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THE INFLUENCE OF EXTERNAL FACTORS ON PROPERTIES OF IRRADIATED SILICON MIS STRUCTURES

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Abstract. The isochronous annealing of radiation defects, that occur during irradiation of MIS structures by \( \gamma \)-quanta with displacement on a metal electrode was investigated. it was found that the built-in charge and bulk states of the dielectric are annealed at 250°C, surface states – at 350°C, and the characteristic radiation defects in the Si-SiO\(_2\) transition layer is fully annealed only at 400°C

Keywords: MIS-structure, external factor, annealing, surface state, irradiation, heat treatment, radiation damage

Despite the large number of works devoted to the study of the properties of MIS structures, there is still much unclear in the understanding of physical processes in silicon MIS structures, especially contradictory results on the study of the influence of external factors on the properties of the Si-SiO\(_2\) system.

It is known [1] that the properties of the SiO\(_x\) transition layer are determined mainly by the oxygen content. For example, reactive cathodic sputtering of Si in a magnetron discharge [2] makes it possible to deposit SiO\(_x\) films in a wide range of oxygen content with a statistically uniform distribution of Si-O and Si-Si bonds [3]. Films of this type can be used as a model for studying the properties of the transition layer between silicon and its thermal oxide; therefore, their study is of particular interest.

This paper presents the results of complex measurements of the CC-DLTS and C-V characteristics of MIS structures irradiated with \( \gamma \)-quanta at a constant bias voltage across the structure and then subjected to isochronous annealing.

For the measurements, we used MIS - structures on n-Si substrates with orientation (100) and \( \rho = 15 \) Ohm-cm. An oxide layer with a thickness of \( d_x = 100 \) nm was thermally grown. Before irradiation, MIS structures had \( N_{SS} (0.44 \text{ eV}) = 4 \cdot 10^9 \text{ cm}^{-2} \text{ eV} \) and \( V_{mg} - 1.4 \text{ V} \). Preliminary annealing of MIS structures at 350°C for 30 minutes in a nitrogen atmosphere, carried out in order to reduce the density of surface states (SS), reduces the concentration and radiation defects introduced by irradiation. Thus, \( Q_f \) is 70%, and \( N_{SS} \) is 50% less than the analogous values in the samples irradiated without preliminary annealing. Isochronous annealing of the structures after irradiation was carried out at temperatures \( T_{ann} = 70 – 400\)°C with holding at each temperature for 30 minutes in a nitrogen atmosphere.
To determine the density of bulk states $N_{ti}$, which are recharged by a tunneling transition of electrons from bulk states of a dielectric to the conduction band of Si, $\Delta U$ was measured at $T = 250$ K and $E_{FS} = 0.20$ eV. Under these conditions, surface states practically do not participate in the formation of the stress relaxation signal.

The CV characteristics were measured at $T = 290$ K and a frequency of 100 kHz. The effective charge density in the oxide $N_q$ is determined from the voltage $V_{mg}$, at which in the stationary state $E_{FS}$ is located in the center of the band gap of silicon:

$$N_q = \frac{V_{mg} \cdot C_{ox}}{A \cdot q}$$  \hspace{1cm} (1)

where $C_{ox}$ is the capacity of the oxide of the MIS structure and the $q$ is the electron charge.

In the presence of radiation damage to the MIS structure, the relaxation signal $\Delta U$ at $T < 150$ K has some specific features (Fig. 1, curves 1-5). The region of a sharp decline with decreasing $T$ shifts with an activation energy $E_t = 0.1$ eV to higher temperatures with decreasing $t_1$ and $t_2$.

Sometimes the resulting signal at $T = 80$ K can become negative. The negative relaxation of $\Delta U$ can be associated with the processes of charge exchange upon injection of electrons from the metal electrode into the oxide or with charge transfer inside the oxide. The low activation energy of the negative component in $\Delta U$ suggests that a more probable mechanism of electron transfer inside the oxide is the hopping conduction along the radiation volume state (VS).

Before annealing a noticeable part of VS from the $\Delta U$ relaxation at 80 K, it is impossible to determine the total density of surface state (SS) with $E_t = 0.09$ eV. It was found that the dependence $N_{SS}$ ($T_{ann}$) calculated from CC-DLTS measurements is non-monotonic, since negative and positive recharges partially compensate each other.

The most thermally stable was the characteristic radiation defect (RD) with the density $N_t$, which creates a peak in the CC-DLTS spectra near 270 K. This characteristic defect, as shown above, is interpreted by the free Si bond distributed in the transition layer between Si and SiO$_2$. Annealing of this defect only begins at $T_{ann} > 100$ °C, and the restoration of the original density occurs at 100°C, $T_{ann} > 400$ °C. Note that this characteristic defect also exists without irradiation, but its density is very low and the corresponding peak in the CC-DLTS spectra is found only in samples with a very low density of other PSs.

The bulk states of the dielectric are almost completely annealed out similarly to the built-in charge at $T_{ann} = 250$ °C. In this case, it is assumed that 3.5 nm is the average distance for electron tunneling junctions [4] during a slow measurement of CV characteristics (at 290 K) with a voltage change rate on the MIS structure of $\approx 5$ mV/s. The BC concentration calculated from CV characteristics includes not only fast SSs, but also slowly recharging bulk states of the dielectric.

Thus, our studies have shown that the values of $N_{ss}$, $N_t$, and $N_{ti}$ are higher when the structures are irradiated at a positive displacement $V_{cm}$. Comparison of the kinetics of annealing of samples irradiated at $+V_{cm}$ and $-V_{cm}$ shows that an additional part of deep levels formed in the structures at $+V_{cm}$ is annealed already at lower temperatures ($T_{ann} = 200$°C) and the kinetics of further annealing of defects does not depend on the polarity of $V_{cm}$ at irradiation (Fig. 1).
Fig. 1. Spectra of the SS-DLTS MIS structure irradiated at $V_{cm} = +10$ V after annealing at different temperatures $T_{ann}$ °C: 1 - 25, 2 - 80, 3 - 180, 4 - 200, 5 - 250

In addition to breaking hydrogen bonds by electron impact, during irradiation at $V_{cm}$, additional defects may also form due to the capture of holes or due to chemical reactions of hydrogen released in the bulk of SiO$_2$ and diffused to the Si surface. A high sensitivity of SSs formed by the latter mechanisms to heat treatment at $T_{ann} = 150$ °C was also observed in [1] upon irradiation of structures with electrons with an energy of 25 keV.

References