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Study of the effect of gamma radiation on MOSFET for space applications

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MOSFET is a basic component of VLSI and ULSI circuits and finds applications in many electronic systems used in satellite design. These devices are susceptible to degradation due to radiation in outer space. Conventional MOSFET can survive 3-10 krad (Si) of total dose without much parametric degradation. However, ionising radiation dose in excess of 35 krad (Si) may turn out to be detrimental to the functioning of the device. The space environment is hostile to the most integrated components such as those for navigation, communication, data processing function in satellites and various space missions. The radiation generally encountered in space includes α, β, γ, X-ray, energetic electrons, protons, neutrons and ions of various kinds. Gamma ray photons deposit energy in the components mainly by ionisation. In this paper, we report the gamma ray induced changes in the electrical characteristics of MOSFET 2N6796 (JANTXV) used in satellites. Pre-irradiation measurements of electrical parameters have been made using TESEC measurement system. Selected devices have been exposed to different gamma dose using a BRIT gamma irradiator. Post-irradiation measurements of electrical characteristics display significant degradation in threshold voltages and the leakage current increases as the gamma dose increases.

Keywords: MOS, Radiation effect, Gamma dose, Threshold voltage, Leakage current

1 Introduction

The metal oxide field effect transistor (MOSFET) is an important device in microprocessors, memory circuits, ICs and mainframe computers of space systems. The MOSFET shown in Fig. 1 is an *n*-channel device which consists of a semiconductor substrate (usually silicon) on which is grown a thin layer of oxide (SiO_2) of thickness 80 to 1000 Å. On the top of the oxide, a conducting layer called the gate electrode is deposited. Two heavily doped regions of depth 0.1 to 1 μm, called the source and the drain are formed in the substrate on either side of the gate. The source and the drain regions are overlapped slightly with the gate. The distance between the source and the drain edges is called the channel length (l) and the lateral distance to which the device is extended is called the channel width (w). The ratio w/l is called as aspect ratio and is used as a design parameter that can be varied to set the desired drain-source conduction properties of the MOSFET. The region between the source and drain junction is called the channel region[1].

Under normal operating conditions, a voltage V applied to the gate terminal creates an electric field that controls the flow of the charge carriers in the channel region between the source and the drain. Some important electrical parameters of MOSFET are mobility of electrons and holes, threshold voltage, drain current and transconductance. Threshold voltage also called TURN-ON or switching voltage is the bias voltage necessary on the gate to form an inversion layer at the silicon beneath the gate, which constitutes the conducting path between the source and the drain.When the inversion region is formed under the gate, current can flow from drain to source on application of drain voltage. This current is called the drain current and is used to evaluate the current

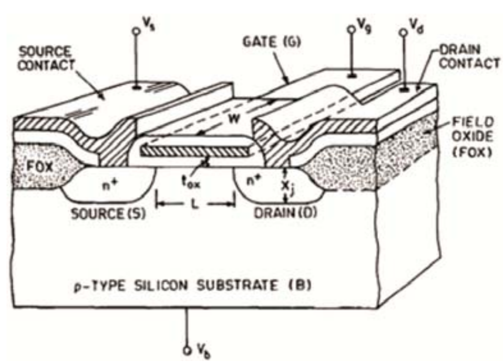

Fig. 1 — Schematic diagram of MOSFET.

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performance of the driver circuitry. Transconductance is the ratio of change in the drain current to the change in the gate voltage while keeping drain and substrate voltages constant.

The amount of radiation that the semiconductor devices encounter during their life cycle depends on the radiation environment and operating conditions. In predicting the response to a MOS device to gamma or any ionizing radiation, it is assumed that on the average, each 18 eV of energy deposited in the oxide by the ionizing radiation would result in the formation of an electron hole pair[2]. The radiation induced electrons are much more mobile than the holes and are swept out of the oxide layer. The holes which are relatively immobile cause a negative shift of the flat band voltage on the electrical characteristics of MOS devices.

Gamma ray photon interacts with semiconductor material mainly by ionization[3]. The energy used for ionization is called the ionizing dose. However, the portion of energy absorbed by the material/device during the whole exposure is determined by the total ionizing dose (TID). The principal ionization based damage effects in a semiconductor are enhancement of conductivity through production of excess charge carriers and trapped charges. Free electrons produced during ionization damage can have enough energy to cross the forbidden gap and create electron hole pairs. Therefore, the conductivity of the bulkmaterial is temporarily enhanced. Electron-hole pairs can also be produced in non-conducting structure like SiO_2. The ionizing damage brought about by gamma photon in SiO_2 layer is primarily due to the trapping of the charges in SiO_2 apart from anomalies in the Si/SiO_2 interface. The electron-hole pairs and trapped charges can significantly influence the electrical properties of MOS devices[4].

2 Materials and Methods

In order to investigate the TID effects of gamma radiation on MOS devices, MOSFET 2N6796 (JANTXV) is selected. The pre-irradiation electrical measurements are done using TESEC 881-TT/A semiconductor test system with SPECTRA software. The parameters namely drain to source breakdown voltage, gate threshold voltage, diode forward voltage, gate to source leakage current in forward and reverse direction, zero gate voltage and drain current are measured under specified conditions. The threshold voltage is measured under biased condition when the gate to source is biased with 12 V through a 10 kΩ resistor for V_{GS} measurement and drain to source is biased with 80 V through 10 kΩ for V_{DS} measurement. Typical output, transfer and source drain forward characteristics are also studied. Several devices, all belonging to the same batch (date code), are selected for exposure to gamma radiation. Each device is exposed to a specified gamma dose from 5 krad to 35 krad in steps of 5 krad. A ^{60}Co based gamma chamber (GC 1200 BRIT Irradiator) available in ISAC, Bengaluru is used for irradiation. Post irradiation measurements are made for each exposed device.

3 Results and Discussion

Gamma radiation generally results in degradation by ionization when the energetic particle deposits energy as it passes through the matter. The energy given up by the incident particle results in the formation of electron-hole pairs which in turn causes the device performance to degrade. Degradation by ionization is a surface effect and mainly occurs in the oxide passivation layer. The threshold voltage of the MOS transistor substantially depends on the electric field in the silicon dioxide layer. Therefore, it is influenced by the generated and trapped charges. The ionizing radiation generated charges cause threshold voltage shift which can be expressed as a sum of two voltage changes caused by the increase of charges in silica and interface trapped charges[5].

$$\Delta V_{th} = -e\frac{1}{C_{ox}}\Delta N_{ot} \pm e\frac{1}{C_{ox}}\Delta N_{it}$$

where e is the electronic charge, c_{ox} is the oxide capacitance per unit area, N_{ot} is the density of oxide trapped charges and N_{it} is the density of interface states. The voltage shift is negative for n-MOSand positive for p-MOS. The shift in the threshold voltage of theirradiated MOS transistor is not only due to holetrapping in the silicon dioxide but also depends on charge state of the interface traps. It is assumed that the traps above mid gap are acceptor like and those below are donor like. Charges trapped in the oxide give rise to a shift in the flat-band voltage, and therefore in the threshold voltage. Measurement of drain to source voltage (V_{DS}) as a function of dose reveals a significant degradation as shown in Fig. 2. Gate threshold voltage (V_{GS}) measured as a function of gamma dose is also shown in Fig. 3(a). When exposed to gamma radiation, the threshold voltage is found to decrease leading to an increase in leakage current. Therefore it causes an increase in sub-threshold

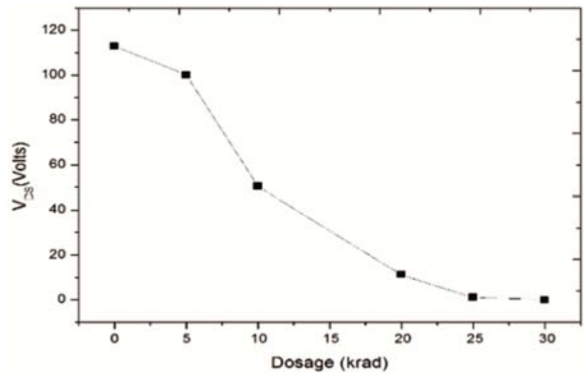

Fig. 2 — Plot of V_{DS} as a function of gamma dose for MOSFET 2N6796.

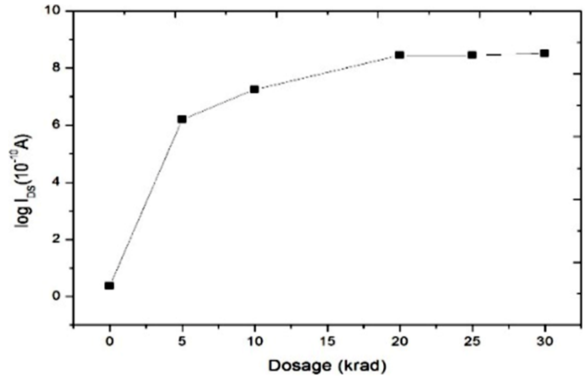

Fig. 4 — The drain to source leakage current as a function of gamma dose in MOSFET 2N6796.

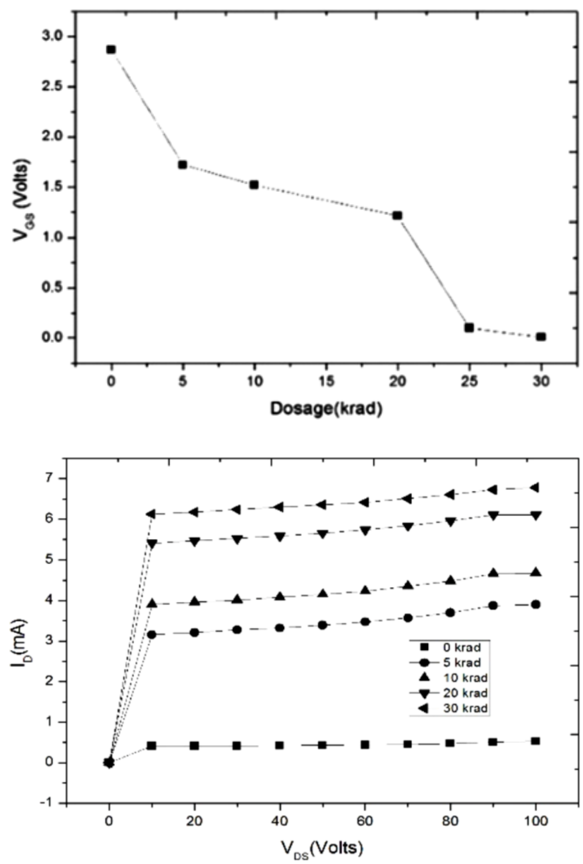

Fig. 3(a) — Gate threshold voltage (V_{GS}) as a function of gamma dose for MOSFET 2N6796 and (b) sub threshold output characteristics of MOSFET 2N6796.

current and generation of parasite current. This affects the performance of transistor when it is used as a switch. The sub threshold output characteristics clearly show that the saturation drain current increases with the increase in irradiation dosage as shown in Fig. 3(b). It is found that the device undergoes permanent damage beyond 30 krad. A study of the change in threshold voltage, leakage current, mobility and transconductance of MOSFET 2N6796 exposed to gamma irradiation has established that the device is sensitive to ionizing radiation. It is found that there is a substantial decrease in the threshold voltage and increase in the leakage current.

The SiO_2 and the Si/SiO_2 interface trapped charges result in a change in carrier mobility in the transistor channel and thus lead to decrease in its transconductance (μ). Since μ depends on the density of trapped charges and density of interface states, gamma radiation induced trapped charges and interface states lead to an increase in leakage current. The “OFF-State” current which flows from drain to source at V_{GS} = 0 is referred as ‘leakage current’ in MOSFET. Figure 4 shows the leakage current measured as a function of gamma dose. It is found that the leakage current substantially increases with increase in dose which could be detrimental to the normal functioning of the device in a radiation environment if the TID is beyond 30 krad.

The transconductance of the device was measured before and after irradiation. It was found that the transconductance of the device decreases by about 20% for the highest accumulated dose of 30 krad. A reduction in the transconductance can affect the switching speed of the MOSFET in digital circuits.

4 Conclusions

The gamma radiation induced ionizing damage on MOSFET device used for space applications was studied as a function of total ionizing dose. It was observed that there is a remarkable degradation in the threshold voltage and the leakage current displays substantial increase with increase in accumulated gamma dose. This increase in leakage current can have significant impact on device performance in a radiation environment if the TID is greater than 30 krad.

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