Defect Evaluation of 4H-SiC Schottky Diode depending on Fast-Neutron Irradiation

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1. Introduction

A Silicon carbide (SiC is a promising material for next-generation semiconductors. It has excellent properties compared to silicon, such as wide bandgap energy and high breakdown voltage. Although SiC has the disadvantage that crystal growth, doping and manufacturing process are difficult due to its chemical properties, many researches have been carried out to develop novel SiC devices which overcome the on-resistance–breakdown voltage limit of silicon devices. The application to nuclear facilities and aerospace has been suggested earlier [1]. In the application fields, crystal defects affecting device performance can be generated by radiations, especially neutrons. Many studies on radiation-induced defects in SiC have been carried out, but studies on defects caused by neutrons are relatively insufficient.

In this study, fast-neutron-irradiated epitaxial 4H-SiC SBDs were evaluated.

2. Methods and Results

The Schottky barrier diodes (SBDs) were fabricated using a 4H-SiC epitaxial wafer (produced by TYSiC). The wafer was cut to 1 × 1 cm size, rinsed with organic solvents and HF-etched to remove the natural oxide layer. Afterward, 100-nm-thick Au-Schottky contact of 3 mm diameter was formed on the epitaxial surface and an Ag-ohmic contact on the entire backside to manufacture an SBD. Fig. 1 shows the structure of the fabricated 4H-SiC SBD sample.

The SBD samples were irradiated with various fluences of fast neutrons using an MC-50 cyclotron (^{9}Be(p,n) neutron source) at the Korea Institute of Radiological & Medical Sciences. Neutron fluxes were calculated using the Monte Carlo N-particle 6.1 transport code. The neutron fluxes were calculated with respect to the distance from the Be target. In the MCNP simulation, the energy and current of the proton beam were assumed to be 30 MeV and 10 μA, respectively. For nuclear data in the simulation, the ENDF/B-VII.0 library was used. Table I shows the neutron flux distribution for each sample.

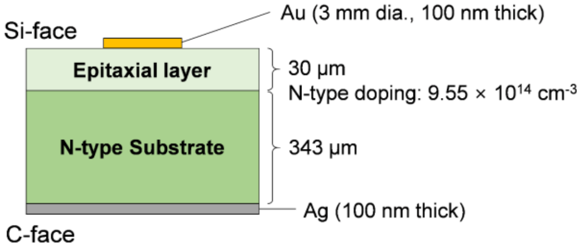

Fig. 1. Schematic diagram of the SBD sample.

Table I: Total neutron fluence for each SBD sample

Sample	Distance from Be target (cm)	Total fluence (neutrons/cm^2)
S0	Bare sample	
S1	35.71	2.70 × 10^{11}
S2	11.25	1.67 × 10^{12}
S3	3.45	1.45 × 10^{13}

To evaluate the defect parameters for fast-neutron-irradiated SiC, deep level transient spectroscopy (DLTS) [2] was performed using the DLTS system developed at Korea Atomic Energy Research Institute. The temperature range was 100–330 K. Capacitance transient signals were obtained with pulse signal injection (2 V and 50 ms) under a reverse-bias environment of -2 V at each temperature. A stabilization time of 1000 s was set at each temperature step to ensure that the heat was sufficiently transferred to the sample. During the measurements, the sample chamber was maintained at a vacuum of 1–2 × 10^{-5} mbar using a turbomolecular pump. The frequency of the AC signal was 2.5 MHz.

Fig. 2 shows the DLTS spectra of the SBD samples. The spectra were plotted only for τ = 0.15, 0.30, and 0.61 s^{-1}. The peak observed around T = 300 K increases with the neutron fluence. In addition, in the case of the S3 sample with a high neutron fluence, the DLTS signal at approximately 300 K shows multiple peaks in a complex region. We fitted the DLTS signals to a Gaussian distribution function to deconvolute the merged peaks.

Fig. 3 shows the deconvolution of the merged peaks and Arrhenius plot for the S3 sample. The 250 K peak (Peak#1) interfered with 300 K (Peak #2). The fitted line for the merged peaks, indicated by the red dashed line in Fig. 3(a), agrees well with the measured DLTS data. In Fig. 3(b), The trapped energy levels were evaluated to be E_C-0.34 and E_C-0.64 eV for Peak#1 and Peak#2, respectively. Peak#1 and Peak#2 are determined to be $Z_{1/2}$, one of the primary intrinsic defects of 4H-SiC. The typical activation energy of the $Z_{1/2}$ is E_C-0.63–0.68 eV; it is known to be a defect caused by carbon vacancies/interstitials and increases with electron or charged particle irradiation [3], and has a concentration of 10^{-12} cm^{-3} order in the as-grown epitaxial layer. The peak in the region below 300 K (e.g., EH1 near 200 K), which is primarily seen in DLTS studies using electron beam irradiation on SiC, was not shown in this experiment. Therefore, we can infer that only carbon-related defects occurred through fast neutron irradiation.

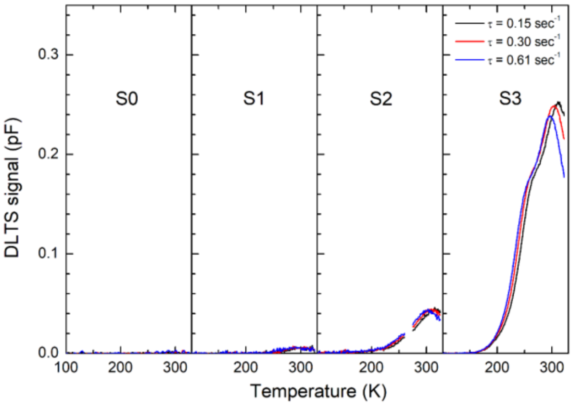

Fig. 3. DLTS spectra measured on the SBD samples with different neutron fluences.

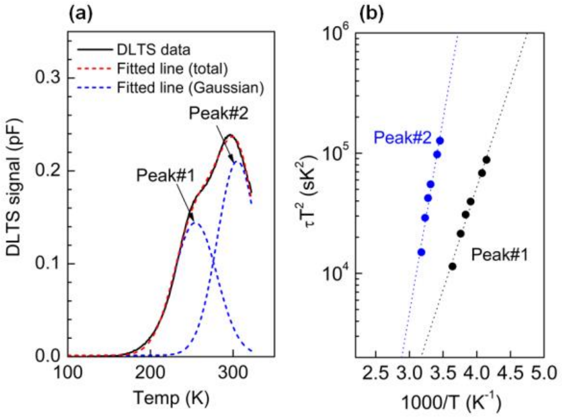

Fig. 4. Deconvolution of the DLTS signal in the complex region containing 250 K and 300 K for the S3 sample (τ = 0.61 sec^{-1}).

Table II shows the evaluated defect and carrier density. In the case of S1, with the lowest neutron fluence, the defect concentration was calculated to be 7.54×10^{12} cm^{-3}. This value is comparable to the $Z_{1/2}$ concentration of as-grown 4H-SiC epitaxial, 0.3–2 × 10^{13} cm^{-3}. This implies that there will be no noticeable change in the electrical properties of 4H-SiC devices irradiated by fast neutrons by up to 2.7×10^{11} cm^{-2}. Fig. 5 shows the dependence of the net carrier density and defect concentration of the 4H-SiC SBD samples on the neutron fluence. It is evident from Fig. 5 that as the neutron fluence increases, the defect concentration increases, whereas the net carrier density decreases. However, the defect concentration and net carrier density did not increase or decrease linearly with increasing neutron fluence. If neutrons irradiate the SBD sample for more than 1.45×10^{13} n/cm^2, we can infer that the defect concentration and net carrier density will be saturated.

Table II: Carrier and defect concentration of fast-neutron-irradiated samples

Sample	Defect density (cm^{-3})	Carrier density (cm^{-3})
S0	-	9.50×10^{14}
S1	7.54×10^{12}	9.33×10^{14}
S2	5.70×10^{13}	7.91×10^{14}
S3	1.50×10^{14}	1.62×10^{14}

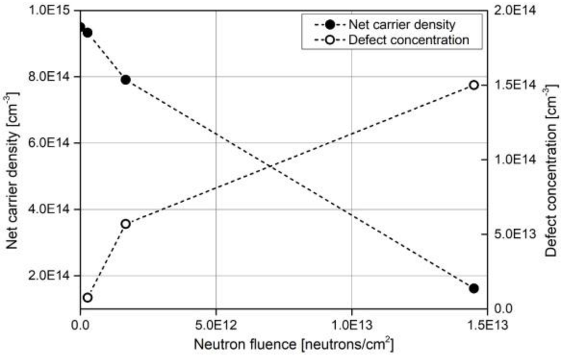

Fig. 5. Dependence of the net carrier density and defect concentration of the 4H-SiC SBD samples versus the neutron fluence.

3. Conclusions

The electrical characteristics and defect concentration of the fast-neutron-irradiated epitaxial 4H-SiC SBDs were evaluated. The fabricated SBD samples were irradiated by neutrons under three neutron fluence conditions using a cyclotron that accelerated protons with an energy of 30 MeV. The neutron beam fluence for each SBD sample was determined through a Monte Carlo simulation using the MCNP code. Moreover, the KAERI-DLTS system was developed for defect analysis of semiconductor materials.

REFERENCES

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