Evaluation of dose response, Sensitivity and annealing of MOSFETs

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Abstract

This paper reports dose response of MOSFETs and fading after irradiation. MOSFETs with three different thicknesses of the gate oxide layer were used. Irradiations were performed at gate biases. Dependence of the radiation sensitivity on the gate bias during irradiation and fading at room temperature without a gate bias was found. It was shown that the dependence of the threshold voltage shift on the radiation dose is linear. The results demonstrate that these MOSFETs are suitable as sensors of gamma radiation.

Keywords: MOSFET, Threshold voltage, Sensitivity, Fading

Introduction

Dose verification of ionizing radiation can be performed using diodes, ionization chambers, thermoluminescent crystals and MOSFETs[1]. For the last two decades, pMOSFETs have been used as dosimeters in different fields like spacecraft, radiotherapy, skin dosimetry and clinical control [2]. It is well known that ionizing radiation causes degradation of the I_{DS}-V_{GS} characteristics in MOSFETs. Several electrical parameters of the transistor are influenced by this degradation since the radiation damages the device as a consequence of the generation of electron-hole pairs in the oxide. These holes have been shown to have lower mobility than electrons and to drift slowly to the Si-SiO_2 interface, and then a fraction of them becomes trapped and constitutes the radiation-induced fixed oxide charge. Interface traps are also created in this process. The response of the threshold voltage shift to radiation presents sensitivity, doserange and reproducibility suitable for use as a reliable dosimetric parameter[1-3]. The aim of this letter is to find the fading of irradiated PMOS dosimeter, after annealing with low voltage on the gate. Also, our work is aimed to compare the results concerning the threshold voltage stability in time and the sensitivity of investigated dosimeters.

Experimental

The shift in threshold voltage with the dose, can be obtained by extracting the complete current-voltage characteristic curves of the device. Simpler methods, based on constant current measurements, require measuring the drain source voltage while the transistor remains biased by a constant drain current and the gate and drain terminals are short-circuited. Under this configuration, the source-drain voltage shift is approximately equal to $\Delta|V_T|$. Usually, in order to minimize thermal drift, the drain current selected is the Zero Temperature Coefficient current, I_{ZTC}. MOSFETs have oxides optimized in order to increase the radiation sensitivity. For that purpose, a very thick gate oxide is grown, that enhances the trapping of radiation induced holes. It is known that the dependence of the voltage shift with the dose follows a power law relationship:

$$\Delta V_T = AD^n \tag{1}$$

where A and n are fit parameters. the sensitivity, S, of the MOSFET dosimeter:

$$S = \frac{\Delta V_T}{D} \tag{2}$$

In unbiased mode, the typical linear range of MOSFET dosimeter is up to several Gy or two tens of Gy, depending on the type. The linear range can be enhanced in biased mode. Moreover, to provide a reliable procedure of measurement, the loss of dosimetric information during spontaneous annealing, the fading F, has to be characterised and analysed:

$$F = \frac{V_T(0) - V_T(t)}{V_T(0) - \mathrm{V}_{\mathrm{T0}}} \tag{3}$$

In this article, PMOSFETs fading dependencies on gate bias and oxide thickness were investigated. The devices used in the study were Al gate p channel enhanced MOSFETs designed specifically for radiation dose measurements. A total of 15 devices on a10×10 cm^2 board were used. The devices were irradiated up to 50 Gy at the dose rate of 0.02 Gy/s at room temperature with a ^{60}Co radiation source. The I–V characteristics were measured with a WQ4832 Semiconductor Characterization system.

Results and discussion

Figs. 1-3 show the sensitivity S as a function of the gate bias during irradiation. The sensitivity increase with increasing gate oxide layer thickness at constant values of the gate bias and radiation dose. Contributions from the positive charge trapped in the oxide, on the one hand, and at the interface, on the other, to the effect on ΔV_T during irradiation can be estimated from subthreshold characteristics I_D–V_G. An increase in the positive charge trapped in the oxide shifts the subthreshold characteristic along the V_G axis, while an increase in the charge trapped at the interface decreases the slope of the subthreshold characteristic. The density of the interface traps formed during the irradiation does not affect the threshold voltage shift significantly. Furthermore, it can be concluded that the increase in ΔV_T during the irradiation was mainly due to the in crease in density of the positive charge trapped in the oxide.

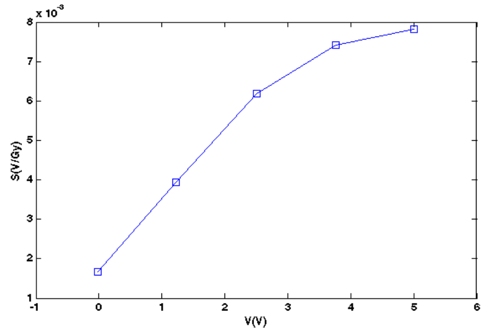

Figure 1. The sensitivity as a function of the gate bias during irradiation to 50 Gy for MOSFETs with the 100-nm gate oxide.

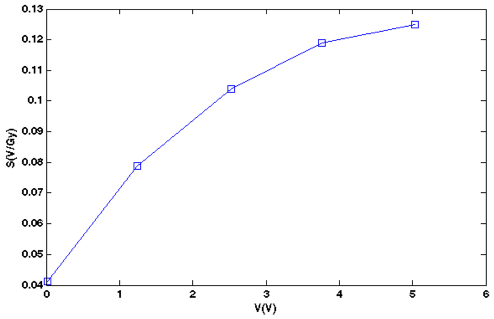

Figure 2. The sensitivity as a function of the gate bias during irradiation to 50 Gy for MOSFETs with the 400-nm gate oxide.

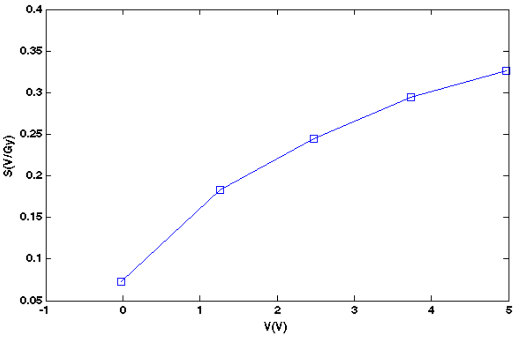

Figure 3. The sensitivity as a function of the gate bias during irradiation to 50 Gy for MOSFETs with the 1-µm gate oxide.

Figs. 4–6 disclose fading of the threshold voltage shifts during storage of irradiated MOSFETs at room temperature with out gate bias. This room temperature annealing dissolves dosimetric information. The data show that the oxide layer thickness significantly affects the MOSFETs fading.The fading is mainly due to neutralization/compensation of the positive charge trapped in the oxide by electron tunneling from Si. In the case of positive gate bias, the increase of electrical oxide field causes the increased probability of electron tunneling from silicon to oxide, leading to intensified oxide trapped charge recovery. Moreover, the increase of the electric field causes the increased changes of interface trap density. However, the intensified recovery of positive oxide trapped charge, for given oxide thickness, does not mean that fading increases. This is the consequence of larger gate oxide charge density, formed during higher bias irradiation.

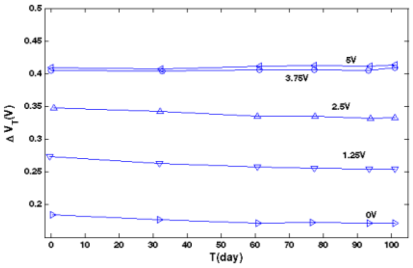

Figure 4. Fading of the MOSFETs with 100-nm-thick oxide layers.

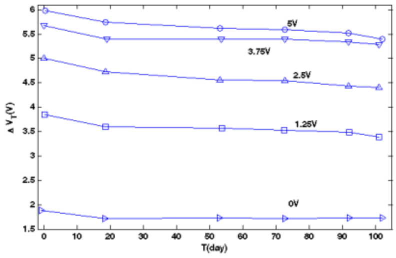

Figure 5. Fading of the MOSFETs with 400-nm-thick oxide layers.

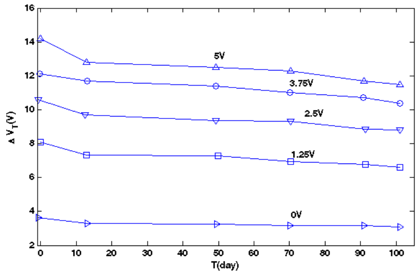

Figure 6. Fading of the MOSFETs with 1-µm-thick oxide layers.

Conclusions

In the end, the following conclusions can be derived. The sensitivity as a function of the gate bias during irradiation can be very well described regardless of the thickness of the oxide layer. During post irradiation storage of the dosimeters at room temperature, the threshold voltage shifts lowly decreases, which distorts dosimetric in formation. The fading is more significant in the MOSFETs with the thicker gate oxide layer. The results obtained show that with the correct electronic amplification and filtering and using the suitable techniques, these transistors in biased mode can be used in dosimetry for clinical control in radiotherapy, reducing noticeably the cost of the future system, extending control in radiotherapy treatments and increasing the safety of the patient.

References

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