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Compound Semiconductor Radiation Detector

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1. Introduction

In 1945, Van Heerden measured α, β and γ radiations with the cooled AgCl crystal. It was the first radiation measurement using the compound semiconductor detector. Since then the compound semiconductor has been extensively studied as radiation detector.

Generally the radiation detector can be divided into the gas detector, the scintillator and the semiconductor detector. The semiconductor detector has good points comparing to other radiation detectors. Since the density of the semiconductor detector is higher than that of the gas detector, the semiconductor detector can be made with the compact size to measure the high energy radiation. In the scintillator, the radiation is measured with the two-step process. That is, the radiation is converted into the photons, which are changed into electrons by a photo-detector, inside the scintillator. However in the semiconductor radiation detector, the radiation is measured only with the one-step process. The electron-hole pairs are generated from the radiation interaction inside the semiconductor detector, and these electrons and charged ions are directly collected to get the signal. The energy resolution of the semiconductor detector is generally better than that of the scintillator.

At present, the commonly used semiconductors as the radiation detector are Si and Ge. However, these semiconductor detectors have weak points. That is, one needs thick material to measure the high energy radiation because of the relatively low atomic number of the composite material. In Ge case, the dark current of the detector is large at room temperature because of the small band-gap energy. Recently the compound semiconductor detectors have been extensively studied to overcome these problems. In this paper, we will briefly summarize the recent research topics about the compound semiconductor detector. We will introduce the research activities of our group, too.

2. Recent Research on CdZnTe

The CdZnTe is the most promising material as a room temperature compound semiconductor detector. The addition of Zn to the melt of Cd and Te during the growth of the crystal helps to produce higher quality substrate material. CdZnTe is usually grown by high pressure Bridgman method. The resistivity of the CdZnTe is known to ~ 10^{11} Ωcm. In general the CdZnTe substrate is cut, lapped, polished, and etched. After that process, the metal contact is applied on the surface of the substrate. Because of the hole trapping inside the CdZnTe, the large tail is appeared when measuring the energy spectrum of high energy radiation. To overcome these difficulties, several methods are proposed. One is to use the pulse-processing-technique. It depends on the fact that the hole produces long pulse and the electron produces short pulse. The other method is the single-carrier-sensing technique. The idea of the single-carrier-sensing is from the Frisch grid in the gas detector. With the coplanar electrode on the CdZnTe surface, one can obtain the energy resolution of 13 keV for 660 keV gamma rays. Also the single-carrier-sensing technique can be developed to study the 3-D sensing device.

The CdZnTe can be used in many application areas. One of them can be the high-resolution detector for the radiation safeguard. In some cases, the small size and high intrinsic efficiency is essential to detect the radioactive material. Access space is limited and some items can be viewed only with small size detection probes. Also some radioactive materials such as uranium or plutonium have complex decay chains. Therefore, one needs the detector with high energy resolution. CdZnTe can satisfy these requirements.

Another application area of the CdZnTe is the medical instruments. Digital Radiography (DR) has been progressed rapidly with the development of the electronic sensor technology, mass data storage, high-speed data transmission. DR has many advantages over the traditional film-based radiography. CdZnTe can be one of the radiation sensors for DR.

An experimental device based on a 64×64-pixel CdTe was fabricated as the high-resolution dental digital radiography sensor. CdTe array can be applied to the bone densitometry.

Nuclear medicine aims at functional imaging based on the administration of a radiotracer. PET (Positron Emission Tomography) and SPECT (Single Photon Emission Computed Tomography) are the famous device for the nuclear medicine. A SPECT system was fabricated based on the CdZnTe detector.

The CdZnTe is useful not only X-ray or gamma ray areas but also charged particle measurement area. The CdZnTe detectors are relatively inexpensive compared with some silicon detectors, and are priced about the same as amorphous silicon and photodiodes which are routinely used for charged particle detection [4]. Therefore the CdZnTe detector can be used as the charged particles detector in an air condition and at room temperature

3. Our Group's Work

A Bridgman method crystal growing device has been designed to grow CdZnTe ingot. The temperature around the crucible is 1200 °C. Fig. 1 shows the sketch of our designed Bridgman vessel.

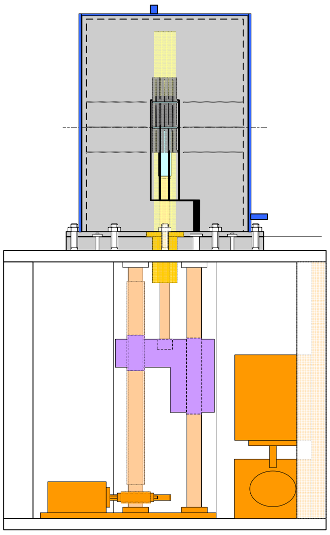

Fig. 1 The designed crystal growing device

The optimum process of the surface treatment of CdZnTe has been investigated. After polishing the CdZnTe surface with 0.05 μm alumina, the surface was etched with Bromine solution. The etched surface was investigated with microscope and AFM. It could be seen that the surface roughness got smaller when the surface was etched with Bromine solution. The indium was evaporated on the both sides of CdZnTe, and the dark current was measured. It was shown that the dark current became bigger when the surface was etched with Bromine solution. The dependency of the dark current on the thermal annealing process was also studied. The CdZnTe was heated on 150 and 300 °C and stayed for 3 hours before evaporation of the metal electrode. It could be seen that the indium surface became stable and the dark current got smaller when the CdZnTe was annealed before the metal evaporation. The energy spectrum of 60 keV gamma rays was measured with our fabricated CdZnTe.

The electric field inside the CdZnTe was calculated. The induced signal on the electrode was obtained from the calculated electric field. From these studies, we can get the dependency of the energy resolution on the design of the strip electrode.

We have fabricated and tested a 5×5×2 mm CdZnTe radiation detector. The CdZnTe detector is directly connected on anode of BNC connector to measure the current-voltage curve and alpha response. The alpha particles were normally incident through the cathode, and signal was extracted to the preamplifier via the anode. Fig. 2 shows the pulse height spectrums of the 2-mm-thick Pt-CdZnTe-Pt detector using 5.5 MeV alpha particles from the Pu-238.

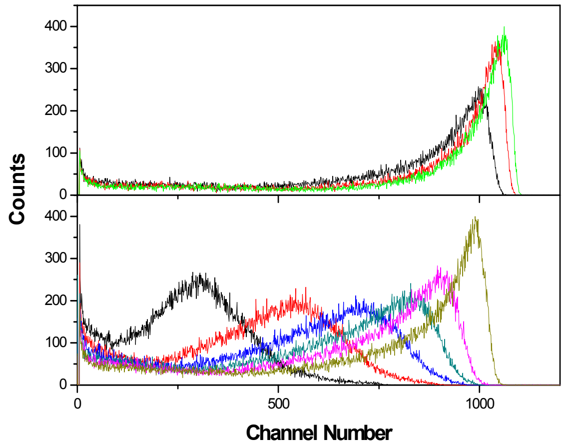

Fig. 2 The alpha spectrum as a function of the bias voltages(top : 100, 150, 200 V bias voltages, collection time 1200s, down : 20, 30, 40, 50, 60, 90 V bias voltages, collection time 1800s)

4. Conclusion

The CdZnTe is the promising material for the next generation room temperature high resolution detector. It can be applied to the radiation safety, industrial control, the medical imaging and the X-ray and gamma-ray astronomy. Our group has studied the optimized fabrication process of CdZnTe. It includes the growing of the CdZnTe crystal, the fabrication process of MS (Metal-Semiconductor) contact, and the design of the electrodes to get the higher energy resolution.

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