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EFFECT OF METAL CONTACT ON THE CZT DETECTOR PERFORMANCE

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Received March 31, 2009 / 1st Revised June 2, 2009 / Accepted for Publication June 5, 2009

Metal-semiconductor contact is very important for the operating property of semiconductor detector. $Cd_{0.96}$ $Zn_{0.04}$ Te semiconductor crystal was grown with Bridgman method, and the crystal was cut and polished. EPMA (Electron Probe Micro Analyzer) and ICP-MS (Inductively Coupled Plasma Mass Spectrometry) analysis were done to obtain the chemical composition and impurity of the crystal. Metal contact was deposited with thermal evaporator on both sides of the crystal. Detectors with Au/CZT/Au and In/CZT/Au structure were made, and I-V curve and the energy spectrum were measured with the detectors. It could be seen that the detector with the In/CZT/Au structure has superior property than the detector with Au/CZT/Au structure when the crystal resistivity was low. However, the metal contact structure effect becomes low when the crystal resistivity was high.

Keywords : Metal-semiconductor Contact, CZT Detector, Bridgman Method, I-V Curve, Energy Spectrum

1. INTRODUCTION

In general semiconductor detector has superior property than the scintillator, because the signal generation in the semiconductor is one-step process while that in the scintillator is two-step one. Conventional semiconductor detectors are silicon or germanium detector, and new material has been investigated to replace the conventional semiconductor detectors. Cadmium Zinc Telluride (CZT) is a candidate material for next generation radiation detector [1]. Since the atomic numbers of composite materials are higher than that of the silicon or germanium, the detection efficiency of X- or γ-ray could be large. The CZT detecting system could be made compact, because the CZT detector could be operated without a cryogenic cooling system. However, the wider applications of CZT detector have been hindered mainly from the mass production of high quality crystal. Recently, the CZT crystal growing technology has been progressed to meet the need for the detector-grade crystal [2].

The metal-semiconductor (MS) contact is very important to make the CZT detector with lower leakage current. It is known that the Schottky metal-semiconductor contact could reduce the leakage current of the detector due to the blocking effect. For example, the Silicon Surface Barrier (SSB) detector is based on the Schottky contact to minimize the leakage current [3]. In the Schottky-type detector, Schottky MS contact is made on one side of the detector, and Ohmic MS contact is deposited on the opposite side of the detector [3]. Then n-type semiconductor is used to make the detector, the gold layer was generally used as Schottky contact, and the aluminum or indium layer was used as Ohmic contact. However, in the case of commercial CZT detector, the same metal such as gold or platinum was generally deposited on both sides of the crystal.

The leakage current could be reduced from the blocking MS contact and the crystal resistivity. One could estimate that blocking MS contact plays important role in making lower leakage current detector when the crystal resistivity is low, and the crystal resistivity plays important role in making the low leakage current when the crystal resistivity is high. Previous experimental studies about the dependency of the MS contact effect on the crystal resistivity were rare [4].

In the present work, the CZT crystal was grown with Bridgman method, and the detector was made with the crystal. Also the CZT detectors were made with high resistivity crystal grown with high pressure Bridgman method. The detectors with gold/CZT/In and gold/CZT/gold

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were made and the detector performance was measured and compared to study the metal contact effect on the detector performance.

2. MATERIALS AND METHODS

CZT crystal was grown with low pressure Bridgman method. A Bridgman crystal-growing furnace was designed and made to obtain the CZT crystal. It was 3 zone furnace with vertical type. The upper zone was used as high temperature region, and the middle and lower zone were used as low temperature one. The high temperature region was set at 1100 ºC, and the low temperature region was set at 1020 ºC High purity materials (6N grade) of Cd, Zn and Te were used to grow the $Cd_{0.96}$ $Zn_{0.04}Te$ crystal. The raw materials were inserted in the carbon-coated quartz ample in the noble gas environment to minimize the oxidization of the cadmium. The ampule contained with raw material was sealed under high vacuum condition of 10^{-6} Torr. In the beginning of the growing process, the ampule was in the high temperature region. The ampule was moved slowly to the low temperature region with the speed rate of 1 mm/h. After the growing procedure, the crystal was slowly cooled to room temperature, which could reduce the thermal stress on the crystal. The diameter of the grown crystal was 2 cm. Fig. 1 shows the grown crystal.

The crystal was cut with a diamond wire saw. The final dimension of the crystal was square shape with size of 10×10 mm^2, and the crystal thickness was 1 mm. The crystal was lapped with silicon carbide paper of 4000 grit. After that, the crystal was mechanically polished with Al_2O_3 powder from 1-μm grade to 0.05-μm grade. The mechanical polishing with 0.3-μm grade powder was inserted as an intermediate step. The crystal structure was measured with X-Ray Diffraction (XRD). EPMA analysis was done to obtain chemical composition of the crystal, and ICP-MS analysis was done to see the impurity of the crystal.

Metal contacts were evaporated on both sides of the crystal. Thermal evaporator was used to deposit the metal contact on the crystal. The deposit rate was kept at 10 Å/sec, and the vacuum inside the evaporator chamber was kept at 10^{-6} Torr during the metal deposition. The diameter of the metal electrode was 3 mm. Two different CZT detectors were made; Au/CZT/Au, and In/CZT/Au structures. The CZT detector with Au/CZT/Au structure is referred as CZT resistive detector, and the CZT detector with In/CZT/Au structure was referred as CZT Schottky detector here after. Signal wires were connected to the metal electrode with silver paste. The I-V curve of the crystal was measured with an electrometer (Keithley 6517 A). High voltage was biased and the leakage current from the detector was measured.

The CZT resistive detector and CZT Schottky detector were also made with CZT crystal grown with high Pressure Bridgman method to see the dependency of the metal contact effect on the crystal resistivity. The crystal was known as discriminator grade, and it was obtained from eV Products Inc [5]. It is known that the resistivity of the CZT crystal grown with the high pressure Bridgman method is higher than that of the CZT crystal grown with low pressure Bridgman method. The resistivity of high pressure Bridgman method is usually larger than 10^{10} Ωcm, and that of low pressure Bridgman method is $10^7 \sim 10^8$ Ωcm. The low resistivity of CZT crystal grown with low pressure Bridgman method is mainly from cadmium vacancy. High pressure inside the crystal growth furnace could prevent the escape of cadmium during the crystal growth.

The detector was made with the same way, however the electrode diameters on the CZT crystal were 10 mm. The I-V curve of each detector was also measured.

Fig. 1. CZT crystal grown with the low pressure Bridgman method.

3. RESULTS AND DISCUSSION

Fig. 2 shows the XRD result of the crystal grown with the low pressure Bridgman method. One could see that the single CZT crystal was grown in the (220) direction. ICP-MS analysis shows that most of the impurities were minimized except silicon. Table 1 is the impurities obtained from ICP-MS analysis. The I-V curves of the CZT detectors, which were made with the grown crystal, was shown in Fig. 3. When the I-V curve of the CZT Schottky detector was measured, it shows the diode characteristics and the leakage current was reduced comparing to that of the CZT resistive detector. One could conclude that the blocking metal contact could reduce the leakage current of the detector.

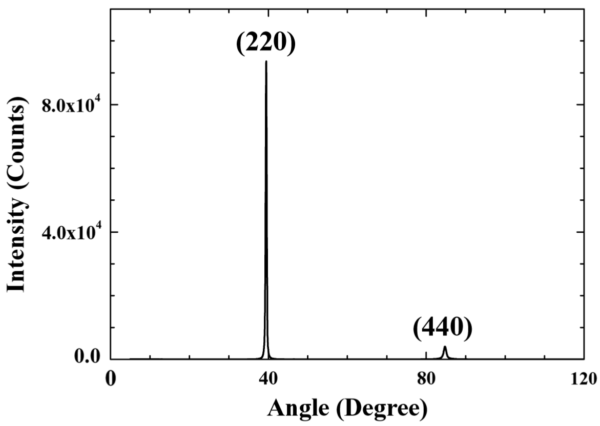

Fig. 2. XRD results of the grown crystal.

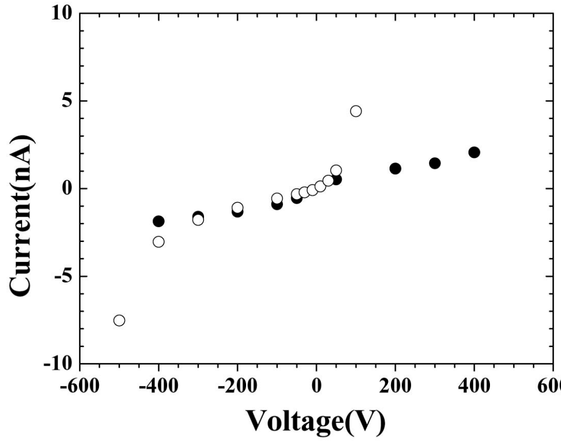

Fig. 4. I-V curve of CZT detector, where the crystal was grown with high pressure Bridgman method. The closed circles are the leakage current of the CZT resistive detector, and the open circles are the leakage current of the CZT Schottky detector.

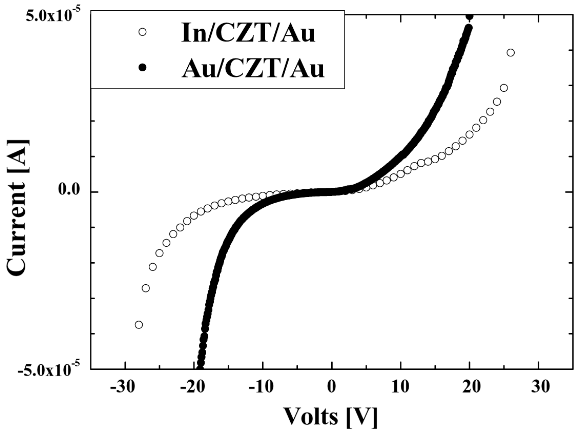

Fig. 3. I-V curve of CZT detector, where the crystal was grown with the low pressure Bridgman method.

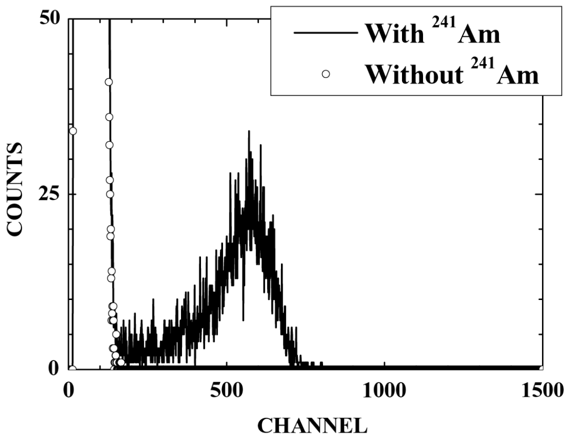

Fig. 5. 5.4 MeV α-energy spectrum measured with CZT Schottky detector. The crystal was grown with the low pressure Bridgman method.

Table 1. Impurity concentration in the grown CZT crystal.

Element	Concentration(ppm)
Al	n.d.
K	n.d.
Si	435.866
Mg	n.d.
Fe	n.d.
Mn	n.d.
Se	n.d.
S	n.d.
Ga	n.d.

Fig. 4 shows the I-V curves of the CZT detectors, which were made with the crystal grown by the high Pressure Bridgman method. Because of higher resistivity of the crystal grown by the high Pressure Bridgman method, the leakage current was smaller comparing to that of the CZT detector, which was made with a crystal grown by the low pressure Bridgman method. The CZT Schottky detector shows the diode characteristics. The leakage current of CZT Schottky detector was larger than 10 nA in the high voltage region above 100 V, the leakage current was not shown in the Fig. 4. The high leakage current was due to the metal contact of the CZT detector. However, the leakage current of CZT Schottky detector was not reduced comparing to that of the CZT resistive detector. The metal-contact effect on the detector performance was small when the CZT resistivity was high. When the CZT detector was made with low resistive crystal, it is better to make the Schottky detector to reduce the leakage current. However, when the detector was made with high resistive crystal, the CZT resistive detector structure is enough to make the detector with small leakage current.

The radiation energy spectrum was measured with the CZT Schottky detector, in which the crystal was grown with the low pressure Bridgman method. High voltage of 10 V was biased and the signal was measured from the anode electrode of the detector. When bias voltage is higher than 20 V, the leakage current was too large to measure the energy spectrum. The signals were processed through a pre-amplifier (eV 550), and a shaping amplifier (ORTEC 572). The energy spectrum was stored with a Multi Channel Analyzer (MCA). The measurement system was checked with a pulse generator. Fig. 5 shows an energy spectrum measured with the CZT Schottky detector. The 5.4 MeV alpha particles from ^{241}Am could be clearly seen in the energy spectrum.

4. CONCLUSION

$Cd_{0.96}Zn_{0.04}Te$ crystal was grown with the low pressure Bridgman method, and the XRD result shows that the grown crystal has one direction. The development of high resistivity CZT crystal growth is underway. Low leakage current is very important for the successful operation of radiation detector. Generally, the blocking contact structure, such as PIN or Schottky metal-semiconductor contact, is used to reduce the leakage current. When the II-VI semiconductor such as CdTe is used to make the detector, the Schottky contact is employed to reduce the leakage current. In the present work, the dependency of the metal contact effect on the crystal resistivity was studied with CZT crystals grown with high pressure Bridgman (high resistivity) and the low pressure Bridgman method. The metal contact effect on the leakage current could clearly be seen in the CZT detector made with lower resistivity. However, the metal contact effect was not clear when the CZT detector was made with higher resistivity. It could be concluded that metal contact effect is very important when the CZT detector is made with low resistivity crystal.

ACKNOWLEDGEMENTS

This work has been carried out under the nuclear R&D program of the Ministry of Education, Science and Technology (MEST) of Korea. We are also partly supported partly by the Basic Research Supporting Program of Korea Research Foundation.

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