Effect of Gamma-Ray Irradiation on the Performance of 600V NPT-IGBT

Hani Baek [a, b], Gwang Min Sun [a*], Sung Ho Ahn [a], Chan Sun Shin [b], Gi Hyun Kown [b]
[a]*Korea Atomic Energy Research Institute, 989-111 Daedeok-daero, Yuseong-gu, Daejeon, Korea*
[b]*Myongji University, Materials Science &Engineering Dept., 116, Myonji-ro, Cheoin-gu, Yongin, Korea*
[*]*Corresponding author: gmsun@kaeri.re.kr*

1. Introduction

Fast neutron irradiation using nuclear reactors is an effective method to improve switching loss and short circuit durability of power semiconductor (IGBT and IGT *etc.*). However, not only fast neutrons but also thermal neutrons and gamma-rays exist in the nuclear reactor. Moreover, the electrical properties of the IGBT may be deteriorated by the irradiation of thermal neutrons and gamma-rays. Thermal neutrons give rise to the doping effect by transmuted atoms. Gamma-gays heat the target and recoil atoms remaining damages, which results in an undesirable energy level within the energy band gap. Research on various kinds of radiation damages is necessary to improve the IGBT device through fast neutron irradiation.

The radiation damages are known to be caused by Total Ionizing Dose (TID) effect and Single Event Effect (SEE) and Displacement Damage [1-2]. Especially, the TID effect deteriorates the electrical properties such as leakage current and the threshold voltage of a power semiconductor [3-4].

In this study, the TID effect by gamma-ray irradiation on electrical properties was evaluated for 600 V NPT-IGBT.

2. Experimental

The device used in this study is a NPT-IGBT. The gamma-ray was irradiated at the low-level gamma irradiation facility of Advanced Radiation Technology Institute (ARTI) [4]. Pencil-type six ^{60}Co sources were used. Its initial activity was 3,800 Ci. The devices irradiated were fixed at a distance of 27.8 cm from the source, where a dose rate of 50 Gy/h was set. The TID of gamma-ray was from 25 to 1000 Gy.

Fig. 1. Experimental of gamma-ray irradiation in NPT-IGBT

The irradiated devices were annealed at 300℃ for 1 hour to stabilize the generated lattice defects. After annealing, the devices were mounted on TO-3 type package for the analysis of electrical properties. The threshold voltage (V_{TH}) and the on-state forward voltage drop (V_{CE}) before and after gamma-ray irradiation were measured by using Keithly 2651 and 2636 high power source meter as shown in Fig. 2(a).

Switching time was measured by using a Tektronix MD3054 oscilloscope, which receives the timing signal from a circuit that permits instantaneous change of high current in inductive loads as shown in Fig. 2(b). Switching time before and after irradiation was compared with the turn-off delay time.

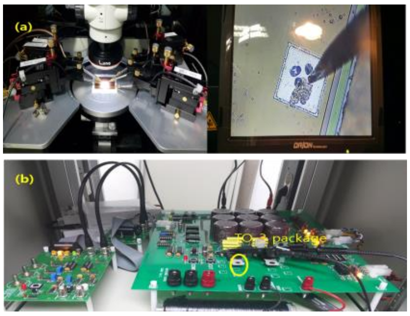

Fig. 2. (a) Instrument in Keithly 2651 and 2636 source meter (b) Circuit of system for turn-off delay time measurement

3. Results and Discussion

Fig. 3 shows the measured collector-emitter current according to the threshold voltage. Energetic gamma-rays cause lattice defects especially in the gate oxide and Si-SiO$_2$ interface, which becomes more severe in the semiconductor like IGBT, IGT and MOSFET and so on. Lattice defects play as trap center and affect V_{TH}. Gamma-ray irradiation negatively shifts the V_{TH} curves as shown Fig. 3(a). The negative shift is attributed to the increase of positive trapped charges in the gate oxide [5-6].

Fig. 3(b) shows the threshold voltage according to TID. The doses are 25, 50, 100, 200, 300 and 1000 Gy. V_{TH} was initially 10 mA before irradiation and decreased to 6.015, 5.982, 4.691, 3.398, 3.420, 2.347 and 2.039 V according to the TID, respectively.

The gamma-ray irradiation is known to create a lot of electron-hole pairs mainly in the SiO$_2$ gate insulator [5].

When the positive gate voltage is applied, holes move toward the Si-SiO$_2$ interface. Phosphorus-vacancy traps these moving holes called an E-center, which produces a positive fixed charge. It induced a decrease of the V_{TH}.

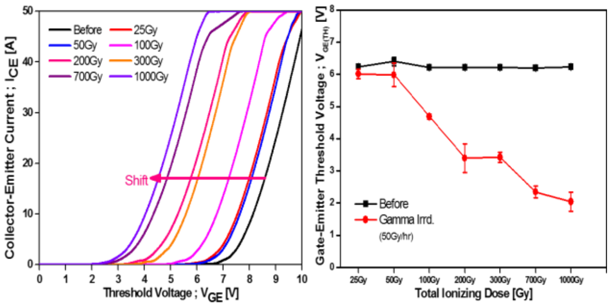

Fig. 3. (a) Transfer characteristics and (b) Threshold voltage of 600 V NPT-IGBT

The charges trapped in SiO_2 and Si-SiO_2 interface result in a change of carrier mobility in the transistor channel and thus lead to a decrease in its conductivity modulation. As shown in Fig. 4, the collector-emitter voltage(V_{CE}) of the device before gamma-ray irradiation was approximately 1.83 V. It was confirmed that V_{CE} decreases to 1.82, 1.81, 1.79, 1.80, 1.78, 1.76 and 1.77 V, respectively as TID increased. The decline of the carrier mobility has a negative influence on the device conductivity.

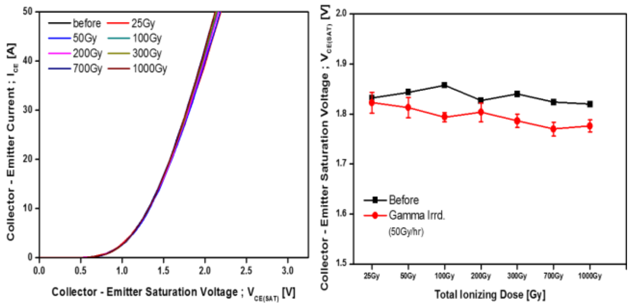

Fig. 4. On-state forward voltage drop of 600 V NPT-IGBT

Turn-off delay times of the device before and after gamma-ray irradiation are compared each other in Fig. 4. The turn-off delay time was initially 212 ns before irradiation, which largely increased to 225, 232, 258, 298, 311, 328 and 350 ns according to the TID. This is because the lattice defect decreases the carrier mobility and increases the lifetime of minority carriers in the device. Gamma-ray irradiation deteriorates the switching characteristics of the device.

4. Conclusion

This work can confirm the effect of the gamma-ray irradiation on the electrical properties of 600 V NPT-IGBT. Gamma-ray generates lattice defects in the gate oxide and Si-SiO_2 interface of the IGBT. The lattice defect acts on the center of the trap and affects the threshold voltage, thereby lowering the threshold voltage according to the TID. In addition to the change in the carrier mobility, the conductivity modulation decreases in the n-drift region which indicates a negative influence that the forward voltage drop decreases.

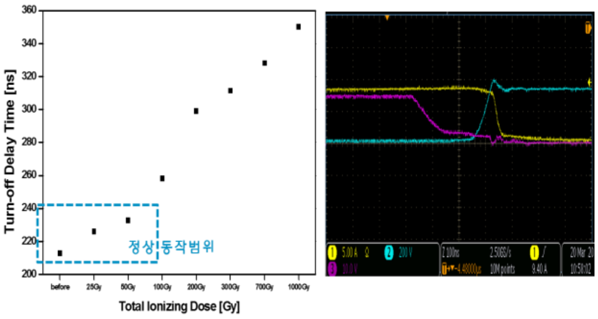

Fig. 5. Turn-off delay time of 600 V NPT-IGBT

The turn-off delay time of the device before irradiation was 212 ns. Those of devices after irradiation increased up to 350 ns at a dose of 1,000 Gy. The gamma-ray irradiation increased the turn-off delay time of the IGBT by about 65%, and the switching characteristics were deteriorated.

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