First result of EDXRD experiment using a gamma-ray TES calorimeter with Sn absorber

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We report the first result of energy dispersive X-ray diffraction (EDXRD) experiment at a synchrotron facility using a gamma-ray TES calorimeter with Sn absorber. Details of the calorimeter is presented by T.Oshima's talk. We successfully detected a diffraction pattern of a NaCl crystal 2-θ = 8 deg, however the energy resolution was significantly degraded to 567 eV at 32 keV due to a malfunction of the TES bias line inside the adiabatic demagnetization refrigerator. Our primary goal is to analyze a phase diagram of complex crystal structures like Bi under the extreme high pressure situation.

Also check T. Oshima's talk

1. Science Goals

Detection of the atomic gamma-ray from SNR [The et al.2006]

Proof of the nucleosynthesis for interior stellar and supernova

elements like ^{26}Al, ^{60}Fe, e^+ are difficult to detect because they are weak lines.

^{44}Ti (68, 78 keV) is the best candidate for our target (SNR younger than 100 yr).

Isotope	Lifetime	Decay chain	Gamma-rays	Source
^{7}Be	77 days	$^7Be \to {}^7Li$	487 keV	N
^{56}Ni	111 days	$^{56}Ni \to {}^{56}Co \to {}^{56}Fe$	847, 1238 keV	SN
^{57}Ni	390 days	$^{57}Ni \to {}^{57}Co \to {}^{57}Fe$	122 keV	N
^{22}Na	3.8 yrs	$^{22}Na \to {}^{22}Ne + e^+$	1275, 511 keV	N
^{44}Ti	89yrs	$^{44}Ti \to {}^{44}Sc \to {}^{44}Ca$	1156, 68, 78 keV	SN
^{26}Al	1.04×10^6 yrs	$^{26}Al \to {}^{26}Mg + e^+$	1809, 511 keV	N
^{60}Fe	2.0×10^6 yrs	$^{60}Fe \to {}^{60}Co$	59, 1173, 1332 keV	SN
e^+	$\sim10^5$ yrs	$e^+e^- \to (Ps) \to \gamma\gamma(\gamma)$	511 keV	SN,N,CR

The isotopes relevant for γ-ray line astronomy

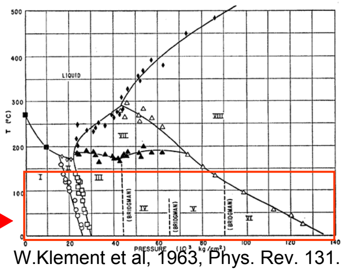
('S' = stars, 'SN' = supernovae, 'N' = novae, 'CR' = cosmic rays, 'Ps' = Positronium)

Real time spectrum analysis for the complicated phase variation under high pressure situation of Bi

Studying deep earth element structure.

Phase diagram of bismuth. Adding high pressure, Bi phase are indicated for the I – VIII transition.

By real time spectrum analysis, we would like to study the detail of its phase diagram.



W.Klement et al, 1963, Phys. Rev. 131. 2

2. Detector – gamma ray TES microcalorimeter

Structure

Restrictions of heat capacity

E_{max}: Maximum energy of incident photon

ΔT: Width of transition edge

$C > E_{max} / \Delta T \sim$ 60keV / 2mK $\sim$ 5 pJ/K

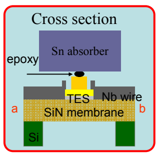
We selected Sn (Z=50) as an absorber

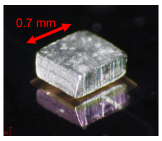
: superconductor and small heat capacity

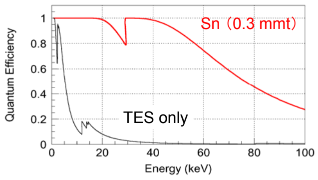
: also used at LLNL (52 eV@60 keV)
[Cunningham et al. 2002]

: size: 0.63 mm × 0.67 mm × 0.3 mm

: C_a=6.85 pJ/K @150 mK

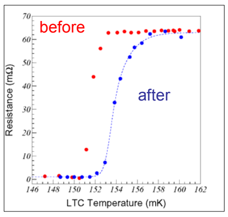




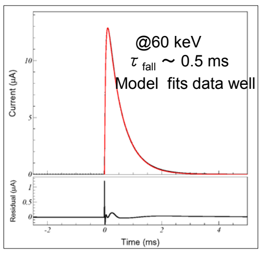


RT - Curve

TES	Ti/Au
Thickness	40/120 nm
absorber	Au
thickness	500 nm
membrane	plane type
C = 1.84 pJ/K @ 150 mK	
ΔE = 12 eV @ 5.9 keV (without Sn absorber)	
Tc	151 mK
Rn	61 mΩ



After bonding absorber with epoxy, transition edge becomes a little dull. *Tc* change might be due to the reproducibility of thermometer.

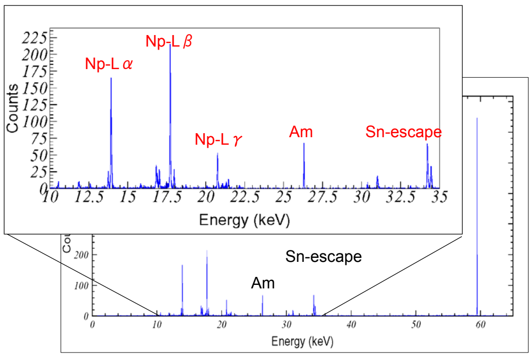


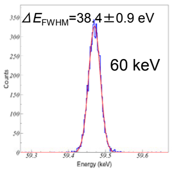
Pulse & Spectrum

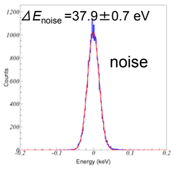
We detected fluorescence line from ^{241}Am

Pulse Model: A [$\exp(-(t-t_0)/\tau_{fall}) - \exp(-(t-t_0)/\tau_{rise})$]

Live time : 5367 sec Photon counts: 20580

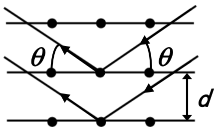






3. Experiment

Energy Dispersive X-Ray Diffraction

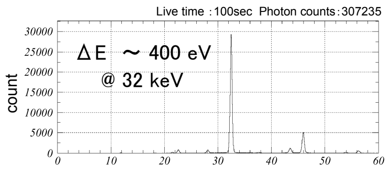


On Bragg's law, by fixing angle θ, and irradiating "white" X-ray, we can detect the grating spectra.

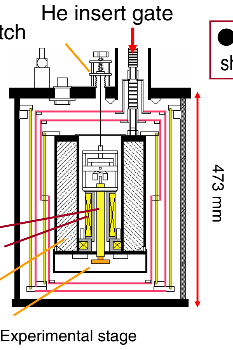
Bragg's law: $\lambda = 2d \sin\theta$

In the extreme high pressure experiment, it is essential to use the EDXRD method because of its instrumental structure. In this field, Ge detector has been applied to detect grating spectra.

Grating spectrum of NaCl with Ge detector

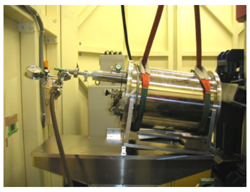


ADR



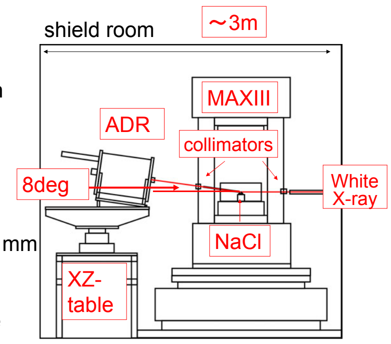
● vapor cooling & transverse operation
show details of this ADR [Shinozaki et al.2006]

We used ADR to operate a TES microcalorimeter at 150 mK.

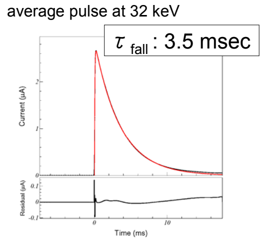


Setup

- Synchrotron facility at KEK in Japan
- Two collimators are fixed at 2θ = 8°
- Standard sample : NaCl powder
- Upstream collimator : 0.05 × 0.3 mm
- Downstream collimator : 0.03 × 0.03 mm
- Detector size: 0.63 × 0.67 mm
- Scan diffraction beam with XZ-table



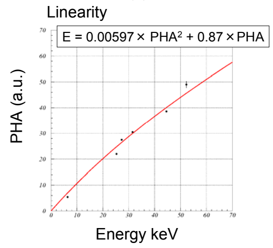
4. First Result

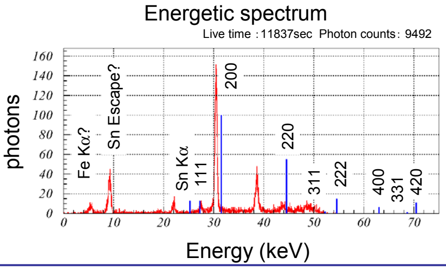


We applied the gamma ray TES microcalorimeter above to a detector of EDXAD at 2θ = 8 deg.

We successfully detected the diffraction spectrum with a standard sample of NaCl powder.

However, circuit trouble made larger noise, smaller pulse height , and longer τ_{fall}. As a result, energy resolution was degraded to ΔE_{FWHM} = 567 eV @ 32 keV.





5. Future Strategy

We applied a gamma ray TES microcalorimeter for EDXRD and detected the first light of the diffraction spectrum. In the next step, we plan to obtain better quality spectrum under high pressure situation of Bi. To execute this, we need to overcome these task:

- Complete wiring & shield setup: suppress electrical noise.
- Automatic analysis system: need for the real time spectrum analysis
- Longer holding time, easy-to-use ADR system.

And, preparing for astrophysical future mission …

♦References

The et al, 2006, A&A 450,

W.Klement et al, 1963, Phys. Rev. 131. 2

Shinozaki et al, 2006, Rev. Sci. Ins. 77, 4

Cunningham M.F. et al. Appl. Phys. Lett, 81,1

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