33rd EPS Conference on Plasma Phys. Rome, 19 - 23 June 2006 ECA Vol.**30I**, P-2.077 (2006)

Properties of multiple double layers in negative ion plasma with a bi-maxwellian electron population

M. Čerček[1,2], T. Gyergyek[3,1]

[1] *"Jožef Stefan" Institute Jamova 39, 1000 Ljubljana, Slovenia*

[2] *University of Maribor, Faculty of Civil Engineering, Smetanova 17, 2000 Maribor, Slovenia*

[3] *University of Ljubljana, Faculty of Electrical Engineering, Tržaška 25, 1000 Ljubljana, Slovenia*

1. Introduction

Multiple double layers have been observed in current carrying bounded plasmas by Hollenstein et al. [1] and Chan et al. [2]. It has been shown that such multiple potential structures develop from single double layers when the ratio of Debay length to system length was decreased. Another type of multiple double layers, so called ionization double layers, were observed by Conde et al. [3] in a glow discharge. Similar phenomenon has been also thoroughly investigated by C. Ioniţa et al. [4] in a DP machine. It is well known that double layers develop also in multicomponent plasmas. In plasma with a bi-maxwellian electron distribution or in negative ion plasma with maxwellian electrons two plasma regions are formed separated by a double layer. It the upstream region the colder negative particles are trapped, in the downstream region only the hotter negative particles and positive ions are present.

Recently we started the investigation of double layer formation in negative ion plasma with bi-maxwellian electron distribution [5]. The fully kinetic bounded plasma model was used to analytically investigate the formation of the potential structure in such bounded plasma. In the presheath potential profile formation of two double layers was identified, whereas the floating potential of the bounding electrode depends continuously on plasma parameters. The analytical findings were further compared with PIC simulation results and excellent agreement was found. In this contribution we present potential and density profiles in the bounded plasma system, as well as spatial velocity profiles for cooler negative particle populations in the plasma. The net charge profile in the plasma system, which is also presented, shows that two double layer potential structures are formed. Trapping and acceleration of different particle populations by these potential structures is clearly observed.

1. Analytical treatment and PIC simulations

As in our previous studies we model the plasma system with one dimensional planar plasma device. The distributed plasma source is represented by a planar source at one side of the device and on the other side a floating electrode or collector bounds the device. The plasma, which is injected from the Maxwellian source, consists of positive ions, negative ions and cool and hot electrons. The collector floating potential $\psi_C = \varphi_c/kT_{ec0}$ and the source sheath potential drop or presheath potential $\psi_P = \varphi_P/kT_{ec0}$ are calculated as functions of negative ion fraction in the source $\alpha_0 = n_{-0}/(n_{ec0}+n_{eh0}+n_{-0})$ using three boundary conditions. Setting the net charge at ψ_P to zero, we obtain the first equation which relates ψ_C and ψ_P. A second equation relating ψ_C and ψ_P is obtained from the assumption of zero electric field at the source boundary ($\psi = 0$) and at the collector sheath boundary ($\psi = \psi_P$). The third equation, which enabled us to express the particle density ratios as a function of the potential ψ_C, was obtained from the zero net collector current condition. In order to study the stratification in such plasma we gave the plasma parameters the following values: $M = m_i/m_e = 40$, $\tau_{+-} = T_{+-0}/T_{ec0} = 0.16 – 0.12$, $\tau_e = T_{eh0}/T_{ec0}$, $= 20$, $\beta_0 = n_{eh0}/(n_{ec0}+n_{eh0}+n_{-0}) = 0.125 – 0.250$. We have chosen a reduced value of the normalized ion mass (positive and negative ions of equal mass) in order to save the computer time in simulations. It has been proven that such small value of M has negligible effect on the obtained results. The negative ion temperature ratio τ_- was higher than $\tau_- > 0.1$. In such cases no DL is formed in negative ion plasma with single Maxwellian cool electron distribution. On the other hand, the electron temperature ratio was set to $\tau_e > 10$ in which case (with α_0=0) a DL is readily formed in certain electron density ratio interval in positive ion plasma. In Fig.1 the potentials Ψ_P and Ψ_C are plotted as functions of negative ion density ratio α_0 for special values of parameters $\tau_{+-} = 0.13$ and $\beta_0 = 0.17$. According to the number of solutions for Ψ_P, three different intervals of α_0 can be identified on the left plot. Two of them have been already discussed in our previous study, here we concentrate on the interval $0.485 < \alpha_0 < 0.525$, where five simultaneous solutions can be observed. Two of them, the second and fourth from the top, are unphysical, the other three determine three regions in the plasma system with different plasma potentials. In the first region, which is closest to the plasma source, the plasma potential is determined by negative ions, hence its low value of $\Psi_P = 0.5$. In the second region, which lies in the middle of the system, the potential is determined by cool electrons, its value being $\Psi_P = 1$. Finally, in the third region the potential is determined by hot electrons and $\Psi_P = 12.5 – 13.5$. The collector floating potential Ψ_C , presented in the right plot, is a continuously decreasing function of α_0, if one takes into account the highest possible solution. From the plot one can also observe that for lower values of α_0 the floating potential is influenced by cool electrons, whereas from the point on where the two branches cross each other, the potential is predominantly determined by hot electrons. From the the crossing point on one would expect that the two DLs, corresponding to the boundaries of negative ions and cool electrons, merge together.

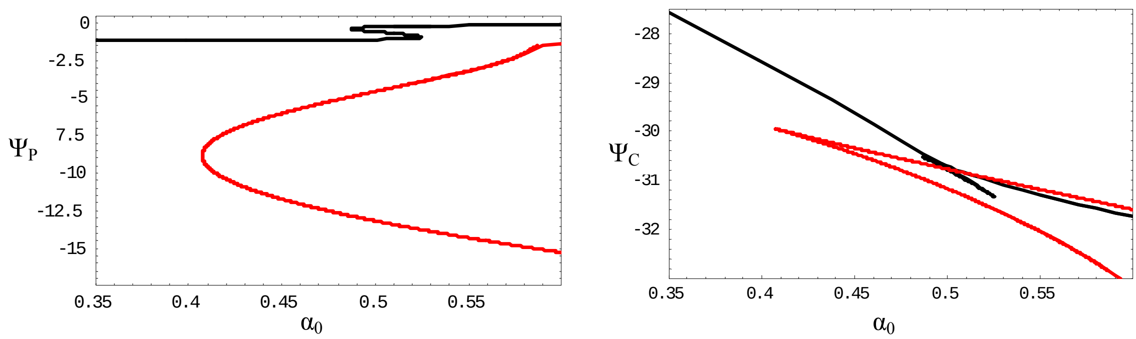

Fig.1. The normalized presheath potential Ψ_P (left) and collector floating potential Ψ_C (right) as the functions of the negative ion density ratio α_0 in a plasma with ion temperature ratios $\tau_{+-} = 0.13$, electron temperature ratio $\tau_e = 20$ and hot electron density ratio $\beta_0 = 0.17$. An interval of α_0 where two DLs exist simultaneously in the system can be clearly seen.

In Fig. 2 are shown the profile of the potential, particle densities and charge in the plasma system, obtained from the PIC simulations. The parameter values were chosen very close to the values from the analytical calculations and one can observe an excellent agreement of the results. On the plot of the potential profile (left) one can clearly observe that the plasma is stratified into three regions separated by two double layers. In the first region, closest to the plasma source the potential is $\Psi_P = 0.5$, in the second region in the middle it is $\Psi_P = 1.2$ and in the third region $\Psi_P = 13.2$. All these values agree very well with the values from the analytical calculations. At the collector, the potential drops through the sheath and reaches the floating potential value of $\Psi_C = 31$, again in excellent agreement with the theoretical result as observed in the right plot of Fig. 1. In the middle plot of Fig. 2 the normalized particle density profiles are shown. The densities are normalized with the positive ion density at the plasma source boundary. The values α_0 and β_0 parameters can be in this way directly obtained from the plot. In the first region of the lowest plasma potential, immediately after the steep density decrease in the plasma source potential drop, all four particle populations are present in the plasma. The potential is determined mainly by the negative ions. In the next potential drop the densities if positive ions again decrease due to acceleration, the densities of cool electrons and negative ions decrease due to reflection. The latter are completely reflected and in the second region with the potential $\Psi_P = 1.2$ only three populations of particles are left. A second potential drop follows and the cool electrons are completely reflected back to the plasma source. The density of hot electrons is also decreased due to partial reflection. The plasma in this third region consists only of positive ions and hot electrons. In the collector sheath the positive ion density is higher then hot electron density. On the right plot, where the charge in the system is presented, one can clearly identify the two DLs which separate the three plasma regions in the system. The positive charge in the collector sheath is also observable. In Fig. 3 the negative ion velocity

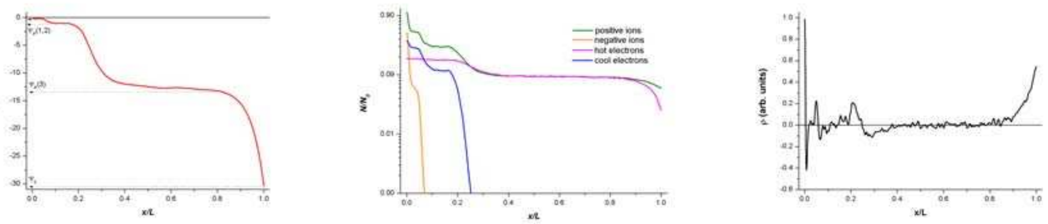

Fig.2. Normalized potential profile (left), density profiles (middle) and charge profile (right) in the plasma with $M_{+,-} = 40$, $\tau_{+,-} = 0.12$, $\tau_e = 20$ and $\beta_0 = 0.17$ obtained by PIC simulation.

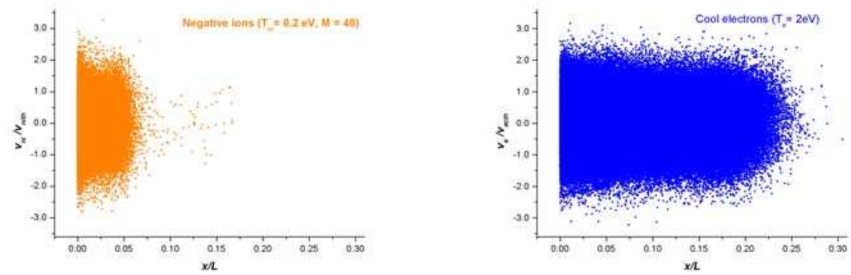

Fig.3. Velocity space of negative ions (left) and cool electrons (right) in the plasma system with the same parameters as in Fig.2. The particle velocities are normalized with their thermal velocities.

space (right) and cool electron phase space is plotted. The negative ions are totally reflected at the first DL potential structure in the system and cool electrons at the second. The corresponding velocity distributions are full Maxwellian.

4. References

[1] Ch. Hollenstein et al., Phys. Rev. Lett. 45 (1980) 2110.

[2] C. Chang and N. Hershkowitz, Phys. Fluids 25 (1982) 2135.

[3] L. Conde and L. Leon, Phys. Plasmas 1 (1994) 2441.

[4] C. Ioniţa et al. Int. J. Mass Spectrom. 233 (2004) 343.

[5] M. Čerček and T. Gyergyek, 32nd EPS Conference on Plasma Physics, Tarragona, 27th June – 1st July 2005, Contr. Papers (2005) P4.131.