The Effects of Gamma rays on P-channel MOSFET

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ABSTRACT

The effect of Gamma rays on PMOS is studied. The range of Gamma rays used from 1M.rad to 3M.rad. and analyzed Threshold voltage, transconductance and output conductance are measured beforeradiation. These parameters are measured and carefully analyzed after irradiation. It has been observed that radiation degrades the device performance by changing the parameters due to oxide trapped charges and interface. When the γ-radiation falls on the device it deposits energy by causing ionization in the oxide layer. The ionization changes the charge excitation, charge transport and decomposition properties of the device. It has been found the threshold voltage increased linearly with increasing dose rate in almost all devices.

1. INTRODUCTION

The device modeling on MOSFET characteristics was developed around 1963 by Ihantola and Moll, Sha, Hofstien and Heiman [1,2,3]. MOS configuration forms the basis of a number of useful semiconductor devices such as a charge couple device (CCD), charge injection device (CID), MOSFETs, etc. In addition the basic MOS structure has got tremendous application in solid-state imaging and gas sensors. However, MOS devices are susceptible to degradation in presence of ionizing radiation. The extent of degradation of the device in presence of ionizing radiation depends on the total dose received by the device. The study of radiation effects on MOS based devices including MOS capacitors has been an active area of research over the past decades [4].

The degradation of metal-oxide semiconductor field effect transistor (MOSFET) devices caused by exposure to ionizing radiation was first noted by Hunhes and Giroux [5] in 1964. Therefore, similar results were reported by others for different ionizing radiations such as X-rays [6, 7] UV light [8] and e-beam [9,10]. Other experiments [11, 12] revealed that the degradation of performance was due to, Positive charge trapped in SiO_2, Interface states induced by irradiation

First provides useful information regarding the behavior of MOS based devices and circuits in the electronic instrumentation parts of satellites or of nuclear reactors environments. The second important significance of the study lies in the fact that sensitivity of MOS devices and structure to ionizing radiation can be exploited for use in nuclear radiation dosimetry. In fact MOS devices are presently being used as dosimeter in the medical field for monitoring the radiation dose delivered to patients undergoing radiation therapy [13]. The manner in which radiation interacts with solid materials depends on the type, kinetic energy, mass and charge of the incident particle and the mass, atomic number and density of the target material. Energetic particles or photons passing through matter lose energy through a variety of interactions and scattering mechanisms. Two major consequences are ionization and displacement damage

In ionization process the valence band electrons in a material are excited to the conduction band and are highly mobile if an electric field is applied. Any solid, even an insulator, thus conducts for a time at a level higher than is normal. The positively charged holes are also mobile, but to a different degree from electron. So they trapped within the oxide, leading to a net positive charge [14]. In displacement momentum exchange occurs between a high-energy particle and an atom in a solid. In this atom will leave its site if it receives energy greater than the displacement energy E_d. Its departure leaves a vacancy (by definition, a defect in the lattice). The removed atom may collide many times with other atoms and produce a “cascade” of displacements [15]. The above mechanisms are generally understood to be responsible for the changes in the characteristics of the device under exposure to ionizing radiation.

When gamma rays or other ionizing rays interact with MOSFETs then electron-hole pair produced. The number of pairs created is proportional to the quantity of energy deposited in the material, which is expressed through the total absorbed dose. To calculate the number of the electron-hole pairs generated, it is important to know the total amount of energy deposited in the matter by the incident particles. This amount is related to their linear energy transfer (LET), This shows the energy transfer to the material, by the incident particle. The electrons are much more mobile than the holes and move closure to the contacts. Holes are relatively immobile and may be trapped within the oxide, leading to a net positive charge [16, 17]. Others may move to the silicon silicon-dioxide interface, where they create interface traps [18].

The defects created by radiation may also serve as interface traps. When holes reach the silicon-silicon dioxide interface, a fraction is captured in trapping sites. While the remainder flow into the silicon. A net positive radiation-induced charge is now trapped in the oxide due to those captured holes. The amount of trapped charge is proportional to the number of defects in the silicon dioxide caused by gamma radiations. Similarly when MOS devices are exposed to ionizing radiation, additional interface states are generated at the Si-SiO2, interface. and acceptor states in the upper half. For this reason for p-channel MOS transistors the threshold voltage increases after irradiation due to the creation of new interface traps [19].

Ausman and McLean [20] followed by Benedetto and Boesh [21] determine that on average, each 18 eV of energy deposited in the oxide by the ionizing radiation would result in the formation of an electron-hole pair. The average energy of Gamma photons coming from CO60 source is about "1.25 Mev". So this energy is enough to produce electron-hole pair in the device.

In this paper we present new information on the generation of interface states caused by exposure of MOS structures to ionizing radiation. It has been found the threshold voltage increased linearly with increasing dose rate in almost devices. These new results parallel those previously reported on the effect of high field stress [22] and serve as strong evidence in support of the argument that interface stats are created as a consequence of trapped holes which causes the degradation of PMOS, The radiation-induces interface states tend to be donor states in the lower half of the band gap.

2. DEVICE FEATURES AND MEASUREMENT SYSTEM

The specimens used in this study were low noise P-channel MOSFETs of different manufactures. These devices are typical of present commercial devices and found to have large effect of radiation. Method used to measure the turn-on voltage is shown in Fig.1.

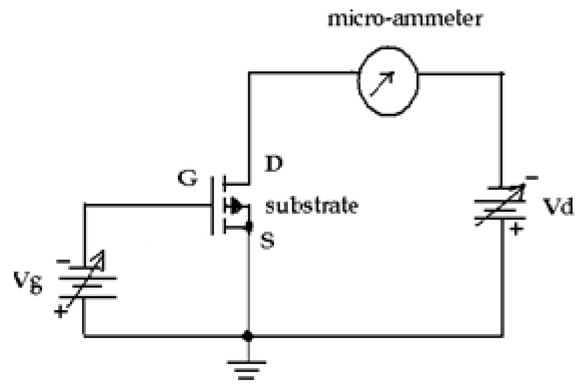

Figure 1: Circuit set-up for measuring V_{th}

Initially drain to source voltage is fixed at level,V_d= -1.5 volt. Then Gate-Source voltage "V_g" is changed at regular intervals and the corresponding drain current is measured. Now a graph between the drain current I_d and '(V_g - $V_{gs}/2$)' is plotted as shown in fig. (2), before and after radiating dose. Gamm radiations dose used from '1 M.rad' to '3 M.rad'. The device parameters were measured using I-V converter circuit. It measures the drain current in weak inversion. A fixed gate-source voltage and substrate voltage generate inversion layer and conductance of this inversion layer is

$$G_{DS} = \frac{\mu . C_{OXX}}{L^2}\left[V_{GS} - V_T\right] \quad (1)$$

Where, C_{oxx} is the total oxide capacitance. In all experiments the substrate voltage was kept constant therefore substrate depletion charge has no effect on the conducting channel. In these results we only consider the gate transconductance because substrate is connected to ground potential. MOSFET drain source resistance effect the operating points in analogue circuitry and switching times in digital circuitry.

$$g_m = \frac{\mu . C_{OXX} V_{DS}}{L^2} \quad (2)$$

Transconductance of the devices was measured and calculated before and after the irradiation. A difference in transconductance was observed after radiation.

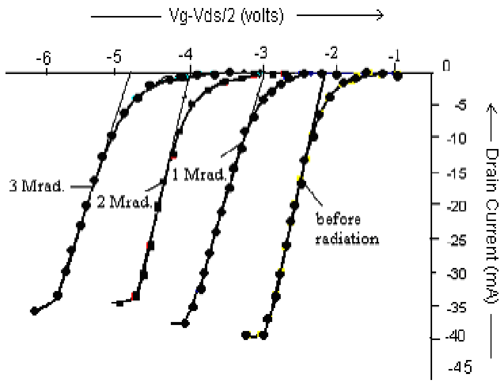

Figure 2: Pre and post irradiation graph between I_{ds} and $(V_{gs}-V_{ds}/2)$.

The intersection curve with voltage axis yields V_{th} at $I_d \approx 0$. The measured value of V_{th} pre-irradiation is -2.4 volts. The shift in V_{th} are -3.0 v, -4.1v and -4.9 volts respectively. Transconductance and output conductance of the device was measured before and after the dose at 1M.rad, 2M.rad and 3M.rad using γ-rays. There is increment in the transconductance, output conductance and decreased in channel resistance was observed after the radiation.

3. RESULTS AND DISCUSSION

The most important part of the MOSFET is metal, silicon dioxide and n-type semiconductor as shown in figure 3.

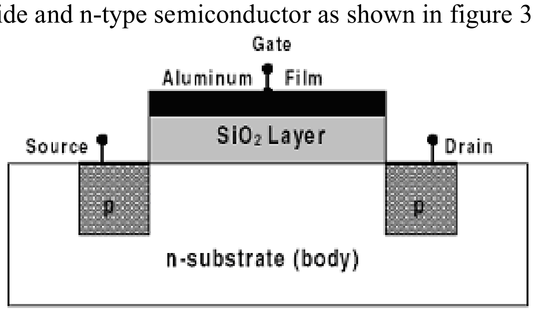

Figure 3: Structure of a PMOS

Note that insulator is sandwiched between two conducting materials like metal (aluminum or heavily doped pollysilicon) and other is n-type semiconductor. So it is called n-type MOS capacitor. Research results revealed that the degradation of performance was due to ionizing radiations. These ionizing radiation damages MOSFET device primarily through building up positive charge (holes) in the oxide layers of the transistors, and trapping negative charges (electrons) at the interface. The applied gate voltage sweeps the mobile electrons out of the gate oxide. The less mobile holes become trapped in the SiO2 where they contribute to a trapped positive oxide charge. This effect the device parameters. The charges trapped in oxide give origin in the flat-band voltage, and therefore it can be expressed as:

$$\Delta V_{ox} = \frac{1}{C_{ox}} \int_0^{tox} \frac{x}{t_{ox}} \rho(x) dx \qquad (3)$$

Where t_{ox} is the gate oxide thickness, C_{ox} is the capacitance per unit area and ρ (x) is the charge distribution in the oxide per unit volume as function of the distance from the gate-oxide interface x. Above expression shows that the voltage shift due to this contribution is positive when the charge is negative. Another important consideration indicated this expression is that the effect of the oxide charge on the voltage shift is weighted by its position in the oxide, the closer the charge to the SiO2-Si interface, the bigger V_{th} shift.

Our result shown in figure 2 clear that as "increased the dose" the "shift in voltage is most prominent it is compare with other researcher gives good conformation to our results shown figure 4.

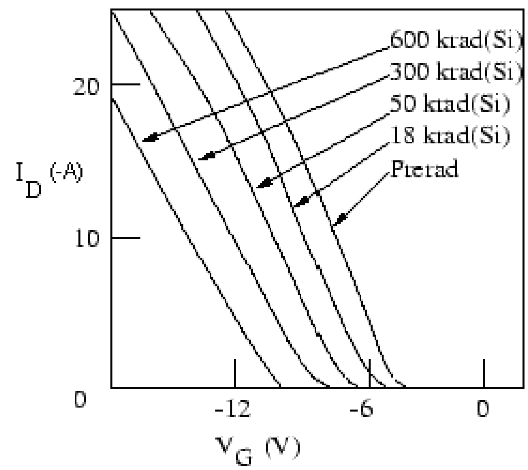

Figure 4: Radiation-induced shift in V_{th} enhancement MOSFET

Table 1: Measurement for Threshold Voltage corresponding Gamma Dose rate

S.No.	Dose rate (Mrad.)	Threshold Voltage (v)
1	0	-2.4
2	1	-3
3	1.5	-3.57
4	2	-4.15
5	2.5	-4.52
6	3	-4.9

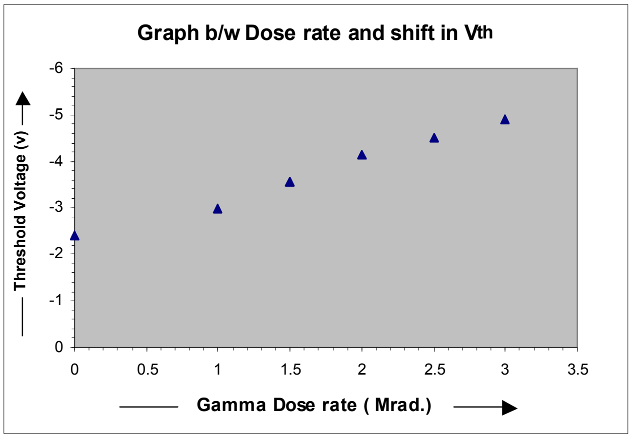

Figure 5: Threshold voltage increased linearly with increasing Gamma Dose

In figure5 at zero dose rate means before radiations and at this the threshold voltage is –2.4 volts. Whereas other values shows after irradiate MOSFET. It is clear that when dose increase the V_{th} increased. The table 2 gives a good comparison pre and post radiation dose.

Table 2: Comparison before and after Gamma Dose

gamma-rays	Before rad.	1.0 Mrad.	2.0 Mrad	3.0 Mrad
G_{ds} mho	0.0996845	0.2624967	0.269452	0.300368
R_{ds} (on) ohm	18.548	5.844	6.028	6.670
g_m mho	0.009998	0.009187	0.008251	0.008148

4. CONCLUSION

Gamma-ray radiation effects on threshold voltage and output conductance were discussed. Post irradiation inversion layer exhibited an increase in drain source resistance due to charge trapping and interface formation. The insulating oxide layers have the main influence on how a MOS device changes in the presence of radiation. Ionization in the silicon dioxide creates electron-hole pairs and subsequent charge trapping leads to the build-up of a potential.

This in turn leads to a shift in threshold voltage V_{th} is increased linearly with increasing radiation dose. Thus if we increased the dose rate then turn-on-voltage also increased. So making it more difficult to turn 'ON' the p-channel device may change from enhancement to OFF mode in radiation environment. For improvement in radiation tolerance a device with thinner thermal oxide on the offset region is proposed.

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