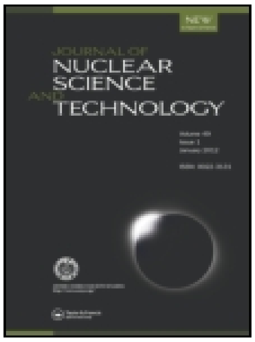

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Fabrication of CZT Planar-Type Detectors and Comparison of their Performance

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CZT is one of the most promising materials for X-ray and γ-ray radiation detectors operated at room temperature. We have studied the fabrication process of the CZT planar-type detector, which includes the physical and chemical surface treatment, the fabrication of metal contact, and the surface passivation. CZT planar-type detectors with various metal-semiconductor contacts were made. The dark current and the γ-rays from ^{241}Am were measured with each detector, and they were compared. From the above studies, the effective fabrication method of CZT detector could be deduced. Our work could be helpful to fabricate the high resolution CZT detector, which could be used in various application areas such as nuclear medicine, radiation safety, X-ray and γ-ray astronomy and homeland security

KEYWORDS: CZT detector, Planar-type detector, Indium, Gold, Metal-semiconductor contact

I. Introduction

Cadmium Zinc Telluride (CZT) is one of the most promising materials for high resolution X-ray and γ-ray energy spectroscopy at room temperature[1)]. Since the energy bandgap of the CZT crystal is large enough that the CZT detector can be used for X-ray and γ-ray measurement without cooling system. Because of the high atomic numbers of composite materials of CZT (Cd, Zn, Te), the efficiency of CZT detector is higher than that of Si or Ge detector. Although the CZT detector has been plagued by material problems for a long time, the recent rapid progress in the crystal growing technique makes the application of CZT detector wider.

CZT planar-type detector has metal/CZT/metal structure. The general procedure to make the CZT planar-type detector is as follows; A CZT crystal is cut, the crystal surface is polished with mechanical and chemical method, and metal contacts are made on CZT surface. After that, the CZT crystal surface is passivated to make the detector performance stable.

Previously many researchers studied the fabrication process of CZT detector. The relation between the surface roughness and the detector performance was studied with various chemical etching methods[2)]. The dependency of the detector's performance on the chemical composition of the metal-semiconductor contact was studied [3)].

In most of the previous works, the data about the fabrication process of CZT detector were obtained with the high quality crystals. However, the CZT crystals with lower grade, which means the crystal has a large number of defects, were used in our work. The CZT is known to have many advantages as radiation detector. However, the CZT detector could not be used widely at present because of its high price. Since the CZT crystal with lower grade could be obtained more easily, the study on the fabrication process of CZT detector with lower grade crystal is also very important.

We made various CZT planar-type detectors. CZT detectors with Indium(In)/CZT/In and Gold(Au)/CZT/Au structure were fabricated, and the dependency of the detector performance on the crystal surface and the crystal quality was studied. Au contact on the CZT crystal was made with two different methods, which include high-vacuum evaporation method and electroless deposition method[4)]. CZT detector with Au/CZT/In structure was made to see the Schottky contact effect on the detector's performance. The CZT detector with capacitive Frisch grid was made to reduce the tail of the peak in the energy spectrum.

II. Experiment and Analysis

1. Detectors with In/CZT/In and Au/CZT/Au Structure

CZT detectors with In/CZT/In and Au/CZT/Au structure were made. Two CZT crystals were used in the experiment; one crystal was slight n-type material with low grade (Saint-Gorbain Inc.) and the other crystal was p-type material with discriminator grade (eV Products Inc.). The geometrical dimension of n-type CZT crystal was 9×9×8 mm^3, and that of the p-type crystal was 10×10×5 mm^3. A number of defects such as Te-inclusion could be found easily on surface of n-type crystal. **Fig. 1** shows the detectors made in our work.

When metal with high work function such as gold is in contact with n-type semiconductor, the contact can be Schottky contact. When metal with low work function such as indium is in contact with n-type semiconductor, it can be Ohmic contact.

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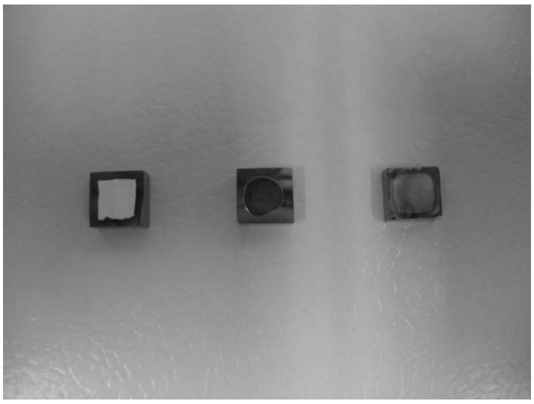

Fig. 1 CZT planar-type detectors made with discriminator grade crystals.

The CZT crystal was grinded with SiC paper and polished finally with 0.05-μm alumina powder. The crystal was chemically etched with 1 % bromine/methanol solution for 1 min. It is known that the bromine/methanol etchant could remove the scratches due to the mechanical polishing. Also, when the CZT crystal is etched with bromine/methanol solution, the CZT surface remains Te-rich[5)]. With the inspection of the low grade CZT crystal with microscope, one could find the increase of the Te-rich defects after the chemical etching with bromine/methanol solution.

Four different planar-type detectors were made with low grade CZT crystal. One was In/CZT/In-structured detector with un-etched crystal surface, the second was In/CZT/In structured detector with etched crystal surface, the third was Au/CZT/Au structured detector with un-etched crystal surface, and the last was Au/CZT/Au structured detector with etched crystal surface. Here, the gold contact was made with the electroless deposition method.

The I-V curve and the energy spectrum of 60-keV γ-ray was obtained with each CZT detector. High voltage of 100 V was biased between the electrodes to measure the energy spectrum. The signals from the detector were passed through a pre-amplifier and an amplifier. Finally, the energy spectrum was stored with Multi Channel Analyzer (MCA).

From **Fig. 2**, one could see that the energy resolution of the detector with In contact became worse when the crystal was etched, and the energy resolution of the detector with gold contact became better when the crystal was etched. Here, the energy resolution of the detector was the Full-Width-Half-Maximum (FWHM) of the peak. Indium could make Ohmic contact with n-type semiconductor. When the low grade CZT was etched with the bromine/methanol solution, the Te-rich defects got bigger. And it deteriorated the In/CZT contact, and make the energy resolution worse.

Gold chloride solution was used to make the gold contact on the CZT surface. It was known that the reaction of gold chloride on CZT was supposed to be a transfer of Cd ions toward the $AuCl_3$ solution, leaving a tellurium layer on CZT and gold ions precipitating on this layer[6)]. The gold could be placed to make chemical equilibrium in the Te-rich defects, which became larger due to the chemical etching. It could explain why the energy resolution of the detector with gold contact was getting better when the crystal was etched.

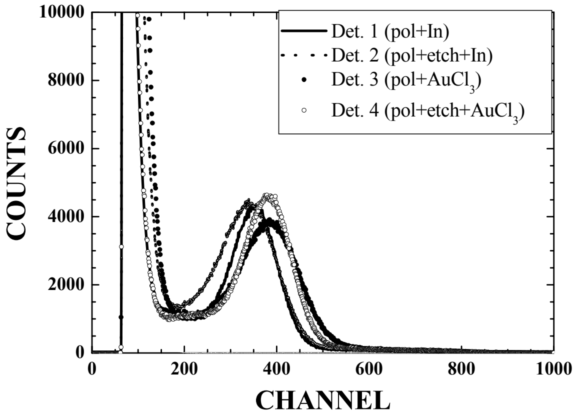

Fig. 2 Energy spectra measured with CZT Planar-type detectors with four different fabrication processes. The detectors were made with a low grade CZT crystal. FWHM of each spectrum was as follows; 34. 5 % (Det. 1), 44.6 % (Det. 2), 40.2 % (Det. 3), and 33.5 % (Det. 4).

CZT detectors with In/CZT/In and Au/CZT/Au structure were also made with discriminator-grade p-type CZT crystals. The number of Te-rich defects on the p-type crystal was smaller than that of the low grade n-type crystal.

In/p-type CZT crystal can be Schottky contact, and Au/p-type CZT crystal can be Ohmic contact. When In was evaporated on both sides of the CZT crystal, the dark current of the detector was too large to measure the energy spectrum. When Au contact was made on the crystal with the electroless deposition method, the energy spectrum could be measured successfully. One could assume that the property of In contact on p-type CZT crystal is similar to that of Au contact on n-type CZT crystal. However, while one could measure the energy spectrum with the detector with Au/CZT(n-type)/Au structure, one could not measure the energy spectrum with the detector with In/CZT(p-type)/In structure. It could be from the deposition method of the metal contact. The indium was deposited with the evaporation method (physical) and the gold was deposited with the electroless deposition method (chemical).

2. Detectors with Au/CZT/Au Structure

Au contact was made on p-type low grade CZT crystal. It is very important to make Ohmic contact on p-type CZT crystal. Two different methods were used to make the gold contact. One was the evaporation method, and the other was the electroless deposition method. Although both methods could be used to make metal contact on CZT crystal, the contact property from both methods is different as explained in the previous discussion.

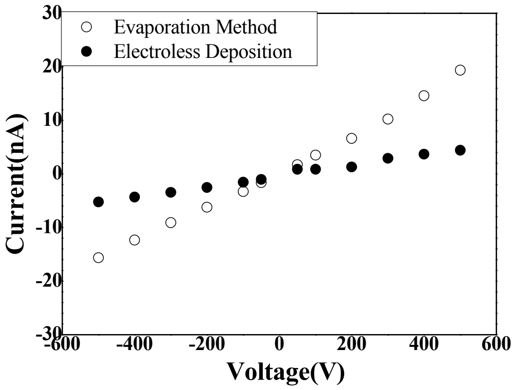

Fig. 3 Leakage currents of Au/CZT/Au detectors. One was made with the evaporation method, and the other was made with the electroless deposition method.

The CZT crystal surface was mechanically polished and chemically etched with 1 % bromine/methanol solution. In the first method, the gold contact was deposited with the evaporation method. Thermal evaporator was used to make gold contact on CZT crystal. The vaccum in the evaporation chamber was kept at around 10^{-5} Torr during the evaporation, and the deposition rate was kept at around 10 n/min. In the second method, the gold contact was made with the electroless deposition method.

Fig. 3 shows the leakage currents of the CZT detectors. As one could see, the leakage current became lower when the gold contact was made with the electroless deposition method. Measurement of 60 keV γ-ray were made with the CZT detectors. The characteristics of the energy spectra measured with the two detectors were similar. However, the energy spectrum of CZT detector made with the evaporation was deteriorated at polarization voltage higher than 200 V. It could be from the increase of the leakage current. **Fig. 4** shows the energy spectrum measured with the CZT detector with gold/CZT/gold structure, where the electrode was deposited with evaporation method.

When gold contact was made with the electroless deposition method, the cadmium layer could be found on the surface of the gold contact. It was found that the passivation with the NH_4/H_2O_2 solution could remove the cadmium layer on the gold contact. When the γ-ray was measured with the detector, which was passivated with the NH_4/H_2O_2 solution, the energy spectrum was enhanced comparing with the energy spectrum measured with the detector before the passivation. The energy resolution of the detector was similiar, however the full peak efficiency was increased after the passivation. The enhancement of the energy spectrum after the passivation was from the removal of the cadmium layer on the gold contact[7]. Fig. 5 shows the energy spectra before and after the surface passivation.

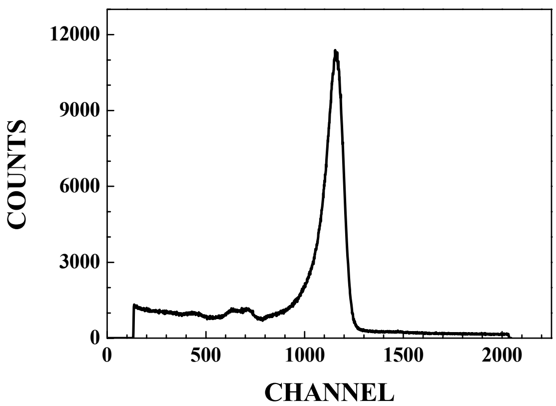

Fig. 4 Energy spectrum measured with CZT detector, where the gold contact was made with the evaporation method. The polarization voltage on the detector was 200 V and the shaping time was 3 μ sec. The FWHM of the peak was 9.4 %.

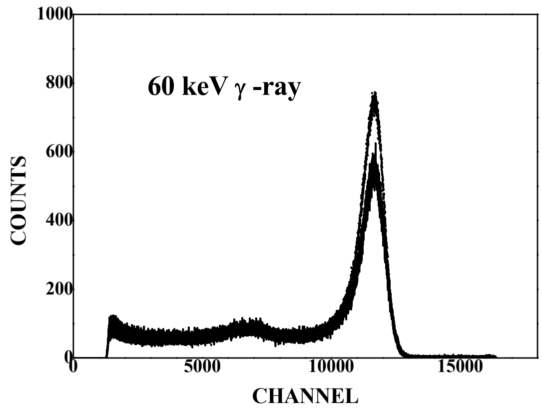

Fig. 5 Passivation effect on the energy spectrum measured with CZT detector. The solid line is from the detector before NH_4/H_2O_2 treatment and the dotted line is from the detector after NH_4/H_2O_2 treatment. The FWHM of the peak was 7.8 % before the surface passivation, and the FWHM of the peak was 7.4 % after the surface passivation.

3. Detectors with In/CZT/Au Structure

CZT Schottky detector was made with In/CZT/Au structure. A p-type CZT crystal was used to make the Schottky detector. Indium contact was deposited with the evaporation method, and gold contact was deposited on the opposite side of the detector with the electroless deposition method. I-V curve and the γ-ray energy spectrum were measured. **Fig. 6** shows the I-V curve of the Schottky detector.

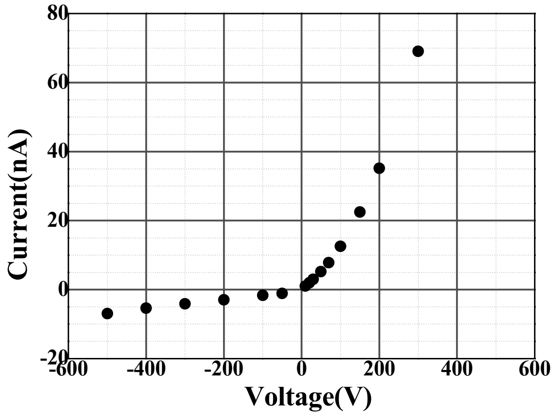

Fig. 6 I-V curve of the CZT Schottky detector.

The energy spectrum of 60 keV γ-ray was measured with the detector and it was compared with the energy spectrum measured with CZT detector with Ohmic contacts. **Fig. 7** shows the energy spectra measured with the CZT Schottky detector and the CZT detector with Ohmic contacts. One could see the slight enhancement of the energy resolution when γ-ray was measured with the CZT Schottky detector.

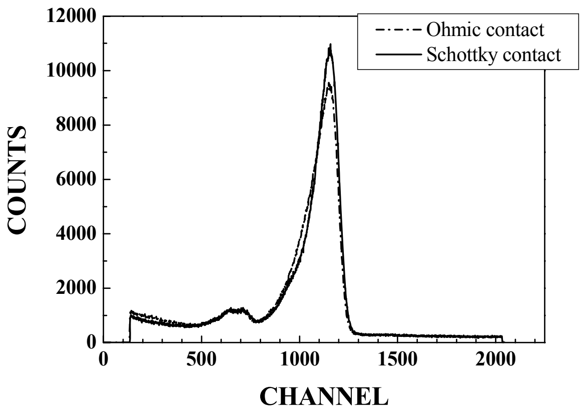

Fig. 7 Energy spectra measured with CZT detector with Ohmic contact, and CZT Schottky detector. The FWHM of peak from the detector with Ohmic contact was 14.6 %, and the FWHM of peak from CZT Schottky was 12.2 %.

It is known that the energy spectrum could be enhanced when the CZT detector with capacitive Frisch grid structure was used for the measurement [8]. The study about the fabrication and measurement of the CZT capacitive grid detector is underway.

III. Conclusion

CZT is very promising material for room temperature γ-ray spectroscopy and radiation imaging. The detector performance depends on the crystal quality, the surface condition, the type of the metal-semiconductor contact, and the electrode design. We studied the dependency of the CZT detector characteristics on the type of metal-semiconductor contact. In most of our study, the CZT crystals with lower grade, which could be used more widely than the high grade crystal, were used. Au layer, made with the electroless deposition method, could be metal contact for CZT detector with p-type crystal. The gold contact on the CZT detectors were made with the evaporation method and the electroless deposition method, and the detector characteristics were compared. The CZT Schottky detector was made, and the γ-ray energy spectrum was successfully measured, and the detector characteristics were compared with the CZT detector with Ohmic contacts. Our work would be helpful to fabricate the CZT detector for high-resolution γ-ray spectroscopy.

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