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Fabrication of double-sided thallium bromide strip detectors

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ABSTRACT

Double-sided strip detectors were fabricated from thallium bromide (TlBr) crystals grown by the traveling-molten zone method using zone-purified materials. The detectors had three 3.4-mm-long strips with 1-mm widths and a surrounding electrode placed orthogonally on opposite surfaces of the crystals at approximately $6.5 \times 6.5\ \mathrm{mm}^2$ in area and 5 mm in thickness. Excellent charge transport properties for both electrons and holes were observed from the TlBr crystals. The mobility-lifetime products for electrons and holes in the detector were measured to be $\sim 3 \times 10^{-3}\ \mathrm{cm}^2/\mathrm{V}$ and $\sim 1 \times 10^{-3}\ \mathrm{cm}^2/\mathrm{V}$, respectively. The ^{137}Cs spectra corresponding to the gamma-ray interaction position were obtained from the detector. An energy resolution of 3.4% of full width at half maximum for 662-keV gamma rays was obtained from one "pixel" (an intersection of the strips) of the detector at room temperature.

1. Introduction

Position-sensitive semiconductor gamma-ray detectors are attractive for constructing gamma-ray imaging systems, including single photon emission computed tomography and Compton cameras. Double-sided strip detectors, in which the strip electrodes on each side of the semiconductor crystal are orthogonally facing, possess position-sensing capabilities and require fewer readout channels than those for pixelated detectors. In double-sided strip detectors, efficient collection of both electrons and holes for corresponding strips is indispensable for determining the position of the gamma-ray interaction [1]. Double-sided strip detectors have been fabricated from silicon and germanium semiconductors [2,3], both of which exhibit large mobility-lifetime ($\mu\tau$) products for electrons and holes. Compound semiconductors, including cadmium telluride and cadmium zinc telluride, which offer high photon-stopping power, have also been used for fabrication of double-sided strip detectors [4,5].

Thallium bromide (TlBr) is a wide-band-gap compound semiconductor characterized with high photon stopping power originating from the high atomic numbers of its constituent atoms (81, 35) and high density ($7.56\ \mathrm{g/cm}^3$). TlBr has a low melting point of 460 °C and exhibits no phase transition below the melting point. Owing to these advantageous properties, simple melt-based processes can be employed for growing TlBr crystals with good charge transport properties ($\mu\tau$ for electrons: $> 10^{-3}\ \mathrm{cm}^2/\mathrm{V}$, $\mu\tau$ for holes: $> 10^{-4}\ \mathrm{cm}^2/\mathrm{V}$ [6]) and high resistivity ($10^{10\text{–}11}\ \Omega\ \mathrm{cm}$ [7–10]) at room temperature. Owing to its large $\mu\tau$ product for holes, collection of holes in thick TlBr detectors was reported in Ref. [11]. Because TlBr crystals possess good charge transport properties for both carriers, TlBr is a suitable material for constructing double-sided strip detectors for gamma-ray imaging applications. Although pixelated TlBr detectors have been investigated by various researchers [9–13], only a few TlBr strip detectors have been reported [14].

In this study, double-sided strip detectors were fabricated from relatively thick (~ 5 mm) TlBr crystals with large $\mu\tau$ products for holes. The charge transport properties for both electrons and holes in the crystals were evaluated because good charge collection is required for obtaining the position information from the device. The spectroscopic performance of the device was measured at room temperature.

2. Crystal growth, detector fabrication, and experimental setup

Double-sided TlBr strip detectors were fabricated from TlBr crystals. Commercially available TlBr beads with 99.999% purity were used for the crystal growth starting material. The raw material of 150 g and hydrogen bromide gas were sealed in a quartz ampule with an inner diameter of approximately 15.5 mm. A horizontal zone-purification system with two resistive heaters was employed for further purification of the raw material in the

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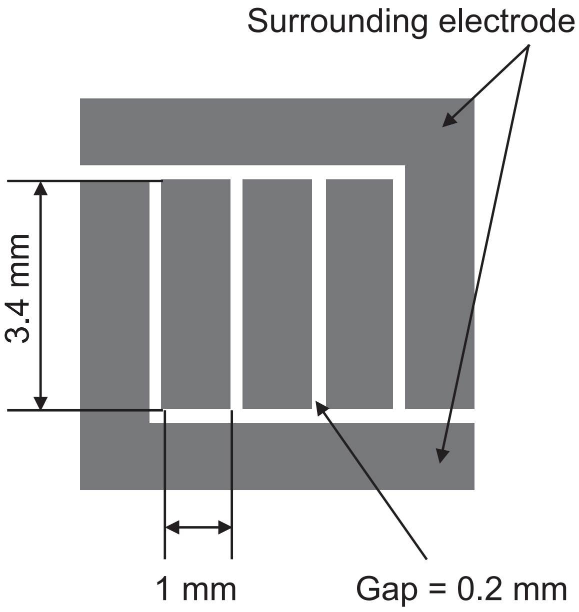

Fig. 1. Electrode design for the double-sided TlBr strip detector.

ampule. The furnace movement speed was 5 cm/h. The process was repeated up to 175 times; i.e., 350 zone purifications. After the purifications, a single zone pass with the furnace movement speed of 5 mm/h was performed to grow a TlBr crystal.

The TlBr crystal was cut into wafers with a diamond wire saw. The two surfaces of the wafers were lapped and polished. The polished wafers were diced into cuboids with the wire saw. The surfaces of the cuboids were etched with a mixture solution of hydrogen bromide and hydrogen peroxide. The resultant cuboids had dimensions of approximately $6.5 \times 6.5 \times 5\ \text{mm}^3$. The electrodes were deposited on both $6.5 \times 6.5\text{-mm}^2$ surfaces of the cuboids by vacuum evaporation of thallium metal through a shadow mask. It should be noted that the thallium electrode suppresses the polarization phenomena in TlBr detectors at room temperature [15–17]. A surrounding electrode and three 3.4-mm-long strip electrodes with 1-mm widths and 0.2 mm in spacing were orthogonally constructed on opposite surfaces of the crystals. The electrode design is shown in Fig. 1. Thin gold wires were attached to each electrode with conductive carbon paste for connection to external circuits.

On one side of the device, the three strips and the surrounding electrode, which served as the cathodes, were connected to a four-channel AC-coupled charge-sensitive preamplifier (Clear-pulse 5005 H). Negative bias voltage was applied to the detector via the preamplifier. The electrodes on the other side, which served as the anodes, were connected to four AC-coupled charge-sensitive preamplifiers (Amptek A250) and were maintained at ground potential. The output waveforms from the preamplifiers were acquired with an eight-channel digitizer with an A/D resolution of 14 bits. All measurements in this study were performed at room temperature.

3. Charge transport properties

The gamma-ray interaction position in double-sided strip detectors can be determined from the amount of charges induced by the motion of the electrons and holes on both strip sets that are orthogonally facing. Therefore, good charge-collection efficiencies for both electrons and holes are indispensable. To evaluate the charge collection properties, the double-sided TlBr strip detectors were irradiated with 59.5-keV gamma rays from a ^{241}Am gamma-ray source. The mean penetration depth of 59.5-keV gamma-rays in TlBr crystals is approximately 0.3 mm, which is much shorter than the detector thickness of ~5 mm. In this study, therefore, the charge carriers produced under the irradiated surface traversed almost the entire detector thickness before collection by the strips on the opposite surface.

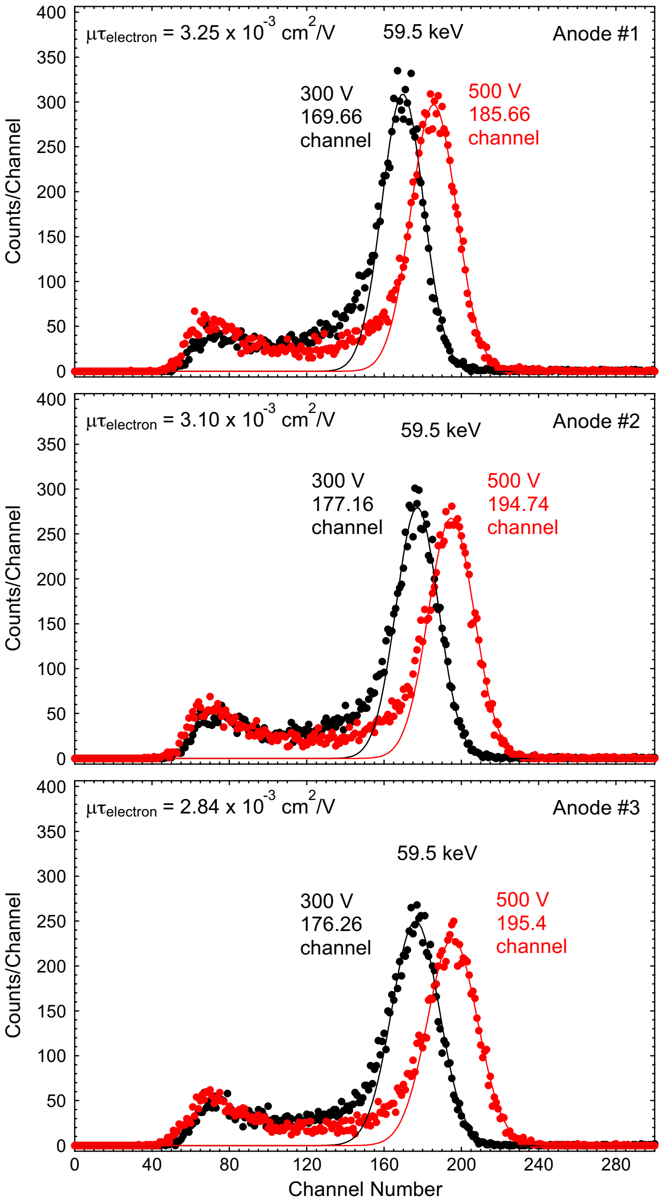

Fig. 2. ^{241}Am gamma-ray spectra obtained from three anode strips of a 4.7-mm-thick double-sided TlBr strip detector. The cathode of this detector was irradiated with the gamma-ray source at room temperature. In this case, electrons primarily traversed the crystal. A digital trapezoidal filter with a peaking time of 18 μs and a flat top time of 4 μs was applied for performing the pulse-height analysis. The $\mu\tau$ products for electrons were estimated from the variations in the peak position with increasing bias voltages.

Fig. 2 shows the ^{241}Am gamma-ray spectra obtained from three anode strips of a 4.7-mm-thick double-sided TlBr strip detector. The cathode of the strip detector was irradiated with the gamma-ray source. In this case, the electrons primarily traversed the crystal (electron traverse). The ^{241}Am gamma-ray spectra obtained from three cathode strips of the anode-irradiated TlBr detector are shown in Fig. 3. In this case, holes primarily traversed the crystal (hole traverse). Clear full-energy peaks are observed in both