DEPENDENCIES OF SPICE LEVEL3 PARAMETERS ON IRRADIATION

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INTRODUCTION

The action of radiation on Integrated Circuits (IC) leads to a significant change of electrophysical characteristics of active bipolar and MOS elements, caused by the formation of load capture and storage centers in dielectric, increase of concentration of the surface states (SS) at the Si–SiO_2 interface and decrease of load mobility in the immediate region of the semiconductor surface [1-3].

Experimental investigations [4-6] have shown that in the process of irradiation the degradation of IC elements characteristics is mainly due to the formation of oxide and SS defects.

One of the methods of forecasting the functioning of the active elements upon irradiation may be reduced to determining the load value in oxide and on SS. The methods of forecasting the functioning developed so far can be divided into several groups which include methods that rely on determining the initial parameters of the structures and their correlation with the values of parameters under the action of IR, testing methods upon irradiation with sources of isotopes Co^{60}, Cz^{137} and Sr_{γ}^{90}–γ^{90} and research methods upon X-ray irradiation.

In the given work are presented the dependencies of bipolar and MOS element parameters on irradiation. On the basis of results obtained, using the schematic simulation program SPICE LEVEL3, were simulated the characteristics of bipolar and MOS elements before and after irradiation.

1. DEPENDENCIES OF BIPOLAR STRUCTURE PARAMETERS ON IRRADIATION

Using the program developed for extraction of parameters the parameter values of bipolar transistors were obtained: *IS* – saturation current; *NF* – direct emission coefficient; *IKF* –threshold current for the high injection level in the literal sense; *IRB* – the current to which the base resistance is halved compared to the maximum value; *RB* – maximum ohmic resistance of base; *NE* – nonideality coefficient; *ISE* –saturation current of BE junction; *BF* – direct transfer factor.

Bipolar structure parameters variation is determined by the structural defects occurring after IR [7]. Parameters extracted from the experimental characteristics obtained before and after the irradiation, for different sources of irradiation, are shown in tab. 1.

Therefore, upon neutron irradiation the saturation current *IS* has a slowly decreasing tendency, due to the fact that at low doses of irradiation the concentration of point defects occurring in the structure is low. When increasing the irradiation dose the *IS* decreases due to the defect concentration increase in the structure which determines the formation of whole regions of defects of “clusters” type. Upon γ quanta irradiation the *IS* decreases due to the dependence of directly proportional relationship between the irradiation flux and the number of electron-hole pairs. Increase of flux intensity causes the increase in the number of electron-hole pairs. The same effect is also observed for X-ray irradiation. Increase in the intensity of the irradiation flux leads to an increase in the number of electron-hole pairs which recombine in the base, an increase in the base current and, therefore, a decrease in the saturation current.

Neutron irradiation causes a decrease in the *IRB* current which has a pronounced downward trend, base resistance still having high values. At high doses of irradiation can be observed that the decreasing trend of the *IRB* current is slower due to the fact that at these doses the value of the base resistance is much smaller, and therefore the decrease of the *IRB* current is also much slower. The same effect is also observed for the γ quanta and X-ray irradiation due to the fact that the increase in the number of electron-hole pairs which recombine in the base tends to saturation, as a result, the saturation of I_B base current occurs.

Neutron irradiation determines the decrease of *RB* base resistance due to point defects occurring in the structure upon irradiation. These defects cause an increase in the number of electron-hole pairs

Table 1. Dependencies of Bipolar Transistor Parameters Depending on Dose.

Doza	**Parameters**							
	IS (A)	**NF**	**IKF (A)**	**IRB (A)**	**RB (Ohm)**	**NE**	**ISE (A)**	**BF**
0	7,95E-18	1,02	1,07	1,88E-3	1,00E+2	1,72	6,00E-14	8,5E+1
Neutrons (n/cm^2)								
2,4E+12	5,72E-18	1,02	9,98E-1	9,11E-4	1,60E+1	1,45	1,52E-14	6,9E+1
2,4E+13	5,49E-18	1,03	9,98E-1	5,17E-4	1,70E+1	1,58	2,64E-13	6,0E+2
2,4E+14	1,99E-19	1,02	9,92E-1	1,88E-4	2,00E+1	1,70	3,53E-11	4,3E+1
γ quanta (Gr(SiO_2))								
1,2E+3	1,49E-17	1,02	1,04E+0	6,64E-4	1,00E+1	1,45	7,08E-16	7,6E+1
1,2E+4	9,79E-18	1,03	9,12E-1	5,74E-4	1,20E+1	1,42	2,95E-15	7,0E+1
1,2E+5	1,25E-18	1,02	1,86E-1	1,96E-4	1,40E+1	1,36	1,04E-13	4,2E+1
X-rays (Gr(SiO_2))								
0,6E+4	4,90E-18	1,02	1,04E+0	2,59E-2	3,26E+2	1,57	2,80E-14	7,0E+1
1,2E+4	1,31E-18	1,02	1,02E+0	2,46E-2	3,36E+2	1,56	2,69E-14	5,9E+1
1,8E+4	7,71E-19	1,00	9,98E-1	2,11E-2	3,24E+2	1,40	4,12E-14	5,5E+1
2,4E+4	5,09E-19	1,03	9,87E-1	1,75E-2	3,18E+2	1,65	5,66E-14	5,0E+1
3,0E+4	2,43E-19	1,03	6,53E-2	1,68E-2	2,63E+2	1,91	2,48E-13	4,2E+1
3,6E+4	9,49E-20	1,02	1,38E-2	1,66E-2	2,17E+2	1,68	3,91E-13	3,9E+1
4,2E+4	7,73E-20	1,02	1,21E-2	1,48E-2	2,06E+2	1,82	2,11E-12	3,0E+1

which recombine in the base. As a result, the increase of base current and decrease of *RB* base resistance takes place. The same trend is also observed upon γ quanta or X-ray irradiation, mentioning that in these cases an increase in the number of electron-hole pairs which recombine in the base region takes place.

Neutron irradiation also determines the increase of BE junction saturation current. It is observed that the *ISE* current has a relatively constant trend, since the irradiation induced defects are point defects and the number of electron-hole pairs which recombine in the base is relatively small. Increase of irradiation dose determines the agglomeration of point defects in the form of clusters and the significant increase in the number of electron-hole pairs. As a result, the increase of the I_B base current, I_E emitter current and *ISE* saturation current of the BE junction takes place. The same trend is also observed in the case of γ quanta or X-ray irradiation.

The amplification coefficient *BF* is decreased for all types of irradiation due to the increase of I_B base current. Increase of irradiation dose leads to a significant increase in the number of electron-hole pairs, which recombine in the base region, influenced by the agglomeration of occurring defects. This leads to the increase of I_B base current and decrease of the *BF* amplification coefficient.

On the basis of these dependences, the comparative analysis of parameters for various types of irradiation was carried out. It was determined that the *IS* parameter value is essentially reduced in the case of neutron and X-ray irradiation. The same is also observed in the case of *ISE* parameter. *BF* parameter indicating the direct current gain decreases essentially in the case of X-ray irradiation for the whole dose range.

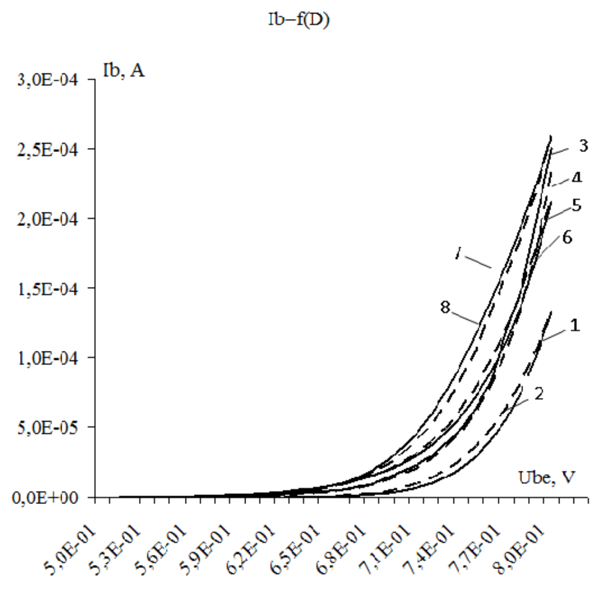

Figure 1. Dependence Ib=f(Ube) (___experimental, --- simulated) for bipolar transistor: *1,2 - before irradiation; 3,4 - irradiated with neutrons, D=2.4E+12 ncm^{-2}; 5,6 - irradiated with γ quanta, D=1.2E+5 Gr(SiO_2); 7,8 – irradiated with X-rays, D=4.2E+4 Gr(SiO_2).*

The degradation of *BF* parameter also determines the decrease of the *IKF* parameter value because it represents the current from which *BF* starts to decrease. For the *IKF* current which is determined by the occurrence of defects in the structure and their agglomeration in the form of clusters, the decreasing trend is higher in the case of X-ray irradiation. It was observed that the decrease of *RB* base resistance is lower in the case of γ quanta irradiation and more pronounced in the case of neutron and X-ray irradiation.By means of a bipolar transistor parameter extraction program, from the experimental dependencies obtained before and after irradiation, the values of these parameters were determined.

Their use in the SPICE LEVEL3
LEVEL3 program allowed the CVA simulation for the investigated structures. The results presented in fig. 1 demonstrate the correlation between the data obtained experimentally and those obtained by simulation at different irradiation doses.

2. DEPENDENCIES OF MOS STRUCTURE PARAMETERS ON IRRADIATION

Using the program developed for extraction of parameters necessary to simulate the characteristics of TMOS [8, 9], the values of the following parameters were obtained: *VTO* – threshold voltage at null polarization, *NSUB* – substrate doping concentration, *KP* – transconductance coefficient, *ETA* – parameter of short channel effect, *THETA* – parameter of mobility modulation by the electric field in the channel, and their dependencies depending on irradiation doses. The obtained results [10] are shown in tab. 2.

Table 2. Dependence of TMOS Parameters on the Accumulated Dose upon X-ray Irradiation.

Doza Gr(SiO_2)	Parametrs				
	VTO (V)	NSUB (m^{-3})	KP (A/V^2)	ETA	THETA (1/V)
0	1,94	4,10E+22	1,73E+5	0,83	1,27E-1
0,6E+4	1,39	5,09E+22	1,41E+5	1,51	5,26E-2
1,2E+4	0,99	6,72E+22	1,18E+5	2,28	0
1,8E+4	0,70	6,67E+22	1,16E+5	3,24	2,08E-2
2,4E+4	0,64	6,60E+22	1,11E+5	4,66	2,29E-2
3,0E+4	0,48	6,80E+22	1,11E+5	6,14	4,03E-2

Variation of MOS structure parameters as a result of IR is determined by the effects occurring in the dielectric and at the Si–SiO_2 interface. When increasing the irradiation dose, the threshold voltage at the null polarization of *VTO* substrate is reduced due to the decrease of parameter value related to the *GAMMA* substrate action and the decrease of *PHI* surface potential. The diminution of carriers' mobility in the channel is due to the appearance of donor and acceptor centers at the formation of electron-hole pairs upon irradiation.

The *NSUB* substrate doping concentration remains practically constant upon irradiation (within the limits of experimental data error) and is not dependent on the dose of irradiation.

On irradiation, the *KP* transconductance coefficient remains practically constant due to the saturation effect at high doses of irradiation. At high doses of irradiation MOS structures enter into the saturation more quickly than at doses of low irradiation intensities and the carriers' mobility no longer acts on the *KP* transconductance coefficient.

When increasing the irradiation dose the parameter *of ET*A short channel also increases. For high irradiation doses of the order 10^4Gr(SiO_2) the faster entry into saturation of the structures takes place and the length of the channel diminishes with the increase of irradiation dose.

THETA parameter decreases with the increase of irradiation dose and increases at the load annealing on the oxide traps after irradiation, which enables its correlation with the SS formation process. The decrease of *THETA* parameter under the action of IR is caused by the reduction of the degree of dependence mobility in the TMOS channel and the action of transverse electric field. Variation of mobility parameter is determined by the following equation:

$$\theta = \frac{\mu_o - \mu}{\mu(V_{GS} - VTH)}, \quad (1)$$

wherein: μ_o – initial mobility; μ – effective mobility; V_{GS} –grid-source junction voltage; *VTH* – threshold voltage.

From this relation is observed that the determinant parameter for small doses of irradiation is the mobility μ, which with the increase of the irradiation dose is reduced. *THETA* parameter at doses of small irradiation intensities has a decreasing trend because the channel diminution process occurs more slowly and the mobility does not act on the mobility parameter. The decreasing trend is due to the reduction of the *VTH* threshold voltage. At higher irradiation doses the channel diminution and saturation process is more pronounced and the mobility acts substantially on the *THETA* parameter. The *VTH* threshold voltage, tending to zero, leads to an increase in the *THETA* coefficient.

The mathematical model and the extracted parameters enable the CVA simulation for the investigated structures, using the SPICE program. Dependencies $I_d = f(U_{ds})$ are shown in fig. 2, 3.

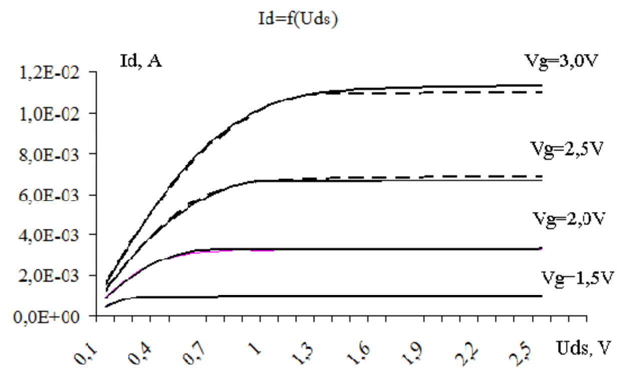

Figure 2. Dependence Id=f(D) (___experimen-tal, --- simulated) for nonirradiated TMOS.

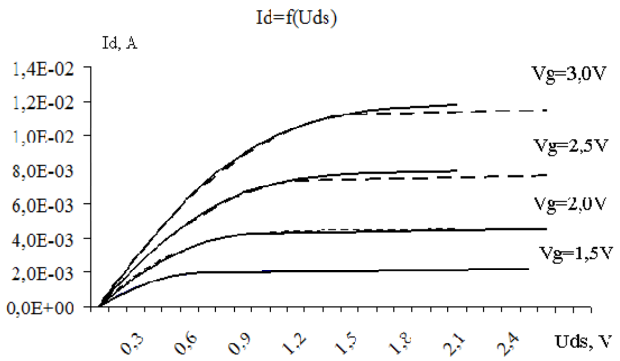

Figure 3. Dependence Id=f(Uds) (___experi-mental, --- simulated) for TMOS, D=3E+4 Gr(SiO_2).

CONCLUSIONS

1. Using the program developed for extraction of parameters, the bipolar transistor and MOS parameter variations before and after irradiation were obtained.

2. Bipolar structure parameters variation is determined by the considerable increase in the concentration of defects in the structure which determines the formation of a whole region of defects of clusters type (neutron irradiation) and the increase in the number of electron-hole pairs (γ quanta and X-ray irradiation).

3. MOS structure parameters variation is determined by the diminution of carriers' mobility in the channel which is caused by the appearance of donor and acceptor centers at the formation of electron-hole pairs upon irradiation. When increasing the irradiation dose the diminution of mobility contributes to the variation of channel length.

4. On the basis of parameter values obtained before and after irradiation, the CVA simulations of bipolar and MOS structures of different topological dimensions were carried out. The discrepancy between the experimental curves and those obtained by simulation differ by about 3%, which confirms that the mathematical parameter extraction model is adequate to the studied processes.

5. On the basis of irradiation research and CVA simulation results, the irradiation stability of active bipolar and MOS elements was determined.

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