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Physics

CONTROL OF HIGH-NONEQUILIBRIUM CONDITIONS OF ECOPROCESSES

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Based on the similarity revealed between the processes occurring in the atmosphere and in semiconductor electron-hole plasma, the issues of controlling the atmospheric conditions in the surface layer have been considered. It was established that on the analogy with multistable semiconductor electron-hole plasma a new method for monitoring the atmospheric conditions and processes taking place in the layer may be developed. Analytical expressions for the control signal and potential formed in the atmosphere of dissipative structures were obtained. These expressions were shown to serve as a sufficient basis for construction of appropriate numerical methods.

Keywords: high nonequilibrium conditions, substance distant quasicontinuous measurements, management of ecoprocesses.

Introduction. The aggravation of environmental conditions in the ambient medium and surface atmosphere sets new problems of scientific and technical nature. Nowadays it is required to conduct the control and monitoring of environmental conditions in the quasi-continuous mode. Besides the knowledge of atmospheric conditions and of the distribution of some substance in it, the problem of the control of these conditions comes out in the forefront. In many problems of environment sciences the knowledge of the parameters of the ecological system and of external influences is indispensable.

Monitoring Technique of High Nonequilibrium Conditions Processes. The values of parameters as determined by means of direct measurements are not always sufficiently accurate and prompt. In these cases the indirect method of determination based on the solution of inverse problem may prove more efficient. E.g., the field of wind velocities affects the dynamics of substance distribution, and if the measurement of the latter is more effective and informative, then based on the results of these measurements one can determine the temperature field in air or other fields. If the required substance is absent at the moment in the atmosphere, it may be introduced in relatively small quantities.

The mathematical model of semiconductor plasma is universal and for the desired phenomena of transfer and kinetics in the atmosphere it is possible to find and select an appropriate formal model in plasma. This assertion refers pari passu also to processes of external influences in general and to their control, in particular.

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It is reasonable to study a composite problem, when there is an external (controlling) influence on the processes in atmosphere, and the information on the change of conditions is obtained by measuring of the distribution of some reference substance (e.g. the smoke pouring from an industrial chimney) for further calculations on the basis of these data.

With this aim in view we shall consider the following kinetic equation [1]

$$\frac{d\rho}{dt} = G(\rho) - R(\rho) + g(\vec{r}, t), \tag{1}$$

where $G(\rho)$ and $R(\rho)$ are the velocities of the formation and disappearance of substant (say, the aerosols) due to inherent causes, and $g(\vec{r}, t)$ characterizes the velocity of substant formation under the effect of an external influence. Here by means of $g(\vec{r}, t)$ both the actual formation of particles and the one allowing for the external influences that would formally lead to an equivalent formation of particles may be described.

It is precisely with the help of equation (1) that the classical motion of electron-hole plasma in semiconductors is described [2, 3].

As the theory of plasma phenomena is sufficiently well developed and its predictions readily permit experimental verification, in what follows we shall use the plasma as an analogue for clearness. Here the obtained results will be transferred to the model of atmosphere using some correspondence rule.

First let us consider the following stationary boundary value problem:

$$a\rho + b\frac{\partial\rho}{\partial t}\ |_{\Sigma} = \varphi(\Sigma)\,. \tag{2}$$

The solution of problem (1), (2) would serve as a basis for investigation of the dynamics of system under study, of the transient processes in it, of fluctuation instability as well as for controlling the conditions.

Following [2, 3] it is appropriate to obtain formulae for the density of flux (in the atmosphere – the particle fluxes), the phenomenological expression of which for the given range is as follows:

$$j = j_{\text{int}} + j_{\text{left, right}} + j^{\text{control}}. \tag{3}$$

The terms included in the right-hand part of expression (3) represent the fluxes due to the internal processes, the inflow-outflow from left and right, and the last term is for the control current. The explicit expressions for these fluxes are obtained for the specific model by solving the problem (1), (2) in case of $\partial / \partial t \to 0$.

If the physical system (plasma or atmosphere) is nonuniform, then the type (3) equations are written for each area in separate and the obtained solutions joined using the continuity conditions:

$$\rho(\Sigma - 0) = \rho(\Sigma + 0), \quad \nabla\rho(\Sigma - 0) = \nabla\rho(\Sigma + 0)\,. \tag{4}$$

Now analyze these processes in more detail based on the example of electron-hole plasma in a four-layer bipolar structure.

Instead of boundary conditions (2) we accept the following ones [2, 3]:

$$\rho_k(l_k) = \bar{\rho}_k e^{V_k}, \quad \rho_k(d_k) = \bar{\rho}_k(e^{-V_k} + a_k j_k(d_k))\,. \tag{5}$$

Here V_k is the voltage on the *k*-th nonuniform area (*p-n* transition) in terms of kT/e; $\rho_k(l_k)$ is the density of (nonbasic) carriers in *k*-th quasineutral areas, $j_k(l_k)$ is the density of current of these carriers.

Analogous to these in atmosphere are: the area of laminar fluxes – the quasi-neutral base, nonuniform areas (drains-sources, vortex-type flows etc.), *p-n* transitions in plasma.

As a result of integration of equations (1), (4) and (5) in diffusion approximation for members of the right-hand side (3) the expressions are obtained:

$$j_{\text{int}} = \begin{cases} i_k(e^{V_k}-1)+i_k\delta_k e^{\frac{V_1}{2}}, \text{ if } k \text{ is even,} \\ i_k(1-e^{-V_k})+i_k\delta_k\sqrt{V_k}, \text{ if } k \text{ is odd,} \end{cases} \quad j_{\text{left, right}} = \begin{cases} \beta_{l,p} i_k(1-e^{-V_k}), \text{ if } k \text{ is even,} \\ \beta_{l,p} i_k(e^{V_1}-1), \text{ if } k \text{ is odd,} \end{cases} \tag{6}$$

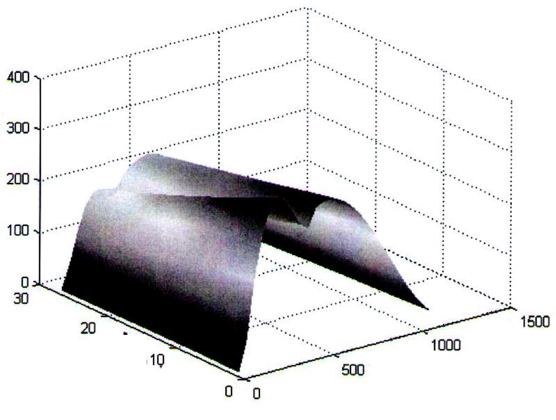
where $\beta_{l,p}$ are the coefficients (probabilities) of the transfer of the *k*-th area, i_k is the density of a saturation current, δ_k is the dimensionless coefficient of the recombination-generation process in the *k*-th nonuniform area.

Now take note of the fact that in the first formula of (6) the V_k-dependences of both the terms are different and when $\delta_k > 1$ their difference may become a sign-variable quantity. This fact along with the condition for continuity of current – the condition of conservation of air mass, leads to an internal negative feedback in the system.

It is easy to show that in case of

$$j_{sr} = \frac{i\delta^2}{4}\left[\left(\frac{\beta_2}{\beta_2+\beta_3-1}\right)^2 - 1\right] - j_{\text{int}}, \tag{7}$$

the differential resistance $R_g = \dfrac{d(V_1+V_2+V_3)}{dj}$ grows negative, i.e. the voltage drop decreases as the current increases. This effect takes place also in the general case, if only the first term in the right-hand side of (3) has two summands having different rates of change. The dependence of the family of current-versus-voltage characteristics on j^{control} is shown in the Figure.



The dependence of the family of the current vollage characteristics on j^{control}.

In the state of system with $R_g < 0$ the question arises as to the instability of system with respect to macrofluctuations. In this connection after integration of equation (1) in a fictitious tube with $\Delta\delta = \Delta x + \Delta y$ dimensions (see Figure) we obtain:

$$C_1\frac{\partial V_1}{\partial t} - C_2\frac{\partial V_2}{\partial t} = j_2 - j_1, \quad C_2\frac{\partial V_2}{\partial t} - C_3\frac{\partial V_3}{\partial t} = j_3 - j_2, \quad V = V_1 + V_2 + V_3\,, \tag{8}$$

where C_i is the capacity of the i -th nonuniform area. The basic state of fluctuation in the homogeneous case with $R_g < 0$ under the boundary conditions

$$V_k\big|_{\Sigma} = V_k^{st}; \quad \frac{\partial V_x}{\partial x} \neq 0, \quad x \in [0, l_x],$$

is described by the distribution [5, 6]

$$V_2(\alpha) = 2\ln\frac{2}{\alpha(1 + x^2/2)}, \tag{9}$$

which corresponds to a dissipative structure with a neutral-steady state.

Conclusion. The fluctuation does neither grow nor disappear, it is in finitary periodical motion, a two-dimensional analogue of which is the cyclone of tornado.

One may prevent the settling of the neutral-steady state condition by using the third term in the right-hand side of (3) or destroying that according to (7).

In the presence of strong fields there may arise multiparticle processes (ionization by collision, Auger-recombination etc.), leading to the avalanche-like effects. The allowance for these effects may be made following [7, 8] by using terms $R(\rho)$ and $G(\rho)$ in formula (1) by means of the aforementioned methods.

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