Effect of transverse magnetic field on domain instability in low-temperature plasma

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The development of the domain instability in a gaseous plasma in a transverse magnetic field has been studied theoretically and experimentally. The boundary of the plasma stability region has been found through a numerical solution of the Boltzmann equation for a nonequilibrium electron energy distribution. Studies have been made of both the case of a "thin" plasma slab, without a Hall electric field, and the case in which such a field does arise. Experimentally, the effect of a magnetic field on the course of the domain instability was studied in plasmas of externally sustained gas discharges in mixtures of CO_2 and Ar. It has been found experimentally that the condition for the onset of the domain instability in a magnetic field which had been derived previously for a solid-state plasma is valid.

1. INTRODUCTION

A domain instability stemming from a decreasing dependence of the drift velocity of the current carriers on the reduced electric field may arise in either a semiconductor plasma[1-3] or a low-temperature gaseous plasma.[4,5] In a solid-state plasma, this dependence arises because the particular structure of the conduction band of certain semiconductors causes the effective mass of the carriers to increase with increasing electric field (the Gunn effect). The corresponding dependence can be observed in a gaseous plasma, for gases and gas mixtures, under two conditions. First, the Ramsauer effect must occur. That effect leads to a sharp increase in the transport cross section for the scattering of electrons by neutral particles with increasing electron energy. Second, in this region of electron energies, the inelastic interactions of electrons with atoms and molecules must be effective (ordinarily, this interaction is the vibrational excitation of molecules). As a result, the increase in the electric field and in the average energy of the electrons leads to an increase in the electron transport frequency and to a decrease in the drift velocity.

While the domain instability in semiconductor plasmas (the Gunn effect) underlies the operation of a long list of solid-state microwave electronic devices, research on this instability in gaseous plasmas is still in its infancy. For example, this instability has been observed for N_2:Ar, CO:Ar (Ref. 6) and HCl:Ar (Ref. 7) mixtures in an externally sustained gas discharge. Several theoretical studies have been carried out on the basis of a numerical solution of the Boltzmann equation for electrons. The boundaries of the instability region have been determined in the linear approximation, and the nonlinear stage of the instability has also been studied.[5]

The effect of a transverse magnetic field on the domain instability has been discussed in the literature only in connection with semiconductor plasmas[2] (see also the bibliography in Ref. 8). In most of these studies (including the monograph by Levinshteĭn *et al.*[2]) it has been assumed that the condition for an instability of the small fluctuations which lead to the formation of domains reduces in the presence of a magnetic field to the inequality

$$dv_x/dE<0, \tag{1}$$

where **E** is the electric field applied to the sample, and v_x is the component of the carrier drift velocity along the direction of **E**. This approach has been taken even though the correct condition for semiconductors with one carrier species, with the trapping of carriers ignored, was derived some time ago by Kurosawa *et al.*[9] on the basis of energy considerations. The same result was derived in Refs. 8 and 10 by a more conventional method based on a plane-wave expansion. According to Refs. 8–10, the imposition of a transverse magnetic field can give rise to a domain instability even if the longitudinal drift velocity of the current carriers is an increasing function of the electric field (with a rising current-voltage characteristic). Some simple models of semiconductor plasmas were used in Ref. 8 to show that the use of the correct instability condition in place of (1) results in a substantial change in the threshold for the occurrence of this instability. Experiments which have been carried out in this area,[11-14] on the effect of a magnetic field on the domain instability, have used relatively weak magnetic fields. Because of the large errors in those results, it was not possible to draw conclusions about the validity of one condition or another for the domain instability in a transverse magnetic field.

There has been no previous study of the effect of a magnetic field on the domain instability. The results found for solid state plasmas cannot be applied to gas discharges, since although the external manifestations of the domain instability are largely the same in the two cases the underlying physical causes are different.

In this paper we are reporting the first theoretical and experimental study of the domain instability in a gaseous plasma in a transverse magnetic field. (Preliminary results of this study were reported in Ref. 15.) As the working gas we selected the mixture CO_2:Ar = 2:98 for convenience in the experiments. A numerical solution of the Boltzmann equation was carried out to determine the energy distribution and the kinetic coefficients of the electrons in a plasma subjected to external electric and magnetic fields. The boundaries of the region of parameter values of the gaseous plas-

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ma in which the domain instability can occur were found. Studies were made of both the case of a "thin" plasma slab, without a Hall electric field, and the case with such a field. Current oscillations in the plasma of an externally sustained gas discharge were found to be caused by the domain instability. The effect of the magnetic field on the course of this instability was studied. For the first time, experimental confirmation has been found for the validity of the condition found in Refs. 8–10 for the occurrence of the domain instability in a magnetic field.

2. CALCULATION OF THE THRESHOLD FOR THE OCCURRENCE OF THE DOMAIN INSTABILITY IN A MAGNETIC FIELD

We consider a weakly ionized gaseous plasma in mutually perpendicular electric and magnetic fields. We assume for definiteness that the electric field vector **E** is directed along the x axis, while the magnetic field **H** is directed along the z axis. Just how a transverse magnetic field affects the domain instability depends on the relation between the electron drift times along the x and y directions, i.e., $\tau_x = L/v_x$ and $\tau_y = d/v_y$, where L and d are the dimensions of the plasma region along the x and y axes, and v_x and v_y are the components of the electron drift velocity[2] (the ion current can be ignored). If $\tau_x \ll \tau_y$, the Lorentz force causes the electrons in the plasma to move by virtue of the Hall current in the direction of the electric field **E**. Since this force has a component associated with the component v_y, the electron mobility decreases along the **E** direction, and there is a change in the region in which the domain instability occurs. In the opposite limit $\tau_x \gg \tau_y$, the Lorentz force acting on the electrons along the y axis is balanced by the force due to the Hall electric field which arises from the charge buildup at the lateral boundaries of the plasma region. The effect of the magnetic field on the domain instability is weaker in this case,[2] reducing to one of simply changing the electron energy distribution.

We first take up the case of a "short" plasma slab, without a Hall field ($\tau_x \ll \tau_y$). The system of equations describing the state of the plasma in electric and magnetic fields reduces to a conservation equation for the electric charge ρ,

$$\frac{\partial \rho}{\partial t} + \operatorname{div} \mathbf{j} = 0,$$

and two electrodynamic equations,

$$\operatorname{rot} \mathbf{E} = 0, \quad \operatorname{div} \mathbf{E} = 4\pi\rho.$$

The electric current density here (the ion current is being ignored) is

$$\mathbf{j} = en\mathbf{v} - e\mathbf{D}\nabla n,$$

where e, n, and **D** are respectively the charge, density, and diffusion tensor of the electrons.[5]

A linear analysis of the plasma stability through a plane-wave expansion $\exp(-i\Omega t + i\mathbf{kr})$ with respect to the homogeneous state yields an expression for the growth rate $\Gamma = \operatorname{Im} \Omega$:

$$\Gamma = -4\pi en \frac{\partial v_i}{\partial E_j} \frac{k_i k_j}{k^2} - D_{ij} k_i k_j.$$

Here and below, a repeated index means a summation. It is assumed here that the dependence of the electron characteristics on the reduced electric field E/N (N is the density of the neutral gas) is local in space and time. This assumption is valid under the conditions $k\lambda_u \ll 1$ and $|\Omega| \ll \nu_u$, where λ_u is the electron mean free path with respect to energy relaxation, and ν_u is a characteristic frequency of the energy transfer from an electron to neutral particles. In deriving the expression for the growth rate Γ, we also used

$$\nu_u \tau_M \gg 1, \tag{2}$$

where τ_M is the Maxwellian relaxation time of the electric charge. The opposite limit $\nu_u \tau_M \ll 1$ was discussed in Ref. 5. The domain instability in a magnetic field occurs under the condition

$$\frac{\partial v_i}{\partial E_j} k_i k_j < 0.$$

By optimizing this expression with respect to the angle between the propagation direction of the perturbations and the direction of the electric field, one finds the following condition for the onset of a domain instability in a plasma:[8–10]

$$1 + \hat{\mu}_{xx} < (\mu_{yx} \hat{\mu}_{yx} / 2\mu_{xx})^2, \tag{3}$$

where μ is the electron mobility tensor, found from the expression

$$v_i = \mu_{ij} E_j, \quad \hat{\mu}_{ij} = \partial \ln \mu_{ij} / \partial \ln (E/N).$$

Condition (1), which is widely used in research on semiconductor plasmas, takes the following form in our notation:

$$1 + \mu_{xx} < 0. \tag{4}$$

The satisfaction of this condition is sufficient for the validity of (3), but the converse is not true. Specifically, it follows from condition (4) that the instability develops along the direction of the electric field. The maximum instability growth rate during the imposition of a transverse magnetic field, on the other hand, should be observed for a different direction.[8]

The problem of finding the threshold for the domain instability in a gaseous plasma thus reduces to one of calculating the electron mobility tensor and its derivatives. We will discuss the case (of practical interest) of a weakly ionized gaseous plasma in electric and in magnetic fields, in which case the characteristic electron energy is high in comparison with the thermal energy of the heavy particles, and the relations $\nu \gg \nu_u \gg \nu_{ee}$ hold. Here ν is a characteristic relaxation rate of the electron momentum, and ν_{ee} is the rate of electron-electron collisions. Under these conditions, the electron energy distribution is nonequilibrium and should be determined from the Boltzmann kinetic equation. For the distribution function in this case one can use the two-term approximation,[16] on the basis of which the homogeneous steady-state Boltzmann equation takes the form

$$\frac{e^2}{3m^2 v_e^2} \frac{d}{dv_e} \left\{ \frac{v_e^2}{\omega^2 + \nu^2} \frac{df_0}{dv_e} \left[\nu E^2 + \frac{(\omega_i E_i)^2}{\nu} \right] \right\} + S_0(f_0) = 0, \tag{5}$$

where v_e is the electron velocity, $f_0(v_e)$ is the isotropic part of the electron velocity distribution, normalized by the condition

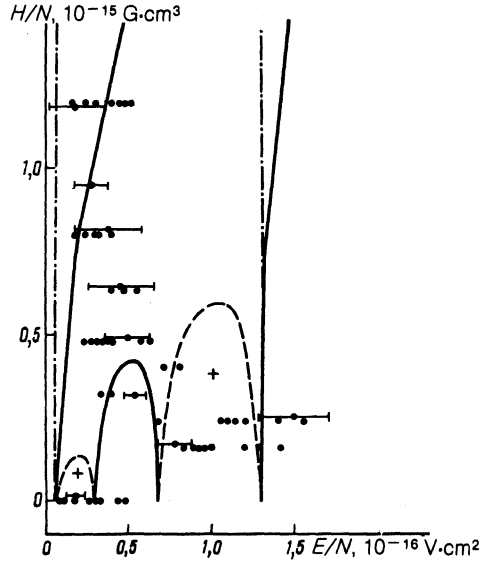

FIG. 1. Plasma instability regions (marked with a +). Solid lines—According to condition (3); dashed lines—according to condition (4); dot-dashed lines—case with a Hall field. The points correspond to the parameter values of the present experiments at which an instability was observed.

$$4\pi \int_0^\infty f_0 v_e^2\, dv_e = 1,$$

$\nu = N v_e \sigma_m$, σ_m is the transport cross section for the scattering of electrons by neutral particles, $\omega = e\mathbf{H}/mc$ is the vector electron cyclotron frequency, and $S_0(f_0)$ is the isotropic part of the electron-neutral collision integral. An expression for S_0 is given in Refs. 17 and 18, among other places.

The components of the electron mobility tensor are found from the expression

$$\mu_{ij} = \frac{4\pi}{3}\frac{e}{m}\int_0^\infty \frac{v_e^3}{\omega^2+\nu^2}\frac{df_0}{dv_e}\left(\nu\delta_{ij} + \varepsilon_{ikj}\omega_k + \frac{\omega_i\omega_j}{\nu}\right) dv_e, \qquad (6)$$

where δ_{ij} is the Kronecker delta, and ε_{ikj} is the Levi-Civita density. Under these conditions the function $f_0(v_e)$ and the product $\mu_{ij}N$ depend on only the parameters E/N and H/N.

In the present study, the region of values of the parameters E/N and H/N in which the domain instability can occur was determined for a weakly ionized CO_2:Ar = 2:98 plasma. For this purpose, Boltzmann equation (5) was solved numerically, the distribution function $f_0(v_e)$, the mobility tensor μ_{ij}, and $\hat{\mu}_{ij}$ were found. Many papers have reported calculations of this type of the properties in a gaseous plasma without a magnetic field.[17,18] The imposition of a magnetic field does not seriously complicate the problem; this problem has been solved numerically in this case in Refs. 19–21, among other places.

The calculations incorporated the elastic scattering of electrons by the Ar atoms and the CO_2 molecules; the excitation of rotational, vibrational, and electronic levels of these particles; and electron-impact ionization. Since the vibrational quantum of the deformation mode of the CO_2 molecule is small, collisions of the second kind of electrons with excited molecules may prove important even if the vibrational temperature is room temperature. However, calculations incorporating the vibrational excitation of the CO_2 molecules revealed that this effect could be ignored. The cross sections for the interaction of the electrons with the CO_2 molecules were taken to be the same as in Ref. 22, while those for the interaction of electrons with Ar atoms were chosen by analogy with those in Ref. 23. It has been shown previously that this set of cross sections leads to a good agreement between calculated electron transport coefficients (in the absence of a magnetic field) and the experimental data available in the literature.

Figure 1 shows the results of the present calculation of the boundaries of the instability region. The correct instability condition, (3), and also the more customary condition (4) have been used. As in the case of a semiconductor plasma,[8] the results of the calculations depend strongly on which condition is used. In particular, there exists a significant region ($H/N > 6\cdot 10^{-16}$ G·cm^3) in which the plasma is in an unstable state, despite an increasing current-voltage characteristic.[8-10]

It follows from Fig. 1 that in the region in which the plasma is unstable there is a "stability region," which corresponds at $H = 0$ to values $E/N = (3\text{–}6.6)\cdot 10^{-17}$ V·cm^2. The existence of this region remains an open question, since calculations with a different set of cross sections for the scattering of electrons by CO_2 molecules, borrowed from[1)] Ref. 24, result in the disappearance of this region. The outer boundaries of the instability region are essentially unaffected.

It follows from general considerations that, as in the case of a semiconductor plasma, the imposition of a transverse magnetic field should lead to a stabilization of a gaseous plasma in the absence of a Hall field. The reasoning here is that the instability is caused by a sharp increase in the function $\nu(v_e)$, because of the behavior $v_x \propto \nu^{-1}$. However, at sufficiently strong magnetic fields ($\omega \gg \nu$) the behavior $v_x \propto \nu$ sets in, and the cause of the instability drops out of the picture. According to condition (3), on the other hand, this event occurs at values of H/N which are too high—too difficult to achieve experimentally. For this reason, these results are not shown in Fig. 1. The effect of a moderate magnetic field reduces to one of causing the instability region to shift rightward, toward larger values of E/N, as H increases. The shift of the left-hand, "low-energy" boundary is noticeably greater than that of the right-hand, "high-energy" boundary. The explanation is that the decrease in the drift velocity along the external electric field caused by the magnetic field results in a cooling of electrons. As a result, the average electron energies corresponding to the region in which the domain instability occurs are realized at larger values of the ratio E/N. This effect becomes stronger as the ratio ω/ν increases. Because of the minimum on the plot of ν versus v_e (for Ar atoms) at low energies, the value of ω/ν is higher, and the shift of the left-hand boundary of the instability region is larger.

Let us consider the case $\tau_x \gg \tau_y$, in which a Hall field E_H is set up along the y direction. The magnitude of this field can be found from the condition $v_y = 0$:

$$E_H = -E\mu_{yx}/\mu_{xx}. \qquad (7)$$

The effect of the Lorentz force on the electrons is offset to a large extent by the Hall field, and the imposition of a magnetic field should have only a slight effect on the course of the domain instability.[2] A condition for instability with respect to small perturbations in the case $\tau_x \gg \tau_y$ is found by analogy with (3); it is

$$[1+\hat{\mu}_{xx}+a(1+\hat{\mu}_{yx})][1+a(1+\hat{\mu}_{xx}-\hat{\mu}_{yx})]$$
$$<{}^1/_4 a[(a-1)\hat{\mu}_{yx}+2\hat{\mu}_{xx}]^2, \quad (8)$$

where $a=(\mu_{yx}/\mu_{xx})^2$. The quantity E^2 in Boltzmann equation (5) should be replaced by the square of the absolute value of the total electric field, $E^2+E_H^2$. The electron distribution function $f_0(v_e)$ thus depends on not only the applied (external) electric field but also the Hall field here. The Hall field in turn depends, through the components of the electron mobility tensor [expression (7)], on the function $f_0(v_e)$.

This self-consistent problem has been solved by an iterative method in the present study. The values found for μ_{xx} and μ_{yx} were used to determine the region of parameter values in which the state of a gaseous CO_2:Ar = 2:98 plasma is unstable. The results of these calculations are shown in Fig. 1. As expected, the magnetic field causes essentially no change in the stability boundary in the presence of a Hall field.

Levinshteĭn *et al.*[2] have pointed out that the changes in processes near the electrodes in a semiconductor sample could have a noticeable effect; they could lower the threshold for the domain instability. That effect cannot be considered on the basis of the homogeneous model we are using here, however, so the changes in the characteristics near the electrodes in a gaseous plasma upon application of a magnetic field must remain an open question.

3. THRESHOLD FOR THE ATTACHMENT INSTABILITY IN A MAGNETIC FIELD

An attachment instability can also occur[4]—along with the domain instability—in the plasma of a CO_2:Ar mixture. It is thus worthwhile to study the effect of a magnetic field on the threshold for the occurrence of this other instability.

Aleksandrov *et al.*[26] have found an expression for the attachment instability in a gaseous plasma with a magnetic field (see also Ref. 5). In the present study, we analyzed this expression and examined the behavior of the growth rate as a function of the direction of the wave vector. The condition for the occurrence of this instability as a function of the magnitude of the magnetic field was found. The general expression for the threshold is quite complicated, but it simplifies considerably in the particular case in which the electron kinetics is determined by an external ionizing agent and by the attachment process, the density of negative ions is low in comparison with that of positive ions, and the rate ν is constant. In this case the highest growth rate corresponds to an angle

$$\varphi={}^1/_2\,\mathrm{arctg}(\omega/\nu)$$

between the perturbation wave vector and the electric field. The condition for the occurrence of the attachment instability in this case is

$$\hat{k}_a[1+(1+\omega^2/\nu^2)^{1/2}]>2, \quad \hat{k}_a=\partial\ln k_a/\partial\ln(E/N), \quad (9)$$

where $\hat{k}_a$ is the logarithmic derivative of the rate constant for electron attachment with respect to the electric field. Here we are assuming a dissociative attachment to CO_2 molecules, for which the relation $\hat{k}_a>0$ would hold. The case $\hat{k}a<0$ is analogous to the ionizational instability of a plasma in a magnetic field.[26,27]

According to condition (9), the imposition of a magnetic field promotes the attachment instability. There can be a situation in which the plasma is stable in the absence of a magnetic field, and the imposition of such a field causes an instability. The reason for this behavior is that perturbations with a wave vector making an angle with the electric field may be amplified when the growth rate is at its highest.

4. EXPERIMENTAL STUDY OF THE STABILITY OF A GASEOUS PLASMA IN A MAGNETIC FIELD

Since the characteristic values of E/N which correspond to the condition for the occurrence of the domain instability are not large, an externally sustained discharge, controlled by an electron beam, was chosen for a study of this instability.

The experimental apparatus is shown schematically in Fig. 2. A quasisteady magnetic field was produced by two multiturn coils connected in series. The design of the coils was chosen in such a way that the magnetic field would be sufficiently uniform in the region of the discharge between two copper electrodes 1×1 cm^2 in size. The coils, with a total inductance of 250 μH and a winding resistance of 0.11 Ω, were fed the discharge current from a 600-μF capacitor bank charged to a voltage up to 5 kV. An IRT-10 igniter was used for switching. The magnetic field pulse was sinusoidal with an oscillation half-period of 1.15 ms (Fig. 3). Over a time of about 250 μs near the maximum, the field varied by about 10%; this time interval was selected for use. The strength of the magnetic field was varied smoothly from 2 to 100 kG by varying the voltage to which the capacitor bank was charged. The magnetic field and the spatial distribution of the field were measured by a magnetic probe 5 mm in diameter and 1 mm thick. This probe was connected to an oscilloscope through an *RC* integrating circuit with a time constant of 10^{-2} s.

An externally sustained atmospheric-pressure discharge was ignited in a square chamber with a cross section of 1×1 cm^2. A square voltage pulse up to 1 ms long and up to 6 kV high was applied to electrodes separated by a distance of 1 ms. The electric field was applied in a direction perpendicular to the magnetic field. The ionizing agent was a beam of fast electrons, with an energy of 120 keV. To prevent the

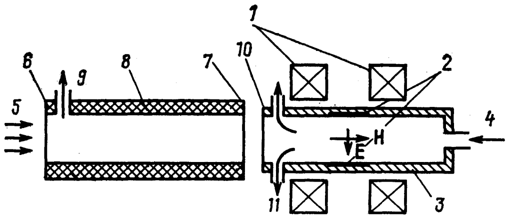

FIG. 2. Experimental layout. 1—Coils; 2—electrodes; 3—quartz chamber; 4—gas flow; 5—electron beam; 6,7—foils; 8—drift tube; 9—pump; 10—Lavsan film; 11—to atmosphere.

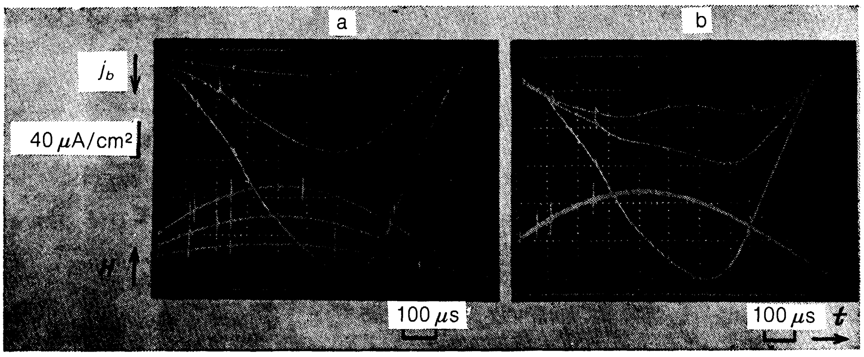

FIG. 3. Oscilloscope traces of the beam current (the upper traces) and of the magnetic field. a—The beam current j_b at maximum magnetic fields $H = 4$, 8, and 12 kG (a larger value of j_b corresponds to a larger value of H); b—beam current at the symmetry axis of the discharge (the highest current) and at a distance of 0.6 cm to the right and left of this axis, at $H = 12$ kG.

fast-electron beam, focused by the magnetic field, from burning through the exit window of the electron gun we used a drift tube 10 cm long. This drift tube was pumped down to the same pressure as that in the gun chamber. A film of Lavsan polyester was used to prevent a discharge from occurring between one of the discharge electrodes and the wall of the drift tube.

A Faraday cup 4 mm in diameter was used to study the distribution of the beam current over the region occupied by the externally sustained discharge. Figure 3 shows oscilloscope traces of the beam current density and of the signal from the magnetic probe for various values of the magnetic field, at various points in the discharge volume. The observed shape of the beam current pulses and the spatial distribution remained the same at higher magnetic field strengths. To increase the duration of the stable stage of the discharge, we subsequently reduced the beam current at stronger magnetic fields. The measurements showed that the magnetic field was uniform within 2.5% over a distance of $\pm$ 1.5 cm from the center of the discharge region, both at the symmetry axis and at a distance of 1 cm from it. This nonuniformity is the same as the relative error in the measurements of the magnetic field strength.

The electric field in the discharge was found from the potential difference across the electrodes, from which the cathode drop, U_c, was subtracted. To determine U_c we carried out some auxiliary studies of an externally sustained discharge in a CO_2:Ar = 2:98 mixture at various beam currents in the absence of a magnetic field. Figure 4 shows the reciprocal of the voltage U_T, at which the externally sustained discharge undergoes a transition from the Thomson regime (T regime) to the electroionization regime, and the typical discharge current density in the electroionization regime, j_d, as functions of the square root of the beam current density j_b. The discharge current density depends only weakly on the discharge voltage at a fixed beam current density; the changes in the discharge current density amount to $\pm$ 25% of the values shown in this figure. It can be seen from Fig. 4 that the points conform well to straight lines, from which we find the following analytic expressions:

$$j_d=12j_b^{1/2}, \quad U_T=2800/j_b^{1/2} \tag{10}$$

(j_d is in milliamperes per square centimeter, j_b in microamperes per square centimeter, and U_T in volts).

The experimental results on the dependence $U_T(j_b)$ found above agree with the theoretical results calculated in Ref. 28 under the assumption of a homogeneous model of the cathode sheath. Photography of the discharge revealed that the cathode sheath under these conditions (with or without the magnetic field) has a spotty structure, similar to that observed in Ref. 29. According to Ref. 29, the voltage at which the transition from the T regime to the electroionization regime occurs is the same as that calculated from the expression in Ref. 28, and the relation $U_c < U_T$ holds. To determine U_c we accordingly used the expression

$$U_c=20\,000/j_d$$

(U_c is in volts, and j_d in milliamperes per square centimeter), which was found from the experimental results in (10). We estimate the error in a determination of U_c in this way to be 50%.

The domain instability was studied as the magnetic field was varied from 0 to 30 kG. At stronger magnetic fields, the spatial and temporal uniformity of the ionization of the gas in the discharge volume suffered because of the strong focusing of the electron beam. This deterioration resulted in a very unstable discharge, as can be seen from the rapid transition

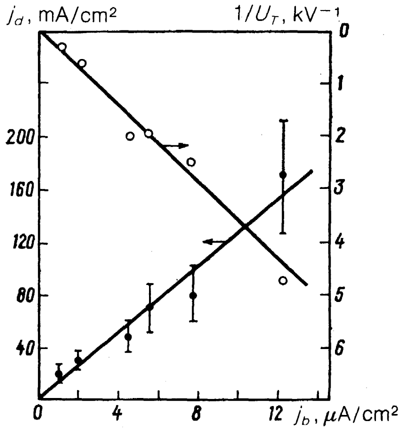

FIG. 4. The voltage U_T, at which the externally sustained discharge switches from the T regime to the electroionization regime, and the characteristic discharge current density j_d versus the current density of the fast-electron beam, j_b.

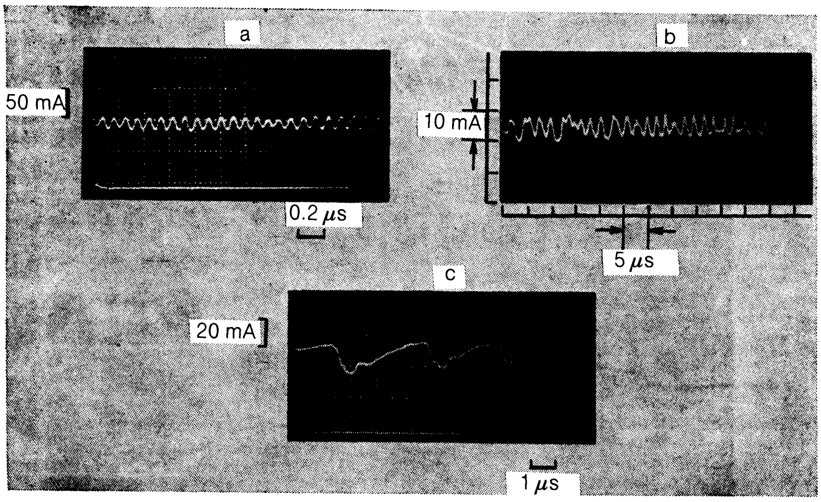

FIG. 5. Oscilloscope traces of the oscillations in the discharge current in a mixture CO_2:Ar = 2:98. a—$H = 0$, discharge voltage $U_{dis} = 500$ V, $j_b = 60$ μA/cm^2; b—$H = 6$ kG, $U_{dis} = 4$ kV; c—$H = 4$ kG, $U_{dis} = 2.8$ kV.

of the discharge from the T regime to arcing, without an electroionization regime.

Oscillations of the discharge current with a period of 10^{-7}–10^{-6} s were detected both with and without a magnetic field. Figure 5 shows some typical oscilloscope traces of these oscillations. Their shape is very sensitive to the discharge parameters and can become quite complex. The period of the current oscillations caused by the domain instability is determined by the transit time of a domain between the discharge electrodes.[2,4] For the experimental parameter values we have a product $\nu_u \tau_M = 3$–300, and condition (2) holds almost everywhere. In this case, the domain velocity is close to the electron drift velocity v. According to the present calculations, we have $v \sim 10^6$–10^7 cm/s, and the period of the current oscillations caused by the domain instability agrees with that observed experimentally. Estimates show that under these conditions the attachment instability should lead to oscillations with a period several orders of magnitude longer.

The points in Fig. 1 show discharge parameter values at which the domain instability was observed. While the current oscillations are well-defined for $H/N < 8\cdot 10^{-16}$ G·cm^3, at higher values of H/N they weaken, and the discharge regime is itself unstable. The Hall parameter here is $\omega/\nu \sim \mu_{yx}/\mu_{xx} \leqslant 10$.

From the calculated values of the tensor components μ_{ij} one can determine the conditions under which regimes with and without a Hall field occur. At $H/N < 6\cdot 10^{-16}$ G·cm^3 we have $\tau_x < \tau_y$, and there is no Hall field. At higher values of H/N, the Hall field must be taken into consideration.

The experimental data of the present study agree with the calculated results: Within the experimental errors, all the points fall in the region of parameter values in which the plasma is unstable. The observation of oscillations in the inner "stability region" at low values of H/N and at $E/N = (3$–$7)\cdot 10^{-17}$ V·cm^2 is indirect evidence that the set of cross sections for the scattering of electrons by the CO_2 molecule from Ref. 24 is better than that from Ref. 22. A comparison of the experimental data with theoretical results found on the basis of the conventional condition for the occurrence of the domain instability, (4), shows unambiguously that the latter condition is erroneous. We are thus seeing the first experimental confirmation of this conclusion, which has been reached previously in theoretical studies.[8–10] When a transverse magnetic field is imposed, the correct condition for the occurrence of the domain instability reduces to expressions (3) and (8).

[1)] The set of cross sections from Ref. 24 differs from that given in Ref. 22 primarily in that the cross section for the excitation of the antisymmetric mode of the CO_2 molecule is larger. Bulos and Phelps[25] suggested this change on the basis of their measurements of the rate constant for this process.

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