Nonlinear oscillations in the Knudsen plasma diodes

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Time-dependent processes occurred in planar plasma diodes are considered. We suppose that the electrons and ions leave the emitter surface with a prescribed velocity distribution functions (DF) and travel collisionlessly between electrodes due to a self-consistent electric field. The theory of nonlinear oscillations in the Knudsen diode with surface ionization (KDSI), where the emitted electrons and ions have the half-Maxwellian DF, is presented. The Knudsen thermionic energy converter and *Q* machine are examples of the KDSI. Both devices exhibit the nonlinear oscillations of the electron current with large amplitude.

The details of time-dependent processes in the vacuum diode, where DF of emitted electron is close to the monoenergetic one, are studied. About 30 years ago, the vacuum diode with directed electron beam has attracted attention in connection with the creation of high power microwave generators such as vircators, reditrons, and reflecting triodes. Under certain conditions, highly nonlinear oscillations can arise the diode. This process is accompanied by an intense energy exchange between the electrons and the time-dependent electric field. As a result, a fraction of energy of the electron beam is transferred to the virtual cathode oscillations, the energy of which is converted into electromagnetic radiation. There is intense energy exchange between charged particles and the electric field in all devices mentioned. This results in a strongly non-equilibrium DFs and even its disruption. In order to describe correctly such processes the kinetic and Poisson equations should be solved.

In the investigations, we extensively use our E,K-code. The code involves the fact that, in the collisionless case, the velocity DF is conserved along the trajectory of each particle. To calculate the DF in a node of the spatiotemporal grid, a number of trajectories of the test particles is computed. The main feature of the method is a calculation of the trajectory of any particle backward in time to the moment when the trajectory reaches the emitter surface. As a result, from a given arrival velocity u, the velocity and time when a particle is injected from the emitter are determined, as well as the value of the DF at the velocity u. In order to guarantee the accuracy in calculating the DF and its moments, the velocity step is chosen such that the difference between two DF-values for neighboring trajectories does not exceed a certain value. The particle density distributions over space being obtained, the Poisson equation is solving. At each time step, iterations of kinetic and field units are performed in order to obtain a self-consistent solution.

The complete theory of the nonlinear oscillations within the KDSI has been created. These oscillations are characterized by periodic sequences of two types of stages: the slow (related to the slow motion of the ions) and fast (compared with the time an electron takes to travel the electrode distance d) ones. When calculating the slow stage we suppose that the electrons overcome the gap d before the ions move over the distance of the Debye length λ_D. Then it can be considered, that to the moment when ions moved over distance about λ_D, the electrons and electric field in the electrode gap have already a time to redistribute and conform with a given ion distribution. Therefore the timescale is selected to be the time for ion to travel λ_D. At each step the electron and electric field distributions for a given ion background are determined as a stationary problem. This task as a rule has several solutions. The potential distributions that can be realized as well as their stability properties, are analyzed by the η,ε-diagram technique. At certain instants during the slow stage the Pierce type instability arises, and a fast stage starts. Here the timescale is selected to be the time for an electron to travel λ_D. During this stage, the ion distribution may be considered as the unchanged one. Oscillation process occurs with severe rearrange of a potential distribution and deep modulation of electron current. In the course of oscillations, electrons intensively transfer their energy to ions via the electric field. Fast ion beams form. Various nonlinear structures: the moving virtual cathode and double layer, as well as the structures, generated when electrons are trapped into the potential well, that being forming during the fast stage of the oscillations, are studied.

The details of oscillation process in the vacuum diode with monoenergetic electron flow are studied. A threshold when the oscillations arise exists as in the KDSI. Regions, within which several oscillation solutions can exist, are discovered. The amplitude of oscillations as a function of the beam current is built. Physical phenomena and structures inherent in the nonlinear oscillations are studied in details. A phenomenon of the sharp jumps in the temporal dependencies of convection current is discovered and clarified. The reason why the long-lived electrons come into being is clarified.