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The Effect of Ultrasound on the Parameters of Metal–Dielectric–Semiconductor Structures

P. B. Parchinskiĭ, S. I. Vlasov, R. A. Muminov, Kh. Kh. Ismailov, and U. T. Turgunov

Tashkent State University, Tashkent, Uzbekistan

Starodubtsev Physicotechnical Institute, Academy of Sciences of Uzbekistan, Tashkent, Uzbekistan

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Abstract—Data on the effect of ultrasound on the metal–oxide–semiconductor structures preliminary irradiated by γ-quanta are presented. It is demonstrated that the ultrasonic action results in a decrease of the radiation-induced charge in the dielectric layer of the structures under study. The observed effects are explained using a mechanism of the ultrasound-stimulated diffusion of radiation defects in the field of elastic stresses in the layer of silicon dioxide. © *2000 MAIK "Nauka/Interperiodica".*

It is known that the action of the radiation on the semiconductor devices results in the formation of various bulk defects and degradation of their electrophysical parameters [1]. Recent discovery of the positive influence of the ultrasonic processing on the defect structure of semiconductor materials [2, 3] explains the interest in the studies of the effect of ultrasound on the semiconductor devices and structures that experienced the action of ionizing radiation. In this work, we report on the effect of ultrasonic processing on the metal–oxide–semiconductor (MOS) structures preliminary irradiated by γ-quanta.

MOS structures were produced by means of the thermal oxidation of silicon with the specific resistance $\rho_0 = 0.2–0.5\ \Omega$ cm and the crystallographic orientation (100). Oxidation was performed in the atmosphere of dry oxygen at $T = 900°C$ during one hour with subsequent slow cooling (10°C/min). A control electrode with the area $S = 4 \times 10^{-2}$ cm^2 and the ohmic contact were formed by the vacuum deposition of aluminum. The samples were irradiated by γ-quanta from a Co^{60} source to a dose of 10^6 rad and then treated for 30 min with ultrasound at a frequency of 1 MHz and a power of 1 W/cm^2.

It is commonly accepted that the process of charge accumulation in the dielectric and increase in the density of surface states (SS) at the $Si–SiO_2$ interface are factors producing the main influence on the parameters of MOS structures irradiated to closes below 10^7 rad [4]. We used the method of high-frequency capacitance–voltage (*C*–*V*) characteristics [5] to determine the charge in the dielectric and the SS charge at the $Si–SiO_2$ interface. Figure 1 shows the experimental *C*–*V* curves of the MOS structures studied. It is seen that the ultrasonic treatment shifts the *C*–*V* curves of the irradiated structures along the voltage axis toward the parameters of the initial structures and changes the slope of the curves. According to [5, 6] this indicates a decrease both in the charge built in the dielectric layer and the SS charge. Figure 2 demonstrates a change of the integral SS charge (Q_s) along the band gap ($E_c - E$) of silicon. It is seen that the ultrasonic processing of the irradiated structures results in the decrease of Q_s down to 1.5–2 × 10^{-8} C/cm^2 at $E_c - E = 0.7$ eV. At the same time, the

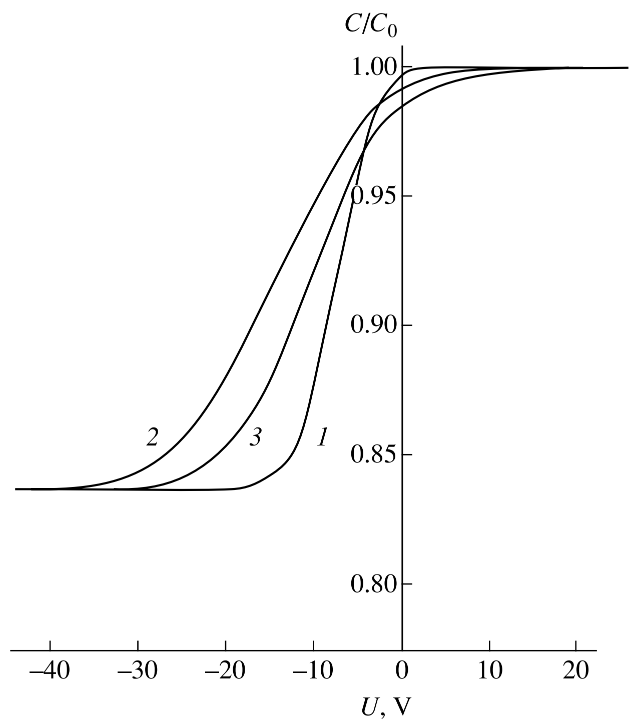

Fig. 1. Experimental capacitance–voltage (*C*–*V*) curves of the MOS structures: (*1*) initial structure, (*2*) the result of γ-irradiation; (*3*) the result of the ultrasonic action on the irradiated structure.

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ultrasonic treatment decreases the value of the effective charge inside the dielectric Q_{ef} (determined from the shift of the *C–V* curves in the same energy interval [5, 7]) by 3.5–4 × 10^{-8} C/cm^2.

It is known that high-intensity electric fields appear inside a dielectric in the course of the *C–V* measurements. In the structures under study, the electric field intensity in the dielectric layer was $E_d = 10^5$ V/cm. Such fields can stimulate the process of self-annealing of the radiation defects and relaxation of the radiation-induced charge in the dielectric layer [8]. However, control measurements of the irradiated structures not treated by ultrasound demonstrated the absence of the distinct changes of Q_{ef} and Q_s. Hence, it can be concluded that the observed changes are caused by the ultrasonic treatment, rather than by the self-annealing of the radiation defects in the course of *C–V* measurements. At the same time, it was demonstrated that the ultrasonic processing of the initial (unirradiated) MOS structures does not lead to changes in the *C–V* curves and does not influence the process of accumulation of the radiation-induced charge in the dielectric layer. Therefore, the energy of the ultrasonic oscillations transferred to the MOS structures is lower than the threshold energy of the defect formation in SiO_2 and in the transition layer near the Si–SiO_2 interface.

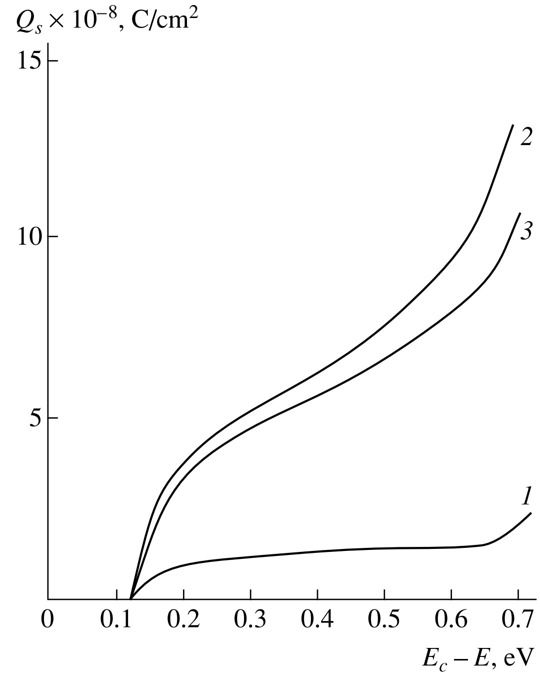

Fig. 2. The distribution of the integral charge of the surface states over the band gap of silicon in the MOS structures: (*1*) initial structure; (*2*) the result of γ-irradiation; (*3*) the result of the ultrasonic action on the irradiated structure.

These results can be explained as follows. It is known that the ionization effects play the main role in the formation of defects at the Si–SiO_2 interface and in the bulk of silicon dioxide under the action of γ-radiation [9]. In this case, two processes take place: the formation of the new charged defects and charging of the existing trap centers. Radiation defects in SiO_2 can be stable or unstable. In the former case, the positions of defects inside the glass structure are determined by the absolute minimum of the free energy. In the latter case, these positions correspond to a local minimum of the free energy [9]. It is known that there are internal compressive stresses in the transition layer near the Si–SiO_2 interface, which become weaker in the bulk of the dielectric layer [4, 8]. The ultrasonic action can stimulate diffusion of the unstable defects inside the glass structure with their further localization in the positions with an absolute minima of the free energy [10]. The gradient of the internal stresses causes a diffusion of the defects from the interface into the depth of the dielectric. The quantity Q_{ef} that causes shifts of the *C–V* curves along the voltage axis is given by the formula

$$Q_{ef} = d^{-1}\int_0^d (\rho(x)x)dx, \qquad (1)$$

where d is the thickness of the dielectric layer, $\rho(x)$ is the space charge distribution function inside the dielectric layer, ($x = 0$ at the metal–SiO_2 interface) [7]. Removal of the charged defects from the interface results in a shift of the maximum of $\rho(x)$ deeper inside the dielectric and a decrease of Q_{ef}. In addition, the removal of a part of defects from the interface makes impossible their recharging by electrons from bulk silicon, which results in the observed decrease of Q_s. Note also that the drift of defects can be accompanied by the process of their annihilation at the internal sinks and rearrangement of their energy levels [8], which can be followed by the liberation of the localized charge (this factor also leads to the decrease of Q_{ef}).

Therefore, the decrease of the radiation-induced charge observed in the dielectric layer of the MOS structures after ultasonic processing can be determined by the process of the ultrasound-stimulated diffusion of unstable radiation defects in field of elastic stresses in SiO_2 structure. The processes that take place in this case provide a partial recovery of the electrophysical parameters of the γ-irradiated MOS structures.

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