermal conductivity are likely to be apparent.

Thermal conductivity [W/(m・K)]	Fe absorber	Au strap
This work (@210 mK)	0.25*	4.83*
Before value (@100 mK)	4E-02	4E-02

* : Yagi+2023b in press

Result of changing Au strap thickness

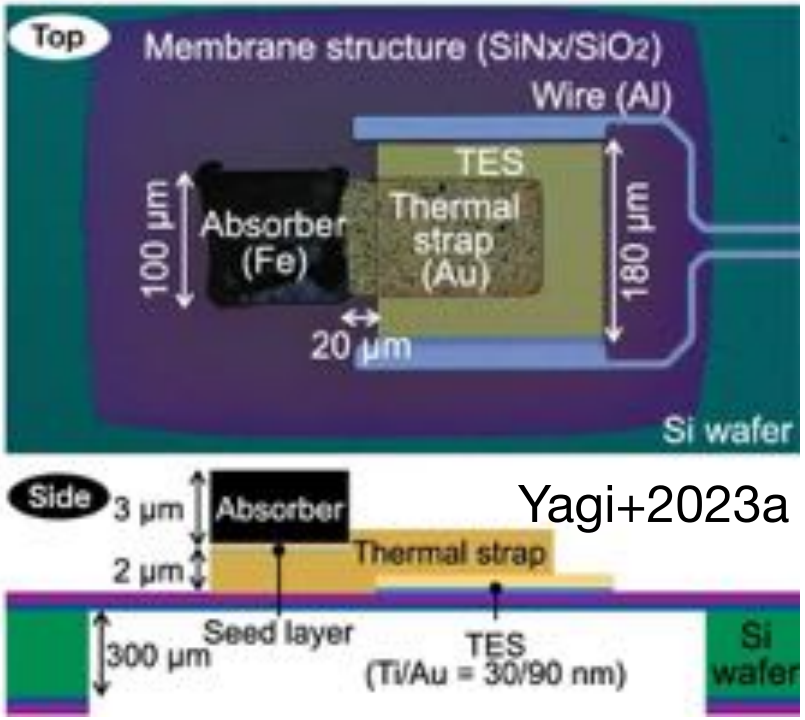




- Previous simulation suggested 5um.
- Energy resolution is best when thickness is 2um.
  (width is current design)

Summary

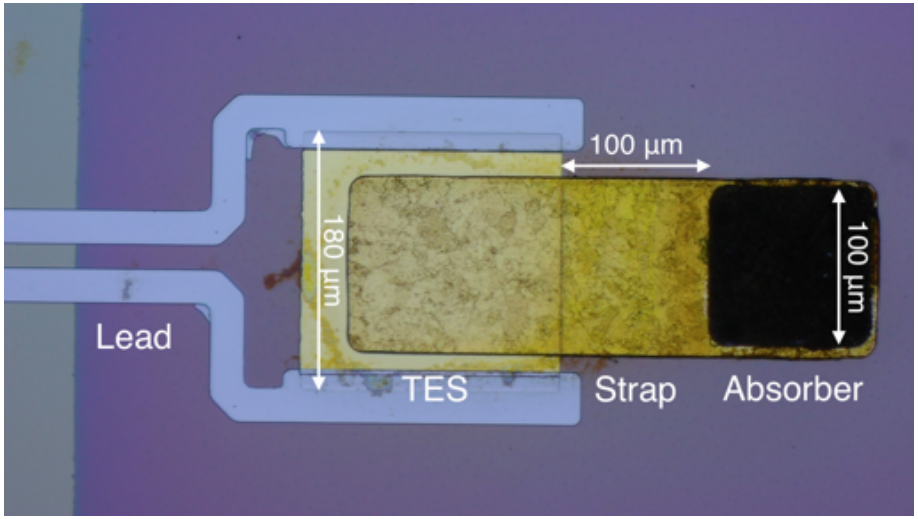
- We have designed TES microcalorimeters for Solar axion search with iron 57 isotopes.
- The degradation of the energy resolution due to this additional thermal component is expected.
- We have simulated this degradation effect under the electro-thermal circuit, and obtained optimized design parameters with realistic physical properties.

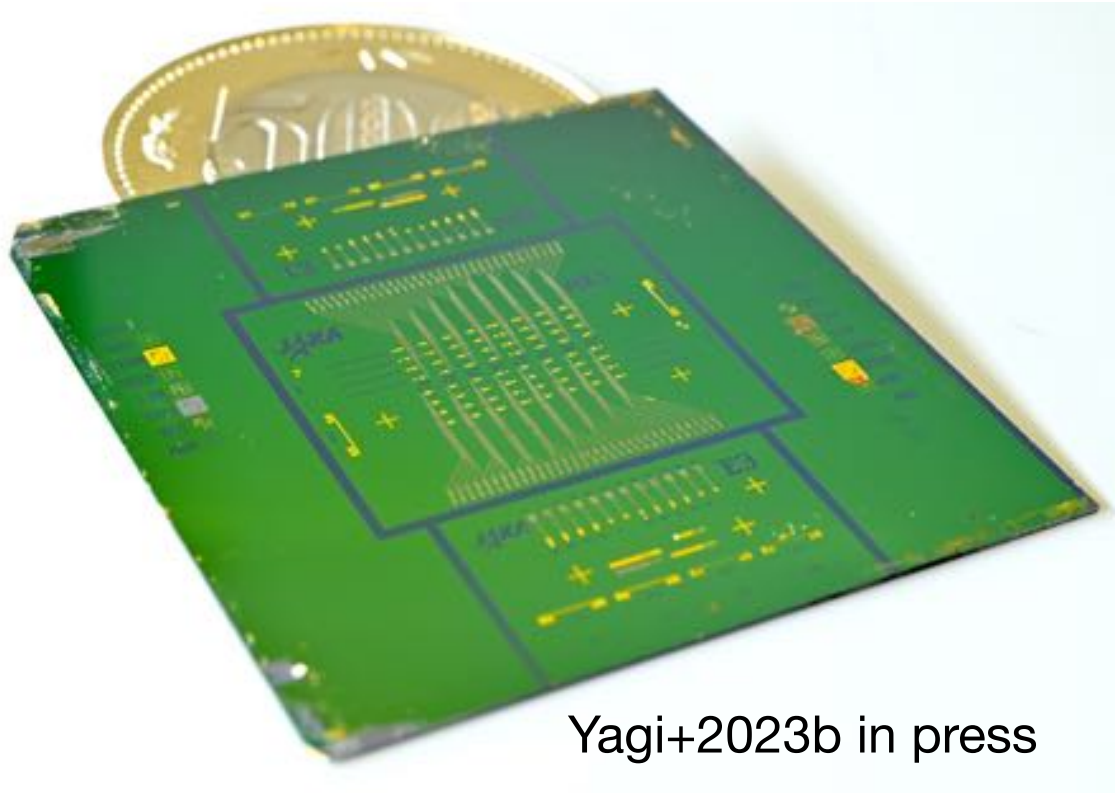


Yagi+2023a

Future Outlook

- The in-house fabrication of this device is on-going.
- We will measure the properties of this device at 100 mK, and update the simulated parameters.
- Then we can optimize and update the design.
- Right figure shows a sample of 64 pixel format array





Yagi+2023b in press