Reliability and Mechanism of Radiation Degradation of Microeletronic Devices

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***Abstract* — This review pape is destinated to investigation the mechanism and radiation degradation of microelectroic devices whith p-n junction, including Space Solar Cells (SSC) on the base of Si, GaAs, InP, InGaP/GaAs by using publicated experimental results of NASDA Engineering Test Satellite – V (ETS-V), Solar Cell Monitor(SCM) and other results publicated in different papers, γ-radiation degradation of MOS-devises on the base of high-k dielectrics (ZrO_2/Si and HfO_2/Si).**

I. THE SPACE INFLUENCE FACTORS

Majority of satelits, which content many microelectronic devices, operate în Low-Erth Orbit (LEO), other in Geosynhronous Orbits (GEO) and very smol number in Middle Orbits (MEO). In this conition solar cells and other semiconductor devices are effected by space influence factors: proton and electron radiation, large light spectrum, UV radiation and higher temperature [1].

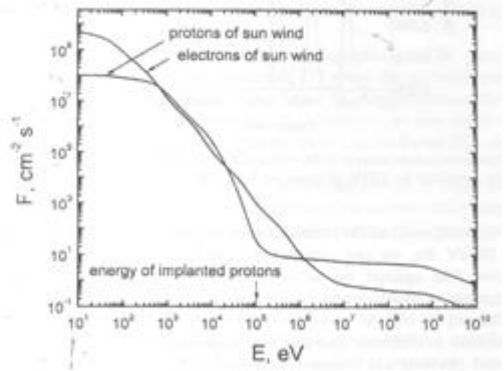


Fig.1. Protons (1) and electrons (2) sun wind.

The hihg-energy electron and proton sun wind, presented in fig. 1, can produce atomic dispacements in semiconductor materials and generate different latice defects wich enhaced process of microelectronic devices degradation; UV radiation and higher temperature produce generation-recombination process and degradation of lifetime and mobility of electron and halls.

II. SPACE SOLAR CELLS DEGRADATION

In acordance with SCM results for 10 years in space radiation environment the Si – SSC degraded by aproximativly 2% ich year and GaAs –SSC by aproximativly 1,5% in dependence of the cell thickness, cell strucrure, coverglass thickness, difference of electrods, fig.2 [2]

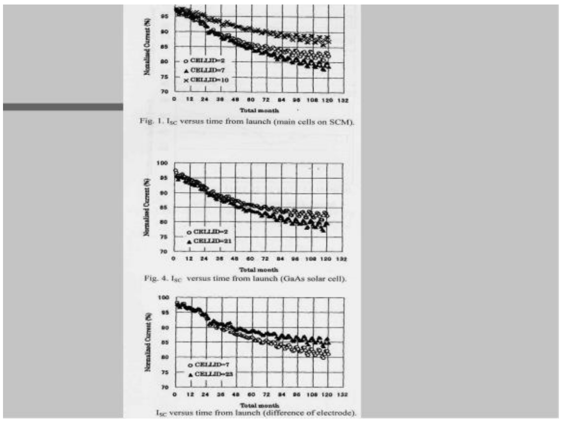


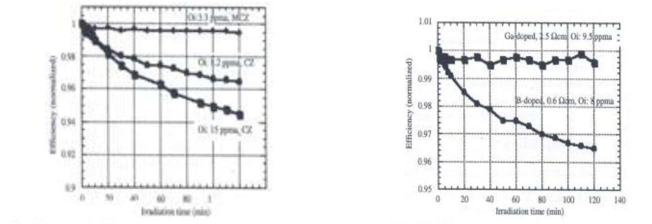
Fig. 1. I_{SC} versus time from launch (main cells on SCM).

Fig. 4. I_{SC} versus time from launch (GaAs solar cell).

I_{SC} versus time from launch (difference of electrode).

Fig.2. The space radiation degradation of Si – solar cells [2]

Experences demonstrated that Si-SSC doped with higher concentration of borum and oxigen (fig.3a) degradat mor intensive that samples with lower concentration; Si-SSC doped with Ga are mor stabil (fig,3b). For the Si-SSC with base field reflection (BSFR) rate of degradation is more that for Si –SSC without base field (BSR) [3].



Effect of oxygen content in CZ crystals on light degradation of carrier lifetimes. (Sharp cells)

Effect of impurity species in CZ crystals on light degradation of carrier lifetimes. (Sharp cells).

Fig.3. Degradation of Si – SSC: a) doped with diferent oxigen concentration, b) doped with Ga and B

The SSC on the base of semiconductors A^3 B^5 (GaAs, InP and InGaP/GaAs) have highr radiation-resistance. Normalized efficiency directly depends of bandgap energy and damage coefficient for minority-carrier diffusion length and optical absorption coefficients [3].

Reliability is higher for higher bandgup energy of seniconductors. The maximum reliability have SSC from InP and semiconductor compounds concerning indium (In) and phosphorous (P) as component; for exemple, demange constant variats from 60 related units for GaAs, to 25 units for InGaAsP, to 15 units for InGaP and to 0,1units for InP [4].

At last time increase attention to the high- efficiensy InGaP/GaAs 2-junction, 3-junction and multy-junction cells with conversion efficiency of 30% - 44% under 500x concentration [4,5].

III. THE γ - RADIATION DEGRADATION OF MOS - HIGH K-DIELECTRICS ZRO_2/SI, HFO_2/SI

For the new generation of nano-devices with nanoscale of gate thickness lower than 2nm conventional SiO_2 dielectric with low k - permittivity (3.9) cannot be used for fabrication of MOS/CMOS nanodevices due to the gate large tunneling current, low threshold voltage, high concentration of interface defects and low radiation reliability. Therefore replacement dielectrics need to be found. Zirconium oxide (ZrO_2) and hafnium oxide (HfO_2) with high-k permittivity (20 - 25) and high band gap energy (3.2 - 3.5) eV are the main candidate for replacement of SiO_2.

The influence of γ-radiation on CV characteristics of ZrO_2/nSi have been investigated at different dose from 0.1Gy to 80Gy, fig.2. On the base of this experimental dates have been estimated the concentration of charge interface defects (ΔN_{if}) by using the relation: $\Delta N_{if} = C_i \Delta U_{mg}/qA$, where C_i is capacity, ΔU_{mg} – middle gap voltage (threshold voltage), q - electron charge, A - aria of capacitor; the radiation sensibility (ΔN_{if} /ΔD) and (ΔU_{mg} /ΔD).

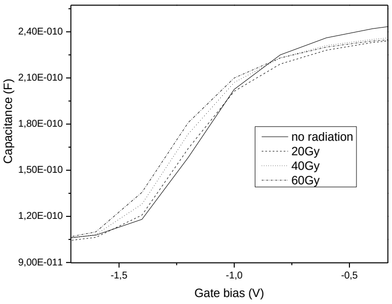


Fig. 4. The CV characteristics of ZrO_2/SiO_2/nSi before and after γ-radiation at different dose (0.1, 2.0, 20, 80)Gy.

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As follow from fig.4 for ZrO_2/nSi at the low dose from 0.1Gy to 40Gy the CV and threshold voltage U_{mg} removed slowly from -1.33V to -1,4V with sensitivity of $S_L = \Delta U/\Delta D = 1.7x10^{-6}$V/rad; at higher dose from 40Gy to 80Gy they removed faster from 1.4V to 1.66V with higher sensibility $S_H = \Delta U/\Delta D = 6.5x10^{-6}$V/rad, Fig.4. The estimated concentration of positive charge interface defects is equal to $\Delta N_{if} = 4x10^{10}cm^{-2}$. This experimental data show that in structures ZrO_2/nSi by γ-radiation have been excited two type of charge defects- with slow energy bond and with higher energy bond (low and high sensitivity- S_L, S_H).

The bidirectional shift of the CV characteristics under γ-radiation at dose from 0.1Gy to 80Gy have been obtained for HfO_2/nSi [15]. Under low dose of 0.1Gy - 2Gy (a) the CV characteristics shifts to positive threshold voltage from -2V to -1.1V, but at higher dose from 2Gy to 16Gy (b) the CV characteristics returned to negative voltage, In the low dose the negative charge defects concentration is equal to $\Delta N_{if} = 6.2x10^{10}cm^{-2}$; the sensitivity ΔN_{if} /ΔD = $4.4x10^6 cm^{-2}rad^{-1}$and $\Delta U_T/\Delta D = 3.6x10^{-5}$ V/rad. For high dose the positive charge defects concentration is equal to $\Delta N_{if} = 8.7x10^{10}cm^{-2}$, the sensibility is ΔN_{if} /ΔD = $4.3x10^7$ $cm^{-2}rad^{-1}$ and ($\Delta U_T/\Delta D = 3.5x10^{-4}$V/rad.

IV. CHARACTERISTICS OF INTERFACE TRAP - CHARGE DEFECTS IN ZRO_2/NSI AND HFO_2/NSI

Bellow on the base of our experimental results and data from other publication we propose the models of interface trap-charge defects responsible for CV shift under gamma radiation of this structures.

Authors[19], by Auger method, have been observed that annealing of ZrO2/chemical SiOx layers in oxygen at temperature of 850 ^{0}C leads to the formation of ZrSixOy interfacial layer. Our sampls are selecte from the same sets of structures, with the same technology [16,19] and consists four layers, ZrO2/ZrSixOy/SiOx/Si, and three interfaces (ZrO2/ZrSixOy, ZrSixOy/SiOx, SiOx/Si). In each interface can be formed different structural defects due to difference of inter-atom length of the atom bonds.

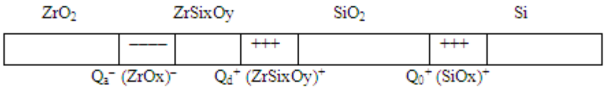

Fig.5. The structure and interface charges of ZrO_2/SiO_2/Si.

In accordance with [5] the inter-atom lengths (L) for different bonds have different values: $L_{Sio} = 1.62A^0$ for (Si-O) bonds; for Zr-O is $L_{ZrO} = 1.94A^0$ and for $ZrSi_x – O_y$ is $L_{ZrSiO}=2.29A^0$. In accordance with this data, on the base of our experimental results we suppos that in this structures there are presented at list three type of interface trap-charge defects: the interface positive defects Q_0^+ $(SiOx)^+$ - conventional defects in SiO_x/Si with bond length equal to $1.62A^0$, interface positive trap-charge defects like donor centres Q_d^+ $(ZrSixOy)^+$ with length 2.29 A^0 and interface negative trap-charge defects like acceptor centres Q_a^- $(ZrOx)^-$ with length equal to $1.94A^0$. Initial, total defects charge in structure is: $Q_T = Q_0^+ + Q_d^+ - Qa^-$. This defects are distributed at interfaces of ZrO_2/SiO_2/nSi consecutively as follow: ZrO_2/Q_a^- $(ZrOx)^-$ / Q_d^+ $(ZrSixOy)^+$ / Q_0^+ $(SiOx)^+$ / nSi. The value of each charge defect concentration depends of composite, technology and post growing thermal treatment of this materials. The analogical structure can be and for HfO_2/nSi.

Bay this model is possible to explain the removing of CV characteristics and Raman spectra and mechanism of degradation under gamma radiation.

V. CONCLUSION

On the base of experimental results we disscused diferent mechanisms and models of SSC degradation including degradation of carrier lifetime, electron and hole concentration and parameters of n+ - p - p+ structures.

Degradation of the high k-dielectrics MOS- ZrO_2/Si and MOS - HO_2/Si is caused by restructuration at lower dose existing defects and by generation of the new positive charge defects at high dose of γ – radiation.

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