Available online www.jsaer.com

Journal of Scientific and Engineering Research, 2017, 4(8):231-237

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Influence γ-irradiation on the parameters of MIS – structures with voltage and without voltage at the field electrode

Khojakbar S. Daliev

National University of Uzbekistan named after Mirzo Ulugbek, 100174, Tashkent, Republic of Uzbekistan

Abstract Using DLTS methods in the mode of constant capacitance (CC-DLTS) and capacitance-voltage characteristics (CV) studied the effect of irradiation γ-quanta of ^{60}Co in the parameters of MIS - structures in the presence of the offset field electrode. It is shown that at the interface Si-SiO$_2$ and in the bulk of the dielectric under irradiation radiation defects are formed, with the increase of their concentration at large doses, appears through current, preventing the formation of a stable inversion layer on the silicon surface. The presence of bias to the field electrode and the change of its polarity during irradiation have little effect on the generation and ionization centers in the dielectric, but the density of surface states is near the middle of the forbidden silicon grows much faster at positive bias.

Keywords capacitance-voltage characteristics, constant capacitance, interface Si-SiO$_2$, dielectric.

Introduction

To determine the parameters of defects, creating deep levels is one of the main DLTS method (Deep Level Transient Spectroscopy) [1]. This method allows to determine the concentration of deep centers, activation energy and capture cross section of traps in the resistor structures, the structures with p-n-transition and the structures of the type metal-insulator-semiconductor (MIS). It is known [2], in MIS-structures the density of fast states depends on the operating mode. While the combined impact of ionizing radiation and various voltages on the control electrode can lead to a shift in threshold voltage. After radiation exposure, at various voltages, can be predicted to work out of the MIS-structure, and optimizing modes and the working point it is possible to improve their radiation resistance and reliability.

In the present work results of research of characteristics of structures Al-SiO$_2$-Si irradiated γ-quanta of ^{60}Co in the presence of an electric field in the dielectric, using methods DLTS in the mode of constant capacitance (CC-DLTS) and capacitance-voltage characteristics (CV).

The studied experimental samples

For measurements was used in MIS-structures on substrates of n-Si with orientation <100> and ρ=15 Ohm·cm. The oxide layer with a thickness of d_{ox} = 650 Å was grown thermally at 900°C in an atmosphere of moist oxygen with the addition of trichloroethylene. Metal electrodes on the SiO$_2$ area S = 0.03 cm^2 and a thickness of 7000 Å , was created by evaporation of aluminum. Irradiation of structures was carried out by flow γ-quanta with an intensity of $3.4\cdot10^{12}$ cm^{-2}s^{-1} at room temperature and with the bias voltage on the aluminum electrode V_{bias} = +10 or V_{bias} = - 10 V. Radiation dose was D = $6\cdot10^{14}$ - $6\cdot10^{15}$ quantum/cm^2.

The concentration of deep levels (DL) N_t the volume of silicon was measured by DLTS on the Schottky barriers fabricated on the Si wafers after etching of the SiO$_2$ layer. It was found that at maximum radiation dose concentration of deep levels does not exceed 10^{12} cm^{-3} and they do not affect the measurement results at the interface Si-SiO_2. In between the measurements of the structure were kept at 77K to eliminate the annealing of deep levels after radiation, since the storage of the samples at 300K for 5 hours led to a decrease in the concentration of deep levels by 20 % .

Spectra of CC-DLTS was measured at different values of E_{FS} in the state of emission of electrons from surface states (SS) where E_{FS} is the energy of quasi wave Fermi energy for electrons on the silicon surface, measured from the lower edge of the conduction band down. E_{FS} is determined from the dependence of temperature on values of constant capacitance C of the structure at the time of emission and the position of the Fermi level in the neutral semiconductor. Measuring modes spectra of CC-DLTS and C-V characteristics are described in detail in [3].

Results and Discussion

In Fig.1 shows the C-V characteristics of the irradiated structures, the capacity normalized to the oxide capacitance C_{ox}. The shift of the bias voltage V, which corresponds to flat band conditions ($V=V_{FB}$, $C=C_{FB}$), and $E_{FS}=E_i$ (E_i is the energy corresponding to the middle of the forbidden zone, $V=V_{MG}$, $C=C_{MG)}$ shows the formation of positive charge in SiO_2 by irradiation, and the change in the slope of C-V curves indicates an increase in the density of surface states (DSS). At high radiation doses D (curve 3) stable inversion layer on the silicon surface is not formed, since the capacity decreases with increasing $-V_{bias}$ the same way as when measuring low-temperature C-V curves. This distortion of the inversion layer associated with the appearance of a through current in the order of 10^{-9}A through SiO_2.

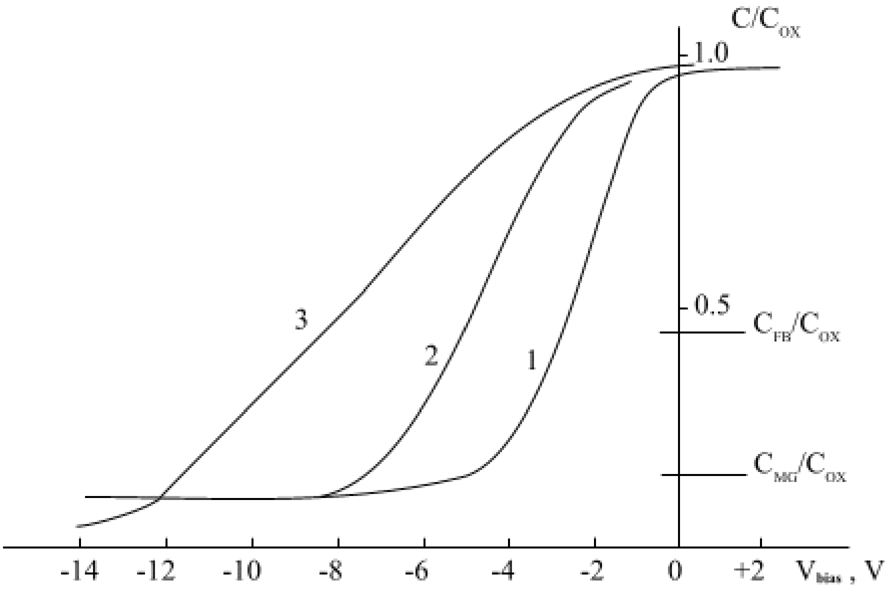

Figure 1: High frequency capacitance-voltage characteristics of MIS-structures before and after irradiation γ-quanta ^{60}Co at V_{bias}= -10 V, D, cm^{-2}: 1 - 0; 2 - 1,3·10^{15}; 3 - 5,7·10^{15}.

In Fig. 2 shows the dependence of V_{FB} (D) (curves 1 and 2) and V_{MG} (D) (curves 3 and 4) at negative and positive bias V_{bias} during irradiation. Effective positive charge in the oxide at positive bias (+ V_{bias}) grows a little stronger, than at negative bias ($-V_{bias}$). But, in contrast to the structures of the oxidized without chlorine, in our case, the influence of polarity V_{bias} by the amount of charge in the oxide is much less pronounced. The change in effective charge in SiO_2 may be due to the drift of holes through the SiO_2 and their capture near the surface of silicon or impact ionization hot electrons of trivalent silicon in the oxide [4]. In the case of the first mechanism, the drift of holes occurs at a relatively large distance and at $+V_{bias}$ the change in the charge should be significantly more than in $-V_{bias}$. In the case of impact ionization of the displacement of the carriers is small and the polarity V_{bias} should have less influence. From this we can conclude that in our case the change of effective charge in SiO_2 probably is due mainly to impact ionization.

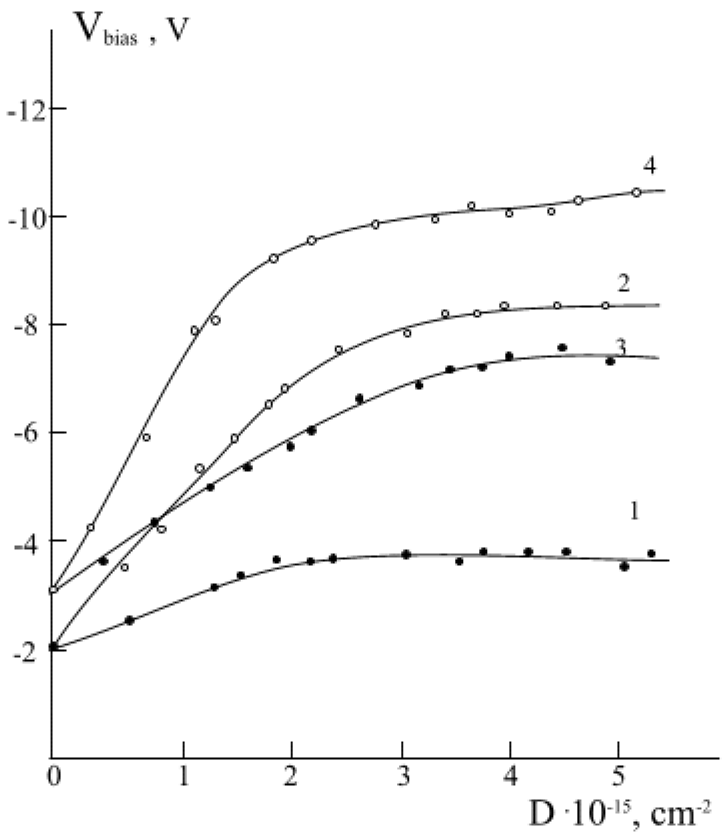

Figure 2: The dependence of the voltage V_{FB}, and the V_{MG} from D at negative and positive bias V_{bias} on the field electrode during irradiation: curves 1, 2 — V_{FB} (D); : curves 3, 4 — V_{MG} (D); V_{bias}, V curves 1, 3 — -10 V; curves 2, 4 — +10 V.

From Fig.2 also shows that with the accumulation of positive charge in the oxide further education slows down.

From Fig.2 also shows that with the accumulation of positive charge in the oxide further education slows down.

The dependence of $|V_{FB}(D)|$ goes to saturation when $D \geq 4 \cdot 10^{15}$ quantum/cm^2 (curves 1 and 2), but the positive charge is partially compensated by negative charge on the surface states. For a symmetrical distribution of the donor surface states in the upper half of the forbidden zone of silicon increase $|V_{MG}|$ (curves 3 and 4) leads to an increase of the effective fixed charge, regardless the total density of surface states [5]:

$$\Delta Q(D) = |\Delta V_{MG}| \cdot C_{ox} / A \qquad (4 - 1)$$

In Fig. 3 shows the effect of irradiation at negative bias ($-V_{bias}$) and positive bias ($+ V_{bias}$) in spectra of CC-DLTS of MIS- structures. Comparison of the curves 2 and 3 (or 4 and 5 at large D) shows that the greatest influence of the polarity V_{bias} has on the formation of deeper radiation surface states, the rechargeable under these conditions at T≥150 K. Such non-uniform formation of shallow and deep surface states is also observed when exposed to other types of radiation, such as electrons [6].

The signal CC-DLTS measured at temperatures of 80, 150 and 250 K, corresponding to energies of ionization E_t = 0.09, 0.24 and 0.44 eV, calculated in the density of surface states N_{ss} by the method described in [7]. Dose dependence of the density of surface states is shown in Fig.4.

The average activation energy E_t corresponding to each temperature was determined from the decrease ΔU with decreasing E_{FS}: if $E_t = E_{FS}$ magnitude of ΔU is reduced to approximately 40 % of maximum signal when $E_{FS} = E_t$ at the same temperature. From Fig. 4 it is seen that the formation of shallow surface states with $E_t \approx 0.24$ eV is only weakly dependent on, and $E_t \approx 0.1$ eV, almost independent from the polarity V_{bias}. In the whole region of energies, there is always superlinear growth of $N_{ss}(D)$ when $D \geq 2 \cdot 10^{15}$ quantum/cm^2, and a tendency to saturation is noticeable only when $D \approx 6 \cdot 10^{15}$ quantum/cm^2. Further increase in irradiation dose does not make much sense, as in the MIS-structures appears through current and as a consequence, the interpretation of the measurement results of CC-DLTS and C-V characteristics becomes unreliable [8]. The average values of the capture cross section of electrons on surface states $\sigma_n(E_t)$ before and after irradiation at V_{bias} = 10 V, calculated from E_t and T values at which they are recharged with the speed issue en=275 c^{-1}, are given in table 1. The values of the capture cross section of electrons for radiation of surface states from E_t = 0.44 eV is not different from σ_n surface states in the samples before irradiation, and at lower E_t are formed, especially the surface states with particularly small cross sections of electron capture.

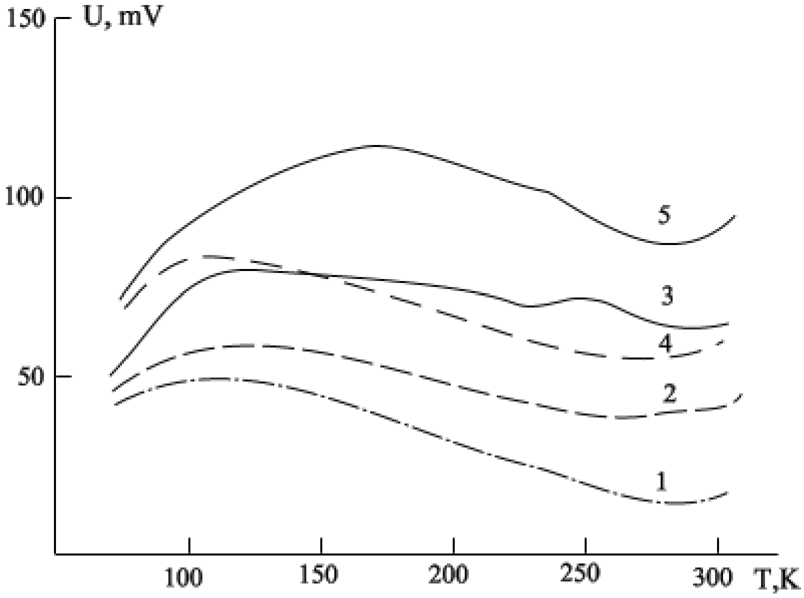

Figure 3: Spectra of CC-DLTS of MIS-structures before and after irradiation γ-quanta with U_f *=+10 V,* t_f *=10 μs,* $t_2 = 3 \cdot t_1$ *= 6 ms,* E_{FS} *(300 K) = 0.6 eV.*
D, cm-^{2} *: 1 – 0; 2, 3 – 1.6·*10^{15}*; 4, 5 – 3.2·*10^{15}*.* V_{bias} *, : 2, 4 – -10; 3, 5 – +10;*

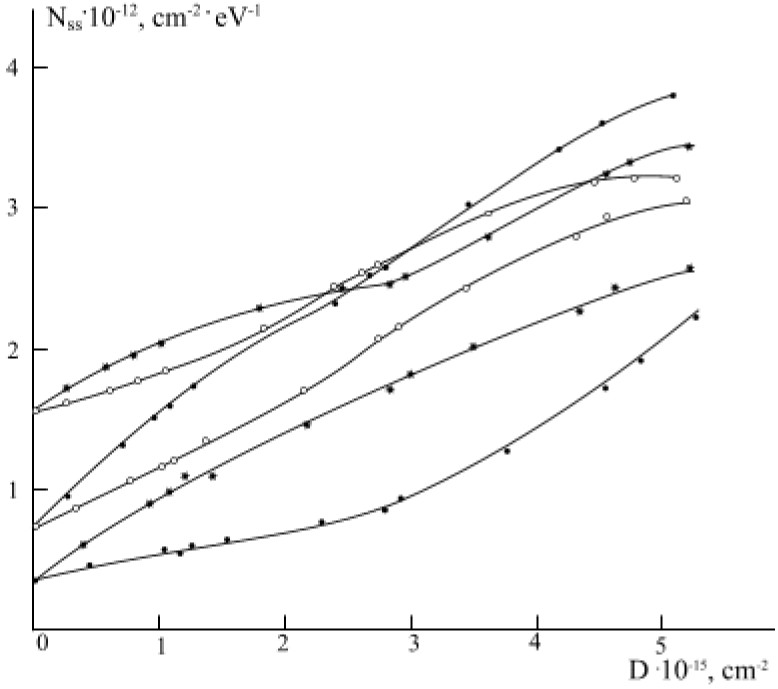

Figure 4: Dependence of density of surface states N_{SS} *from D at positive and negative* V_{bias} *calculated from the spectra of CC-DLTS at different temperatures and the corresponding average energies of ionization* E_t *of surface states: T K (*E_t*, eV): 1,2– 250 (0.44); 3,4 – 150 (0.24); 5,6– 80 (0.09).*
V_{bias}*: 1, 3, 5 – -10; 2, 4, 6 – +10*

Table 1

D=0			D=2.7·10^{15} q/cm^2	
E$_t$, eV	**T, K**	**σ$_n$, cm^2**	**T, K**	**σ$_n$, cm^2**
0.44	250	$1\cdot10^{-15}$	250	$1\cdot10^{-15}$
0.24	150	$4\cdot10^{-16}$	155	$2\cdot10^{-16}$
0.10	80	$3\cdot10^{-17}$	90	$4\cdot10^{-19}$

A variety of such slowly rechargeable centers are observed upon detailed examination of the spectra of CC-DLTS in different E_{FS} (Fig. 5). First, there is a characteristic peak of the radiation defects near T=270K at E_{FS}= 0.5 - 0.6 eV (curves 1.2, peak A), that when reducing E_{FS} is shifted to higher temperatures (curves 3-5). The direction of the shift of this peak is opposite to the direction of the shift of the peak recharge of surface states minority carriers at T>300 K (a peak In Fig. 5). The results of numerical calculation of the parameters of the characteristic radiation defects showed that they do not differ from the parameters of the corresponding defects at the interface Si and a cathode-sprayed film of SiO_2 [9]. Capture cross sections of electrons with these defects are reduced from 10^{-15} to 10^{-20} cm^2 with decreasing E_t from 0.5 to 0.2 eV. Such surface states can be interpreted spatially distributed defect in the transition layer between Si and SiO_2. The effective capture cross section of electrons decreases due to tunneling of electrons at the centres, more remote from the surface of the silicon, in which E_t changes depending on the local composition of the transition layer SiO_x. On the background of continuous spectrum of other surface states cannot be measured reliably the dependence of the density of these States of the dose, but at D=1.6·10^{15} quantum/cm^2 and V_{bias} = +10 V, the total concentration of about 10^{10} cm^{-2}.

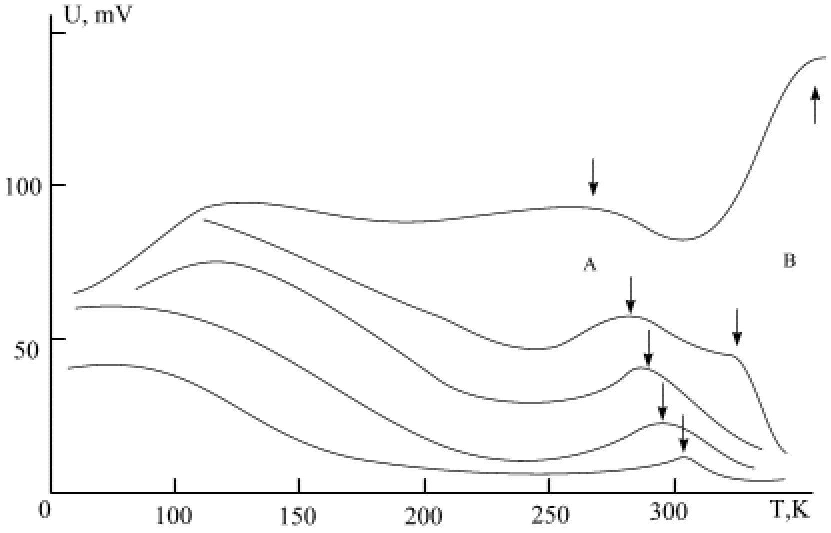

Figure 5: Spectra of CC-DLTS MIS-structure irradiated by γ-quanta with D =1.6·10^{15}cm^{-2}, with V_{bias}= +10 V at different constant E_{FS}, eV: 1- 0,6; 2- 0,5; 3 - 0,4; 4 - 0,3; 5 - 0,2.

Second, at small E_{FS} part of the signal CC-DLTS ΔU_o does not depend on temperature. When E_{FS} = 0.2 eV in the temperature region T≥170 K to the value ΔU_o does not depend on T (see Fig. 5, curve 5). Reduction E_{FS} this region T is expanded, as the number of "normal" surface states only recharge centers with $E_t \leq E_{FS}$ and reduced participation in the exchange near 300 K characteristic radiation defects. In [10] describes the features of the recharge of the various centers in MIS-structures and it is shown that ΔU_o due to recharging such bulk states in the dielectric, which are located relatively close to the silicon surface and sharing of electrons is controlled by the tunneling mechanism practically without thermal activation, i.e., these bulk states of the dielectric have the energy near the lower edge of the conduction band of silicon.

The value ΔU_o was proportional to U_f and ln t_f when $U_f \leq 20$ V and $10^{-6} \leq t_1 \leq 10^{-1}$s, i.e., there are no sharp dependence of density of these volume states N_{ti} from the energy and the distance z from the surface Si at $10 \leq z \leq 18$ Å. In Fig.6 shows the dose dependence of the signal CC-DLTS and counted in them the values of N_{ti} at positive and negative bias to the field electrode V_{bias}.

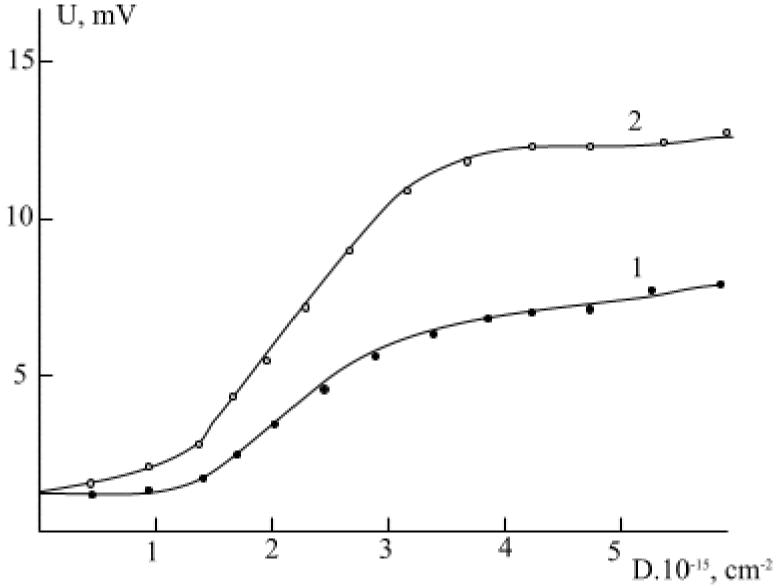

Figure 6: The dependence of the signal CC-DLTS from D at low $E_{FS} = 0.13$ eV and V_{bias}: 1 – 10 V, 2 - +10 V, $U_f = +15$ V, $t_f = 0.1$ ms, $t_2 = 3t_1 = 6$ ms, T = 290 K.

From Fig. 6 shows that the dependence of the N_{ti} (D) is similar to that according to V_{MG} (D), shown in Fig.2. This suggests that, at least near the surface of silicon by irradiation is not only the ionization of the preexisting electronic states in the dielectric, but are formed in large quantity new bulk states. It is assumed that the same bulk states can occur in the whole volume of SiO_2. At high density of bulk sates becomes possible a hopping conductivity occurs through current, electrons from the metal electrodes reach the silicon surface and there recombine with holes. If this electric current exceeds the generation current of holes, the holes concentration on the silicon surface decreases and, consequently, distorted the inversion layer and the C-V characteristics of the structure (Fig.1, curve 3).

Dose, which decreases the slope of the curve $-V_{MG}$ (D), only weakly dependent on polarity V_{bias} and the V_{MG} (Fig.2). Therefore, the conditions of production of the SiO_2 the change in the tilt is more a reverse tunneling capture of electrons by ionized centers in the oxide [9] than with the distortion of the electric field in the dielectric [10]. Opportunities for such capture also grow with the formation of large concentrations of bulk sates, which is observed in the region of change of the slope V_{MG} (D) at dose $D = (2\text{-}3)\cdot10^{15}$ cm^{-2}. Opposite compared to V_{MG} (D) behavior characteristics of the N_{ss}(D) can be explained by the fact that the resulting positive charge near the surface of the silicon weakens the ties on the surface, reduces the maximum energy to rupture and therefore increases the rate of formation of surface states during irradiation. Such an increase in the slope of the N_{ti}(D) at dose $D = (1\text{-}2)\cdot10^{15}$cm^{-2} shown in Fig.6. The reason for the saturation N_{ti}(D) starting at $D>3\cdot10^{15}$cm^{-2} remains unclear. It can be assumed that filling of the bulk states at these doses occurs partially due to the occurrence of the through current and the value of ΔU_0(D) при $D>3\cdot10^{15}$ quantum/cm^2 not is determined by the total concentration of N_{ti}(D).

Conclusion

From the results of studies of C-V characteristics and DLTS spectra in different modes can be set by the dose dependence of the bulk states, the surface states (with different kinetics of recharge) and the integrated charge in the oxide, but the main causes of degradation of structures under the influence of ionizing radiation.

At the interface Si-SiO_2 and in the bulk of the dielectric under irradiation the formation of radiation defects, with the increase of their concentration in large doses, appears through current, preventing the formation of a stable inversion layer at the silicon surface.

When irradiated structures without displacement observed large scatter of the experimental data, in particular, the density of surface States and bulk States lie between the results at $+V_{bias}$ and $-V_{bias}$. This, apparently, can be linked with the fluctuations of the built-in charge in oxide. Irradiation structures with $V_{bias} \neq 0$ stabilizes the conditions of formation of radiation defects and allows to establish a clear dependence of their density on the dose.

The presence of bias to the field electrode and the change of its polarity during irradiation have little effect on the generation and ionization centers in the dielectric, but the the density of surface states is near the middle of the forbidden silicon grows much faster at positive bias.

Reference

[1]. M. N. Levin, A. E. Bormontov, A. E. Ahkubekov, E. A. Tatokhin. Spectroscopy of deep levels by the method of laplace-dlts kinetics of ionization of metastable centers / Condensed matter and interphase boundaries, 2010, Volume 12, No. 2, Pp. 133-142.

[2]. T. R. Oldham, Total ionizing dose effects in MOS oxides and devices / T. R. Oldham, F. B. McLean / / IEEE Trans. Nuclear Physics. – 2003. – vol. 50, No. 3. – pp. 483-99.

[3]. Lebedev A. A., Beck V. Evaluating the distribution profile of the degree of oxidation of the silicon in the transition layer of Si-SiO2. FTP, 1985, vol. 19, V. 6, pp. 1156-1158.

[4]. Aleksandrov O. V. the Effect of bias on the behavior of MOS structures under ionizing irradiation. FTP, 2015, V. 49, V. 6, pp. 793-799.

[5]. Popov V. D. Two stages of surface defect formation in MOS structure at low-intensity exposure to gamma radiation. FTP, 2016, vol. 50, V. 3, 354-359.

[6]. Y. Khlifi, K. Kassmi, A. Aziz Ionizing Radiation Effect on the Electrical Properties of Metal/Oxide/Semiconductor Structures. M. J. Condensed Matter. - 2005. - Vol.6 (1). - R. 20-26.

[7]. Wang, K. L. MOS Interface-State Density Measurements Using the DLTS. IEEE Trans.Electron.Devices, 1980, V. ED-27, No. 12, p.2231-2239.

[8]. V. A. Gurtov, Solid-state electronics: study. a manual / V. A. Gurtov. Petrozavodsk: Petrozavodsk State University, 2004. – 312 c.

[9]. Lebedev A. A., Beck, V. investigation of the density of deep centers in a cathode-sputtered SiOx films depending on the oxidation state of silicon. – FTP, 1985, vol. 19, V. 6, pp. 1087-1091.

[10]. Krasnikov G. Ya., Zaitsev N.. The system silicon - silicon dioxide submicron VLSI - M.: Technosphere, 2003. - C. 384.