§32. Kinetic Simulation on Nonlinear Oscillation in Gas Discharge Plasma with Convective Scheme

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Our motivation for present research is to discuss the physics of plasma and sheath system consistently. It has been reported that the system of DC discharged Ar plasma with thermionic cathode exhibits forced or self-excited chaotic oscillation. We showed the result of analysis of chaotic oscillation on forced-oscillation system by assuming charge distributions for each species and solving the Poisson equation with a linear approximation[1]. To improve the approximation for describing electric current composed of many ions motion, the self-consistent method is necessary. The convective scheme has an advantage that statistical errors arising from the limited particle number are small, because the distribution function can be treated as continuous function[2]. In the research, we report the simulation results of ion acoustic wave in the plasma-sheath system and report the theoretical analysis on the mode. The growth of the wave can be interpreted as the linear phenomena.

Simulation setting is one dimensional system described by the velocity-coordinate phase space, and we investigate only ion motion. The force acting on the ion is considered only electric field from the Poisson equation. We assume electron distribution as the Boltzmann distribution. The kinetic equation of ion distribution function and the Poisson equation are coupled together.

$$\frac{\partial f}{\partial t} + v\frac{\partial f}{\partial x} + \frac{e}{M}E\frac{\partial f}{\partial v} = -\frac{\partial}{\partial v}(-\nu v f) + S\delta(v), \quad (1)$$

$$-\frac{\partial^2 \phi}{\partial x^2} = \frac{e}{\epsilon_0}\left[n - n_{e0}\exp\left(\frac{e\phi}{T_e}\right)\right]. \quad (2)$$

Then f denotes ion distribution function. We express the time variation due to collision by a simplified Fokker-Planck collision term and a source term, neglecting the diffusion. Then S denotes the intensity of uniform source in space and ν denotes the friction coefficient, which is a model of ion-neutral collision, n and n_e denote ion and electron density, respectively. We arrange numerical mesh in two dimensional phase spaces and move the particles associated with individual cells to new locations determined by the equation of motion under the electric field, $M\ddot{x} = eE - \nu\dot{x}$. Boundary condition is that two electrodes are set as constant potentials, i.e., anode is zero and cathode is kept constant ϕ_0. We take notice of the concave electric potential (well-type potential), which has been confirmed by our previous theory and experiments[1]. We summarize simulation results. 1. Equidistant spectral lines of ion current are observed and they peak at a low and a high frequencies. 2. Standing waves exist in the flat part of the electric potential.3. We obtain the dispersion relation such as linear line with respect to wave number. These modes are found to be the ion acoustic wave with mode number 1, 2 and so on. 4. If we examine the relation between remained ion density in the system and mode number, it is found that the product of wave number and the Debye length, i.e., characteristic length, is kept constant. 5. The spectrum of low-frequency component becomes clearer than the high frequency component in dissipative case.

By a linear fluid theory, we introduce a characteristic equation and examine the dispersion relation of the growth rate. We express the unperturbed solution with ^{0} and the first order perturbation with ^{1}. Combining the equation of continuity and the equation of motion, and using condition of charge neutrality, we obtain next equation.

$$\frac{\partial^2 n^1}{\partial t^2} + \nu\frac{\partial n^1}{\partial t} = C_s^2\frac{\partial n^1}{\partial x^2} + \frac{\partial^2}{\partial x^2}\left[2v^0\Gamma^1 - (v^0)^2 n^1\right], \quad (3)$$

where C_s is the ion acoustic speed $\sqrt{T_e/M}$. We assume the distribution of ion flow velocity and solve eq. (3) under the condition of continuation of the solution between sheath regions and bulk plasma. In sheaths the flow is approximated by a linear function of x and in the bulk plasma the flow can be set to zero. At the cathode sheath or the anode sheath, we expand the first order density as the Taylor series. In the bulk plasma region, we set the density change as a wave form sinusoidally. Considering that the mode is ion acoustic wave, we substitute these conditions into eq. (3) and use next relations, $\omega = \Omega + i\gamma$, $k = k_r + i\kappa$, $\Omega = C_s k_r(1 - \frac{\nu^2}{8C_s^2 k_r^2})$, $\kappa = \frac{1}{C_s}(\gamma(1-\frac{\nu^2}{8C_s^2 k_r^2}) + \frac{\nu}{2})$, where γ denotes the growth rate. Setting $\kappa^2 << 1$, we examine the dependence of growth rate γ on wave number k_r. It is found that the product of peak mode number and sum of sheath width is constant. Also, in the dissipative case $\nu \neq 0$, the condition of parameters, which the fundamental mode increases, is found. The increasing of intensity of low frequency component in the dissipative system can be explained.

From numerical and theoretical results, it is found that asymmetry of the boundary conditions, whose factors are ion flow velocities and sheath widths at cathode and anode, destabilizes strongly a mode of the ion acoustic wave in the bulk plasma. Our result suggests that the oscillation of electric current observed in undriven experimental system can be interpreted by the fundamental mode of destabilized ion acoustic wave.

References

1) Matsunaga, Y. and Kato, T. : J. Phys. Soc. Jpn. **63**(1994)4396.
2) Hitchon, W. et. al. : J. Compt. Phys. **83**(1989)79.