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Schottky barrier heights of semi-insulating 6H-SiC irradiated by high-dose γ-rays

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Abstract

The 6H-SiC radiation detector samples were irradiated by ^{60}Co γ-rays. The irradiation was performed with dose rates of 5 and 15 kGy/h for 8 hours, respectively. Metal/semiconductor contacts on the surface were fabricated by using a thermal evaporator in a high vacuum condition. The 6H-SiC detectors have metal contacts of Au(200 nm)/Ni(30 nm) at Si-face and of Au(200 nm)/Ti(30 nm) at C-face. *I–V* characteristics of the 6H-SiC radiation detectors were measured by using the Keithley 4200-SCS parameter analyzer with self-voltage sources. From the *I–V* curve, we analyzed the Schottky barrier heights (SBHs) on the basis of the thermionic emission theory. As a result, the 6H-SiC semiconductor detector showed similar SBHs independent of the dose rates of the irradiation with ^{60}Co γ-rays.

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Keywords: Schottky barrier height; Radiation detector; SiC; Semiconductor detector

1. Introduction

The harsh radiation environments such as a nuclear reactor core, high-energy physics experiments, or outer space can cause radiation damage to detectors [1–3]. A radiation damage which deteriorates the performance of devices can be a serious and important problem for semiconductor radiation detectors. A SiC semiconductor has recently emerged as an attractive material for the ionization radiation detection [4,5]. Studies of the properties of commercially available SiC as a material for radiation detection have been initiated [6,7]. Its high band gap energy (from 2.2 to 3.2 eV for the most common polytypes) and high displacement threshold energy (21.8 eV) [8] should lead to a radiation detector capable of operating at high temperature and in harsh radiation fields. In particular, SiC is expected to be more resistant to radiation damage due to high atomic binding energies within the material [9,10].

2. Experimental procedure

2.1. Cutting process

We used a 6H-SiC wafer of 2 in diameter supplied by the Dow Corning Company. The 6H-SiC wafer has a resistivity higher than $10^6\,\Omega$ cm, 380 μm thickness, and (0 0 0 1)-oriented type. We prepared $10\times10\,\text{mm}^2$ samples by using a semiconductor diamond saw with the UV tape. The adhesive strength of the UV tape keeps the wafers in position during dicing. After the process, tapes are easily peeled off the wafer by irradiating an ultraviolet lamp. Generally, a wax is used during the cutting process for fixing the wafer onto the working table of the sawing device. After the cutting process, the wax is removed from the wafer surface by using an organic solvent or acetone. The use of wax causes a wafer surface pollution and an increase of process time. Therefore, the use of UV tape

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provides two advantages, time reduction and cleaner process. After cutting, we clearly observed that there were no stains on the SiC wafer surface due to the UV tape. We also drew a line at 100 μm depth using the diamond saw to discriminate between the Si-face and the C-face because the 6H-SiC single-crystal wafer is transparent. Accordingly, the Si-face has two lines at intervals of 2.5 mm.

2.2. γ-Ray irradiation

We irradiated the samples contained in a bottle with ^{60}Co γ-rays. Irradiation was performed at a ^{60}Co γ-irradiation facility at the Korea Atom Energy Research Institute (KAERI) for 8 hours with dose rates of 5 and 15 kGy/h. The total doses for the two samples were 40 and 120 kGy, respectively. The dose rate of 15 kGy/h corresponds to the maximum capacity of the ^{60}Co γ-irradiation facility. After irradiation, the transparent glass bottles became brown.

2.3. Fabrication of the SiC radiation detectors

In the normal process, surfaces of SiC wafer are generally etched by H_2SO_4 and H_2O_2 solutions and rinsed with de-ionized (DI) water; the removal of an oxidation layer by a HCl solution is also performed. In this study, only acetone was used in the etching process and the samples were rinsed with DI water because of their excellent chemical properties. This could shorten the work time of the etching process. Metal contacts on the surfaces were processed by thermal evaporation under vacuum (1.2×10^{-5} Torr), at 353 K and a 180°/min rotation of the SiC sample holder. The final SiC detector samples have metal contacts of Si-face/Ni (30 nm)/Au (200 nm) and C-face/Ti (30 nm)/Au (200 nm). The diameter of the circular metal contact was 5 mm (Fig. 1).

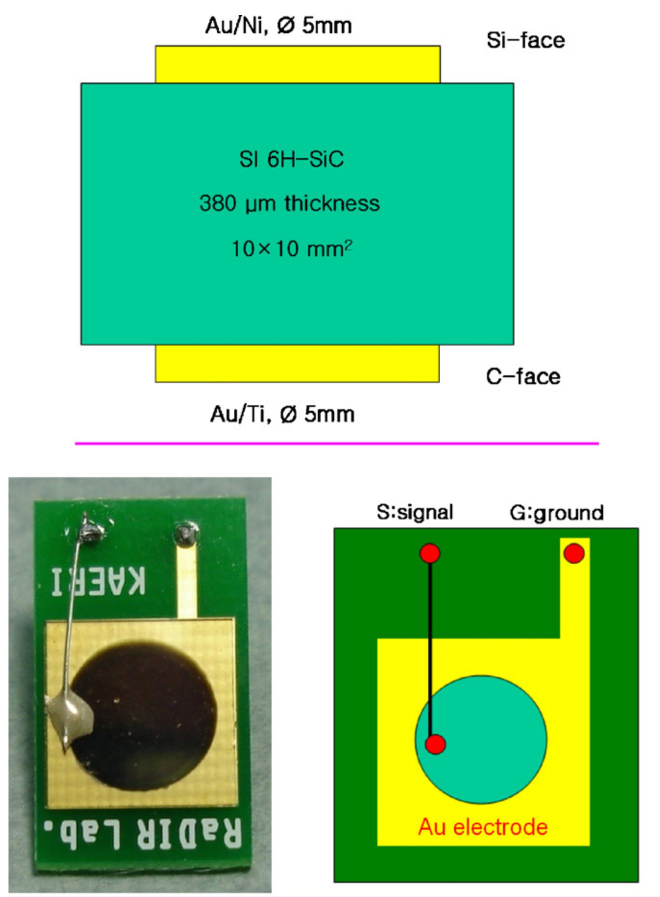

Fig. 1. Cross-section of the SiC sample after metallization process (top), photograph of the SiC semiconductor detector (bottom-left), and the schematic FR4 PCB layer (bottom-right).

2.4. Measurement of I–V characteristics

To measure the current–voltage curve, the PCB layer was made of a FR4 substrate with a $10 \times 10\,mm^2$ Au electrical contact pad. The SiC sample was fixed with a conducting epoxy onto the PCB layer and connected by a wire for the electrical property measurements. The current–voltage characteristics of the bulk-SiC radiation detector were measured using Keithley 4200-SCS with a self-voltage source. A typical measurement was made under a biased voltage in the range 0–100 V. The wire terminal was connected to the bias voltage and the PCB electrical contact pad was connected to the ground.

3. Results and discussion

The leakage currents of the non-irradiated sample and two 40, 120 kGy irradiated samples with the Si-face/Ni/Au interface were measured in the range 0–100 V bias and the results are shown in Fig. 2. The lowest value of the leakage current is that for the sample irradiated with 120 kGy. Fig. 3 shows the measured *I–V* curves of the C-face/Ti/Au interface for the three SiC samples under bias voltages in the range 0–100 V. The leakage current of the sample with

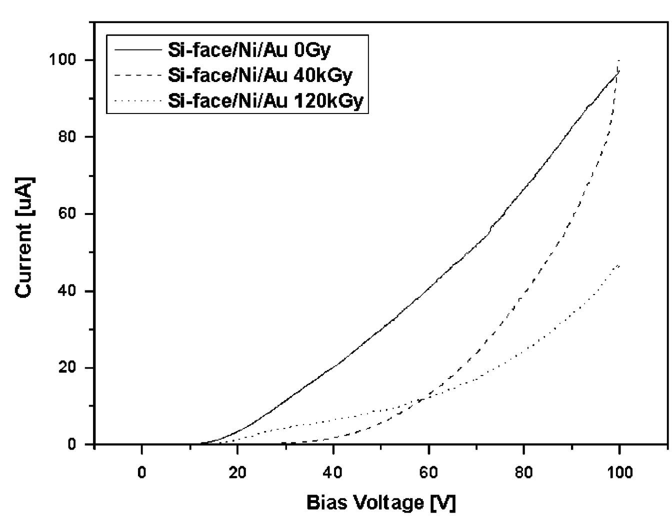

Fig. 2. The *I–V* curve of the samples with the Si-face/Ni/Au interface. (0 Gy: solid line, 40 kGy: dashed line, 120 kGy: dash dotted line.)

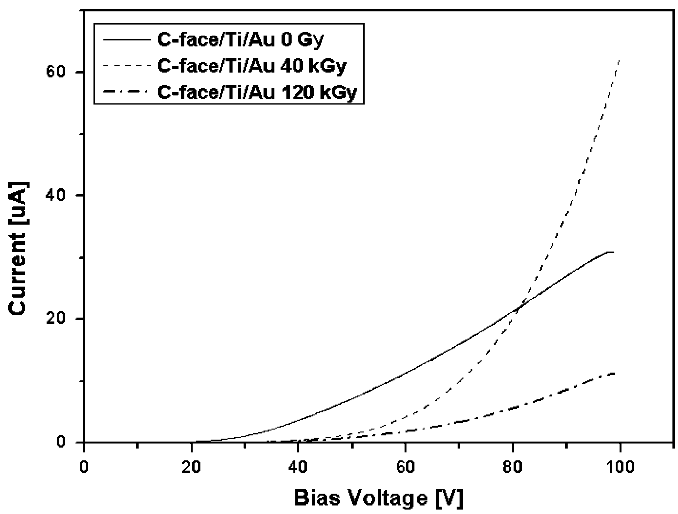

Fig. 3. The I–V curve of the samples with the C-face/Ni/Au interface. (0 Gy: solid line, 40 kGy: dashed line, 120 kGy: dash dotted line.)

the highest irradiation has the lowest value; this is similar to what is observed in Fig. 2.

The radiation-induced damage can be classified into two categories: bulk and surface effects. The most fundamental type of bulk radiation damage is the Frenkel defect, produced by the displacement of an atom of the semiconductor material from its normal lattice site. The vacancy left behind, together with the original atom now at an interstitial position, constitute trapping sites for normal charged carriers. These are called point defects to distinguish them from more complex "clusters" of crystalline damage. γ-Rays can create only point defects. When a given number of such defects have been formed, the carrier lifetime is reduced [11].

The surface effects are directly related to the increase in the leakage current. In our study, however, this was not observed because the metal contact process is processed after an irradiation at ^{60}Co γ-ray.

As a result, the effect of the point defects caused by the γ-ray irradiation is to decrease the leakage current as compared to the non-irradiated SiC sample except in the case of the Si-face/Ni sample irradiated by 40 kGy γ-dose.

The current transport at metal–semiconductor contact is mainly due to majority carriers, in contrast to p–n junctions, where the minority carriers are responsible for it. For high-mobility semiconductors, the transport can be adequately described by the thermionic emission theory [12].

According to the thermionic emission theory, the flow is limited by the rate at which carriers try to cross the barrier; the Schottky barrier height (SBH) was determined by using the forward current–voltage characteristics of the metal/semiconductor Schottky contacts. The total current density over potential barrier height is analyzed within the framework of the thermionic emission model originally described by Bethe [13]:

$$\mathrm{Jn} = J_{\mathrm{ST}}\left[\exp\left(qV/kT\right) - 1\right]$$

$$J_{\mathrm{ST}} = A^{*}T^{2}\exp\left[-\left(q\Phi_{\mathrm{Bn}}/kT\right)\right]$$

where J_{ST} is the saturation current density, k is the Boltzman constant, q is the carrier charge, T is temperature and A^* is the effective Richardson constant for thermionic emission, neglecting the effects of optical phonon scattering and quantum mechanical reflection. By using the Richardson constant $A^* = 194\,\mathrm{A/cm^2\,K^2}$ [14], the SBHs of non-irradiated SiC sample and two samples irradiated by 40 and 120 kGy γ-rays were determined as 1.06, 1.11 and 1.13 eV, respectively. The 6H-SiC semiconductor showed similar SBHs independent of the irradiation dose rate.

4. Conclusion

The bulk semi-insulating SiC detectors were fabricated by the simple process. The current–voltage curve patterns of the samples with the Si-face/Ni/Au and C-face/Ti/Au interface are found to be similar. The effect of the point defects caused by a ^{60}Co γ-ray irradiation is to decrease the leakage current as compared with the non-irradiated SiC sample except for the Si-face of sample irradiated by 40 kGy γ-ray dose.

The SBHs of the three SiC samples with different γ-ray doses were determined by using thermionic emission theory and the values of the SBHs were 1.06, 1.11 and 1.13 eV, respectively. As a result, the 6H-SiC semiconductor showed similar Schottky barrier heights independent of the dose rates of ^{60}Co γ-rays.

Acknowledgments

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