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ORIGINAL ARTICLE

RADIATION EFFECTS ON THE POWER MOSFET FOR SPACE APPLICATIONS

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ABSTRACT

The electrical characteristics of solid-state devices, such as bipolar junction transistors (BJTs), metal-oxide-semiconductor field-effect transistors (MOSFETs), and other active components, are influenced by photon radiation and temperature variations in the space environment. This paper examines the threshold voltage, breakdown voltage, and on-resistance for two types of MOSFETs (with VDSS ratings of 200 V and 100 V) under γ-irradiation. We compare these electrical specifications before and after irradiation at low dose rates of 4.97 and 9.55 rad/s, and at a maximum total dose of 30 krad. The γ-radiation facility at the Korea Atomic Energy Research Institute (KAERI) was used to apply low-dose radiation to two commercially available International Rectifier (IR) products, the IRFP250 and IRF540, in our experiment.

KEYWORDS: *Radiation effect, MOSFET, threshold voltage, breakdown voltage, dose rate, total dose, γ-radiation.*

INTRODUCTION

Electronic radiation-hardened components are essential for satellites and nuclear power plants due to the presence of various radiation particles in space and radiation environments. Over the past 40 years, countries with advanced satellite technology have been researching radiation effects on both passive and active electronic circuit components, primarily for space and defense applications. Researchers in these countries have shared numerous reports, facilitating the exchange of satellite technology. However, Korea's technology level in this field is significantly lagging, necessitating a focused effort to catch up.

Radiation types are generally categorized into particle radiation and photon radiation. Particle radiation includes charged particles such as protons, electrons, α particles, and ions, as well as neutral particles like neutrons. This type of radiation can induce ionization, generating excess carriers within semiconductor devices and materials. Photon radiation consists of γ rays and/or x-rays. The primary unit used for measuring the ionization effects induced by γ rays is the rad, defined as the amount of radiation that deposits 100 ergs of energy per gram of material. For particle radiation, the relevant units are flux (number/cm^2-s) and fluence (number/cm^2).

Commercial devices typically incorporate a channel stopper or guard band to provide isolation between adjacent devices. However, the threshold voltage in this region is often insufficient to prevent inversion in a radiation environment. To counteract this, the guardband must be doped heavily enough to prevent inversion post-irradiation and should be designed so that the gate oxide extends over the guardband between the source and drain. The gate voltage V_{GS} needed to form an inversion layer below the SiO_2 is known as the threshold voltage h V^{th} and can be represented as [1]:

$$V_{th} = \Phi_{ms} + 2\Phi_f - Q_{BO}/C_{ox} - Q_{tot}/C_{ox}\ , \qquad (1)$$

where Φ_{ms} is the metal-semiconductor work-function difference, Φ_f is the Fermi level, Q_{BO} is the depletion charge by inversion, Q_{tot} is the charge in the SiO_2, and C_{ox} is the capacitance of the SiO_2.

A simple method for estimating the threshold voltage shift due to ionizing irradiation at a low dose rate was recently proposed for power metal-oxide semiconductor field-effect transistors (MOSFETs). This method involves estimating the threshold voltage shift by assessing the oxide charge trapping in the gate oxide immediately after irradiation and annealing at 100°C. The minimum required gate threshold voltage, denoted as Vth, is 2 V.

The breakdown voltage (BVDSS) between the drain and source with the gate short-circuited to the source is the lowest voltage that prevents an avalanche across the termination ring. An avalanche occurs at a lower VDS value when the channel is turned on at VGS = 0. The breakdown voltages of the International Rectifier (IR) products we have tested should be 200 V.

In response to a small applied voltage VDS, the n-type bar behaves as a simple semiconductor resistor, causing the current ID to increase linearly with VDS. As the current increases, the ohmic voltage drop along the n-type channel region reverse-biases the gate junction, establishing the conducting portion of the channel. The I-V characteristics for very small VDS show that the MOSFET acts like a variable resistance whose value depends on VGS. The ratio VDS/ID in this region is known as the on-resistance RDSON, a crucial parameter in switching applications that use a few ohms. The ideal switch has 0 ohms, and the maximum on-resistance requirement for the product is 85 mΩ.

[1] Radiation Effects on Power MOSFET

Comparing the effects of ionizing radiation on two distinct MOSFET devices, it's evident that MOS devices are highly susceptible to radiation-induced alterations, with even low doses causing significant changes. The primary factor influencing these changes in electrical characteristics is the structure of the gate oxide. When exposed to radiation, charge trapping at the gate oxide occurs, resulting in a shift of the I-V characteristic towards more negative gate voltage values. This shift is particularly problematic for n-channel devices, as it can lead to the I-V curve surpassing zero volts, causing a sharp increase in current. This phenomenon is commonly interpreted as a modification of the gate threshold voltage. By differentiating equation (1), a relationship between the threshold voltage (Vth) and the total charge (Qtot) in SiO2 can be derived.

$$\Delta Q_{tot} = - C_{ox}\, \Delta V_{th}\ , \qquad (2)$$

For each type of MOSFET, Cox remains constant, while ΔQtot varies according to the radiation dose. Qtot is affected by both the fixed oxide charge (QF) and the interfacial trap charge (QI), as illustrated in equation (3).

$$\Delta Q_F - \Delta Q_I = - C_{ox}\Delta V_{th} \qquad (3)$$

When the oxide undergoes irradiation, an increased number of dangling bonds are formed. These bonds, situated near the interface between silicon and silicon dioxide (SiO_2), trap charge QI. In the case of an n-channel MOSFET, where the applied gate voltage VGS has an opposite sign, this trapped charge is negative. Conversely, the fixed oxide charge QF results from the capture of holes generated by irradiation, leading to a positive charge accumulation in defects within the oxide. Due to the significantly lower mobility of holes compared to electrons in SiO_2, they readily accumulate in defects, causing the threshold voltage of a MOSFET to become more negative. Radiation predominantly affects the fixed oxide charge rather than the interfacial trap charge, which remains relatively consistent across different MOSFETs.

To enhance the electrical characteristics, particularly the breakdown voltage, a termination technique utilizing a field-limiting ring structure has been widely adopted. This technique exploits the junction curvature to achieve the desired breakdown in planar devices, thereby mitigating the effects of radiation.

The on-resistance, determined by the slope of ID versus VDS, serves as an indicator of a MOSFET's performance, with steeper slopes indicating lower resistance values and better characteristics. Interestingly, the static drain-to-source on-resistance remains unaffected by low doses of radiation.

Experimental Results

1. Two types of commercial-grade IR MOSFETs with voltage ratings of 200 V and 100 V (VDSS) were selected for testing. Both threshold voltage and breakdown voltage (BVDSS) were evaluated and compared against specifications before and after exposure to low dose rates of 4.97 and 9.55 rad/s, with a maximum total dose of 30 krad. The testing followed Mil-Std-883 Method 1019, utilizing a γ source employing 60^o for irradiation. Each test involved five pieces.
2. Figures 1.1 to 1.5 depict the characteristics of threshold voltage, breakdown voltage, and on-resistance of irradiated MOSFETs, varying with dose quantity and post-irradiation annealing at 100°C for 168 hours. Total doses ranged from 0 to 30 krad, with dose rates of either 9.55 or 4.97 rad/s. Annealing at 100°C for 168 hours occurred immediately after irradiation.
3. In Figure 1.1, it's observed that the threshold voltage (Vth) of the 200 V MOSFET decreases as the total dose increases up to 30 krad at a dose rate of 9.55 rad/s. However, this voltage does not recover even after annealing at 100°C for 168 hours.

In Figure 1.2, at a dose rate of 4.97 rad/s, the voltage recovers to 1.9 V, equivalent to the voltage at 20 krad irradiation, after annealing at 100°C for 168 hours. However, this recovery fails to meet the minimum threshold voltage requirement of 2.0 V.

Figure 1.3 illustrates the slope of the threshold voltage for the 100 V MOSFET at a dose rate of 4.97 rad/s, which is less steep compared to that of the 200 V MOSFET shown in Figure 1.2. This discrepancy can be attributed to the difference in gate oxide thickness. Consequently, the threshold voltage satisfies the minimum requirement.

Tables 1.1 and 1.2 present the descent rate of threshold voltage (ΔV^{th}) for the 200 V and 100 V MOSFETs, respectively, demonstrating compliance with equation (2).

Breakdown voltage characteristics are depicted in Figure 1.4, meeting the specification of a minimum 200 V. Notably, the breakdown voltage remains unchanged following irradiation and subsequent annealing.

Table 1.1 Threshold voltage and change of threshold voltage of a MOSFET (200 V) as the total dose increases.

Total dose (krad)	0	2.5	5	7.5	10	20	30
V^{th} (V)	2.82	2.68	2.55	2.42	2.3	1.87	1.57
ΔV^{th}		-0.14	-0.13	-0.13	-0.12	-0.43	-0.30

Table 1.2 Threshold voltage and change of threshold voltage of a MOSFET (100 V) as the total dose increases.

Total dose (krad)	0	2.5	5	7.5	10	20	30
V^{th} (V)	2.98	2.93	2.86	2.81	2.76	2.57	2.38
ΔV^{th}		-0.05	-0.07	-0.05	-0.05	-0.19	-0.19

Figure 1.1 Threshold voltage (V_{th}) characteristics of a MOSFET (200 V) under a dose rate of 9.55 rad/s

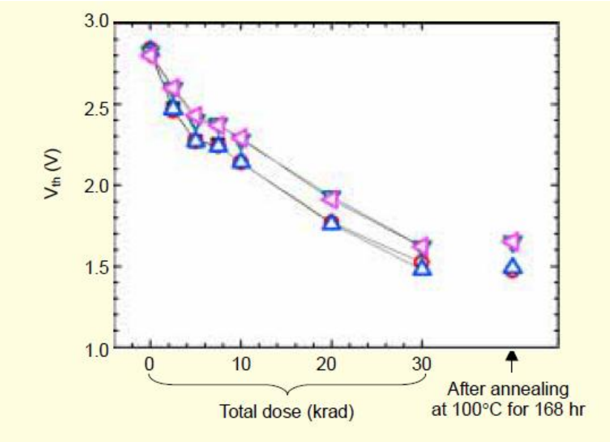


Figure 1.2 Threshold voltage characteristics of a MOSFET (200 V) under a dose rate of 4.97 rad/s

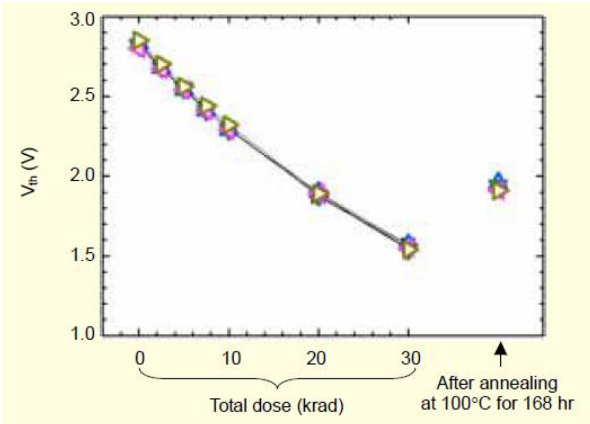


Figure 1.3 Threshold voltage characteristics of a MOSFET (100 V) under a dose rate of 4.97 rad/s. expected that the field limit ring for achieving a breakdown

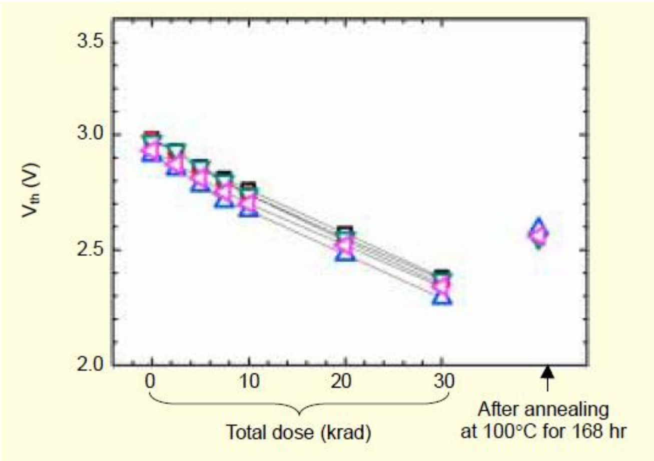
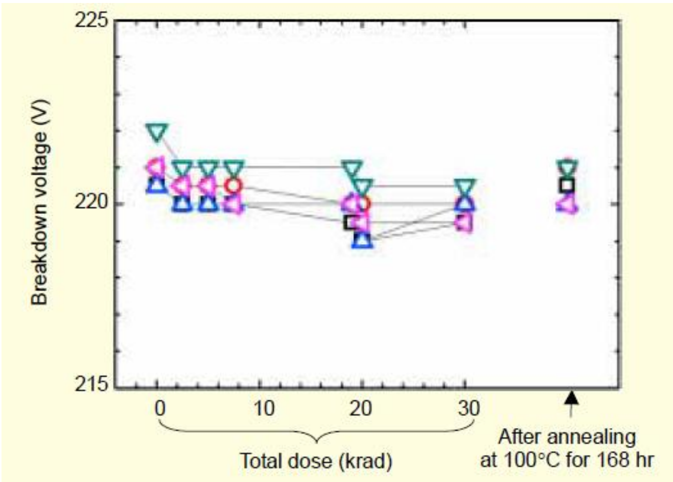


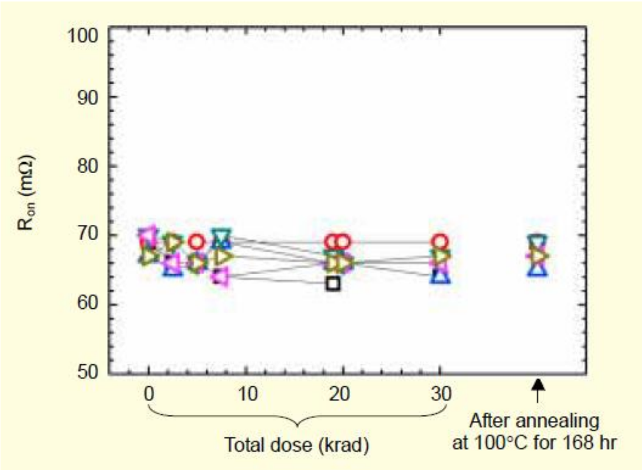
Figure 1.4Breakdown voltage characteristics of a MOSFET (200 V) under a dose rate of 4.97 rad/s



The voltage of the sample device possesses a sufficiently wide margin to accommodate the charge accumulation that occurs at the oxide termination when exposed to the radiation source.

Figure 1.5 displays the on-resistance characteristics, meeting the requirement of a maximum 85 mΩ.

Figure 1.5 On-resistance characteristics of a MOSFET (200 V) based onthe quantity of dose and after annealing at 100 C for 168hours



CONCLUSION

The breakdown voltage remains relatively stable regardless of the dose rate or total dose. Our experiments confirm that IR commercial products consistently meet the breakdown voltage specifications of 100 and 200 V. Additionally, the on-resistance remains unaffected by radiation exposure, indicating the robustness of these products. The study observed a linear decrease in the slope descent rate of the threshold voltage as the total dose increased. Notably, this descent rate correlates with the threshold voltage, indicating that it increases with higher threshold voltages. Both devices successfully revert to their original specifications after annealing, except for the 200 V MOSFET at a dose rate of 9.55 rad/s, where slight deviation occurs. However, no permanent damage is observed. For doses exceeding 20 krad and in the case of a 200 V MOSFET, the threshold voltage fails to meet the minimum requirement of 2.0 V. Therefore, we recommend that device manufacturers consider this point when designing new structures to mitigate threshold voltage shifts at higher dose rates.

I. REFERENCES:

1. International Rectifier, 200 V N-Channel MOSFET, IRFP250 Datasheet, May 2001.
2. Jim Schwank, “Total Dose Effects in MOS Devices,” IEEE Nuclear Space Radiation Effects Conf., Short Course III-47, July 2002.
3. Jacob Milman and Arvin Grabel, Microelectronics, McGraw-HillInt’l ed., pp. 138-1987.
4. Lee S.Y, Lho Y.H., and Kim J.D., ‘On the Design of Field Limiting Ring for Improving Corner Breakdown Voltage’, Proc. PEMC ‘98, Prague, Czech, 1998, pp. 41-44.
5. Ma T. P. and Paul V. Dressendorfer, Ionizing Radiation Effects inMOS Devices and Circuits, John Wiley & Sons, 1989.
6. Paul R. Gray and Robert G. Meyer, Analysis and Design ofAnalog Integrated Circuits, John Wiley & Sons Inc., 1993.
7. WON-SO SON, SANG-GI KIM, YOUNG-HO SOHN, AND SIE-YOUNG CHOI, “A NEW SOI LDMOSFET STRUCTURE WITH A TRENCH IN THE DRIFT REGION FOR A PDP SCAN DRIVER IC,” ETRI J., VOL. 26, NO. 1, FEB. 2004.