CURRENT DISCONTINUITIES IN SAMPLES WITH MULTIPLY-VALUED CURRENT-VOLTAGE CHARACTERISTICS

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It is predicted that current discontinuities can occur on the overheat branch of an S-shaped current-voltage characteristic (CVC) of a semiconductor placed in a magnetic field perpendicular to the current flow.

If the transverse dimensions of a semiconductor with S-shaped current voltage characteristic (CVC) exceeds a characteristic parameter ℓ_c (with the dimension of length) [1], then the carrier-temperature distribution becomes inhomogeneous. If the problem is one-dimensional[1)], i.e., if all the quantities depend, say, on z, then the equation for the electron temperature $\Theta(z)$, in the absence of surface energy-relaxation mechanisms [3, 4], has two solutions $\Theta^{(\pm 1)}(z)$, whose values coincide at the middle of the cross section (curves 1 of Fig. 1) [1].

If the surface energy-dissipation mechanisms are taken into account, including the case when these mechanisms have different powers at the sample boundaries, only one of these two distributions remains, and its form depends on the relation between the quantities η_0 and η_a (the characteristic powers of the surface mechanisms on the boundaries z = 0 and z = a, respectively). In particular, if $\eta_0 \ll \eta_a$, then the $\Theta(z)$ distribution takes the form of curve 2 of Fig. 1, and the form of curve 3 if $\eta_0 \gg \eta_a$ [4]. If $\eta_0 = \eta_a$ and at the same time $\eta_0 = \eta_a < \eta_{cr}$ (where η_{cr} is a certain critical value of η [5]), then there are two solutions for the temperature, $\Theta = \Theta^{(\pm 1)}(z)$, [5], just as in the absence of surface mechanisms. These are shown in Fig. 2 (curves 1). On the other hand, if $\eta_0 = \eta_a > \eta_{cr}$, then there is only one temperature distribution (curve 2 of Fig. 2). The foregoing enables us to trace the variation of the temperature distributions in the case when the power of the surface mechanisms on one of the walls (say the wall z = a) is fixed (η_a = const), and varies on the other wall from $\eta_0 < \eta_a$ to $\eta_0 > \eta_a$. So long as $\eta_0 < \eta_a$, the temperature $\Theta(0)$ on the wall z = 0 exceeds the temperature $\Theta(a)$ on the wall z = a, and the electron temperature gradient $\partial\Theta/dz$ averaged over the cross section is negative. When η_0 becomes equal to η_a, but $\eta_a < \eta_{cr}$, this average gradient is negative for one of the existing distributions, $\Theta^{(\pm 1)}(z)$, and positive for the other, $\Theta^{(-1)}(z)$ [5]. On the other hand if $\eta_a > \eta_{cr}$, then the gradient is equal to zero at $\eta_0 = \eta_a$ [5]. Finally, when η_0 becomes larger than η_a, the gradient averaged over the cross section becomes positive [4, 5].

It is perfectly obvious that a continuous variation of the power of the surface mechanisms is artificial. However, as shown in [6], application of a magnetic field along the y axis, i.e., along a direction perpendicular to the plane of the electric current and of

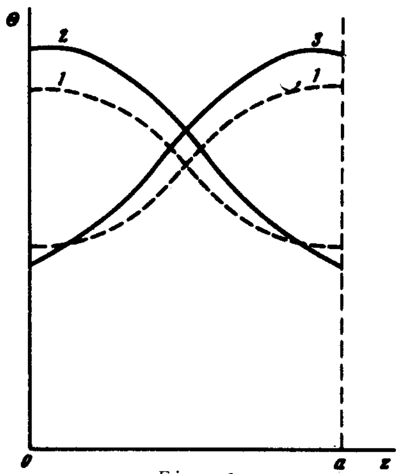

Fig. 1

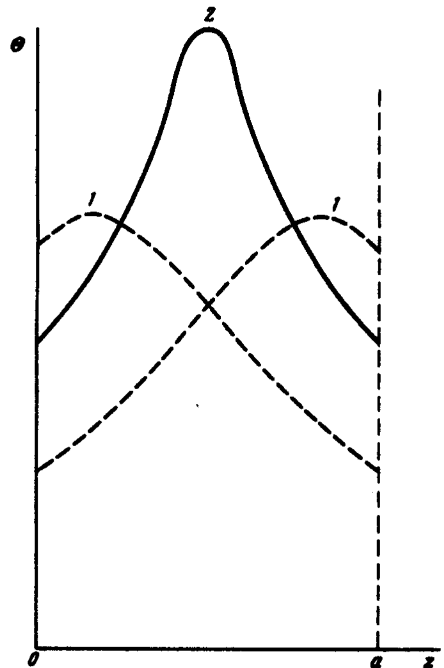

Fig. 2

Fig. 1. Temperature distributions: 1) $\eta_0 = \eta_a = 0$, 2) $\eta_0 \ll \eta_a$, 3) $\eta_0 \gg \eta_a$.

Fig. 2. Temperature distributions: 1) $\eta_0 = \eta_a < \eta_{cr}$, 2) $\eta_0 = \eta_a > \eta_{cr}$.

the electron temperature gradient, leads to an effective "change" in the value of the surface mechanisms. Assuming for simplicity that the surface mechanisms are present only on one of the sample walls (say the boundary z = a) and assuming that the magnetic field H is weak ($(\omega_H\tau)^2 \ll 1$, where ω_H is the cyclotron frequency and τ is the relaxation time), the boundary conditions for the electron temperature take the form [6]

$$\left.\frac{d\Theta}{dz}\right|_{z=0} = \left.H\Phi(\Theta)E\right|_{z=0}, \quad \left.\frac{d\Theta}{dz}\right|_{z=a} = \left.(H\Phi(\Theta)E - \eta F(\Theta))\right|_{z=a}, \tag{1}$$

where $\Phi(\Theta)$ is the coefficient of the transverse Nernst-Ettingshausen thermomagnetic effect [6], E is the applied electric field, and $F(\Theta)$ is a function that takes into account the temperature dependence of the surface mechanisms.

It is seen from (1) that in the case when H is parallel to the y axis (H > 0), an increase of the magnetic field from H = 0 to $H = H^{(\eta)} = \eta F(\Theta)/2\Phi(\Theta)E$ is equivalent to a change of η_0 from 0 to η_a. With further increase of H ($H > H^{(\eta)}$), η_0 becomes effectively larger than η_a.

Consequently, when the field changes from H = 0 to $H > H^{(\eta)}$ the temperature distribution is deformed in the manner described in the connection of the change of η_0 (see Figs. 1 and 2). It follows from this, in particular, that if $H^{(\eta)}$ is less than a critical value $H^{(\eta_{cr})} = \eta_{cr}F(\Theta)/2\Phi(\Theta)E$, then the electron-temperature gradient averaged over the cross section reverses sign and experiences a discontinuity.

Since the expression for the current $\bar{j}$ averaged over the cross section contains in the presence of a transverse magnetic field a term proportional to the product of the magnetic field H by the electron-temperature gradient averaged over the cross section [6], the discontinuity of the gradients in a field $H = H^{(\eta)} < H^{(\eta_{cr})}$ leads to a discontinuity in the current in the same magnetic field. We note that an increase of η leads to an increase of $H^{(\eta)}$ and consequently when η is increased the discontinuity of the current occurs in stronger magnetic field. It is obvious that there is no break in the current at $H = H^{(\eta)} > H^{(\eta_{cr})}$, since the average gradient is then equal to zero, is indicated above. An exact calculation similar to that performed in [4, 6] yields the following expression for the discontinuity ("jump") $\overline{\Delta j}$ of the average current in a field $H = H^{(\eta)}$, when $H^{(\eta)} < H^{(\eta_{cr})}$, as a function of the power of the surface mechanisms

$$\left.\overline{\Delta j}\right|_{H=H^{(\eta)}} \sim \eta\sqrt{1-(\eta/\eta_{cr})^2} \quad .$$

Such a dependence of the average current discontinuity is understandable. As $\eta \to \eta_{cr}$, the average discontinuity tends to zero, since the electron-temperature gradient averaged over the cross section decreases monotonically to zero. As $\eta \to 0$, the corresponding value of $H^{(\eta)}$ also tends to zero. Therefore, although the average gradient differs from zero as $\eta \to 0$, it makes no contribution to the expression for the current, because $H^{(\eta)} \to 0$. It can be shown that when H is increased the current jump in a field $H = H^{(\eta)} < H^{(\eta_{cr})}$ occurs in larger values of the latter. On the other hand, if $H^{(\eta)} > H^{(\eta_{cr})}$, then there is no discontinuity in a field $H = H^{(\eta)}$, and the $\bar{j}(H)$ curve has a minimum.

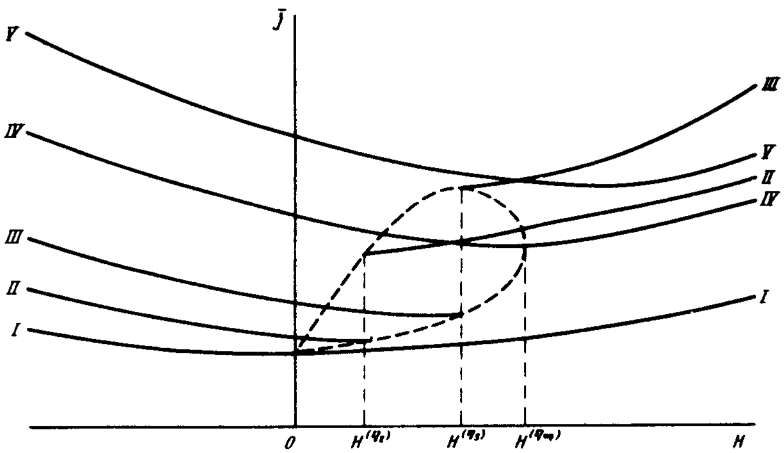

Fig. 3. Gauss-ampere characteristics: I) $\eta_1 = 0$, II) $\eta_{cr} > \eta_2 > 0$, III) $\eta_{cr} > \eta_3 > \eta_2$, IV) $\eta_4 = \eta_{cr}$, V) $\eta_5 > \eta_{cr}$.

Reversal of the direction of the magnetic field (i.e., H < 0, antiparallel to the y axis) leads (see (1)) to the appearance of "negative" surface mechanisms (i.e., $\eta_0 < 0$). The corresponding mean values of the electron temperature and of the temperature gradient can be readily shown to be monotonic functions of the magnetic field in this case. Consequently, the current at H < 0 is a monotonic function of the field H.

Figure 3 shows the gauss-ampere characteristics for different values of the parameter η.

It is natural to expect the current discontinuities on the $\bar{j}(H)$ plot to lead inevitably to current jumps on the CVC.

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1)The limiting dimensions at which the problem can be regarded as one-dimensional are given in [1, 2].

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