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A STUDY OF TOTAL IONISING DOSE EFFECTS ON HFO2 AND AL2O3 GATE OXIDE SOI FINFET

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ABSTRACT

This study examines the effects of total ionising radiation on various gate oxides used in silicon on insulator (SOI) FinFETs (TID). For a three-dimensional (3-D) SOI 30nm n-channel FinFET, the system structure in issue consists of a high-k hafnium oxide (HfO2) gate electrode and an aluminium oxide (Al2O3) gate electrode. To determine how TID affects the FinFET system, 3-D simulations were run in Visual TCAD utilising radiation-specific code for various gate oxides. The TID impacts change the electrical properties of the computer, degrading it as well as the systems to which it is connected. The oxide trapped charge density has been shown to be higher than the interface trapped charge density. TID increases transconductance and leakage current after irradiation. As the dose of ionising radiation increases, a threshold voltage change is seen for both gate oxide materials.

Keywords: insulator, FinFET, Silicon, ionizing dose voltage shift threshold

INTRODUCTION

Industrial applications are increasingly using SOI technologies. Multiple gate devices are an excellent choice for meeting the ITRS requirements. As a result, it's important to research the radiation properties of equipment used in nuclear environments and space applications. Since semiconductor devices are exposed to high-intensity radiation, special attention must be paid to them. One of the most noticeable effects on irradiated semiconductor devices is the Total Ionizing Dose effect. There is well-documented evidence to show that incoming radiation dose on the system causes device characteristics to deteriorate. Modern SOI and multi-gate technologies have minimised these deteriorations. It has been established that SOI devices are more radiation-resistant than their bulk silicon equivalents when exposed to an entire ionising dose [1]. Their response is more complicated than that of bulk devices, but they are not immune to TID effects [2]. When brand-new devices are developed, it's critical to look into how they react to radiation. In this article, the effects of TID on a 30nm gate SOI FinFET are examined. Radiation degrades the device's properties by destroying the buried oxide layer and thin gate oxide. TID effects are significantly influenced by the system's geometry, manufacturing process, dose rate, biassing voltage, and post-irradiation temperature [3, 4]. TID is caused by the accumulation of trapped charge in insulating layers and the formation of an inversion channel along the top and sidewalls of the fins [5]. TID exposures cause major changes in device characteristics in ultra-small SOI applications.

2. *MECHANISM OF RADIATION*

Particle radiation and photon radiation are the two primary types of radiation. Particle radiation is made up of charged particles including protons, electrons, alpha particles, ions, and neutrons. Particle radiation that starts the ionisation process inside a semiconductor device or material causes excess carriers to be created. X-rays and gamma radiation are two examples of photon radiation. The radiation effects that deal with ionisation brought on by rays are referred to as total ionising exposure. TID is evaluated in terms of the radiation absorbed by the substance and is expressed in rad (radiation absorbed dose) or grey (Gy) [6–9]. A radar is the unit of measurement for the amount of radiation that deposits 100 ergs of energy content.

When exposed to radiation, the SOI FinFET structure has been the subject of extensive study. The portions of the SOI FinFET structure that are most susceptible to a full dose response are the gate oxide, buried oxide (BOX), and the sidewall of the fin. The most significant physical process that influences the properties of the system in a radiation environment is electron hole pair production [3]. The volume density of created charge pairs per rad in oxide content is 8.1 x 1012 pairs/cm3. Electrons are whisked out of the oxide in a matter of picoseconds due to their tremendous mobility. However, in the initial picoseconds, a limited number of electrons recombine with holes. The line density is inversely proportional to the distance between electron hole pairs. Given that it is reliant on linear energy transmission, it is also a function of incident particle form and energy. Due to their relative immobility, the holes that avoid initial recombination become stuck close to their site of origin. The production of traps in the gate oxide, BOX, and the interface traps at the sidewalls of the fin have an impact on the electrical properties of an irradiated FinFET system. It is obvious that the three damage mechanisms take place when a device is exposed to radiation.

3. RESULT AND DISCUSSION

The effect of TID was examined on a computer model of the 3D FDSOI n-channel FinFET device structure using the Visual TCAD device simulator. Current-voltage parameters were recorded at room temperature both before and after gamma radiation exposure. Two different gate oxide materials, hafnium oxide HfO2 (k = 22) and aluminium oxide Al2O3 (k = 9.3), were used in the simulations. In each scenario, the total dose was adjusted in increments of 100krad to 1M while the dose rate remained constant at 10rad/s. The Id-Vgs features, voltage sources, conductivity, oxide trapped charge concentrations, and interface captured charge concentrations were computed, assessed, and recorded as they changed.

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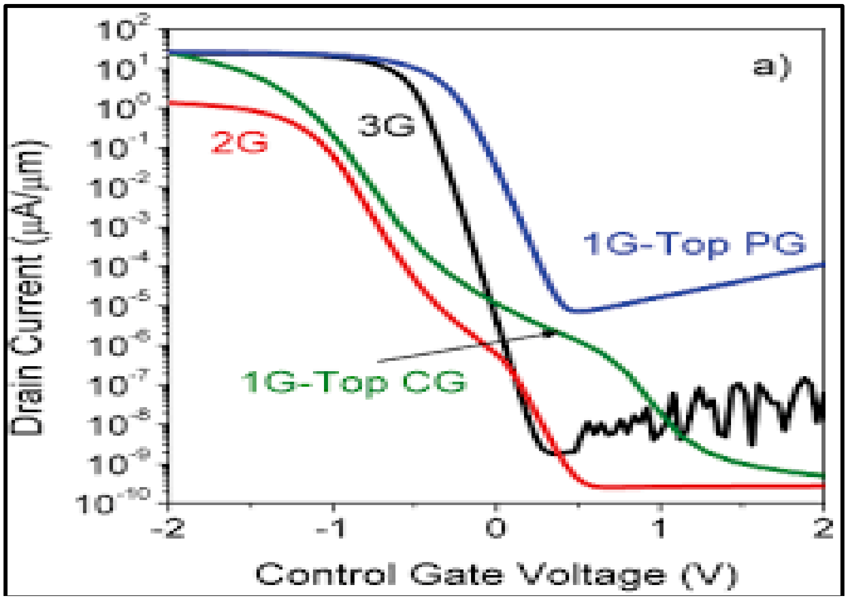
Fig.1 Id-Vgs curves for HfO2 and Al2O3 gate oxide materials in both virgin and gamma-irradiated devices.



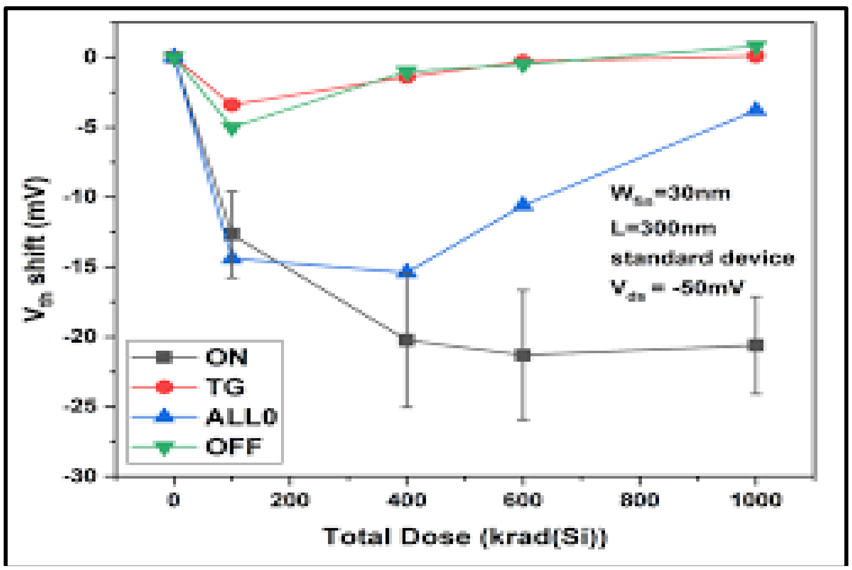


Fig. 2 Id-Vgs characteristics

An important analogue output characteristic of FinFET devices is transconductance (gm), which is closely connected to the drain current. The transconductance of a FinFET system is defined as the rate of increase in drain current per unit change in gate voltage at a given drain voltage. Carrier mobility controls the n-peak channel's transconductance. The carriers in the channel disperse as a result of the irradiation, reducing transconductance. As seen in Fig. 3, transconductance rises with increasing total dose rate up until the threshold voltage.

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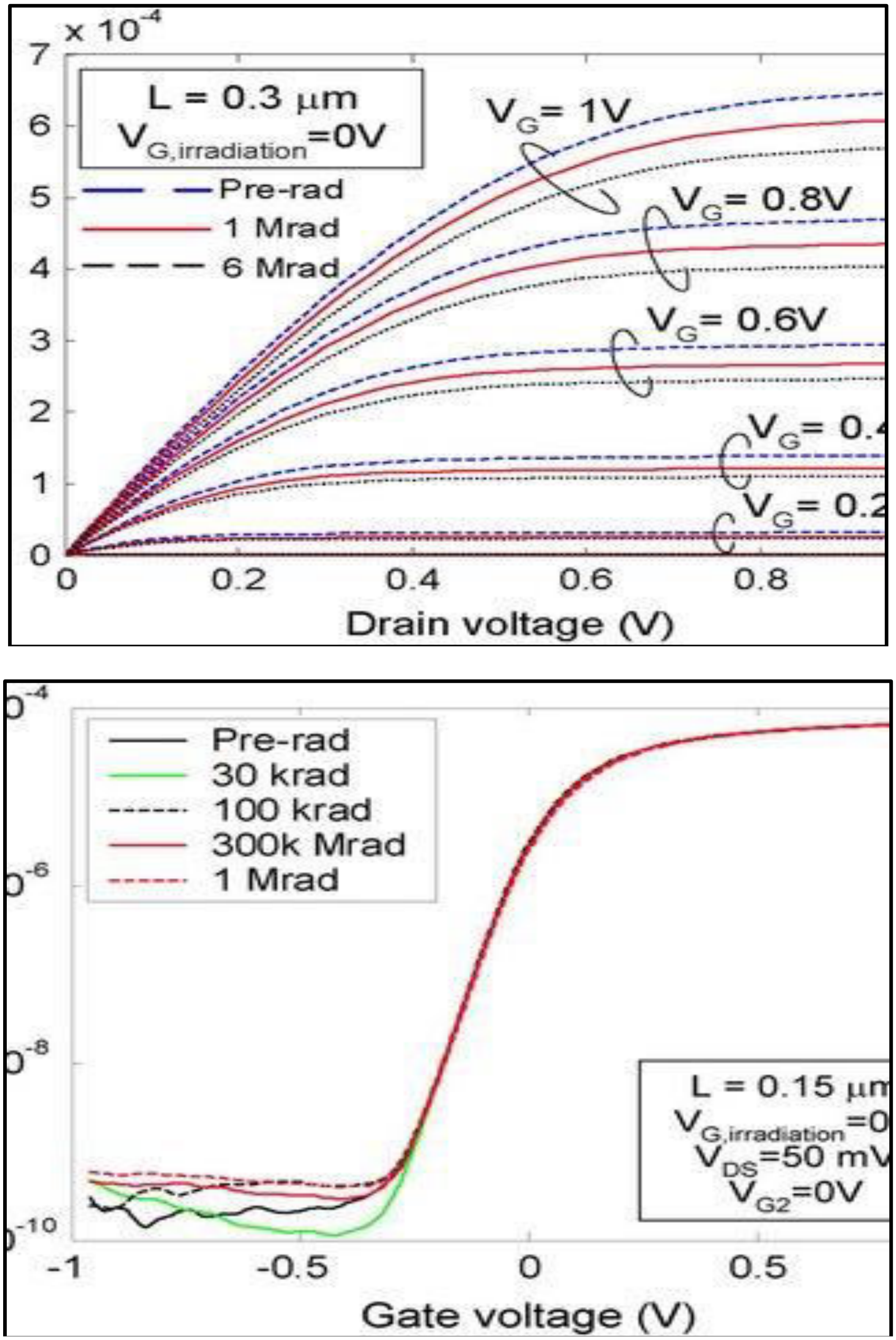

Fig. 3 Transconductance of a 30 nm n channel SOI FinFET device with gamma radiation for (a) gate oxides made of HfO2 and (b) gate oxides made of Al2O3 at Vds = 50 mV.

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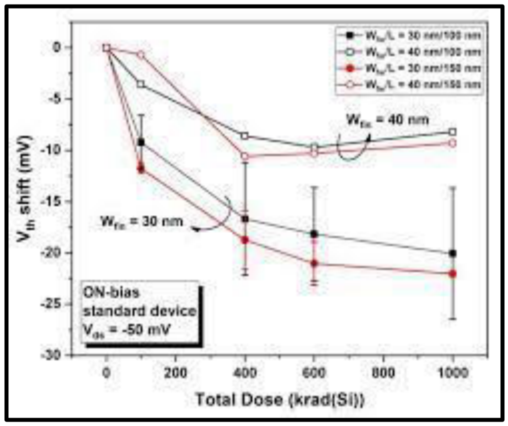
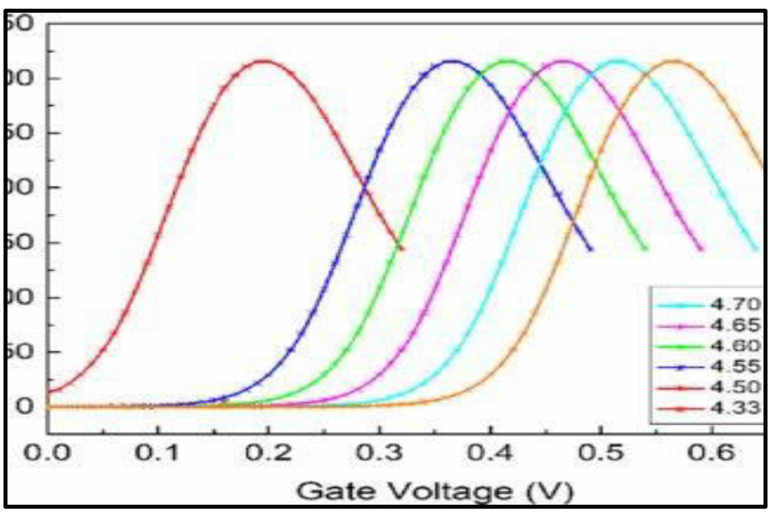


Fig. 4 During the irradiation of 30nm, the threshold voltage and threshold voltage shift are shown in (a) and (b), respectively.

When the system is conducting, the lines seem to touch. For gate oxide materials made of HfO2 and Al2O3, the threshold voltage of a virgin 30nm n-channel SOI FinFET device was discovered to be 227.85mV and 231.18mV, respectively. The threshold voltage of the irradiated system shifts to 188.52 mV and 194.30 mV, respectively, when exposed to a 1Mrad gamma radiation.



. **Fig. 5 the variance in charges trapped at the oxide and interface for different gamma dosages.**

As depicted in Fig. 4 to 6, the increase in oxide and interface trapped charges is what causes the shift in threshold voltage. Al2O3 has a higher absolute threshold voltage value than HfO2, but HfO2 has a better improvement in threshold voltage shift.

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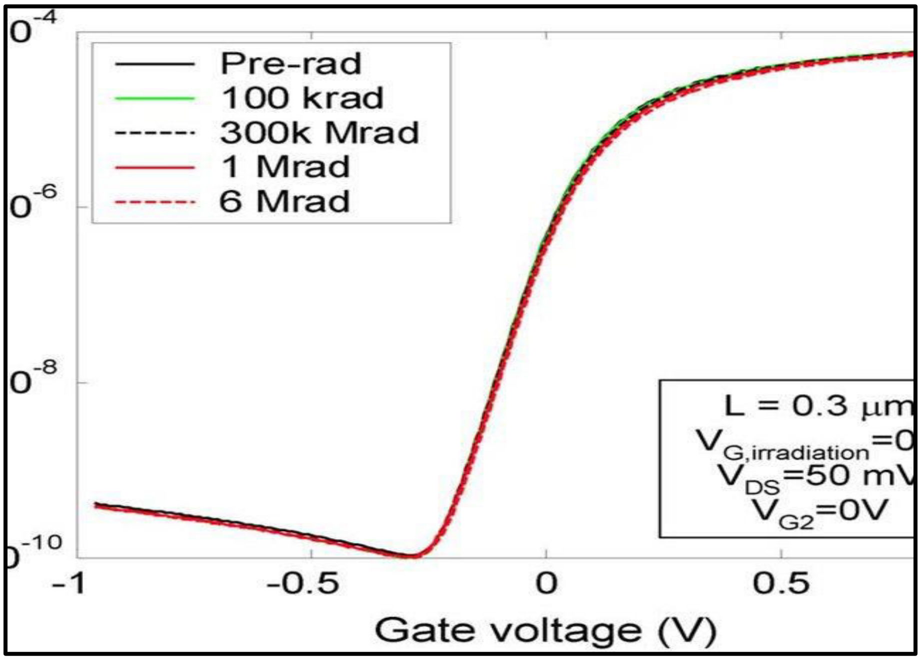

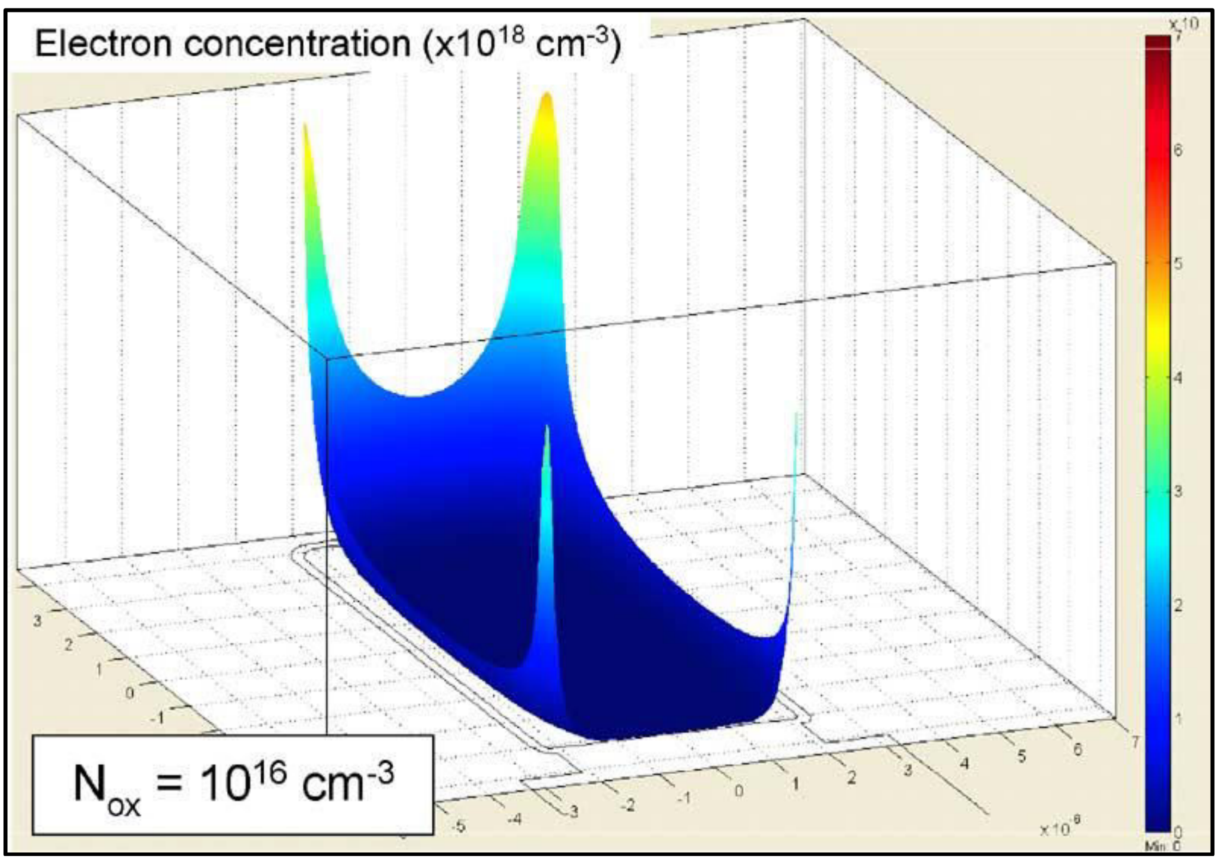

Figure 6Interface and oxide trapped charge density in relation to different gamma doses of 30 nm, in (a) and (b), respectively.

As a result, device engineers should design their devices to stop the threshold voltage from shifting for a greater dose rate. The values are listed for threshold voltages and threshold voltage shift .

CONCLUSION

The overall dose response of the 30nm n channel SOI FinFET system for the gate oxide materials HfO2 and Al2O3 was investigated under radiation at room temperature. The TID impact caused the device's many output settings to shift. Gamma irradiated systems deteriorate mostly due to an increase in trapped charge density. It was found that the oxide trapped charge was higher than the interface trapped charge. The irradiated FinFET device's threshold voltage was drastically lowered, and it was discovered that more deterioration is brought on by rising radiation exposure. HfO2 gate oxide materials have a greater improvement in threshold voltage than Al2O3 gate oxide compounds. The threshold voltage fluctuates equally when the total dose is low, but as the total dose increases, HfO2 demonstrates a larger shift in the threshold voltage, despite Al2O3 having a thicker oxide layer.

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