Mechanism of radiation-stimulated displacement of *n-p-* junction in memory devices

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Low-temperature radiation-stimulated diffusion (RSD) in solids has been studied for a long time [1]. These processes have a special importance for the operation of electronic devices in conditions of radiation effects.

Elements B and P are dominating doping elements in silicon electronics. The electronic structure of these doping atoms and silicon are close and this determines their arrangement in Si lattice. B and P are located in the center of Si tetrahedron. In the ionized state P forms with surrounding Si atoms usual two-electron bonds similar to Si-Si bonds. P impurities create shallow traps in the forbidden gap of silicon, and the third sp electron is located at large distance from P atom (~100 Å). Its influence on P-Si bonds is small. Proceeding from these considerations one can write the potential of P-Si bonds using the potential for Si-Si (U_{Si-Si}) bond with some correcting terms. The correcting terms account the difference between nuclear charges of Si and P (ΔU_1) and the screening action of the third sp electron (ΔU_2). Thus the expression for the P-Si bond potential can be written as:

$$U = U_{Si-Si} + \Delta U_1 + \Delta U_2 . \qquad (1)$$

The potential for Si-Si bond is known and used in many works [1]. The correcting terms can be calculated using the stationary perturbation theory:

$$\Delta U_1 = \int \psi^* H^{'} \psi d\tau . \qquad (2)$$

In (2) *H'* is a perturbation operator, ψ is the hybrid wave functions for Si-Si bonds. The perturbation operator *H'* is:

$$H^{'} = \frac{\Delta Z Z^*}{r} . \qquad (3)$$

Here ΔZ accounts the difference between nuclear charges of P and Si. Z^* is an effective charge of Si atom. $\Delta U_1 \gg \Delta U_2$.

Calculations showed that P-Si potential provides a displacement of nearest Si atoms to interstitial sites with low activation energy. This leads to formation of E-center: P+V, which determines the mechanism of P diffusion in silicon [1].

In the region of space charges of *n-p* junction P atoms are ionized. The field of *n-p* junction stimulates their slow diffusion and consequently the natural ageing of device.

In conditions of γ – irradiation the ionization of deep electronic shells of P atoms leads to multiple charging of P atoms due to Auger transitions. In its turn additional vacancies are formed and the diffusion coefficient increases. Fig. 1 illustrates this qualitative mechanism of the radiation-induced displacement of *n-p* junction. In Fig. 1 the black line shows a concentration of B atoms. The blue curve shows the distribution of P atoms before (down) and after (up) irradiation. As a result of γ – irradiation gradient of P atoms distribution decreases due to RSD of P atoms in the region of *n-p* junction. As a result of this redistribution of P atoms the *n-p* junction shifts from position 1 to position 2.

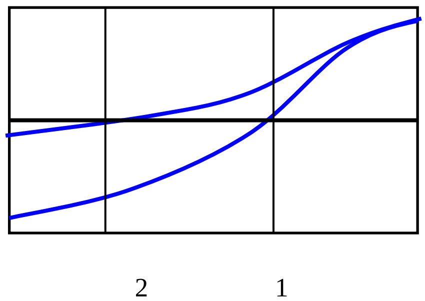

FIGURE 1 Explanation in text

The main effect in memory devices in conditions of γ – radiation is a radiation-stimulated redistribution of doping impurities in the region of *n-p* junction. This effect leads to the lost of rectifying properties of *n –p* junctions. It is clear that a shift of *n –p* junctions causes a shrink of channel length in memory transistor. It is also clear that the spreading of *n –p* junctions leads to a weak programming ability of memory device.

References

[1] Vavilov V S, Kiv A E, Niyazova O R 1981 *Mechanisms of defects formation and migration in semiconductors* Nauka, Moscow *(in Russian)*