Nuclear Instruments and Methods in Physics Research B 351 (2015) 46–50

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research B

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

Investigation of the Compton Rescue technique

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ARTICLE INFO

Article history:
Received 19 January 2015
Accepted 31 March 2015
Available online 13 April 2015

Keywords:
Gamma detection
Semiconductor detector
Compton scatter
Compton rescue
Positron

ABSTRACT

This paper summarizes an investigation of a process to improve the efficiency of position-sensitive gamma-radiation measurements from thin, planar semiconductor detectors. The method entails the use of a second, more efficient coaxial bulk detector placed behind a position-sensitive planar detector to collect Compton scattered photons that escape the volume of the position-sensitive detector. The technique is termed Compton rescue. The investigation consisted of two phases. First, a Monte-Carlo simulation was conducted to test feasibility of employing the technique. The simulation predicted the increase in detection efficiency by directly counting the number of photons added to the data set by Compton rescue and comparing to the number detected without the use of the technique. The simulation indicated that the technique could improve detection efficiency by approximately doubling the number of full-energy photons detected. The technique was tested in a laboratory setting using a coaxial semiconductor detector in coincidence with a thin, planar position-sensitive semiconductor detector. An efficiency improvement of approximately 20% was measured. The effect of Compton rescue data on the energy resolution of the position-sensitive detector was also determined.

1. Introduction

The Compton rescue technique was investigated as a method to increase the detection efficiency for a thin, planar, semiconductor detector. Photons are more likely to interact with a thin detector by Compton scattering than by the photoelectric (PE) effect for photons in the energy range above several hundred keV as evidenced by Fig. 1. When a photon Compton scatters in a thin detector, no useful data is added to the position-sensitive energy spectra because the full energy of the incident photon cannot be determined from the scatter interaction alone. By adding a second, or *rescue*, detector to the system, photons scattered out of the thin primary detector may be collected in the second detector by PE absorption [1]. Similar work was performed by Decman and Namboodiri [2] using a different detector setup and geometry. Summing the energy deposited in both the secondary interaction and the Compton scatter interaction in the primary detector may result in the recovery of the full energy of the original incident photon and the inclusion of the event in the full-energy peak of the collected spectrum. The principle of restoring a photon scattering interaction that would otherwise be incomplete, or "lost," is the basis for the term "Compton Rescue".

Before testing the technique in a laboratory setting, a simulation was conducted to probe the feasibility of Compton rescue as a possible method to improve collection efficiency. The simulation was used as a benchmark to compare with the experimental data. The simulation tested the physics of the photon interactions with the detectors, but did not account for the charge or signal generation characteristics of the detectors. In the laboratory experiment, the position-sensitive detector and the rescue detector were arranged to collect radiation from a gamma-ray source. Coincident data from the instruments were analyzed according to selection criteria to separate Compton rescue data and full-energy event data representing PE interactions within the primary detector. The simulation geometry was designed to represent the experimental environment as practically as possible.

The thin-planar detector was a special type of position-sensitive detector that uses two orthogonal arrays of metal charge collection strips on either side of the photon-sensitive crystal. This type of detector is known as a double-sided strip detector (DSSD) [3–5]. Using a DSSD, an experimenter is able to deduce the location of a photon interaction in the crystal volume by observing which two strips on either side of the crystal collect the charges created by the photon interaction. Since the strips on one side of the crystal run perpendicular to the strips on the other side, the photon is considered to have interacted somewhere in the area that intersects both strips. Additionally, the location of the interaction could be inferred even more accurately within the intersection region, or "pixel", by analyzing the transient charge signal induced on the surrounding strips by the charge moving through the crystal to

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http://dx.doi.org/10.1016/j.nimb.2015.03.086
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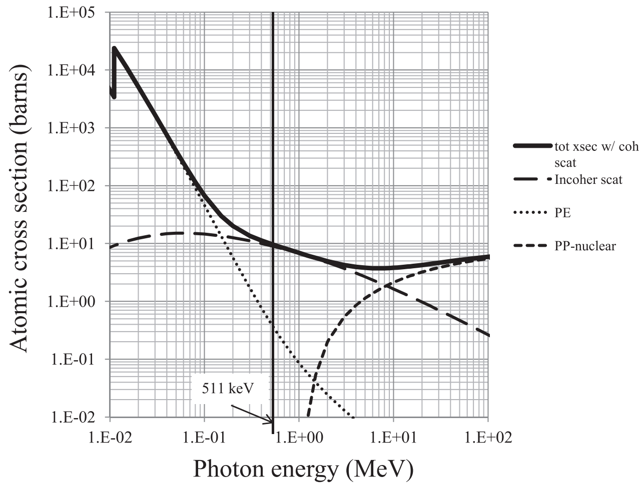

Fig. 1. Photon interaction cross section data for germanium [8]. In the regime of interest (∼511 keV) Compton scattering effect dominates.

the collection strips [6]. The shape and relative magnitude of these transient charge signals can be characterized and compared to narrow down the identified interaction location within the pixel. This allows a set of arbitrary subpixel boundaries to be defined within the width of the intrinsic charge collection strip that allow for increased precision in the location measurement (Fig. 2). The precision of this subpixel measurement and the effect of Compton Rescue on that precision was analyzed in this experiment.

While there are many radiation detection applications that could benefit from the use of this technique, this experiment was conducted specifically to improve measurements of positron annihilation. The position-sensitive DSSD can be used to gather data for angular correlation of annihilation radiation (ACAR) experiments [6]. The ACAR technique can be used to gather information about the atomic structure of materials noninvasively by collecting two-dimensional radiation signatures from positron interrogation. Positrons incident on a material sample annihilate with positrons in the atomic structure and emit radiation that can be collected to determine material properties. The annihilation reaction between electrons and positrons emits photons with a nominal energy of 511 keV. Additionally, the measurements require a high degree of energy resolution to observe the Doppler broadening of annihilation radiation (DBAR). Because of the high energy of the photons and the fine energy resolution requirement, solid state germanium detectors such as the planar detector used in this experiment are ideal.

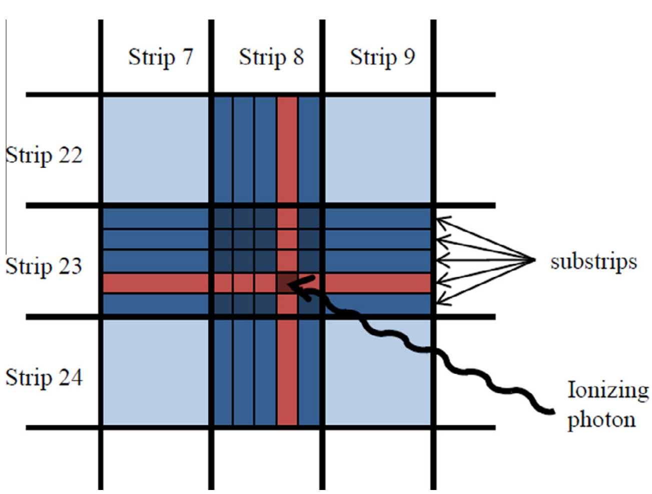

Fig. 2. Illustration of DSSD position sensitivity mechanism. The charge collection strips are oriented perpendicularly to each other. The substrips are arbitrarily defined zones within each strip that are used to locate photon interactions more accurately within a detector pixel using transient charge analysis.

2. Methods

The Monte-Carlo N-Particle transport (MCNP) code, version 5, was implemented for the simulation. The simulation was designed to represent the laboratory experiment as closely as possible. To this end, material cells were defined to match the dimensions and material properties of the detectors based on design specifications provided by their manufacturers. The primary detector was a DSSD manufactured by PHDs Co (Fig. 3), and had a single-crystal of high-purity Germanium (HPGe). The crystal was approximately circular with a diameter of 8 cm and a thickness of 1 cm. The rescue detector was a coaxial HPGe detector manufactured by Ortec Co which has a cylindrical detector crystal with an 8 cm diameter and 4 cm thickness. The simulation included defined detector housing components such as aluminum faceplates and vacuum seal layer cells for both detectors in addition to the detector crystal cells (Fig. 6). The rescue detector was located axially-aligned and as close as possible to the primary detector to maximize the solid angle the planar detector generated with the coaxial detector. To account for the thickness of the detectors' housings, this positioned the detector crystals approximately 5 cm apart.

The photon source was defined as a small circular disc with a diameter of 2 cm located in front of the primary detector at varying offset distances, along the same axis as the centers of both faces of the DSSD and coaxial detectors. The photon energies were defined uniformly at 511 keV and the source location was distributed uniformly over the whole disc. The propagation direction of the sourced photons was restricted to a cone representing the solid angle covered by the primary detector's active crystal volume. The energy of 511 keV was chosen to represent the energy of photons produced by positron annihilation, since Positron Annihilation Spectroscopy (PAS) experiments are a useful application of position-sensitive detectors [6] and the intended application of this technique.

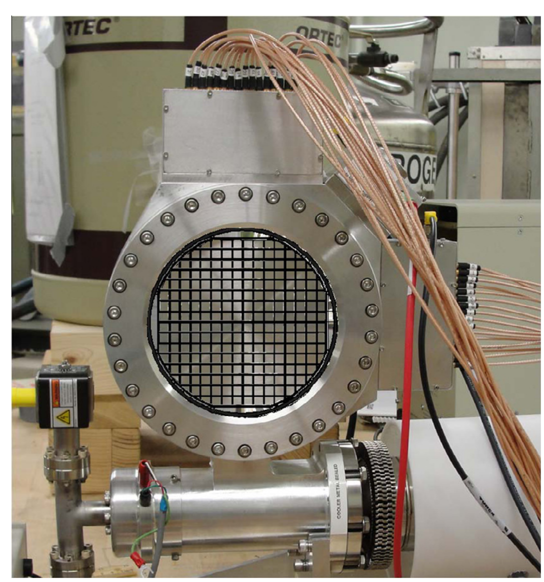

Fig. 3. PHDs Co. double-sided strip detector with pixel array superimposed. The crystal is cooled to 63 K by an internal mechanical cooler, visible on the lower portion of the unit.