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Analysis on Bulk Radiation Damage of SiC Semiconductor Radiation Detector irradiated by Co-60 Gamma Ray

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1. Introduction

Semiconductor radiation detectors have been investigated 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 damages to detectors [1].

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 point defects to distinguish them from more complex "clusters" of a crystalline damage. Gamma rays create only point defects. When enough of these defects have been formed, a carrier lifetime is reduced [2]. Therefore, a radiation damage which deteriorates the performance of a device is a serious and important problem for semiconductor radiation detectors.

It has been shown that SiC is a useful material for radiation-resistant electronics, high-temperature electronics and high-frequency/high-power devices due to its excellent electronic and physical properties [3]. Due to the similar properties as 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 sensing the charge created during an ionization [4].

In this study, we fabricated a SiC semiconductor radiation detector and analyzed the bulk radiation damage for a 6H-SiC semiconductor irradiated by Co-60 gamma ray by using the thermionic emission theory [5].

2. Methods and Results

2.1. Manufacture and Experimental Procedures.

We used a 6H-SiC wafer of 2 inch in diameter supplied by Dow Corning Co.. The properties of the 6H-SiC wafer are an upper 1E6 ohm-cm resistivity, a 380 um thickness, and a (0001)-oriented type. We prepared 10×10 mm samples by using a semiconductor diamond saw. Among the SiC samples, we irradiated two different doses with Co-60 gamma rays. The irradiation was performed at the Co-60 gamma source at the Korea Atom Energy Research Institute (KAERI) with dose rates of 5 KGy/hour and 15 KGy/hour for 8 hours. The total doses of the two types of samples were 40 KGy and 120 KGy, respectively. 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(300Å) /Au(2000Å) and C-face/Ti(300Å)/Au(2000Å) . Also, the diameter of the circular contacts was 5 mm. The current-voltage characteristics of the 6H-SiC semiconductor detectors were measured by using the Keithley 4200-SCS parameter analyzer with voltage sources included. We measured the leakage currents at the biased voltage range from 0 to 100 V range. From the I-V curve, we analyzed the Schottky barrier heights on the basis of the thermionic emission theory.

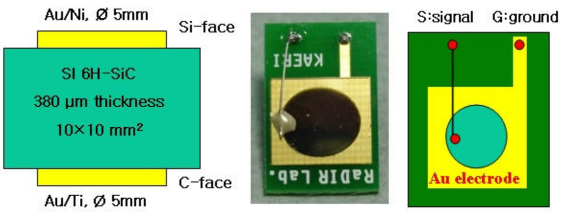

Fig. 1 Cross section of the SiC sample after metallization process(left) , photograph of the SiC semiconductor detector(middle), and the schematic FR4 PCB layer(right)

2.2. Discussion and Result.

The leakage currents of the non-irradiation sample and 40 KGy, 120 KGy-irradiation samples with the Si-face/Ni/Au interface were measured in the range from 0 to 100 V and they are presented in Fig. 2.

The lowest current value is the sample(dash dot line) irradiated by a 120 KGy gamma 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 is the lowest value, similar to Fig. 2.

The current transport in metal-semiconductor contacts is mainly due to majority carriers, in contrast to

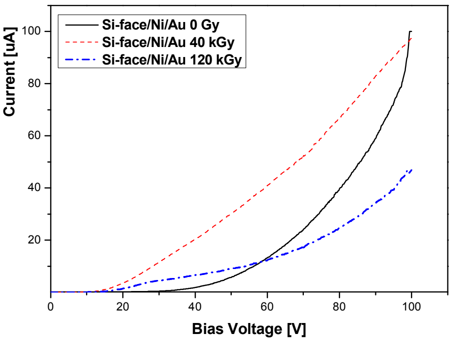

Fig. 2. The I-V curve of the samples with the Si-face/Ni/Au interface. (0 Gy-solid line, 40 KGy-dash line, 120 KGy-dash dot line)

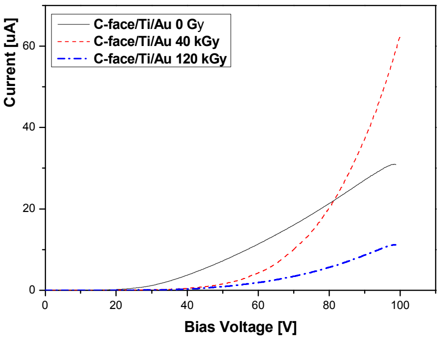

Fig. 3. The I-V curve of the samples with the C-face/Ni/Au interface. (0 Gy-solid line, 40 KGy-dash line, 120 KGy-dash dot line)

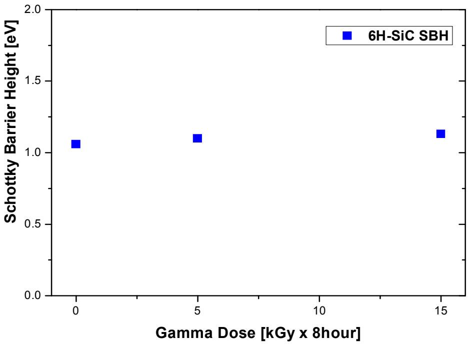

Fig. 4. The Schottky barrier heights of non-irradiation sample and 40 KGy, 120 KGy irradiation samples was determined by using the thermionic emission theory. The SBHs of non-irradiation, 40 KGy and 120 KGy samples are 1.06 eV, 1.11 eV, 1.13 eV, respectively.

p-n junctions, where the minority carriers are responsible. For high-mobility semiconductors the transport can be adequately described by the thermionic emission theory. 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 the potential barrier is analyzed within the framework of the thermionic emission model originally described by Bethe [6]:

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

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

Where J_{ST} is the saturation current density, k is the Boltzman constant, q is the carrier charge, T is the temperature and A* is the effective Richardson constant for a thermionic emission, by neglecting the effects of optical phonon scattering and a quantum mechanical reflection. By using the Richardson constant A* = 194 A/cm^2K^2 [7] the SBHs of the non-irradiated SiC sample and two SiC 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 with respect to the different dose rates of the irradiation with Co-60 gamma rays.

3. 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 when compared against the non-irradiated SiC sample except for the Si-face of the sample irradiated by 40 KGy gamma dose.

The SBHs of the three SiC samples were determined by using the 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 with respect to the different dose rates of the irradiation with Co-60 gamma rays.

Acknowledgements

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