STABILIZATION OF A HELICAL INSTABILITY IN AN ELECTRON-HOLE PLASMA IN A SEMICONDUCTOR BY AN ALTERNATING ELECTRIC FIELD

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A study was made of the influence of an alternating electric field on the development of a helical current instability in a semiconductor plasma in a magnetic field. Experiments revealed regions of suppression and enhancement of the instability under the action of an alternating electric field. The results obtained confirmed the possibility of using time-varying electromagnetic fields for the stabilization of a plasma.

CALCULATIONS have shown[1,2] that it is possible to stabilize some types of hydromagnetic instability in a plasma by means of rapidly varying electromagnetic fields. The mechanism of the suppression of instabilities is analogous to the strong focusing of charged particles in accelerators, or the dynamic stabilization of an inverted pendulum with an oscillating suspension.[1-3]

In the present study, we have attempted to detect experimentally the stabilization, using an alternating electric field, of one of the widely investigated types of helical current-convective instability in the electron-hole plasma of a semiconductor[4] in a magnetic field. Such an instability in the semiconductor plasma is identical[4] with the instability observed earlier in the positive column of a gas discharge.[5]

The method of observing the instability was analogous to that described in[6,7]. A sample of germanium of 50 Ω · cm resistivity and measuring 1 × 1 × 7 mm was placed in a magnetic field H = 3500 Oe, applied parallel to the long dimension of the crystal. The current was supplied to the sample's ends through indium—tin contacts. In the region of constant electric field intensities $E > 30-50$ V/cm in the crystal, strong current oscillations, having frequency of the order of several hundred kilocycles per second, were observed in a resistor connected in series with the crystal. The oscillations, due to the current instability, were observed also in probes with point pressure contacts, placed on the crystal faces.

The threshold value of the electric field E_0, at which the oscillations appeared, was inversely proportional to the square of the thickness of the rod sample and in satisfactory agreement with the calculations given in[4]. The frequency of the oscillations was a linear function of the field E_0, also in good agreement with[4]. Figure 1a shows an oscillogram, which shows the behavior of the frequency and amplitude of the current oscillations when E_0 is altered in steps. The increase of the amplitude and frequency of the current oscillations with increase of E_0 is evident in this figure.

To study the role of alternating fields in our case, we selected the simplest variant of high-frequency modulation of the electric field applied to a crystal. In spite of the lack of accurate calculations for our case, we may assume, by analogy with the simplest mechanical and electrical systems, that to stabilize the investigated instability we can choose any parameter which acts on the frequency of the oscillations as a forcing parameter.

The measurements using an alternating field were carried out in the intrinsic conduction region of germanium. We used electric field intensities which did not affect the carrier distribution function, and employed a pulse regime which made it possible to maintain a constant temperature in the crystal lattice in spite of the use of relatively strong currents. We employed an electronic circuit which kept the electric field component E_0 rigidly constant and independent, in particular, of the amplitude of the current oscillations and the value of the alternating field $\tilde{E}$. The spatial distributions of magnetic and electric fields in the region of the sample were uniform.

Under these conditions, we eliminated completely the relatively trivial plasma stabilization effects associated with the additional high-frequency ionization, which have been detected under the action of an alternating electric field on a similar helical instability in the positive column of a gas discharge.[8,9] The effects, associated with the presence of field gradients,[9] were also absent.

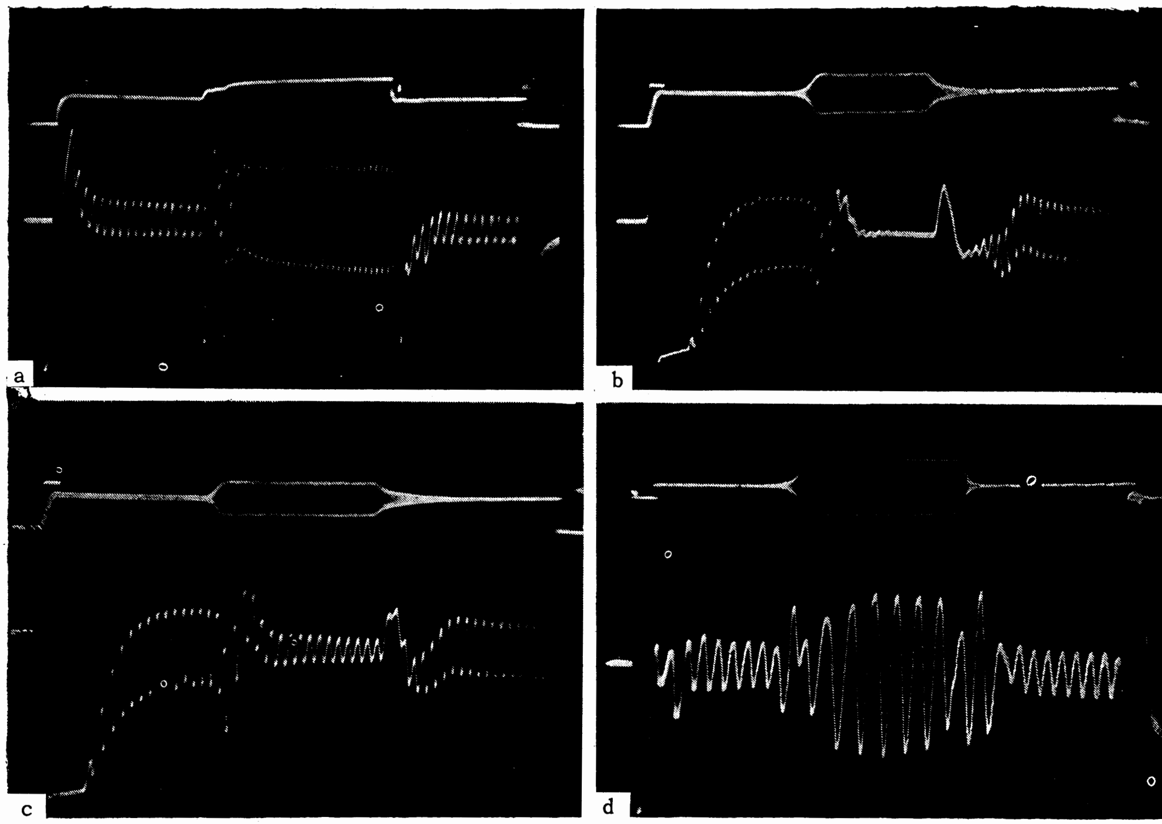

FIG. 1. Effect of constant and alternating fields on the instability. The upper trace represents the electric field intensity, while the lower trace represents the instability current (frequency f = 370 kc). In oscillograms b and c, the value of E_0 is 170 V/cm.

Figure 1b shows an oscillogram of the current oscillations under the action of a constant electric field as well as a field modulated at a frequency of 10 Mc. To obtain a clear picture, the high-frequency field amplitude $\tilde{E}$ was selected to be equal to the value of the constant field step in Fig. 1a. Figure 1b shows clearly the reduction in the amplitude and frequency of the current oscillations under the action of the field $\tilde{E}$ on the crystal. A comparison of Figs. 1a and 1b clearly proves the existence of the stabilization effect. Figure 1c shows practically complete suppression of the instability in the plasma when a sufficiently strong alternating field $\tilde{E}$ is applied.

It must be mentioned that, as a rule, the generation and stabilization of the oscillations was observed also over a certain range of angles φ between the crystal axis and the direction of the magnetic field H. In the region where oscillations were generated the angle φ did not usually exceed 20°. A more careful study of the action of the modulated electric field on the current instability at non-zero values of φ, led to the discovery of a narrow range $\varphi \approx (6 \pm 1)^\circ$, in which the high-frequency field $\tilde{E}$ amplified the instability instead of suppressing it (Fig. 1d). When φ was close to zero, this amplification of the instability by an alternating electric field was not observed in the majority of the investigated crystals of various geometries.

In spite of the obvious complexity of the phenomenon, the existence of a characteristic region in which the instability is amplified by a high-frequency field indicates a close analogy between the phenomena investigated in our work and the process of strong focusing having characteristic regions of stable and unstable solutions.

The dependence of the stabilization effect on the amplitude of the high-frequency field $\tilde{E}$ obtained in our experiments is also rather interesting. The process of the instability suppression is clearly of the threshold type, as shown in Fig. 2, which gives the dependence of the amplitude of the instability current on the modulation coefficient of the electric field $\tilde{E}/E_0$ for three values of E_0. It is evident also that the effectiveness of the instability-suppression process, characterized by the value of $\tilde{E}/E_0$, increases with increase of E_0. Usually, the stabilizing action of an alternating electric field decreased with increase of the length of a crystal.

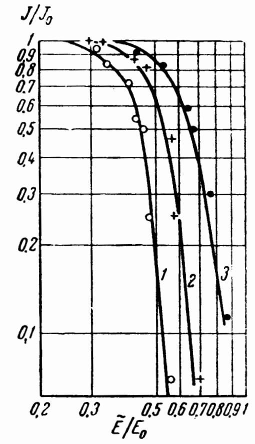

FIG. 2. Dependence of the reduced amplitude of the instability current $\tilde{J}/J_0$ on the modulation coefficient of the electric field $\tilde{E}/E_0$: 1) $E_0 = 220$ V/cm; 2) $E_0 = 169$ V/cm; 3) $E_0 = 124$ V/cm.

In conclusion, it should be mentioned that the absence of a more or less complete theory of the process of stabilization of a plasma by alternating electric fields, which involves great mathematical difficulties, does not allow us to generalize reliably the experimental data. However, the fact of the suppression of the instability by a high-frequency electric field indicates that it would be useful to carry out similar tests on gaseous plasma systems because of the similarity of many phenomena in semiconductors and gaseous discharges. On the other hand, the simplicity of experiments on semiconductors and the high degree of reproducibility of the results, difficult to achieve in experiments on gas-discharge plasma, allow us to hope that further development and refinement of the theory of the observed effect will help to expand investigations of the process of high-frequency stabilization in semiconductors.

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114