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Fabrication and characteristics of bulk semi-insulating 6H-SiC semiconductor detector for an α radiation at room temperature

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Abstract

The fully depleted SiC Schottky barrier detector was fabricated from a semi-insulating (SI) bulk crystal with a thickness of 388 μm and an orientation of the on axis (0 0 0 1). The bulk SI 6H-SiC detector structure consists of a Ni/Au contact at the Si-face and a Ti/Au contact at the C-face. The fabricated detector dimensions are 10 × 10 mm with a diameter of 6 mm for the contact dimension. The band gap of the 6H-SiC was determined by using an optical photon absorption spectroscopy in the ranges between 200 and 600 nm. The band gap of 6H-SiC is determined as 3.03 eV. The current density response according to the biased voltage was measured. The Schottky barrier height was determined as 0.86 eV on the basis of the thermo-ionic emission theory. The bulk SI 6H-SiC detector with a multi-layer structure, Au/Ni/6H-SiC/Ti/Au showed a good response for the α radiation in air and at room temperature.

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Keywords: 6H-SiC; Semi-insulation bulk detecotor; α Radiation

1. Introduction

A SiC is known as a useful material for the harsh environments needed for a radiation resistance, a high-temperature operation and high-critical breakdown voltage, and a high thermal conductivity [1]. Radiation detectors based on semiconductors like SiC, AlN, and BN with large band energy gap are the most promising for an ionizing detector in the fields of a harsh radiation environment. For the purposes of a fabrication of a radiation hard detector, a large band gap and a low-leakage current are important parameters. SiC has over 170 polytypes [2]. The commercially available single crystals are the hexagonal 4H and 6H. Large diameter single crystals are grown by a physical vapor transport (PVT) process which is based on a modification of the original SiC sublimation method [3]. In the metal/semiconductor Schottky device the current is induced by the major carrier. Therefore, the switching time is faster than that of the pn junction device [4]. However, the characteristics of the Schottky device are sensitive to the interface property on the semiconductor surface. The surface treatments with an oxidation/HF etching and a boiling water immersion during the fabrication of the metal/6H-SiC Schottky device decreased the Schottky barrier heights by about 0.3–0.5 eV with respect to that of a 5% HF etching [5]. It means that a surface treatment is a major parameter for the electric property of the Schottky device. Alpha spectrometry in a vacuum is known to give a good resolution to be sufficient enough to separate an isotope abundance in a nuclear material, especially actinides [6].

Present study is focused on the fabrication of a radiation hard detector for α-rays within a moderate resolution which is applicable in air and at room temperature.

2. Detector fabrication technology

A 6H-SiC is a wide band gap semiconductor with 3.03 eV at room temperature. Detector structure has been fabricated by the semi-insulting(SI) 6H-SiC wafer produced by Dow Coring Co., which had an orientation of the (0 0 0 1) on-axis, a diameter of 50.8 mm and a thickness of 388 μm.

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Two types of SI 6H-SiC, low and high grades, were used. The Si-face of the SI 6H-SiC wafer surface was polished to epi-ready and the C-face was etched after a lapping. Resistivity was measured as $3.53 \times 10^{6}\,\Omega\,\mathrm{cm}$. The dimensions of the 6H-SiC SI bulk detectors are 10×10 mm.

The SI 6H-SiC detector was prepared by the standard processes; dicing with a diamond saw, and an etching by a H_2SO_4 and H_2O_2 solution and a H_2O_2 , H_2SO_4 and H_2O_2 solution, and rinsed with de-ionized water, and the removal of an oxidation layer by a HF solution. Metal contacts to extract the electric charges from the 6H-SiC detector were fabricated on the surfaces by using a thermal evaporator which was operating in a vacuum of 10^{-6} Torr. The metal contacts consisted of 230 nm of Ni and 100 nm of Au at the Si-faced surface, and 100 nm of Ti and 100 nm of Au at the C-faced surface. The thickness was monitored by a thickness gauge. The detector was mounted onto the epoxy substrate with an electric signal readout by using a conductive epoxy.

3. Analysis and discussion

3.1. Determination of band gap energy

The band gap energy of a transparent semiconductor is determined by the optical absorption property. The band gap in a semiconductor is related to the fundamental optical absorption edge. The fundamental absorption process is a phenomenon where a photon is absorbed and an electron is excited from an occupied valence band state to an unoccupied conduction band state. The band gap was determined by a fitting of the optical absorption edge, which was related to the valence band-to-conduction band transition and Urbach tail [7].

Measurement of the optical absorption edge is the most common means of measuring the energy gap in semiconductors.

The absorption rate is described by [7]

$$\alpha(h\nu) = A(h\nu - E_c) \quad \text{for } h\nu \geqslant E_c,$$

$$\alpha(h\nu) = A(kT/2\sigma)^{1/2} \exp\{\sigma/kT(h\nu - E_c)\} \quad \text{for } h\nu < E_c,$$

where $\alpha(h\nu)$ is the photon absorption rate with respect to the photon energy, E_c is the optical absorption edge related with the band gap energy, k is the Boltzman constant and T is the temperature.

The band gap of the 6H-SiC was measured by an optical photon absorption spectroscopy in the range between 200 and 600 nm with a SCINCO S-300 UV spectrometer. Fig. 1 is the observed photon absorption spectrum obtained from the two different grade wafers, and the wavelength was converted into units of eV. The band gap of the 6H-SiC is determined as 3.03 eV, which is the same result as that reported previously elsewhere.

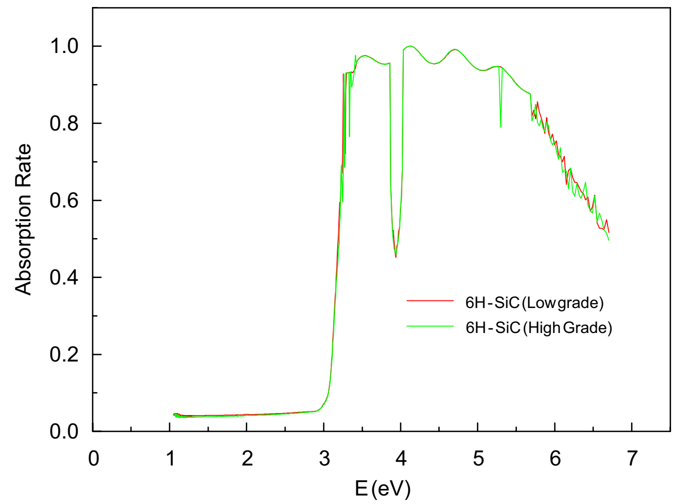

Fig. 1. Photon absorption spectrum obtained in the range between 1 and 7 eV, which correspond to 200–600 nm wavelength.

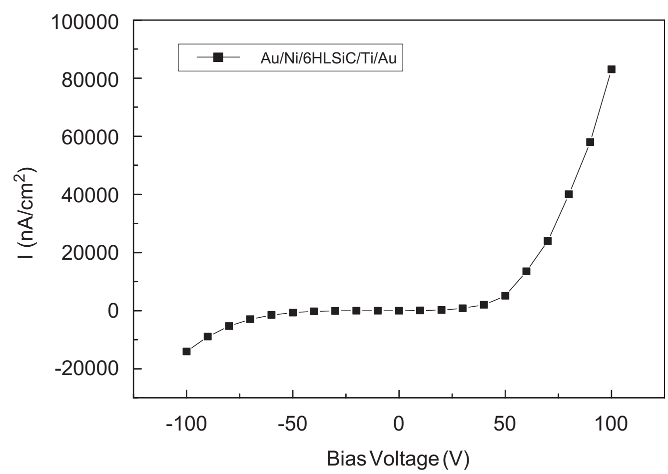

Fig. 2. $I-V$ characteristics of the SI 6H-SiC bulk detector.

3.2. Determination of Schottky barrier height

The Schottky barrier heights (SBHs) at the metal/SiC interfaces were estimated from I–V, the leakage current measurement. The measurement was performed by using a high-precision electrometer, Kethley 6517A, from −100 to 100 V. Electric measurement was carried out at room temperature in a box shielded from the light. The electrical I–V characteristic at the metal/ semiconductor interface is described by the potential distribution between the interface, and the current transport over and through the potential barrier. Fig. 2 is the measured current density with respect to the biased voltages with a Au/Ni/6H-SiC/Ti/Au structure.

According to the thermo-ionic emission theory [8] SBHs were determined by using the forward $I-V$ characteristics of the Ni/6H-SiC Schottky contacts. The current density over the potential barrier is analyzed within the framework of the thermo-ionic emission model originally