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Transconductance and Transfer characteristics of 8 MeV Electron Irradiated Dual N-channel MOSFETs

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***Abstract* — The electrical characteristics of dual N-channel enhancement metal-oxide semiconductor field-effect transistors (MOSFETs) were altered by irradiating with 8 MeV electron beam for different doses ranging from 200 Gy to 1 kGy at ambient air. The irradiation experiments were conducted with gate bias ($V_{GS} = -2, 0, +1.5$ and $+2$ V). Significant increase in transconductance (g_m) was observed after irradiation. The g_m was found to increase drastically for the dose of 1 kGy with positive bias (1.5 and 2 V). The transfer characteristics at V_{DS}=12 V revealed that the drain current (I_D) increases with the increase of dose and also increases with the increase of gate bias voltage during irradiation. The results of these investigations are presented and discussed.**

***Keywords* — MOSFET, Radiation effect, Electron radiation, Transconductance, Transfer Characteristics, Si/SiO$_2$ interface.**

I. INTRODUCTION

Over the last few decades, semiconductors have become most important material for the fabrication of electronic and opto-electronic devices. The invention of transistors almost 65 years ago has resulted in the development of present day society with advanced information systems. The electronic systems embarked on board of spacecraft's are submitted to permanent radiance of either cosmic or solar origin. These radiations may cause malfunctioning of electronic devices and components [1]. The study of radiation induced defects in semiconductors would be extremely useful in estimating the lifetime of devices working in radiation environment such as space applications, atomic energy installations etc. Metal-oxide semiconductor (MOS) devices are among the most sensitive of all semiconductors to radiation, in particular ionizing radiation, showing much change even after a relatively low dose and are prone to parametric or even functional failure on exposure to radiation environments [2-6]. In metal-oxide semiconductor field-effect transistors (MOSFETs), the gate oxide structures influence on the changes in the electrical characteristics due to irradiation [7].

Because of their faster switching speeds and simple drive requirements, MOSFETs are preferred for our investigation. An attempt has been made to understand the effect of 8 MeV electron beam on dual n-channel MOSFETs.

II. IONIZING RADIATION EFFECTS ON MOSFETS

The MOSFET is a four-terminal device consisting of a p-type Si substrate with n$^+$ source and drain regions separated by a channel, which is covered by a thin insulating film (SiO$_2$) with a metal or polysilicon gate electrode on the insulator (figure 1). The basic operation of this device consists of applying voltage to the gate, which causes the p-type substrate to invert the region near the SiO$_2$/Si interface under the gate, creating a conduction path for electrons between source and drain. As the gate voltage is increased, the current between source and drain increases for a given drain voltage until saturation is reached.

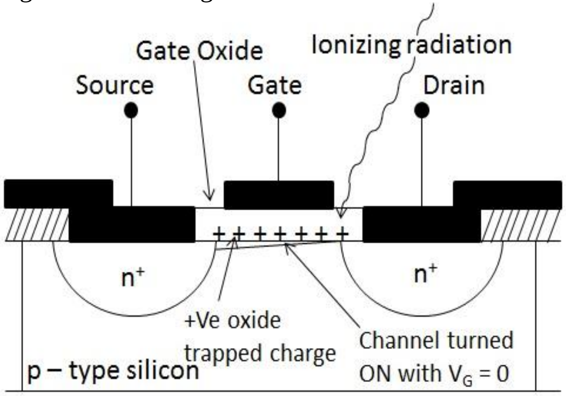

Figure 1. Schematic illustration of an n-channel MOSFET during the ionizing radiation on the gate oxide

When MOS devices are exposed to 8 MeV electrons, these high-energy electrons easily pass through the gate oxide layer. These electrons transfer energy into the MOSFET through electronic excitations, which in turn produce ionization or breaking bonds and displacement of atoms along its path during the irradiation process [8].

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Some of the positively charged holes are trapped at the Si/SiO_2 interface (see figure 1) which results in additional oxide charge and reduces the threshold voltage. Hence there is necessary to study the changes in transfer and transconductance characteristics of the device due to high energy radiation.

Figure 2. Experimental setup made for irradiation at Microtron Centre. (Inset shows the MOSFET placed to irradiate at bias condition)

III. Devices And Methods

In this study, we have used the monolithic dual N-channel and dual P-channel matched transistor pair of enhancement-mode MOSFETs (ALD1103) with 14-Pin plastic DIP package procured from Advanced Power Components, UK for irradiation studies. The devices were irradiated with 8 MeV electron beam (shown in figure 2) for the doses ranging from 200 Gy to 1 kGy in steps of 200 Gy, using variable energy Microtron accelerator facility available at Microtron Centre, Mangalore University, India. The features of the Microtron are detailed elsewhere [9, 10]. Also, the devices were irradiated for different gate bias (V_{GS} = −2, 0, +1.5 and +2 V) at room temperature (insets of figure 2). The electrical characterization of the non-irradiated and 8MeV electron-irradiated N-channel MOSFETs were performed using computer interfaced Keithley 2612A source measure unit. The current resolution with the test setup was of the order of 1–100 pA. Detailed studies were carried out on the transconductance and transfer characteristics of n-channel MOSFET devices and the results are presented and discussed herein.

IV. Results And Discussion

A. Transconductance

The transconductance (g_m) of the MOSFET is determined from the drain current (I_D) versus gate-source voltage (V_{GS}) characteristics defined as the rate of increase in I_D per unit increase in V_{GS} at fixed drain-source voltage (V_{DS}) [11], i.e.

$$g_m = \partial I_D / \partial V_{GS} | V_{DS} = \text{constant } (12\ V) \quad (1)$$

The primary effect of ionizing radiation is to produce electron-hole pairs in the thermally grown insulator and also causes additional interface traps to be formed at the Si/SiO_2 interface. Figure 3 represents the variation of transconductance of the N- channel MOSFETs for before and after irradiation. There is a drastic increase in g_m after 200 Gy electron irradiation and no significant changes from 400 Gy to 1 kGy.

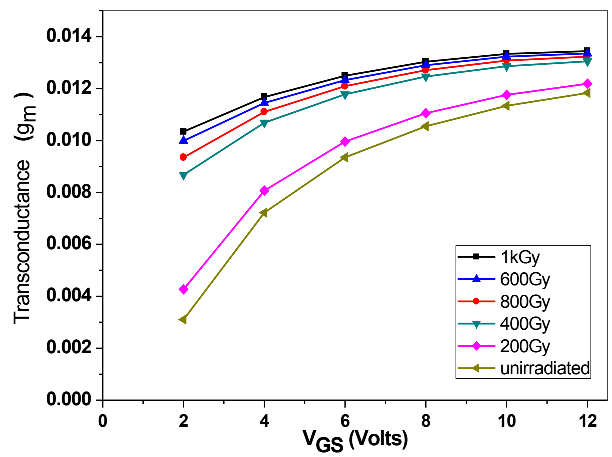

Figure 3. Variation of g_m versus V_{GS} with respect to electron dose (at V_{DS} = 12 V)

In the enhancement MOSFETs, bias voltage is necessary to enhance the channel to flow drain-to-source current, because of the device is completely isolated and there is no current flow at V_{GS} =0 V. Figure 4 shows the effect of bias voltage on the g_m of the 8 MeV electron irradiated MOSFET for the dose of 1 kGy during irradiation. The gate bias during irradiation enhances the device performance by providing channel i.e., by inverting the p-type substrate sufficiently to cause a current of at least 1 A to flow between source and drain.

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Also, g_m of the irradiated devices increases drastically after applying the forward bias of 1.5 and 2 V respectively. Further, there is a decrease in the g_m due to reverse bias of -2 V compared to positive bias ie., greater than 0 V.

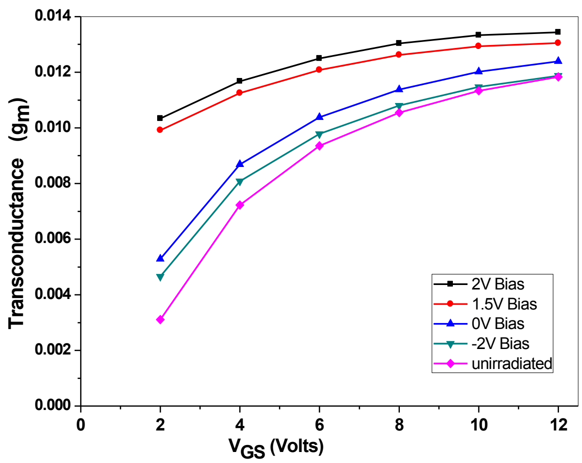

Figure 4. Variation of g_m verses V_{GS} with respect to gate bias during irradiation (at Dose = 1 kGy & V_{DS} = 12 V)

The peak transconductance (g_{mPeak}) was extracted from the I_D versus V_{GS} plot taken at V_{DS} = 12 V and values of g_{mPeak} after 8 MeV electron irradiation of different dose were given in table 1. It can be observed that around 1 to 10% increases in the g_{mPeak} after a total dose of 1 kGy for different gate bias during irradiation. The maximum g_{mPeak} was observed for device irradiated with 1 kGy dose with positive gate bias of 2 V. This is due to decreased trapped holes and interface traps which weakens the carriers moving in to the channel and hence increase the transconductance. Similar trend of observation was made with decrease in g_{mPeak} after total dose irradiation in case of dual gate depletion mode [11].

TABLE I

VARIATION IN g_{mpeak} AFTER 8 MeV ELECTRON IRRADIATION TAKEN AT V_{DS} = V_{GS} = 12V FOR DIFFERENT BIASING VOLTAGE DURING IRRADIATION

Electron Dose	Peak Transconductance (g_{mPeak})			
	V_{GS}= 2V Bias	V_{GS}= 1.5V Bias	V_{GS}= 0V Bias	V_{GS}= -2V Bias
200 Gy	0.01219	0.01185	0.01206	0.01168
400 Gy	0.01305	0.01270	0.01220	0.01169
600 Gy	0.01335	0.01290	0.01230	0.01185
800 Gy	0.01323	0.01288	0.01233	0.01181
1000 Gy	0.01344	0.01305	0.01239	0.01188

B. Transfer Characteristics

The transfer characteristic relates drain current (I_D) response to the input gate-source driving voltage (V_{GS}) for a fixed drain-source voltage (V_{DS}). Since the gate terminal is electrically isolated from the remaining terminals (drain, source, and bulk), the gate current is essentially zero, so that gate current is not part of device characteristics. The transfer characteristic curve can locate the gate voltage at which the transistor passes current and leaves the OFF-state. Also, it is useful for visualizing the gain from the device and identifying the region of linearity. The gate voltage at which the current turns on is called the threshold voltage, V_T. For the ALD1103, the data sheet gives V_T = 0.4 V to 1 V, depending of V_{DS}.

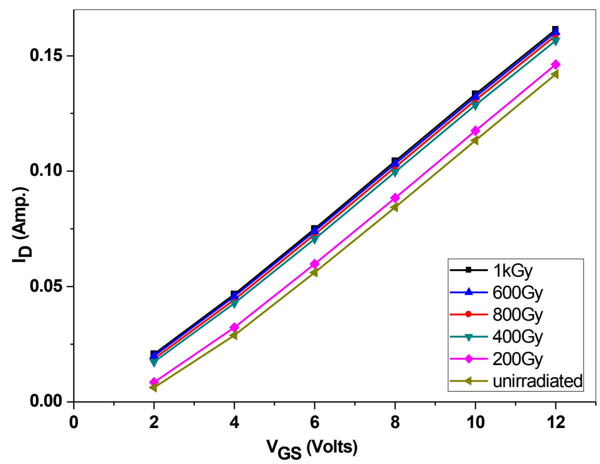

Figure 5. Transfer Characteristics of 8 MeV electron irradiated MOSFETs (at V_{GS}=2V Bias) with different dose (V_{DS}=12V)

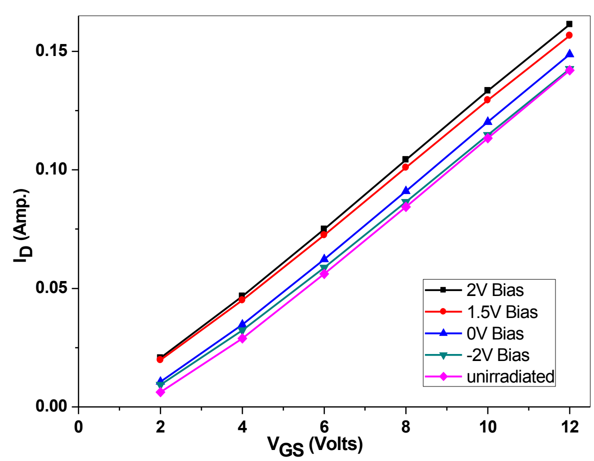

Figure 6. Transfer Characteristics of 8 MeV electron irradiated MOSFETs (at 1 kGy dose) for different bias voltage (V_{DS}=12V)

Figure 5 and 6 depict the transfer characteristics (I_D versus V_{GS}) of 8 MeV electron irradiated MOSFETs at V_{DS} = 12 V. In figure 5, it is clearly seen that the I_D increases with the increase of dose. And also I_D increases with the increase of gate bias voltage during irradiation which is evidenced in figure 6. The I_D was increased due to the shift in threshold voltage and it is a resultant effect of both trapped charges at Si/SiO_2 surface and in bulk oxide.

V. CONCLUSIONS

The effect of 8 MeV electron radiation on dual N-channel MOSFETs were investigated and it was observed that, the transconductance and transfer characteristic increases with electron dose as well as positive gate bias during irradiation. Peak transconductance g_{mpeak} was increased around 1 to 10% after a total dose of 1 kGy for different gate bias. The results indicate that the dual N-channel MOSFET is very sensitive to radiation environment.

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