EFFECTS OF ENERGETIC ELECTRONS ON COLLECTOR AND SOURCE POTENTIALS IN A HYDROGEN PLASMA

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1. Introduction

The effects of an additional energetic electron population on collector and source sheath potentials in a hydrogen plasma are investigated. A simple multi-fluid formulation of the sheath formation was already presented in [1], where also the secondary electron yield from target materials was included. Later, the steady state potential formation in a two-electron discharge plasma was theoretically investigated [2] to clarify the potential structure and to evaluate the potential drop in such cold ion plasma. In a certain range of parameters a current-free double layer was found to form in the plasma. The modelled and simulated plasma system can represent plasma flowing to a fusion tokamak first wall divertor. In these experiments using various RF heating methods, the electron distribution composed of two contributions with highly different temperatures is readily observed. Similar situation can be encountered in freely expanding laser-produced plasma [3].

2. Model

The bounded plasma system is modelled after Schwager and Birdsall [4]. The distributed plasma source is represented by a planar source at one side of the system. At the opposite side, a floating collector bound the system. The plasma, which is injected from the source, consists of ions, electrons and additional hot electron component. At the floating collector all the ions are absorbed and nearly all electrons are reflected. They are then refluxed in the system in the source region. The electrostatic potential is assumed to be decreasing with position. The ions are therefore described by an accelerated half-Maxwellian velocity distribution and the electrons by a truncated full Maxwellian distribution to which a hot truncated Maxwellian component is added. In order to calculate the collector floating potential ψ_C and source sheath potential drop ψ_P, we characterised the potential between the source and collector sheaths by $\nabla^2 \psi_P = 0$. Setting the net charge to zero, we obtained the expression which relates ψ_C and ψ_P. A second equation relating both potentials was obtained by assuming zero electric field at ψ_P and, according to Poisson equation, by integrating the zero net charge expression. The solutions of ψ_C (ψ_P) for both equations are shown in Fig. 1. Beside the simultaneous solution at $\psi_P \rightarrow 0$ three simultaneous solutions are found in a narrow range of hot electron density ratio α for the temperature ratio $t > 15$.

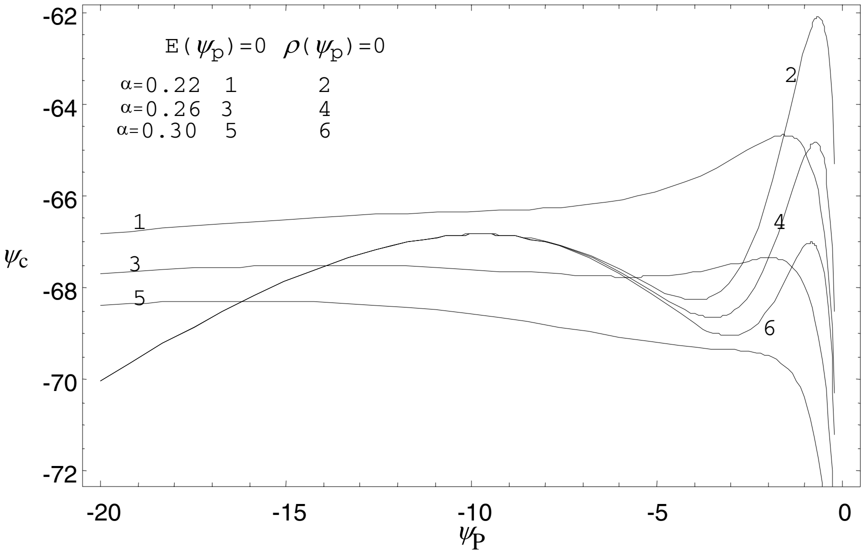

Figure 1. Solutions of ψ_C versus ψ_P for the zero neutral charge density and electric field expression at ψ_P for a hydrogen plasma with $\tau = T_i/T_{ec}$=0.1 and $t = T_{eh}/T_{ec}$=20 at the source. For 0.22 >α >0.30, three simultaneous solutions are found; (ψ is the normalized potential $e\phi/T_{ec}$; T_{ec}, T_{eh} and T_i are cold, hot electron and ion temperatures, respectively).

The solutions were also investigated as a function of mass ratio $\mu = m_i / m_e$. The collector potential ψ_C follows the functional dependence on ion mass, $\psi_f \propto \ln[2\pi\mu f(\tau)]$, as already given by Stangeby [5] for a plasma with a single electron population. The potential ψ_P seems to be independent of the ion mass, one can only observe a rapid increase of its value between α = 0.22 and α = 0.32. The dependence of both potentials on ion temperature ratio τ for the hydrogen plasma was also investigated and it can be concluded that the source sheath potential drop ψ_P varies much more with τ then with mass ratio. In Fig. 2 the potentials ψ_C and ψ_P are plotted as functions of hot electron density ratio α. The collector potential ψ_C is continuously changing in the whole range of α, regardless of ψ_P behaviour and is mainly dominated by the hot electrons. This can be understood since already a small value of hot electron current is sufficient to compensate the ion saturation current to the floating collector. For pure Maxwellian plasma with cold or hot electrons, the calculation recovers, with proper normalisation, the well-known value for the floating potential, ψ_C = - 3.6. The potential ψ_P has three different values in a narow range of α whereas downside and upside of this region it has quite different values and is only slightly but continuously changing. In the narrow region

0.23 < α < 0.29 the smallest value of ψ_P is chosen as the value of the potential at the source side and the largest value at the collector side of the plasma system. The third value lies in the transition region between these potentials. It corresponds to the layer of cold electron total reflection as also confirmed by simulations.

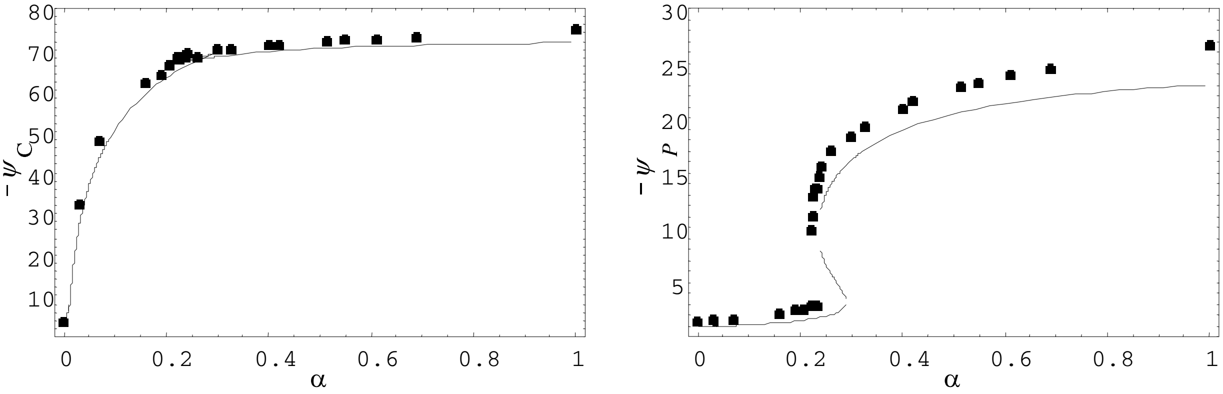

Figure 2. Potentials ψ_C and ψ_P as functions of hot electron density ratio α, in a hydrogen plasma using hot electron temperature ratio t = 20 and ion temperature ratio τ = 0.1. Simulation data points are measured at the collector, x= 0, and in the mid of E = 0 region in the plasma.

3. Simulations

A PIC simulation code XPDP1 composed at Berkeley [6] was used to study the plasma system. The set of fixed and variable parameters was similar to those used in [4]. A second hot electron population was added to the input file and the mass ratio for hydrogen plasma was utilised. Typical potential, particle density and electric field profiles, which evolved in these simulations, are shown in Fig. 3. For the reference, in the first column the results for plasma with only cold electrons are shown. They are in accordance with those already obtained in similar investigations [4]. The same situation is met in the third column where a plasma system with only hot electron component (t = 20) was simulated. In the second column the results for a plasma with both electron components are shown (α = 0.23). In the potential profile all the analytically evaluated results are recovered: higher value of collector potential ψ_C, three values of ψ_P. It can be clearly seen in this plot that the cold electrons are totally reflected in the transition region and that only the hot electrons partially hit the collector to compensate the ion current. The simulated values of the potentials are also plotted in Fig. 2 and they fit the theoretical curves qualitatively good. The whole set of simulation points is systematically shifted for 15% to higher values.

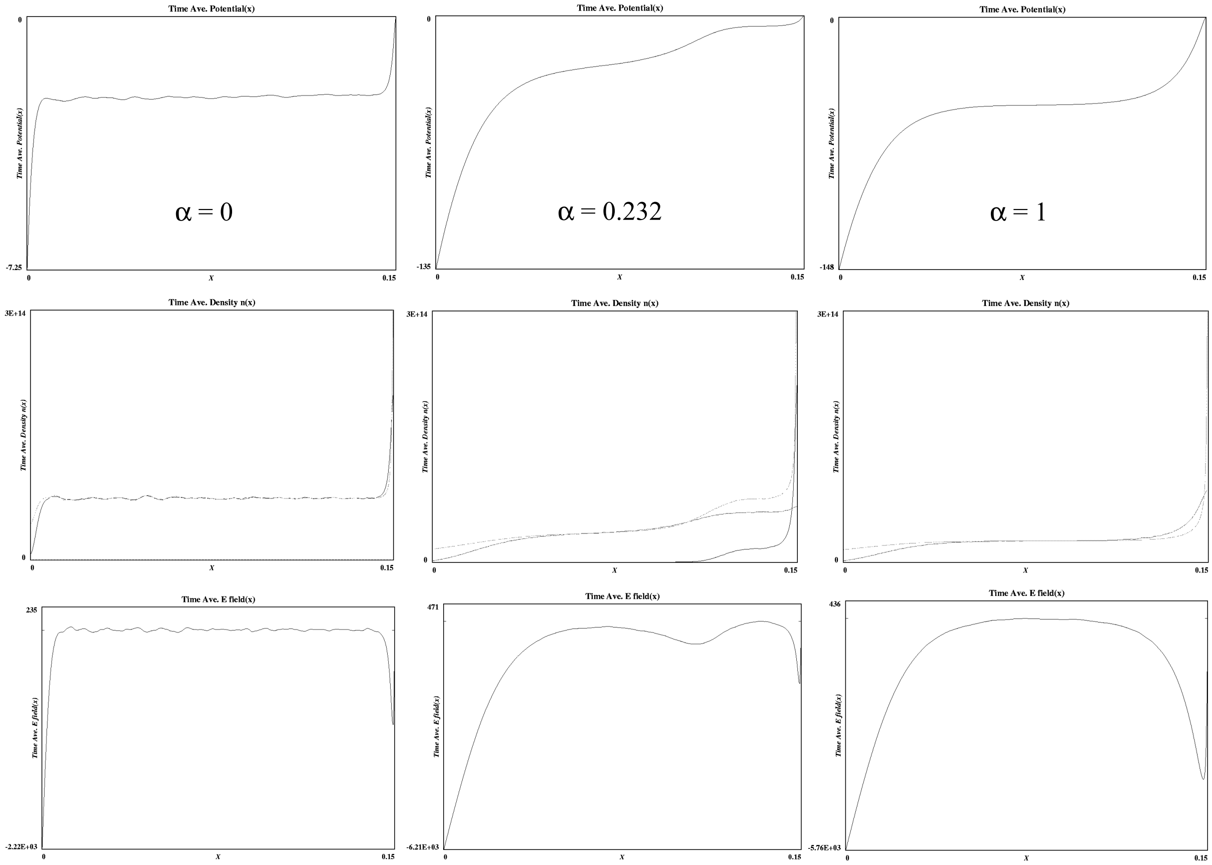

Figure 3. Spatial profiles from PIC simulation of potential, particle densities and electric field for three values of hot electron density ratio α in a hydrogen plasma with *t* = 20.

4. Conclusions

We have investigated, theoretically and by PIC simulation, the potential formation in a two-electron temperature collisionless plasma flowing to a solid surface. Analytically, in certain range of parameters three values for source sheath potential drop were simultaneously found. We ascribed the higher value to the plasma potential near the collector, the lower value to the plasma near the source and the third value to the transition region in between. The results were confirmed by simulation and were in good accordance. It was also observed that the higher potential region corresponded to the plasma with only hot electrons and the lower potential region to the plasma in which both electron components were still observed.

References

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