γ-ray measurements of Th-229 isomer using TES microcalorimeters

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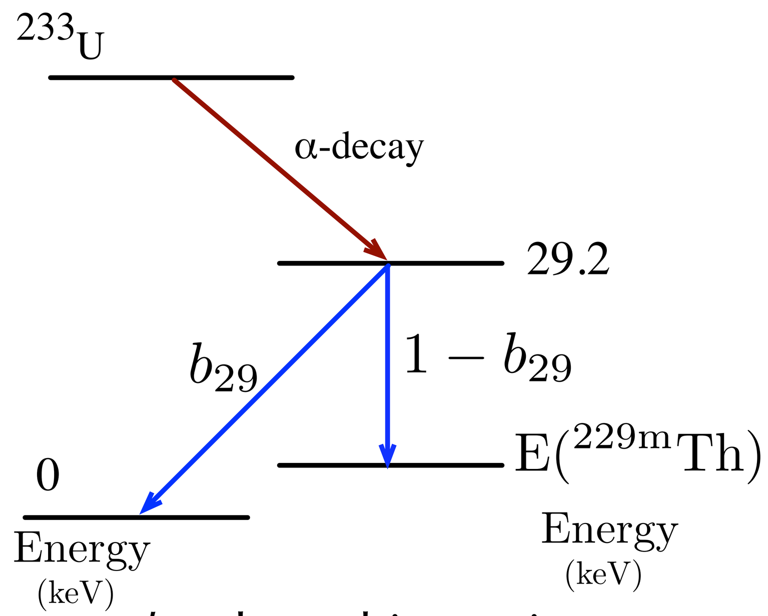
1.Introduction

The lowest energy of ^{229}Th isomeric state, E(^{229m}Th), is widely known to be only a few eV [1,2]. By utilizing this extremely low level, a nuclear clock with an uncertainty of 10^{-19} may be realized.

The methods used to measure the E(^{229m}Th) are

(1) Splitting the 29.2 keV doublet

(2) Determining the energy decay from the 29.2 keV state to the isomer state with γ-ray measurements and calculating the difference between the isomer state and the ground state with high accuracy [3].



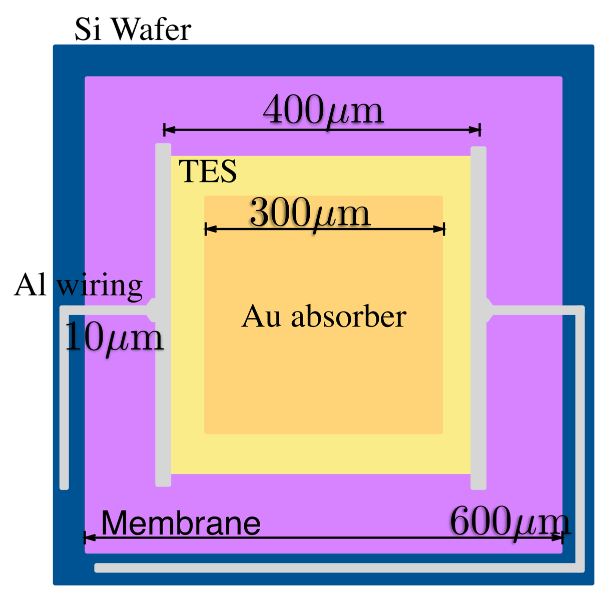
b_{29}: branching ration

2.Design and performance of TES devices

We designed the TESs not to saturate the pulse shape and set the saturation energy to be larger than the energy of interest (29.2 keV).

TES #A with higher saturation energy

C (pJ/K)	T (mK)	Thickness of absorber (μm)	Esat (keV)
3.97	164	3.6	51



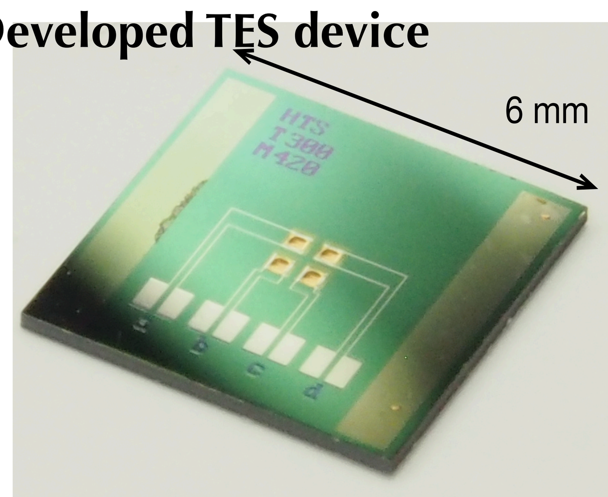
- The energy resolution at 26 keV in the laboratory was 20.9 ± 2.8 eV
- In the ^{233}U measurement, the energy resolution increased up to 41.3±1.0 eV due to thermal fluctuation caused by γ-rays hitting the Si substrate.

TES #B with lower saturation energy

- To improve the energy resolution, we set the target saturation energy to 40 keV

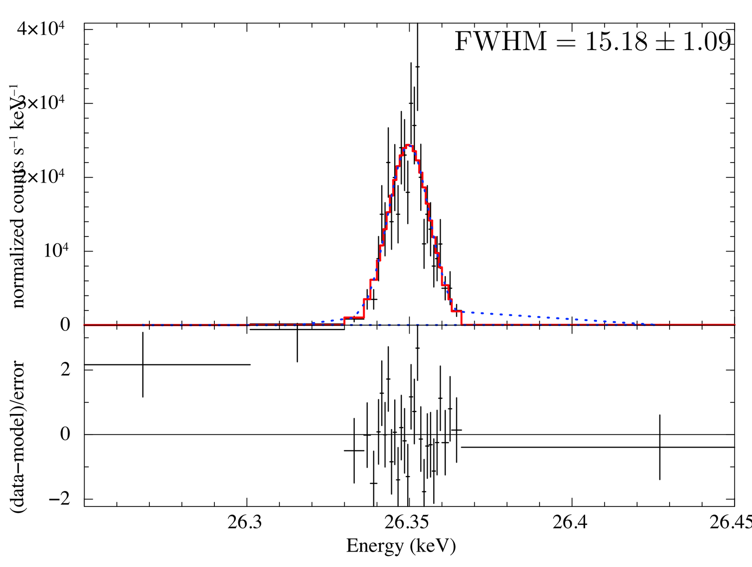
C (pJ/K)	T (mK)	Thickness of absorber (μm)	Esat (keV)
3.57	122	3.9	40

Developed TES device



- We measured the energy resolution of 3 pixels in the same counting rate of the ^{233}U isotope

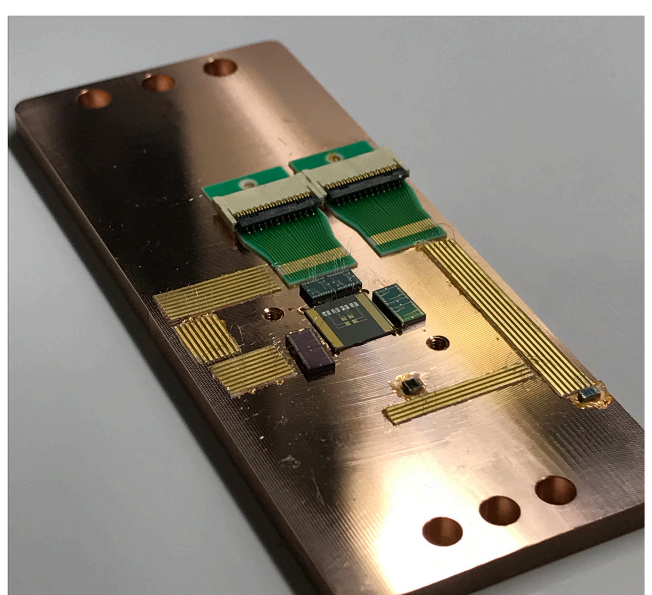
FWHM= 15.2 ± 1.0 eV at 26 keV



3.Experiment setup at JAEA

We measured the 29.2 keV doublet decay from 233U with TES #A device

- Intensity of ^{233}U isotope : 26 MBq
- Operating period : 18 days
- Standard lines : Am-241 , Ba-133
- Bath temperature : 90 mK
- Number of readout pixels : 1



Detector stage

4.Pulse analysis

Accumulated pulse events

Events selection

- Selection of noise data using dispersion of noise data
- Reduction of double pulse data using a box car filter
- Selection of pulse events using rise and decay time constants

Convert I(t) to R(t)

- Correction nonlinearity caused by pseudo-constant voltage

$$\Delta R = -(R_0 + R_s)\frac{\Delta I}{I_0 + \Delta I} \qquad I_0 = \frac{I_{\mathrm{bias}}}{R_0 + R_s}R_s$$

Rs: Shunt resistance, I_{bias}: Bias current, I_0/R_0: Current/Resistance of TES in equilibrium state

Optimal filtering method

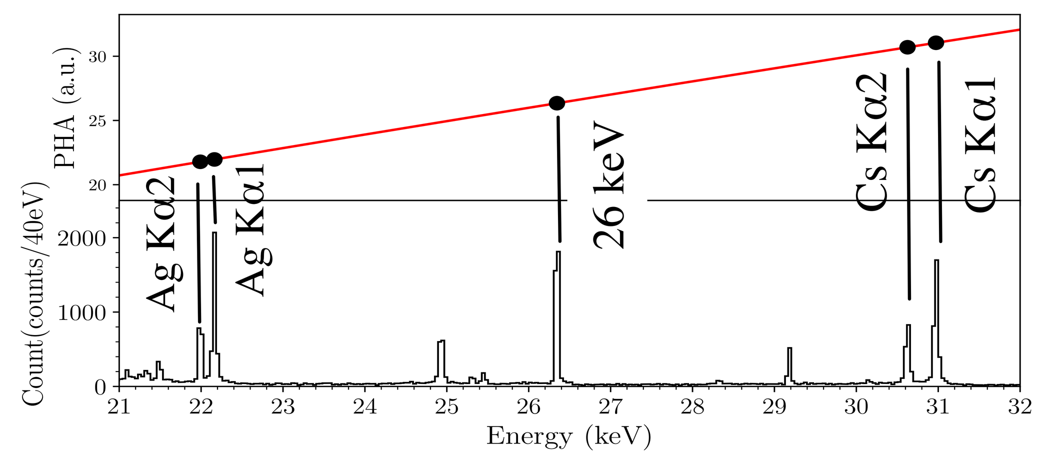
Model fits of PHA spectra

- Estimate the PHA values by fitting their respective spectrums (AgKα1, AgKα2, 26 keV, CsKα1, and CsKα2) with their emission models [4]
- Fitting of 29.2 keV doublet line with gaussian function

Calculation of gain curve

- Fit function :

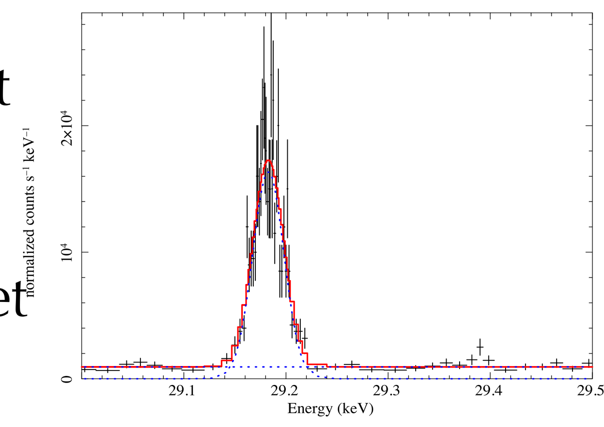
$$PHA = a \cdot E^2 + b \cdot E + c$$



Convert PHA to E

5.Results

- The statistical error of the 29.2 keV doublet included the fitting error of 29.2 keV and parameter errors of the gain curve
- The systematic error of the 29.2 keV doublet included the uncertainty of calibration energy



29.2 keV doublet : E=29182.51 ± 0.74 (stat) ± 0.24 (sys) eV

- The E(^{229m}Th) is obtained by using the energy from 29.2 to 0 and the branching ratio [3]
- The systematic error of the ^{229}Th isomer included both the uncertainty of calibration energy and the error of the branching ratio [3]

E(^{229m}Th) = 8.30 ± 0.74 (stat) ± 0.36 (sys) eV

6.Summary and future work

- The energy resolution of the TES was 40 eV at 26 keV with the ^{233}U isotope
- The energy of the 29.2 keV doublet was 29182.51 ± 0.74(stat) ± 0.24 (sys) eV
- We calculated the energy to be E(^{229m}Th)=8.30±0.74 (stat)±0.36 (sys) eV using the branching ratio and the results from [3]
- We will split the ground state doublet in the ^{229}Th using the TES with 15 eV FWHM

References

[1] Wensen et.al., (2016)[2] Beck et al., (2009)
[3] T.Masuda et al., arXiv(2019) [4] Muramatsu et. al., (2017)

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