THE MODELING OF THE TWO-DIMENSIONAL POTENTIAL IN THE CHARGE-COUPLED DEVICE -STRUCTURES

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The modeling of charge –coupled device (CCD)-structures in the approximation of the electrostatic potential, allowing to optimize their parameters and to reduce terms of the device projection on their base, has been carried out.

By projecting a topology it is possible to achieve functional peculiarities of CCD elements: for example, narrowing of the transfer channel by the stop-region increases the sensibility, and the complicated configuration of the shutter allows to increase the drift field [1].

Therefore, it is expedient to use the modeling for the projection of CCD-structures, which allows to optimize their parameters and to shorten terms of the device mocking up [2]. So, in the matrix photosensitive CCD (PCCD) with the element number ~10^6 the choice of alloying parameters and the structure topology provide the storage and the directed charge transfer only at the expense of two-dimensional effects [3]. The use of the quick thermal treatment for gettering of PCCD [4] allowed to increase the efficiency of the signal transfer.

The volume character of current processes causes the necessity of the corresponding modeling [5]. In spite of the fact, that CCD are devices of a dynamic type, higher values of the accumulation time in comparison with the transfer time and thermogeneration of the parasitic charge allow to use for CCD-structure modeling the Poisson and Laplace equations for the electrostatic potential provided, that the currents through p-n junctions are zero [6]. The modification of this two-dimensional model presented below takes into account the specific peculiarities of CCD-structures and allows to carry out the analysis of the potential diagrams and charge capacities of devices with complicated topologies.

The potential distribution on each work step of the CCD may be assumed as quasi-static and described by Poisson equation with standard boundary conditions [7].

The main task is the algorithm choice for the equation solution with the regard of CCD specification. The reference analysis shows, that in modern CCD, characterized by complicated impurity profiles, for the calculation of charge capacities it is necessary to consider the mobile charge carriers [8]. By this it is considered, that in the quasi-static regime of work the current in CCD-cell is absent, what allows to choose the values of quasi- Fermi levels φ_n and φ_p locally-constant. The change of the quasi- Fermi level from one constant value to another under the condition of zero current is possible in those structures regions, where concentrations of the mobile charge carrier are close to zero [9].

The depletion layers of *p-n* junctions are such regions. Therefore, region boundaries in which the constant values of quasi- Fermi levels are localized, must penetrate the depletion layers.

The depletion voltage has been determined from the relationship:

$$V_d = \varphi_d + V_c , \qquad (1)$$

where φ_d is the potential of the channel depletion, V_c is the contact potential between the ohmic-contact and a channel.

The depletion potential φ_d has been determined from the two-dimensional potential distribution in the structure by application of the voltage channel to the *p-n* junction, which is more, than the depletion voltage, but V_c value has been calculated from the potential distribution in the potential well filling:

$$Vc = \varphi_{max} - V_\alpha , \qquad (2)$$

where φ_{max} is the maximum potential in the channel at the presence of the charge, V_α is the voltage, applied to the channel at the filled well.

One of the main characteristics of CCD potential diagram is a value of potential barrier between potential wells, which gives the information about the charge transfer.

The calculation of potential barriers has been carried out on the base of the hydraulic model, according to which filling of potential wells by charge occurs analogously to the capacities filling by the fluid. The algorithm of the barrier search is as follows. The local potential maxims, which are the bottoms of the potential wells have been determined in the modeling region W. The well filling begins with the deepest one, having the maximum potential, then the next wells are consequently filled. The values of φ_k potential, at which the wells regions W_i and W_j, filled up to this level, will close up, will be the point potential of the minimal potential barrier φ_{ij} between them. The potential barriers for the junction from the potential well W_i to the well W_j have been obtained by subtraction of φ_k value from maximal potentials of wells $\varphi_{max\,i}$ and $\varphi_{max\,j}$ and vice versa.

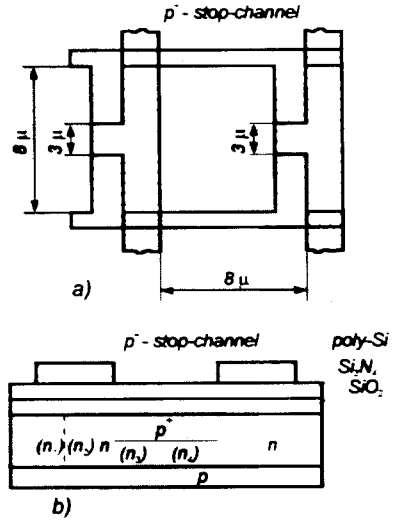

Fig.1. The topology (a) and the structure (b) of the CCD-cell with the virtual phase.

The described mathematical model and the calculation algorithm of electric characteristics are the further development of the BRK2D program, outlined in [10].

The topology of the CCD-cell is presented on fig. 1.a, peculiarity of which is the creation of the potential controllable barrier n_2 between the region of the controllable well n_1 and regions of the "virtual" well n_3 and the "virtual" barrier n_4 (fig.1.b).

For the analysis of the potential diagram of such structure at the charge transfer along the channel the algorithm of the potential reduction law in the narrow channel region by means of the shutter splitting into 2 parts has been worked out. The shutter, lying above the region of the "controllable" potential well n_1, will have the given voltage V_g, but to the shutter part, lying above the region of the "controllable" barrier n_2, will be applied some effective shutter voltage V_g^*, which is less than the real shutter voltage for the potential reduction in the channel (fig.2).

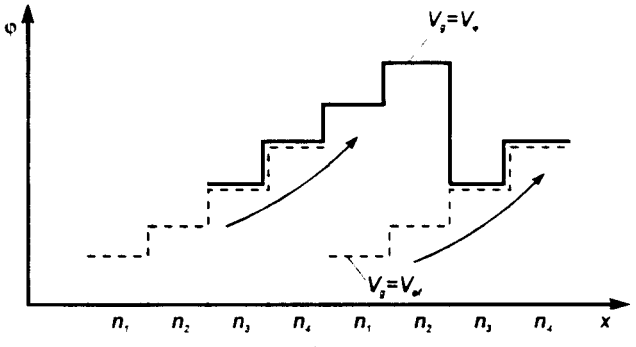

Fig.2. The potential diagram of the CCD-cell.

The algorithm of the automatic projection of the impurity profile consists of six main stages, on each of which the dose of the channel region alloying or one of the phase voltage is determined.

The voltage V_1 and alloying dose of the "controllable" well D_{n1} provided, that the surface potential barrier conservation are determined on the first stage, and dependences of the charge capacity on the voltage on the phase electrode are also calculated. On the second stage the effective shutter voltage V_g^* is determined . The phase voltage and alloying dose of D_{n2} barrier provided, that barrier retention between the filled "controllable" well and "virtual" well (near 0.5V) and the weak inversion on the interface Si-SiO_2 is determined on the third stage. The alloying dose of the virtual shutter D_p is chosen on the forth stage, and the alloying dose of the virtual barrier D_{n4} on the condition, that the barrier retention between the "controllable" and "virtual" wells are chosen on the fifth stage. The alloying dose of the "virtual" well D_{n3} at the condition of the charge transfer in the region of the "controllable" well through the "virtual" barrier is chosen on the sixth stage.

The final check of the choice correctness of the given dose is realized by the criteria of the breakdown absence in the p-n junction of the "virtual" shutter-channel and the approximate equality of the charge capacities of the "virtual" and "controllable" regions.

If the last two conditions are not fulfilled, then it is necessary to reduce the alloying dose of the "virtual" well region.

The similar algorithm of the projection was applied earlier for the optimization of the photodiode CCD-element [11].

The distribution profiles of the mobile charge for different time intervals, calculated for the structure with the shutter length L=4 mcm, with concentration of the alloyed impurity in the substrate N_D= 10^{15}cm^{-3}, with the oxide thickness d=0.2 mcm, with the gap width between shutters 200 nm, has been shown on fig.3. It is seen, that the drift fields determine the process of the charge transfer after 800 ps, and the influence of self-inducted drift becomes negligibly small.

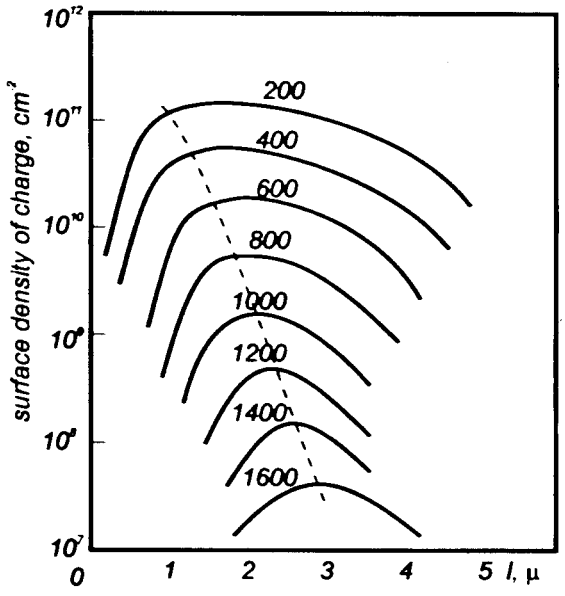

Fig.3. Profiles of the charge distribution under the transfer electrode for different time moments (ps)

The charge profile moves to the right with the time increase, i.e to the accumulation side, however instead of the constant shift after 1400ps the form of the charge distribution stabilizes.

The reason of this is in the large drift fields, accelerated by the carriers near boundaries between the transfer electrode and the accrual electrode.

Hence, on the initial stage of the charge transfer the self-inducted drift may be the main reason of the carriers motion at the large charge densities, however during 1ns the influence of the thermal diffusion and drift fields will determine the final part of the charge transfer process.

Consequently, if even 99% of the charge may be carried by the influence of the self-inducted drift, the thermal diffusion and the drift field, which at the absence of carriers capture may provide the indicated efficiency of the transfer for some nanoseconds, play the important part for the achievement of the transfer efficiency 99.99% (i.e. the transfer inefficiency $\varepsilon=10^{-4}$). In the absence of drift fields the final stage of the transfer process is determined by the thermal diffusion and characteristic times increase to some hundreds of nanoseconds.

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YƏC-STRUKTURLARDA İKİÖLÇÜLÜ POTENSİALLARIN MODELLƏŞDİRİLMƏSİ

Elektrostatik potensiallar yaxınlaşmasında YƏC-strukturların modelləşdirilməsi aparılmışdır, bu da ki, onların parametrlərini optimallaşdırmağa və onlar əsasında cihazların layihələndirmə müddətlərini azaltmağa imkan verir.

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МОДЕЛИРОВАНИЕ ДВУМЕРНОГО ПОТЕНЦИАЛА В ПЗС-СТРУКТУРАХ

Проведено моделирование ПЗС-структур в приближении электростатического потенциала, позволяющее оптимизировать их параметры и сократить сроки проектирования приборов на их основе.

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