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Electrical Characterization of Commercial Power MOSFET under Electron Radiation

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Abstract

This paper presents the threshold voltage shifts for both p-channel and n-channel commercial power MOSFET before and after electron irradiation. The experiment was done under the 3MeV energy of electron with dose level varies from 50KGy until 250KGy. The results were plotted and analyzed in terms of the shifted voltage characteristics. It is observed that after irradiation, both p-channel and n-channel MOSFET experiences negative threshold voltage shifts. For n-channel devices, this is due to the radiation-induced positive charges dominated in the oxide traps while for p-channel devices it is believed due to radiation-induced ionization damage.

Keywords: *commercial power mosfet, threshold voltage shifts, electron radiation*

1. Introduction

Semiconductor devices have become significant nowadays as they are used in almost all electronic devices. Power MOSFET, in particular, is actually among all the devices, designed and fabricated from the semiconductor material and vertical double diffused metal oxide semiconductor field effect transistor (VDMOS) is one of the examples of the available commercial power MOSFET. Typically, most of commercial power MOSFETs are used in special applications like in the space environment. Electronic devices that are radiation hardened are important for radiation-exposed applications so that their lifetime can be extended.

The majority of modern electronic systems are composed of silicon devices, so the effects of radiation on these devices must be well-versed [1]. Electronic power devices are being increasingly used throughout the defense and aerospace industries where the applications frequently demand operation in high transient and total dose radiation environments. In a transient radiation environment, excess carriers generated by ionizing radiation at or near the device junctions can affect the device operation [2]. For power devices, where the collection volumes, as well as the magnitude of operating currents and voltages, are large, the effect of radiation can be critical, in some cases challenging the survivability of the device.

2. Research Method

The selection criteria for commercial silicon-based n-channel and p-channel power MOSFET sample comprises size, maximum voltage ratings, breakdown voltage and material type. Silicon-based commercial power MOSFETs manufactured by Fairchild Semiconductor and Diode Inc were chosen to be investigated consisting of n-channel (2N7000TA, ZVNL120A) and p-channel (ZVP2110A, ZVP4105A). For measurement compatibility reason, samples with the continuous drain current around 180mA are selected and the voltage ratings of the selected devices were ranging from 20-200V. The electrical characterization of all devices before and after the irradiation process was carried out using Keithley Measurement System 4200 in the electronics laboratory at International Islamic University Malaysia. The electron beam irradiations of the selected power MOSFET were performed at ALUTRON electron beam source with 3MeV energy with the dose level of 50KGy, 100KGy, 150KGy, 200KGy and 250KGy at

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Nuclear Agency Malaysia. All the test components were placed in a metallic tray for proper exposure during the electron beam irradiation. For each n-channel and p-channel power MOSFET, three devices from the same model were measured for each dose levels.

3. Results and Analysis

This section presents the experimental results of the n- channel and p-channel power MOSFETs. The I-V characteristic curves, as well as the threshold voltage shift for the electron radiation dose level of 50KGy, 100KGy, 150KGy, 200KGy, and 250KGy, were plotted. These dose levels have been chosen based on the selected devices radiation stability. Further, these dose levels had shown the changes in the degradation of the same energy radiation.

3.1. Threshold Voltage Characteristics

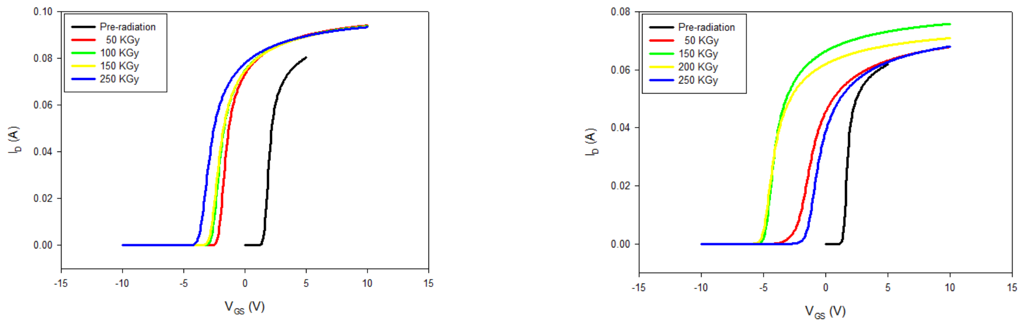
The room temperature sub-threshold I-V characteristics of the n-channel 2N7000TA, ZVNL120A and the p-channel ZVP2110A, ZVP4105A before and after radiation are shown in Figure 1 and Figure 2 respectively. It is observed that the device turns on voltage, V_{th}shifted as a function of radiation doses for all devices. The threshold voltages for both n-channel and p-channel devices are shown in Table 1.

Table 1. The threshold voltage for both n-channel and p-channel before irradiation

Type	Device	Threshold Voltages
	2N7000TA	1.54V
N-channel	ZVNL120A	1.42V
	ZVP2110A	-3.2V
P-channel	ZVP4105A	-1.9V

For 2N7000TA, it was irradiated with 50KGy, 100KGy, 150KGy and 250Kgy while for ZVNL120A, the doses were 50KGy, 150KGy, 200KGy, and 250KGy. For ZVP2110A, the irradiation doses were 50KGy, 100KGy, 200KGy and 250KGy whereas for ZVP4105A the doses were 50KGy, 150KGy, 200KGy, and 250KGy.

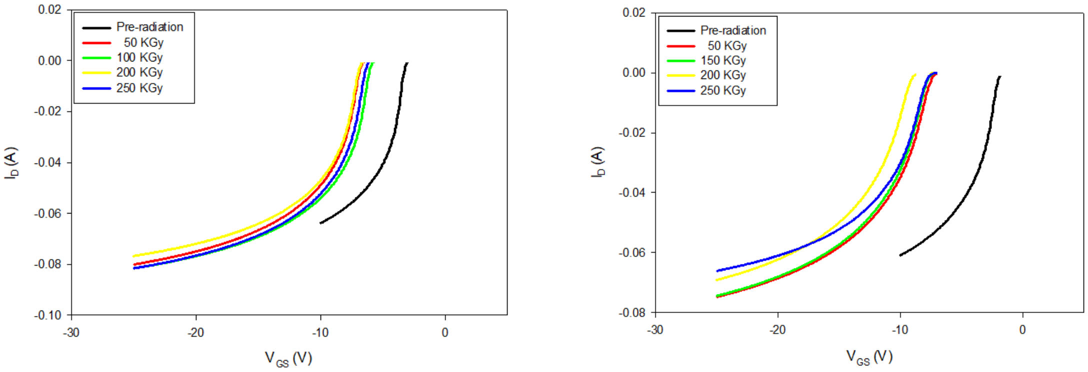
Figure 1 shows the graph plotted for both n-channel MOSFET before and after irradiation. From the graphs, it can be concluded that after the irradiation, the threshold voltage decreased for both n-channel devices. Threshold voltage of 2N7000TA decreased to -2.16V, -2.70V, -2.85V, and -3.73V respectively for each dose while for ZVNL120A the threshold voltages decreased to -2.39V, -4.88V, -5.05V and -1.55V for each dose.



(a) (b)

Figure 1 I-V characteristics of n-channel (a) 2N7000TA and (b) ZVNL120A before and after electron radiation

For the n-channel power MOSFET, the threshold voltage becomes negative due to the radiation-induced positive charges dominated in the oxide traps [3]. Charges in the traps made the device to be turned on at negative bias. As the radiation doses increase, more positive charges will be dominant in the oxide traps thus requiring less voltage at the gate terminal to turn on the MOSFET.



(a) (b)

Figure 2 I-V characteristics of p-channel (a) ZVP2110A and (b) ZVP4105A before and after electron radiation.

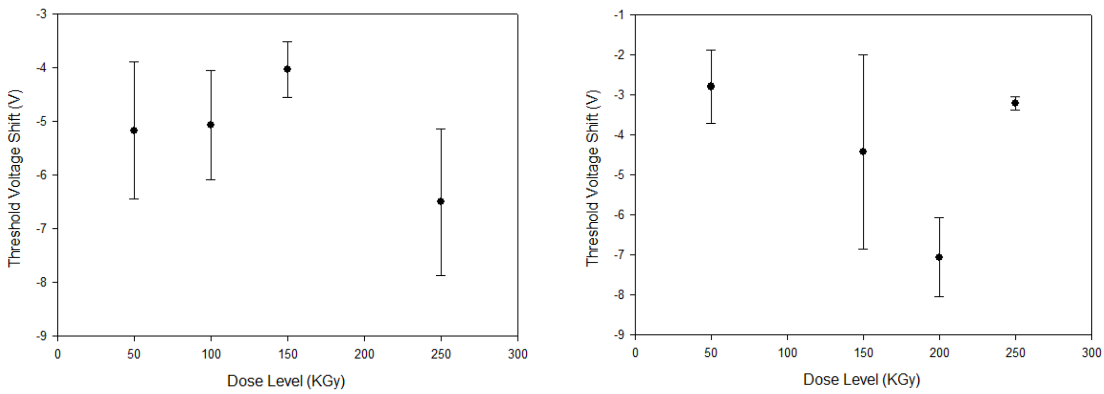
The threshold voltage characteristics of ZVP2110A and ZVP4105A p-channel power MOSFET before and after electron beam radiation are plotted. Figure 2 above shows the threshold voltage characteristics of ZVP2110A and ZVP4105A with respect to the electron beam radiation doses. From the graph, it can be seen that for ZVP2110A, the threshold voltages decreased to -6.03V, -6.77V, -6.83V and -6.31V whereas for ZVP4105A the threshold voltages decreased to -7.43V, -7.70V, -9.04V and -7.76V respectively each dose. It is observed from the figure above that p-channel MOSFET also experience negative threshold voltage shifts after irradiation. It is believed that the negative threshold voltage shifts are due to radiation-induced ionization damage [3]. Also, from both Figure 1 and 2, it clearly can be seen that for ZVNL120A, ZVP2110A, and ZVP4105A, the threshold voltage for the dose of 250KGy is increasing compared to the other values. It is believed that the trend happened due to annealing process where the carriers are able to escape the trap thus improving the threshold voltage.

When a MOS transistor is exposed to high-energy ionizing irradiation, electron-hole pairs are created in the oxide. Electron-hole pair generation in the oxide leads to almost all total dose effects. The generated carriers induce the buildup of charge, which can lead to device degradation. The negative threshold voltage shifts in p-channel MOSFET is due to the predominantly positive interface traps in the lower region of the bandgap [4].

3.2. Threshold Voltage Shifts

Figure 3 and figure 4 show the threshold voltage shift trends of each device with respect to different dose levels which are 50KGy, 100KGy, 150KGy, 200KGy, and 250KGy. The equation for the threshold voltage shift is given by:

$$\Delta V_{th} = V_{th}(after\ radiation) - V_{th}(before\ radiation)$$



(a) (b)

Figure 3 Threshold voltage shifts of n-channel (a) 2N7000TA and (b) ZVNL120A

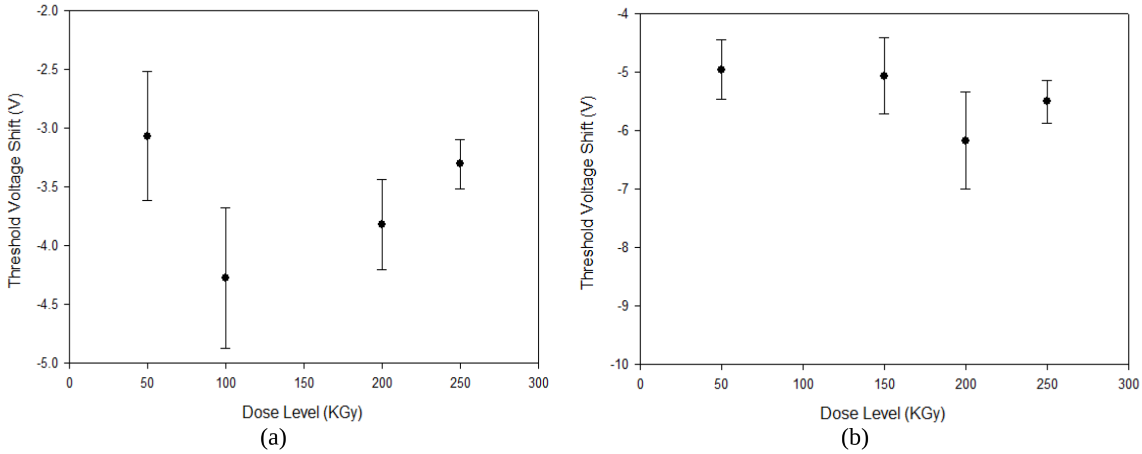


Figure 4 Threshold voltage shifts of p-channel (a) ZVP2110A and (b) ZVP4105A

The threshold voltage shifts for both n-channel and p-channel devices were not uniform. These situations occur due to the variation in the defects inside the MOSFET before radiation. Besides, three samples for each dose levels are not enough to investigate the threshold voltage shifts for each power MOSFET. It is expected that as dose levels increases, the threshold voltage is becoming more negative. It is suggested that for future works, the number of samples for each radiation doses are increased so that more accurate analyses can be deduced.

4. Conclusion

The effects of radiation to the power MOSFET with the electron radiation dose level of 50KGy, 100KGy, 150KGy, 200KGy, and 250KGy were investigated. Results show that both n-channel 2N7000TA, ZVNL120A and p-channel ZVP2110A, ZVP4105A commercial power MOSFET's threshold voltage shifts to the negative value with increasing dose level. At a very high dose level, it is believed that the threshold voltage shifted towards increasing trend perhaps due to annealing. These conclude that exposure of semiconductor devices particularly MOSFET will degrade its electrical characteristics and lead to failure of the system.

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References

[1] S. F. O. Abubakkar, N. F. Hasbullah, N. F. Zabah. 3MeV -Electron Beam Induced Threshold Voltage Shifts and Drain Current Degradation on ZVN3320FTA & ZVP3310FTA Commercial MOSFETs. *IEEE Scopus Indexed*, 2014; 273-276.
[2] J. A. Felix, M. R. Shaneyfelt, P. E. Dodd, S. Member, B. L. Draper, J. R. Schwank, S. M. Dalton. Radiation-Induced Off-State Leakage Current in Commercial Power MOSFETs. *IEEE Transaction, Nuclear Science.* 2005; 52 (6): 2378–2386.
[3] J. R. Schwank, M. R. Shaneyfelt, D. M. Fleetwood, J. A. Felix, P. E. Dodd, P. Paillet, A. Overview. Radiation Effects in MOS Oxides. *IEEE Transaction, Nuclear Science.* 2008; 55 (4): 1833–1853.
[4] K. G. Naik, S. Bhat, G. Sangeev. The effect of electron irradiation on BJTs and MOSFETs at elevated temperatures. *Archives of Physics Research*. 2013; 4 (2):74-86.
[5] Chaoming Liu, Xingji Li, Jianqun Yang, Guoliang Ma, Zhongliang Sun. Radiation Defects and Annealing Study on PNP Bipolar Junction Transistors Irradiated by 3-MeV Protons. *IEEE Transactions, Nuclear Science*. 2015; 62 (6): 3381-3386.
[6] Chaoming Liu, Xingji Li, Jianqun Yang, Guoliang Ma, Zhongliang Sun, Lidong Jiang. Synergistic Effect of Ionization and Displacement Defects in NPN Transistors Induced by 40-MeV Si Ion Irradiation with Low Fluence. *IEEE Transactions on Device and Materials Reliability*. 2015; 15 (4): 511-518.

[7] M. Alexandru, M. Florentin, A. Constant, B. Schmidt, P. Michel, P. Godignon. 5MeV Proton and 15MeV Electron Radiation Effects Study On 4H-SiC Nmosfet Electrical Parameters. *IEEE Transactions On Nuclear Science*. 2014; 61: 1732-1738.
[8] Gao Bo, Liu Gang, Wang Li-Xin, Han Zheng-Sheng, Song Li-Mei, Zhang Yan-Fei, Teng Rui, Wu Hai-Zhou. The effects of radiation damage on power VDMOS devices with composite SiO_2 Si_3N_4 films. *Chin. Phys. B.* 2013; 22 (3).