

Floating-sheath formation in a collisional magnetized plasma

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The sheath dynamics in front of a floating conductive planar absorbing plate collector in contact with a collisional magnetized plasma is investigated. The problem is treated using 1d3v particle-in-cell (PIC) simulations by means of the BIT1 code [1] developed on the basis of the XPDP1 code [2]. The magnetic field is uniform and is inclined at the angle θ with the normal to the collector surface. The plasma parameters chosen correspond to the conditions of the scrape-off layer (SOL) region of a tokamak plasma. During the observation time, approximately sixty electron plasma oscillations, we analyze the spectrum of the longitudinal waves.

Introduction

We consider a single-emitter plasma diode filled with an initially uniform magnetized plasma, mimicking a half-bounded plasma. Collisions between charged particles and the neutral gas are taken into account but do not play an important role for the time scale of the processes considered here.

For the case $\theta = 0$, the dynamics of floating-sheath formation is similar to the one for non-magnetized plasma [3]. Due to the much higher thermal velocity of the electrons, negative electric charge starts to accumulate on the collector. Electrons with low energy are repelled and ions are attracted, gradually establishing a positive space charge. The plates are externally disconnected and the charging-up process ceases when the electron and ion currents onto the collector cancel each other and the potential difference reaches its floating value. During the initial stage of the charging-up process, electron plasma waves are excited and propagate into the unperturb plasma region [3].

For $\theta \neq 0$, the charged-particle dynamics during floating-sheath formation is more complicated, additional frequencies being observed in the plasma oscillation spectrum. Due to the

presence of the magnetic field, longitudinal hybrid waves are observed.

Plasma and simulation parameters

We consider a hydrogen plasma with two charged-particle species, electrons and singly charged ions. The collector and the emitter are placed at $x = 0$ and $x = L > 0$, respectively. At time $t = 0$, the temperatures and densities of the charged species, loaded in the system, are equal: $T_e = T_i = 20 \text{ eV}$ and $n_e = n_i = 1 \times 10^{18} \text{ m}^{-3}$; the potential is zero everywhere in the system, including the collector; the distribution functions of the charged-particles are Maxwellians.

The background gas is hydrogen with a time-independent uniform density of $n_n = 5 \times 10^{19} \text{ m}^{-3}$. The condition $\lambda_D \ll \rho_i \ll l$ is fulfilled, where λ_D is the Debye length, ρ_i is the ion gyro-radius and l is the mean free path for collisions between charged particles and the neutrals.

Throughout the entire simulation the following boundary conditions are applied: At the collector, all particles impinging are absorbed and no particles are emitted. At the emitting plate, all particles impinging are absorbed but new particles with half Maxwellian distribution functions are injected at a constant rate.

Simulation results and conclusions

Figure 1 shows the time evolution of the collector potential for different values of the angle θ . It is observed that for small values of θ the evolution is similar to the case of non-magnetized plasma [3]. The dominant frequency of the oscillations is the electron plasma frequency. At higher values of θ , the motion of the charged particles along the magnetic field affects the charging-up process of the collector. In the spectrum we observe two frequencies, corresponding to lower- and upper-hybrid-mode oscillations.

The dispersion equation of the hybrid modes [4] is given by

$$\omega_{2,1}^2 = \frac{\omega_{pe}^2 + \Omega_e^2}{2} \pm \frac{1}{2} \sqrt{(\omega_{pe}^2 + \Omega_e^2)^2 - 4\omega_{pe}^2 \Omega_e^2 \cos^2 \theta}, \quad (1)$$

where ω_{pe} and Ω_e are the electron plasma frequency and electron cyclotron frequency, respectively. From here on we will denote the lower and higher hybrid frequencies by ω_1 and ω_2 respectively.

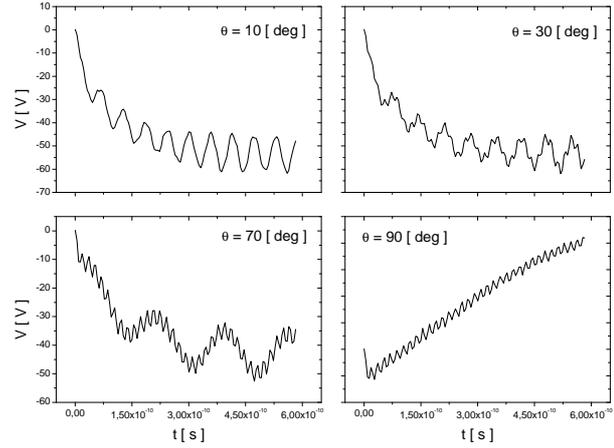


Figure 1: Potential evolution at the collector for different values of θ . In all cases $B = 1 \text{ T}$

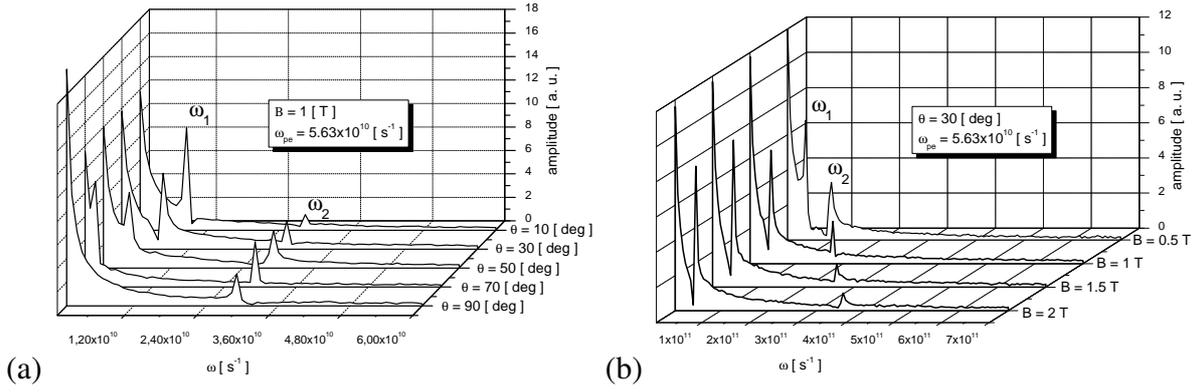


Figure 2: The spectrum of the potential oscillations at the collector for (a) constant $B = 1 [T]$ and different θ , (b) different magnetic field strength at constant angle $\theta = 30^\circ$.

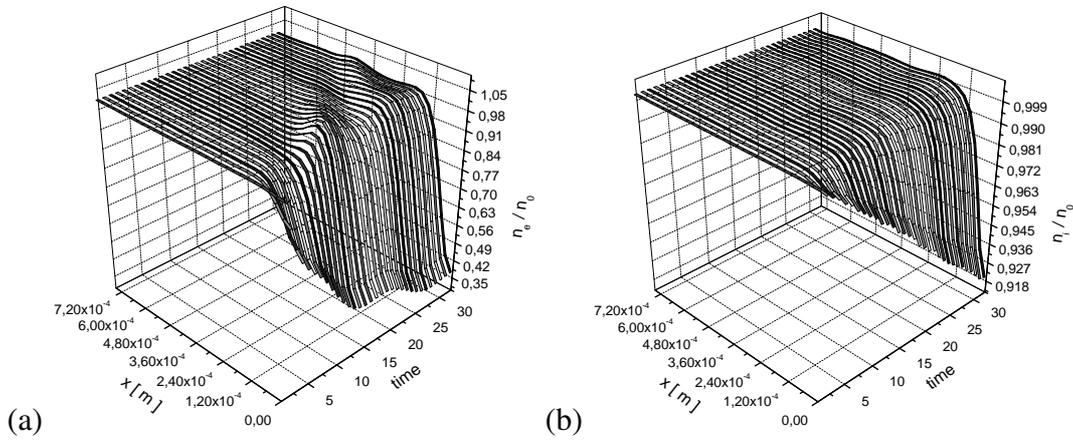


Figure 3: (a) Electron- and (b) ion-density evolution for $B = 1 [T]$ and $\theta = 10^\circ$.

When the magnetic field direction is changed from almost perpendicular to parallel to the collector plane (Fig. 2(a)), we observe the upper and lower hybrid frequencies. These "measured" values of ω_1 and ω_2 are in very good agreement with the results obtained from Eq. (1) for the corresponding angles. We also observe the well-known fact that the approximation obtained from Eq. (1) is not valid for magnetic fields almost parallel to the wall. Consequently the spectrum for $\theta = 90^\circ$ (Figure 2.(a)) indicates only one frequency, given by $\omega^2 = \omega_{pe}^2 + \Omega_e^2$.

In order to verify whether the observed frequencies are indeed related to the magnetic field we fix the angle θ and change the magnetic field strength. In Fig. 2(b) we see that the upper hybrid frequency changes its value linearly with the field and the lower hybrid frequency is constant. This can easily be explained in the following way: If we consider that $\Omega_e \gg \omega_{pe}$ (valid for our parameters) and rewrite the dispersion relation (1), we find that $\omega_1^2 \cong \omega_{pe}^2 \cos^2 \theta$ and $\omega_2^2 \cong \Omega_e^2 + \omega_{pe}^2 \sin^2 \theta$. This shows that indeed only ω_2 depends on the magnetic field.

In order to explain the behavior of the collector potential at $\theta = 90^\circ$ (Fig. 1), the electron-

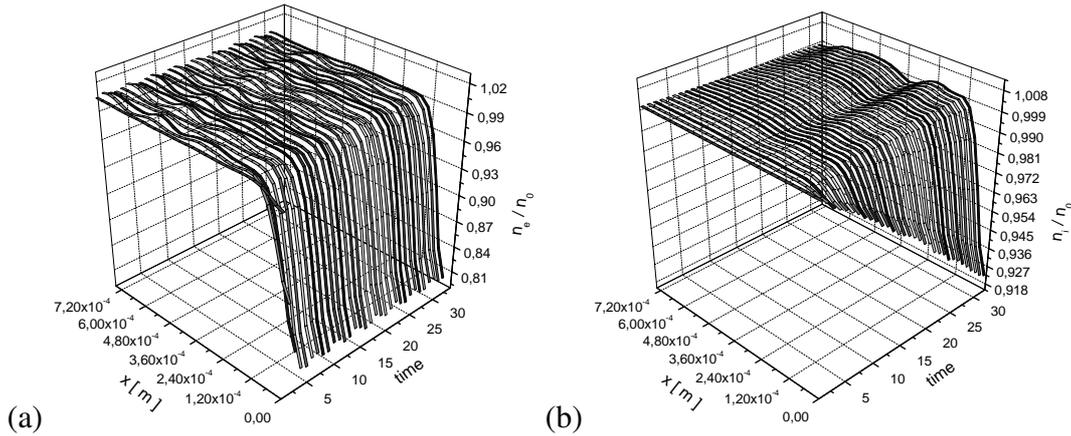


Figure 4: (a) Electron- and (b) ion-density evolution for $B = 1 [T]$ and $\theta = 90^\circ$.

and ion-density evolution in time and space are investigated in the perturbed region (Fig. 4). In contrast to the case $\theta = 10^\circ$ where the electron density constantly decreases and oscillates (Fig. 3), we observe for $\theta = 90^\circ$ that only at the very early stage the electron density decreases strongly, charging the collector negatively. After this stage the density remains almost constant, showing only small oscillations due to the gyromotion. Because of the small electron gyroradius and the much larger ion gyroradius, the number of positively charged particles reaching the collector is larger than the number of negatively charged ones, thus increasing the collector potential. The detailed description of this process will be the subject of our future investigations.

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