

Photon detection by an InSb compound semiconductor detector with reduced leakage current



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Introduction

Li, Be, Pb etc... Hazardous elements must be detected
 X-ray fluorescence spectroscopy (XFS)
 Si detectors are used as X-ray detectors.

However...

- Small atomic number and density
- ➡ Low photon absorption rate for K X-rays of Pb (3% @ ~80 keV). (3 mm thickness Si)
- Energy resolution : approximately 120 eV for 6 keV X-rays
- ➡ Not enough to separate the characteristic X-rays of Li and Be.

Compound semiconductor InSb

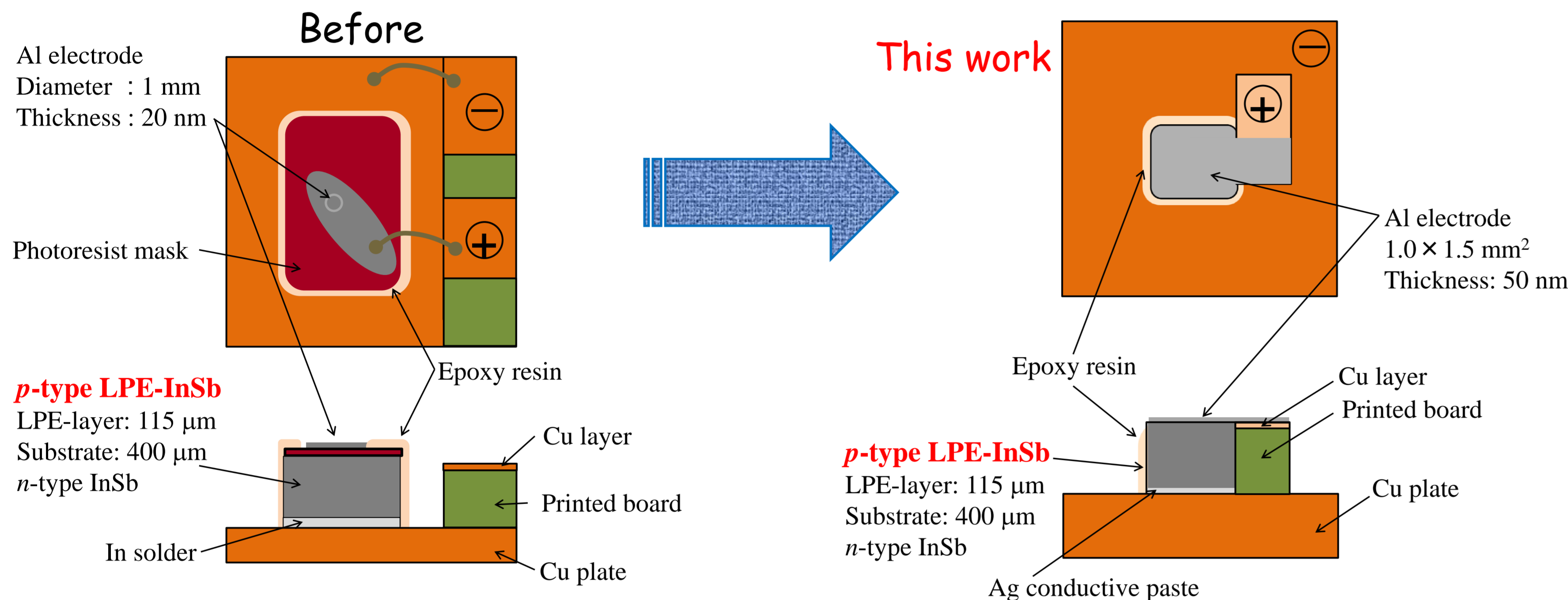
- 1000 times higher photon absorption than Si.
- Twice better energy resolution than Si detectors.
- Cooling is necessary for operation.

Table 1. Physical Properties of InSb and Si.

	Atomic number	Density [g/cm ³]	W value [eV] @RT
InSb	49,51	5.78	0.6
Si	14	2.33	3.62

Topic: Change of the detector electrode design to reduce the leakage current

Detector electrode design InSb crystal was grown by the Liquid Phase Epitaxy (LPE) Method.



- Wafer size: 3.0 × 5.0 mm²
- 1-mm-diameter electrode was patterned by photo-resist.
- LPE-InSb wafer was cut into small dimensions 1.0 × 1.5 mm².
- The Al electrode covered the entire area of the wafer.

Fig. 1. Schematic drawing of the (a) previous InSb detector and (b) present InSb detector.

Current-Voltage curves

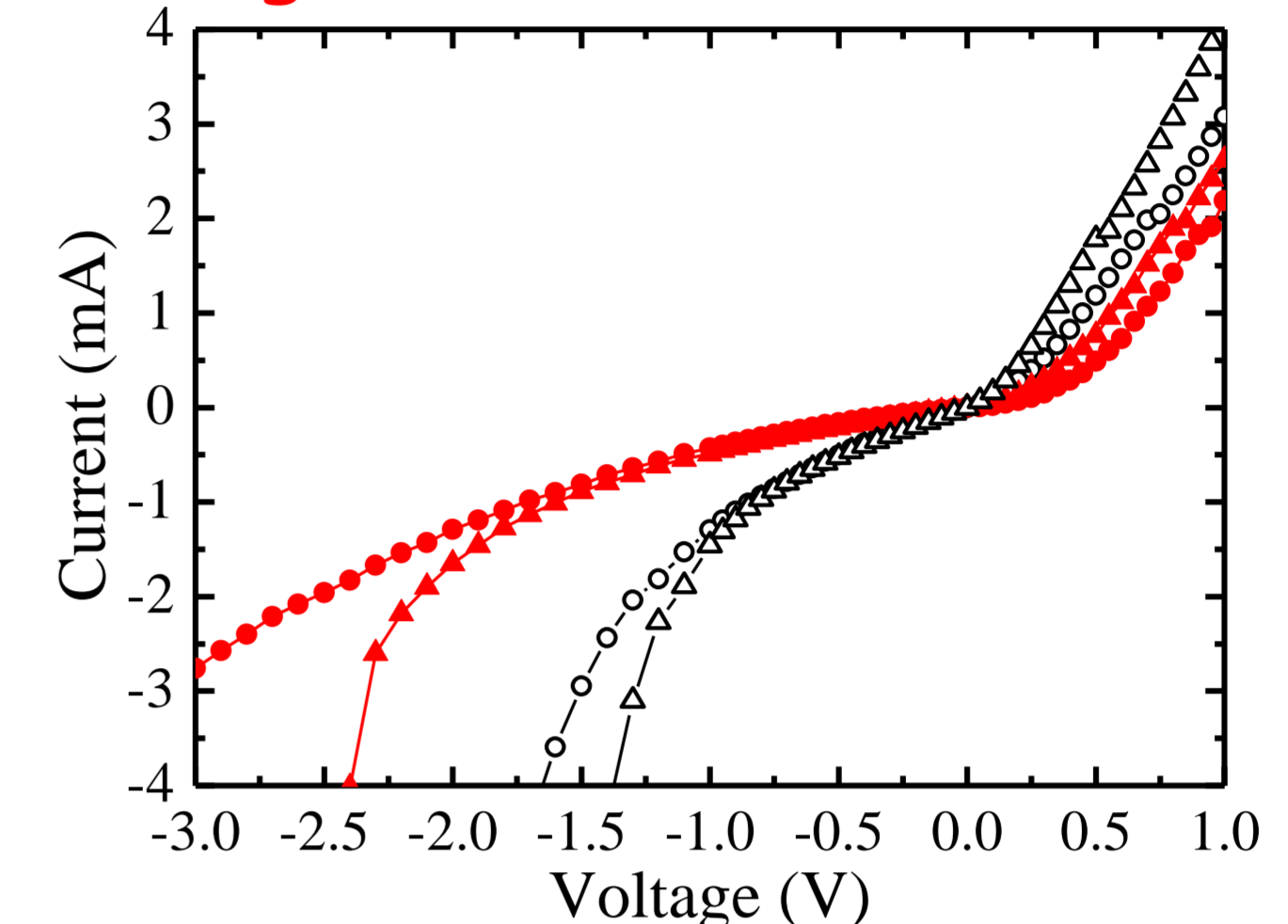


Fig. 2. Current-voltage curves of the LPE-InSb detector measured at 24 K (circles) and 73 K (triangles), and ones of the previous detector measured at 25 K (open circles) and 77 K (open triangles).

- Electrode area { Before 1 mm-diameter-circle ~0.8 mm²
 After 1.5 mm² ~2 times
- ...However,
- Leakage current was decreased.
 - Breakdown voltage was improved.

How effective is the reducing of leakage current?

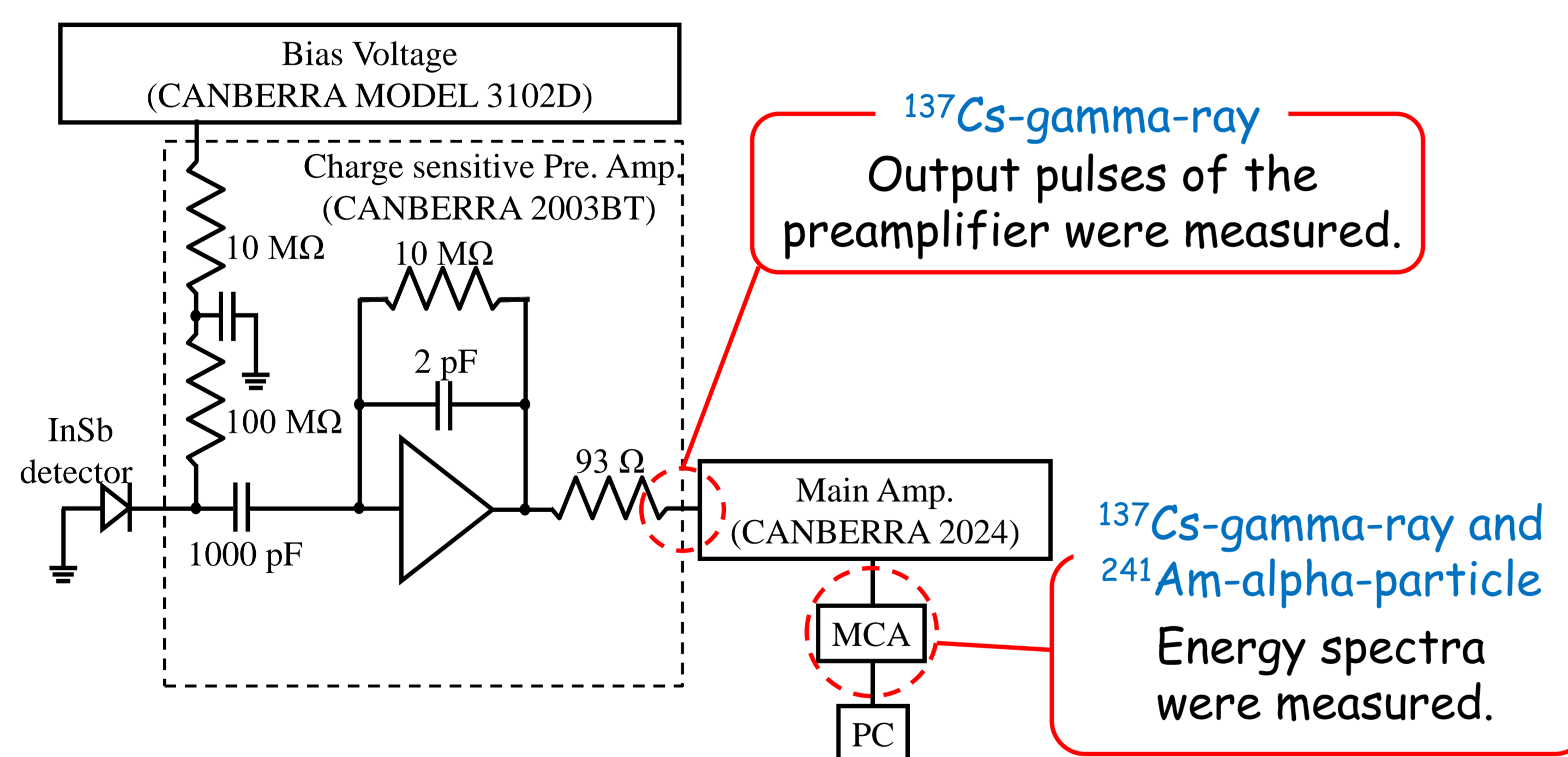


Fig. 3. Block diagram of the electronic circuit used in the radiation measurements. MCA: multichannel analyzer.

Preamplifier output pulses of ¹³⁷Cs-gamma-ray

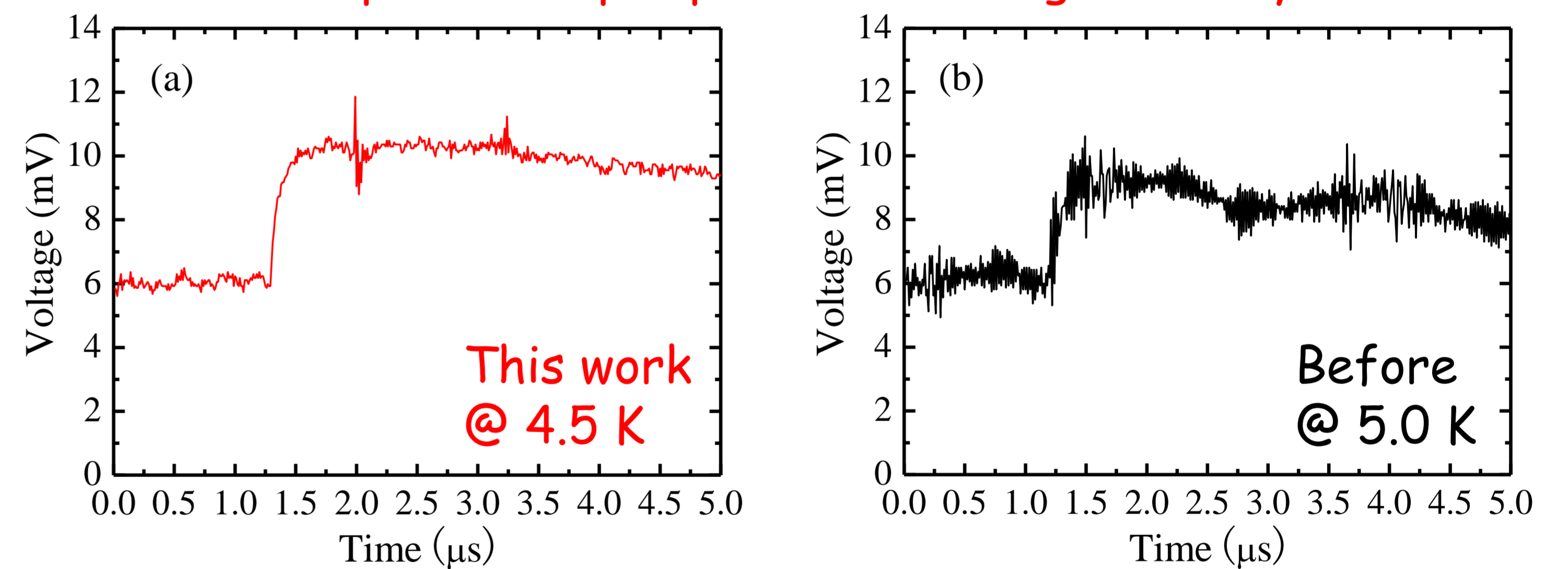


Fig. 4. Typical preamplifier output pulse of ¹³⁷Cs-gamma-ray measured by (a) the present detector at the temperature 4.5 K, and by (b) the previous InSb detector at the temperature 5.0 K

The electric noise level ±1 mV → ±0.4 mV

Energy spectra of ²⁴¹Am-alpha-particle

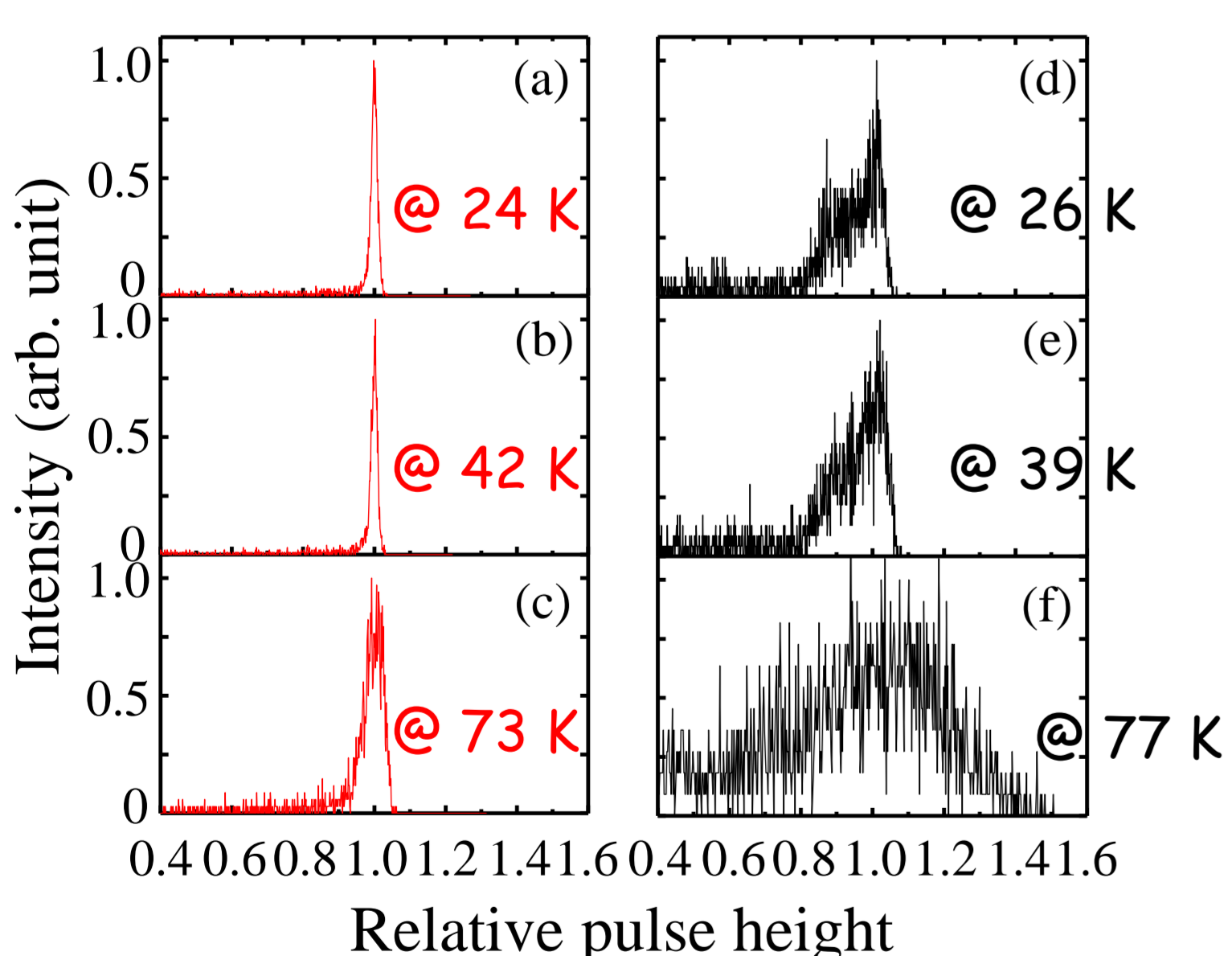


Fig. 5. Energy peaks of ²⁴¹Am-alpha-particles (5.486 MeV) at (a) 24 K, (b) 42 K, and (c) 73 K. Figures (d) 26 K, (e) 39 K, and (f) 77 K were measured by the previous InSb detector.

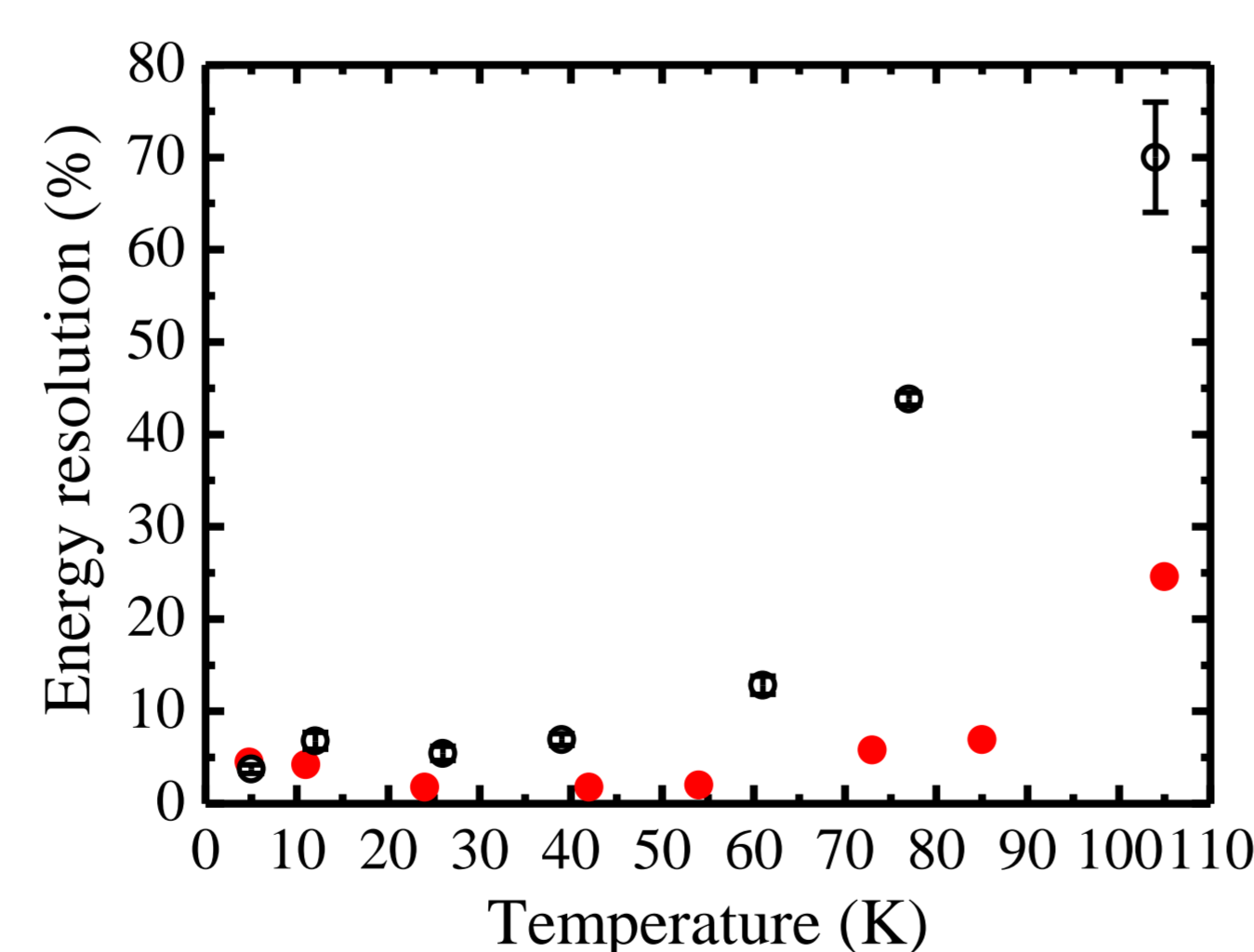


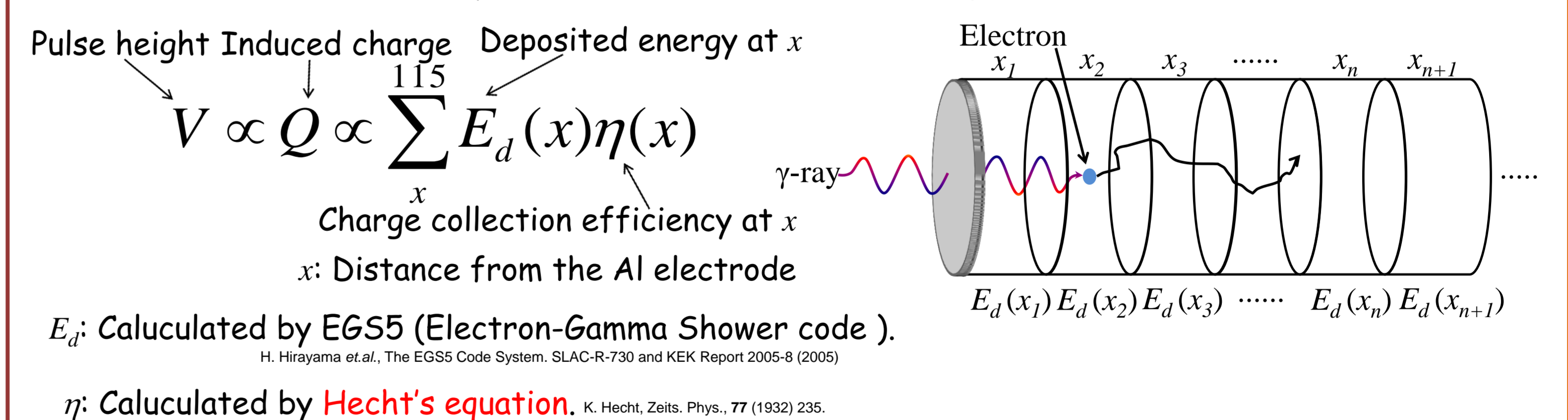
Fig. 6. Energy resolution as a function of temperature for 5.486 MeV alpha particles. Solid and open circles show the present data and previous data, respectively.

Energy resolution was improved. 5.4% @ 26 K → 1.8% @ 24 K
 6.9% @ 39 K → 1.8% @ 42 K

Demonstration Energy spectrum of ¹³⁷Cs-gamma-ray

~Charge collection model by authors~

The 115-μm-thick LPE layer was divided into 115 regions each with 1 μm thickness.



E_d : Calculated by EGS5 (Electron-Gamma Shower code).
H. Hirayama et al., The EGS5 Code System. SLAC-R-730 and KEK Report 2005-8 (2005)

η : Calculated by Hecht's equation. K. Hecht, Zets. Phys., 77 (1932) 235.

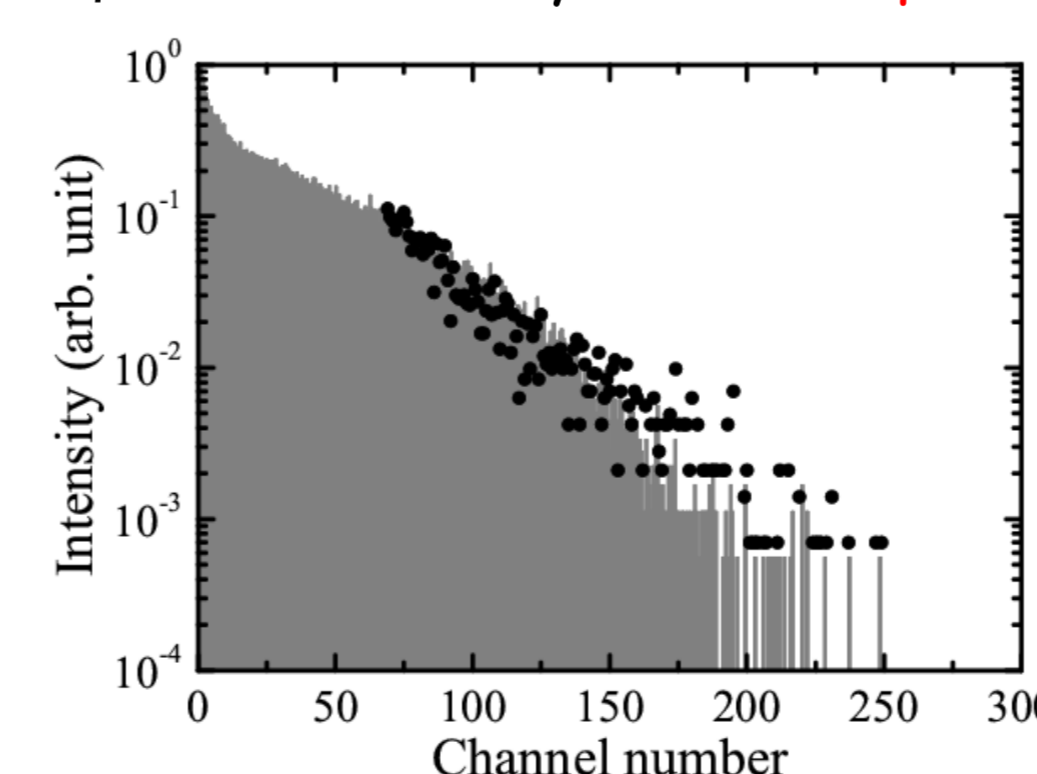


Fig. 7. Solid circles and filled region show the experimentally obtained energy spectrum and simulated one for the ¹³⁷Cs-gamma-rays, respectively.

The shapes of simulated energy spectrum showed good agreement with the experimental spectrum.

Conclusions

- Although the active area was increased, the noise level of the detector showed one half of the one of previously detector.
- The energy resolution for radiation was improved.
- Gamma-rays and alpha-particles were measured by an LPE-InSb detector.
- We explained the experimentally obtained energy spectrum by using the charge collection model. The entire LPE-InSb crystal including outside the depletion layer worked as a sensitive volume.