International Journal of Electrical and Computer Engineering (IJECE)
Vol. 9, No. 2, April 2019, pp. 1453∼ 1460
ISSN: 2088-8708, DOI: 10.11591/ijece.v9i2.pp1453-1460

Impact of gamma-ray irradiation on dynamic characteristics of Si and SiC power MOSFETs

Saranya Krishnamurthy[1], **Ramani Kannan**[2], **Chay Che Kiong**[3], **Taib B Ibrahim**[4], **and Yusof Abdullah**[5]
[1,2,3,4]Department of Electrical and Electronic Engineering, Universiti Teknologi PETRONAS, Malaysia
[5]Material Technology Group, Malaysian Nuclear Agency, Malaysia

Article Info

Article history:
Received Jun 28, 2018
Revised Des 18, 2018
Accepted Des 29, 2018

Keywords:
Power MOSFET
Total ionizing dose effects
Radiation response
Electrical characterization
Gamma ray

ABSTRACT

Power electronic devices in spacecraft and military applications requires high radiation tolerant. The semiconductor devices face the issue of device degradation due to their sensitivity to radiation. Power MOSFET is one of the primary components of these power electronic devices because of its capabilities of fast switching speed and low power consumption. These abilities are challenged by ionizing radiation which damages the devices by inducing charge built-up in the sensitive oxide layer of power MOSFET. Radiations degrade the oxides in a power MOSFET through Total Ionization Dose effect mechanism that creates defects by generation of excessive electron–hole pairs causing electrical characteristics shifts. This study investigates the impact of gamma ray irradiation on dynamic characteristics of silicon and silicon carbide power MOSFET. The switching speed is limit at the higher doses due to the increase capacitance in power MOSFETs. Thus, the power circuit may operate improper due to the switching speed has changed by increasing or decreasing capacitances in power MOSFETs. These defects are obtained due to the penetration of Cobalt60 gamma ray dose level from 50krad to 600krad. The irradiated devices were evaluated through its shifts in the capacitance-voltage characteristics, results were analyzed and plotted for the both silicon and silicon carbide power MOSFET.

Corresponding Author:
Ramani Kannan,
Department of Electrical and Electronic Engineering,
Universiti Teknologi PETRONAS,
32610 Seri Iskandar, Perak, Malaysia.
Email: ramani.kannan@utp.edu.my

1. INTRODUCTION

Power Metal-Oxide Semiconductor Field-Effect Transistors (MOSFETs) play a significant role in space, power plant, military and harsh environment applications [1], [2]. Semiconductor devices present in radiation harsh environment would be exposed to different types of radiations which lead to malfunctions of the devices [3]. The space radiation environment is mainly classified into particle and proton radiation. The radiation effects of power MOSFETs mainly includes ionizing radiation and single event effects [4], [5]. Power MOSFET exposed to ionizing radiation cause an accumulation of charges in interface and gate oxide layer, thereby degrading the performance of devices. Assessing the radiation hardness of a device with one radiation on the ground and anticipating its reaction to a diverse radiation in space could be a intricate task. In this way, it is exceptionally fundamental to assess the radiation hardness of a device to diverse radiations from the application perspective.

Several studies have shown the changes in static electrical characteristics of commercially available silicon (Si) and silicon carbide (SiC) power MOSFET under radiation [6], [7]. The results show that the ionizing total dose damage of power MOSFETs mainly appears as changes in I-V characteristics, especially the decrease of threshold voltage and the increase of current drive [8]. Neutron irradiation can cause functional failure of the commercial grade SiC power MOSFETs devices, mainly due to the ionizing effect caused by the recoil nucleus the obtained from collision of the neutron and the lattice atoms so to make the devices fail [9]. The results of heavy ion and proton radiation test report that the permanent damage caused by ion irradiation at high LET values will lead to increase in the gate and source leakage of the device. The study [10], [11] demonstrated that the safe working voltage of the device was significantly reduced and the current was attenuated after the heavy ion irradiation test on SiC power MOSFETs of 1200 V. The decrease of safe working voltage will directly affect the device's reliability index as well as the device's space applications. Akturk et al. detailed that SiC MOSFETs irradiated with gamma-rays under gate voltage biasing condition showed the negative voltage shift in threshold voltage (Vth),though in their examinations the aggregate measurement of gamma-ray dose level was limited to kGy [12]. The investigation of threshold voltage shift and drain current degradation was conducted for both N-channel and P-channel Si MOSFET subjected to electron beam radiation and gamma ray irradiation [13], [14]. However, it is necessary to consider the dynamic electrical characteristics on power MOSFETs during the total ionizing radiation. Therefore, this work aims to investigate the capacitance voltage shifts of commercial Si (TOSHIBA 2SK2662) and SiC (ROHM SCT2H12NZ and SCT3160KL) power MOSFETs subjected to radiation by analysing its C-V characteristics before and after cobalt-60 gamma ray radiation.

In this study, the relation between variable drain voltage and gamma-ray irradiation response of Si and SiC power MOSFETs was investigated by applying a constant or variable bias to gate terminal.The experiments indicate that Si and SiC MOSFETs operate within specification up to 100 krad, and may reliably operate after receiving doses up to 300 krad, provided that a gate bias of 0V, which is specified as the lowest recommended gate bias in the datasheet, is used to turn off the power MOSFET. In addition it clears that SiC power MOSFET capacitance value changes is less compared to silicon power MOSFET. Furthermore, experiments indicate that the switching applications such as buck and boost converters will be more affected due to increases and decreases in interface state densities and device capacitances such as output ($Coss$), input ($Ciss$) and reverse transfer ($Crss$) capacitances, than changes in threshold voltage and device current drive.

The remaining part of the article is structured as follows, Section 2. presents the theoretical concepts of radiation effects on power MOSFET. Section 3. details the experimental test set-up for the investigation of dynamic characteristics due to gamma ray irradiation, Section 4. discuss about the results and comparative analysis, Section 5. provides Conclusion.

2. RADIATION EFFECTS ON POWER MOSFET

Power MOSFET is a three terminal device Gate (G), Source (S) and Drain (D), which used in DC-DC converter, power amplifier and switching electronic signals. In addition, Power MOSFET is a superior switching speed with very low current required to turn on gate drive, due to the rate of charge removed or supplied from capacitance. In high voltage power MOSFET, only electrons are flowing during forward conduction. This is the reason that it can switching fast at high switching frequency with low switching loss. Many studies have been carried out to investigate the radiation effects on silicon based power MOSFET. SiC replaces a silicon material due to their realistic advantages such as wide band gap, high critical field and high thermal conductivity. 4H-polytype SiC material is most promising semiconductor for power MOSFETs compared to other polytypes 6H-SiC and 3H-SiC. The SiC power MOSFETs reduces the specific on-resistance, which are more suitable for high voltage, high temperature and harsh radiation environment. The design process used for SiC power MOSFETs as similar as silicon power MOSFETs [15].

Radiation is a transmission and emission of energy that travel in a form of particles or waves through space or material. The radiation is categorized as ionizing and non-ionizing radiation based on the type of particle. The ionizing radiation induced the ionization mechanism in the device which tends to device degradation and performance failure by changing the electrical characteristics. During the radiation exposure, the highly charged particle such as electrons, protons and gamma rays passing through the oxide layer that ionize atom to creates the electron-hole pairs in the power MOSFET. The generated electrons are much more mobile than the holes and they will move out of the oxide in a very fast times. However, some electrons and holes that escape initial recombination and they are immobile and remain behind in oxide. Trapped charge at the SiO2/ Si interface induces an inversion layer during the off-state that is responsible for increasing leakage current and threshold voltage shifts. The ionizing radiation of the space environment mainly causes Total Ionizing Dose (TID) [16].

The cumulative effect of ionizing radiation is referred as TID. Dose is defined as the quantitative measure of accumulated energy absorbed from ionizing radiation per unit mass as given in equations (1).

$$d = \phi \frac{1}{\rho}\frac{dE}{dx} \tag{1}$$

where, d is the dose, ϕ is the flux of incident particles. The SI unit for radiation dose is the radiation absorbed dose (rad) or Gray [Gy] i.e.1 Gy = 100 rad. The units are material-specific, it consists of accumulation of charges over time in different materials such as silicon or silicon carbide.

The SiC power is the leading high voltage technology in current market and there are number of research on going for analysis of radiation hardness. There is compulsion to investigate impact on dynamic characteristics of Si and SiC power MOSFET during radiation for using in space applications. Hence in this work the investigation of gamma ray irradiation on silicon carbide power MOSFETs by measuring the capacitance-voltage (C-V) characteristic as a function of drain-source voltage and radiation dose level and also compared with silicon power MOSFET.

3. EXPERIMENTAL TEST SET-UP FOR ANALYSIS OF RADIATION EFFECTS

The goal of this experiment is to investigate and analysis the cobalt-60 gamma ray effects on the dynamic characteristics of both Si and SiC power MOSFETs. Commercially available Si (TOSHIBA 2SK2662) and SiC (ROHM SCT2H12NZ and SCT3160KL) power MOSFETS were investigated and compared. The power MOSFETs details are collected from the data sheet. A sample size of five devices for each radiation level in total twenty devices used for this experiment. First, the capacitances including output capacitance ($Coss$), input capacitance ($Ciss$) and reverse transfer capacitance ($Crss$) were characterized prior to the radiation exposure by varying the Drain-Current Voltage (Vds) in the Electrical characterization laboratory at University Teknologi PETRONAS, Malaysia. The capacitances of power MOSFET calculated by using equation, as in (1).

$$\begin{aligned} Ciss &= Cgs + Cgd \\ Coss &= Cds + Cgd \\ Crss &= Cgd \end{aligned} \tag{2}$$

where the Cgs, Cds and Cgs are gate-to-source, drain-to-source and gate-to-drain respectively. Next, the cobalt-60 gamma ray irradiations were performed at Agency Nuclear Malaysia, Bangi for a dose level of 50krad to 600krad. The devices are measured at pre-rad, 50krad, 100krad, 300krad and 600krad for variable bias condition using Agilent E4980A LCR meter. To achieve the analysis of radiation effects on dynamic characteristics of power MOSFET, Funaki et al method is used to measure the inter electrode capacitance values. In this method the LCR meter with external power source and simple circuit configuration to measure the capacitance value. However, the LCR meter has a limited of up to 40V for Vds biasing. Hence, the circuit is connected to the extra high voltage source with resistance and dc-blocking capacitance in order to measure the capacitance of the higher voltage in Vds. A schematic of the test circuit for different capacitance measurement is shown in Figure 1. To achieve accurate measurement value of the internal capacitance different electrical test schematic circuits were used in this experiment.

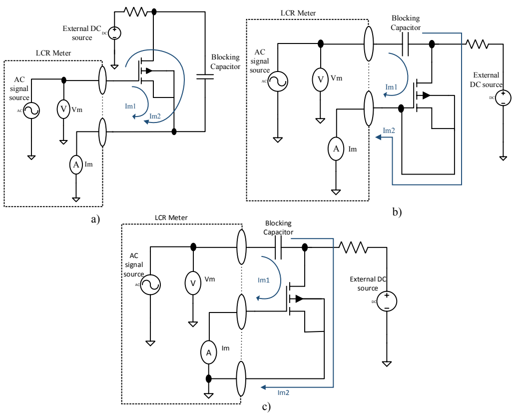

Figure 1. Experiment electrical schematic for a) Ciss, b) Coss and c) Crss measurement

4. RESULT AND ANALYSIS

Previous related studies have shown that after gamma irradiation, the power MOSFET threshold voltage (Vth) shifts negative and the drain current (Ids) was increased. However, the changes in dynamic electrical characteristics are neglected, yet the internal capacitances are introduce leakage current effects. Therefore, the analysis of capacitance voltage curves as a function of radiation dose is necessary to reflect reliable circuit operation. The measurement includes input ($Ciss$), output ($Coss$) and reverse transfer ($Crss$) capacitances of both Si and SiC power MOSFETs. Table 1 shows the result of total ionizing dose dependent changes in leakage characteristics of Si and SiC MOSFETs irradiated at room temperature. Here the power MOSFETs capacitance-voltage characteristics measured at Vgs = 0V and Vds changes from 0 to 30 V for before and after 50krad, 100krad, 300 krad and 600 krad.

The measured capacitances are related to the terminal capacitances of power MOSFET, refer (2). According to the formula Cgd is the key of these capacitances its depends on equation (3),

$$Cgd = \frac{Cox \times (Cinv + Cdp)}{Cox + (Cinv + Cdp)} \tag{3}$$

where, Cdp is a depletion capacitance which is inversely proportional to the depletion width of MOSFETs neck region under the oxide layer, Cox is a oxide capacitance and $Cinv$ is an inversion capacitance. During off state and low Vds, the threshold voltage increase $Cinv$ due to the radiation and this gives rise to larger Cgd. The increased capacitance as a function of low Vds and lateral shift during high drain-source voltage for pre and post radiation plotted in Figure 4. In expansion to the change in Cgd, the measurements subordinate changes in $Coss$ and $Ciss$ moreover incorporate the changes in Cds and Cgs, separately. Primarily, the gate-source capacitance Cgs is included fringe capacitance between gate and source, overlap, depletion, oxide and interface trap capacitances. Especially, the interface trap capacitance will change due to changing interface trap levels. Moreover, the drain-source capacitance Cds will change less with gamma irradiation it also includes the power MOSFET structure junction capacitance. Figure 2 shows input capacitances ($Ciss$) of Si and SiC power MOSFETs as a function of Vds and dose level.

Hence, the result clear that the shifts in capacitances $Ciss$, $Coss$, and $Crss$ due to radiation dose level is primarily due to the variations in Cgd. Whereas in the case at 300 krad and 600krad, the dose dependent shift of Crss and Coss are considerably larger than pre radiation but contrariwise Ciss is decreases than pre radiation. The Coss of Si MOSFETs have increased 25.9% at 600krad and 2.6% at 300krad for 0 to 30V after irradiation compared to the pre radiation which is shown in Figure 3. In addition, Crss of Si MOSFETs have a significant increment which is more than 26.17% at 300krad while at 600krad the increment is more than 6% from 0 to 30V. In the Ciss measurement of Si MOSFETs, which is up to 5.61% at 600krad but at 300krad the decrement is up to 6.5% from 0 to 30V .This is because the Ciss determines driving condition while Crss and Coss are dictated switching speed. Hence, the Coss is the key factor component of switching loss to affect the power loss due to the discharging and charging in switching mode. In addition, the Crss and Coss have voltage dependency due to the device depletion region modulating with applied varying operating voltage.

The capacitance of Rohm SiC 1200V and Rohm SiC 1700V power MOSFETs have a significant influent by the radiation at 300krad and 600krad. The Coss of Rohm SiC 1200V has decrease up to 17.36% at 600krad while at 300krad the decrement is up to 45.47% from 0 to 30V whereas it slightly increase after 30V at 600krad compared to preradiation. However, the Coss of Rohm SiC 1700V has increased significantly which is up to 50% at 600krad while at 300krad the increment is up to 48% from 0 to 30V. In addition, the Crss of Rohm SiC 1200V has increased up to 24.5% at 600krad while at 300krad has significant increased and slightly decrease at 300krad from 0 to 30V. However, the Crss of Rohm SiC 1700V has significant increased which is up to and around 80% at 300krad and 600krad. Also, the Ciss of Rohm SiC 1200V and Rohm SiC 1700V have decrement trends after irradiation gamma-ray. Rohm SiC 1200V has small decreased up to 7.85% whereas the Rohm SiC 1700V has significant increased which up to 29.8% at 600krad while at 300krad the Rohm SiC 1200V has decreased up to 10.15% and Rohm SiC 1700V has decreased up to 26.40%.

It concluded that the switching speed is limit at the higher doses due to the increase capacitance in power MOSFETs. Thus, the power circuit may operate improper due to the switching speed has changed by increasing or decreasing capacitances in MOSFETs. For instance, the larger $Ciss$ in the MOSFET which requires more gate charge that supply by gate driver, so the Ciss is changed, this required to redesign the gate driver in order to turn on the device channel. Also, the larger output switching losses due to the larger $Coss$. Power MOSFETs are used to in high switching application due to the changes of the terminal capacitance. The power circuit has to redesign in order to reduce the unwanted transients in the circuit due to the gate driver or switching speed is changed.

Table 1. Experimental Results of Pre and Post Irradiated Power MOSFETs

Capacitance (pF)	Power MOSFETs	Radiation Dose (krad)	Drain-Source Voltage Vds (V)						
			0	1	2	8	10	20	30
Ciss	Toshiba Si 500 V	Pre-Rad	1230.00	1230.00	1220.00	1210.00	1210.00	1190.00	1215.00
		Post 50	1230.00	1230.00	1220.00	1210.00	1210.00	1190.00	1215.00
		Post 100	1228.00	1229.00	1220.00	1212.00	1211.00	1189.00	1214.00
		Post 300	1150.00	1151.00	1159.00	1161.00	1162.00	1162.00	1175.00
		Post 600	1161.00	1161.00	1163.00	1163.00	1167.00	1168.00	1170.00
	Rohm SiC 1200V	Pre-Rad	745.00	720.29	617.63	519.00	484.99	461.866	415.50
		Post 50	745.00	720.29	617.63	519.00	484.99	461.866	415.50
		Post 100	744.55	721.39	618.66	518.00	487.00	460.90	450.30
		Post 300	705.58	647.16	609.68	493.10	478.84	475.42	447.32
		Post 600	706.05	663.75	619.54	499.98	479.24	455.98	445.07
	Rohm SiC 1700V	Pre-Rad	398.00	363.40	359.64	289.20	216.15	210.89	210.35
		Post 50	398.00	363.40	359.64	289.20	216.15	210.89	210.35
		Post 100	399.12	365.30	358.64	287.5	218.15	210.91	211.32
		Post 300	359.91	356.16	349.70	212.84	209.85	207.29	206.90
		Post 600	340.00	311.7	261.87	203.03	201.81	200.10	200.10
Coss	Toshiba Si 500 V	Pre-Rad	795.38	765.38	534.0	268.00	200.00	85.11	70.00
		Post 50	795.38	765.38	534.0	268.00	200.00	85.11	70.00
		Post 100	794.14	764.28	535.4	268.2	199.01	84.22	69.8
		Post 300	1610.0	1610.0	1238.0	280.27	205.26	105.23	77.69
		Post 600	1724.0	1724.0	1724.0	437.97	314.28	119.83	88.13
	Rohm SiC 1200V	Pre-Rad	777.66	737.66	531.92	272.02	244.49	173.92	133.89
		Post 50	777.66	737.66	531.92	272.02	244.49	173.92	133.89
		Post 100	776.89	736.96	514.12	272.08	244.23	173.81	133.72
		Post 300	647.15	565.53	460.96	181.62	133.32	168.94	133.08
		Post 600	747.66	609.59	492.22	272.02	237.96	170.00	134.53
	Rohm SiC 1700V	Pre-Rad	281.00	266.87	152.37	80.00	57.12	42.145	36.528
		Post 50	281.00	266.87	152.37	80.00	57.12	42.145	36.528
		Post 100	283.53	267.87	153.37	80.80	57.43	42.183	36.534
		Post 300	333.00	288.00	226.25	67.41	58.91	42.78	36.65
		Post 600	338.00	297.00	229.21	68.4	59.016	43.21	36.80
Crss	Toshiba Si 500 V	Pre-Rad	612.10	542.34	542.34	320.11	210.00	83.34	69.50
		Post 50	612.10	542.34	542.34	320.11	210.00	83.34	69.50
		Post 100	611.56	541.40	543.30	322.19	211.12	83.87	69.50
		Post 300	1723.00	1710.00	1328.00	410.27	305.26	115.23	87.69
		Post 600	1147.60	1106.2	1071.8	491.00	345.20	95.12	73.90
	Rohm SiC 1200V	Pre-Rad	435.00	400.00	395.80	286.31	220.53	174.50	133.00
		Post 50	435.00	400.00	395.80	286.31	220.53	174.50	133.00
		Post 50	435.00	400.00	395.80	286.31	220.53	174.50	133.00
		Post 50	435.00	400.00	395.80	286.31	220.53	174.50	133.00
		Post 50	435.00	400.00	395.80	286.31	220.53	174.50	133.00
		Post 100	434.98	400.00	396.20	287.21	220.43	175.50	133.00
		Post 300	505.50	473.06	421.26	254.10	229.95	174.83	143.98
		Post 600	541.56	473.68	421.00	250.19	225.65	174.8	143.00
	Rohm SiC 1700V	Pre-Rad	150.00	140.00	137.00	78.00	53.00	40.00	35.28
		Post 50	150.00	140.00	137.00	78.00	53.00	40.00	35.28
		Post 100	150.62	140.50	136.8	77.80	52.60	39.70	35.16
		Post 300	271.13	246.12	213.34	64.54	57.48	41.65	35.60
		Post 600	275.5	252.03	218.30	78.10	63.40	43.50	37.30

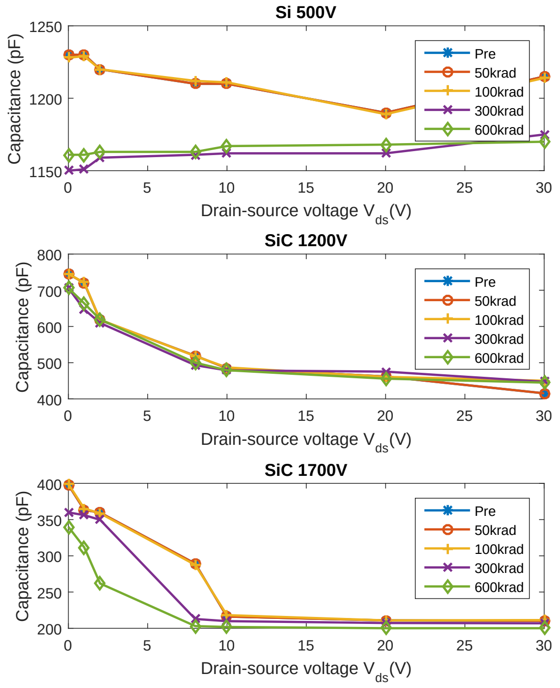

Figure 2. Ciss for Si and SiC power MOSFETs

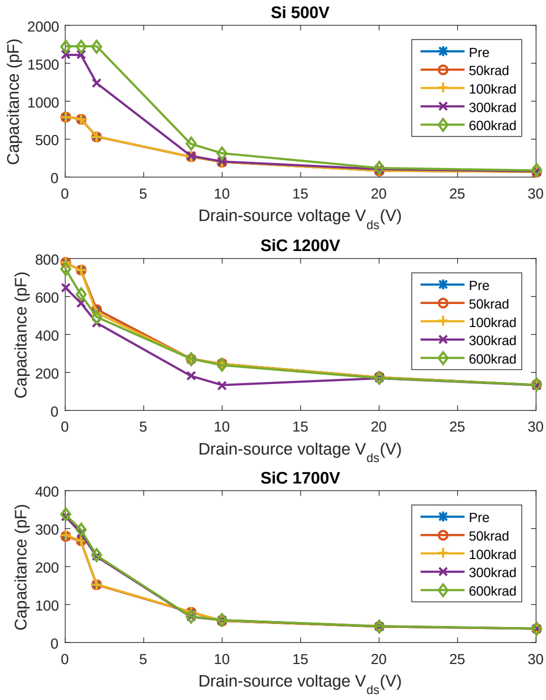

Figure 3. Coss for Si and SiC power MOSFETs

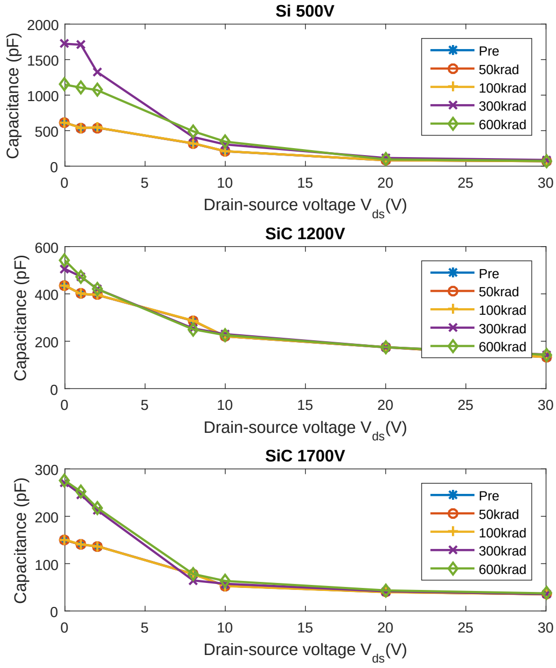

Figure 4. Crss for Si and SiC power MOSFETs

5. CONCLUSION

The gamma ray induced total dose effects on Si (TOSHIBA 2SK2662) and SiC (ROHM SCT2H12NZ and SCT3160KL) MOSFETs have resulted in dynamic characteristics as a function of variable drain bias and dose level. These power MOSFETs perform well after a total dose of 100 krad, and may operate up to 300 krad. From the preceding results, it is very clear that changes in device capacitances are accounted for switching operations. Increase in oxide and interface trap densities is found to be the main degradation mechanism of gamma irradiated transistors. The measurements confirm the fact that gamma rays seriously degrade the device performance to a greater extent. Additionally, the failure modes in SiC power MOSFETs can differ depending on the component and the vendor for similar values of bias normalized by rated voltage. Therefore, the research and development is continuing to investigate SiC power MOSFETs in order to make high switching and high current device that available operate normally at radiation region.

ACKNOWLEDGEMENT

The research was supported by Fundamental Research Grant Scheme No. 0153AB-L30. The authors would like to thanks Industrial Technology Division, Agency Nuclear Malaysia for the gamma-ray irradiation facility. The authors also acknowledge the support of Universiti Teknologi PETRONAS for their research facilities.

REFERENCES

[1] S. F. O. Abubakkar, N. F. Hasbullah, N. F. Zabah, and Y. Abdullah, ”3MeV-Electron Beam Induced Threshold Voltage Shifts and Drain Current Degradation on ZVN3310FTA and ZVP3310FTA Commercial MOSFETs,” in *International Conference on Computer and Communication Engineering (ICCCE)*, pp. 273-276, Sep 2014.

[2] H. Jung, ”Centeral Electric Field and Threshold Voltage in Accumulation-mode Junctionless Cylindrical Surrounding Gate MOSFET,” in *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 8(2),pp.673-679, Apr 2018 .

[3] P. Hazdra, S. Popelka, V. Zahlava, J. Vobecky, ”Radiation Damage in 4H-SiC and its Effect on Power Device Characteristics[J],” in *Solid State Phenomena*, vol. 242, pp. 421-426, 2016.

[4] A.M. Taberkit, A. Guen-Bouazza, and B. Bouazza, ”Modeling and Simulation of Biaxial Strained P-MOSFETs: Application to a Single and Dual Channel Heterostructure,” in *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 8(1), pp.421-428, 2018.

[5] G. Soelkner, W. Kaindl, M. Treu, D. Peters, ”Reliability of SiC Power Devices Aagainst Cosmic Radiation-Induced Failure[C]”, *Materials Science Forum*, vol. 556-557, pp. 851-856, 2007.

[6] Gnana Prakash, A.P., Pradeep, T.M., Hegde, V.N., Pushpa, N., Bajpai, P.K., Patel, S.P., Trivedi, T. and Bhushan, K.G., ”Comparison of effect of 5 MeV proton and Co-60 gamma irradiation on silicon NPN rf power transistors and N–channel depletion MOSFETs,” *Radiation Effects and Defects in Solids*, vol.172(11-12), pp.952-963, 2017.

[7] E. Mizuta, S. Kuboyama, H. Abe, Y. Iwata, and T. Tamura, “Investigation of single-event damages on silicon carbide (SiC) power MOSFETs,” *IEEE Transactions on Nuclear Science*, vol. 61, no. 4, pp. 1924–1928, 2014.

[8] George, J.S., Clymer, D.A., Turflinger, T.L., Mason, L.W., Stone, S., Koga, R., Beach, E., Huntington, K., Lauenstein, J.M., Titus, J. and Sivertz, M., Response variability in commercial MOSFET SEE qualification, *IEEE Transactions on Nuclear Science*, 64(1), pp.317-324, 2017.

[9] A Griffoni, J Van Duivenbode, D Linten, E Simoen, R Paolo, L. Dilillo, ”Neutron-Induced Failure in Silicon IGBTs Silicon Super-Junction and SiC MOSFETs[J]”, *IEEE Transactions on Nuclear Science*, vol. 59, no. 4, pp. 866-871, Aug. 2012.

[10] A. Akturk, J. M. McGarrity, S. Potbhare, and N. Goldsman, ”Radiation Effects in Commercial 1200 V 24 A Silicon Carbide Power MOSFETs,” *IEEE Transactions on Nuclear Science*, vol. 59, pp. 3258-3264, 2012.

[11] J M Lauenstein, M C Casey, K A LaBel, ”Single-Event Effects Silicon Carbide Power Devices”, *NEPP Electronic Technology Workshop*, June 23-26, 2015.

[12] A. Akturk, R. Wilkins, J. Mcgarrity, and B. Gersey, “Single Event Effects in Si and SiC Power MOSFETs Due to Terrestrial Neutrons,” IEEE Transactions on Nuclear Science, vol. 64, no. 1, pp. 529–535, 2017.

[13] Nagaraj, S., Singh, V., Jayanna, H. S., Balakrishna, K. M., and Damle, R. (2013). 60Co-Gamma Ray Induced Total Dose Effects on P-Channel MOSFETs. *Indian Journal of Materials Science*, http://dx.doi.org/10.1155/2013/465905, 2013.

[14] K. Murata, S. Mitomo, T. Matsuda, T. Yokoseki, T. Makino, S. Onoda, A. Takeyama, T. Ohshima, S. Okubo, Y. Tanaka and M.Kandori, "Impacts of gate bias and its variation on gamma-ray irradiation resistance of SiC MOSFETs," *Phys. Status Solidi Appl. Mater. Sci.*, vol. 214, no. 4, 2017.

[15] Li, P., Zeng, L., Li, X., Luo, L., Zhang, H., Bo, M., Sun, Y., Yu, Q., Tang, M., Xu, W. and Zhang, B., "Analysis of the influence of single event effects on the characteristics for SiC power MOSFETs, in*IEEE Prognostics and System Health Management Conference (PHM-Harbin)*, pp. 1-4, July 2017.

[16] Erman Azwan, Ramani Kannan, Zuhairi Baharudin, and Saranya Krishnamurthy. "An overview of instanteneous radiation effect on MOSFETs for harsh environment applications." Proc. In 3rd International Symposium Robotics and Manufacturing Automation (ROMA), Malaysia, pp. 1-6. IEEE, 2017.

BIOGRAPHIES OF AUTHORS

Saranya Krishnamurthy received B.E degree from Department of Electronics and Communication Engineering, Coimbatore Institute of Engineering and Technology, Coimbatore, India in the year 2011 and M.E degree from Department of Applied Electronics, Sri Krishna College of Engineering and Technology, Coimbatore, India in the year 2013. She is currently pursuing the Ph.D. from Department of Electrical and Electronics Engineering, Universiti Teknologi PETRONAS, Malaysia. Her current research interest includes the Power electronics, VLSI design, Digital Electronics and Semiconductor Devices. From 2013 to 2015, she was an Assistance Professor at Institute of Bannari Amman Institute of technology, Erode, India. She is affiliated with IEEE as student member.

Ramani Kannan is a senior lecturer in Universiti Teknologi PETRONAS (UTP), Malaysia. He received his B.E degree from Bharathiyar University, India. Later on completed his M.E and PhD in Power Electronics and Drives from Anna University respectively. He was an Associate Professor in the department of Electrical and Electronics Engineering at the K.S. Rangasamy College of Technology (Autonomous), India. He is a senior member IEEE, IETE, ISTE, and Institute of Advanced Engineering and Science Member. He obtained Carrier Award for Young Teacher (CAYT) from AICTE, New Delhi (2012), and obtained an award of Young Scientist in Power Electronics and Drives, INIDA (2015). He is the Editor-in-Chief of the Journal of Asian Scientific Research and Regional editor South-Asia in International Journal of Computer Aided Engineering and Technology, Inderscience publisher (UK). His research interest involves power electronics, inverters, modeling of induction motors, and optimization techniques.

Chay Che Kiong received Bachelor degree from Department of Electrical and Electronics Engineering, in Universiti Tecknologi PETRONAS (UTP), Malaysia in the year 2017. He is currently working as System Sales Engineer in AEX SYSTEM Pty Ltd,Malaysia. His research interest includes the power electronics, power systems and networking. He was worked as business development engineer trainee at Robert Bosch sdn bhd, Selangor, Malaysia.

Taib B Ibrahim graduated from Coventry University,UK, post graduated and Ph.D.Degrees in Electrical Machine Design, from University of Strathclyde, UK. Currently working as Associate Professor in Electrical and Electronics Engineering Department,Universiti Teknologi PETRONAS, Malaysia. He has published more than 115 papers in international/national conferences and journals and seven book chapters. He is active and professional member for many editorial and advisory boards of international journals and IEEE conferences. His research interest involves Linear and rotary electrical machine design, Renewable energy, Power electronic converter.