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■ 논 문 ■

Development and Testing of CdZnTe Detector for Pocket Surveymeter

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CdZnTe 검출기를 이용한 개인용 Pocket Surveymeter의 제작및 특성

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Abstract－In this paper, we discussed the fabrication and characterization of bulk type CdZnTe detector for pocket surveymeter. The resistivity of CdZnTe single crystal grown by the High Pressure Bridgman method is in the mid of 10^9 ohm-cm. The detector structure is Au/CdZnTe/Au and gold electrode is formed by electroless deposition method. Resolutions of 4.8keV and 2.2 keV were observed at 22.2 keV line of ^{109}Cd and 59.6 keV line of ^{241}Am at room temperature, respectively. We also constructed the small size pocket surveymeter using home made CdZnTe detector. It shows the good linearity over a range from 1mR/hr to 10R/hr with deviation less than 5%. The sensitivity of the surveymeter developed is 2.2×10^3 cps/Rad hr^{-1} for the 662 keV of ^{137}Cs γ-ray.

Key words : Radiation detector, CdZnTe, Surveymeter, Imaging sensor

요약－본 논문에서는 bulk형 CdZnTe 감마선 검출기의 제작과 이를 이용한 개인용 선량율계의 제작 및 그 특성에 관하여 기술하였다. 감마선 검출기는 고압 Bridgman법으로 성장된 비저항이 10^9ohm-cm 이상인 단결정을 사용하였으며 electroless deposition법으로 금전극을 형성시켜 사용하였다. 제작된 CdZnTe 검출기는 ^{109}Cd의 22.2 keV 감마선과 ^{241}Am의 59.6 keV 감마선에 대하여 상온에서 각각 4.8 keV와 2.2 keV의 분해능을 보였다. 또한 이 검출기를 이용하여 개인용 선량율계를 제작하였는데 662 keV의 ^{137}Cs의 감마선에 대하여 1mR/hr에서 10R/hr의 선율에서 변동율 5%이하의 좋은 직진성을 보였고 온도변화 및 조사선율의 각도분포에 대하여도 좋은 응답 특성을 보였다.

중심단어 : 감마선 검출기, CdZnTe, 개인용 선량율계, Imaging sensor

INTRODUCTION

CdTe and CdZnTe were attractive and unique candidate materials for X-ray and low energy gamma ray detector, especially where compact size and room temperature operation are important [1~3]. Because of the high atomic number of CdTe and CdZnTe compared to the other two most common semiconductor detector materials, Si and Ge, the absorption coefficient of CdTe and CdZnTe shown to be roughly 20 times that of Si and Ge at below 100keV. The detector size is, however, limited by mobility-life time product (ν, τ), i.e. electron and hole mobility-life time products are very small compared with Si and Ge. As a result of it, the high energy gamma ray detection response of CdTe and CdZnTe detector is poor. Nevertheless the detection efficiency of CdTe and CdZnTe detector is superior to that of Si and Ge in the X-ray and low energy gamma ray. A way to overcome the need for large volume detectors is to replace air filled ionization chambers, GM tube, by solid state detector, such as CdZnTe detector[4]. As so, there are so many application fields of CdTe and CdZnTe detector, such as personal dosimetry, nondestructive testing, transmission computed tomography and medical purpose[5, 6]. Specially, CdZnTe and CdTe gamma ray detector seem attractive for use in portable personnel dosimeter.

In this paper, we discuss the fabrication and characterization of the CdZnTe X-ray and low energy gamma ray detector with planar structure. We also report the properties of the personal pocket surveymeter using a home-made CdZnTe detector.

EXPERIMENTS

Detector fabrication

We used the CdZnTe(Zn=20%) single crystal (Aurora Co.) which was grown by HPB(High Pressure Bridgman method) for the detector material [7]. The wafer orientation is (111) and it's size is $10x10x2mm^3$. The resistivity of CdZnTe single crystal was up to 10^9 Ohm-cm and etch pit density was less than $10^4/cm^2$. Nuclear radiation detectors were prepared in the forms of plate about $2\times2\times2$ mm^3 whose faces were etched by Br-methanol solution. To fabricate a CdZnTe detector with metal-semiconductor-metal structure, we formed the Au electrode to use the $AuCl_3$ solution by the electroless deposition method. For the formation of Gold electrode, the CdZnTe wafer was dipped in the solution which was prepared by dissolving $AuCl_3 \cdot H_2O$ in deionized water for 30min. The concentration of gold chloride solution was $0.03g/cm^3$. From the RBS(Rutherford Backscattering Spectroscopy), the thickness of the gold film on CdZnTe detector chip was meassured to be 184nm. And we also observed the heavily Gold dopped layer.

Measurement

After formed the electrodes, the I/V and C/V properties of detector were tested to use the semiconductor parameter analyzer(HP 4145B) and 1MHz capacitance meter (HP 4280A). The CdZnTe detector chip encapsulated in Al shielding case with very thin Al foil window, it is connected to a charge sensitive preamplifier(Tennelec TC 170) with short BNC connector. The output signal of preamplifier is amplified(Tennelec, research amplifier) and shaped pulse output is sent to a PC-based multichannel analyzer(PCA, Tennelec).

Pocket surveymeter

We constructed the small size pocket surveymeter using a home-made CdZnTe detector. For this purpose, we constructed the CdZnTe detector using TO-5 transistor case and mounted it on the analog PCB board. The preamplifier was designed to match the characteristics of the CdZnTe detector.

To reduce the dead time from electronics and to obtain the higher count rate, we used the field effect transistor for the impedance matching between detector and preamplifier with a several hundred nsec shapping time. Semiconductor detector can be operated much lower bias voltage(9V, Alkaline) compared to GM tube base surveymeter. All circuit components mounted in a thick aluminum case.

RESULT AND DISCUSIONS

Gold contact

Forming the ohmic contact for nuclear radiation detector is necessary, in order to avoid the distortion of the detection signal and to obtain the more large size of detection volume than the pn junction or Schottky type detector. But it is very hard to get the ohmic contact using the vacuum evaporation and the sputtering metal deposition in p-type CdTe and CdZnTe, because there is none of the available metals which have a large enough work function compared to that of CdTe and CdZnTe[8, 9]. Electroless deposition of gold has been the most widely used method to produce ohmic contacts on p-CdTe and CdZnTe[10, 11]. In Fig. 1, the current dependence of the applied voltage for Au/CdZnTe/Au detector chip of thickness 2mm is shown. For an applied voltage in range of -5 to 5kV/cm, the I/V characteristic is linear and symmetric below -1 to 1KV/cm. This Ohmic behavior is attributed to an enhanced current flow by tunneling of carriers between the gold electrodes and the gold doped zones. The calculated resistivities are in the mid of 10^9 ohm-cm range which represents the bulk plus interface resistivity.

Radiation detector characteristics

CdTe and CdZnTe detector are useful as an X-ray and low energy gamma ray detector. The

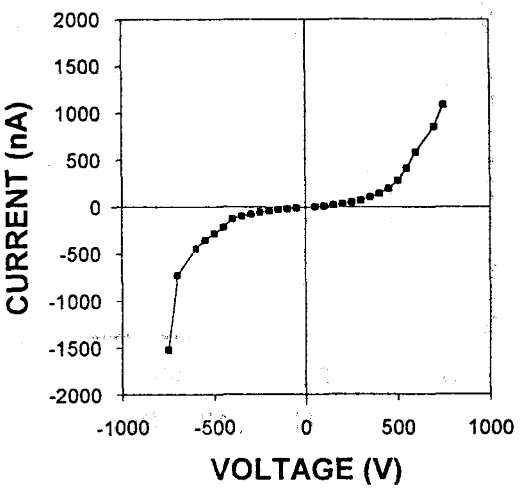

Fig. 1. Current-voltage characteristic at room temperature for electroless deposition technique (Detector area $4mm^2$, thickness 2mm).

absorption coefficency is quite large at small photon energies. Fig. 2 shows the X-ray spectrum of ^{109}Cd with CdZnTe detector at room temperature. The resolution of 22.2 keV K peak is 4.8keV. The X-ray and gamma ray spectra of ^{241}Am are displayed Fig. 3. The 59.5 keV photo peak is well resolved with a FWHM of 2.2keV. The 59.5keV peak shows tailing because charge collection of holes was incomplete[12]. We observed that Np Lx(13.9 keV), Np L (17.8 keV) and 26.4 keV gamma ray peaks were well resolved. We also obtained the spectrum of ^{137}Cs with the CdZnTe detector. While the spectrum was significantly more degraded by incomplete charge collection than X-ray and low energy gamma ray spectrum. The 662 keV line of photo peak was not clearly resolved. Fig. 4 shows the gamma ray spectrum of low energy part of mixed source(^{125}Sb, ^{155}Eu). The 27.4 keV peak is from ^{125}Sb and 42.8 keV, 86.5 keV, 105.3 keV peaks are from ^{155}Eu. The all photo peaks well resolved.

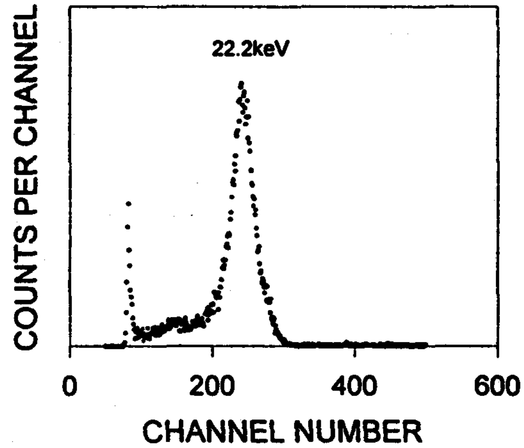

Fig. 2. ^{109}Cd spectrum detected with CdZnTe detector with Au/CdZnTe/Au structure at room temperature. Detector bias is 200V and 1μsec shapping time.

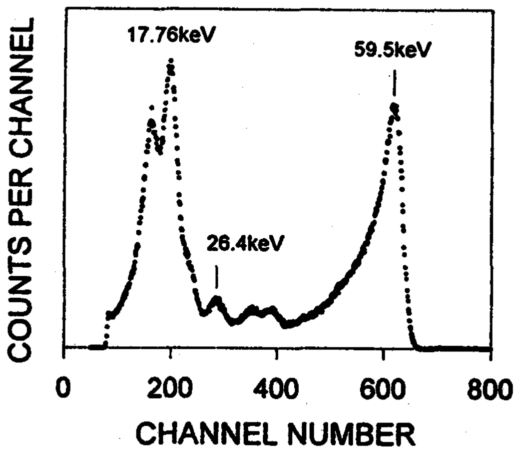

Fig. 3. Spectra of X-ray and gamma ray due to ^{241}Am obtained by Au/CdZnTe/Au detector. Detector bias is 200V and 1 μsec shapping time.

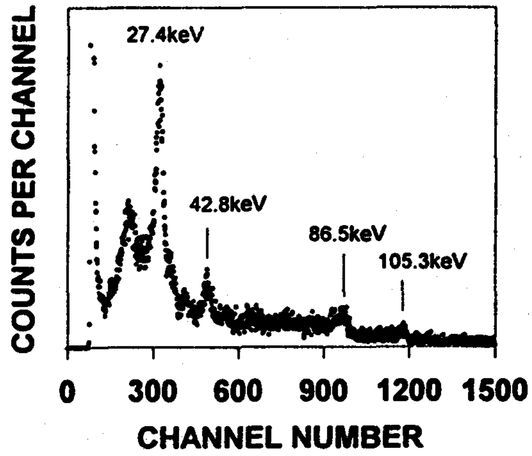

Fig. 4. Spectra of the mixed gamma ray source (^{155}Eu and ^{125}Sb) obtained by Au/CdZnTe/Au detector. Detector bias is 200V and 1μsec shapping time.

Mobility-Life time product

The result of good detector operation is from the quick and complete transport of charge carriers toward the electrical contacts. Therefore, the semiconductor detector material should have a higher value of electron and hole's mobility-life time products[13, 14]. The mean free path of charge carriers should be long compared to the detector thickness to achieve good charge carrier collection efficiency. The mean free path of charge carrier of semiconductor detectors is expressed by :

$$\lambda = \mu\tau\ V \qquad (1)$$

The μ denotes the mobility of charge carrier, τ is life time of charge carrier and V is applied bias voltage. In laboratory, the applied bias voltage is a few KV/cm and the detector thickness is a few mm in CdTe and CdZnTe detector. At this case, in order to obtain the good charge carrier collection efficiency, the value should be more than 10^{-4}cm/Vsec. From the charge collection efficiency curve, the mobility-life time product of majority charge carrier of CdZnTe detector is $0.8\times 10^{-3}cm^2/V$. This value means that the CdZnTe crystal which is grown by HPB is superior to the other crystals which is grown by Bridgman method or THM[15]. Fig. 5. shows the temperature dependence of CdZnTe gamma ray detector.

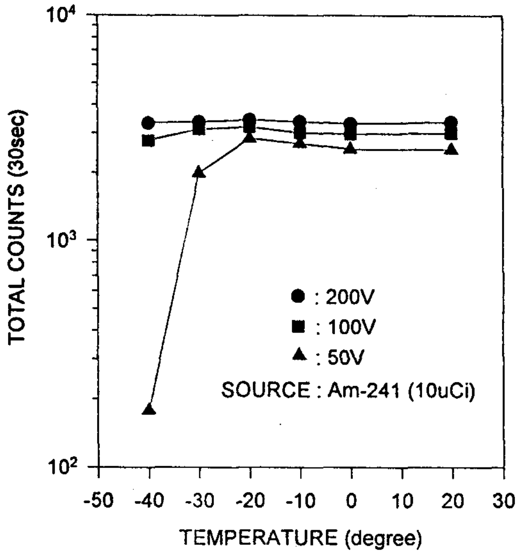

Fig. 5. The temperature dependence of Au/CdZnTe/Au gamma ray detector.
The gamma ray energy is 59.5keV from ^{241}Am.

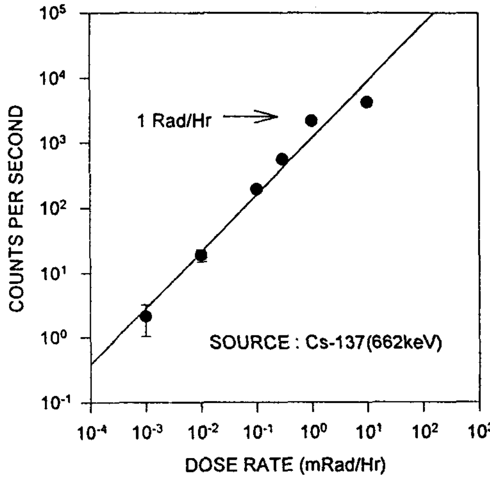

Fig. 6. The dose rate response of pocket surveymeter using a home-made CdZnTe gamma ray detector. The response deviation is less than 5%. The gamma ray energy is 59.5keV from ^{137}Cs.

When we applied the low bias voltage, the count rate rapidly decreased rather than the others. It implies that the mean free path of charge carrier is very sensitive about the variation of bias voltage. When the low bias voltage was applied to the detector, the charge carrier did not collect fully by the electrode. Also we checked the effect of very high gamma dose with ^{60}Co radiation source and there was no significent variation of detection response until 10^6 Rad.

System performance

The counting rate vs. dose rate relation of pocket surveymeter using a home-made CdZnTe detector for ^{137}Cs source is shown in Fig. 6. It shows the good linearity over a range from 1mR/hr to 10R/hr with deviation less than 5%. When we changed the gamma ray source(^{137}Cs→^{60}Co, it means to change the gamma ray energy.) We still observed only 4% deviation of the counting response. The sensitivity of it is 2.2×10^3 cps/R hr^{-1}.

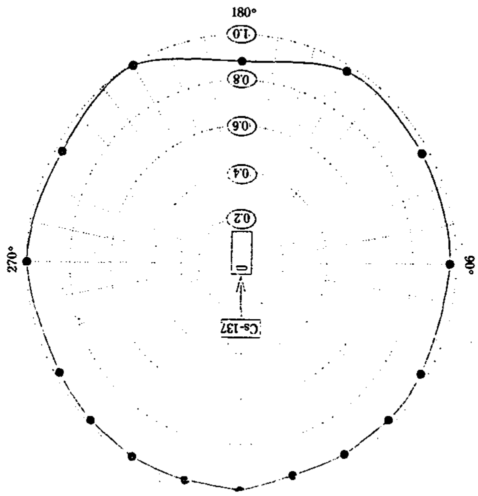

Fig. 7. The counting response of angle variance of pocket surveymeter. The response deviation is less than 20%.

Fig. 7 shows the counting rate vs. angle variation. Because of it's planar structure, the counting response deviation is less than 10%.

CONCLUSION

In this paper, we report the fabrication and characteristics of low energy CdZnTe gamma ray detector and pocket surveymeter. We used the eletroless deposition method using $AuCl_3$ solution for ohmic contacts for the both sides of CdZnTe detector. The thickness of gold film which was measured by RBS is 184nm. The current-voltage dependence of detector is ohmic in the range of -1 to 1 KV/cm. Resolutions of 4.8 keV and 2.6 keV were observed at 22.2 keV line of ^{109}Cd and 59.6 keV line of ^{241}Am at room temperature. From the charge collection efficiency curve, the mobility-life time product is $0.8\times10^{-3}cm^2/V$. It implies that the crystal which grown by HPB is superior to the other crystals. We also construct and test the pocket surveymeter using a home-made CdZnTe detector. It shows the good linearity over a range from 1mR/hr to 10R/hr with deviation less than 5%. The sensitivity of it is 2.2×10^3cps/mRad hr^{-1} for the 662 keV ^{137}Cs γ-ray. In summary, the CdZnTe detector can be applied to the various field, such as personal dosimetry, computed tomograph, low energy gamma ray spectroscopy and space science, etc.

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