A Study on the Improvement of Switching Speed of NPT-IGBT by Fast Neutron Irradiation

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1. Introduction

Among the characteristics of a power semiconductor, the lifetime of the minority carrier is one of the most important parameters. A minority carrier with a long lifetime in a power semiconductor device may cause switching delay or power loss in switching [1].

The insulated gate bipolar transistor (IGBT) has been widely used for high power switching devices due to low on-state forward voltage drop and fast switching speed. But, turn-off delay time occurs due to the tail current generated by the minority carrier existing in the n-drift region during turn-off, which reduces the switching speed [2]. Recently, to mitigate this problem, studies on the control of the MCLT to improve the switching speed of IGBTs are carried out [3]. A crystal defect is formed in the n-drift region of an IGBT to realize a deep energy level within the energy band. The deep level act as the recombination center of the minority carrier to reduce the turn-off delay time and control the lifetime by reducing the lifetime of the minority carrier injected during the device operation. The particle-beam irradiation method, such as electron, proton, fast neutron and others, has been used to control the lifetime of the minority carrier of a silicon power semiconductor device [4-5].

In this study, the various electrical properties like on-state forward voltage drop and switching speed of NPT-IGBT devices were measured before and after irradiating by fast neutron.

2. Experimental

The device used in this study is an NPT-IGBT., which is currently used for mass production.

The fast neutron was irradiated using the MC-50 cyclotron at the KIRAMS as shown in fig 1. The IGBT was irradiated in the horizontal direction.

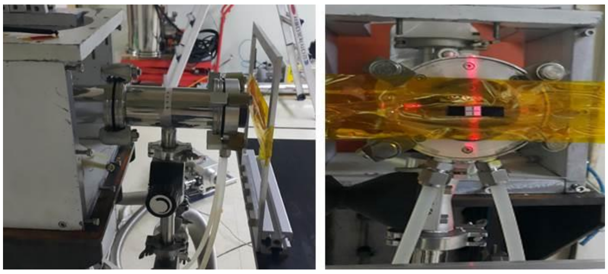

Fig. 1 Align the samples at the end of the collimator

To generate the neutron beam, the proton beam in which the energy was fixed at 30 MeV was irradiated on a beryllium target with a thickness of 0.5 cm. The neutron spectrum at the position 1 cm after the opening of the graphite collimator was simulated using MCNP6.

Fig 2 shows the simulated neutron spectrum generated by 20-μA incident proton. The dose of the irradiated fast neutron was varied between 1×10^9 and 1×10^{11} n/cm^2 [6].

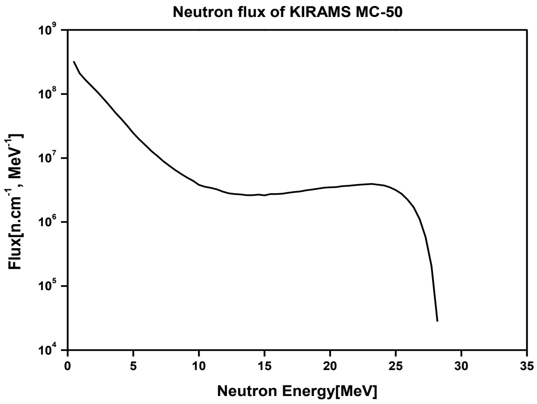

Fig. 2 Neutron spectrum generated by the ^{9}Be(p,n) reaction in the MC-50 cyclotron

After fast neutron irradiation, the specimen was thermally treated at 300 ℃ for 1 hour to stabilize the generated crystal defects. To analyze the electrical properties before and after fast neutron irradiation were measured.

3. Results and Discussion

Fig. 4 shows the on-state forward voltage drop characteristics. The voltage drop of the device before fast neutron irradiation was 2.075 V, which increased to 2.2, 2.315 and 2.445 V, respectively, depending on the irradiation doses compared with that of the before irradiation device. This phenomenon appeared because the crystal defect generated by the fast neutron irradiation acted as the recombination center of the minority carrier to increase the resistance component of the device.

We can also see that the more the irradiation dose increased, the more the voltage drop rapidly increased. The reason for this is that the more the irradiation dose increased, the more the crystal defects generated over the entire device by the irradiation of fast neutron increased to significantly increase the resistance component.

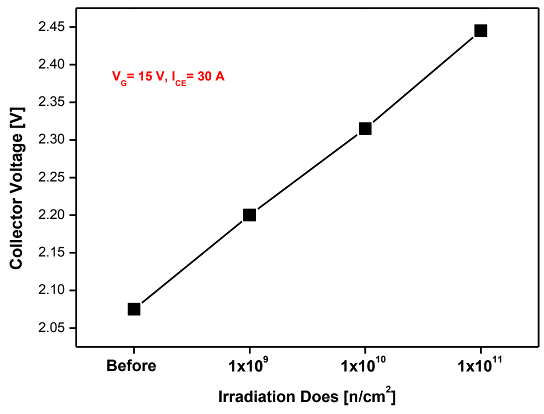

Fig. 4 On-state forward voltage drop of the IGBT

The comparison of the turn-off delay time before and after irradiation. The turn-off delay time of the device before irradiation was 170 ns, which significantly decreased to 134, 116 and 92 ns when fast neutron was irradiated in doses of 1×10^9, 1×10^{10}, 1×10^{11} n/cm^2, respectively. This result was obtained because the amount of generated crystal defect increased as the irradiation dose of the fast neutron increased, which means that it increased the recombination of the minority carrier injected into the n-drift region to effectively reduce lifetime. In other words, the switching speed of the IGBT improved as a result of the fast neutron irradiation.

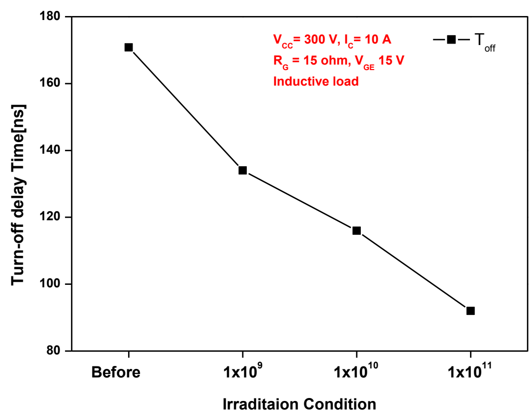

Fig. 5 Turn-off delay time of the IGBT

Although the lifetime of the minority carrier can be effectively reduced by irradiation fast neutron onto the IGBT, a phenomenon is increase in the on-state forward voltage drop. The switching speed is improved depending on the fast neutron irradiation condition, as shown in fig 6, the on-state forward voltage drop value increases due to the increase in the resistance component the device.

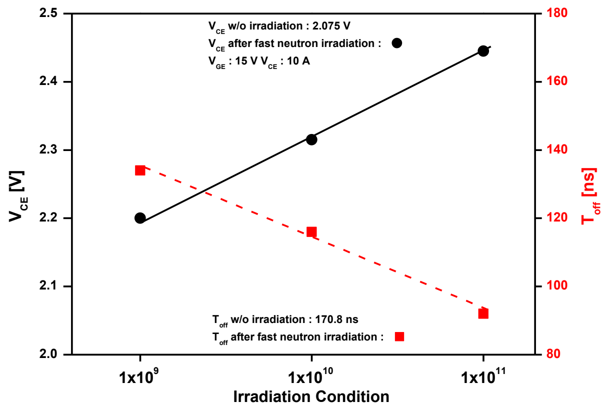

Fig. 6 On-state forward voltage drop of the IGBT

The increase in the on-state voltage drop becomes a factor that lowers the energy efficiency by increasing the energy loss of the device operation. For this reason, fast neutron irradiation conditions should be set by trading off the on-state forward voltage drop and switching speed which are major characteristics of the IGBT operation.

4. Conclusion

To improve the switching speed of a IGBT, devices were produced by irradiating various doses of fast neutron, and electrical properties were comparatively analyzed with the IGBT device where before irradiated.

The turn-off delay time of the device where before irradiated was approximately 170 ns and those of devices where fast neutron was irradiated in doses of 1×10^9, 1×10^{10}, 1×10^{11} n/cm^2 were 134, 116 and 92 ns respectively.

The reduced in the lifetime of the minority carrier flowing into the n-drift region due to the crystal defect helps improve the switching speed of the IGBT. But, the resistance component increased due to the crystal defect generated by the fast neutron irradiation in the on-state, increasing of the forward voltage drop.

So, to improve and optimize the IGBT performance, appropriate condition should be determined by trading off each electrical properties.

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