



Gamma radiation effect on space application MOSFET

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Abstract

MOSFET is the 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 most integrated components such as those for navigation, communication, data processing function in satellite and various space missions. The radiation generally encountered in space are 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 gamma ray induced changes in the electrical characteristics of MOSFET 2N6796 (JANTXV) used in satellites. Pre-irradiation measurements of electrical parameters are made using TESEC measurement system. Selected devices are 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.

Key Words: MOS, radiation effect, 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 sides 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 trans conductance. Threshold voltage also called TURN-ON or switching voltage is the bias voltage necessary on the gate to form the inversion layer at the silicon beneath the gate, which constitute 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

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

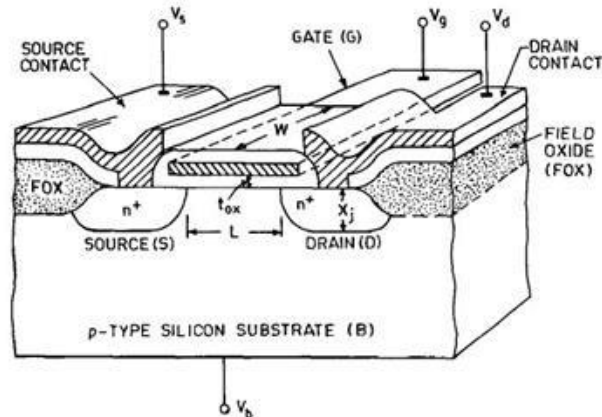


Figure 1. Schematic diagram of MOSFET.

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 as 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 pair. Therefore, the conductivity of the bulk material 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. 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

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 causes

threshold voltage shift which can be expressed as the 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-MOS and positive for p-MOS. The shift in the threshold voltage of the irradiated MOS transistor is not only due to hole trapping in the silicon dioxide but also depends on charge state of the interface traps. 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 reveal a significant degradation as shown in Figure 2. Gate Threshold voltage (V_{GS}) measured as a function of gamma dose is also shown in Figure 3. It is found that the device undergoes permanent damage beyond 30 krad.

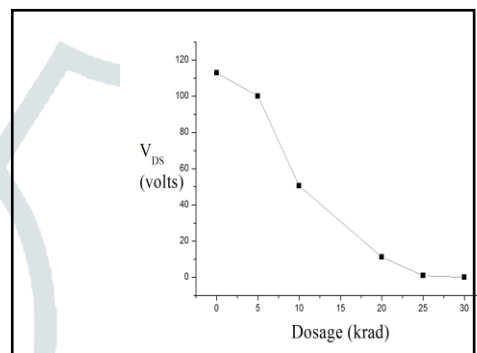


Figure 2. Plot of V_{DS} as a function of gamma dose for MOSFET 2N6796

The SiO_2 and the Si/SiO_2 interface trapped charges results in a change in carrier mobility in the transistor channel and thus lead to decrease in its trans conductance (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.

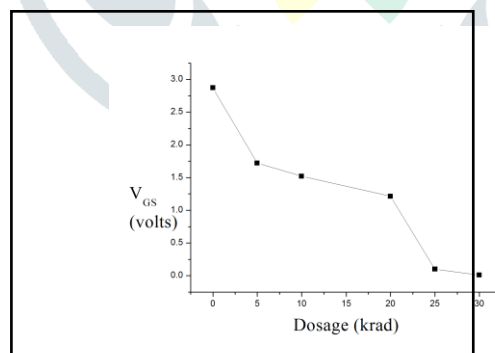


Figure 3. Gate threshold voltage (V_{GS}) as a function of gamma dose for MOSFET 2N6796

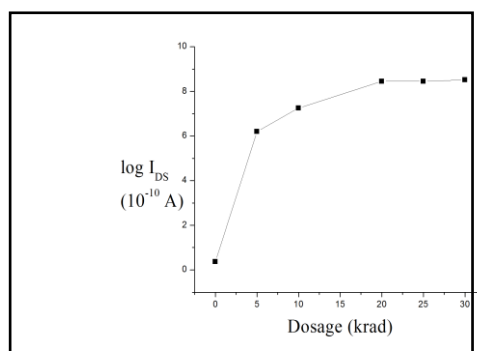


Figure 4. The drain to source leakage current as a function of gamma dose in MOSFET 2N6796

4. Conclusion

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

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