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THE SCREENED POTENTIAL OF THE IMPURITY IN THE SEMICONDUCTOR FILM

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The potential of charged impurity in thin semiconductor film was calculated. The film is considered to be cut out from the massive compensated semiconductor, in which the three-dimensional Debye-Huccel correlation of the impurity ions is frozen at the crystallization temperature. For the films, the thickness of which is much larger than the screening radius, the potential depends essentially on the position of the impurity ion with respect to the film's boundaries. It decreases exponentially in the middle of the film and tends to the half of its unscreened value on the film's boundaries.

The potential of the impurity ions in thin semiconductor films differes essentially from that of the massive semiconductor. This is the result of the fact that the largest part of the force lines of electrostatic field of the impurity ion inside the film is located in the environment, dielectric properties of may strongly differ from those of the film's material [1]. From the other hand, there is Debye-Huccel correlation of the impurity ions in the melted semiconductor and this correlation is frozen during the process of crystallization [2]. The screened potential of the impurity depends essentially on the method of the preparation of film. If the film is prepared by the vacuum evaporation method with the thermal treatment, then correlation between the impurity ions and therefore there screening is formed by the potential, which differs from the Coulomb potential in the massive sample. In this case the screened potential of the impurity has formally the same form as the potential in film, screened by the free electrons [3]. The difference is that the Debye-Huccel radius in this case is determined by the impurity ion's concentration and the thermal treatment temperature. But if the film is prepared from the layered semiconductor by cutting out method, then the correlation between impurity ions is the same as in the massive sample, frozen during the process of its thermal treatment. The potential of impurity ion in this case must be found as a solution of Poisson equation inside the film. Right part of this equation must contain the charge density of ion in the form of δ-function and additional charge density, which appeares near this ion because of frozen correlation of the impurity ions.

We consider the compensated semiconductor, in which the average concentrations of positive and negative ions are $\overline{n}_+ = \overline{n}_- = n$.

The screened potential of ion with the charge e in the environment with the dielectric constant ε is

$$\varphi(R) = \frac{e}{\varepsilon R} e^{-æR} \tag{1}$$

where the inverse radius of screening æ is determined by expression

$$æ = \sqrt{\frac{8\pi e^2 n}{\varepsilon kT}} \tag{2}$$

The temperature T in (2) is the temperature of crystallization at which the correlation between the positive and negative impurity ions is frozen.

During the screening of the ion's field the additional charge density appeares near this ion. It may be easely found acting by Laplace operator on the potential (1):

$$\delta\rho(R) = -\frac{1}{4\pi}\Delta\varphi(R) = -\frac{æ^2 e}{4\pi\varepsilon}\cdot\frac{e^{-æR}}{R} \tag{3}$$

Let now solve Poisson equation for the potential inside the film with the additional charge density (3). The Poisson equation for the Fourier-component of the potential may by written in the form:

$$\frac{d^2\varphi_{\vec{k}}(z,z')}{dz^2} - k^2\varphi_{\vec{k}}(z,z') = -4\pi\left[\frac{e}{\varepsilon}\delta(z-z') + \delta\rho_{\vec{k}}(z-z')\right] \tag{4}$$

Here

$$\varphi_{\vec{k}}(z,z') = \int \varphi(\vec{r},z,z') e^{-i\vec{k}\vec{r}} d^2 r \quad , \tag{5}$$

$\vec{k}$ and $\vec{r}$ are two-dimensional vectors on the film's plane, z - axis is perpendicular to the film's boundaries and the beginning of z - coordinates is chosen to be in the centre of the film. The charge e is located on the z-axis in the point z'.

The Fourier-component of the density is determined as (5):

$$\delta \rho_{\bar{k}}(z-z') = \int \delta \rho(\vec{r}, z-z') e^{-i\bar{k}\bar{r}} d^2 r \tag{6}$$

The partial solution of the equation (4) may be easily found by substitution into the formula of Fourier-transformation of potential

$$\varphi_{\bar{k}}(z-z') = \frac{1}{2\pi} \int_{-\infty}^{\infty} \varphi_{\bar{k},k_z} e^{ik_z(z-z')} dk_z \tag{7}$$

well-known expression of the three-dimensional Fourier-component of the screened potential (1):

$$\varphi_{\bar{k},k_z} = \frac{4\pi e}{\varepsilon(\vec{k}^2 + k_z^2 + æ^2)} \tag{8}$$

Thus, substituting (8) in (7) and calculating the integral by means of the integration in the complex plane, we obtain:

$$\varphi_{\bar{k}}(z-z') = \frac{2\pi e}{\varepsilon \tilde{k}} e^{-\tilde{k}|z-z'|} \quad , \quad \tilde{k} = \sqrt{\vec{k}^2 + æ^2} \tag{9}$$

As a result, general solution of the equation (4) may be written as a sum of general solution of equation (4) without right part and expression from (9):

$$\varphi_{\bar{k}}(z, z') = A_+ e^{kz} + A_- e^{-kz} + \frac{2\pi e}{\varepsilon \tilde{k}} e^{-\tilde{k}|z-z'|} \tag{10}$$

Coefficients $A_\pm$ are found from the conditions of continuation of potential and z - components of the electric induction vector on the film's boundaries (dielectric constant of surrounding environment is ε_1):

$$A_\pm = \frac{\pi e}{\varepsilon \tilde{k}} \left[e^{-2\tilde{\eta}+2\gamma-\tilde{k}\left(\frac{d}{2}\pm z'\right)-k\frac{d}{2}} + e^{-\tilde{k}\left(\frac{d}{2}\mp z'\right)+k\frac{d}{2}} \right] e^{-\tilde{\eta}+\eta-\gamma} sh^{-1}(2\eta + kd)$$

$$\tilde{\eta} = \frac{1}{2} \ln \frac{\varepsilon k + \varepsilon_1 k}{\varepsilon \tilde{k} - \varepsilon_1 k}, \eta = \frac{1}{2} \ln \frac{\varepsilon + \varepsilon_1}{\varepsilon - \varepsilon_1}, \gamma = \frac{1}{2} \ln \frac{\varepsilon k - \varepsilon_1 k}{\varepsilon \tilde{k} - \varepsilon_1 k}, \tag{11}$$

d is the film's thickness.

Taking into account (11), one can write the expression (10) for the Fourier-component of potential in the form:

$$\varphi_{\tilde{k}}(z,z')=\frac{2\pi e}{\varepsilon\tilde{k}\,sh\,(2\eta+kd)}\cdot\left\{e^{-2\tilde{\eta}+\eta-\tilde{k}\frac{d}{2}}\cdot\left[e^{kz}ch\left(\tilde{\eta}-\gamma+k\frac{d}{2}+kz'\right)+\right.\right.$$

$$\left.\left.+e^{-kz}ch\left(\tilde{\eta}-\gamma+k\frac{d}{2}-kz'\right)\right]+sh\,(2\eta+kd)\cdot e^{-\tilde{k}|z-z'|}\right\} \qquad (12)$$

In the case, when screening radius is much larger than the film's thickness $æd<<1$, potential (12) has the known form of unscreened potential inside the film [1].

Let us consider the situation, when the dielectric constant of film $\varepsilon>>\varepsilon_1$ and screening radius is much less than film's thickness $æd>>1$. For the distances $r>>d$ the Fourier-components with such k as $kd<<1$ are essential. In this case we have approximated expression:

$$\varphi_{\tilde{k}}(z,z')\approx\frac{4\pi e}{\varepsilon k\,(2\eta+kd)}\cdot e^{-\frac{æd}{2}}\cdot ch\,(æz') \qquad (13)$$

The expression (13) differes from that obtained in [1] without screening by the multiplier $e^{-\frac{æd}{2}}\cdot ch\,(æz')$, which does not depend on k and changes from $e^{-\frac{æd}{2}}$ in the middle of the film till $\frac{1}{2}(1+e^{-æd})$ on its boundaries. Thus the dependence of the potential on r in this case is such as in the unscreened case but it depends essentially on z'-ion's coordinate in z-direction.

In conclusion it must be mentioned, that the condition $æd>>1$ means that in this case average distance between impurity ions is much less than distances for which one can use the expression (13). That is why it will be wrong to consider one-impurity states using approximate expression (13).

References

1. *Keldysh L.V.* Pisma v Zh. Exp. Theor. Fiz., 1979, v. 29, p. 716-719.
2. *Keldysh L.V., Pzoshko G.P.* Fiz. Tv. Tela, 1963, v. 5, № 12, p. 3378-3389.
3. *Rytova N.S.* Vestnik MGU, 1967, s. 111, № 3, p. 30-37.

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YARIMKEÇİRİCİ TƏBƏQƏDƏ EKRANLAŞMIŞ AŞQAR POTENSİALI

Nazik yarımkeçirici təbəqədə yüklü aşqarin potensialı hesablanmışdır. Hesab olunur ki, kristallaşma temperaturunda aşqar ionların 3-ölçülü Debay-Hükkel kor-

relyasiyası dondurulmuş kompensə olunmuş həcmi kristaldan kəsilmişdir. Bir o qədər də nazik olmayan, yə'ni qalınlığı ekranlaşma radiusunu aşan təbəqələr üçün potensial təbəqənin sərhəddinə nəzərən aşqar ionun yerləşməsindən əhəmiyyətli dərəcədə asılıdır. Təbəqənin mərkəzində potensial ekspotensial olaraq azalır, sərhədlərdə isə özünün ekranlaşmamış qiymətinin yarısına yaxınlaşır.

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ЭКРАНИРОВАННЫЙ ПОТЕНЦИАЛ ПРИМЕСИ В ПОЛУПРОВОДНИКОВОЙ ПЛЕНКЕ

Рассчитан потенциал заряженной примеси в тонкой полупроводниковой пленке. Считается, что пленка вырезана из объемного кристалла компенсированного полупроводника, в котором заморожена трехмерная Дебай-Хюккелевская корреляция примесных ионов при температуре кристаллизации. Для не очень тонких пленок, когда толщина их превышает радиус экранирования, потенциал существенно зависит от расположения примесного иона относительно границ пленки. Он экспоненциально уменьшается в центре пленки, а на границах стремится к половине своего неэкранированного значения.