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Physical basis of prediction MOS function prediction method under ionizing condition

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Abstract. Effects occurring in the active elements of integrated circuits(IC) depend on dose accumulation summary, the absorption unit defects under the action of high energy particles. Presented method refers only to predict degradation parameters due to accumulated dose of integrated circuits summary absorption. MOS structures response prediction under ionizing action will be reduced to determination of oxide charge value and surface state charge value.

I. INTRODUCTION

Supposing that irradiation situation in space environments are knowledge. Absorption summary dose is determined as products power doses at total function time of electric equipments. If this summary dose will be cumulate at high dose intensity under laboratory condition, the result may be different from the same accumulate dose in space environments. This deference is caused due to oxide charges and interface state charges that appear under ionizing irradiation. In space condition the annealing charge phenomenon appear in long time function ofMOS structure components and interface state charge increasing continually. It is important in this case to accord modulate strategy with this condition in aim to obtain the same effect for dose accumulation.

This new strategy imply to create such condition for dose accumulation so when the summary absorption dose are accumulate in oxide, oxide charge it is annealed and interface state charge continually increasing to highest value.

II. DISCUSSION

In the presented paper is proposed one prediction method without taking in to account thermic annealing. This method is based on conversion model [1] in which positive charge is converted in surface state.

1.Threshold voltage components separation

At irradiation electrons and holes are separated by oxide electric field, depending on the polarity of the voltage applied to the grid. Following the positive charge formed oxide Q_{ot} volume, density and charge states of surface N_{ot},Q_{it}, N_{it} density. Surface state sign is negative for fornMOS, and positive for pMOS.

The charge sign of $Q_{ot}$and $Q_{it}$is essencial because if we increasing the charge in oxide volume will obtain the threshold voltage decreasing for nMOS, and in the same time, increasing surface state charge will increase threshold voltage. The sign for Q_{it} is determined by semiconductor type. At high levels of volume charge, Q_{0t}, induced in nMOS, by ionizing irradiation, in the p type area of MOSFET take place the substrate conductibility inversion, when the Fermi level is near to conduction zone. This mean that the surface state is neutral or negative charged.Therefore with increasing irradiation dose occursthe density increasing of surface states Q_{it}, which compensates positive charge Q_{0t}.

Thus, threshold voltage can be describe as follow:

$$V_{th} = V_{ot}+V_{it}=\frac{Q_{ot}}{C_{ox}}+\frac{Q_{it}}{C_{ox}} \qquad (1)$$

where: “-” is for nMOS and “+” for pMOS, C_{ox} – oxide capacity.

Si-SiO_2 structure contains an layer crossing with an chemical components describe as SiO_n. There may be 3 cases:

a) The nearest semiconductor defects region ($n<1$)
b) SiO ordered region ($n = 1$)
c) Defects region ($1<n<2$)

The cause of defects region apparition is the mismatch of O_2 atoms for each Si atom and also the mismatch of geometrical location of dielectric and semiconductor atoms. This causes the apparition of voltage peaks and broken bounds in transition region.

Defects in transition region represents active centers, named surface state situated near semiconductor surface at distance of up to 10nm and have an recharge time of 1µs. Therefore this type of of surface state are named rapid surface state. Surface state situated inside transition region, have the

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relaxation time up to 1 ms, and are named slow surface state.

If we apply a positive voltage to the MOS grid terminal, the density of Q_{0t} will have a maximum at 10÷40 nm, after this distance, density decrease. When we apply negative polarity to the grid terminal the charge distribution at Si – metal interface is much complicated. This fact is determined by the diffusion of metal atoms in SiO_2 volume. Al, Cr, Au atoms form in SiO_2 oxide electrons traps, therefore in this case at Si – metal interface will appear two electrical regions: positive and negative charged. Experiments [4] have shown that positive charges are located in a thin layer (5nm) and negative charges in 10 nm thickness layer. In case of missing terminal at Si – metal interface we obtain only positive charge. When we switch between positive and negative polarity applied to the grid terminal, the layer can be repolarized and in this case the exact determination of their thickness can not be obtained.

Modeling results using threshold voltage components separation concur with positive charge accumulation mechanism in MOS structure oxide. MOS structure irradiation at different voltage polarity amplify the charge accumulation in oxide structure. Therefore, effective charge is maximum when irradiation affect MOS structure with positive charge on grid terminal.

Regarding on charge oxide generating mechanism, at positive and negative voltage polarization to the grid, we can say that amplification of surface state generation at SiO_2 interface occurs only at positive polarization.

For irradiation process, at negative polarization of MOS grid terminal, V_{it} depending on dose deviation is smaller compared with irradiation process without polarization voltage. This result can be explained by increasing or decreasing of holes speed generated by irradiation process to Si-SiO_2 interface, depending by voltage polarity applied to grid terminal.

Also, holes captured by SiO interface contributeto the occurrence ofsurfacestatesdue irradiation process.

2. Conversion model

To extract the threshold voltage components we started from the idea that irradiation leads to lower threshold voltage. The threshold variation is made by following equation:

$$V_{th} = V_{ot} + V_{it} \qquad (2)$$

where: V_{th} – MOS structure threshold variation, V_{ot} and V_{it} – its components which depend by accumulated charges in oxide volume and by surface state charges.

If, during ionizing irradiation action, charge from oxide volume is not annealing, then V_{ot} get his maximal value:

$$V_{o\max} = -\Delta V_0 D \qquad (3)$$

where: $V_{o\ \max}$ – maximal variation, D – summary absorption dose.

The variation of threshold voltage component V_{it}, depended by interface charge accumulation, may by divided in two components: slow and fast.The fast component is proportional with summary dose absorption:

$$V_{infast} = \pm V_i D \qquad (4)$$

where: V_i – V_{it} variation for dose unit, “-” is used for MOS structure with n channel, and “+” for MOS structure with p channel.The slow component is proportional to “hidden” accumulation of interface state charges after ionizing irradiation action. According to conversion model, the “hidden” accumulation interface state charge cause is positive charge annealing, when each act of positive charge disappearing leads to formation of K_{oi} interface state. K_{oi} coefficient is introduced for a quantity characteristic of conversion process. The slow component may by describe as:

$$V_{itslow} = \pm K_{oi} (V_{th\max} - V_{ot})(5)$$

where: “-” is used for MOS structure with channel n, and “+” for MOS structure with channel p.

The positive charge accumulation in oxide volume take place in the same time with its annealing. For taking to account of this process we use convolution integral as function of unitary response [2].

$$\Delta V_{ot} = \frac{\Delta Vo}{\left(1 + \frac{t}{t_0}\right)^{v}} \qquad (6)$$

where: t_oşiv – adjustment coefficients , ΔV_o – variation of threshold voltage component V_{ot} for dose unit without taking to account annealing process.

Based on previous relation we obtain the following equation for threshold voltage variation

$$\Delta V_{ot} = \frac{\gamma_0 t_0 \Delta V_0}{v-1}\left[\left(1 + \frac{t}{t_0}\right)^{1-v}\right] \text{for t=t}_0\,(7)$$

$$\Delta V_{ot} = \frac{\gamma_0 t_0 \Delta V_0}{v-1}\left[\left(1 + \frac{t}{t_0}\right)^{1-v} - \left(1 + \frac{t - t_0}{t_0}\right)^{1-v}\right]$$

for t >> t_0(7)

where: t_{ir} – ionizing irradiation length of time; t – total time [4], [5], [6]

Expressions (5-7) contains five unknown adjustable parameters: K_{oi},V_0, ν ,t_0, γ_0 .

The values of this parameters permit calculation of threshold voltage variation and of each component for dose value at any moment of time.

To effectuate a measurement of adjustment coefficients we must follow few steps:

1. MOS structure irradiation at high dose level for threshold voltage obtaining.
2. After irradiation process stop follow components V_{it}andV_{ot}measurements for three moment of time.
3. Parameters V_0, ν ,t_0 extraction from resolved equation (8) for three moments of time.
4. Parameters K_{oi}, $\gamma_0$extraction from resolved equation (8) for three moments of time.

The prediction result for threshold voltage variation at different dose power at different absorption doses is obtained from (6) using (7) equation [7], [8], [9].

To select three moment of time to effectuate the measurements after irradiation we must respect following rules: first measurement will be effectuate right away after irradiation stop ($t_l=t_{ir}$); the second measurement will be effectuate after a period of time equally with double irradiation time ($t_2=2t_{ir}$); the third after moment $t_3=100t_{ir}$.

III. CONCLUSION

As rule, the consecutively of applied gate polarization during prediction period is:

1. The transistor is irradiated with positive polarization during t_0 period to form initial threshold voltage polarity (V_{0t}) and to obtain admissible value of annealing voltage;
2. The irradiation process is permanent during application of alternative polarity impulse set. The number of impulses is choosing in such way to obtain a summary absorption dose. This summary dose must has in all moments of positive polarization maximal value. The following equation shows how this process will take place:

$$D_{max}=N_tD_o \qquad (8)$$

where: D_{max}– maximal value of dose during effectively function period; N – number of positive impulses.

In this article it was proposed a analyses which permit to avoid discrepancies that may appear between real condition of space environment and laboratory condition. Also this analyses permit to understand how physics processes have influence above semiconductor materials.

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