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InSb cryogenic radiation detectors

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Abstract

The compound semiconductor InSb is a promising substrate for photon detectors due to its smallest band gap energy among developed semiconductors, its high atomic numbers and its high density. In spite of these advantages, no other research groups are studying the development of InSb detectors. Here, our recent research activities on InSb radiation detectors are summarized. A method is also proposed for further improving InSb detectors.

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1. Introduction

In order to help preserve the environment, industrial products containing poisonous elements such as Cd and Pb are to be avoided. Industrial companies are expected to monitor carefully their products for these prohibited elements. In addition to the heavy elements listed above, light elements such as Be and Li should also be monitored. These elements are also poisonous though remain in use in the manufacturing of false teeth and batteries. For monitoring nuclear waste, U is the object of soil surveillance.

For the detection of such elements in materials, X-ray fluorescent analysis is commonly used. Commercially available X-ray fluorescent analysis systems are equipped with Si devices operating as X-ray detectors. Because of the small atomic number and density of Si, Si detectors are not suitable for detecting heavy elements such as Pb and U, which emit high-energy K X-rays of nearly 80 keV and higher. Their L X-rays have energies of less than 20 keV and can be detected by Si detectors.

The K X-rays of medium–heavy elements and the L X-rays of other heavy elements are, however, in this energy range of around 20 keV. For example, the energy of L X-rays of U is 13.6 keV and the energies of K X-rays of Y and Zr, which elements are contained with U in Uranite, are 15.0 and 15.7 keV. Sometimes, the L X-rays of U might be buried in the K X-rays of Y and Zr, because the number of K X-rays is greater than the one of L X-rays. The L X-rays of Pb has energy of 10.6 keV, whereas the K X-rays of Ge, which element belongs to the same group in the periodic table, has energy of 9.9 keV. Identifying special elements by measuring L X-rays is sometimes not an easy task.

On the other hand, the K X-rays of light elements such as Be and Li have energies below 100 eV. Si detectors can easily absorb these low-energy X-rays. However, their energy resolution is not sufficiently good to allow the identification of elements.

In short, photon detectors with higher absorbing efficiencies for X-rays with energies of about several 10 keV and with better energy resolution for X-rays below 100 eV are necessary for the detection of poisonous elements in the environment. Super-conducting detectors have superb energy resolution. However, the thickness of their absorbers is insufficient for the measurement of high-energy X-rays.

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A candidate for the detector substrate, which meets the requirements described above, is the compound semiconductor InSb. As pointed out by McHarris, InSb is a very promising substrate due to its high atomic numbers (In: 49, Sb: 51), high density (5.78 g cm^{-3}), and its smallest band gap energy (0.165 eV) among the semiconductors that have been developed [1]. These features predict higher photon absorption efficiencies (400–1000 times higher than Si, and 7–10 times higher than Ge), and two times better intrinsic energy resolution than those of Si and Ge detectors, provided that the energy required to produce an electron–hole pair is nearly three times the band gap energy and the Fano factor is the same with Si and Ge. The high mobilities of the electrons and holes (78,000 and 750 cm^2 V^{-1} s^{-1} at 77 K) may prevent the buildup of charge during its operation. This remains a significant problem for CdTe detectors. The shortcomings in using InSb as detector substrate are the requirement of cooling system for detector operation and the insufficient status of crystal quality in commercially available InSb wafers, not like Si wafers.

Although InSb is a very promising substrate for photon detection, it has yet to be reported upon in the literature in work other than our own. Here, we summarize our research activities into InSb detectors. So far, we have fabricated InSb detectors and measured the alpha particles of ^{241}Am [2–3]. The fabrication method and results of the measurements are briefly described. The gamma rays of ^{241}Am and ^{133}Ba have also been detected, though photopeaks were not observed [4]. Finally, a method for improving the performance of InSb detectors is discussed.

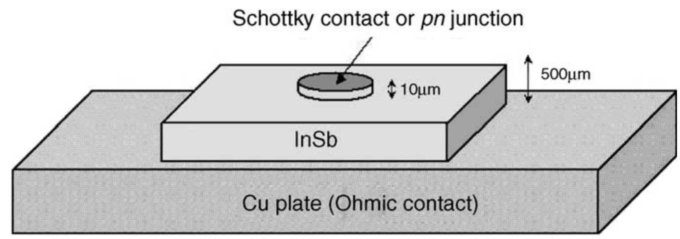

Fig. 1. Schematic drawing of an InSb detector.

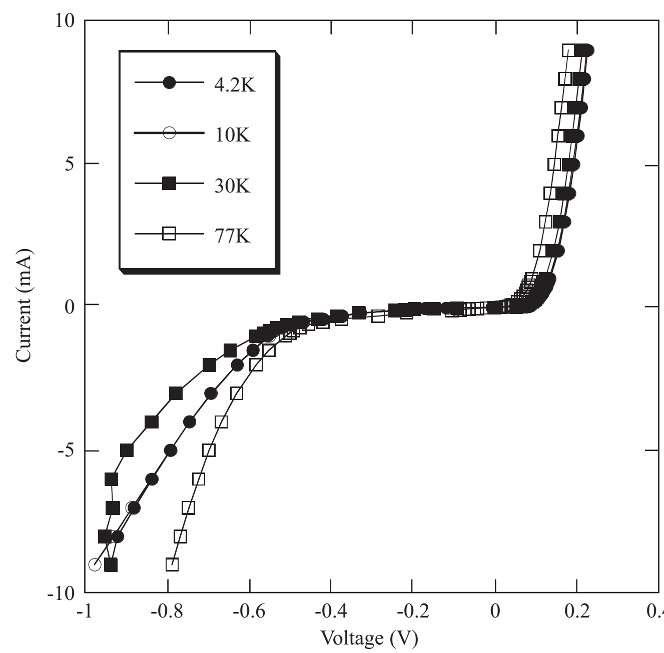

Fig. 2. Current–voltage curves of undoped Schottky InSb detector. Temperature is shown in the figure.

2. Radiation measurements

2.1. Detector fabrication

Schottky detectors were made with p-type [2] and undoped type of InSb wafers. With the p-type wafer, a pn junction detector was also fabricated [3].

The wafers used were the ones of Wafer Technology, England (p-type) and Sumitomo Electric Industries, Japan (undoped type). Both had diameters of 2 in. and thicknesses of 0.5 mm. A wafer was cut to the dimensions of approximately 5 mm × 7 mm. Employed etchant was a mixture of nitric acid and lactic acid with the ratio of 1:10. Both sides of the wafer were etched for 5 min.

In the case of Schottky detectors, Au–Pd (40%) alloy was deposited with a thickness of 5 nm by evaporation on one side of the wafers. For pn junction detectors, Sn and Al were deposited by evaporation on p-type InSb wafers with thicknesses of 5 and 100 nm, respectively. After evaporation, Sn was diffused into the InSb by the heat of a lamp resulting in an n-layer.

The electrode area of 3 mm in diameter was defined by the photo-resist, and the rest of this area was etched away to have a mesa structure with a height of nearly 10 µm. For ohmic contact, the other side of the wafer was attached to a Cu plate with In solder. A schematic drawing of the InSb detector is shown in Fig. 1.

Typical current–voltage curves of an undoped InSb Schottky detector are shown in Fig. 2. The leak currents at −0.2 V are 56 and 62 µA for 4.2 and 30 K operation, respectively. These high leak currents are due to low resistivity of InSb substrate.

2.2. Alpha particle measurements

The detectors of interest were installed in the cold stage of a cryostat (Infrared Co.) and cooled down to 4.2 K, sometimes to 0.5 K. An electro-deposited alpha particle source of ^{241}Am (mainly 5.5 MeV in energy) was placed some millimeters from the detector and collimated to nearly 4 mm in diameter.

The electronic circuit is shown in Fig. 3. The 100 MΩ resistance of the preamplifier was replaced with a 2 MΩ resistance, because the resistance of the InSb detector was some orders of magnitude smaller than the ones of typical Si detectors.