CdZnTe x-ray detector for 30 ~ 100 keV energy

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ABSTRACT

High-pressure-Bridgman (HPB) grown CdZnTe x-ray detectors 1.25~1.7 mm thick were tested using monochromatic x-rays of 30 to 100 keV generated by a high energy x-ray generator. The results were compared with a commercially available 5 cm thick NaI detector. A linear dependence of the counting rate versus the x-ray generator tube current was observed at 58.9 keV. The measured pulse height of the photopeaks shows a linear dependence on energy. Electron and hole mobility-liftetime products ($\mu\tau$) were deduced by fitting bias dependent photopeak channel numbers at 30 keV x-ray energy. Values of $2x10^{-3}$ cm^2/V and $2x10^{-4}$ cm^2/V were obtained for $\mu\tau_e$ and $\mu\tau_p$, respectively. The detector efficiency of CdZnTe at a 100 V bias was as high as, or higher than 90 % compared to a NaI detector. At x-ray energies higher than 70 keV, the detection efficiency becomes a dominant factor and decreases to 75 % at 100 keV.

Keywords: CdZnTe, CdTe, x-ray, x-ray detector, radiation detector,

1. INTRODUCTION

X-ray detectors for the 30~150 keV energy range are extremely useful for Compton inelastic scattering measurement and diffraction scattering at high energies. In order to achieve a momentum resolution of sub atomic units, a one dimensional array, which are made on high stopping power materials, such as CdTe or CdZnTe, should be one of the most suitable approaches[1].

HPB grown CdZnTe has been of great interest due to the ability of producing a large volume radiation detection quality materials[2,3]. Recently extensive research works were carried out to achieve high efficiency detectors using this material[4,5]. CdTe diluted with 10~20 % Zn was reported to have an intrinsic resistivity nearly two orders of magnitude higher than that of CdTe alloy[6]. Polarization effect, which causes a progressive decrease in the counting rate with time, is often seen in Cl doped CdTe detectors. This seems to be a limitation of using the CdTe material for advanced radiation detector applications. It was reported this adverse effect does not appear for HPB grown CdZnTe detectors at least for a week and the variation of the counting rates observed during the period was within the noise level of their electronic system[7].

2. EXPERIMENTS

CdZnTe detectors with 10 % Zn were purchased from eV Products. The thickness varies from 1.25 to 1.7 mm with 1x1 cm^2 area. For a few of the purchased detectors, the samples were mechanically thinned to the desired thickness and chemically polished, followed by electroless gold deposition on both sides of 1x1 cm^2 area. Current-voltage measurements were carried out under dark conditions. A good ohmic behavior was reproducibly observed. The resistivity obtained from current-voltage measurement was consistent before and after fabrication, in the range of 10^{10}~10^{11} Ωcm at room temperature.

A high energy x-ray generator (Phillips MG-225) with a tungsten target was used to test the detectors. Continuous x-ray energy was obtained by changing the diffraction angle of a (311) orientation single crystal Si monochromator. The measured x-ray photon energy varied between 30 to 100 keV. The x-ray beam size was small (2x2 mm^2) enough to avoid the radiation onto the edge of the detectors. A 5 cm thick NaI detector of 100 % efficiency at these energies was used as a reference[8].

For the x-ray energy scan measurements, the x-ray generator tube power was set to 120 KV and 1 mA and pulses were counted by a CAMAC based counter. However, with the high tube voltage, the third harmonic x-ray energy photons appeared at the monochromatic x-ray energies less than 40 keV. Therefore for energy spectrum measurements, the set tube voltage never exceeded three times of the monochromatic x-ray energy. The tube current was adjusted so that the deadtime of the multichannel analyzer (MCA) lies below 1 %. For the CdZnTe detectors, the best spectrum was obtained with 0.5 μsec shaping time. Bias from 10 to 220 V was applied to the electrode opposite of the radiation side.

3. RESULTS AND DISCUSSION

The number of x-ray photons is linearly proportional to the x-ray tube current. The CdZnTe detector pulse counts were measured with the tube current using both a high frequency CAMAC counter and a MCA. The window of the single channel analyzer (SCA) was set above the noise level so that all the pulses generated from the CdZnTe detector were counted. Fig. 1 illustrates the linear dependence of CdZnTe detector counting rate to the x-ray generator tube current measured at 58.9 keV monochromatic x-ray energy.

Energy spectra were obtained from three different quality CdZnTe detectors and the results are compared in Fig. 2. The quality of the detectors was graded using the FWHM of photopeaks measured with ^{241}Am by the vendor. At the measurement energy, theoretically calculated absorption rate is over 98 % for a 1.25 mm thick CdZnTe. However we observed that the total count rate of the poorest quality detector is 7 % less compared with that of the best quality as illustrated in Table 1. At the photopeak, a notably poor counting rate was obtained for the poor quality detector and the photopeak count was 36% less than that of the best. In spite of relatively higher electric field of the 1.25 mm thick CdZnTe detector, the low photopeak count of the poor quality CdZnTe is blamed for the trapping and recombination of the generated carriers before they are collected by electrodes. This becomes more serious for the collection of low mobility holes.

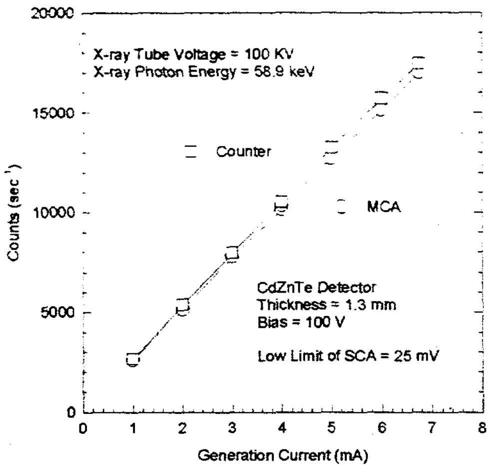

Fig. 1. Linear dependence of pulse counts of CdZnTe detector. Because of deadtime of MCA, the counts obtained by MCA are slightly lower.

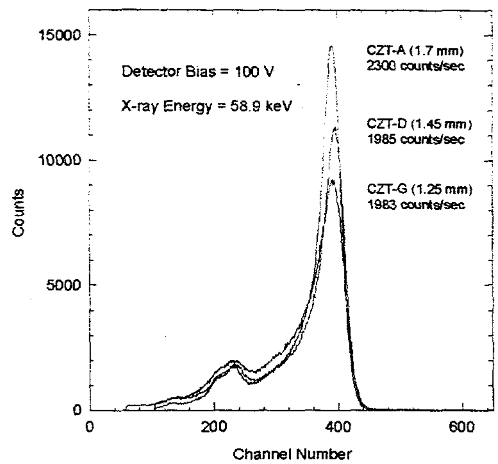

Fig. 2. Energy spectra measured with CdZnTe detectors of various qualities. The photopeak counts vary significantly with the detector qualities.

Detector	t(mm)	E(V/cm)	C_{Total}	$Ratio_{total}$	C_{Peak}	$Ratio_{peak}$
CZT-A	1.7	588	930370	1	14576	1
CZT-D	1.4	714	873400	0.94	11349	0.78
CZT-G	1.25	800	858112	0.92	9303	0.64

Table 1. Comparison of pulse counting efficiency of different grade CdZnTe detectors. The pulse counts were measured for 3 minutes and the monochromatic x-ray photon energy is 58.9 keV.

We performed similar measurements at low x-ray energies. At 30 keV energy, most of the x-ray photon absorption occur within the first 300 μm thickness near the radiation entrance electrode. The generated holes within the reach of their transit time are easily collected by the electrode, whereas the generated electrons travel relatively equal distance of the detector thickness. The total count rate for all the CdZnTe detectors was within 2 % variation for all the CdZnTe detectors. However at the photopeak, the count rate was dependent on the quality and a 22 % decrease was observed for the poorest detector. In this case, the poor electron $\mu\tau$ is responsible for the decrease in the photopeak count. Energy spectra were measured using both a 5 cm thick NaI and 1.7 mm CdZnTe detectors. The channel numbers of photopeaks were obtained from each spectra, and the observed linear dependence to the x-ray energy is illustrated in Fig. 3. For the 1.7 mm thickness CdZnTe, the calculated detection efficiency decreases down to 80 % at 100 keV. In spite of partial transmission of the x-ray photons, the pulse heights of the photopeaks exhibit a linear dependence to the x-ray photon energy.

Full-width-half-maximum (FWHM) of the photopeaks obtained by both CdZnTe and NaI detectors is compared in Fig. 4. Because of its thickness, the CdZnTe detector resolved narrower FWHM of the energy spectra than the 5 cm thick NaI detector, especially in the low energy range where the low energy tail is absent. However in the energy higher than 70 keV, the presence of the low energy tail results in the increase of FWHM of the CdZnTe detector spectra.

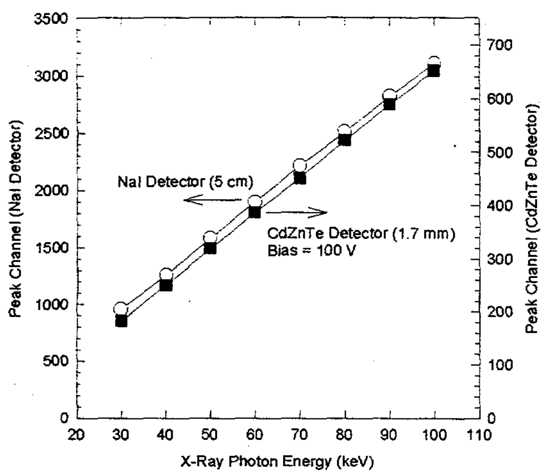

Fig. 3. Linear dependence of peak channel number to monochromatic x-ray photon energy.

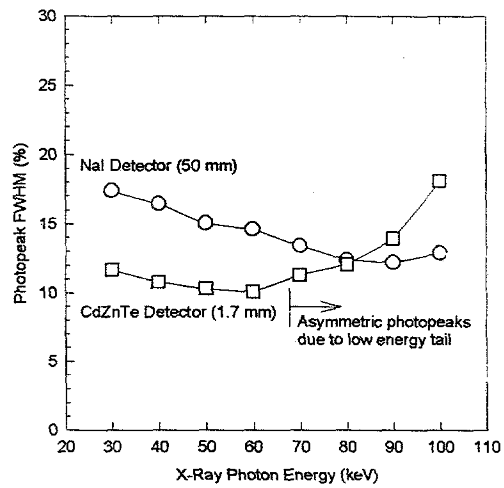

Fig. 4. Comparison of FWHM's obtained from energy spectra at various energies. Note that the 1.7 mm thick CdZnTe detector shows better FWHM in low energies.

X-ray energy scan measurements were made by using both detectors as shown in Fig. 5. Two peaks observed at 58.9 keV and 67.2 keV are k_α and k_β x rays of the tungsten target. The saturation of the counts in the low energy below 40 keV is due to the presence of the third harmonic x-ray photons as mentioned earlier. For the NaI detector, a slight increase of the count rate in the low energy is observed. This is due to the increased number of the third harmonic energy photons by diffraction from the Si crystal. Because of the partial transmission at high energy, CdZnTe detectors does not show the slight increase in counts. It is also noted that, for the CdZnTe detector, relatively low count rate is observed in the low energy range. This is due to significant attenuation of the low energy x-ray photons caused by the conductive rubber contact placed in the radiation side of the CdZnTe detector, which contains a significant amount of silver.

The attenuation rate due to the conductive rubber contact is not exactly known at this moment and more work will be done for the effort of eliminating the rubber contact. However the attenuation is believed to have a negligible transmission of high energy x-ray photons. By ignoring the effect of the attenuation at high energy, the overall CdZnTe detector counting efficiency was determined with respect to the NaI detector. We obtained a counting ratio of 90 % between the CdZnTe and the NaI detector near 60 keV from the energy scan measurements. The ratio decreases with the x-ray photon energy, and reaches 75 % at 100 keV. The calculated detection efficiency for the 1.7 mm thick CdZnTe detector is 100 % at 60 keV and decreases to 80 % at 100 keV. This fact illustrates that the pulse counting efficiency of the CdZnTe detector reaches over 90 % with the applied bias.

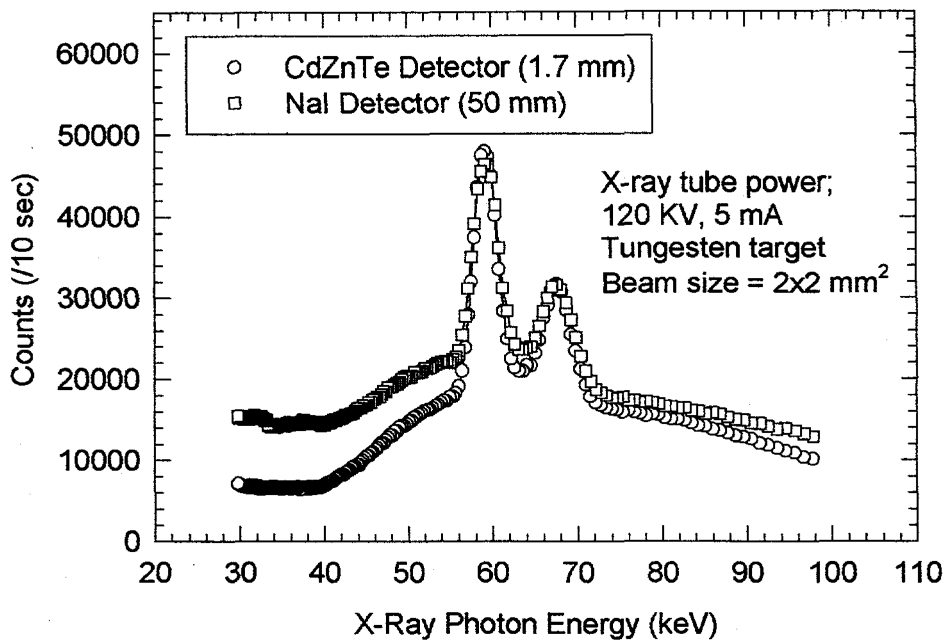

Fig. 5. Comparison of x-ray energy scan measured by CdZnTe and NaI detectors.

Similar results were noticed during the attempt to deduce the $\mu\tau$ of electrons and holes. The charge collection increases with the applied electric field and the measured pulse height increases with the bias. As a result, the photopeak channel is shifted with applied bias. A series of energy spectrum were measured at 30 keV using CdZnTe detectors with bias of 10 to 220 V. No attempts were made for the calibration of the reference charge injection into the preamplifer in order to determine the maximum channel number which represents complete charge collection. The maximum channel number was calculated using a 4.43 eV ionization energy and amplifier gain[9]. By simply assuming that no charge trapping and detrapping occur in the CdZnTe detector, Hecht equation was fitted to the bias dependent photopeak channel numbers[10] and the carrier $\mu\tau$'s were extracted from the fitting.

Fig. 6 represents one of the successful fitting results. It is observed that the collection efficiency is higher than 90 % at 100 V bias for this CdZnTe detector. The deduced $\mu\tau$'s of the measured CdZnTe detectors are illustrated in Table 2. As expected, electron $\mu\tau$ is roughly one orders of magnitude higher than hole $\mu\tau$ for all the detectors. Because of the low mobility of holes, the influence of hole collection seems negligible. However hole $\mu\tau$ term was needed in order to obtain the meaningful electron $\mu\tau$. It is also noticed that the obtained electron $\mu\tau$ of the CdZnTe detectors correlates with FWHM of the photopeaks, supporting the charge collection is mainly due to electrons. Slight decrease of the electron $\mu\tau$ results in broadening of the photopeak by incomplete electron collection.

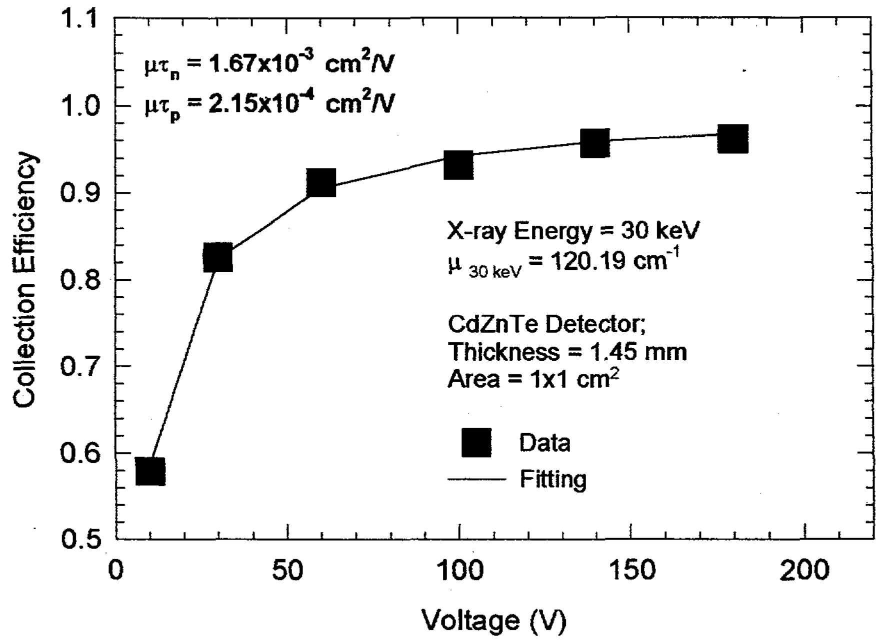

Fig. 6. Electron and hole $\mu\tau$'s obtained by fitting the bias dependent photopeak channel numbers at 30 keV.

Detector	$\mu\tau_n$(cm^2/V)	$\mu\tau_p$(cm^2/V)	FWHM(%)
CZT-A	2.1×10^{-3}	2.1×10^{-4}	11.9
CZT-D	1.7×10^{-3}	2.5×10^{-4}	13.3
CZT-G	1.2×10^{-3}	2.1×10^{-4}	17.1

Table 2. Mobility-liftetime products obtained from different grade CdZnTe detectors. The thickness of the CdZnTe detectors is listed in Table 1.

4. CONCLUSION

The efficiency of CdZnTe detectors was compared with a NaI detector. Because of the attenuation of the conducting rubber contact, the efficiency in the low x-ray energy was not measured. However at high energy, we obtained the CdZnTe detector counting efficiency as high as 90 % compared with the NaI detector. Linear response with x-ray photon energy and intensity was observed. In the low energy region (below 60 keV), the 1.7 mm thick CdZnTe detector exhibited superior energy resolution to the NaI detector. Assuming no trapping and detrapping, electron and hole $\mu\tau$'s were obtained for different grade CdZnTe detectors and the results were consistent with the measured FWHM of the photopeaks.

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