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Schottky and pn junction cryogenic radiation detectors made of p-InSb compound semiconductor

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Abstract

Schottky and pn junction detectors were fabricated with p-InSb. Fabrication methods, energy spectra of ^{241}Am alpha particles and rise times are shown. We could observe pulses at operating temperatures up to 77 and 115 K for the Schottky and the pn junction detectors, respectively.

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1. Introduction

The superconducting detectors bring us excellent energy resolution 30 times as good as conventional semiconductor detectors, however, they must be operated at very low temperature. In industrial application and in general research with using radiation detectors, extreme operating conditions, such as very low temperature and small sensitive areas of detectors, are not very welcomed by general users, although they would like to have better energy resolution than the ones of Si and Ge detectors.

A candidate for the substrate of radiation detectors described above is compound semiconductor InSb: band gap energy, 0.165 eV, atomic numbers 49 (In), 51 (Sb), density 5.78 g cm^{-3}, mobilities 78000 cm^2 V^{-1} s^{-1} (electrons), 750 cm^2 V^{-1} s^{-1} (holes) at 77 K. The small band gap energy predicts the energy resolution of InSb detector as less than 60 eV for 6 keV X-rays. The high density and high atomic numbers guarantee the high absorption probability of photons. The high mobilities make InSb even more attractive as substrate for radiation detectors.

Although, McHarris [1] pointed out these merits of InSb in 1986, no work was reported on InSb radiation detectors before our study on the rectifying characteristics of InSb device [2] and on the detection of alpha particles with it [3]. In this paper, we report our recent activities on

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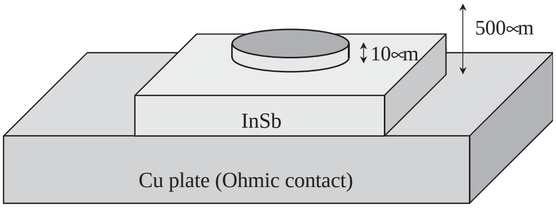

Fig. 1. Schematic drawing of an InSb detector.

p-InSb detectors, focusing on newly fabricated Schottky detector, comparing to a pn junction detector [4].

2. Detector fabrication

Employed InSb wafer was p-type one (Wafer Technology Ltd., England) with 2 in. in diameter and 0.5 mm in thickness. As impurity, Ge is doped with the concentration of $3.5 \times 10^{15}\,cm^{-3}$. The resistivity of the wafer is 0.29 Ωcm at 77 K.

The wafer was cut to nearly 7 mm × 10 mm square and both sides of the wafer were etched by the mixture of nitric and lactic acids (1:10) for 5 min. After evaporating suitable metals on one side of InSb wafer, an electrode 3 mm in diameter was defined by photo-resist. With etching the evaporated metals and InSb, we fabricated mesa electrode with the height of nearly 10 μm as shown in Fig. 1.

As a Schottky electrode, Au–Pd (40%) was evaporated with the thickness of 4 nm.In case of making a pn junction, Sn and Al were evaporated with the thicknesses of 5 and 100 nm, respectively. After the evaporation process, Sn was diffused into p-InSb by lamp anneal and resulted in an n-layer. For ohmic contact, the other side of the wafer was soldered to a Cu plate with In solder.

3. Current–voltage curves

As electric characteristics of the Schottky and the pn junction detectors, current–voltage (*I–V*) curves were measured. The *I–V* curves of the Schottky detector are shown in Fig. 2. The estimated resistances of the Schottky and the pn junction detectors at 4.2 K were 50 and 250 kΩ, respectively.

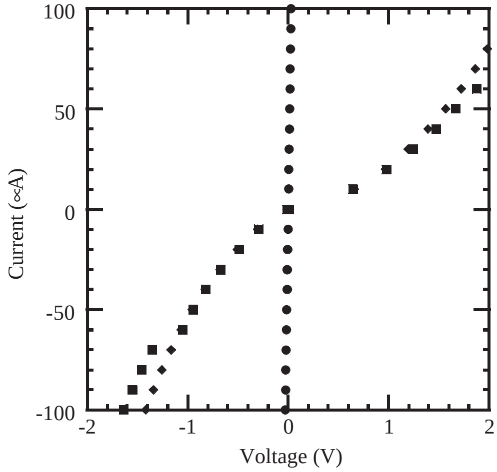

Fig. 2. The *I–V* curves of the Schottky detector at the temperature of 4.2 K (squares), 40 K (diamonds) and 77 K (dots).

4. Alpha particle measurements

Although these detectors are aimed for X-ray and γ-ray measurements, photon detection has not been successful yet. In this stage, we study the properties of InSb detectors with measuring α particles.

4.1. Energy spectra

With changing operating temperature, energy spectra of ^{241}Am alpha particles were measured. Typical energy spectrum measured by the Schottky detector is shown in Fig. 3.

Comparing energy spectra obtained by the Schottky to the ones measured by pn junction detectors [4], energy peak is obviously separated from a noise part: in pn junction detector, a part of electrons and holes created in the n-layer diffused into the depletion layer and caused contribution in lower channels. With subtracting noise as a function of exponent of the channel number, however, we obtained peaks due to α particles [4]. We could observe signals due to α particles at

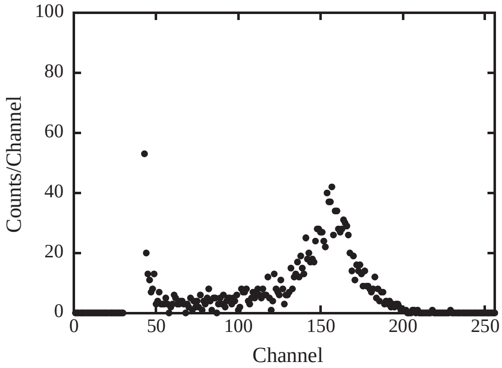

Fig. 3. Energy spectra of ^{241}Am α particles measured by a Schottky p-InSb detectors at the operating temperature of 20 K.

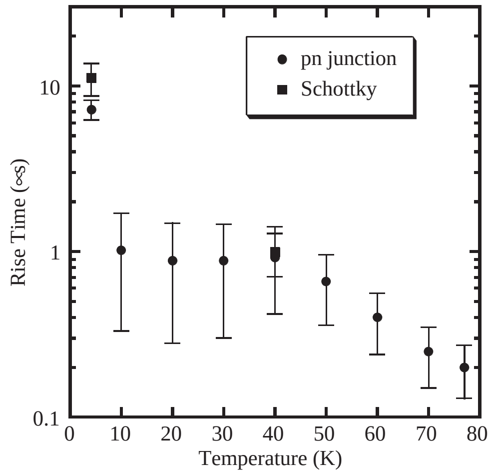

Fig. 4. Rise times of Schottky and pn junction p-InSb detectors as a function of operating temperature.

the temperature up to 77 K with the Schottky detector, and up to 115 K with the pn junction detector.

In most of the measurements, energy spectra were measured without applying bias voltage. With the pn junction detector, however, energy spectra were measured with changing bias voltage from −100 to +100 V at 77 K. The voltage actually applied to the detector, V_d, was calculated as 0.17 V for the bias voltage of 100 V, with taking into account the 12 MΩ of resistance in the preamplifier and the resistance of the detector 20.9 kΩ at 77 K. From the change of the channel number of the energy peak, inherent voltage was estimated 0.68 V, assuming the linear relationship between the thickness of the depletion layer in the InSb detector and the deposited energy, i.e., the channel number of the energy peak [4].

4.2. Pulse rise time

The preamplifier output pulses were recorded by a digital storage oscilloscope for the analysis of rise times at 4.2 and 40 K for the Schottky detector and from 4.2 to 77 K for the pn junction detector. The rise times of each detector had nearly the same value and were shorter than the ones of superconductor detectors, as shown in Fig. 4. The shorter rise time at higher temperature is the result of thinner depletion layer due to the smaller resistivity. For precise discussion, we have to measure mobilities of electrons and holes as a function of operating temperature.

5. Conclusion

The InSb detectors had shorter rise times than superconducting detectors. This is important for InSb detectors, which have larger active areas and greater number of incident radiations than superconducting detectors. Higher operating temperature is also encouraging for industrial applications.

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