center of the trap. The maximum beam-heating efficiency, calculated for $nT = 6 \times 10^{15}$ eV/cm^3 and $H_0 = 2000$ Oe, is 1.7%. A concentration of the main potential drop in a small region of the plasma column [2, 3] and the transport of the bulk of the current by a small fraction ($10^{-2} - 10^{-3}$) of the plasma electrons, similar to those observed in [2] and in the present investigation, may occur also in toroidal setups with longitudinal magnetic fields exceeding the critical Dreicer field.

In conclusion, the authors thank I. K. Kikoin, B. B. Kadomtsev, and Ya. B. Fainberg for a number of useful discussions.

[1] A. I. Karchevskii, A. P. Babychev, Yu. A. Muromkin, and V. N. Bezmel'nitsyn, Zh. Eksp. Teor. Fiz. 53, 1195 (1967) [Sov. Phys.-JETP 26, 701 (1968)].

[2] A. I. Karchevskii, V. N. Bezmel'nitsyn, G. N. Makeev, and Yu. A. Muromkin, ibid. 57, No. 9 (1969) [30, No. 3 (1970)].

[3] V. S. Koidan, A. N. Papyrin, A. G. Ponomarenko, and B. A. Yablochnikov, ZhETF Pis. Red. 8, 389 (1968) [JETP Lett. 8, 241 (1968)].

[4] Yu. G. Kalinin, D. N. Lin, V. D. Ryutov, and V. A. Skoryupin, Zh. Eksp. Teor. Fiz. 56, 426 (1969) [Sov. Phys.-JETP 29, No. 2 (1969)].

[5] T. H. Jensen and F. R. Scott, Phys. Fluids 12, 1808 (1968).

[6] Ya. B. Fainberg, Atomnaya energiya 11, 313 (1961).

[7] A. P. Babichev, A. I. Karchevskii, Yu. A. Muromkin, and E. M. Buryak, Zh. Eksp. Teor. Fiz. 53, 3 (1967) [Sov. Phys.-JETP 26, 1 (1968).

[8] T. G. Roberts and W. H. Bennet, Plasma Physics 10, 381 (1968).

SOME SINGULARITIES OF THE KINETICS OF A CURRENT PINCH

M. E. Alekseev and V. P. Sondaevskii
Research Institute for Physics Problems

Submitted 27 May 1969
ZhETF Pis. Red. 10, No. 1 31 - 35 (5 July 1969)

The known experimental papers (e.g., [1, 2] contain information on current pinches in semiconductors only under stationary conditions, or else deduce the kinetics from the manifestation of effects in the external circuit. In the present paper we present the results of a study of the formation of a pinch and its displacement in a transverse magnetic field.

1. To investigate the illustration of the density of the current j over the sample cross section, we developed a method based on the measurement of the distribution of the voltage U along one of the contacts having a small longitudinal resistance. From the expression for the current along the contact and from the continuity equation in the one-dimensional case we can readily get

$$j = \sigma_K \delta \frac{d^2 U}{dx^2},$$

where σ_c is the conductivity of the contact, and δ is its thickness (the x axis is directed along the contacts, see Fig. 1).

Assuming that the conductivity σ_0 of the sample is constant, we get

$$U = U_0 \,\mathrm{sch}\, \frac{l}{2L} \,\mathrm{ch}\, \frac{2x - \ell}{2L},$$

where $L \equiv \sqrt{\sigma_c/\sigma_0}h\delta$, ℓ is the sample length, and h is the distance between contacts. To derive this expression we used the boundary conditions $U(0) = U(\ell) = U_0$, i.e., the current is fed to the edges of the contact. When $L \gg \ell$ we obtain a quadratic distribution of the voltage along the contact:

$$U = U_0 \left(1 - \frac{x(\ell - x)}{2L^2}\right),$$

hence $j(x) = \text{const}$. Thus, in the absence of a current pinch, U(x) has a practically constant curvature and an extremum at $x = \ell/2$.

When a pinch is produced, the curvature of the individual sections of U(x) changes strongly, reflecting the redistribution of the current density. Since the maximum current density occurs at the point x_0 with maximum conductivity, the extremum of U(x) will also occur at this point. Thus, the point x_0 characterizes the position of the current pinch.

2. To produce a negative differential resistance, we used in our investigation the mechanism of injection breakdown of n-Si doped with gold, with a resistivity 5×10^4 ohm-cm at room temperature. The samples were strips 1 mm wide, with thickness (distance between contacts) 0.2 mm, and various lengths up to 25 mm. The contacts were made by fusing-in aluminum and an alloy of gold with antimony on opposite faces of the sample. The total longitudinal resistance of the contacts was several ohms.

The distribution of the voltage along the contact U(x) at a given instant of time t was measured with the aid of an electric probe of 0.1 mm diameter and a stroboscopic system that made it possible to fix, during the measurement of U(x), the instant t of the pulsed modulation. In addition, we measured the dependence of the voltage on the time at x = const.

Following the switching to the state with higher conductivity, the voltage pulse on the sample, in a mode close to that of a current generator, has a steplike form characterizing the delay time at high voltages, and the time of change of state at low voltages. An investigation of the distribution of the voltage over the contact at instants of time during the delay has shown that prior to the switching the current density is uniformly distributed over the cross section of the sample. When the voltage is decreased, the current density is redistributed and the pinch is produced. The distribution U(x) established after the sample voltage had reached a stationary value has an extremum that characterizes the location of the produced current pinch. The time of formation of the pinch is several microseconds.

3. Measurements made in a transverse magnetic field have shown that the maximum of the voltage pulse $U_0 - U(x)$ observed on the probe at the point x shifts with changing position of the probe, indicating that the region with maximum current density is displaced. The data obtained from these experiments make it possible to determine the rate of displacement of the current pinch.

Figure 1 (curves 1 - 16) shows a family of $U_0 - U(x)$ curves measured at the instants of time designated by the arrows on the sample voltage pulse U_0 (lower curve of Fig. 1). The curves indicate that prior to the switching the current density is uniformly distributed over the sample cross section (Fig. 1, curve 1). After the current pinch is formed, the

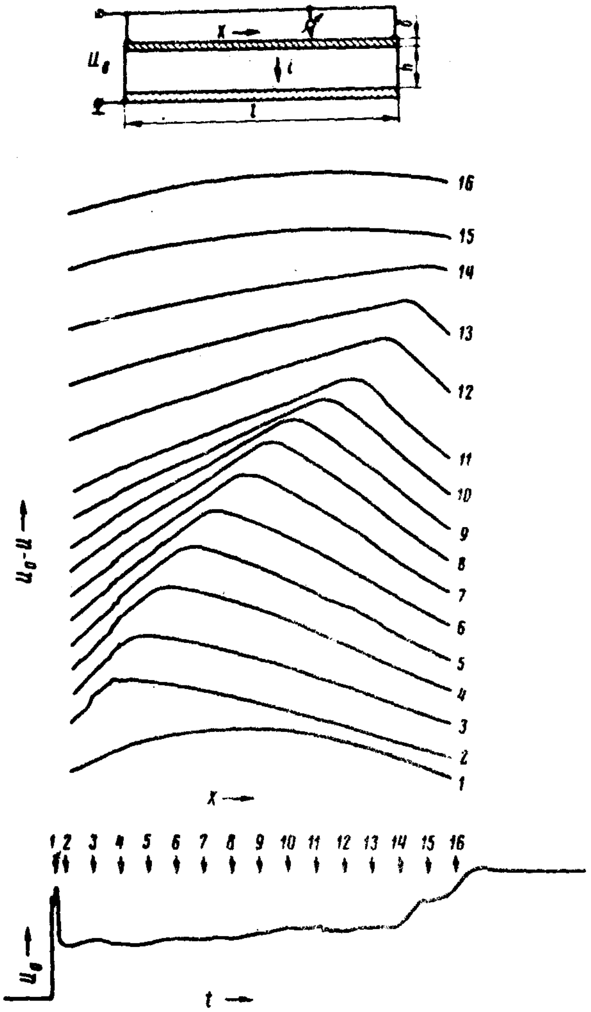

Fig. 1. Distribution of voltage $U_0 - U(x)$ along the sample contact in a transverse magnetic field H = 2.3 kOe (curves 1 - 16) at the instants of time designated by the arrows on the lower curve (sample voltage pulse U_0). The curves were obtained with a two-coordinate potentiometer with stroboscopic attachment. Scales: U - 5 mV/cm, x - 0.7 mm/cm, U_0 - 5 V/cm, t - 50 μsec/cm, repetition frequency of pulses U_0 - 70 Hz; load resistance 4 K. A system transofrming x linearly into an electric signal was used.

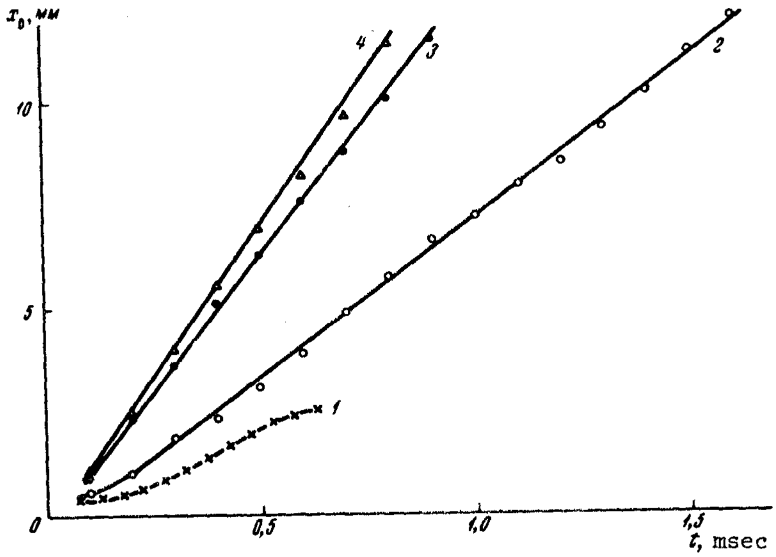

Fig. 2. Position x_0 of current pinch vs. time t at various transverse magnetic field intensities H: 1 - 1.2 kOe, 2 - 1.4 kOe, 3 - 2.2 kOe, 4 - 2.4 kOe. The current through the sample is fixed at 30 mA.

maximum of $U_0 - U(x)$, whose position characterizes the location of the region with the maximum current density, shifts in the course of time (Fig. 1, curves 2 - 14), thus indicating displacement of the pinch. When the end of the sample (or some other built-in inhomogeneity) is reached, the sample voltage begins to increase, and the pinch is destroyed (Fig. 1, curves 15 and 16), since the current in the remaining area of the sample increases. When the pinch travels through the sample, the variation of the voltage U_0 reflects the inhomogeneity of the material along x.

It was observed that the destruction of the pinch by inhomogeneities of the material leads to restoration of the pinch at the previous place, to a subsequent displacement, and to destruction. The periodic repetition of these processes causes voltage oscillations across the sample in a transverse magnetic field. When the total current through the structure is increased, a "thick" pinch may pass through those inhomogeneities that were able to destroy a "thin" pinch.

4. Measurement of the U(x) curves at a specified instant of time makes it possible to determine uniquely the location of the current pinch. Figure 2 shows plots, obtained on the basis of such experiments, of the position of the current pinch x_0 on the time t for various magnetic field intensities. The plots show that the time of establishment of a constant velocity and the magnitude of the velocity depend on the magnetic field intensity, but in all cases (Fig. 2) the pinch begins a uniform motion after traveling not more than 1 mm away from the place where it originates.

The measurements have shown that the dependence of the steady-state pinch velocity on the intensity of the transverse magnetic field is linear for magnetic fields up to 2.5 kOe. The velocity of the pinch can be characterized in this case by its mobility (i.e., by the velocity in a unit magnetic field) which amounts to 0.6 cm/sec-Oe. This is much lower than the corresponding value for gold-doped germanium at 77°K which our data indicates to be about 40 cm/sec-Oe.

Thus, the procedure developed in this investigation has made it possible to show that a) formation of the current pinch proceeds via contraction of the current lines during the course of switching the sample to a low-resistance state, b) the pinch moves in a transverse magnetic field at a velocity that reaches a steady-state value after the pinch travels about 1 mm from the point of its origin, and c) the dependence of the steady-state value of the velocity on the transverse magnetic-field intensity is linear and is characterized by a pinch mobility equal to 0.6 cm/sec-Oe.

[1] I. Melngailis and A. G. Milnes, J. Appl. Phys. 33, 995 (1962).
[2] M. E. Alekseev, I. V. Varlamov, and V. P. Sondaevskii, Elektronnaya tekhnika (Electronic Engineering), Ser. 6, No. 1, 8 (1968).