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Radiation Hardness Test of GaN Diode for Irradiation with High Energy Electron Beam

S. Narita[1], Y. Yamaguchi[1], Y. Chiba[1], H. Yuki[2], F. Hinode[2], and J. Kasagi[2]

[1]*Department of Electrical and Electronic Engineering, Iwate University, Morioka, 020-8551*
[2]*Laboratory of Nuclear Science, Tohoku University, Sendai, 982-0826*

The GaN is expected to be a new material for the particle detector with radiation hardness, as substitution of Si. We have developed the GaN Schottky diode which is a prototype of the ionizing detector. In this study we performed the test of radiation tolerance for the diode we fabricated, irradiating a high energy electron beam. As the result, we found that the performance of the diode was not changed significantly even after irradiating 10^{16}/cm^2 electrons.

§1. Introduction

In high-energy collider experiments, the beam luminosity has been increasing, and a semiconductor detector with radiation hardness is strongly desired in the current and future experiments. Several semiconductor materials have been investigated for developing new particle detectors as the substitution of Si [1, 2]. Among them, a wide-gap nitride semiconductor, especially gallium nitride (GaN), is one of the possible candidates. Recently, GaN devices have been widely used (e.g., light emitting device) and the technology to produce high quality substrate has been improved remarkably, so that development of the particle detector with GaN is now promising [3].

We have been developing the GaN based particle detector and successfully fabricated the GaN Schottky diode which has high quality in electrical and optical characteristics. Now it enables us to realize the GaN particle detector. In this study, we irradiated the diodes with high energy electrons and discussed the radiation hardness of GaN material.

§2. Experiment

2.1 GaN diode sample

The Schottky barrier diodes used in this study were fabricated with heterostructure substrate produced by Powdec K.K. growing an epitaxial GaN layer on n-type SiC substrate. Most of the current GaN devices are based on GaN on Sapphire substrate. For the Schottky diode device using GaN/Sapphire substrate, both Schottky and Ohmic contacts have to be made on the same surface because Sapphire is insulator. However, the diode with such a structure is not preferred to use for the particle detector because the device design is complicated and its sensitive area is limited. On the other hand, the diode with GaN/SiC substrate can be designed more simply due to the electric conductivity of SiC. The Ohmic contact can be put on the SiC side. The diode structure is shown in Fig.1.

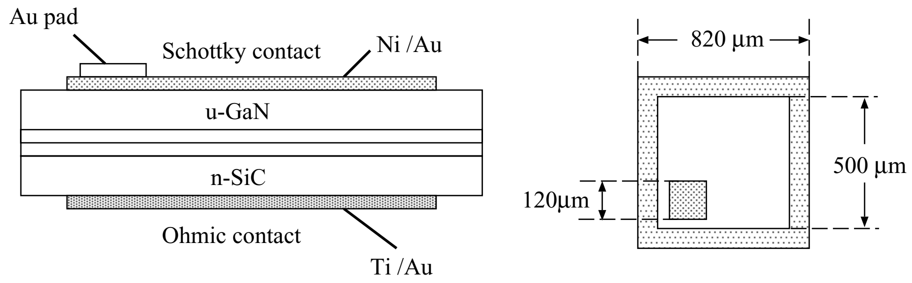

Fig.1. GaN diode structure.

The chip size of the diode was 0.5×0.5 mm^2, and the thickness of the GaN and SiC layers were ∼900 and ∼280 nm, respectively. The Ti/Au Ohmic contact was deposited on to the SiC and the Schottky Ni/Au electrode was put onto the GaN layer. For the irradiation test, the diode was placed onto the metal package. The current-voltage (I-V) characteristics of the diodes were measured by the ultra high resistance meter (ADVANTEST R8340). The leakage current was well suppressed (∼10 nA/cm^2) and the breakdown voltage was typically above 20V. These performances were comparably good to the present GaN diode. We also investigated the photo-conductivity to the UV light, and it showed a good performance as the photo diode. Actually, the thickness of the sensitive layer was too thin to evaluate the performance for the charged particle (even for, e.g., α particles), for now.

The I-V characteristics were measured before and after irradiation in order to determine the effects of the incident electrons.

2.2 Electron beam irradiation

Beam irradiation was carried out at Laboratory of Nuclear Science, Tohoku University (LNS), using a 150 MeV pulsed electron beam. The beam current was measured by the SEM placed at the downstream of the target diodes. The conversion factor from the SEM current to the beam current was calibrated in advance of the experiment, which has about 30% uncertainties. The mean beam current value in this experiment was found to be 2.5 μA. We assumed that the beam condition was stable during the irradiation, then the current measurement was employed just once in prior to the irradiation. In this experiment, we prepared several diodes and irradiated them with electrons with various fluences. During the irradiation, the target diodes were not applied voltage, then the output currents from the diode were not monitored.

The beam profile was measured by the radio-activity of aluminum foil irradiated with the electron beam with the same conditions in the irradiation to the diodes. After irradiating the foil, the activity of the segmented area of the foil was measured by a Ge detector. The profiles along X and Y axes with the fitted Gaussian curves are shown in Fig.2. The electron fluences on the diode were obtained considering the mean current of the beam and these profiles. The fluence for each sample is shown in Table 2.2. The errors in the list were from the uncertainties of the SEM calibration data.

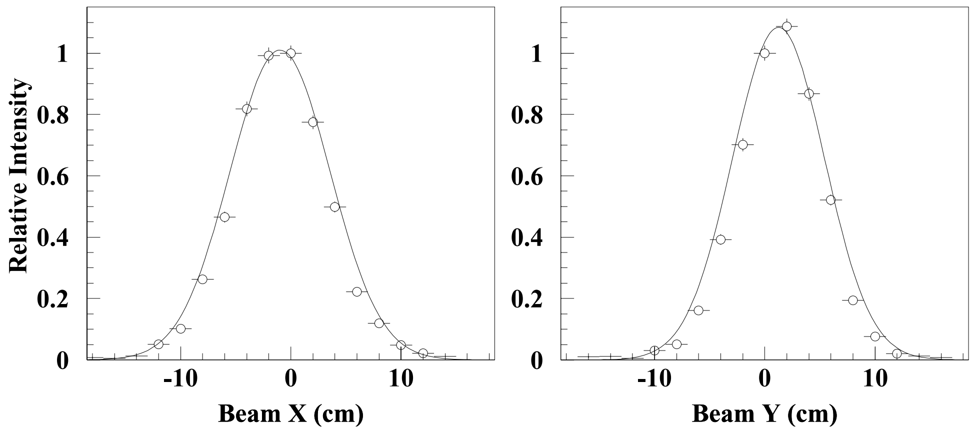

Fig.2. Beam profile fitted with the Gaussian. (left:X, right:Y). The fitted curves represent $f(x) = 1.01e^{\frac{(x+0.98)^2}{6.44^2}}$ for X-axis and $f(y) = 1.08e^{\frac{(y-1.24)^2}{5.90^2}}$ for Y-axis, respectively.

Table 1. Calculated electron fluences for each sample.

	Electron fluence $[/cm^2]$
Sample 1	$2.2 \pm 0.7 \times 10^{14}$
Sample 2	$2.2 \pm 0.7 \times 10^{15}$
Sample 3	$1.8 \pm 0.4 \times 10^{16}$
Sample 4	$3.4 \pm 1.0 \times 10^{16}$

§3. Results and Discussion

Figure 3 shows the I-V curves before and after irradiation for each fluence. No significant increase of leakage currents was seen even with the electron fluences above 10^{16}/cm^2. The break down voltage was not changed clearly. These results would prove the radiation hardness of the GaN.

The degradation of the semiconductor detector is strongly dependent on the energy loss of particles irradiated in both non-ionizing (atomic displacement) and ionizing (form of electron-hole pair) processes in the material. The non-ionizing energy loss of a 150 MeV electron is estimated to be 0.1 keV cm^2 g^{-1} [4], and this is smaller than that of other charged particles and a neutron. Besides the type of the particles, we should consider that the thickness of the diode used in this experiment was just $\sim 1\mu$m. The particle detectors used practically have much thicker structure, so that non-ionizing and ionizing effects are supposed to increase in such detectors. Therefore we still need to perform the irradiation test using heavy charged particles such as protons or α particles to discuss precisely the radiation hardness of the GaN material. Furthermore, we should repeat the test with changing the experimental conditions since the damage effects depend on various parameters (e.g., with/without applying the voltage, temperature, device structure, and so on).

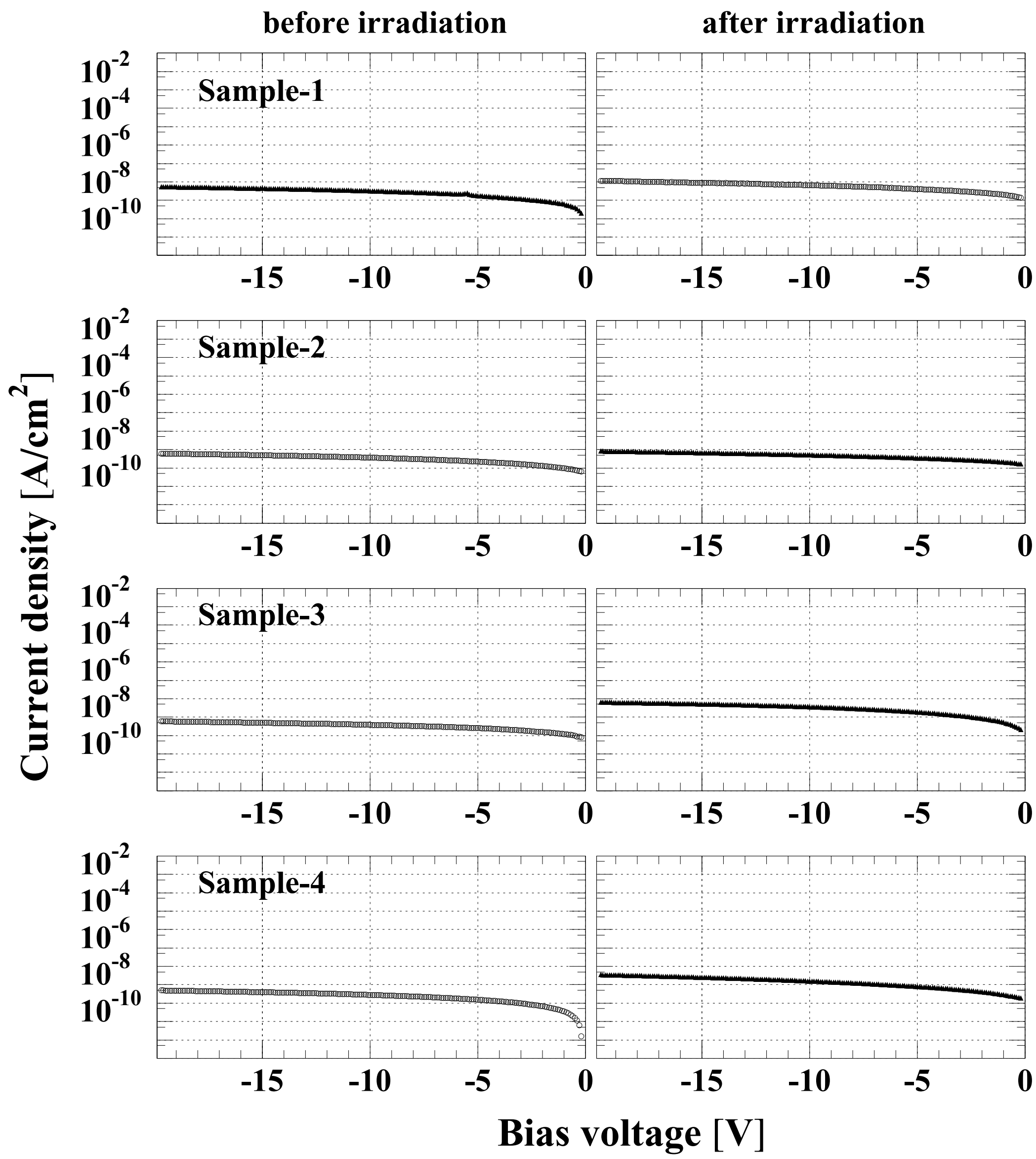

Fig.3. Current-Voltage characteristics for the sample before and after electron beam irradiation.

§4. Summary

We have evaluated the tolerance of the GaN material for the radiation damage irradiating with high energy electron beam. The performance was not significantly changed after irradiating 10^{16} /cm^2 electrons. The GaN might be a promising candidate for the material of future particle detectors. We should keep investigating the performance under various conditions and ensure the advantages.

Acknowledgment

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