Radiation Damage of SiC Detector Irradiated by High Dose Gamma Rays

Yong Kyun Kim*
Department of Nuclear Engineering, Hanyang University, Seoul 133-791, Korea

Sang Mook Kang, Se Hwan Park and Jang Ho Ha
Korea Atomic Energy Research Institute, Daejeon, 305-600, Korea

Jong Sun Hwang
Department of Electrical Engineering, Namdo Provincial College,

E-mail : ykkim4@hanyang.ac.kr

Two SiC radiation detector samples were irradiated by Co-60 gamma rays. The irradiation was performed with dose rates of 5 kGy/hour and 15 kGy/hour for 8 hours, respectively. Metal/semiconductor contacts on the surface were fabricated by using a thermal evaporator in a high vacuum condition. The SiC detectors have metal contacts of Au(2000 Å)/Ni(300 Å) at Si-face and of Au(2000 Å)/Ti(300 Å) at C-face. I-V characteristics of the SiC semiconductor were measured by using the Keithley 4200-SCS parameter analyzer with voltage sources included. 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 showed similar Schottky barrier heights independent to the dose rates of the irradiation with Co-60 gamma rays.

Keywords : Schottky Barrier Height , radiation detector, SiC, semiconductor detector

1. INTRODUCTION

Semiconductor radiation detectors have been investigated for many applications within various environments. The harsh radiation environments such as a nuclear reactor core, high energy physics experiments, or outer space can cause radiation damages to detectors [1]. A 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 the ionization radiation detection [2]. Due to its similar properties with a diamond such as the band gap, 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 currents, a good radiation resistance and a reasonable sensing capability of the charges created during the ionization process [3].

2. EXPERIMENTAL PROCEDURE

2.1. Cutting Process

We used a 6H-SiC wafer of 2 inch supplied by the Dow Corning. The properties of the 6H-SiC wafer are an upper 10^6 ohm-cm resistivity, 380 um thickness, and (0001)-oriented type. We prepared 10×10 mm^2 samples by using a semiconductor diamond saw. Generally, a cutting process uses a wax to fix the wafer onto the working table of the diamond saw devise. After the cutting process, the wax is removed by an organic solvent or acetone from the wafer surface. The use of wax causes a wafer surface pollution and an increase of process time. Therefore, the use of UV tape provided two advantages, a time reduction and a clean process. After the cutting process, we clearly observed that there were no stains on the SiC wafer surface due to the UV-tape. The Si-face 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 bottle with Co-60 gamma ray. The irradiation was performed at a Co-60 gamma irradiation facility at the Korea Atom Energy Research Institute (KAERI) with a dose rate of 5 kGy/hour and 15 kGy/hour for 8 hours. Consequently, the total doses of the two samples were 40 kGy and 120 kGy, respectively. The dose rate of 15KGy/hour is the maximum capacity of the Co-60 gamma source at KAERI. After an irradiation, the glass bottles were changed into brown color.

2.3. Fabrication of the SiC Radiation Detectors

The surface of a SiC wafer was generally etched by using the standard process by H_2SO_4 and H_2O_2 solutions and rinsed with de-ionized (DI) water, and the removal of an oxidation layer by a HCl solution was performed. In this study, the etching process only used acetone and it was rinsed with DI water because of its excellent chemical properties. It could shorten 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 ℃ heating, and a 180°/min rotation speed of the SiC samples holder. The SiC radiation detector had metal contacts of Si-face/Ni(300 Å)/Au(2000 Å) and C-face/Ti(300 Å)/Au(2000 Å). The diameter of the circular contacts was 5 mm.

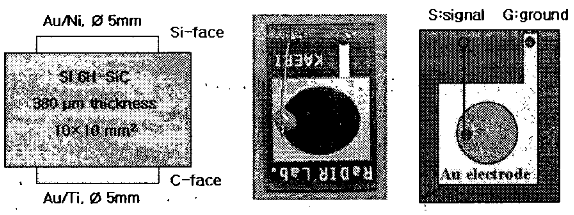

Fig. 1. Cross-section of a SiC sample after metallization process (left), photograph of the SiC semiconductor detector (middle), and the schematic FR4 PCB layer (right).

2.4. Measurement of I-V characteristics

To measure the current-voltage curve, the PCB layer was made of a FR4 substrate with a 10×10 mm^2 electrical Au contact pad. The SiC sample was fixed by a conducting epoxy onto the PCB layer and contacted by a wire for the electrical characteristics. The current-voltage 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.

3. RESULTS AND DISCUSSION

The leakage currents of the non-irradiated sample and two 40 kGy, 120 kGy-irradiated samples with the Si-face/Ni/Au interface were measured in the range from 0 to 100 V and the results are presented in Fig. 2. The lowest current value is the sample (dash dot line) irradiated by 120 kGy gamma-ray dose.

Fig. 3 shows the I-V curves of the C-face/Ti/Au interface for the three SiC samples. It was also measured under a biased voltage from 0 to 100 V range. The leakage current of the highest irradiated sample shows the lowest values, similar to Fig. 2.

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 called as point defects to distinguish them from more complex "clusters" of a crystalline damage. Gamma rays can create only point defects. When these defects have been formed enough, a carrier lifetime is reduced [4].

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

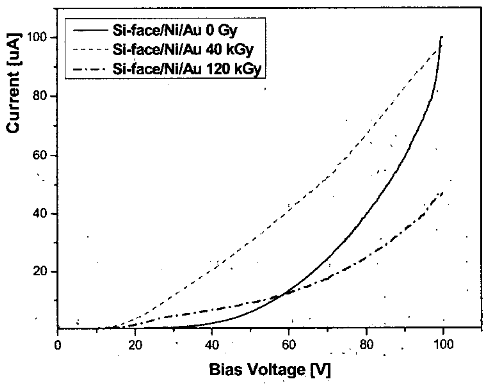

Fig. 2. The I-V curve of the samples with the Si-face/Ni/Au interface. (0 Gy-solid line, 40 KGy-dash line, 120 KGy-dash dot line)

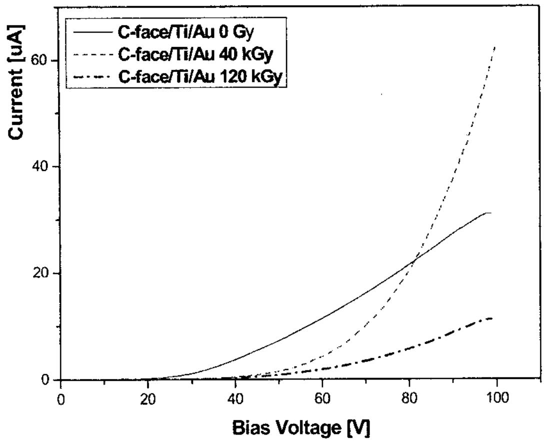

Fig. 3. The I-V curve of the samples with the C-face/Ni/Au interface. (0 Gy-solid line, 40 kGy-dash line, 120 kGy-dash dot line)

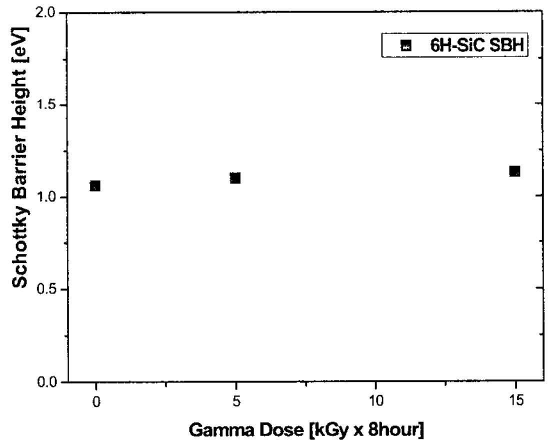

Fig. 4. The Schottky barrier heights of non-irradiation sample and 40 kGy, 120 kGy irradiated samples were determined by using the thermionic emission theory. The SBHs of non-irradiation, 40 kGy and 120 kGy samples are 1.06 eV, 1.11 eV, 1.13 eV, respectively.

As a result, the effect of the point defects caused by the gamma ray irradiation decreased the leakage current as compared to the non-irradiated SiC sample except to Si-face of sample irradiated by 40 kGy gamma dose.

The current transport in metal-semiconductor contacts is mainly due to majority carriers, in contrast to p-n junctions, where the minority carriers are responsible. For high-mobility semiconductors the transport can be adequately described by the thermionic emission theory [5].

According to the thermionic emission theory, the flow is limited by the rate at which carriers try to cross the barrier and 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 is analyzed within the framework of the thermionic emission model originally described by Bethe [6]:

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

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

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 $A^* = 194\ A/cm^2K^2$ [7], the SBHs of non-irradiated SiC sample and two samples irradiated by 40 kGy and 120 kGy gamma rays were determined as 1.06 eV, 1.11 eV and 1.13 eV, respectively. The 6H-SiC semiconductor showed similar Schottky barrier heights independent to the different dose rates of the irradiation with Co-60 gamma rays.

4. CONCLUSION

A bulk semi-insulating SiC detector was fabricated by a sample 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 Co-60 gamma ray irradiation decreased the leakage current as compared against the non-irradiated SiC sample except to Si-face of sample irradiated by 40 kGy gamma dose.

The SBHs of the three SiC samples were determined by using thermionic emission theory and the value of the SBHs were 1.06 eV, 1.11 eV and 1.13 eV, respectively. As a result, the 6H-SiC semiconductor showed similar Schottky barrier heights independent to the dose rates of the Co-60 gamma rays.

ACKNOWLEDGMENTS

This work has been carried out under the Nuclear R&D program of the Ministry of Science and Technology (MOST) and supported by the iTRS Science Research Center/Engineering Research Center program of MOST/Korea Science and Engineering Foundation.

REFERENCES

[1]. Larry A. et al., Nucl. Inst. Meth. A 428 (1999) 95
[2]. F. Nava et al., Nucl. Inst. Meth. A 437 (1999) 356
[3]. M. Rogalla et al., Nucl. Phys. B (Proc. Suppl) 78 (1999) 516.
[4]. G. F. Knoll, Radiation Detection and Measurement, 3rd ed., John Wily & Sons, Inc. New York, 1999.
[5] S. M. Cze, Physics of semiconductor device, 2nd ed., Wiley-Interscience, New York, pp353-409 (1981)
[6]. H. A. Bethe, MIT radiat. Lab. Rep. 43-12, (1942)
[7]. L. M. Porter et al., J. Mater. Res, 10, 26 (1995)