UDC 537.226.8

ABOUT THE POSSIBILITY OF THE ESTIMATION OF SUPERFICIAL POTENTIAL OF SEMICONDUCTOR FILMS FROM THICKNESS DEPENDENCE OF KINETIC FACTORS

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In work the expressions describing dependences of kinetic factors of carriers of a charge from a thickness of semiconductor films at certain values of superficial potential are received. The estimation of a value of superficial electrostatic potential in films p-Ge on the basis of experimental data on research of thick dependences of kinetic factors is resulted. Satisfactory conformity of values of the superficial potential received by a calculating way and from experimental data is established.

Keywords: semiconductor films, superficial potential, kinetic factors, films p-Ge.

Superficial electronic processes serve as basis of functioning of many semiconducting electronics products, including the superlarge integrated schemes (SLIS) on the basis of structures metal-dielectric-semiconductor (MDS), devices with a charge connection (DCC), integrated sensor devices etc.

Integrated schemes (IS) take an important place among electronics products. The main direction of their development is the increase in degree of integration, informational capacity and speed.

The increase in degree of integration IS is connected with reduction of the sizes of their elements. It leads to that fact that electronic processes (taking place in superficial layer of semiconductor) start to play a leading role, as this layer can have the thickness, comparable with the sizes of elements IS. Besides, as the physical and chemical processes occurring on a surface of semiconductors, render a great influence on their volume properties, hence electric parameters of semiconducting devices and elements of integrated microcircuits can be defined by conditions in which there is a semiconductor surface [1,2].

Thus, studying the electronic processes taking place on a surface of semiconductors is an important and actual problem.

Filling in the superficial conditions of the semiconductor with carriers creates a superficial charge, and in area about a surface there is a volume charge of an opposite sign [3-5]. So oversuperficial layers are formed which are enriched or have been impoverished by carriers of a charge, and between "surface" and "volume" there is a potential difference - superficial potential, its size defines change of equilibrium concentration of carriers on a surface in comparison with volume. Near to a surface carriers test additional (in comparison with volume) dispersion characterized by superficial mobility of carriers of a current.

On a surface of epitaxial layers next to a substrate, there is always a superficial layer enriched with carriers with the thickness $d < 2mkm$.

The superficial layer with the raised conductivity can arise for the various reasons. For example, it can be formed at the expense of a superficial charge on border a film-substrate or because of dissimilar distribution of dashes between a substrate and a film. Anyway the superficial layer with the raised conductivity can essentially influence the physical processes occurring in a film and on functioning of devices, created on the basis of these films [3,5,6,7[.

Let in considered films in all interval of temperatures the diffusive length of carriers of charge L_D and length of free run on an impulse l_u will be much less than the thickness of a film d, i.e. inequality L_D, $l_u << d$ will be carried out. In this case, for the analysis of the thickness dependence of kinetic characteristics of semiconductor films it is possible to apply the results received by R.L. Petritz [8] for two-layer model of the sample.

Effective superficial mobility and concentration of carriers of a charge are defined as follows:

$$\langle \mu_S \rangle = \langle \mu_{об} \rangle + \left[\Delta \langle \mu \rangle \right]_{ср},$$
$$\langle \mu_S^2 \rangle = \langle \mu_{об}^2 \rangle + \left[\Delta \langle \mu^2 \rangle \right]_{ср}, \qquad (1)$$
$$p_S = p_{об} + \Delta p_S,$$

where $\left[\Delta \langle \mu \rangle \right]_{ср} = \frac{1}{d_S} \int_0^{d_S} \Delta \langle \mu(z) \rangle dz,\quad \left[\Delta \langle \mu^2 \rangle \right]_{ср} = \frac{1}{d_S} \int_0^{d_S} \Delta \langle \mu^2(z) \rangle dz,\quad \Delta p_S = \int_0^{d_S} \Delta \langle \mu^2(z) \rangle dz$

Here the symbol $\langle\ \rangle$ – means averaging in pulse space, and a symbol $[\ ]$ – averaging in coordinate space. Signs «об», «s», «т», «л» mean an reference of those or other sizes, accordingly, to volume and superficial layers, heavy and light holes.

Having neglected so called correlation mobility we have:

$$\sigma = \frac{\sigma_{об}}{1 + \nu в} \cdot \alpha_1, \qquad (2)$$

$$R = R_{об} \cdot \frac{(1 + \nu в)^2}{1 + \nu в_1^2} \cdot \frac{\gamma}{\alpha_1^2}, \qquad (3)$$

$$\mu = \mu_{об} \cdot \frac{1 + \nu в}{1 + \nu в_1^2} \cdot \frac{\gamma}{\alpha_1}, \qquad (4)$$

where, $\alpha_1 = (1 + \nu в) + \frac{d_S}{d} \cdot \frac{\Delta p_S}{p_{об}} \cdot (\beta_T + \nu b \beta_л) - \frac{d_S}{d} \cdot \left[(1 - \beta_T) + \nu b (1 - \beta_л) \right]$,

$$\gamma = (1 + \nu b_1^2) + \frac{d_S}{d} \cdot \frac{\Delta p_S}{p_{об}} (\beta_{T1}^2 + \nu b_1^2 \beta_{л1}^2) - \frac{d_S}{d} \left[(1 - \beta_{T1}^2) + \nu b_1^2 (1 - \beta_{1л}^2) \right],$$

$$R_{об} = \frac{1}{p_{об}} \cdot \frac{\langle \mu_{T.об}^2 \rangle}{\langle \mu_{T.об} \rangle^2} \cdot \frac{1 + \nu b_1^2}{(1 + \nu b)^2}, \quad \mu_{об.} = \frac{\langle \mu_{T.об}^2 \rangle}{\langle \mu_{T.об} \rangle^2} \cdot \frac{1 + \nu b_1^2}{(1 + \nu b)^2}.$$

It is known [2, 3], while replacing the expressions

$$\frac{\langle \mu_{лs}^2 \rangle}{\langle \mu_{л.об}^2 \rangle}, \frac{\langle \mu_{лs}^3 \rangle}{\langle \mu_{л.об}^3 \rangle}, \frac{\langle \mu_{T.S}^2 \rangle}{\langle \mu_{T.об}^2 \rangle}, \frac{\langle \mu_{T.S}^3 \rangle}{\langle \mu_{T.об.}^3 \rangle}$$

for expressions, correspondingly

$$\frac{\langle \mu_{лs} \rangle^2}{\langle \mu_{л.об.} \rangle^2}, \frac{\langle \mu_{лs} \rangle^3}{\langle \mu_{л.об.} \rangle^3}, \frac{\langle \mu_{T.S} \rangle^2}{\langle \mu_{T.об.} \rangle^2}, \frac{\langle \mu_{T.S} \rangle^3}{\langle \mu_{T.об.} \rangle^3}$$

there is an error about 10%.

Supposing the performance of correlations

$$b^2 = \frac{\langle \mu_л \rangle^2}{\langle \mu_T \rangle^2} = \frac{\langle \mu_л^2 \rangle}{\langle \mu_T^2 \rangle} = b_1^2 \quad \text{and} \quad \beta_T = \frac{\langle \mu_{T.S} \rangle}{\langle \mu_{T.об} \rangle} = \frac{\langle \mu_{л.s} \rangle}{\langle \mu_{T.об} \rangle} = \beta_л = \beta$$

we receive:

$$\frac{\sigma}{\sigma_{об.}} = 1 + \frac{d_s}{d} \left(\frac{p_s}{p_{об.}} \beta - 1 \right), \qquad (5)$$

$$\frac{R}{R_{об}} = \frac{1 + \frac{d_s}{d}\left(\beta^2 \cdot \frac{p_s}{p_{об.}} - 1\right)}{\left[1 + \frac{d_s}{d}\left(\beta \cdot \frac{p_s}{p_{об}} - 1\right)\right]^2}, \tag{6}$$

$$\frac{\mu}{\mu_{об}} = \frac{1 + \frac{d_s}{d}\left(\beta^2 \cdot \frac{p_s}{p_{об}} - 1\right)}{1 + \frac{d_s}{d}\left(\beta \cdot \frac{p_s}{p} - 1\right)}, \tag{7}$$

where, $\sigma_{об.} = ep_{Т.об}\left\langle \mu_{Т.об} \right\rangle + ep_{л.об}\left\langle \mu_{л.об} \right\rangle$, $R_{об} = \frac{1}{p_{Т.об}} \cdot \frac{\left\langle \mu^2_{Т.об} \right\rangle}{\left\langle \mu_{Т.об} \right\rangle^2} \cdot \frac{1+\nu b^2}{(1+\nu b)^2}$, $\mu_{об} = \frac{\left\langle \mu^2_{Т.об} \right\rangle}{\left\langle \mu_{Т.об} \right\rangle} \cdot \frac{1+\nu b^2}{1+\nu b}$,

$p_s = p_{об} + \Delta p_s$, $d = d_{об} + d_s$, $\beta_T = \frac{\left\langle \mu_{TS} \right\rangle}{\left\langle \mu_{Т.об} \right\rangle}$, $\beta_л = \frac{\left\langle \mu_{лs} \right\rangle}{\left\langle \mu_{л.об} \right\rangle}$, $\left\langle \mu^2_{об} \right\rangle = \frac{1}{1+\nu} \cdot \left(\left\langle \mu^2_{Т.об} \right\rangle + \nu \left\langle \mu^2_{л.об} \right\rangle\right)$,

$b_1^2 = \frac{\left\langle \mu^2_{л.об} \right\rangle}{\left\langle \mu^2_{Т.об} \right\rangle}$, $\beta^2_{T1} = \frac{\left\langle \mu^2_{T.S} \right\rangle}{\left\langle \mu^2_{Т.об} \right\rangle}$, $\beta^2_{л1} = \frac{\left\langle \mu^2_{лs} \right\rangle}{\left\langle \mu^2_{л.об} \right\rangle}$.

(The equality $\beta = \beta_л = \beta_T$ corresponds to the assumption that the film surface equally cooperates with heavy and light holes)

Analyzing the received correlations, it is possible to draw following conclusions:

- thickness dependences of kinetic factors of films with two-layer structure are defined not only by the parameter $\frac{d_s}{d}$, but also with the parameters $\frac{p_s}{p_{об}}$, β_T, $\beta_л$, $\left\langle \mu^2_{об} \right\rangle$, b_1^2, β^2_{T1}, $\beta^2_{л1}$;
- investigating the thickness dependences of kinetic factors it is possible to estimate superficial potential if the obvious kind of dependence of the parameter $\beta = \frac{\left\langle \mu_s \right\rangle}{\left\langle \mu_{об} \right\rangle}$ from superficial potential $Y_S = \frac{eU_S}{k_0 T}$ is known.

For definition of an obvious kind of dependence of parameter $\beta = \frac{\mu_s}{\mu_{об}}$ (here and further for the purpose of simplification, the sign «$\langle\ \rangle$»is lowered) from the superficial potential Y_S,, the valid course of potential in the enriched layer is replaceable with a rectangular potential hole [3,4]. We will accept the height of this hole equal to superficial electrostatic potential Y_S, and we will consider its width to an equal thickness of the flat condenser which capacity is equal to average capacity of a spatial charge

$$C_{пр.} = \frac{e}{kT} \cdot \frac{\left|Q_{пр.зар.}\right|}{\left|Y_S\right|}. \tag{8}$$

For the flat condenser, $C = \frac{\chi S}{4\pi d_s}$, where S and d_s – and accordingly the area and distance of surfaces of the condenser.

Then from (8) we have:

$$d_S = \frac{\chi S}{4\pi} \cdot \frac{kT}{e} \cdot \frac{|Y_S|}{Q_{пр.зар.}} \tag{9}$$

The superficial firmness of a charge caused by surplus of holes, is equal [3,4]:

$$\frac{|Q_{пр.зар.}|}{S} = ep_i L \cdot F(Y_S, \lambda)\,, \tag{10}$$

$$F(Y_S, \lambda) = \left[\lambda \left(e^{-Y_S} - 1 \right) + \lambda^{-1} \left(e^{Y_S} - 1 \right) + \left(\lambda - \lambda^{-1} \right) Y_S \right]^{1/2}, \tag{11}$$

where

$$\lambda = \left(\frac{p_{об.}}{n_{об.}} \right)^{1/2} = \frac{p_{об.}}{p_i} = \frac{n_i}{n_{об.}}\,,\ L = \left(\frac{\chi kT}{8\pi^2 e^2 n_i} \right)^{1/2}$$

From (9), (10), (11) we will receive the following correlation:

$$d_S = \left(\frac{\chi kT}{2e^2 p_{об.}} \right) \left[\frac{e^{-Y_S} - 1}{Y_S^2} + \frac{1}{Y_S} \right]^{-1/2} \tag{12}$$

Assuming that probabilities of dispersion of carriers of a charge a surface and volume gears are independent, we have:

$$\frac{1}{\tau} = \frac{1}{\tau_s} + \frac{1}{\tau_{об.}} \tag{13}$$

Between $\tau_{об.}$ and volume length of free run on an impulse $l_{об.}$ there is the connection defined by the correlation $\tau_{об.} = {}^{l_{об.}}\!/\upsilon_z$, where υ_z – is a component of speed of thermal movement of carriers of a charge, perpendicular to a surface of the sample.

If not all impacts of carriers of a charge with a surface are accompanied by diffusion dispersion, but only their some part, then average time before collision with a surface, leading to loss of energy of carriers of a charge in the field, increases

$$\tau_s = \frac{d_s}{p' \upsilon_z} \tag{14}$$

Assuming that the average field operating on the carrier of a charge, is defined by half of size of superficial electrostatic potential, we have:

$$\upsilon_z = \sqrt{\frac{kT}{2m}} \cdot \sqrt{1 + |Y_S|}\,, \tag{15}$$

$$\tau_S = \frac{L}{\sqrt{kT/2m}} \cdot \frac{Y_S}{F(Y_S, \lambda)\sqrt{1 + |\ |}}\quad \tau_S = \frac{L}{\sqrt{kT/2m}} \cdot \frac{Y_S}{F(Y_S, \lambda)\sqrt{1 + |Y_S|}} \tag{16}$$

Finally from (13) and (16) we will receive for average time between collisions at movement of carriers of a charge along a film surface:

$$\tau = \frac{\tau_{об.}}{1 + \frac{l_{об.}}{L} F(Y_S, \lambda) \cdot \frac{\sqrt{1 + |Y_S|}}{Y_S}} \tag{17}$$

Defining superficial mobility of carriers of a charge by a correlation $\mu_S = \frac{e\tau}{m}$ we have

$$\beta = \frac{\tau_{об.}}{1 + 2p' \cdot \pi \cdot \mu_{об.} \sqrt{\frac{mp_i}{\chi}} \cdot \sqrt{\frac{1+|Y_S|}{Y_S^2}} \cdot F(Y_S, \lambda)} . \qquad (18)$$

For semiconductor $p-$type from (11) and (18) it is easy to receive:

$$\beta = \frac{\mu_s}{\mu_{об.}} = \frac{1}{1 + 2p' \cdot \pi \cdot \mu_{об.} \sqrt{\frac{mp_i}{\chi}} \cdot \left[\frac{(1+|Y_S|)(e^{-Y_S} - 1)}{Y_S^2} + \frac{1+|Y_S|}{Y_S} \right]^{1/2}} \qquad (19)$$

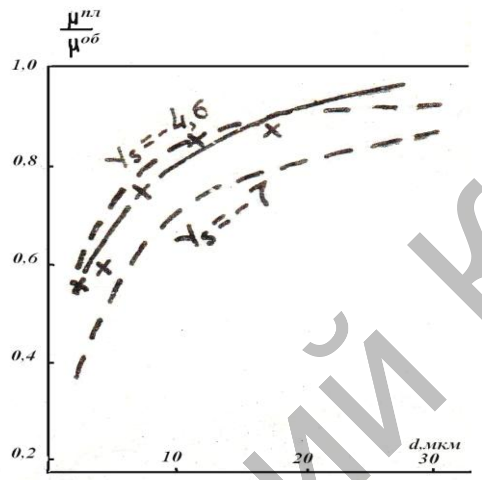

Fig.1. Dependences of relative mobility ($\mu^{пл.}/\mu^{об.}$) of charge carriers from the thickness of the film T=78^0 K. The experimental curves are represented by a continuous line, and the theoretical. ones are represented by a dotted line

Considering (12), (19), under formulas (6) and (7) it is possible to construct theoretical curves in the thickness of dependence of values $\frac{\mu}{\mu_{об.}}$ and to compare them to corresponding experimental data. In figure 1 theoretical and experimental curve dependences of relative mobility of carriers of a charge in a film p-Ge from a thickness of a film are presented, received at 78^0 K [8]. From the presented data it follows that the satisfactory consent of the experimental and the theoretical data occurs at values of the superficial potential lying in an interval $-7 < Y_S < -4,6$.

Thus, using experimental data on the research of dependence of kinetic factors from a thickness of semiconductor films, it is possible to estimate size of superficial potential.

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