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Alpha-particle response of an InSb radiation detector made of liquid-phase epitaxially-grown crystal

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ABSTRACT

We fabricate a radiation detector using a *p*-type InSb crystal grown using the liquid-phase-epitaxy (LPE) method. The energy resolution for 5.5-MeV alpha particles was improved 2.4% from 2.9% through the application of bias voltage. This value represents a significant improvement over that of previously fabricated devices, 15–40%.

1. Introduction

For environmental preservation, an important method for detecting hazardous elements such as Li, Be, and Pb is the X-ray fluorescence analysis method. In X-ray fluorescence analysis, Si detectors are generally used for X-ray detection. Si detectors are, however, not very suitable for detecting heavy elements, such as Pb, which emit high-energy K X-rays that are nearly 80 keV in energy. The small atomic number and density of Si result in an absorption efficiency less than 3% for a 3-mm-thick Si(Li) detector (Gallagher and Cipolla, 1974). In addition, the K X-rays of light elements such as Li and Be have energies below 100 eV. For the measurement of low-energy X-rays, the energy resolution of the Si detectors is insufficient. Photon detectors that have high detection efficiency for X-rays that have energies of several tens of keV and high-energy resolution for X-rays below 100 eV are necessary for the detection of these hazardous elements.

Compound semiconductor InSb has advantages as a substrate for high performance photon detectors. The high atomic numbers (In: 49, Sb: 51) and high density (5.78 gcm^{-3}) result in photon absorption efficiency nearly three orders of magnitude greater than those of Si detectors. In addition, it has the smallest bandgap energy (0.165 eV at 290K) among developed semiconductor substrates, which brings twice the energy resolution of that of Si detectors (McHarris, 1986). Work has been done on the development of InSb detectors using commercial InSb wafers (Kanno et al., 2002, 2003, 2004, 2005, 2006, 2007, 2008; Hishiki et al., 2005, 2006, 2007). In addition, it has been shown that InSb detectors can detect the alpha-particle emission of ^{241}Am with energy resolution that varies from 15 to 40% (Kanno et al., 2006).

The InSb detectors described above, however, could not operate with an applied bias voltage, due to their small diode resistances. In this work, response of an InSb detector made using LPE InSb crystals to alpha particles is investigated. We show that the resistance of the InSb detector as a diode is high enough to operate with bias voltage.

2. Experiment

2.1. Detector fabrication

The LPE InSb crystal was grown on a 0.4-mm-thick InSb substrate (*n*-type: Galaxy Compound Semiconductor, Inc., U.S.A) and had a thickness of 115 μm. The electrical and growth properties of LPE InSb are described in the reference (Sato et al., 2010). Using Hall measurements, the electric conductivity of the LPE InSb crystal was found to be *p*-type at temperatures below 140K. A schematic of the InSb detector is shown in Fig. 1. The LPE InSb crystal was cut to a dimension of 3 × 5 mm. For a rectifying contact, we patterned a 1-mm-diameter electrode on the epitaxial side of the LPE crystal using photoresist. Both sides of the crystal were etched for 30 s with a mixture of hydrogen fluoride, hydrogen peroxide, and de-ionized water (48%HF:H_2O_2:H_2O = 1:1:3). To serve as a rectifying contact, Al was deposited by heat evaporation with a thickness of 17 nm on the epitaxial side. The substrate surface of the LPE

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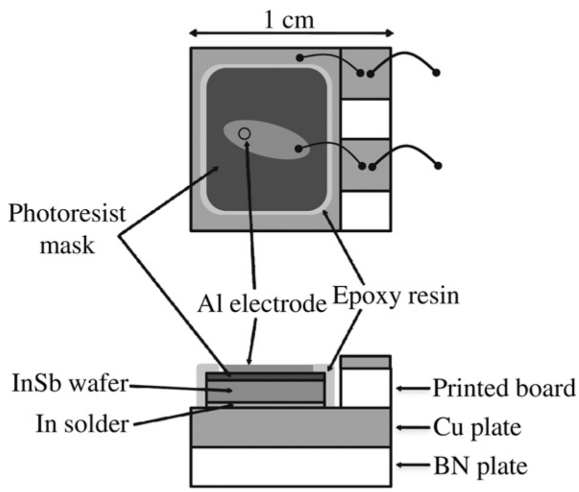

Fig. 1. Schematic drawing of the InSb detector.

crystal was attached to a Cu plate using In solder as an Ohmic contact. The edge of the LPE crystal was coated with an epoxy resin to adhere it to the Cu plate.

2.2. Alpha particle measurements

To detect alpha particles using the LPE-InSb detector, the detector was mounted on a Cu sample holder of a liquid-He flow cryostat (Helitran LT3: Advanced Research Systems, Inc., Pennsylvania, USA). A schematic of the experimental apparatus for measuring the alpha particles is shown in Fig. 2. An ^{241}Am (5 kBq) source was installed inside of the vacuum shroud of the cryostat. The distance between ^{241}Am source and the InSb detector was 15 mm. The alpha-particle measurements were performed with and without applying bias voltage at the temperature of 5.4K. Fig. 3 shows a block diagram of the electronic circuit for the alpha-particle measurements. The energy spectra of the ^{241}Am alpha particles were measured using a multichannel analyzer. The bias voltage was applied via the series connection of resistances of a preamplifier (110 MΩ in total).

3. Results and discussion

The energy spectra of the alpha particles emitted by the ^{241}Am source with and without applying bias voltage are shown in Fig. 4.

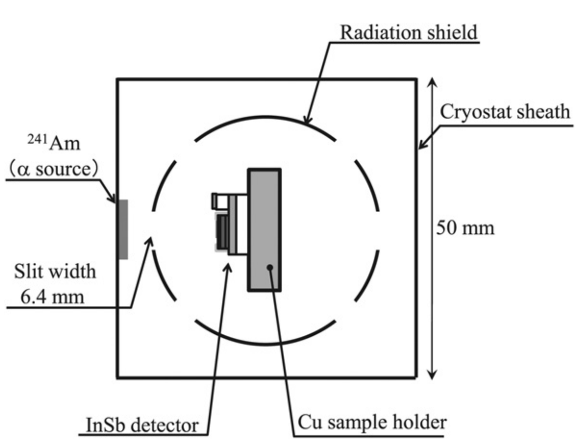

Fig. 2. Schematic drawing of the experimental setup.

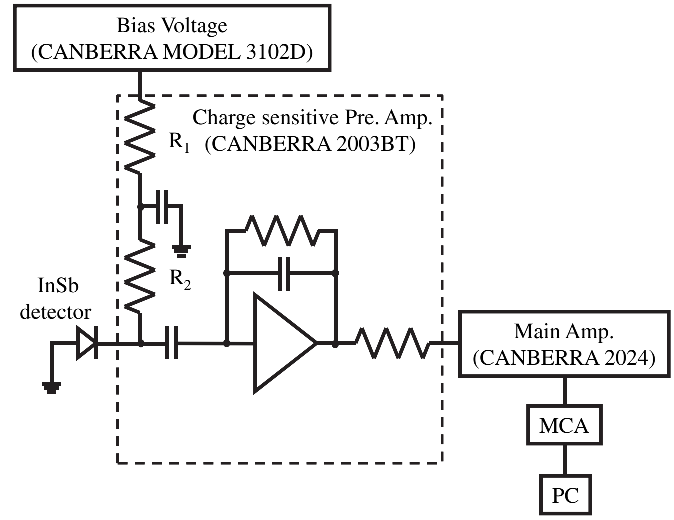

Fig. 3. Block diagram of the electronic circuit used in the alpha-particle measurement. MCA refers to the multichannel analyzer. The internal resistances R_1 and R_2 in the preamplifier were 10 MΩ and 100 MΩ, respectively.

The energy resolution obtained, through the measurements in which the bias voltage was not applied, was 2.9%. This value is superior to previously obtained values measured by InSb detectors made from commercially obtained InSb wafers, 15–40%. This is caused by the decreased number of recombination and trapping of electrons and holes in the LPE-InSb crystal, because the carrier concentrations of LPE InSb crystal are smaller than those of commercial InSb crystals (Kanno et al., 2006; Sato et al., 2010).

The peak channel numbers and energy resolutions are shown in Fig. 5(a) and (b) as a function of the output voltage of the bias supply. When the bias voltage is applied, the peak channel number increased and energy resolution improved to 2.4%. In addition, by applying bias voltage, the tail of the energy peak in Fig. 4 disappeared, because of the improved carrier collection efficiency caused by the higher electric field.

In this detector, the thickness of the depletion layer with no bias voltage was estimated to be a 2.3 μm (Sato et al., 2010). However, the travel range of the 5.5-MeV alpha particles was nearly 20 μm in InSb (Gobeli, 1956). Therefore, the alpha particles did not deposit all

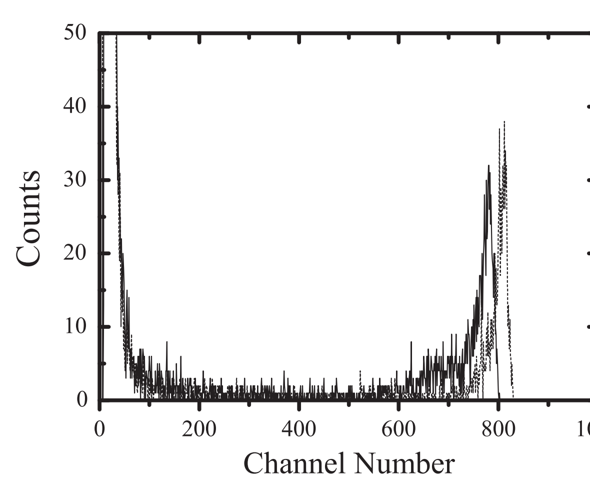

Fig. 4. Energy spectra of the ^{241}Am alpha particles (5.5 MeV) measured at 5.4K. The shaping time of the main amplifier was 0.25 μs. The solid and dotted lines show the results of the measurements without and with the 600-V bias supply output.