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Electrical characterizations of Neutron-irradiated SiC Schottky diodes

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Abstract−Neutrons with an average energy of 9.8±0.8 MeV were irradiated onto silicon carbide Schottky diodes. After bombardment at a fluency of 2.75×10^{11} neutron/cm^2, the Schottky barrier height, ideality factor, and the leakage currents remained unchanged. The electrical properties began to deteriorate after bombardment at a fluency of 5.5×10^{11} neutron/cm^2. In this study, we demonstrate that SiC SBD is robust under neutron irradiations and is well suited for space operations up to bombardments at a fluency of 2.75×10^{11} neutron/cm^2.

Key words: Neutron Irradiation, Silicon Carbide, Diode

INTRODUCTION

Silicon carbide is considered one of the most promising materials in power electronics due to its wide bandgap (3.2 eV for 4H-SiC), high electron mobility (~900 cm^2/V·s), high thermal conductivity (3.7 W/cm·K) and high breakdown field (0.6 MV/cm) [1-3]. It is known that the radiation hardness of semiconductor materials is inversely proportional to the lattice constant, where the lattice constant of 4H-SiC is a=3.0730 Å and c=10.053 Å, which is lower than that of Si (5.43095 Å) and GaAs (5.6533 Å) [4]. In addition, high quality SiO_2 with low surface states enabled SiC to be compatible with silicon microelectronics because most compound semiconductors, such as InP, GaAs and GaN, suffer from a lack of native oxide with low surface states and high breakdown field [1]. Therefore, the demonstration of normally-off metal-oxide-semiconductor field effect transistor (MOSFET) is very difficult without a high quality insulation layer. Also, the SiC Schottky barrier diodes (SBD) have been shown to have an exceptionally high switching frequency with almost zero reverse recovery current [5]. The effects of gamma-ray and proton irradiations have been widely reported, compared with those from neutron irradiation [6,7]. Since one of the future applications will be military and space applications and electronic devices in space are exposed to high energy protons and neutrons during operations, it will be necessary to investigate the effects of neutron irradiations on SiC devices under various fluencies. It is known that the lifetime of a space aircraft such as artificial satellites is determined by the lifetime of the electronic devices inside [8]. Therefore, it is highly important to characterize the effects of neutron irradiations on SiC SBDs, which have potential applications in space operations.

EXPERIMENTAL

A 4H-SiC epilayer (10 μm thick, n-type) was grown on a highly doped 4H-SiC substrate. The backside was deposited with Ni (1,000 Å) by e-beam evaporation after being cleaned with a BOE (buffered oxide etchant) solution. The sample was then annealed at 900 °C for 1 min under nitrogen ambient conditions to form the ohmic contact. Using photolithography and e-beam evaporation, circular patterns of Ni (1,000 Å) were deposited on the front face of the 4H-SiC wafer, followed by annealing at 300 °C for 1 min. The diameter of the circular patterns was 100 μm. The neutron irradiations were performed with an MC-50 cyclotron in KIRAMS (Korea Institute of Radiological and Medical Sciences). Neutrons were generated by 35 MeV protons irradiating on the beryllium target. One proton generated 1.22×10^{-4} neutrons when colliding with beryllium target. This generated a high-energy neutron beam (E<30 MeV) that included thermal neutrons (E<1 eV) and fast neutrons (E>10 keV) with an average energy of 9.8±0.8 MeV. To approximate realistic irradiation conditions, neutrons that had a distribution of energy from zero to 30 MeV were irradiated onto our samples. To compare the effects from the fluencies, neutron irradiations were performed twice. The first fluency was approximately 2.75×10^{11} neutron/cm^2 at 1 atm. This fluency was calculated in conditions where the proton current was 20 μA and the time for irradiation was 120 min. The condition of the second neutron irradiation was the same as the first experiment. Current-voltage characteristics (I-V) were monitored with an Agilent 4155C parameter analyzer before/after each irradiation.

RESULTS

Fig. 1 shows a schematic diagram of vertical SiC SBDs. To characterize the effects of neutron irradiation, the Schottky barrier height, leakage currents at −40 V and ideality factor were compared before and after neutron irradiation. After the 1st neutron irradiation, there was only a nominal change in the Schottky barrier height and ideality factor. The Schottky barrier height (ϕ_B) was calculated by the equation $J=A^*T^2\exp(-(q\phi_B/kT))(\exp(qV/nkT)-1)$, where J is the forward current density, A^* is the Richardson constant, k is the Boltzmann constant (8.617×10^{-5} eV/K), q is the electronic charge (1.6×10^{-19} C) and T is the absolute temperature. The only difference was a reduction in the currents in the forward bias, which was due to the traps created by the incoming neutrons. After the 2nd neutron irradiation experiment, the Schottky barrier height was reduced from

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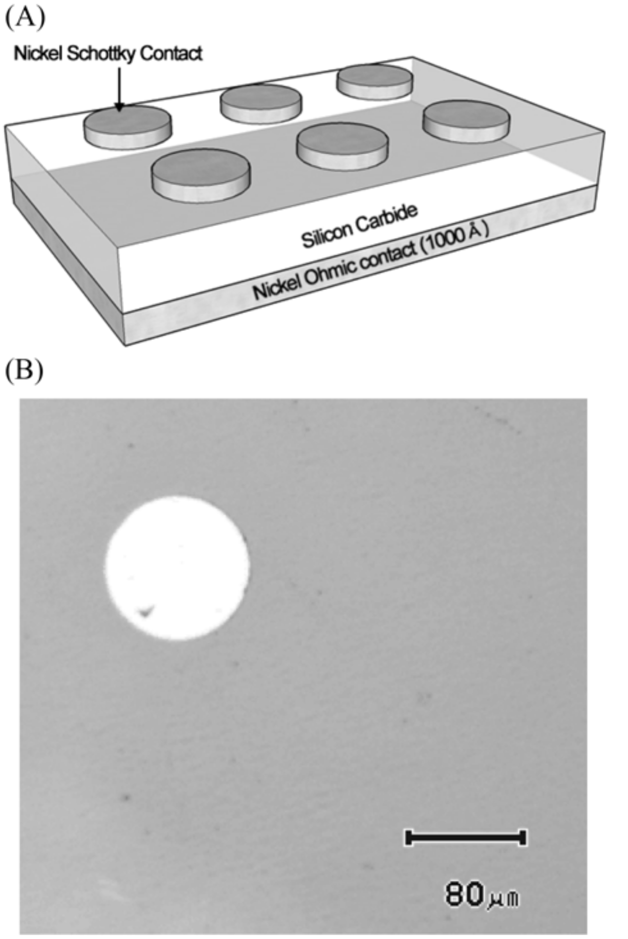

Fig. 1. (A) Schematic diagram of the SiC SBD. (B) Top view of the 100 μm diameter SiC SBD.

Table 1. Schottky barrier height before and after irradiations

	Schottky barrier height (eV) at room temperature
Reference	1.54
1st Neutron irradiation	1.53
2nd Neutron irradiation	0.95

Table 2. Leakage current density at −40 V

	Leakage current density (A/cm^2) at −40 V
Reference (25 °C)	5.24×10^{-8}
1st Neutron irradiation (25 °C)	1.36×10^{-8}
2nd Neutron irradiation (25 °C)	1.32×10^{-6}

1.53 eV to 0.95 eV at room temperature. The ideality factor, which was calculated by using the equation ($n=(q/kT)(\partial V/\partial(\ln J))$), was 1.1 before neutron irradiations and did not change after the 1st irradiations at room temperature. However, after the 2nd irradiation at room temperature it increased to 1.9. Based on the electrical properties, the threshold damage was reached after the 2nd irradiation.

The leakage current density is summarized in Table 2. For an ideal diode, the leakage currents should be independent of bias. However, due to the decreased Schottky barrier, the reverse leakage current will increase along with the bias condition [9]. As calculated from Fig. 2, the Schottky barrier height did not change after the 1st neutron irradiation. Therefore, the observed decrease in the reverse leakage current at −40 V can be explained by the change in the carrier concentration through the irradiation process, which can cause electrical traps. After the 2nd neutron irradiation, the decrease in the Schottky barrier height resulted in an increase in the reverse leakage current [9]. The electrical properties did not change much after the 1st neutron irradiation, which is critical to ensure the long term reliability of SiC-based electronics under high energy irradiation environments. The outstanding radiation robustness of SiC makes it a promising material for space and military applications.

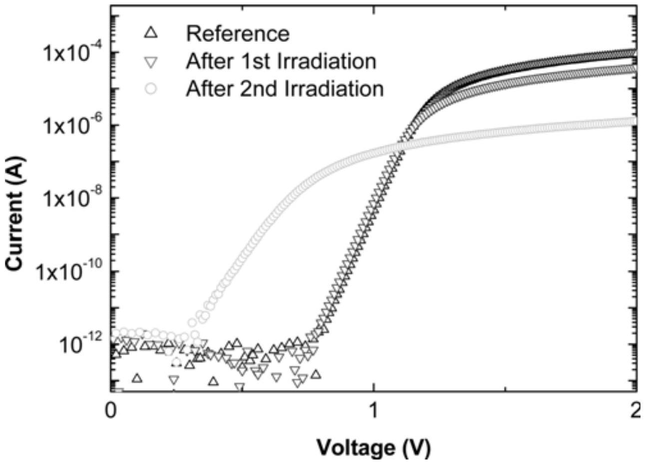

Fig. 2. Current-voltage characteristic at room temperature after irradiated with neutrons.

CONCLUSION

An SiC Schottky barrier diode was bombarded by neutrons (up to 30 MeV energy) at various fluencies. After the 1st neutron irradiations with a 2.75×10^{11} neutron/cm^2 fluency, the ideality factor and Schottky barrier height did not change. However, the SiC SBD began to degrade after the 2nd neutron irradiation with the same fluency. In addition, the Schottky barrier height was lowered and both the ideality factor and the leakage currents were increased after the 2nd neutron irradiation.

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