EXPERIMENTAL AND THEORETICAL INVESTIGATION OF THE MECHANISM CURRENT PASSING IN PIP STRUCTURES

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Platina bilan legirlangan monokristal kremniy asosida yaratilgan pip struktura VAX turli temperatura va yoritilganlikda o`rganildi. Strukturaning energetik zonalar parametrlari aniqlandi va tok o`tish mexanizmi o`rganildi.

Kalit so'zlar: *silitsid, nanonaycha, legirlash, baryer, struktura, ionlashish.*

Изучены ВАХ pip структуры, созданные на основе кремния легированного платиной при различных температурах и освещенности. Определены параметры энергетической структуры, изучен механизм токопрохождения через неё.

Ключевые слова: *силицид, нанотрубка, легирование, барьер, структура, ионизирование.*

The article discusses volt–ampere characteristic of pip structure on the basic of diffusive silicon by platinum in various temperatures and illuminations. The parameters of zonal shart of structure were accounted and mechanism of current transmission through structure was investigated

Key words: *silicide, nanotube, doping, barrier, structure, ionization.*

From ingots monocrystal silicon p-type conductivity with a specific resistance of $\rho=10^2$–10^3 Ω·cm, and n–type conductivity with ρ=5–20 Ω·cm the diamond disk cut out samples in the form of a parallelepiped with sizes of (1÷2)×(3÷10)×(10÷12) mm^3. For the purpose of removal the impaired during grinding of the surface layer samples were degreased in toluene washed out in HF in deionized water. Further samples were exposed to chemical etching in a solution of HF: $HN0_3$: CH_3COOH–1:5:0,5 within 2 minutes, washed out in the deionized water and dried at a temperature 80°C. Proceeding from experimental data in which it is revealed formation of silicides, we got out a diffusive alloying of the put layer and of a gas phase. The diffusion of platinum from a gas phase was carried out in the quarts ampoules containing samples of silicon and twice sublimed metal platinum in vacuum.

Diffusion from the applied surface layer was carried out in the range at temperature 400-1100°C within 15-120 minutes in vacuum. After annealing the samples were quenched cooling with the speed of 125 deg/sec with the subsequent cooling in water to the temperature 4-6°C. In the process of a diffusive alloying the silicon from the gas phase platinum formed silicides of platinum (mono -, di -, the highest silicides of platinum) in the form of nanotubes and volume part of crystals of silicon became the low - impedance conductivity n-type, and also high-resistance n-or p-types of conductivity, and also high-resistance with conductivity close to own. For creation of structure silicide - semiconductor silicide on the basic of diffusive silicide and silicon, from the alloyed sample was ground by line of six parties of 50-100 microns for removal of a silicide layer. We apply metal contacts with a gap on the row side, and in these gaps were opened flutes with a diameter of 0.2 mm. Thus depth of a flute makes 100-150 microns. Metal contacts are created by pollination of aluminum or nickel at substrate temperature at 100°C. Calculation of pip structure on the basic of diffusive silicide of platinium and silicon were assumed as a basic operation of the injection photo diode and the injection and flying diode [1-3]. In the process of calculation of structure were used experimental results distribution of conductivity, concentration of carriers of current on depth of a sample [4], thickness of a silicide layer, height of a barrier to electrons and to hole φ_{be} silicide of platinium silicon [2,3,5].

The height of barrier between the highest silicide of platinium n-type of silicon makes $q\varphi_{bh}$=0.72 eV. In such structures in the area of concentration of carriers current makes 10^{20}÷$10^{21}cm^{-3}$, and on silicon area – 10^{10}÷$10^{12}cm^{-3}$. The energy diagram p–i–p structure is representated on the picture 1. Width of the area of a space charge (ASC) of structure was estimated on formulas:

$$W_1 = \sqrt{\frac{2\varepsilon S}{qN_b}(V_{bi} - V_1)}, \quad W_2 = \sqrt{\frac{2\varepsilon S}{qN_b}(V_{bi} + V_1)} \qquad (1)$$

Where W_1 and W_2 – width of ASC direct - and reverse biased barriers, N_B concentration of ionized impurity, V_1 and V_2 – the external enclosed tension direct-and reverse biased a berries, respectively, V_{bi} – contact potential difference. For calculation of W_x, V_{bi} it is necessary to know, it was defined from expression at thermodynamic balance (V=0);

$$q \cdot V_{ib} = (\Phi_c - c) = q\varphi_{bn} - E_F, \qquad (2)$$

where Φ_c and $\Phi_п$ is work function of silicide and the semiconductor, respectively, c – electron affinity of silicon, E_f –Fermi level. At known c (c=4.05eV) for silicon was determined the value of φ_c from expression:

$$\varphi_c = q\varphi_{bn} + c; \text{ where } \Phi_c = 4.77 \text{ eV}.$$

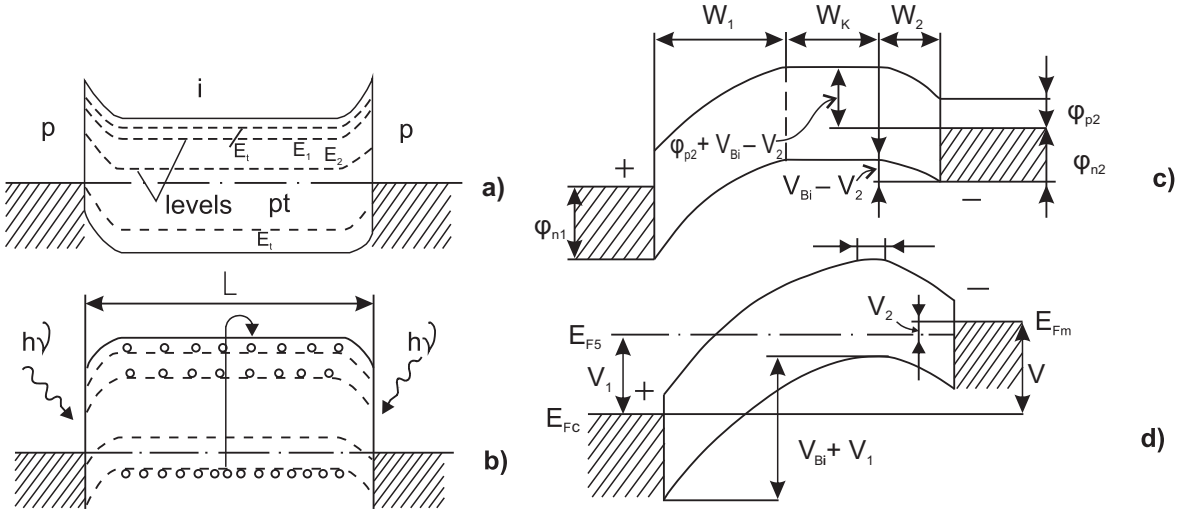
Substituting these data in (2) we will get:
$qV_{bi}=(0.23\div0.2)$eV and $E_F=E_c-(0.47\div0.49)$eV. At these values V_{bi}; $N_D=n_i=10^{11}\div10^{12}$cm^{-3}. The width SCR (space-changing region) from the equation (1) W=110–46 micrometers, respectively. Debye length of shielding:

$$l_\Delta = \left(\frac{\varepsilon\varepsilon_0\lambda T}{e^2 N_B}\right)\frac{1}{2} = 13\div4\ \mu\text{m}.$$

In order to get real structure it was estimated that the value of basic area at W_0 ¹0 and U = 0, corresponding to the above mentioned concentration. Width of the quasineutral area W_0 was defined from expression:

$$W_0 = L - (W_1 + W_2),$$

here L – length of basic area of structure. At L=1000 microns and $N_D=10^{11}$cm^{-3}, W_0 equaled 780 microns. For silicon, having different types of conductivity (n,v,i,p and ρ) at a contact with silicide the sum of height of barriers (for electrons φ_{bn} and holes for the same type of conductivity of semiconductor) must be equal width of forbidden zone, it means: at known value φ_{bn}=0.72 eV from (3) we will receive φ_{bp}=0.4 eV. As the size N_b is influenced by eternal influence, for example, the light radiation, temperature and so on, concentration of the ionized impurity can be regulated. Results of calculation of parameters of structure silicide - semiconductor - silicide (C–S–C) and silicide – the semiconductor (C–S) is given in the following table.



Pic1. ***The power chart of pip structure. a–Without the external tension of shift and lightning; b – E1, E2 – Platinium levels; Et – Level of sticking. c – at the application of external tension of shift and lighting; d – W in case of space – limited current.***

On the basic of certain parameters: N_b, E_F, W_{bi}, W_1,W_2,W_3,W_0 length of basic area, tension of shift, tension of flat zones were defined. Research volt-ampere characteristics of pip structures pip were produced at various temperatures and conditions of illumination with energy of quantum hv=0.2÷1.4eV, and also at white (integrated) light. In picture №2 the current-voltage characteristics (CVC) considered structure long base of L=1000 microns at lighting by light with hv ³ E_g (l=0.63 m) is given.

$N_b(cm^{-3})$	$1,45\cdot10^{10}$	10^{11}	10^{12}	10^{12}	10^{14}
$E_c–E_F$, eV	0,56	0,49	0,47	0,39	0,32
l_D(m)	34,5	13	4,1	1,3	0,4
V_{bi}(eV)	0,16	0,23	0,25	0,33	0,4
W_1(m) (C-S)	121	55	23	6,6	2,3
$W_1–W_2$ (m) (C-S-C)	242	110	46	13,2	4,6
W_0(m) (S-S)	879	945	977	993,41	997,7
W_0(m) (C–S–C)	758	890	954	986,8	995,4

The research showed that CVC has a site of fast increase current at increase in voltage above than under tension. This effect is explained by injection of holes through transition silicide semiconductor in completely hole depletion semiconductor layer. Changing external influence (for example, light) concentration of ionized atoms of the alloyed atom (platinum) it is possible to shift area of rapid growth of current at reduction or increase in the enclosed area under tension.

At theoretical consideration of features of passing of current model of the contact metal semiconductor (CMS) was used. For definition of distribution of a field on limit of the section it is necessary to solve Poisson's equation:

$$\frac{d^2}{dx^2}\varphi(x) = -\frac{\rho}{\varepsilon\varepsilon_0} \qquad (4)$$

The volume charge of ρ is defined by number of the motionless ionized center N_D and free electrons. Considering, that impurity total ionized, i.e. $N_D=n_0$ and the semiconductor isn't degenerated, that is submits to Boltzmann's statistics, we will receive:

$$\rho = q(N_D^+ - n) = qn_0\left(1 - e^{\frac{-q\varphi(x)}{kT}}\right) \qquad (5)$$

In the field of the blocking layer $\varphi>0$ and $\exp(\frac{-q\varphi(x)}{kT})$ quickly falls down in process of increase φ, therefore $q\varphi>>kT$. That's why $\rho=qn_0$. Therefore:

$$\frac{d^2}{dx^2}\varphi(x) = -\frac{qn_0}{\varepsilon\varepsilon_0} = -\psi \qquad (6)$$

where $\psi = \frac{qn_0}{\varepsilon\varepsilon_0}$. Solution of this equation:

$$\int d\left(\frac{d}{dx}\varphi(x)\right) = -\int\psi dx;\ \frac{d}{dx}\varphi(x) = -\psi_x + A;\ \varphi(x) = -\frac{\psi x^2}{2} + Ax + B \qquad (7)$$

Eq.(7) is a common decision of the equation (6). Boundary conditions, necessary for solving this equation are:

$$\text{at } x = L_0;\ \varphi(L_0) = 0;\ -D\varphi(L_0) = 0$$

where L_0 - width of the depletion area (the blocking layer).

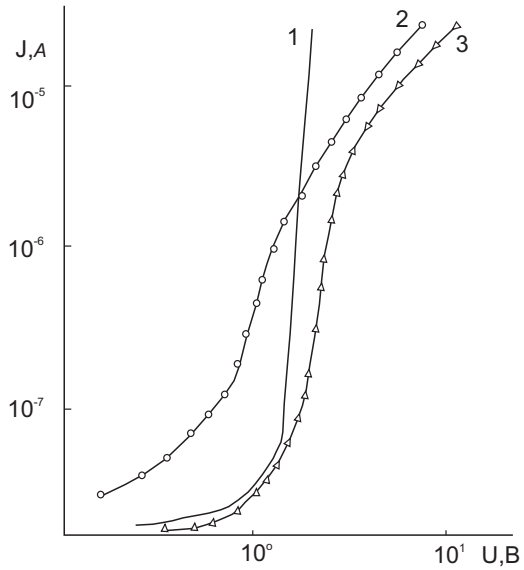
$$\varepsilon = \frac{4\phi}{4x} = \frac{qP_0}{\varepsilon\varepsilon_0}x$$

That is intensity of a field is linear function x. The field is directed in each point x along the direction x, that is to silicide.

$$\text{At } x = L; \varphi(L) - \frac{\psi L^2}{2} + Al + B = 0 \quad \frac{d}{dx}\varphi(L) = 0. \tag{8}$$

From the equation of electric field in a transitional layer we will receive:

$$\begin{cases} -\dfrac{\psi L^2}{2} + AL + B = 0 \\ -\psi L + A = 0 \end{cases} \quad B = -\frac{\psi L_0^2}{2}, \; A = \psi L_0 \tag{9}$$



Pic.2. ***Volt–ampere [current–voltage] characteristics is double logarithmic scale at T=77 K and hv≥E_g. 1–settlement; 2,3–for different polarity of the enclosed tension.***

Substituting (9) in the equation (7) we have:

$$\varphi(x) = -\frac{\psi x^2}{2} + \psi L_0 x_0 - \frac{\psi L_0^2}{2} = \frac{qp_0}{2\varepsilon\varepsilon_0}x^2 + \frac{qp_0 L_0}{\varepsilon\varepsilon_0} - \frac{qp_0}{2\varepsilon\varepsilon_0}L_0^2 = -\frac{qp_0}{2\varepsilon\varepsilon_0}(L_0 - x)^2$$

At $x = 0; \; \varphi(0) = -\frac{qp_0}{2\varepsilon\varepsilon_0}L_0^2$. And now, φ as is considered known, we find L_0:

$$L_0^2 = -\frac{2\varepsilon\varepsilon_0}{qp}; \; \varphi(0) = \frac{2\varepsilon\varepsilon_0}{qp}\varphi_k.$$

As at $x = 0, \varphi = \varphi(0) = -\varphi_k$. From here we will determine the size of width of the blocking layer:

$$L_0 = \sqrt{\frac{2\varepsilon\varepsilon_0}{qp_0}\varphi_k} \tag{10}$$

For finding of density of the current proceeding through structure, we will solve the continuity equation, with the corresponding boundary conditions:

$$L_p^2 \frac{d^2\Delta p}{dx^2} - \Delta p = 0 \tag{11}$$

We will enter designation: $X = \frac{x}{L_p}$ therefore (11) it will assume an air:

$$\frac{d^2\Delta p}{dx^2} - \Delta p = 0; \; \Delta p = p - p_n = p_n\left(\frac{p}{p_n} - 1\right) = p_{n0}\left(e^{-\frac{qV_1}{kT}} - 1\right), \tag{12}$$

ω here V_1 – the external tension, P_{n0} – equilibrium concentration of holes in the field of the semiconductor. Boundary conditions:

$$\Delta p = \begin{cases} P_{n0}\left(e^{-\frac{qU_1}{kT}} - 1\right), \ at \ \ x = 0 \\ 0, \ \ at \ \ x = \dfrac{W}{L_P} \end{cases}$$

Where w-width of neutral area; L_p – diffusive length of holes.

$$\frac{d^2\Delta p}{dx^2} - \Delta p = 0; \ \ \Delta p = e^{\lambda x}$$

$$Dp = c_1 e^{x} + c_2 e^{-x} = c_1\left(Shx + Chx\right) + c_2\left(Chx - Shx\right) =$$
$$= c_1 Shx + c_1 Chx + c_2 Chx - c_2 Shx = \left(c_1 - c_2\right) Shx + \left(c_1 + c_2\right) Chx \qquad (13)$$

(13) there is a common decision of the equation (12)

$$Dp\left(x\right) = Ash + BChx$$

$$Dp\left(0\right) = Ash\left(0\right) + BCh\left(0\right); \ \ p_{n0}\left(e^{-\frac{qU_1}{kT}} - 1\right) = A\cdot 0 + B\cdot 1; \qquad (14)$$

$$Dp\left(\frac{W}{L_p}\right) = ASh\frac{W}{L_p} + BCh\frac{W}{L_p}; \ A = -p_{n0}\left(e^{-\frac{qU_1}{kT}} - 1\right) Cth\frac{W}{L}; \qquad (15)$$

$$B = p_{n0}\left(e^{-\frac{qU_1}{kT}} - 1\right) \qquad (16)$$

We will substitute (16) in (13)

$$Dp(x) = -p_{n0}\left(e^{-\frac{qU_1}{kT}} - 1\right) Cth\frac{W}{L} Shx + p_{n0}\left(e^{-\frac{qU_1}{kT}} - 1\right) Chx$$

For differentiating on x, we will receive expression for density current:

$$\frac{d}{dx} Dp = -p_{n0}\left(e^{-\frac{qU_1}{kT}} - 1\right) Cthx\frac{W}{L} Chx + p_{n0}\left(e^{-\frac{qU_1}{kT}} - 1\right) Shx$$

$$J = \frac{qD_p}{L}\cdot\left.\frac{d\Delta p}{dx}\right|_{x=0} = \frac{qD_p p_{n0}}{L_p}\left(e^{-\frac{qU_1}{kT}} - 1\right) Cth\frac{W}{L_p} \qquad (17)$$

Using a formula (10) it is possible to copy expression (17) in a look:

$$J = \frac{qD_p}{L}\cdot\left.\frac{d\Delta p}{dx}\right|_{x=0} = \frac{qD_p p_{n0}}{L_p}\left(e^{-\frac{qU_1}{kT}} - 1\right)\times Cth\left\{\frac{L}{L_p}\left[1 - \frac{\sqrt{\dfrac{2\varepsilon\varepsilon_0}{qN}\varphi_{bi}}}{L}\left(1 + \sqrt{1 + \frac{U}{\varphi_{bi}}}\right)\right]\right\} \qquad (18)$$

On the basic of these formulas were carried out calculations VAC (volt-ampere characteristic): φ_{bi}=0.23eV, L=1000 m, T=77K. Observed sharp jump of current happens because of linkup fields in basic area. Theoretically VAC will be well coordinated with experimental curve (picture 2).

At removal VAC of pip structure at T=77K, it isn't revealed sharp increase of current to U=1000V, the size of current was from ~10^{-12} till ~10^{-9} Å. At illumination of structure light of various intensity ($hv>E_g$) found jump of current and the area of jump was displaced towards the smaller tension (from 50V to 5V). The shift of area

of the jump of current is explained by filling donor levels of atoms of the metal. There aren't jump of current, and with a connection and disconnection of a field changes. Besides, at fillings donor levels of the alloyed atom comes injections of holes from silicide area in the basic - semiconductor area of structure, therefore increases the hole component current.

CONCLUSIONS

1. Possibility of creation of pip structure on the basic of a diffusive alloying of silicon is shown by platinum. Created zonal chart of structure taking into account parameters: p_x, E_F, Φ_c, Φ_S, n, p. It is shown that contact potential difference on border makes silicide semiconductor 0.2÷0.25eV at $\Phi_c > \Phi_S$.

2. The research VAC of pip structures with various lengths of bases depending on temperature and illumination. The analysis of injection strengthening of a photo signal at direct shift is carried out and it is shown in providing strengthening of initial photocurrent at the expense of the injected carriers through transition silicide-semiconductor.

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