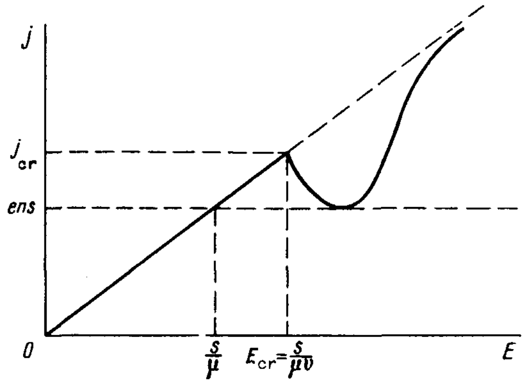
sample) will be amplified until a stationary amplitude is established, determined by the nonlinear effects and by the value of the field E [3,4] (we assume that the sample is sufficiently long). With this (see [4]), if the supercriticality is sufficiently large, the amplitude of the stationary wave becomes so large that almost all the electrons are captured by the wave and consequently drift with a velocity close to that of sound. Thus, when $E > E_{cr}$ the current drops below ints critical value and approaches the value ens, i.e., a region with NDC appears on the voltage-current characteristic. Contributing further to this drop is also the fact that an ever increasing fraction of the conduction electrons is gathered into bunches and their average mobility decreases, tending to μ_α. With further increase of the field E, the amplitude of the stationary wave decreases [4], and the voltage-current characteristic should again return to its ohmic section. We thus obtain a voltage-current characteristic of the type shown in the figure.



It seems to us that the indicated NDC mechanism may be responsible for the occurrence of domain instability in CdS crystals in the sound-amplification mode (see [5,6]), since these crystals always contain a large number of traps.

The author thanks V. L. Bonch-Bruevich, S. G. Kalashnikov, and V. V. Proklov for a discussion of the work.

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*We have neglected here the lattice absorption of sound, which also leads to an increase of the threshold field E_{cr}.

PINCH EFFECT IN SEMICONDUCTORS WITH INTRINSIC CONDUCTIVITY

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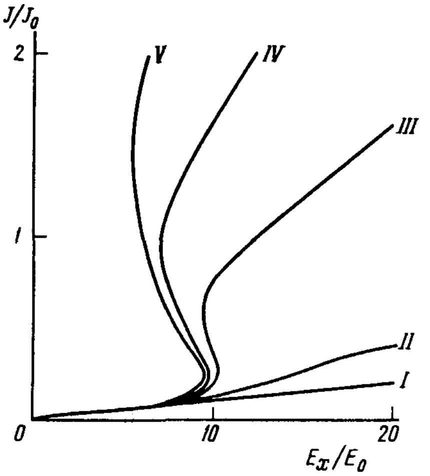
Semiconductors with inctrinsic conductivity (number of band electrons equal to number of band holes) having high carrier density and carrier mobility are convenient objects for the observation of the pinch effect - the spatial redistribution of the carriers in a crystal under the influence of the magnetic field of the current flowing through the crystal.

A phenomenological study of the pinch effect was made for a homogeneous crystal with isotropic conductivity, in the form of a plate $(-\infty < x < \infty;\ -d \le y \le d;\ -\ell \le z \le \ell)$, with $d \sim L$, where L is the bipolar diffusion length of the carriers, $\ell \gg d$, and the current is directed along the x axis. The stationary spatial carrier distribution was obtained by solving simultaneously Maxwell's equations and the continuity equation with standard boundary conditions, taking the recombination of the non-equilibrium carriers on the surfaces $y = \pm d$ into account. A decrease in the number of carriers on the surface causes the crystal surfaces to act as sources feeding additional carriers into the volume when the surface-recombination rate s differs from zero. The increase in the number of carriers in the crystal with increasing current causes the voltage across the crystal to drop (in the controlled-current mode) and a section with negative differential conductivity to appear on the current-voltage characteristic. If s is a finite quantity, then the surface generation reaches saturation with further increase in current, and the crystal conductivity tends to a finite value independent of the current. The net result is that the current-voltage characteristic has a well pronounced s-shaped form with two linear sections in the regions of weak and strong currents (see the figure). If the crystal resistance in the pre-pinch mode is R_0, then its value in the strong-current limit is $R_0(1 + \Phi)^{-1}$, where $\Phi = s\tau/d$ and τ is the recombination time. According to estimates, negative differential resistance should be observed in intrinsic InSb at $T \sim 300^\circ K$ in the region of electric fields $E_x \sim 200$ V/cm.



Current-voltage characteristic of crystal for $d/L \ll 1$. I) $\Phi = 0$; II) $\Phi = 1$; III) $\Phi = 7$: IV) $\Phi = 15$; V) $\Phi = 30$. Here $J_0 = Ic^2/\pi U_n$; $E_0 = 2kT/ed$; U_n is the electron mobility and is assumed to be much higher than the hole mobility.

We also studied the pinch effect in the plate in the case when the semiconductor was placed in an external constant magnetic field directed along the z axis. In this case there is produced, in addition to the pinch effect, also the size effect described in [1]. The rates of surface recombination on opposite faces ($y = \pm d$) were assumed different. In the absence of the external magnetic field, a layer with increased carrier density is produced near one of the faces of the plate (at the opposite face if the electric or magnetic field is reversed). The asymmetry of the recombination conditions on the surfaces $y = \pm d$ leads to an asymmetrical current-voltage characteristic (with respect to the sign of the electric field). On the whole, the form of the characteristic is essentially determined by the magnitude of the external magnetic field. In particular, the characteristic may have an s-shape.

A recent paper [2] describes the experimental observation of an s-shaped characteristic in a thin InSb sample placed in a strong transverse magnetic field. In the opinion of the author of [2], the negative differential resistance is connected with breakdown in the transverse Hall field. Since no data on the value of s are presented, it is impossible to make at present a definite conclusion concerning the actual mechanism of the phenomenon observed in [2].

The author thanks E. I. Rashba for suggesting the topic and for continuous interest in the work.

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QUANTUM SIZE EFFECTS IN THE ELECTRIC CONDUCTIVITY OF THIN FILMS

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We report here the calculation of two quantum size effects in the kinetic characteristics of thin films: 1) oscillations of the resistivity ρ with the film thickness L; 2) oscillatory dependence of the current density j on the electric field intensity E (quantum corrections to Ohm's law). We note that size effects in Bi films were observed recently [1,2]; the theory of these effects was considered in [3,4]. Sandomirskii's paper [4] contains some results pertaining to the first of the aforementioned size effects (oscillations of ρ with L). Unlike his work, in which the calculation is based on the use of the kinetic equation, we shall use quantum field-theoretical methods [5], which yield the connection between j and E for small values of these quantities. Specular reflection of the electrons from the film boundaries is assumed, the resistance being due to scattering by point impurities with a volume mean free path greatly exceeding the film thickness.

The Hamiltonian of the system is of the form $H = H_0 + H_1$, where

$$H_0 = \sum_\alpha \epsilon_\alpha a_\alpha^+ a_\alpha, \quad H_1 = g \sum_{\alpha \neq \alpha'} a_{\alpha'}^+ a_\alpha . \tag{1}$$

Here $\alpha = (p_x, p_y, n)$ is the aggregate of the quantum numbers of the electron in the film, $\varepsilon_\alpha = (\vec{p}^2/2m) + (\pi^2 n^2/2mL^2)$ (it is assumed also that H_0 contains implicitly the interaction between the electrons). H_1 is the effective electron-impurity interaction Hamiltonian [6]. According to [6], the interaction constant g is connected with the free-path time $\tau = \tau_{tr}$ by the relation $g = (\pi\nu/mp_0)^{1/2}$, $\nu = 1/\tau$.

In the zeroth approximation ($H_1 = 0$) we consider a state with specified current $j = Nev_T$ (shifted Fermi surface), where v_T is the transport velocity and N is the electron density. There is no electric field in this system. When H_1 is included, dissipation of the momentum takes place, and therefore conservation of the stationary state calls for creation of an electric field $\vec{E}$, defined by

$$Ne\mathbf{E} = -\left\langle \frac{d\mathbf{P}}{dt} \right\rangle = -i\langle [H_1 \times \mathbf{P}] \rangle, \quad \mathbf{P} = \sum_\alpha \mathbf{p} a_\alpha^+ a_\alpha \tag{2}$$

($\vec{E}$, $\vec{j}$, and $\vec{p}$ lie in the plane of the film).

Commuting H_1 with $\vec{P}$ and calculating the resultant mean values $\langle a_{\alpha'}^+ a_\alpha \rangle$ in the first nonvanishing approximation in H_1,, we arrive at the formula

$$Ne\mathrm{E} = 2\pi g^2 \sum_{\alpha\alpha'} (\mathrm{p} - \mathrm{p}')[f_0(\epsilon_\alpha - \mathrm{p} v_T) - f_0(\epsilon_{\alpha'} - \mathrm{p}' v_T)]\delta(\epsilon_\alpha - \epsilon_{\alpha'}), \tag{3}$$

where $f_0(\varepsilon) = [\exp(\varepsilon - \mu/T) + 1]^{-1}$ is the Fermi distribution function.

It is easy to verify that when summation over n and n' is replaced in the resultant expression by integration, we get the usual Ohm's law $\vec{E} = \rho_0 \vec{j}$, where $\rho_0 = m\nu/Ne^2$. The quantity