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Interaction between electron-hole drops and dislocations in semiconductors

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Elastic interaction between an electron-hole drop and a dislocation in a semiconductor is considered. It is shown within the framework of the isotropic model that the EHD interacts with an edge dislocation but not with a screw dislocation. The binding energy of the EHD with an edge dislocation is calculated and found to be three orders larger than the EHD–impurity binding energy. The trajectories of EHD in the elastic field of zero-initial velocity dislocation are calculated. Allowance for the EHD energy loss to emission of elastic waves and for friction against the lattice can cause the EHD to "fall" on the dislocation. It is shown that near the dislocation axis the EHD finds it more convenient to assume a cylindrical shape (to flow along the dislocation axis). If the semiconductor contains a network of dislocations, this flow of the electron-hole liquid (EHL) can lead to formation of a conducting cluster made up of EHL filaments.

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1. It was shown by a number of experiments[1-3] that electron-hole drops (EHD) are localized in semiconductors on donor and acceptor impurities. For Ge samples with impurity density $n_i = 3\times 10^{13}$ cm^{-3} the force needed to detach the EHD from the impurity per electron-hole pair is approximately $f \sim 10^{-20}$ N (for a drop radius of the order of 10^{-4} cm). This value agrees with a theoretical calculation of the EHD–donor binding energy.[4,5] At lower densities, $n_i = 3\times 10^{10}$ cm^{-3}, however, the dependence of the EHD detachment force on the drop radius turns out to be different than in the case of pinning of an EHD on an impurity,[2] thus pointing to the existence of other trapping centers. This is also attested to by the experimental data of Westervelt,[2] who notes that the coefficient of diffusion of an EHD in a Ge crystal with dislocations in an order of magnitude lower than in a crystal without dislocations. This is an indirect indication that dislocations can also serve as EHD trapping centers.

In the present study we have investigated the elastic interaction of an EHD with a disloaation, and determined the influence of this interaction on the pinning of the EHD. We show that the force needed to detach an EHD from an edge dislocation, per electron-hole pair, is inversely proportional to the square of the drop radius and, for example for a spherical drop of radius $a = 2\times 10^{-4}$ cm, amounts to 4.8×10^{-18} N. This exceeds by more than two orders the force needed to detach an EHD from an impurity. The results is attributed to the fact that the radius of the electrostatic interaction of the EHD with the impurity is small and equals approximately the Debye screening radius r_d, whereas the elastic interaction of an EHD with a dislocation is not screened and the entire EHD volume interacts with the dislocation.

2. Consider a crystal with an isolated dislocation and containing an EHD. It is known that the EHD has elastic-stress fields[6] and that the density of the crystal elastic energy, with allowance for the interaction of the EHD with the strain field, can be represented in the form[7,8]

$$w = D_{ij} n(\mathbf{r}) u_{ij}(\mathbf{r}) + {}^1/_2 c_{ijkl} u_{ij}(\mathbf{r}) u_{kl}(\mathbf{r}), \tag{1}$$

where $u_{ij}(\mathbf{r})$ is the strain tensor, D_{ij} is the combined strain potential of the electrons and hole, $n(\mathbf{r})$ is the coordinate-dependent density of the electrons and holes in the EHD, and c_{ijkl} are the elastic constants. Since the crystal contains two sources of elastic stresses, the strain tensor can be represented by the sum $u_{ij}(\mathbf{r}) = u_{ij}^{d}(\mathbf{r}) + u_{ij}^{di}(\mathbf{r})$, where $u_{ij}^{dr}(\mathbf{r})$ is the strain tensor produced in the crystal by the EHD and $u_{ij}^{di}(\mathbf{r})$ is the strain tensor produced by the dislocation. The total elastic energy of the crystal $U = \int d\mathbf{r}\, w(\mathbf{r})$ consists of the drop's elastic energy U_{dr}, of the dislocation elastic energy U_{di}, and of the energy U_{int} of the EHD interaction with the dislocation, for which the following expression

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holds:

$$U_{int}=\int d\mathbf{r}D_{ij}n(\mathbf{r})u_{ij}^{\mathrm{di}}(\mathbf{r})$$
$$+\int d\mathbf{r}c_{ijkl}u_{ij}^{\mathrm{di}}(\mathbf{r})u_{kl}^{\mathrm{dr}}(\mathbf{r}). \tag{2}$$

We consider first the interaction of an infinite straight dislocation with a spherical EHD in an isotropic medium.[1)] Let the dislocation axis be parallel to the z axis. Using the formulas obtained in Refs. 8 and 9 for $U_{ij}^{dr}(\mathbf{r})$ and $u_{ij}^{di}(\mathbf{r})$ respectively, we can verify that in the isotropic case the second term of (2) is zero, and the interaction of the EHD with the dislocation is determined only by the first term. Recognizing that in the isotropic case $D_{ij}=D\delta_{ij}$, where $D=D_e+D_h$ is the combined strain potential of the electrons and holes, we can represent the interaction energy (2) in the form

$$U_{int}=\int d\mathbf{r}Dn(\mathbf{r})u_{ii}^{\mathrm{di}}(\mathbf{r}), \tag{3}$$

with $n(\mathbf{r})=n_0$ inside the drop and zero outside. It follows from this expression that in the isotropic case the EHD interacts only with an edge dislocation, since a screw dislocation produces in this case pure shear stresses.

Substituting $u_{ij}^{di}(\mathbf{r})$ (Ref. 9) in (3) and integrating, we obtain the energy of the interaction of an EHD with an edge dislocation

$$U_{int}=-D\frac{1-2\sigma}{1-\sigma}\frac{b_x}{2\pi}N\frac{\sin\varphi}{\rho}\begin{cases}1 & \rho\geqslant a\\ 1-(1-\rho^2/a^2)^{3/2} & \rho<a\end{cases}, \tag{4}$$

where $N=(4/3)\pi n_0 a^3$ is the total number of electron-hole pairs in the EHD; a is the drop radius; ρ and φ are the polar coordinates of the center of the drop in a plane perpendicular to the dislocation axis, with the angle φ reckoned from the z axis, which lies in the slip plane xz (Fig. 1); b_x is the dislocation Burgers vector, and σ is the Poisson coefficient. U_{int} does not depend on the coordinate z, owing to the translational symmetry along the z axis.

We note that at $\rho>a$ the interaction energy (4) is determined by the dilatation produced by the dislocation at the center of the drop. The minimum of the energy of the EHD interaction with the dislocation corresponds to a drop center located at the point $\rho=(3/4)^{1/4}a$, $\varphi=\pi/2$ (see Fig. 1), with

$$U_{int}^{min}=-\gamma D\frac{1-2\sigma}{1-\sigma}\frac{b_x}{2\pi a}N,\quad \gamma=(4/3)^{1/4}[1-(1-(3/4)^{1/2})^{3/2}]\approx 1.02. \tag{5}$$

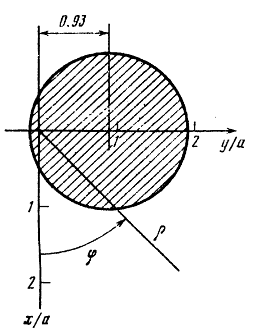

FIG. 1. Equilibrium position of spherical drop near a dislocation axis. The rest of the half plane corresponds to $x=0$ and $0<y<\infty$.

We assume here and elsewhere that the combined strain potential of the electrons and holes is positive: $D>0$.

The force needed to detach the EHD from the dislocation in a direction perpendicular to the z axis, per electron-hole pair, is

$$f=\frac{D(1-2\sigma)}{2\pi(1-\sigma)}\frac{b_x}{a^2}. \tag{6}$$

Estimating this quantity for Ge and assuming that $D=3$ eV, $b_x=5\times10^{-8}$ cm, and $\sigma=1/3$, we find that $f=4.8\times10^{-18}$ N at $a=2\times10^{-4}$ cm. This value is larger by more than two orders than the force needed to detach an EHD from an impurity, and unlike the latter is inversely proportional to the square of the drop radius. This dependence of the force on the drop radius agrees qualitatively with the experimental data.[3]

We present also comparative estimates of the binding energy of EHD with various crystal-lattice defects. The binding energy of an EHD with an impurity does not depend on the drop radius, and in the case of Ge, for example, equals 7 meV.[5] For crystal-lattice defects such as vacancies or interstitial atoms, the binding energy due to elastic interactions turns out to be of the order of $U_{int}\sim D(b/a)^3N$, where b is the lattice constant. This energy, just as in the case of EHD-impurity interaction, does not depend on the drop radius and is of the order of 0.5 meV for Ge. On the other hand, the EHD-dislocation binding energy (5) is proportional to the square of the drop radius. For a drop of radius $a=2\times10^{-5}$ cm in Ge it is of the order of 5 eV ($n_0=2.7\times10^{17}$ cm^{-3}), or larger by three orders than the binding energy of the EHD with an impurity, and points to the important role played by the dislocation in the EHD pinning process.

It follows from the foregoing analysis that at equilibrium the EHD sits on the dislocation. In the calculation of the interaction energy, however, we did not take into account the redistribution of the electron and hole densities in the EHD under the influence of the forces exerted by the dislocation. Allowance for this redistribution is important, for example, when EHD interaction with shallow donor and acceptor impurities is considered, and limits the effective radius of the force exerted by the impurity. This radius turns out then to be of the order of the Debye screening radius r_d, while the energy of the interaction of the EHD with the impurity is independent of the drop radius [cf. (5)] and its order of magnitude is $U_{int}^{i}\sim e^2/\varepsilon r_d$, where e is the electron charge and ε is the static permittivity of the semiconductor.

In interactions of EHD with dislocations, however, owing to the difference between the electron and hole strain potentials D_e and D_h, the bare potentials produced by the dislocations at the electrons and holes, $V^e(\mathbf{r})=D_e u_{ii}^{di}(\mathbf{r})$ and $V^h(\mathbf{r})=D_h u_{ii}^{di}(\mathbf{r})$ respectively, are different in magnitude, so that the screening potential $e\varphi(\mathbf{r})$ due to the inhomogeneous fluctuations of the electron and hole densities near the dislocation axis, cannot cancel them out simultaneously. In our case, consequently, the reaction of the electron-hole plasma on the dislocation potential does not screen the latter.

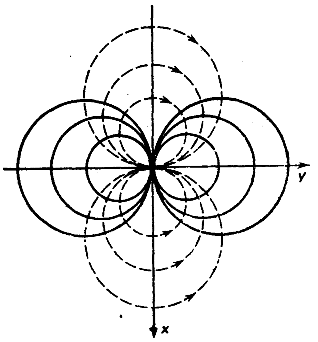

FIG. 2. Family of equipotential lines of the potential of the interaction of an EHD with an edge dislocation (solid lines). The dashed lines are the force lines, which comprise an analogous family of circles orthogonal to the family of the equipotential lines. The arrows mark the direction of the force acting on the EHD.

This conclusion pertains to the asymptotic value of the potential, i.e., it is valid at distances ρ much larger than the Debye screening radius, which is of the order of $r_d \sim 10^{-6}$ cm for the degenerate electron-hole plasma in an EHD in Ge. These qualitative arguments are supported by the corresponding quantitative calculations.

3. We have considered above the case of an equilibrium position of a spherical EHD near a dislocation axis, but it in experiment it is possible for the drops to be produced at a certain distance away from the axis. It is therefore of interest to consider two-dimensional drop motion in a potential (4) produced by an edge dislocation. We confine ourselves here to the case $\rho > a$, when the equipotential lines of the give potential $U(\rho, \varphi) = U_0$ form in the xy plane the family of circles shown by the solid lines in Fig. 2. Their radius is

$$R = \frac{ND}{|U_0|}\frac{b_x}{4\pi}\frac{1-2\sigma}{1-\sigma},$$

and their centers lie on the y axis at points with coordinates $y_c = -R \operatorname{sign} U_0$. The equipotential lines corresponding to negative energy $U_0 < 0$ are located in the right-hand half-plane $0 < \varphi < \pi$, while those for positive energies $U_0 > 0$ are in the left-hand half-plane $\pi < \varphi < 2\pi$. Corresponding to the energy $U_0 = 0$ is a straight line that coincides with the x axis. The drop executes finite motion in such a potential if its total (kinetic + potential) energy E is negative. The region of finite motion is contained in this case in the circle $U(\rho, \varphi) = E$. Infinite motion corresponds to positive energies $E > 0$.

We examine now in greater detail the finite motion of an EHD with zero initial velocity. Let the initial coordinates of the drop be ρ_0 and φ_0, with $0 < \varphi_0 < \pi$. The region of finite motion of the drop corresponds in this case to a circle of radius $R = \rho_0/2 \sin \varphi_0$, whose center lies on the y axis at a point with coordinate $y_c = R$. Unfortunately, the potential (4) does not admit of separation of the variables in the Hamilton-Jacobi equation, so that the equations of the EHD motion in this potential were solved numerically with a computer for the case $\rho > a$. It is possible, however, to make several general statements concerning the character of this motion.

First, since the EHD mass and the potential of the interaction of the EHD with the dislocation are proportional to the total number $N = (4/3)\pi n_0 a^3$ of the particles in the drop, this number drops out of the equations of motion, and trajectories of drops with different radii turn out to be identical in this case (if ρ_0 and φ_0 are same). This is true if the distance between the drop and the dislocation becomes smaller than the radius of the drop in the course of its motion.

Second, according to the virial theorem,[10] the average kinetic energy $\overline{K}$ of a drop moving in a potential that is (at $\rho > a$) a homogeneous function of the coordinates with a homogeneity exponent -1, is given by the expression $\overline{K} = -E = -U(\rho_0, \varphi_0)$. From this we can readily determine the mean squared velocity of the drop:

$$(\overline{v^2})^{1/2} = \left(\frac{Db_x}{\pi}\frac{1-2\sigma}{1-\sigma}\frac{\sin\varphi_0}{(m_e+m_h)\rho_0}\right)^{1/2}. \qquad (7)$$

We note that it is likewise independent of the drop size. Figure 3 shows the computer-calculated two-dimensional trajectory of the drop for initial conditions $x_0 = -10a$, $y_0 = 10a$, and $\varphi_0 = 3\pi/4$.

It is of interest to cite also the functions $\rho(t)$ and $\varphi(t)$. They are shown in Fig. 4, from which it follows that the motion of the drop in such a potential can be approximately characterized by a certain period of motion T. In addition, interest attaches to the maximum velocity v_{max} on the trajectory and to the minimum distance ρ_{min} from the trajectory to the dislocation axis On the basis of similarity theory, the dependences of these quantities on the initial conditions can be expressed in the form

$$T = t_0\left(\frac{\rho}{a}\right)^{3/2}\Psi(\varphi_0), \qquad (8)$$

$$v_{max} = \frac{a}{t_0}\left(\frac{a}{\rho_0}\right)^{1/2}\Phi(\varphi_0), \qquad (9)$$

$$\rho_{min} = \rho_0 F(\varphi_0), \qquad (10)$$

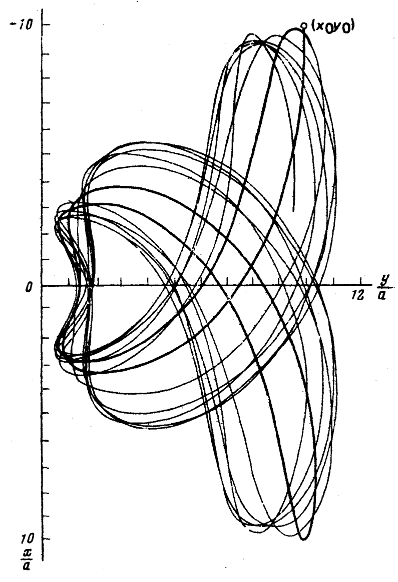

FIG. 3. Trajectory of EHD at an initial drop position $x_0 = -10a$, $y_0 = 10a$ $\varphi_0 = 3\pi/4$; a is the radius of the drop.

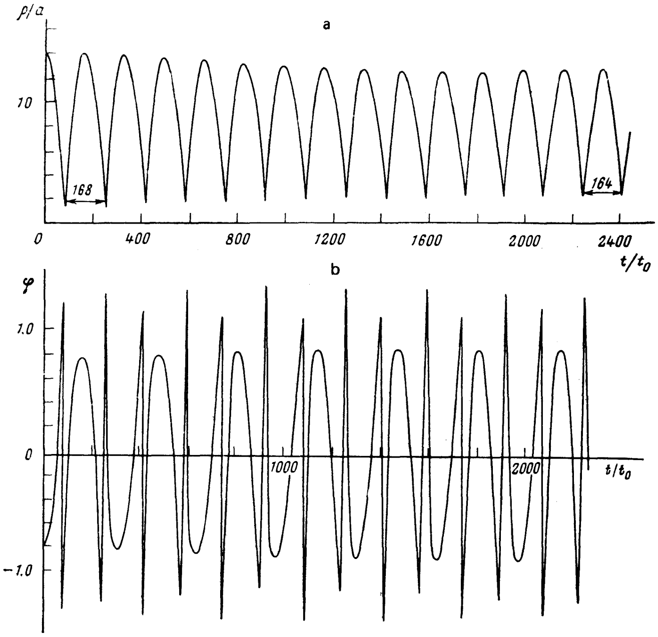

FIG. 4. Time dependences of $\rho(t)$ (a) and $\varphi(t)$ (b) for $x_0 = -10a$, $y_0 = 10a$, and $\varphi_0 = 3\pi/4$; a is the drop radius, t_0 is defined in (11).

$$t_0 = \left[\frac{2\pi(m_e+m_h)(1-\sigma)a^3}{(1-2\sigma)Db_x}\right]^{1/2}. \tag{11}$$

Here $\Psi(\varphi_0)$, $\Phi(\varphi_0)$, and $F(\varphi_0)$ are certain functions that depend only on the initial angle φ_0. The drop radius was introduced into these formulas for convenience. None of these quantities depend, naturally, on the drop radius. For Ge we have $m_e + m_h = 5\times10^{-28}$ g, so that the times are $t_0 = 1.5\times10^{-11}$ sec and 4.6×10^{-10} sec for drop radii $a = 2\times10^{-5}$ and 2×10^{-4} cm, respectively.

The numerical values of the functions Ψ, Φ, and F for three initial positions of the drop A, B, and C are listed in Table I. In the calculation of these functions we have assumed that $\rho > a$. As follows from (10) this calls for satisfaction of the condition $\rho_0 > a/F(\varphi_0)$. We note that at the initial drop positions

$$\varphi_0 = \frac{\pi}{2} + \operatorname{arctg}\frac{1}{10}, \quad 67a \leqslant \rho_0 \leqslant 1.9\cdot10^{-2}\ \text{cm}\ \ (a \leqslant 2.9\cdot10^{-4}\ \text{cm}),$$

$$\varphi_0 = 3\pi/4, \quad 11a \leqslant \rho_0 \leqslant 3\cdot10^{-3}\ \text{cm}\ \ (a \leqslant 2.8\cdot10^{-4}\ \text{cm})$$

the maximum speed of the EHD on the trajectory exceeds the speed of longitudinal sound $c_l \sim 5\times10^5$ cm/sec. As for the mean squared velocity, calculation by formula (8) yields for $(\overline{v^2})^{1/2}$ a value of the order of 7.3×10^5 cm/sec at $\rho \sim 10^{-4}$ cm and $\varphi_0 \sim 3\pi/4$, which also exceeds the speed of sound.

TABLE I. Computer-calculated values of the functions $\Psi(\varphi_0)$, $\Phi(\varphi_0)$, and $F(\varphi_0)$ which characterize respectively T, v_{max} and ρ_{min} [Eqs. (8)–(10)] for three different trajectories A, B, and C.

Trajectory	Initial angle	$\Psi(\varphi_0)$	$\Phi(\varphi_0)$	$F(\varphi_0)$
A	$\varphi_0=\pi/2+\operatorname{arctg}(1/10)$	2.20	11.2	$1.49\cdot10^{-2}$
B	$\varphi_0=3\pi/4$	6.11	4.40	$9.19\cdot10^{-2}$
C	$\varphi_0=\pi/2+\operatorname{arctg}10$	119	1.30	0.597

The drop motion was investigated above without allowance for the friction forces acting on the EHD. As shown by Keldysh,[6] the EHD velocity is limited in many cases by the viscous-friction force due to incoherent emission and absorption of acoustic phonons by the electrons and the holes of the drops. This force, calculated per electron-hole pair, does not depend on the drop radius and, for example, equals $f_1 = 1.5\times10^{-19}$ N for Ge at $T = 1$ K and an EHD speed of the order of but less than the speed of sound.[11] In addition, when the drops moves faster than sound, a deceleration force is produced by the Cherenkov emission of sound by the moving drop.[11,12] This force (likewise calculated per electron-hole pair) is inversely proportional to the radius of the drop and exceeds appreciably the viscous-friction force. Thus for a drop moving in Ge at a speed v not much higher than the speed of sound and having a radius $a = 2\times10^{-5}$ cm the force (which is inversely proportional to v^2) amounts to $f_2 = 2.3\times10^{-17}$ N.

We note also that at subsonic but near-sonic speeds and at sufficiently low temperatures $T \leqslant 1$ K it may be important to take into account the friction forces connected with emission of elastic waves by the drop if its motion is not uniform. The calculation of the energy lost to emission of elastic wave by an EHD moving around a dislocation along a calculated trajectory is a laborious task. We have therefore confined ourselves to a model estimate of the energy lost by an EHD moving uniformly along a circle. Thus for a drop moving in Ge at a speed $v \approx 0.9c$ the friction force (per electron-hole pair) due to emission of elastic waves by the drops is $f_3 \sim 10^{-18}$ N. This estimate was made for a circular orbit of radius $R_0 = 2.5a$ with $a = 2\times10^{-5}$ cm. These numbers correspond approximately to the nearly heart-shaped segment of the trajectory shown in Fig. 3.

All the listed friction forces turn out to be substantially less than the force f_d with which the dislocation acts on the drop. The value of this force per electron-hole pair is independent of the drop radius and is inversely proportional to the square of the distance ρ between the EHD and the dislocation axis[4] at $\rho > a$. For example, in Ge at $\rho = 10^{-4}$ cm we have $f_d = 2\times10^{-17}$ N, therefore in first-order approximation the drop motion will behave as described by us.

Friction forces can cause, however, the EHD to land on the dislocation. Let us estimate this effect quantitatively. The energy lost by the EHD per period is determined by the work of the friction forces f_{tr}. At initial angles φ_0 not much different from $\pi/2 \pm \pi/4$ this work is of the order of $A = f_{tr}N\rho_0$. The number n of revolution that the moving drop makes before it loses all its energy is determined from the condition $nA = |U(\rho_0\varphi_0)|$. Hence $n \sim Db_x/2\pi f_{tr}\rho_0^2$. For $\rho_0 \sim 10^{-4}$ cm the average drop speed (7) is of the order of the speed of sound, therefore, using the value $f_{tr} \sim f_1 \sim 1.5\times10^{-19}$ N (for viscous friction), we get $n \sim 260$. If the average drop speed is higher than that of sound, n turns out to be of the order of 3 (we recall that this estimate is obtained for a drop radius $a = 2\times10^{-5}$ cm; if $a = 2\times10^{-4}$

cm we have $n=30$). The time of one revolution of the target on the trajectory at $\rho_0 \sim 10^{-4}$ cm turns out to be of the order of 10^{-9} sec (8). Thus, in this concrete case the drop loses its energy at respective times 0.3 μsec ($n=30$) and 0.03 μsec ($n=3$). The drop lifetime, however, is usually from 1 to 30 μsec.

4. We have considered above the interaction between a spherical EHD and a dislocation. The reason was that in an anisotropic crystal in the absence of external forces the surface tension causes the drop to assume a spherical shape. The drop shape can change, however, in the dislocation field, and this effect manifests itself most strongly near the dislocation axis.

In the equilibrium position the drop energy, which consists of the potential energy of the drop in the dislocation field and the surface-tension energy, is a minimum.[2)] On the one hand, it is favorable for the drop to "flow" along the dislocation axis and decrease thereby its potential energy, but the surface energy is increased thereby because of the increased surface area of the EHD. To estimate quantitatively the possibility of this "flow," let us find the energy of the interaction of an edge dislocation with a cylindrical EHD whose cylindrical axis is parallel to the dislocation axis. This energy is calculated in the same manner as in the case of a spherical EHD, using Eq. (3), and its value is

$$U_{int}=-D\frac{1-2\sigma}{1-\sigma}\frac{b_x}{2\pi}N\frac{\sin\varphi}{\rho}\begin{cases}1, & \rho\geqslant d\\ \rho^2/d^2, & \rho<d\end{cases}, \tag{12}$$

where $N=\pi d^2Hn_0$ is the total number of the electron-hole pairs, d is the cylinder radius, H is the height, and ρ and φ are the polar coordinates of the cylinder axis. The energy minimum corresponds to $\varphi=\pi/2$ and $\rho=d$, while the sum of the surface energy and the energy of interaction of the cylindrical drop with the dislocation can be represented in the form

$$\varepsilon_c=-D\frac{1-2\sigma}{1-\sigma}\frac{b_x}{2\pi}N\frac{1}{d}(1-\delta_c), \tag{13}$$

$$\delta=\frac{4\pi\alpha(1-\sigma)(1+d/H)}{(1-2\sigma)Db_xn_0}, \tag{14}$$

where α is the surface-tension coefficient.

For a spherical EHD with the same number of electron-hole pairs, the sum of the surface energy and the drop–dislocation interaction energy in the equilibrium position (5) is

$$\varepsilon_s=-\gamma D\frac{1-2\sigma}{1-\sigma}\frac{b_x}{2\pi}N\frac{1}{a}(1-\delta_s), \tag{15}$$

$$\delta_s=\frac{6\pi\alpha(1-\sigma)}{\gamma(1-2\sigma)Db_xn_0}. \tag{16}$$

The dimensionless quantities δ_c and δ_s characterize the ratio of the surface energy to the energy of the elastic interaction of the EHD with the dislocation. Estimating them for Ge (at $d\ll H$): $n_0=2.7\times10^{17}$ cm^{-2}, $b_x=5\times10^{-8}$ cm, $D=3$ eV, $\sigma=1/3$, and $\alpha=2\times10^{-4}$ erg/cm^2 (Ref. 13) we obtain respectively $\delta_c=0.08$ and $\delta_s=0.1$. It is important that both are much less than unity, i.e., the contribution of the surface energy is in both cases much smaller than the energy of the elastic interaction of the drop with the dislocation.

It follows from (13) and (15) that at $d<a$ the energy of a cylindrical EHD is lower than that of a spherical one by an approximate factor a/d. Thus, it is profitable for an EHD near the a dislocation axis to assume a cylindrical shape (to flow along the dislocation axis), and the gained elastic energy of the interaction of the EHD with the dislocation exceeds the surface-energy loss to the surface tension. Within the framework of the assumed model, the cylinder length can be limited either by the dislocation length L or by the condition imposed on the cylinder radius d, which naturally cannot be less than the average distance $n_0^{-1/3}$ between the particles in the liquid. If a dislocation grid is present in the semiconductor, this flow of the electron-hole liquid (EHL) can lead to formation of a conducting cluster made up of EHL filaments.

It is important to note this behavior of an EHL near a dislocation axis hinders the formation of spherical drops. It is clear that when the condition $\delta_{c,s}\ll1$ is satisfied such a drop will be simply squashed by the forces applied to them by the dislocation. Formulas (5) and (6) should then pertain to the case $\delta_{c,s}\gg1$.

We have disregarded in our analysis the change of the properties of an EHL under influence of elastic-stress fields due to the dislocation. Yet these forces can influence significantly the band structure of the semiconductor[14] and lead thereby to a change of the EHL properties. To clarify this point we turn to the experimental data of Ref. 15, where the properties of EHL in uniaxially deformed Ge were studied. The data of that reference indicate that the properties of the EHL change substantially at pressures $p\gtrsim5$ kgf/mm^2, when the EHL density decresses by an approximate factor of five, the binding energy to one-half, and the drop lifetimes increase by about ten times. This change of the EHL properties is due to the lifting of the degeneracy of the energy spectrum in a uniaxially deformed crystal and to the change of the populations of the electron and hole valleys. Of course, the structure of the stress fields in a crystal with a dislocation is more complicated than in a uniaxially deformed crystal, but these results can be satisfactorily used for estimates. Using the known value of the shear modulus $\mu\approx6\times10^6$ N/cm^2 for Ge (Ref. 16), we find that stresses on the order of 5 kgf/mm^2 are reached at distances on the order of 10^{-5} cm from an edge dislocation. At larger distances it can be assumed that the properties of the EHL remain the same as in an ideal crystal.

The change produced in the EHL properties by the deformation might influence the flow of the EHL along the dislocation axis and, in particular limit this flow. Thus, the parameter $\delta_{c,s}$ [Eqs. (14) and (16)], which characterizes the ratio of the surface energy of the drop to the energy of the elastic interaction, contains the electron-hole pair density n_0, which can become much smaller near the dislocation axis. As for the surface-tension coefficient α, which also enters in the formulas for $\delta_{c,s}$, we know of no experiments in which this coefficient was measured in a deformed crystal, and confine ourselves here therefore to a rough estimate.

The surface tension coefficient decreases with decreasing binding energy Φ and of the particle density n_0 in the EHL. This decrease is given by $\alpha \sim \Phi n_0^{2/3}$ (for underformed Ge this formula yields $\alpha \sim 10^{-3}$ erg/cm^2). Thus, the EHL surface tension is decreased upon deformation. As a result, the parameter $\delta_{c,s} \sim \Phi n_0^{-1/3}$ remains practically unchanged, therefore the change of the EHL properties near the dislocation axis can apparently not limit its flow along the dislocation axis. However, the change of the EHL properties near the dislocation axis should increase the EHL lifetime and change the luminescence, in analogy with what observed in uniaxially deformed Ge crystals.[15]

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[1)] The manner in which the dislocation affects the EHD shape will be discussed in Sec. 4.

[2)] The elastic energy of the drop itself in an isotropic medium depends only on its volume and does not change when the drop shape is changed. In addition, we also assume that the energy of the interaction of the electrons and holes inside the drop is constant.

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