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DEVELOPMENT OF A GAMMA AND NEUTRON DETECTOR USING THE TlBr CRYSTAL

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ABSTRACT

In recent years there has been an increasing demand for new types of gamma and neutron detectors to be used in applications such as spectrometers, photodetectors, surgical probes, detection of nuclear weapons, materials characterization, etc. For these applications it is necessary to dispose of small, portable and reliable detectors. Semiconductor detectors based on wide-gap materials, like TlBr, can be used to detect gamma and neutrons radiations. In this work the results of studies concernig the response of the TlBr detectors to gamma and neutrons are presented. The spectrometric performance of the TlBr detector was evaluated by ^{22}Na (511 keV) and ^{137}Cs (662 keV) gamma-ray excitation sources at room temperature. The detectors showed satisfactory resolution values. To evaluate this crystal as a neutron semiconductor detector, systematic measurements with AmBe source were carried out. This source has a large energy spectrum, approximately from 1 MeV at 12 MeV, with a peak around 4.2 MeV. At the present time, results have been demonstrated that neutrons can be detected by TlBr detector. The TlBr detector characterization has shown good response to gamma and neutron radiation.

1. INTRODUCTION

A great interest has being focused on the development of the room temperature radiation detector, using semiconductor materials that have high atomic number and wide band gap. This type of the detector has a large applicability as X-ray and gamma-ray detector spectrometer, operating at room temperature [1,2]. Furthermore, semiconductor detectors based on wide-gap materials, like TlBr, can be used to detect neutrons.

Thallium Bromide crystals are semiconductors composed of high atomic number elements (Z_{Tl}=81 and Z_{Br}=35) and with high resistivity ($>10^{10}\Omega$cm) [3,4]. It exhibits higher photon stopping power than other radiation detector materials such as CdTe, CdZnTe and HgI_2 [2]. Nevertheless, the crystals have low electron and hole mobility plus significant hole trapping. Because of these crystalline characteristics, efficient detectors can only be obtained with thin samples less than 1mm thick [3]. Mobility-lifetime ($\mu\tau_e$ and $\mu\tau_h$ for electrons and holes, respectively) products of TlBr crystals were reported to be $\mu\tau_e = 1.7 \times 10^{-4}$ cm^2. V^{-1} and $\mu\tau_h = 6.4 \times 10^{-5}$ cm^2. V^{-1} [2].

In recent years there has been an increasing demand for new types of gamma and neutron detectors, to be used in applications such as spectrometers, photodetectors, surgical probes, detection of nuclear weapons, drugs inspections, boron neutron capture therapy, materials characterization, etc. The fast response and general ruggedness of solid-state semiconductor detectors makes them attractive for this variety of gamma and neutron detection applications. While recent research has concentrated on silicon and diamond detectors to neutron applications, others such as germanium, CdZnTe and GaAs have also been the subject investigation [5,6]. Like these detectors, thallium bromide semiconductors detectors exhibit remarkable advantages. They are small, simple and can work at low bias voltage with fast response. The TlBr has an apreciable thermal neutron absorption cross section. The natural abundance of Br-79 is 50.69% and the Tl-203 is 29.52%, which yields an absorption cross section of 2.4 b and 11.4 b to thermal neutrons, respectively. It yields the Br-80m with lifetime of 4.42 h and it produces a 37.05 keV gamma. Hence, a Tl based semiconductor detector would be capable of both absorbing neutrons and the corresponding gamma-ray emissions. Moreover, the capture with Tl-204 leads to a (n,β) reaction yielding 763.40 keV beta energy [7].

A large TlBr based semiconductor detector would be capable of absorbing neutrons and the corresponding prompt gamma-rays emissions. The device also is capable of high resolution such that the prompt gamma-rays corresponding to neutron absorption can be easily identified and distinguished from background gamma-ray events [6]. In our previous work, TlBr detectors showed promise as resolution gamma-ray spectrometer [3,8], hence a TlBr device of respectably size could serve as an alternative neutron detector.

In this work, TlBr detectors obtained from crystals grown and purified by zone melting techniques have been characterized to be used as room temperature gamma radiation detectors. Preliminary results from neutrons measurements acquired with a TlBr solid state semiconductor detector are presented.

2. MATERIALS AND METHOD

To produce pure TlBr crystals, commercial TlBr material (99.999%) was purified by zone refining process. 25 zone refining passes were carried out in a furnace at the speed of 5 cm/hr. A small section of TlBr purified material was used for Bridgman crystal growth. Details of the purification and crystal growth were described in our previous papers [3,4,8]. TlBr crystals of 1cm diameter and 3cm long, transparent, uniform and without visual defects, were obtained for this work. The crystals purity was evaluated by the ICP-MS technique. The impurities concentrations found were <10ppm [3, 4].

Crystals were then sawn into several thick wafers with a diamond saw, followed by mechanical polishing. In order to remove damage from the crystal cleavage, wafers surfaces were then etched using 10% bromine in methanol solution and rinsed with a methanol solution. The resulting wafers were clear, with a good quality surface.

To prepare the TlBr wafers as radiation detectors, 0.12 mm diameter Pd wires were attached to Au electrodes using a colloidal graphite suspension. To gamma measurements the detector was assembled inside an aluminum box coupled to the Amptek A250 charge sensitive preamplifier. The pulse height spectra were analyzed using an EG&G Ortec model 918A multichannel analyzer and ^{22}Na and ^{137}Cs gamma-ray sources. The sources were placed outside the Al box, about 1cm from the detector. To neutron measurements the detector was assembled inside aluminum box coupled to Ortec 142A charge sensitive preamplifier. The response was analyzed using an AmBe radiation source, about 1 cm from the detector. The conventional electronic setup, including the Ortec 556 voltage power supply, Ortec 450 amplifier and an oscilloscope, was used to evaluate the radiation responses. The measurements were performed using the same set up and conditions for gamma and neutron measurements, namely, bias of 100V, shaping time of 3μs and amplifier gain of 500.

3. RESULTS AND DISCUSSION

The spectrometric performance of the planar TlBr detector with thickness of about 0.4 mm at room temperature is showed in Figures 1 and 2. The Fig. 1 present the pulse height spectra under ^{22}Na (511.5keV) and the Fig. 2 under ^{137}Cs (662keV) gamma radiation excitations.

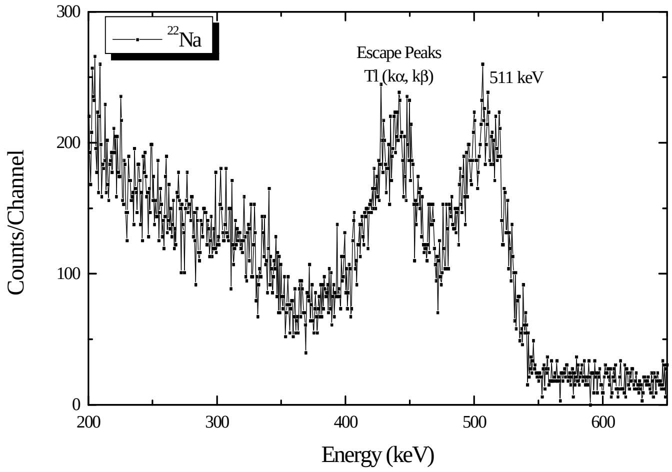

Figure 1. ^{22}Na spectrum obtained from TlBr detector (0.43mm thickness).

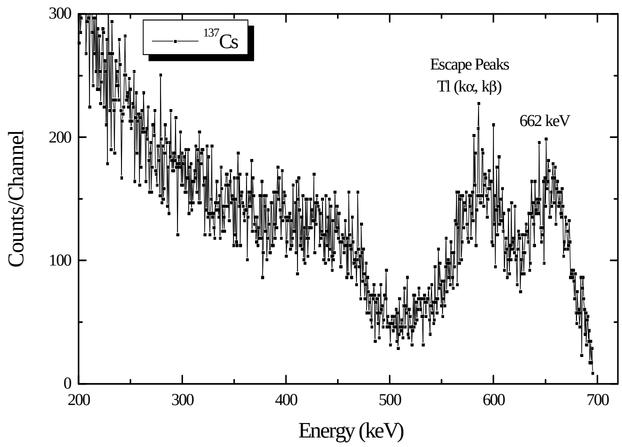

Figure 2. ^{137}Cs spectrum obtained from TlBr detector (0.43mm thickness).

The full-energy peak at 511 and 662 keV and the X-ray escape peaks are discernible in the spectra. Energy resolutions of 31 keV (6%) and 36.5 keV (5.5%) to 511 and 662 keV were obtained, respectively.

The peaks at around 450 keV (Fig.1) and 600 keV (Fig. 2) are X-ray escape peaks due to escapes of Kβ and Kα X-rays of Tl atoms from the active volume of the detector. Escape peaks due to Br atoms are unobserved because of low energy of the X-rays and the high photon stopping power of the crystals [2]. In addition, the height of the X-ray escape peaks originated from K X-ray of Tl is comparable to the main photopeaks corresponding to the 511 and 662 keV gamma-rays because the volume of the detector was not large enough. However, thicker detectors presented presented worse results due to low charge carrier mobility in TlBr detectors.

The TlBr detector can operate no only as gamma spectrometer but also as neutron detector. In order to demonstrate the availability of the TlBr neutron detector, some measurements were carried out.

In Fig. 3, two spectra obtained at 100V bias voltage using the same gamma detector, i.e., 0.4mm thick, are shown. The white circle symbol is related to the electronic noise (background). The black square symbol represents the neutron response without any converter. The general sensitivity of detector to neutron radiation was observed.

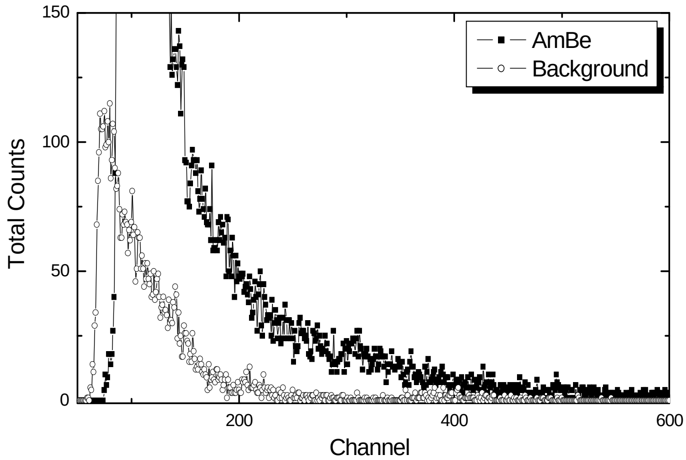

Figure 3. Resulting pulse height spectra measured with TlBr detector irradiated with AmBe neutron source.

A comparison of the gamma (^{133}Ba: 355keV and ^{137}Cs: 662keV) and neutron detection (AmBe) is shown in Fig. 4. A large difference in the event spectra for neutrons is observed as compared to gamma. The counts acquired extend to much higher than in case of gamma. The TlBr semiconductor detector is capable of both absorbing gamma and neutrons. These results have been demonstrated that the TlBr detector is also clearly sensing the neutrons.

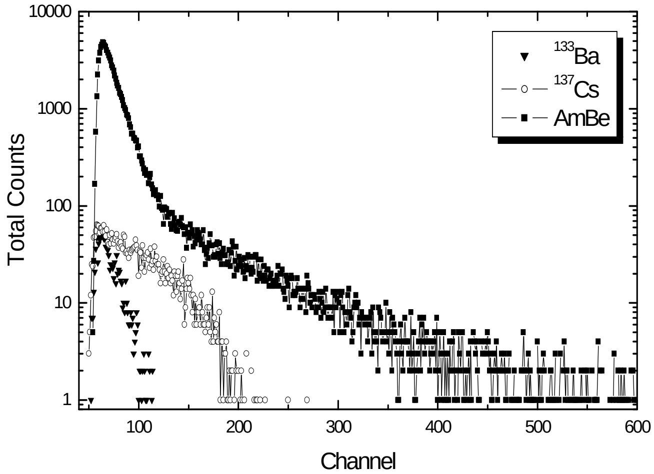

Figure 4. ^{133}Ba, ^{137}Cs (gamma radiation) and AmBe (neutron radiation) spectra obtained from TlBr detector (0.43mm thick).

4. CONCLUSIONS

Investigations for the development of neutron radiation detector based on TlBr crystals are now being performed at the Institute. These investigations are continuing.

Nonetheless, interest in developing detectors base on semiconductors compounds not only remains but it is moving in new directions. This work reports preliminary studies on the application of TlBr-based neutron detectors.

Concluding, planar TlBr detectors have been fabricated and tested as gamma-ray and neutron detectors at room temperature in this study. The detectors successfully detected the full-energy peaks of 511 and 662 keV gamma-rays.

At the present time, results have been demonstrated that neutrons can be detected by TlBr detector.

The TlBr detector characterization has shown good response to gamma and neutron radiation.

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