The Improvement of Switching Time in Silicon Bipolar Junction Transistor by 8 MeV Electron Irradiation

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Abstract

The switching investigations on the silicon bipolar junction transistors (Si BJT) for improved the switching time and power losses of switching by reducing minority carrier lifetime have done by electron irradiation. This paper has presented the switching time developed by 8 MeV electrons irradiation to NPN H1061 transistors with 5, 10, 15, 20 and 25 kGydosages to compare with no treatment transistors. The result shows that electron irradiation can reduce the minority carrier lifetime. The switching time and switching loses are decreased obviously at all 1, 10 and 100 kHz frequency oscillated in switching mode testing. However, the power loses while transistors have continue carried voltage and current (amplifier mode, P_{CE} = I_C * V_{C-E}) on irradiated transistors have higher than no treatment transistors due to the corrector-emitter resistance (R_{C-E}) of the irradiated transistors were increased by electron irradiation which induced defect at the lattice in silicon crystal shell. In addition, this experiment shows that the switching properties of bipolar junction transistors in state-off functionhave a better quality after electron irradiation.

Keywords: switching improvement, electron irradiation, bipolar junction transistors, carrier lifetime

Introduction

The bipolar junction transistor is widely used in many applications including amplifier mode and switching mode. The switching time and switching loses of transistors using on switching mode are primary concern in power applications. The switching speed of a bipolar junction transistor is often limited by the excess minority charge storage in the base and collector regions of the transistor during the saturation state. Power loses from switching while high loading will be make a heating and can be damage itself and another nearly devices. The electrical characteristics of semiconductors devices and transistors depend on minority carrier lifetime (M. Byczkowski et al., 1957 and Rober H. Kingstone, 1954). The power loss of the transistors is still occurs by limited improvement of material properties. One way to improved switching property is reducing minority carrier lifetime. Therefore, this paper is presented for improve of silicon bipolar junction transistor (Si BJT) by using electron irradiated modification. The 8 MeV electrons irradiated by high-energy electron through silicon caused defects all over structure. Deep level concentration and result in minority carrier lifetime depends on the electron dosage as many

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experimenting of the semiconductor devices have been mentioned. The electron beams could be used to irradiate to improve their characteristics (F. Frisina et al., 1990)

According to the previous research on diodes, electron irradiation could produce defects in material lattice and several studies point out that it can reduce carrier lifetime, creating traps in energy band by produced defects in material (silicon) structure (Wiwat I. et al., 2013). As a result,the quality of Si BJT is improvement on switching while the defect induced resistivity then slightly degradation of the devices amplifier with voltage, current and power. That's how to know the electron radiation dose is suitable for condition.

This study purpose is to presents the switching time improvement and reducing the power loses (heat) occurring while Si BJT switching by exposed with 8 MeV electron irradiation at different dose. All irradiated Si BJT at higher different doses were measured the switching characterize compare with no treatment at room temperature.

Materials and methodology

Materials

The samples of this study are triple diffused silicon NPN power transistors H1061 TO-220AB packaged with high power dissipation and medium speed power switching. In each electron radiation dose,using 5 pieces of sample.The electron irradiation was used the electron beam linear accelerator at Thailand Institute of Nuclear Technology Public Organization (TINT).

Methods

Electron irradiation was performed at room temperature (25°C) using 8 MeV for 5, 10, 15, 20 and 25 kGy dosage without any devices bias. The bipolar junction transistors were irradiated from the front surfacewith pulsed beam of average current 100 mA and duration 15.7 μs. The doses were measured using GEX B3Windose dosimeters. The irradiated transistors were characterized after irradiation at room temperature. It was connected on the common emitter amplifier with base resistance (R_B), corrector resistance (R_C) and emitter resistance (R_E) at 100, 1 and 52 Ohm respectively. Connect to GW INSTEK AFG-2112 function generator for pulsing generated as 1, 10 and 100 kHz as frequency on base-emitter connect adjustable power supply 5-20 volt to collector-emitter of the Si BJT. The switching's signals were measured by TSD3034C Tektronix Oscilloscope. After that, considering the on-state and off-state pulse signalized at the higher doses rates to comparison with untreated Si BJT.

The next step, changed connect from function generator to adjustable power supply 5-12 volt at the base-emitter position, and adjust the base current (I_B) to 250 mA for characterize the corrector current (I_C) and corrector-emitter volte ($V_{C\text{-}E}$) to calculate the power lose holding in transistors.

Results and discussion

The switching time result

The switching time can be measured by oscillated at high frequency. The effect of switching time average values were decrease at pulsing state-off all irradiated Si BJT showed in Figure 1. The imminent significantly changed in the state-off with Si BJT due to the irradiation created lattice defects, which become center traps for decreasing of lives of minority carriers of p-n junction. Linking as reaction electric reverse recover (switching) time decreased and forward voltage of the device increased that can be explained why the load voltage decreasing (Hang D. et al., 2000 and Wiwat J., 2015), while the state-on signal unchanged.

Table 1 The silicon bipolar junction transistors average switching time at different doses with 1, 10and 100 kHz oscillated testing.

Frequency / Dose		0 kGy	5 kGy	10 kGy	15 kGy	20 kGy	25 kGy
1 kHz	state-on	1 µs	1 µs	1 µs	1 µs	1 µs	1 µs
	state-off	30 µs	10 µs	7 µs	5 µs	4 µs	4 µs
10 kHz	state-on	2 µs	2 µs	2 µs	2 µs	2 µs	2 µs
	state-off	35 µs	20 µs	6 µs	5 µs	4 µs	4 µs
100 kHz	state-on	0.5 µs	1 µs	1 µs	1 µs	1 µs	1 µs
	state-off	5* µs	5 µs	4 µs	4 µs	4 µs	3 µs

*incomplete period state-off switched.

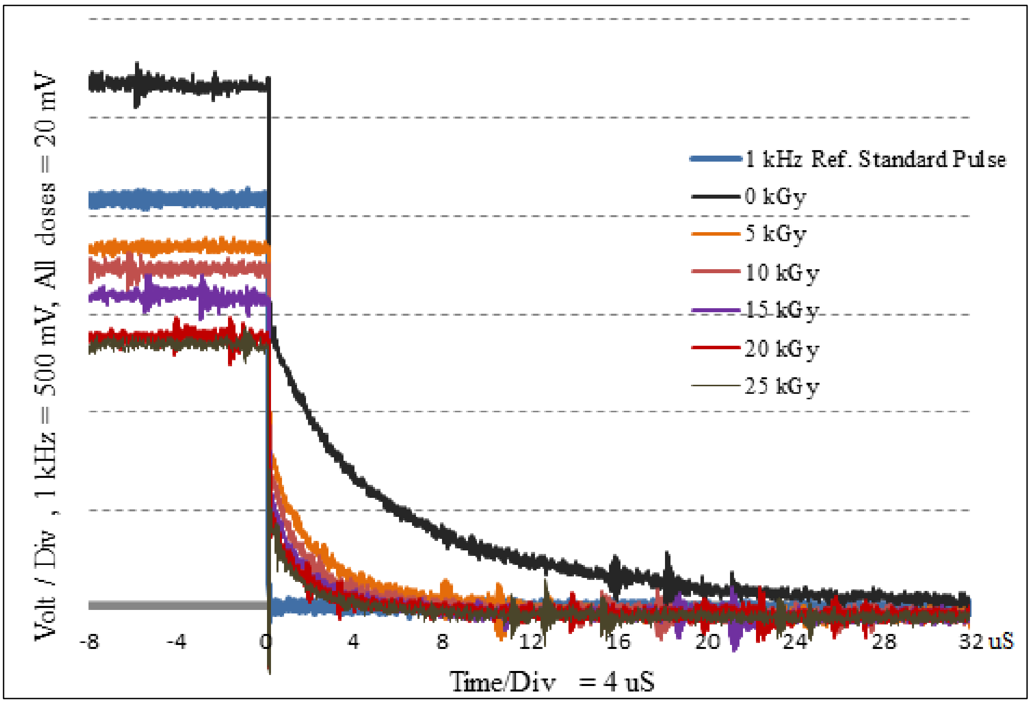

Figure 1 H1061 Si BJT state-off switching time result of the 1 kHz pulse standard testing at 0 kGy (no treatment), 5 kGy, 10 kGy, 15kGy, 20 kGy and 25 kGy electron irradiated.

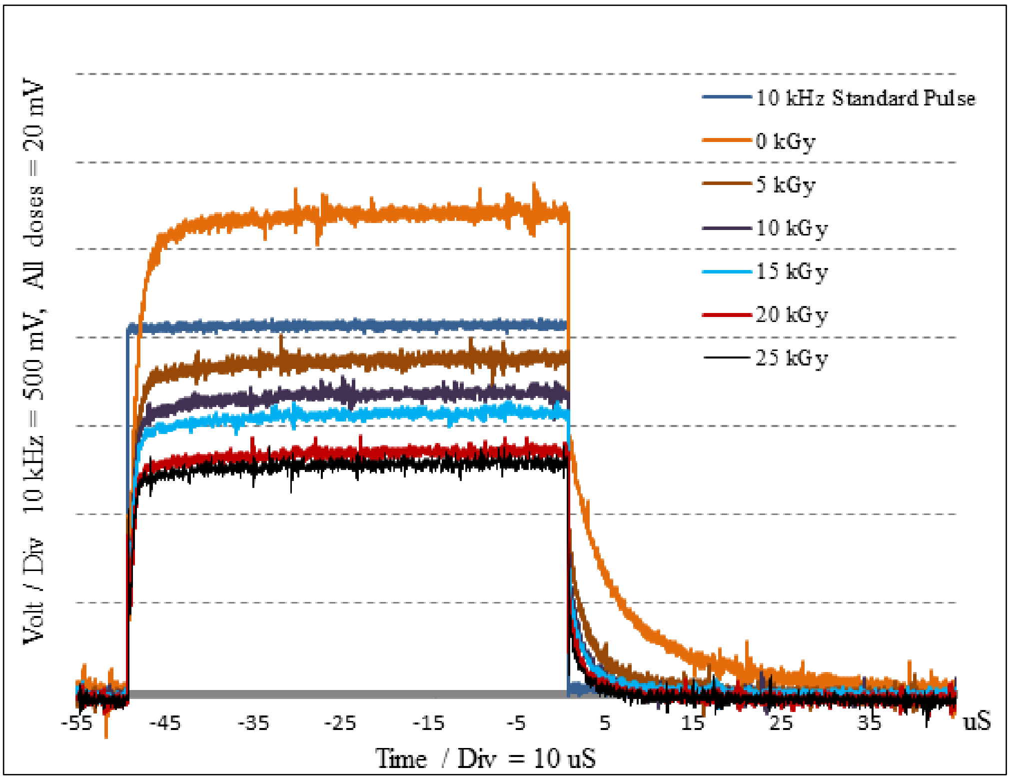

Figure 2 H1061 Si BJT state-off switching time result of the 10 kHz pulse standard testing at 0 kGy (no treatment), 5 kGy, 10 kGy, 15kGy, 20 kGy and 25 kGy electron irradiated.

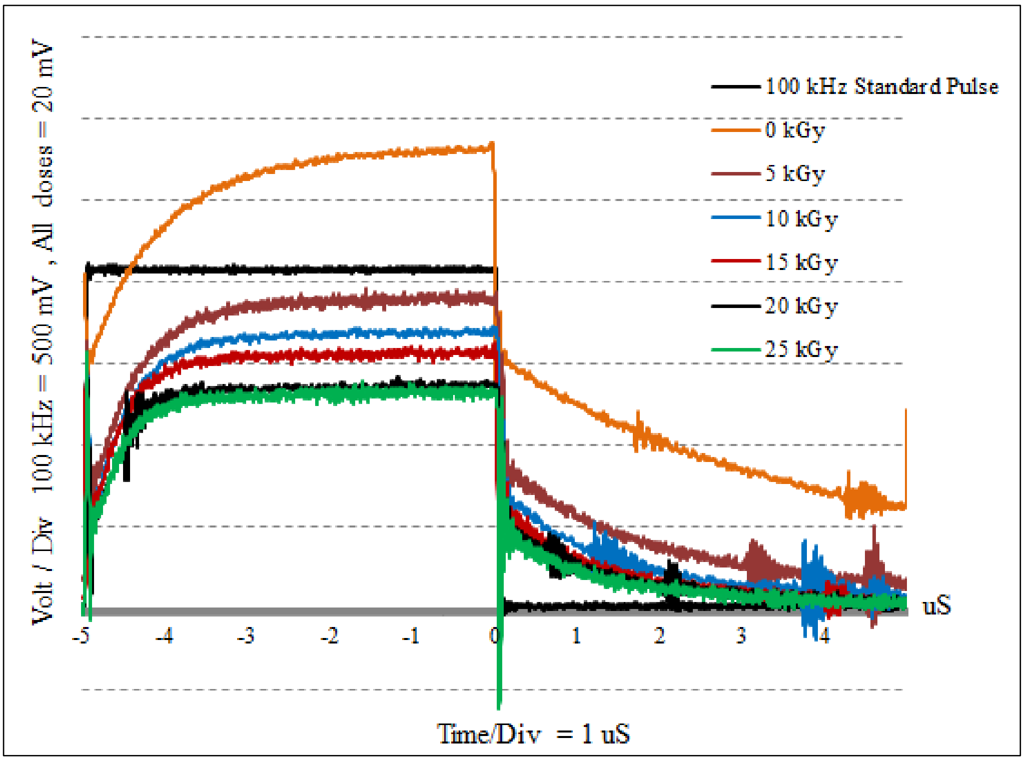

Figure 3 H1061 Si BJT state-off switching time result of the 100 kHz pulse standard testing at 0 kGy (no treatment), 5 kGy, 10 kGy, 15kGy, 20 kGy and 25 kGy electron irradiated.

From the result, the switching losses are depending on the state-off switching time that could be explained why the switching losses have development by electron irradiation.

The conduction losses of the Si BJT

The conduction losses on amplifier mode testing have significant changed in higher doses. The collector current (I_C) was controlled by base current (I_B), which stable all Si BJT electrons irradiated, In addition, found that the collector-emitter voltage ($V_{C\text{-}E}$) is increase on higher doses due to the conduction of the transistor losses that define by P= $I_C.V_{CE}$ (watt). The result show that the internal Si BJT conduction loses have follow $V_{C\text{-}E}$ for higher than no irradiated devices as shows in figure 4.

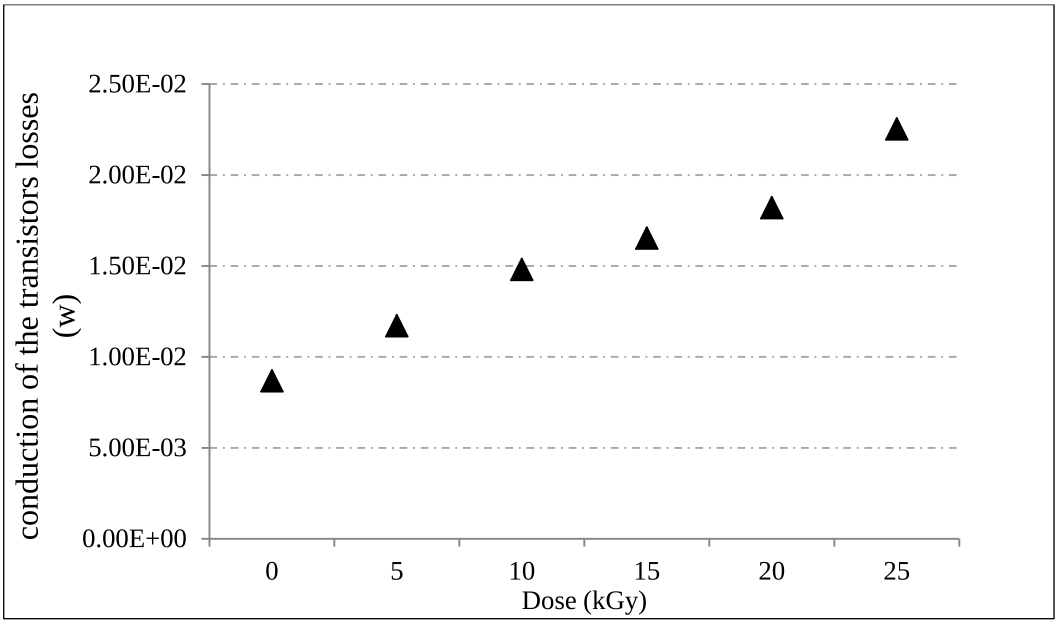

Figure 4 H1061 Si BJT average conduction loses on amplifier mode; testing at 0 kGy(no treatment), 5 kGy, 10 kGy, 15 kGy, 20 kGy and 25 kGy electron irradiated with biasing I_B = 250 mA.

The material structure of collector-base in silicon is thicker than base-emitter structure. Moreover, the high energy of electron radiation was induced lattice defect in bulk crystal and increasing the resistivity of the transistors (H. Ohyama et al., 2007). In some structure of metal pin-silicon junction has damaged by electrons irradiation when V_{C-E} (volt) = I_C * R_{C-E}.That is reason why the conduction loses is higher.

The studies of the switching time of Si BJT improvement by 8 MeV electrons irradiation showed the reverse internal result between switching which decreased and the conduction loses increased as increased the dosage. From the studies found that the dose rate of 8 MeV energy electrons irradiation should be within 5-10 kGy for Si BJT H1061 NPN for the improvement. Considering at figure 4, the electron irradiated at 5-10 kGy can be decrease switching time at state-off about 80 percentages. However, found that the internal conduction losses are increasing 30 percentages when compared with untreated devices.

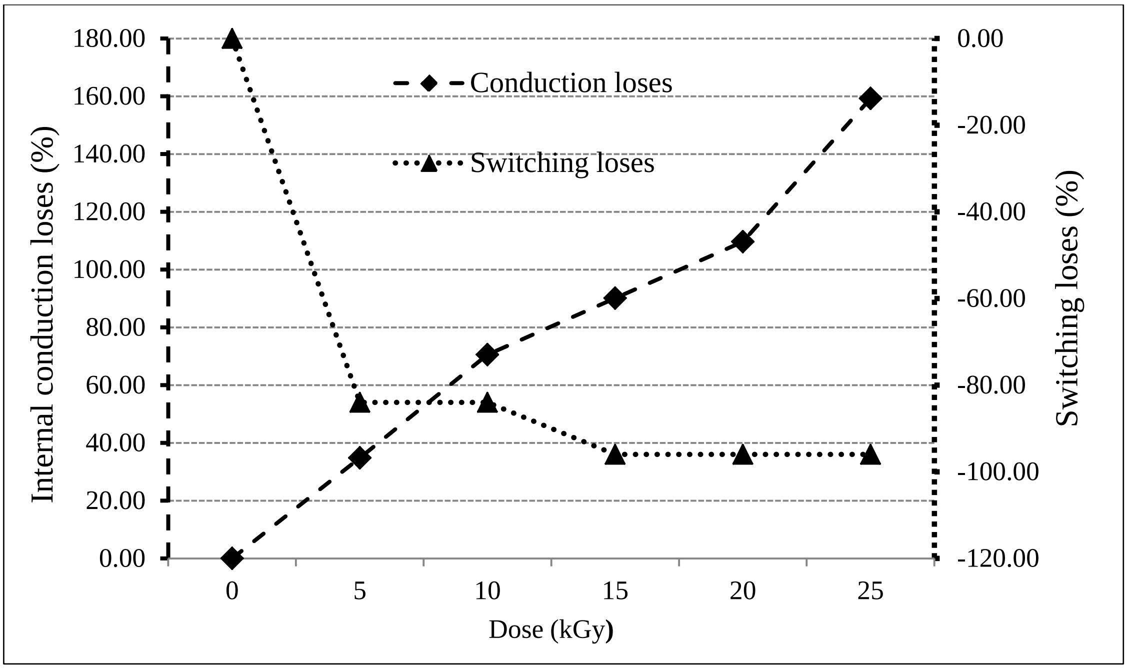

Figure 5 Show to compared the switching loses decreasing and conduction loses increasing on 0 kGy, 5 kGy, 10 kGy, 15 kGy, 20 kGy and 25 kGy on 8 MeV electrons irradiation dose rate.

Conclusion

The commercial silicon bipolar junction transistor H1061 in this studied appeared to be sensitive to 8 MeV electrons irradiation. The switching time has decreased for higher doses rate which found at state-off to 80 percentages, while the state-on has unchanged compared to untreated transistors. The electrons irradiation inducted lattice defect make the resistance of transistor has higher, as a result of collector-emitter voltage ($V_{C\text{-}E}$) increased. Then the conduction loses on amplifier mode testing has higher when increased irradiation dose but if consider it at 5 kGy irradiated transistors have too small effect to switching utility. From the result of this experiment, the switching time of H1061 bipolar junction transistor at all 1 kHz, 10 kHz and 100 kHz are improved with electrons irradiation. The radiation doses at 5 kGy and 10 kGy has the best results.

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