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ANALYSIS OF PREDICTION OF RELIABILITY OF LONG-CHANNEL FIELD-EFFECT TRANSISTORS WITH APPLICATION OF POWER-LAW DEPENDENCE OF LIFETIME T_L ON SUBSTRATE CURRENT I_{SUB}

This paper covers the influence of structural and technological parameters of field metal-oxide-semiconductor-transistors (MOSFET) on reliability prediction in power-law dependence of lifetime t_L from substrate current of I_{su}. The structural and technological parameters capable to influence degradation of MOSFET instrument characteristics caused by injection of hot carriers are defined.

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Keywords: *reliability prediction, lifetime, substrate current, hot carrier injection.*

1. Introduction

There are several different methods of prediction of reliability (lifetime) of electronic instruments. One of such methods is prediction of MOSFET lifetime by a method of accelerated tests. This method is based on carrying out of accelerated tests for determination of functionality of integrated circuits with selection of failure criteria and characteristic dependences of lifetime on the substrate current. The author of paper [1] presents dependences of statistical approach to the forecast of lifetime by a method of accelerated tests. Lifetime or life span can be determined by the empirical formula:

$$t_L = B\times(I_{sub}/W)^{-v}, \qquad (1)$$

where B is a factor, which is determined by many structural and technological parameters; x is a parameter determining a slope of straight line of the graph, which is constructed by results of accelerated tests. As it is shown in paper [1], the process of trap generation in MOSFET structures can occur by means of two mechanisms: 1) interaction of hot electrons and hot holes with interface Si-SiO2; 2) Si-H bond opening in gate oxide. In the first case, surface-trapping centers are formed as a result of secondary collision ionization. In the second case, the recombination of electrons with holes leads to liberation of energy sufficient for Si-H bond opening and trap generation. The author of paper [2] offers a general model for effects of hot carriers and considers x = $ц_{it}$ / $ц_i$, where $ц_i$ is minimum energy in electron-volt, which should be acquired by hot electrons for the creation of collision ionization, and $ц_{it}$ is critical energy, an electron should possess to create surface-trapping center. Thus, factor x not only shows the slope of straight lines, but also allows determination of the relation of energies of degradation process. In paper

[2] it was shown that $ц_i$ is approximately equal to 1,3 eV, and $ц_{it}$ in different references is in a range from 3,5 to 4 eV. In paper [3] it is proved that owing to difference of mechanisms of Si-H bond opening, critical energy $ц_{it}$, the electron should possess to create surface-trapping center, is not constant. Figure 1 (paper [1]) shows dependences for prediction of lifetime with different energy of degradation process and, as a consequence, with different values of slope x. The first straight line is received as dependence $t_L I_d$ from I_{sab}/I_d. Processes of interaction of hot electrons and holes with Si-SiO2 interface are reflected there and, as a consequence, generation of surface-trap centers and bulk traps. The second straight line ($t_L I_d$ from I_{sab}/W) reflects the process of Si-H bond opening and, as a consequence, generation of surface-trap centers.

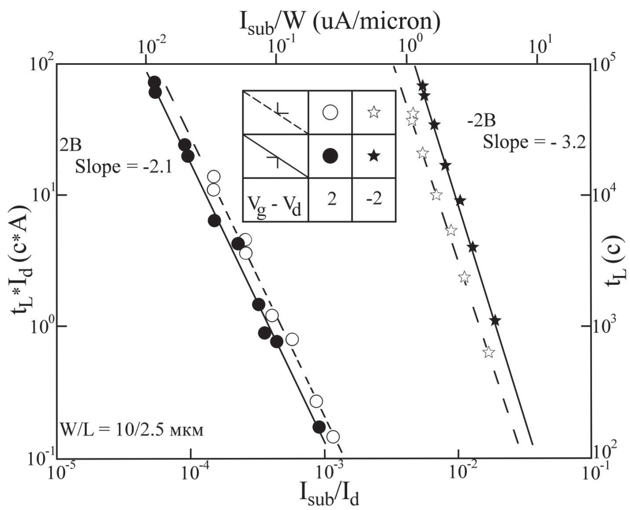


Fig. 1. Dependences for lifetime prediction at different energy of degradation process

In paper [1] it was shown that generation of surface-trap centers (surface states) is the dominant reason for degradation of MOSFET devices owing to the influence of hot carriers, while substrate current I_{sub} is the most simple and qualitative indicator of processes of hot carriers in MOSFET structures. Thus, prediction of reliability by method of approximation of power-law dependence of lifetime t_L from substrate current I_{sub} is positioned in many references as the most simple and effective method.

2. Problem statement

In this article, graphs of dependence of lifetime t_L from substrates current I_{sub} taken from different references [1, 4, 5, 6, 7] were analyzed for the purpose of determination of structural and technological parameters connected with factor B in empirical formula (1) and influencing the result of prediction of lifetime. Thus, determination of structural and technological parameters connected with factor B, as well as determination of their influence on its value plays an important role in reliability prediction.

3. Description of experiments

In this paper the following experiments were analyzed:

1) Experiment on determination of lifetime for samples with different characteristics.

In this experiment, samples with characteristics shown in Table 1 were used. The value of relative change of drain current $ДI_d/I_{d0}$ = 1 % was a criterion of loss of functionality.

Table 1

Structure	T_{ox} (nm)	N_D^+ (cm^{-2})	N_D^- (cm^{-2})	L_{spacer} (micron)	L_{eff} (micron)
1 без LDD	40	10^{16} *As*	-	-	1,7
2 (LDD)	20	$6{\cdot}10^{15}$ *As*	10^{13} *P*	0,15	1,0
3 (LDD)	17	$6{\cdot}10^{15}$ *As*	10^{13} *P*	0,13	1,0

2) Experiment on determination of dependence of lifetime from channel's length.

In this experiment, samples with identical structure without LDD areas with oxide thickness of T_{ox} = 8,5 nanometers, but having different effective channel's length L_{eff} = 1,5; 0,8; 0,5; 0,3 micron were used. The value of relative change of drain current $ДI_d/I_{d0}$ = 10% was a criterion of loss of functionality.

3) Experiment on determination of the influence implantation angle on lifetime.

In this experiment, samples with structural characteristics shown in Table 2 were used.

Table 2

Technology	L_m, micron	W, micron	T_{ox}, nm	Angle of implantation LDD	Angle of implantation LATID	L_{spacer}, micron
0,35 CMOS	0,4 – 1	40	8	7º	42º	0,12

4. Evaluation of results

Figure 2 shows a graph of dependence of lifetime t_L on substrate current I_{sub} for three variants of samples [4]. Table 3 shows values of factors B derived from dependences of functions of lifetime t_L on substrate current I_{sub} presented in Fig. 1.

Table 3

B_1 LDD samples, T_{ox} = 17 nm	$2{,}1259159{\cdot}10^{-11}$
B_2 Samples without LDD, T_{ox} = 40 nm	$2{,}9791178{\cdot}10^{-11}$
B_3 LDD samples, T_{ox} = 20 nm	$13{,}419189{\cdot}10^{-11}$

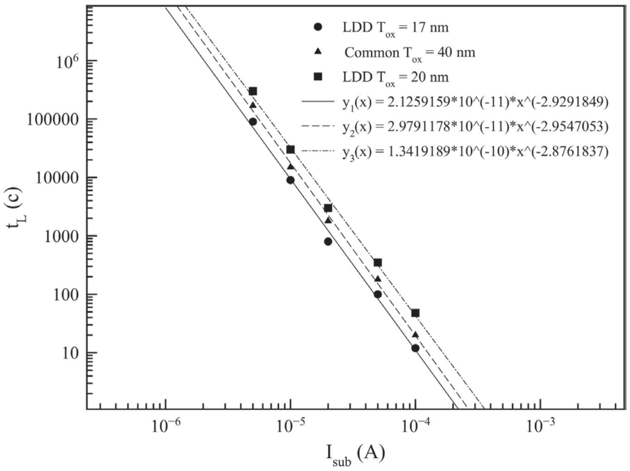


Fig. 2. Graph of dependence of lifetime t_L from substrate current I_{sub}

It can be seen from table 3 that the greatest spread of values is observed for factors B corresponding to variants of samples with LDD areas, but having different thickness of gate oxide (д$B_{3.3}$ = B_3 / B_1 = 6,3121). Thus, it is possible to draw a conclusion that factor B, and, hence, also the result of prediction of reliability depends on thickness of gate oxide. It is known that with decrease of thickness of gate oxide the probability of injection of hot carriers grows and, as a consequence, degradation of instrument characteristics increases. For decrease of effects of hot carriers the LDD areas are used. In this experiment it can be seen well that use of LDD areas substantially increases the value of factor B and on the basis of empirical equation (1) also the lifetime. Thus, factor B in empirical equation (1) has strong dependence on presence of low-alloyed areas. However, in view of presence of dependence of factor B on thickness of gate oxide, it is impossible to tell with high accuracy that use of LDD areas will always lead to increase of value of factor B and, as a consequence, to the lifetime increase. Comparing the samples having LDD areas and different thickness, it can be seen that an increase of thickness of gate oxide only by 3 nanometers leads to increase of factor B and, hence, also lifetime by 6 times. Thus, in this case the result of prediction of reliability for samples having insignificant difference of thickness of gate of oxide will have a big scattering.

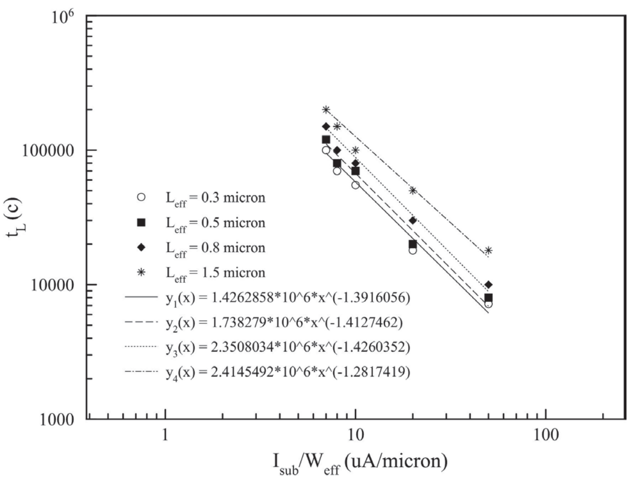


Fig. 3. Dependence of lifetime t_L on I_{sub}/W_{eff} at different channel length L_{eff}

The following figure (Fig. 3) shows experimental data of accelerated tests on determination of time of preservation of functionality t_L depending on I_{sub}/W_{eff} for samples with different channel length [5]. Additionally Table 4 presents the values of factors B derived from dependences of functions of lifetime t_L on substrate current of I_{sub}/W_{eff} shown in fig. 3.

Table 4

B_1, L_{eff} = 0,3 micron	1,4262858·10^6
B_2, L_{eff} = 0,5 micron	1,738279·10^6
B_3, L_{eff} = 0,8 micron	2,3508034·10^6
B_4, L_{eff} = 1,5 micron	2,4145492·10^6

It can be seen from Table 4 that the spread of factor B is in small range. Figure 4 shows, how the increase of the channel's length influences factor B.

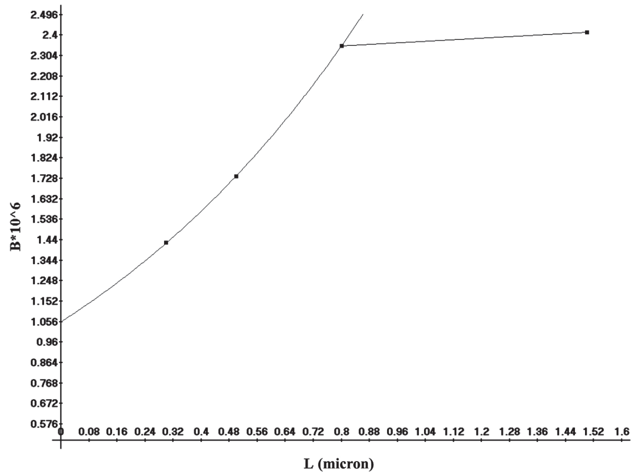


Fig. 4. Dependence of factor B on channel length L_{eff}

It can be seen from Figure 4 that up to the value L_{eff} = 0,8 microns, all points lay down well on an exponential curve described by the equation:

B = 1,0557927·exp (0,9999067·L_{eff}),

The following point at L_{eff} = 1,5 micron lays practically on one horizontal straight line with point at L_{eff} = 0,8 micron. Hence, it is possible to assume that dependence of factor B from channel's length is exponential up to the value of channel's length L_{eff} = 0,8 micron, and subsequent increase of channel's length practically does not influence the change of factor B. It is necessary to note that such exponential dependence of factor B from channel's length is observed particularly in this experiment, whereas in other similar experiments this dependence cannot be traced. In paper [6] it is shown that at change of criterion of loss of functionality, the dependence of factor B from channel's length disappears (Fig. 5) and all experimental data lay down on one straight line.

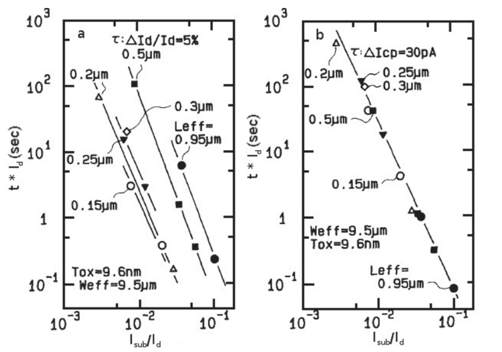
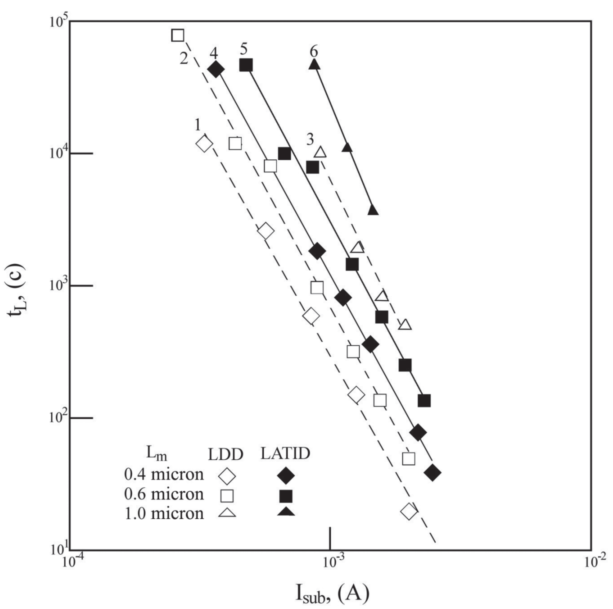


Fig. 5. Dependence of the given lifetime $t \cdot I_d$ from the given substrate current I_{sub}/I_d a) criterion of loss of functionality ДI_d/I_{d0} = 5 %; b) criterion of loss of functionality ДI_{cp} = 30 Pa

Consequently, it is possible to draw a conclusion that factor B has dependence from channel's length, but only at selection of a certain criterion of loss of functionality, which in turn gives different results of approximation and, therefore, the difference in lifetime and reliability prediction. Moreover, it is necessary to note that in this experiment the change of channel's length influences the value of factor B not so significantly, as the thickness of gate oxide in the previous experiment. It means that the contribution to the value of factor B from the channel's length is smaller than the contribution from thickness of gate oxide.

Figure 6 shows graphs of dependence of lifetime on substrate current for two types of samples (LDD and LATID)



1) y = 1.0436555*10^(-8)*x^(-3.4813813) 2) y = 1.13763*10^(-8)*x^(-36000825)
3) y = 5.3943929*10^(-8)*x^(-3.6915151) 4) y = 1.7954248*10^(-8)*x^(-3.6063543)
5) y = 1.1657934*10^(-8)*x^(-3.7994218) 6) y = 2.9085351*10^(-10)*x^(-4.6309805)

Fig. 6. Dependence of lifetime t_L on substrate current I_{sub} for technologies LDD and LATID with different channel length L_m 0,4 – 1 micron

with different channel length. As it can be seen from Table 2, the samples used in this experiment differ only by implantation angle during creation of low-doped drain regions (LDD and LATID). In this experiment (Fig. 6) 6 samples were taken with different channel length (three for LDD areas with angle of implantation 7° and three for LATID with angle of implantation 42°) [7].

Table 5 shows values of factors B received from dependences of functions of lifetime t_L from substrate current I_{sub} presented in Fig. 6.

Table 5

B_1, L_m = 0,4 micron (LDD)	$1{,}0436555 \cdot 10^{-8}$
B_2, L_m = 0,6 micron (LDD)	$1{,}13763 \cdot 10^{-8}$
B_3, L_m = 1 micron (LDD)	$5{,}3943929 \cdot 10^{-8}$
B_4, L_m = 0,4 micron (LATID)	$1{,}7954248 \cdot 10^{-8}$
B_5, L_m = 0,6 micron (LATID)	$1{,}1657934 \cdot 10^{-8}$

It can be seen from the figure that practically all straight lines have an identical slope, except for the LATID sample with a channel length L_m = 1 micron, therefore factor B related to this sample is impossible to compare with the others. It can be seen from the table that the greatest value of factor B has the sample with LDD area and channel length L_m = 1 micron, while spread of factor B depending on channel's length is in a bigger range, unlike the experiment presented in figure 4 (which was conducted on samples without LDD areas). Comparing the value of factor B corresponding to LDD area with a channel length L_m = 1 micron, and the value of factor B corresponding to LDD area with a channel length L_m = of 0,4 micron, it can be seen that it increases by 5 times at the increase of the channel's length by 0,4 micron, which shows the strong influence of the channel's length on the result of prediction of lifetime and reliability. Thus, it confirms once again the assumption that both – the channel's length increase and the presence of LDD and LATID areas have influence on the value of factor B and also on lifetime. It can be seen from the figure that straight lines corresponding to LATID structures are above the straight lines corresponding to LDD structures; it means that value of factor B is influenced by presence of low-doped drain areas (LDD and LATID) and by implantation angle.

5. Conclusion

Significant influence on the value of factor B has thickness of gate oxide and in some cases it prevails over the structure influence (presence of LDD areas). Factor B is influenced also by channel length. The most considerable influence on factor B is brought by a structure type, namely such structural and technological parameter as the presence of LDD or LATID areas and implantation angle.

The prediction of reliability with the use of approximation of power-law dependence of lifetime t_L on substrate current I_{sub} can have a big error due to strong influence of a number of structural and technological parameters described above, as well as due to the selection of criterion of functionality loss. Such approach to prediction of reliability requires tests for all samples with even insignificant differences (e.g. small difference of thickness of gate oxide or implantation angle).

This method requires improvement by means of more exact determination of influence of structural and technological parameters on empirical factor B in power-law dependence of lifetime t_L on substrate current I_{sub}.

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