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Study of the current–voltage characteristics of a SiC radiation detector irradiated by Co-60 gamma-rays

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Abstract

The SiC semiconductor has recently emerged as an attractive material for an ionization radiation detection. A wide bandgap (3.03 eV) and high radiation damage resistance allow for the fabrication of detectors capable of operating at a high-temperature and in high radiation fields. The major aim of our study is to develop a robust detector which will be applied to harsh radiation environments. In this study, we fabricated the SiC radiation detectors and measured the current–voltage characteristics of SiC detectors irradiated by Co-60 gamma-ray source. The *I–V* curves showed a decrease of the leakage current with increasing dose rate of Co-60 gamma-ray in the 0–100 V bias voltage range.
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1. Introduction

Solid-state radiation detectors have been investigated and developed for many applications within various environments. The harsh radiation environments such as a nuclear reactor, high-energy physics experiments, or outer space can cause radiation damage to detectors [1]. Radiation damage, which deteriorates the performance of the devices, is a serious and important problem for semiconductor radiation detectors.

The SiC semiconductor has recently emerged as an attractive material for ionization radiation detection [2]. Due to its similar properties with a diamond such as the bandgap, the intrinsic carrier density, the resistivity, the cohesive energy, and the tightly bound structure, a detector based on semi-insulating SiC has the possibility of low leakage current, a good radiation resistance, and sensing the charge created during an ionization [3].

2. Experimental

2.1. Cutting process

For the experiment, we used a 6H-SiC wafer of 2 in. diameter supplied by Dow Corning Company. The properties of the 6H-SiC wafer are an upper $10^6\,\Omega$cm resistivity, 380 μm thickness, and (0 0 0 1)-oriented type. We prepared $10 \times 10\,\mathrm{mm}^2$ samples by using a semiconductor diamond saw. Because the Mohs hardness of the SiC semiconductor is about 9.0, the cutting process worked at more than 30,000 rpm of the blade speed and a 2.0 mm/min moving speed. This condition does not show a chipping at the edges of the SiC samples. Also, during the cutting process, we used a UV-tape to fix the wafer to the cutting table. Generally, a cutting process uses a wax to fix the wafer onto the working table of the diamond saw. After the cutting process, the wax is removed by an organic solvent or acetone from the wafer surface. The use of wax eventually causes a wafer surface pollution and a process time increase. Therefore, UV-tape provided two advantages, time reduction and pollution prevention. After the cutting process, we clearly observed that there were no

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stains on the SiC wafer surface due to the UV-tape. The Si-faces of the 6H-SiC samples have two tapes to discriminate between the Si-face and the C-face because the 6H-SiC single crystal wafer is transparent.

2.2. Gamma irradiation

We irradiated the samples in a glass bottle with Co-60 gamma-rays. The irradiation was performed at the Co-60 irradiation facility in the Korea Atom Energy Research Institute (KAERI) with dose rates of 5 and 15 kGy/h for 8 h. The total doses of the two samples were 40 and 120 kGy, respectively. The dose rate of 15 kGy/h is the maximum capacity of the Co-60 gamma source at KAERI. After the irradiation, the surfaces of the glass bottles were changed to a brown color.

2.3. Fabrication of the SiC radiation detectors

The surface of a SiC wafer was generally prepared by using the standard etching process by H_2SO_4 and H_2O_2 solutions and rinsed with deionized (DI) water, and the oxidation layer was removed by an HCl solution. In this study, the etching process only used acetone and it was rinsed with DI water because of its excellent chemical properties. It shortened the work time of the etching process. Metal contacts on the surface were fabricated by using a thermal evaporator in a vacuum condition. The contact process was implemented under the following conditions: 1.2×10^{-5} Torr, 80 °C heating temperature, and a 180°/min rotation speed of the SiC sample holder. The metal contacts were fabricated into two types (Fig. 1). The Si-face had the same metal contact with Ni(300 Å)/Au(2000 Å). But the C-face had the two different metal contacts with Ni(300 Å)/Au(2000 Å) and Ti(300 Å)/Au(2000 Å). Also, the circular contact diameters of the two faces were 5 mm.

2.4. Measurement of I–V characteristics

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

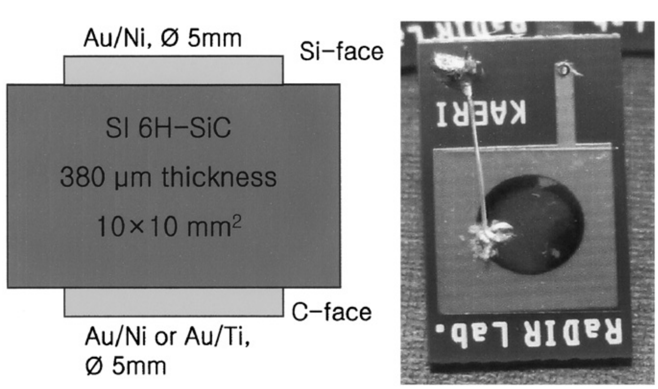

Fig. 1. Cross-section (right) and photograph (left) of the SiC sample.

3. Result and discussion

The leakage currents of the non-irradiated sample and 40 and 120 kGy-irradiated samples with the Si-face/Ni interface were measured in the bias range from 0 to 100 V and the results are presented in Fig. 2.

The highest current value is measured at the non-irradiated sample and the lowest current value is at the 120 kGy-irradiated sample. Fig. 3 shows the *I–V* curves of the C-face/Ti for the non-irradiated sample and the 40 and 120 kGy-irradiated samples. It was also measured under a biased voltage range from 0 to 100 V. The leakage current of the 120 kGy-irradiated sample is the lowest value, similar to Fig. 2.

Fig. 4 shows the leakage currents of the two sets. One set has a C-face/Ni interface and another set has a C-face/Ti interface. Each set is composed of 0 and 120 kGy-irradiated samples. The leakage current of the non-irradiated samples with the C-face/Ni and C-face/Ti interface is similar and the difference between the 120 kGy-irradiated samples is minor. Here, the leakage currents of the irradiated samples are decreased relative to the non-irradiated ones.

In this study, we fabricated the C-face/Ni and Ti interface. By the way, the use of the same metal on the Si and C face is advantageous to sample metallization process. Fig. 4 shows that the leakage current of non-irradiated samples with Ni and Ti interface is similar.

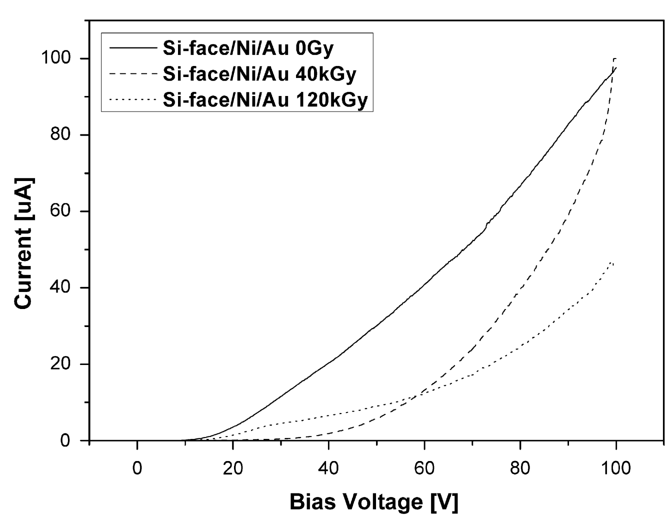

Fig. 2. The *I–V* curve of the samples with the Si-face/Ni interface (0 Gy—solid line, 40 kGy—dash line, 120 kGy—dot line).

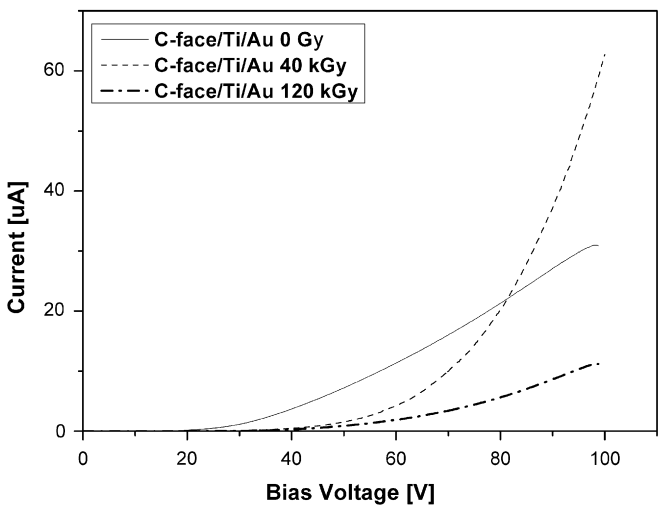

Fig. 3. The I–V curve of the samples with the C-face/Ti interface (0 Gy—solid line, 40 kGy—dash line, 120 kGy—dot line).

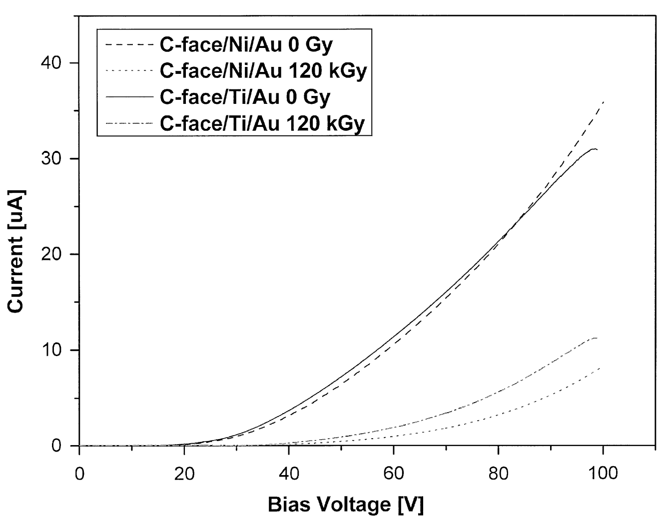

Fig. 4. The I–V curve of the two sets with the C-face/Ti and C-face/Ni (Ni: 0 Gy—dash line, 120 kGy—dot line, Ti: 0 Gy—solid line, 120 kGy—dash dot line).

Therefore, we will continually fabricate the C-face/Ni interface at the other study.

The radiation-induced damage can be classified into two categories of the 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, constitutes a trapping site for normal charged carriers. These are sometimes called as point defects to distinguish them from more complex "clusters" of a crystalline damage. Gamma rays can create only point defects. When enough of these defects have been formed, a carrier lifetime is reduced [4].

The surface effects are directly related to the increase in the leakage current. In our study, however, we did not consider it because the metal contacts process is operated after an irradiation at Co-60 gamma-ray.

As a result, the effect of the point defects caused by the Co-60 gamma-ray irradiation decreased the leakage current as compared to the non-irradiated SiC sample.

4. Summary

A bulk semi-insulating SiC detector was fabricated by a simple process. We carried out the experiment process of our study as follows: 6H-SiC wafer cutting process by using a semiconductor diamond saw; Co-60 gamma-ray irradiation (40 and 120 kGy); Si-face/Ni/Au, C-face/Ni/Au, and C-face/Ti/Au interface metal contact process; and the current–voltage characteristics measurement by using Keithley 4200-SCS with a self-voltage source. The I–V curve patterns of the samples with the Si-face/Ni and C-face/Ti interface are found to be similar. In each curve, the lowest leakage current is shown in the case of 120 kGy-irradiated sample. Also, the difference between the C-face/Ni interface and the C-face/Ti interface is minor under the same irradiation conditions, 0 Gy and 120 kGy. The present experimental results show that the effect of the point defects caused by Co-60 gamma-ray irradiation decreased the leakage current compared to the non-irradiated SiC sample.

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