

Simulation and theory of the initial stage of floating-sheath formation

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Abstract The problem of sheath formation in front of a conductive planar absorbing plate collector is formulated. We consider a single-emitter plasma diode filled with an initially uniform plasma. Electron plasma (Langmuir) waves are excited [1] at the initial stage of the collector charging-up process. Assuming a simplified time dependence of the potential on the collector, the boundary value problem for this excitation of Langmuir waves is solved analytically.

Introduction

Since the thermal velocity of the electrons is much higher than that of the ions, negative electric charge starts to accumulate on the collector, so that electrons are gradually repelled, ions are attracted, and a positive-space-charge sheath begins to form. Keeping the plates externally disconnected, 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. The establishment of the floating potential between the plates is a time-dependent process and its description represents a rather complex mathematical and physical problem.

Analytic description and wave excitation

The collector and the emitter are placed at $x = 0$ and $x = L > 0$, respectively. The length L is to be chosen large enough in order to fulfill the condition $L \gg \lambda_D$, where λ_D is the Debye length. The emitter potential is chosen to be zero at all times. At the initial time, ($t = 0$), the electron and ion densities are equal and spatially uniform ($n_{e0} = n_{i0} = n_0$), the velocity distribution functions of both particle species are full Maxwellians, and the electric potential is zero everywhere in the system. Throughout the entire simulations the following boundary conditions are used: At the collector, all particles impinging are absorbed and no particles are emitted. At the emitter, all particles impinging are absorbed as well, but new particles with half Maxwellian distribution functions are injected.

The electric potential in the region considered is denoted by $V(x, t)$ or, in normalized form, $\Phi(x, t) = -eV(x, t)/T_e$. According to Fig. 1(a) the collector potential, $V_c(t) = V(0, t)$, decreases

only qualitative agreement for the potential evolution on the collector (Fig. 1(a)). In the same figure we present the potential in space at a given time $t = 6.43 \times 10^{-8} s$, the dots along the potential curve denoting the positions where we perform Electron Velocity Distribution Function (EVDF) diagnostics. Analyzing the distributions of the electron density in time and space (Fig. 1(b)) we clearly demonstrate the formation of electron Langmuir waves. In the unperturbed plasma region (i.e., $x \rightarrow L$) the electron velocity distribution function will not change appreciably, whereas close to the collector it will acquire a cut-off form (Figs. 2,3). With increasing

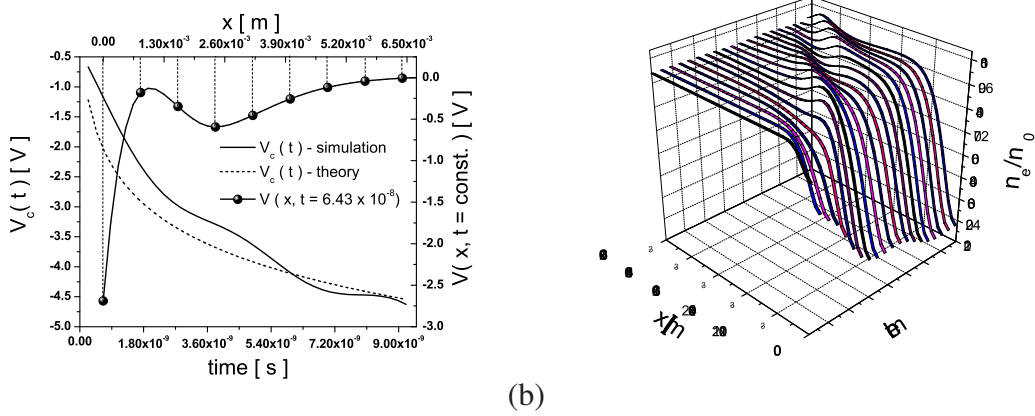


Figure 1: (a) Potential evolution vs. time on the collector $V_c(t)$, and in space at a given time $V(t = 6.43 \times 10^{-8} s, x)$; (b) Electron density evolution in time and space;

negative collector surface charge, the potential drop in the region becomes higher (Fig. 1(a)) and more and more electrons are reflected by the potential barrier back towards the plasma.

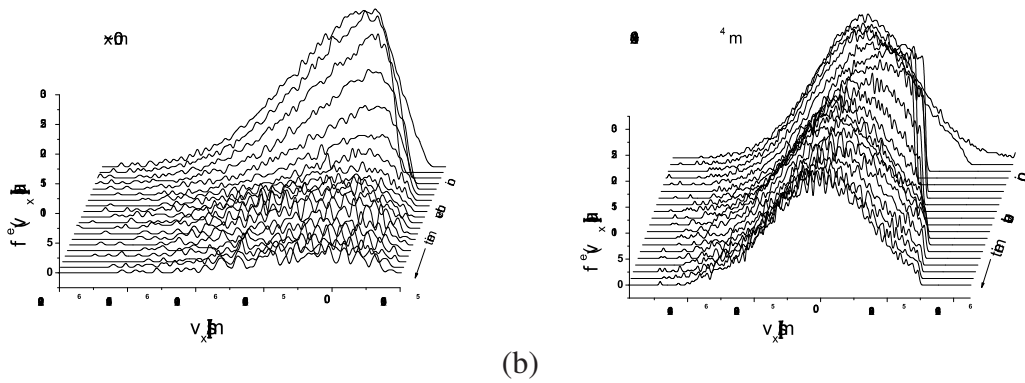


Figure 2: EVDF evolution in time at positions (a) $x \simeq 0.0 m$ and (b) $x \simeq 8.4 \times 10^{-5} m$ from the conductive collector plate.

The electrons density increases locally, forming a potential well in which, the slow electrons are trapped and transported with the wave velocity towards the bulk plasma.

A clear indication of the slow-electron trapping and transport is the shifting of the EVDF maximum (Figs. 2,3). Keeping a fixed position in space and analyzing the EVDF evolution in time, one can easily observe the moment when the wave perturbs the local electron distribution.

At the same time, the EVDF becomes a cut-off Maxwellian due to absorption of fast particles at the collector. Since the shape of the distribution function essentially depends on the potential between the plates, the cut-off of the EVDF changes in time. These perturbations in the region

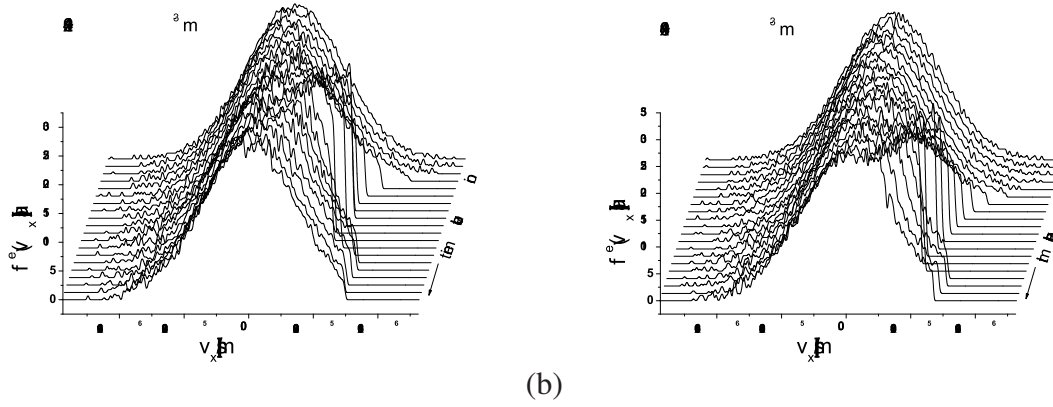


Figure 3: EVDF evolution in time at positions (a) $x \simeq 2.44 \times 10^{-3} \text{ m}$ and (b) $x \simeq 4.84 \times 10^{-3} \text{ m}$ from the conductive plate.

close to the collector, whose characteristic time scale is of the order of the electron plasma period, generate the electron Langmuir waves propagating into the plasma.

In conclusion we may state that the processes taking place in the plasma during the sheath formation reflect the time evolution of the collector potential and vice versa.

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