Applied Radiation and Isotopes 127 (2017) 130–136

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

Study of inactive layer uniformity and charge collection efficiency of a p-type point-contact germanium detector

J.L. Ma[a,b], Q. Yue[b,*], Q. Wang[a,c,d], J. Li[b], H.T. Wong[e], S.T. Lin[f], S.K. Liu[b], L. Wang[b], H. Jiang[b], L.T. Yang[a,b], L.P. Jia[b], J.H. Chen[e], W. Zhao[b]

[a] *Department of Physics, Tsinghua University, Beijing 100084, China*
[b] *Key Laboratory of Particle and Radiation Imaging (Ministry of Education) and Department of Engineering Physics, Tsinghua University, Beijing 100084, China*
[c] *Center for High Energy Physics, Tsinghua University, Beijing 100084, China*
[d] *Collaborative Innovation Center of Quantum Matter, Beijing 100084, China*
[e] *Institute of Physics, Academia Sinica, Taipei 11529, Taiwan*
[f] *College of Physical Science and Technology, Sichuan University, Chengdu 610064, China*

HIGHLIGHTS

- Inactive layer thickness and its uniformity in a p-type point-contact germanium detector, which serves as the detector for dark matter search experiment of CDEX collaboration, were measured, and some main achievements are listed as follows:
- Both top/lateral scans and liner/circular scans were performed on a novel p-type point-contact germanium detector.
- A new charge collection efficiency function of the inactive layer was developed.
- Experimental surface, bulk, and total spectra were compared with the simulated results for the first time. Simulation results with different sources based on the charge collection efficiency function are in good agreement with experimental data in the energy range below 18 keV.

ARTICLE INFO

Keywords:
PPCGe
CDEX
Inactive layer
Charge collection efficiency

ABSTRACT

The characteristics of the surface inactive layer of a 1-kg-mass p-type point-contact germanium detector were studied. The thickness of the inactive layer and its uniformity on the top and lateral surfaces were measured. A charge collection efficiency function was developed according to the Monte Carlo simulation to describe the charge collection capacity along the depth within this inactive layer. In the energy range below 18 keV, the surface, bulk, and total spectra of ^{57}Co, ^{133}Ba, ^{137}Cs, and ^{60}Co from simulations based on the charge collection efficiency function were well consistent with those from experiments.

1. Introduction

Because of the advantages of good energy resolution and high efficiency, high-purity germanium (HPGe) detectors are widely used in nuclear physics, particle physics, and astrophysics. Point-contact germanium (PCGe) detectors with significant low energy threshold have been used in the China Dark matter EXperiment (CDEX), which aims at the direct searches of light weakly interacting massive particles (WIMPs) at the China Jinping Underground Laboratory (Kang et al., 2013). CDEX has reported the experimental limits on WIMPs' dark matter with one p-type PCGe (PPCGe) detector (CDEX-1A) of mass 994 g (Yue et al., 2014; Zhao et al., 2013). A new PPCGe detector (CDEX-1B) of mass 1008 g and with lower energy threshold less than 300 eV was fabricated and used for further research.

Evidence in literature (Aguayo et al., 2013; Aalseth et al., 2011; Shutt et al., 2000; Campbell et al., 1974) supports the idea that there is an inactive N^+ layer on the surface of a p-type HPGe detector and that the layer is composed of two parts. The outermost part of the inactive layer caused by lithium diffusion is conductive. Free charges originated in this layer by incident charged particles could not produce any induced signal. Therefore, this layer is regarded as a totally dead layer. There is then a transition layer with a weak electric field where charges are partially collected and has a charge collection efficiency of less than 100%. Both transition layer and conductive layer together have been known as the inactive layer, which is approximately 1 mm near the outside N^+ surface of a p-type HPGe detector. Knowing the exact

* Corresponding author.
E-mail address: yueq@mail.tsinghua.edu.cn (Q. Yue).

http://dx.doi.org/10.1016/j.apradiso.2017.05.023
Received 7 October 2016; Received in revised form 14 May 2017; Accepted 28 May 2017
Available online 30 May 2017
0969-8043/

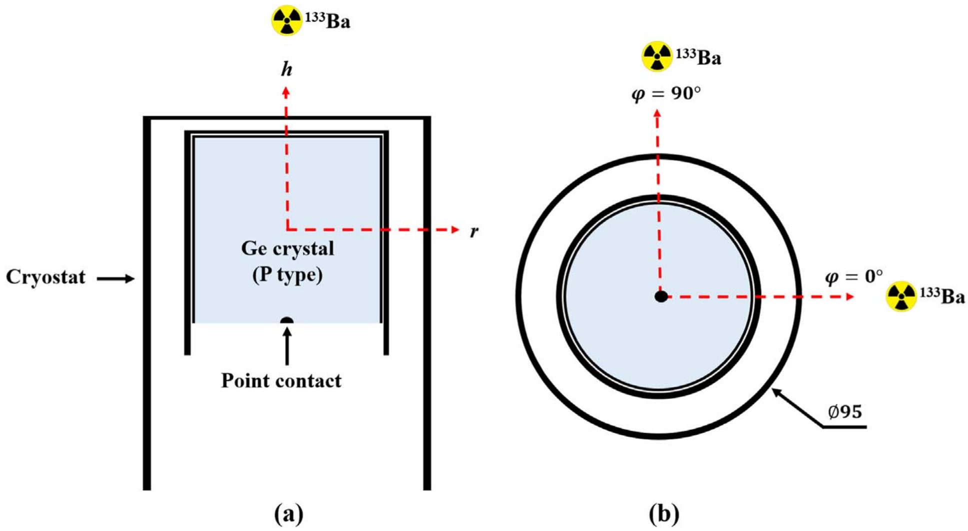

Fig. 1. Schematic of the measurement setup. Dashed lines represent the cylindrical coordinate system with the origin at the geometric center of the Ge crystal. (a) Side view of the detector. (b) Top view of the detector, and the diameter of the cryostat is 95 mm.

thickness and the structure of the inactive layer is of critical importance for a PPCGe detector, so that necessary correction about the mass of the active volume can be made, and it is helpful to further understand the characteristics of the energy spectrum.

Measurement procedures and results on the inactive layer thickness of p-type HPGe detectors were discussed in the literature (Ródenas et al., 2003; Agostini et al., 2015, 2011a; Jiang et al., 2016). The present work adopts an earlier approach and deepens the researches on (1) the measurement of the uniformity of the inactive layer and (2) the quantitative derivation of the "charge collection efficiency function" for the CDEX-1B PPCGe detector.

2. Detector and experimental setup

The CDEX-1B PPCGe detector was manufactured by Canberra, France. Compared with coaxial HPGe detectors, the small readout capacitance, ~ 1 pF of the point-like millimeter-scale electrode, allows the PPCGe detectors to achieve a quite low energy threshold down to 400 eV or even lower. Fig. 1 shows the schematic structure of CDEX-1B detector. A 1008-g Ge crystal, cylinder with a height of 62.3 mm and a diameter of 62.1 mm, is surrounded by a 0.5-mm-thick polytetrafluoroethylene (PTFE) foil and held by a copper cup with a thickness of 2.0 and 1.0 mm on the lateral and top surfaces, respectively. The detector was mounted inside a vacuum copper cryostat with a thickness of 2.0 and 1.1 mm on the lateral and top surfaces, respectively. The operational voltage was +3750 V. Signals were read out from the p+ point contact, which was at the bottom of the crystal and connected to an electrode pin.

The coordinate system used here was cylindrical with the origin at the geometric center of the crystal, as shown in Fig. 1. Measurement of the CDEX-1B inactive layer thickness on the top was performed with a source-to-detector distance of 120 mm, as shown in Fig. 1(a). Measurements on the side were taken separately at $\varphi = 0^\circ$ and $\varphi = 90^\circ$ with the same height of the crystal center, as shown in Fig. 1(b). An uncollimated ^{133}Ba source was used in both the cases. Two measurements at $\varphi = 0^\circ$ with source distances of 45 and 70 mm gave the inactive layer thickness, the measurement at $\varphi = 90^\circ$ with the source distance of 45 mm together with the measurement on the top surface allowed cross checks.

The uniformity of the inactive layer was measured using a collimated ^{57}Co source. Scans of the lateral surface of the detector include two vertical linear scans from $h = -25$ mm to $h = 25$ mm separately at $\varphi = 0^\circ$ and $\varphi = 90^\circ$ and two horizontal circular scans at a height of −10 and 10 mm. Linear scans of the top surface were performed along two orthogonal diameters from $r = -25$ mm to $r = 25$ mm at $\varphi = 0^\circ$ and $\varphi = 90^\circ$. The step size was 5 mm for linear scans and 30° for circular scans.

3. Analysis method

Events induced by 81.0, 276.4, 302.9, and 356.0 keV photons from the ^{133}Ba source were selected. Fig. 2 shows the spectra around 81 and 356 keV of the measurement at $\varphi = 0^\circ$ with the source distance of 45 mm. For the 81.0 keV peak, because the 79.6 keV peak, which also

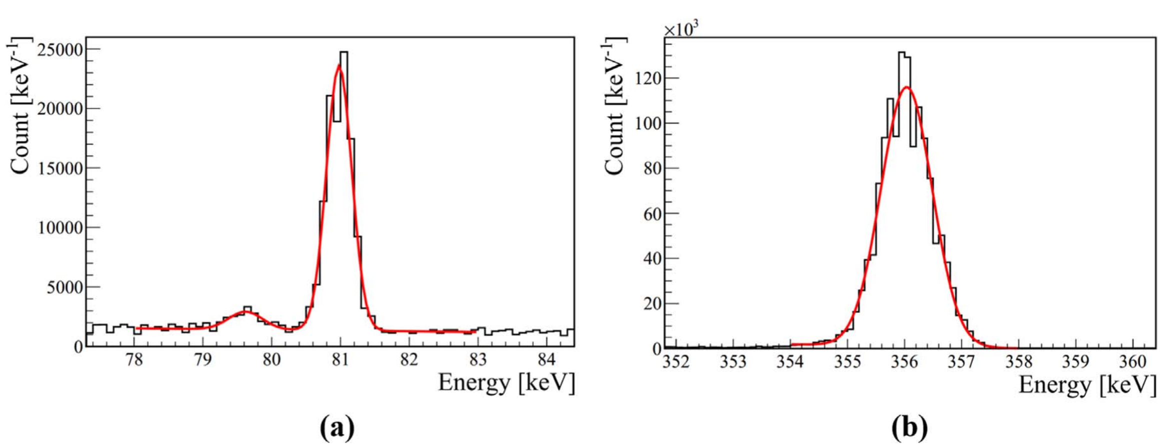

Fig. 2. Energy spectra around the 81.0 keV peak and the 356.0 keV peak, shown as black lines. (a) Fitting of the 79.6 and the 81.0 keV peaks by using two Gauss functions and a first-order polynomial. (b) Fitting of the 356.0 keV peak by using a Gauss function and a first-order polynomial.