Comparative study of fixed and switching oxide traps behavior

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Abstract

In this article, the sensitivity of pMOS dosimeters up to high dose without gate bias investigated. Many fixed traps created in the bulk, far away from oxide-semiconductor interface. The equation for fitting the threshold voltage components induced by FTs and by STs proposed and very good fittings obtained. It shown that five experimental irradiation points are sufficient to draw a good conclusion about the values of the fitting parameters.

Keywords: MOS transistors, Radiation dosimeters, Fixed traps, Switching traps

Introduction

MOSFETs allow for the measurement of absorbed radiation doses using the threshold voltage shift, ΔV_T, which is caused by both radiation induced oxide charges and radiation induced interface traps [1]. Additionally, MOSFETs could be used to obtain radiation dose rate measurements. Irradiation results in the trapping of holes that generated by the radiation in the SiO_2 and in the creation of interface states at the SiO_2/Si boundary [2]. The increasing sensitivity to the radiation can be achieved by increasing the gate oxide thickness [1]. pMOS dosimeters have several advantages and disadvantages, with one disadvantage being non linearity,i.e., the saturation of the dosimetric parameter ΔV_T at high radiation doses, which is investigated here [3].

Experimental

The experimental samples were irradiated at room temperature in V_{Gi} =0 V using the ${}^{60}_{27}Co$ ionizing source. The electrical characteristics were measured in the reader circuit (RC) configuration every 15 min such that the measurements lasted only a few seconds. The transistor threshold voltages were determined by the transfer characteristics at saturation, i.e., as the intersection between the V_G-axis and the extrapolated linear region of the $(I_D)^{1/2} - V_G$ curves.

The midgap subthreshold technique (MGT) [4] has been used to determine both the increase in the number of radiation induced traps in the oxide (fixed traps), ΔN_{ft} [cm^{-2}], and the increase in the number of the radiation induced traps near and at the oxide/silicon interface (switching traps), ΔN_{st} [cm^{-2}].The STs consist of traps near the oxide/silicon interface called slow switching traps (SSTs) and traps at the oxide/silicon interface called fast switching traps (FSTs). ΔN_{st} is equal to

$$\Delta N_{st} = \Delta N_{sst} + \Delta N_{f\,st} \qquad (1)$$

Because the electrical measurement technique was employed, ΔN_{ft} and ΔN_{st} are more suitable than the more commonly used quantities that imply the physical location of the traps, i.e., the density of oxide traps ΔN_{ot} and the density of interface traps ΔN_{it} (the MG technique does not truly determine these densities). The correlations between these quantities are

$$\Delta N_{ot} = \Delta N_{ft} + \Delta N_{s\,st} \qquad (2)$$

$$\Delta N_{it} = \Delta N_{st} - \Delta N_{s\,st} = \Delta N_{f\,st} \qquad (3)$$

ΔN_{ft} has two main contents: positively charged FTs (PCFTs) and negatively charged FTs (NCFTs). The contribution of FTs (ΔV_{ft}) and STs (ΔV_{st}) to the net threshold voltage shift (ΔV_T) of p channel MOSFETs by MGT can be expressed as

$$\Delta V_T = \Delta V_{ft} + \Delta V_{st} = \frac{e}{c_{ox}} \Delta N_{ft} + \frac{e}{c_{ox}} \Delta N_{St} \qquad (4)$$

where e is the absolute value of the electron charge and Cox is the gate oxide capacitance per unit area. The ΔV_T and ΔV_{ft} versus dose D curves are usually fitted using the following equation:

$$\Delta V_{T,ft} = aD^b \qquad (5)$$

Ideally,this dependence is linear,i.e., b=1. However,this equation does not make any physical sense because the fitting of ΔV_T and ΔV_{ft} does not reach a plateau but increases monotonically ($\Delta V_{T,ft} \rightarrow \infty$, for $D \rightarrow \infty$). This would mean that ΔV_{ft} and/or ΔV_{st} go to infinity, which can not be reasonable because the oxide electric field and defect precursor density of the oxide are finite, not infinite.Thus, the following equation is proposed

$$\Delta V_{ft} = a - \frac{a}{1 + bD^c} \qquad (6)$$

where a, b, and c are the fitting parameters (a also represents the saturation voltage), with boundary conditions: $\Delta V_{ft} \rightarrow 0$ for $D \rightarrow 0$and $\Delta V_{ft} \rightarrow a$ for $D \rightarrow \infty$, which has much more physical sense and fits ΔV_{ft} very well. Here, it is shown that Eq. (7) also fits ΔV_T and ΔV_{st} very well. It can thus be written as

$$\Delta V_{T,ft,st} = a - \frac{a}{1 + bD^c} \qquad (7)$$

Although ΔV_T could be fitted by Eq. (7), giving a much better fit than Eq. (6), it is much more correct to find the fitting values of ΔV_T as the sum of the fitting values of ΔV_{ft} and ΔV_{st} obtained by Eq. (8):

$$\Delta V_T = (\Delta V_{ft})_{fit} + (\Delta V_{st})_{fit} \qquad (8)$$

Results and discussion

During irradiation,electron–hole pairs are created, and the released electrons quickly seep out of the oxide while the holes remain in the oxide and move towards one of the interfaces, depending on the direction of the electric field in the oxide. In our case, a small gate oxide electric field occurs because a work function difference between the Al- gate and n-type silicon substrate has a direction towards the SiO_2/Si interface.This difference causes the holes to move towards the SiO_2/Si interface where they are trapped and create positively charged FTs (PCFTs). The increase in PCFTs will increase the internal electric field in the oxide, which has a direction opposite to that of the external electric field. This causes a decrease in the number of holes that are moving to and trapped near the SiO_2/Si interface. Because the external electric field is very low,the internal electric field over comes the external electric field.

Figs. 1–3 show the dependencies of the three parameters a, b, and c, respectively, on the number of points that were included in the fitting of ΔV_{ft}. The mean values ($\langle a\rangle$, $\langle b\rangle$, $\langle c\rangle$) and the standard deviations (s) are also displayed.The results show that the first three fittings, with3,4,and5 fitting points, are not reliable and lie far outside the standard deviation range. However, the values of these three parameters for the fitting with more than 5 fitting points are satisfactory and lie primarily in the interval mean value $\pm\sigma$. The values of the parameters a, b, and c do not show a correlation with the number of points included in the fittings, which represents a very interesting and very significant result. Together with the analysis from the previous paragraph, it could be concluded that it is not necessary to have many points during irradiation to draw a good conclusion about the values of the fitting parameters from Eq. (7). This is very important for the prediction of the saturation voltage values (parameter a), and the degree of linearity (parameter c), because as many as ten points are usually measured during irradiation.The same conclusion could be derived by analyzing the fittings of ΔV_{st}.

Conclusions

It was shown that the threshold voltage shift and its components, as induced by fixed and switching traps, reach a plateau. For doses up to700 Gy, ΔV_{ft} is higher than ΔV_{st}, and the trend is reversed at larger doses. The saturation in FTs creation could be expected if the internal electric field induced by fixed traps is equal to the external electric field, which, in our case, corresponds to the voltage of a work function difference of 0.33V. However, the saturation voltage value of ΔV_{ft} is much higher because the density of trapped holes in the bulk is high and its influence on channel carriers is not negligible. Although the number of FTs is probably much higher than the number of STs, many FTs are created in the bulk, far from the Si/SiO2 interface. It is shown that five experimental irradiation points are sufficient to draw a good conclusion about the voltage saturation values and the degree of linearity.

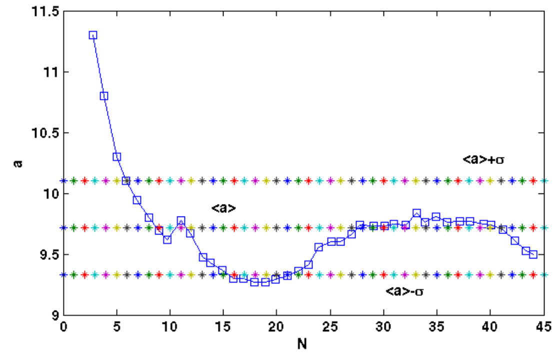

Figure 1. Dependence of a on the number of fitting points.

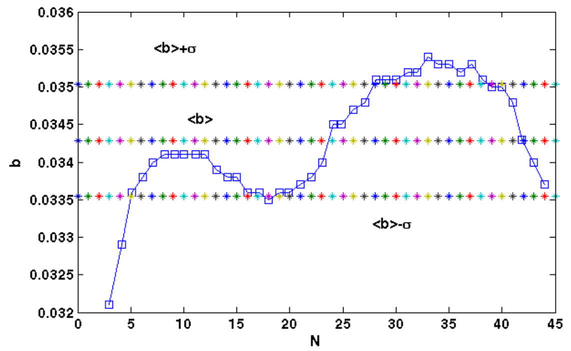

Figure 2. Dependence of b on the number of fitting points.

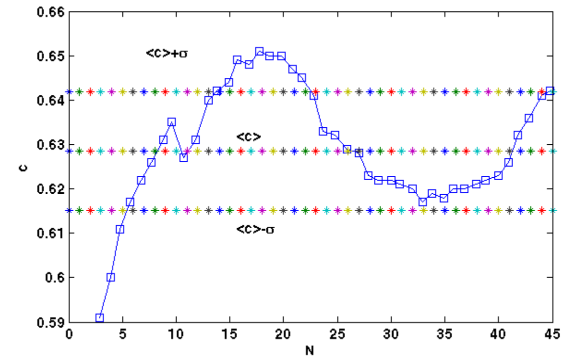

Figure 3. Dependence of c on the number of fitting points.

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