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Tada T.[1]*, Tanaka T.*[2]*, Kim S.-Y.*[1]*, Wu Y.*[1]*, Hitomi K.*[1]*, Yamazaki H.*[1]*, and Ishii K.*[3]

[1]*Cyclotoron and Radioisotope Center, Tohoku University*
[2]*Graduate School of Electronics, Tohoku Institute of Technology*
[3]*Graduate School of Engineering, Tohoku University*

Introduction

Thallium bromide (TlBr) is a new promising semiconductor material for X- and gamma-ray detectors. It has the wide band gap (2.68 eV), the high density (7.56 g/cm^3) and the high atomic numbers (Tl: 81, Br: 35). Also, its low melting point (460˚C) makes it easy to grow the crystal.

Improvement of the energy resolution is one of the main issues for researches on semiconductor detectors such as CdTe, CZT, HgI_2, and TlBr. Various methods including pulse shape discrimination, depth sensing technique, and co-planar grid structure have been applied to these detectors in the past decades[1-6]. In this paper, the digital pulse processing method is proposed to improve the energy resolution for planar TlBr detectors. The method is based on the fact that the energy resolution of TlBr detectors is limited by the drift properties of charge carriers[7,8]. The mobilities for holes are very small and it results in the long carrier transit times in the detectors. Although a long time constant (~10 ms) is required for the pulse shaping in order to obtain sufficient energy resolutions from TlBr detectors, the low-frequency noise and the pulse pile-up problems are severe for such case. The proposed digital pulse processing is effective to minimize the problems and is a simple method without complex electronics used by other previous techniques.

In this study, the digital pulse processing method was applied to the output pulses of planar TlBr detectors in order to improve the energy resolutions. The low-frequency noise was suppressed by using an optimum short shaping time and the effect of pulse height deficit due to incomplete charge collection was minimized by the depth correction.

TlBr detectors and experimental setup

The TlBr detectors were fabricated from a crystal grown by the traveling molten zone (TMZ) method. The starting material for the crystal growth was commercially available TlBr powder with nominal purity of 99.999%. The material was zone-purified with a horizontal zone furnace. After the purification, single zone pass was performed to improve crystallinity. In order to fabricate planar TlBr detectors, the grown crystals were cut into wafers with a diamond wire saw. The two surfaces of the wafers were polished mechanically. The resultant wafers had the dimensions of $5\times5\times0.5$ mm^3. Circular electrodes with a diameter of 3 mm were deposited on the polished surfaces by vacuum deposition of thallium through a shadow mask. Then, aluminum was deposited onto the thallium electrodes and thin palladium electrodes were attached to the electrodes by using a carbon paste. The detector was encapsulated in an aluminum box with a BNC connector for connection to a charge-sensitive preamplifier (Clear Pulse 580K). The preamplifier output pulse was directly digitized by means of a digital oscilloscope (Tektronix DPO3032) with a sampling rate of 100 MS/s and 8 bit resolution. The pulses were transferred to a personal computer for analysis. The analysis was performed using a program written in Labview programming environment. All measurements in this study were performed at room temperature and the detectors were operated at 150 V.

Digital pulse processing and results

The height of output pulse obtained from a TlBr detector depends on the depth of interaction (DOI) of incident gamma-rays because holes are trapped within the detector due to its low mobility-lifetime product. In order to correct the pulse height deficit causing degradation of energy resolutions, the depth information (DOI parameter) was extracted from a ratio between pulse heights for fast-shaped and slow-shaped signals. The shaping time of 1 ms was used as the fast shaping to select the pulse height originating from an electron component. The sum of electron and hole components was obtained by using 2 and 10 ms time constants (slow shaping). A digital version CR-$(RC)^4$ filter was constructed and was used for the shaping. The calculated ratios were grouped into 100 bins and the energy spectrum of signals associated with each bin was obtained to correct the depth effect.

Figure 1(a) shows ^{137}Cs spectrum obtained by using the time constant of 10 ms for the pulse shaping. The shaping time was determined to give the best energy resolution without the depth correction. The energy resolution of 5.8% at 662 keV was obtained. The relationship between the pulse height and the estimated depth of interaction is shown in Fig. 1(b). The photo-peak position in the spectrum seems to be almost independent on the depth of interaction. The result indicates that the depth effect is enough small at the shaping time. However, the energy resolution is apparently restricted by a large low-frequency noise. The noise can be reduced by using a short shaping time. The energy spectrum at the shaping time of 2 ms is shown in Figs. 2(a) and 2(b). In this spectrum, although the low-frequency noise is appreciably suppressed, the depth effect is considerably large compared to that of 10 ms shaping (Fig. 1) and is the dominant factor causing degradation of the energy resolution. The depth effect was minimized by the depth correction. In order to minimize the depth effect, the photo-peak channel associated with each depth of the spectrum was aligned to form an overall energy spectrum with an improved energy resolution. The results are shown in Figs. 3(a) and 3(b). The energy resolution of 4.2% at 662 keV was obtained. The spectra with distorted energy resolution can be rejected based on the depth information to construct the energy spectrum with a better resolution. The best energy resolution of 3.1% was recorded at the DOI parameter between 95 and 99 (Fig. 4).

Conclusion

A digital pulse processing was applied to the output pulses from planar TlBr detectors. The spectra were considerably suffered from a low frequency noise when an only conventional CR-$(RC)^4$ filter with a long time constant was applied to the pulses. In order to suppress the low frequency noise, a short shaping time constant was applied to the output pulses. The depth effect due to the use of the short shaping time was corrected based on the depth information. The energy resolution of the spectrum was appreciably improved by the method.

Since the output pulses contain various information on the detector property, the digital pulse processing can be used not only to improve the energy resolution but also to investigate the other detector properties such as timing performance and carrier mobilities.

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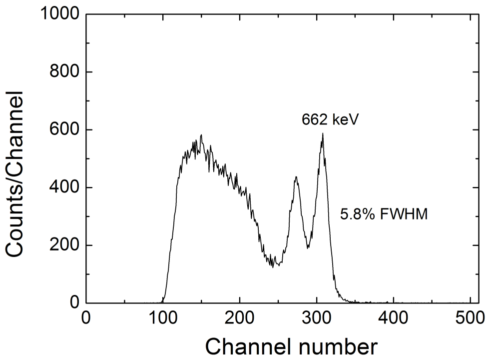

Figure 1(a). ^{137}Cs spectrum obtained from a TlBr detector 0.5 mm thick. Shaping time was 10 ms.

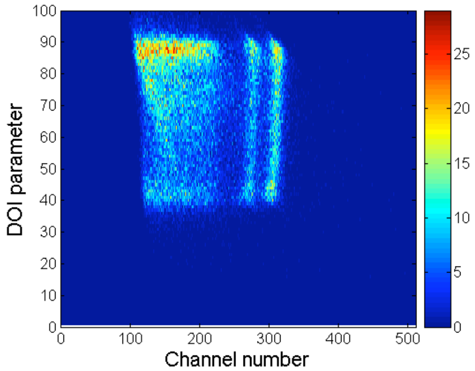

Figure 1(b). Relationship between the pulse height and the estimated interaction depth.

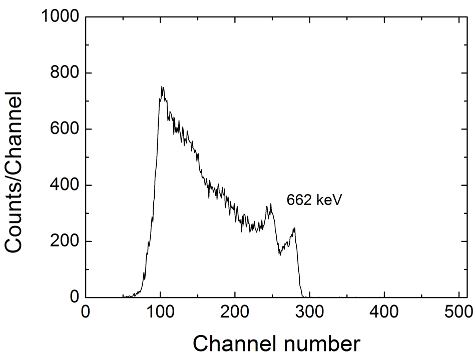

Figure 2(a). ^{137}Cs spectrum obtained from a TlBr detector 0.5 mm thick. Shaping time was 2 ms.

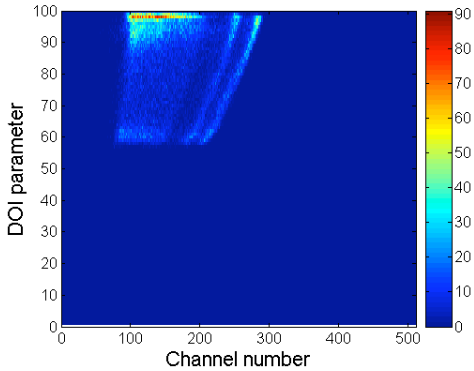

Figure 2(b). Relationship between the pulse height and the estimated interaction depth.

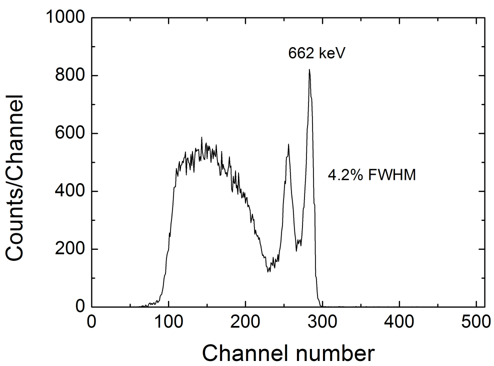

Figure 3(a). ^{137}Cs spectrum obtained with correcting the depth effect. Shaping time was 2 ms.

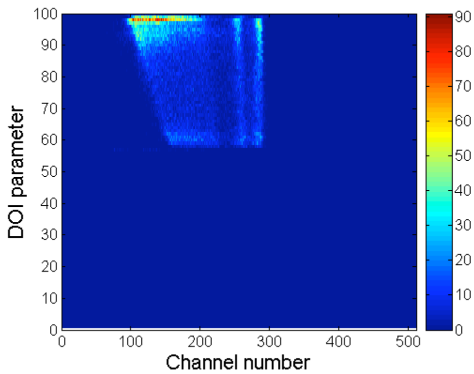

Figure 3(b). Relationship between the pulse height and the estimated interaction depth.

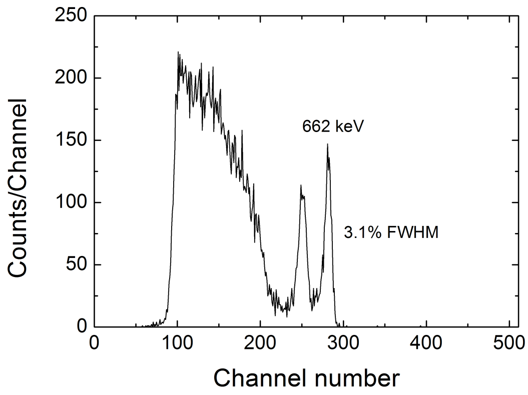

Figure 4. ^{137}Cs spectrum for the depth parameter between 95 and 99. Shaping time was 2 ms.