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Collection of holes in thick TlBr detectors at low temperature

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ABSTRACT

A $3.5\times3.5\times4.6\ \mathrm{mm}^3$ thick TlBr detector with pixellated Au/Cr anodes made by Radiation Monitoring Devices Inc. was studied. The detector has a planar cathode and nine anode pixels surrounded by a guard ring. The pixel pitch is 1.0 mm. Digital pulse waveforms of preamplifier outputs were recorded using a multi-channel GaGe PCI digitizer board. Several experiments were carried out at $-20\ ^\circ$C, with the detector under bias for over a month. An energy resolution of 1.7% FWHM at 662 keV was measured without any correction at -2400 V bias. Holes generated at all depths can be collected by the cathode at -2400 V bias which made depth correction using the cathode-to-anode ratio technique difficult since both charge carriers contribute to the signal. An energy resolution of 5.1% FWHM at 662 keV was obtained from the best pixel electrode without depth correction at $+1000$ V bias. In this positive bias case, the pixel electrode was actually collecting holes. A hole mobility-lifetime of $0.95\times10^{-4}\ \mathrm{cm}^2/\mathrm{V}$ has been estimated from measurement data.

1. Introduction

Thallium bromide (TlBr) is a promising compound semiconductor detector material for X- and gamma-ray detection applications, including homeland security, astrophysics and medical imaging. It has a high gamma-ray stopping power due to its high density ($7.56\ \mathrm{g/cm}^3$) and high atomic number (Tl: 81, Br: 35). Also, its wide band gap (2.68 eV) makes it very suitable for room temperature operation. TlBr has a low melting point (460 °C) and simple cubic structure which makes growing crystals by conventional melt growth techniques relatively simple compared to other compound semiconductor detectors [1].

The main drawback of current TlBr detectors is the polarization effect which degrades spectroscopic performance over time when bias voltage is applied. It has been suggested [2] that ionic conductivity causes polarization in TlBr detectors. It is shown that the polarization effect is partially mitigated by reversing the polarity of the high bias applied to the detector [3].

In this work, a 4.6 mm thick TlBr detector was kept under bias for over a month and digital pulse waveforms were recorded from four anode pixels and the cathode for spectroscopy measurements at $-20\ ^\circ$C. The detector was relatively stable over the measurement time. Results of these spectroscopic measurements are discussed in more detail in Ref. [4]. This work presents experimental evidence of the collection of holes in thick TlBr detectors. The collection of hole charges in relatively thick (>2 mm) wide band gap semiconductors has not been observed before.

2. Experimental setup

The detector studied is a $3.5\times3.5\times4.6\ \mathrm{mm}^3$ pixellated TlBr detector with Au/Cr contacts manufactured by Radiation Monitoring Devices Inc. The cathode is a planar electrode while the anode has nine pixels with 1 mm pitch (0.9 mm in size) surrounded by a guard ring. The detector is connected to charge sensitive Amptek A250 preamplifiers for readout. Digital pulse waveforms from four anode pixels and the cathode were recorded using a 14-bit GaGe Octopus CompuScope PCI bus on a personal computer. Pulse waveforms of each event are recorded with 512 points sampled every 100 ns on each channel. Example waveforms for a photopeak event close to the cathode surface for a typical collecting anode pixel and the cathode can be seen in Fig. 1. The drop of the signal amplitude after charge collection (during $0\le t\le 25\ \mu$s) is due to the time constant of the preamplifier used in the detection system.

Recorded waveforms for each channel are analyzed with software written in MATLAB[1] and ROOT[2] For this analysis, a digital CR-RC shaping filter is used, with 10 μs shaping time for anode signals and 24 μs shaping time for the cathode signal.

The detector test box was placed inside a temperature chamber where it was kept at $-20\ ^\circ$C during experiments, so that polarization effect can be avoided.

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[1] http://www.mathworks.com.
[2] http://root.cern.ch.

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3. Experimental results

3.1. Collection of holes at −2400 V

Several experiments were carried out with the detector described above and the stability of the detector was studied at −20 °C. The detector was successfully operated for over a month [4]. Fig. 2 shows a ^{137}Cs spectrum (left) and depth separated spectrum (right) using the cathode-to-anode signal ratio from a typical pixel at −1000 V (top) and −2400 V (bottom) bias. The measured energy resolution without any depth correction at 662 keV was 2.7% and 1.7% at −1000 V and −2400 V, respectively.

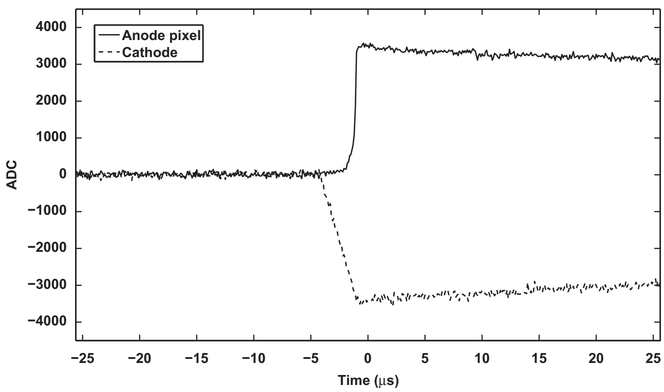

Fig. 1. Typical anode pixel (solid line) and cathode (dashed line) waveforms for a photopeak event close to the cathode surface with a ^{137}Cs source and −2000 V bias [4].

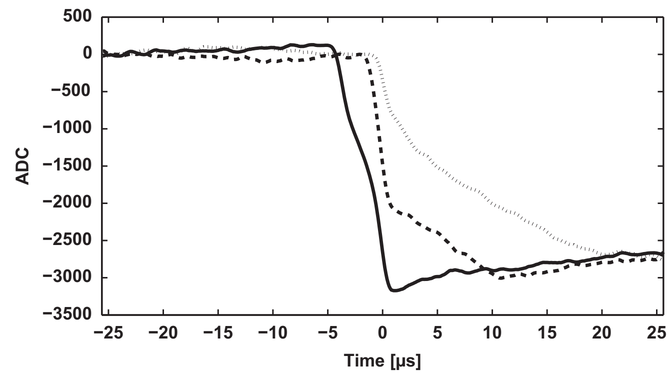

Fig. 3. Cathode waveforms chosen by the electron drift time, 5 μs (solid line); i.e. near to cathode surface, 2.5 μs (dashed line); i.e. close to the middle of the detector bulk and 0.4 μs (dotted line); i.e. close to anode surface. Data were collected with a ^{137}Cs source and −2400 V bias. Detector irradiated from the planar cathode side. Data were collected at −20 °C.

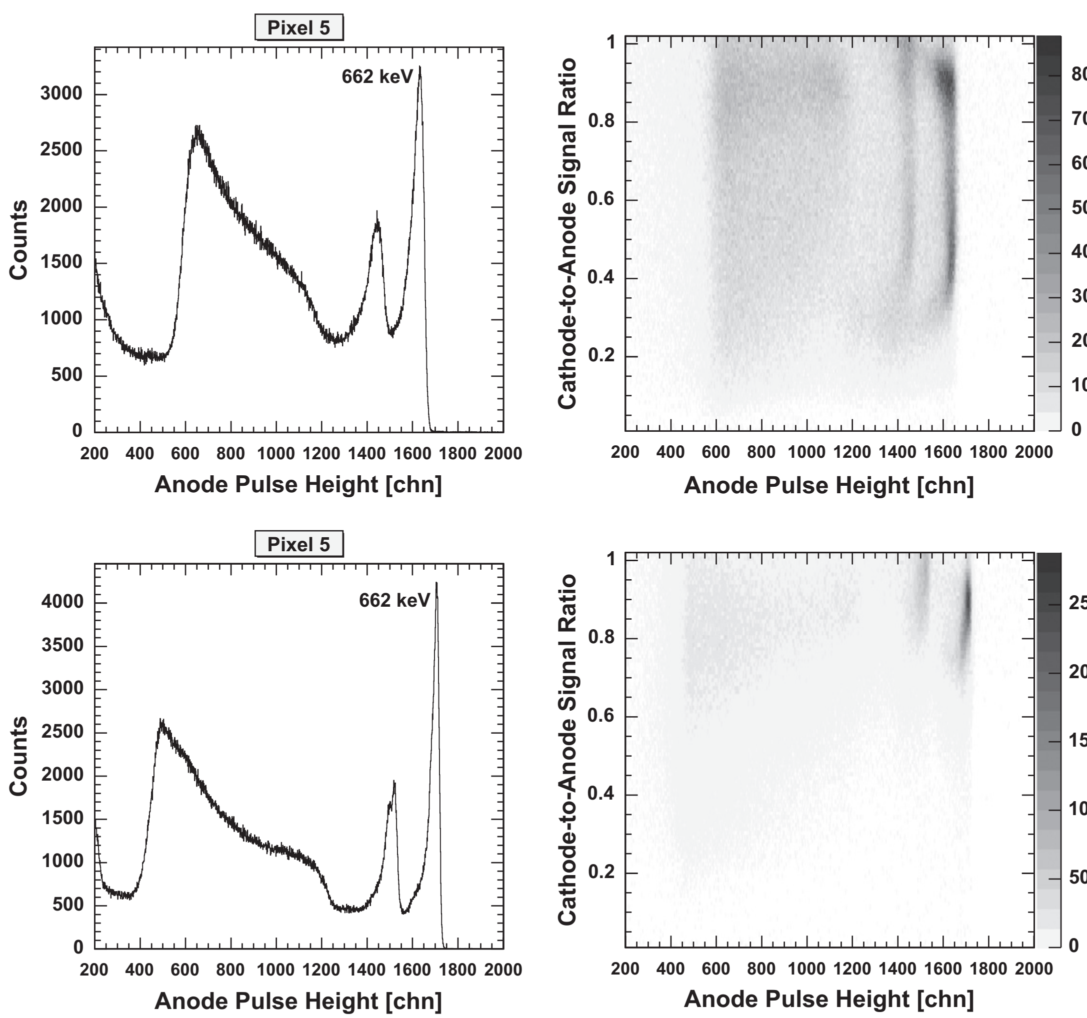

Fig. 2. ^{137}Cs spectra and depth separated spectra using the cathode-to-anode signal ratio for a typical pixel at −1000 V (top, [4]) and −2400 V (bottom). The smaller peak located at the lower energy side of the 662 keV peak is the Tl X-ray escape peak (581 keV). Measured energy resolution without any depth correction was 2.7% and 1.7% at −1000 V and −2400 V, respectively. Data were collected at −20 °C.