Negative Ions Extraction and Acceleration

N. Oudini[1], F. Taccogna[2], P. Minelli[2], J.-L. Raimbault[3], P. Chabert[3] and A. Aanesland[3]

[1] *Laboratoire des Plasmas de Décharge, Centre de Développement des Technologies Avancées, Cité du 20 Aout BP 17 Baba Hassen, 16081 Algiers, Algeria*

[2] *Istituto di Metodologie Inorganiche e dei Plasmi, CNR, via Amendola 122/D, 70126 Bari, Italy*

[3] *Laboratoire de Physique des Plasmas, École Polytechnique, 91128 Palaiseau Cedex, France*

Negative ions extraction and acceleration represents, today, an important issue in low temperature plasma, since the use of these ions might provide a very useful advantage for a large variety of technological applications, e.g. plasma etching [Sak02], neutral beam injector for controlled thermo-nuclear fusion and electric propulsion applications (PEGASES) [Aan09].

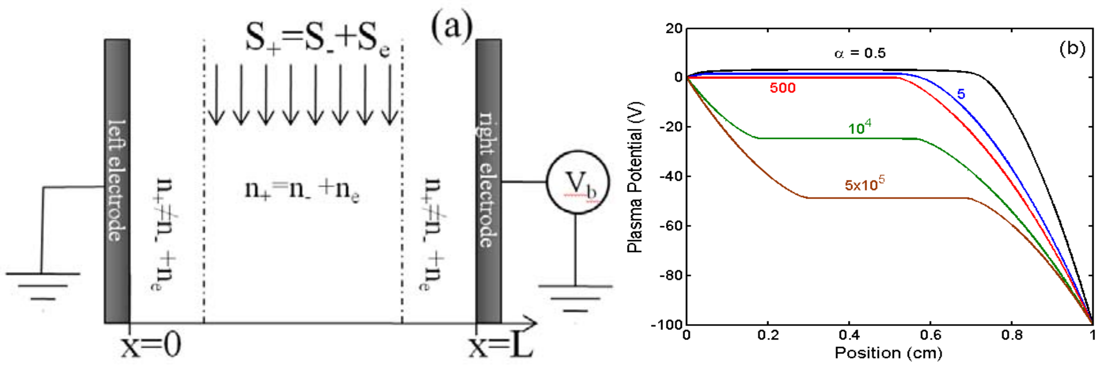

FIG. 1. Illustration of the 1D PIC-MCC system. Illustration of some plasma potential profiles calculated for different value of electronegativity in the conditions summarized [Oud13a]

The negative ion to electron density ratio (electronegativity $\alpha \equiv n_- / n_e$), is one of the most important parameter characterizing electronegative plasmas. The study of electronegative plasma situated between two parallel electrode under DC bias for a large range of electronegativity [Oud13a], as illustrated in Figure 1, shown that unmagnetized electronegative plasmas could be classified in four regimes according to α. In regime I ($\alpha < 50$), the plasma potential profile adapts itself to confine and traps the negative ions within the plasma bulk. In regime II ($50 < \alpha < 2000$), the left sheath net charge changes from positive to negative allowing a fast increase of the negative to positive ion fluxes leaving the plasma, i.e. Γ_- / Γ_+. In regime III ($2000 < \alpha < 10^5$), the bulk plasma potential decreases rapidly (Fi.g 2.a) while Γ_- / Γ_+ increases slowly. However, the asymmetry of the plasma potential profile demonstrates the influence of the electrons on the sheath formation and shows that the plasma cannot be considered as a pure ion-ion plasma. In regime IV ($\alpha > 10^5$), both the electron density and flux are negligible compared to the negative ion density and flux. In this regime, only, electronegative plasmas can be identified as ion-ion plasmas.

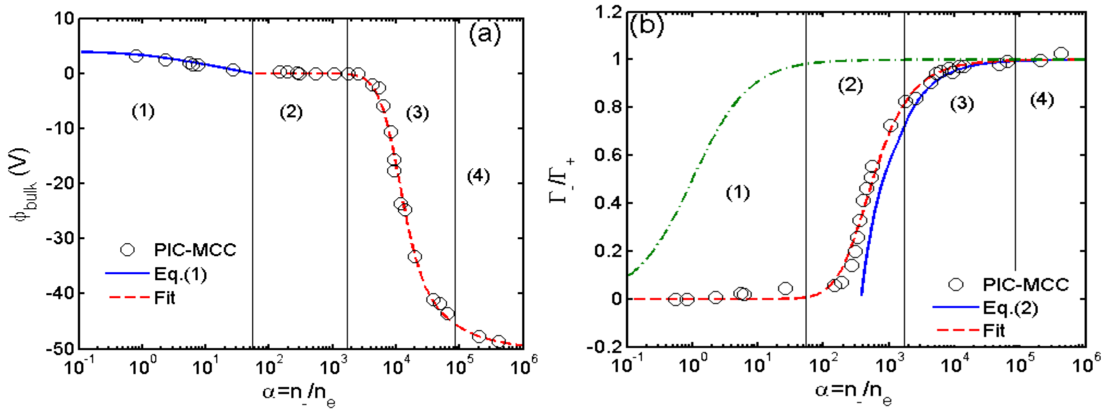

FIG. 2. (a) The bulk plasma potential as a function of the electronegativity α. (b) Evolution of the negative ion flux collected by the electrodes and normalized by the positive ion flux as a function of the electronegativity α.

Theoretical simplifications shows that the plasma potential at the first regime and the negative ion to positive ion fluxes leaving the plasma can be predicted from

$$\phi \approx T_e \ln\left(\frac{1}{\alpha+1}\sqrt{\frac{m_+}{8\pi m_e}}\right), \qquad (1)$$

$$\frac{\Gamma_-}{\Gamma_+} \approx 1 - \frac{1}{2\alpha}\sqrt{\frac{1}{\pi}\frac{T_e}{T_-}\frac{m_+}{m_e}}, \qquad (2)$$

where ϕ is the bulk plasma potential, T is the temperature and m is the particle mass. The index +, - and e are dedicated for positive ion, negative ion and electron.

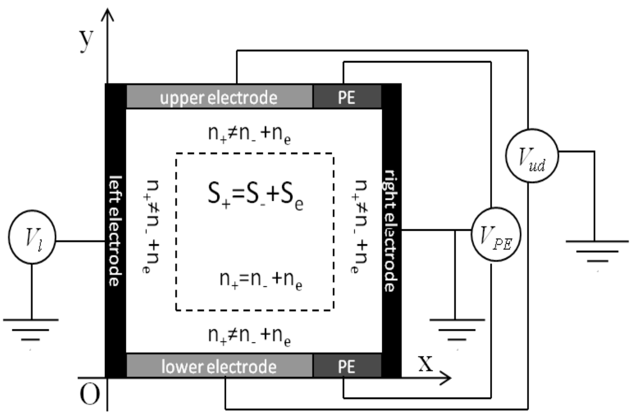

Fig. 3. Illustration of the 2D PIC-MCC system, where a magnetized electronegative plasma exists between four flat electrodes that form a perfect square. Plasma electrodes (PE) are introduced between the transversal electrodes and the right electrode. S_+, S_- and S_e represent positive ion, negative ion and electron source term, respectively. The magnetic field is oriented in the y direction and is considered constant and homogeneous.

From another side, more recent work [Oud13b] shows that by inserting a magnetic field barrier plus a transversal electrode, as illustrated in figure 3, makes the negative ion extraction possible independently from the electronegativity value by forcing the formation of a reverse sheath. Furthermore, the magnetic field limits the electron mobility and reduces significantly the co-extracted electron current.

Indeed, figure 4 shows the 2D map of plasma potential. The left electrode is grounded, the right one is biased at -100 *V* and the transversal electrodes are biased at -50 *V*. In panel (a) the plasma electrodes (PE) are biased at V_{PE}=-70 *V* (that is lower than bulk plasma potential); while, in panel (b), the PE are biased at -30 *V* (positively biased). The arrows represents the direction of the electric field (arrow length is not proportional to the magnitude of the electric field). It appears that .1) the bulk plasma potential is close to the transversal electrodes bias .2) for negative bias the sheath in front of the plasma electrodes is classical confining the electrons in the system, while 3) for plasma electrodes biased positively with respect to the transversal electrodes, electrons are attracted and collected on the plasma electrodes, reducing the electron flow towards the right electrode.

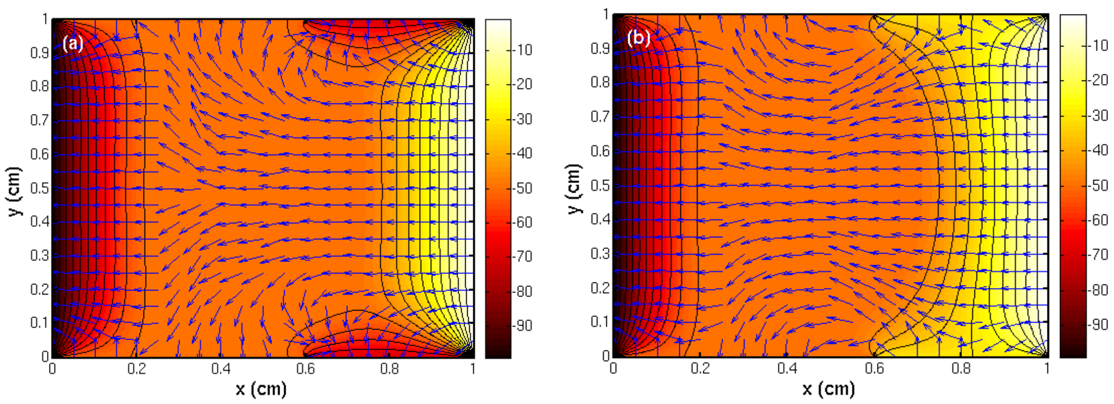

Fig. 4. Plasma potential map averaged over 0.1 µs. The solid lines show the equipotentials and the potential drop between two successive lines is 5 V. The arrow shows the direction of the electric field (a) with plasma electrodes biased at V_{PE}=*-70 V* (b) with plasma electrodes biased at V_{PE}=*-30 V*.

The negative ion and electron fluxes collected at the right electrode are reported in figure 5 as a function of PE bias. It appears that with the increase of plasma electrode bias the co-extracted electron current decreases, jumping down 4 times (from 0.8 Am^{-2} to 0.2 Am^{-2}) just crossing the plasma potential value and remaining almost constant for higher bias. The collected negative ion current increases with PE bias reaching a maximum of 2.2 A/m^2 for PE bias of V_{PE} =-49 V (just 1 V above plasma potential). Then, it starts to decrease with the increase of the PE bias. Therefore, using plasma electrodes can maximize negative ion to electron current ratio, e.g. this ratio passes from 1.5 when V_{PE} is negatively biased in comparison to V_{ud} (transversal electrodes bias) to about 20 when V_{PE} is slightly positive respect to V_{ud}. This result has been already seen in different experiments [Sva09, Fuk92].

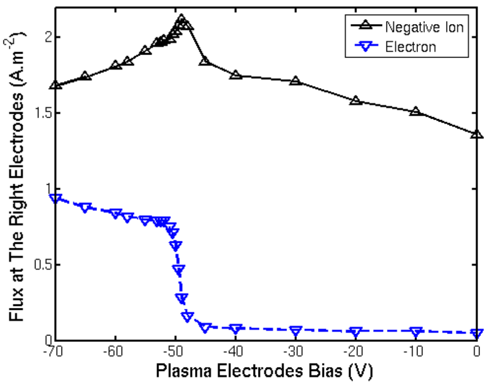

Fig. 5. Collected fluxes at the right electrode as function of the plasma electrodes (PE) bias in a electronegative magnetized (*B*=70 Gauss in the *y* direction) hydrogen plasma, $\alpha \approx 1$, between four electrodes, the left one biased with -100 V, the right one grounded while the two transversal electrodes are biased at -50 V. The peak of the positive ion density is ~10^{16} m^{-3}.

It is important to point out that for some electronegative discharge and due to collisional mechanisms that converts part of negative ions to electrons, it might be not possible to reach extremely high electronegativity. In this case and without using a magnetic field barrier the co-extracted electron current is always significant. However, by coupling a magnetic field barrier plus a transversal electrodes system it is probably possible to reduce the co-extracted electron current to almost zero. The use of plasma electrodes (PE), may collect a large part of the co-extracted electron current leading to an almost pure negative ion beam extraction.

This research has received funding from "Centre de Développement des Technologies Avancées" (CDTA) under MASSINISSA project.

References:

[Sak02] S. Sakamoto, and K. Ichiki, J. Vac. Sci. Technol. A, 20, 1566 (2002).
[Boe11] J. P. Boeuf, G. J. M. Hagelaar, P. Sarrailh, G. Fubiani, and N. Kohen, Plasòa Sources Sci, technol. 20,015002 (2011).
[Aan09] A. Aanesland, A. Meige, and P. Chabert, J. Phys: Conf. Ser. **162**, 012009 (2009).
[Oud13a] N. Oudini, J.-L. Raimbault, P. Chabert, A. Meige, and A. Aanesland, Phys. Plasmas **20**, 043501 (2013).
[Oud13b] N. Oudini, F. Taccogna, P. Minelli, A. Aanesland and J.-L. Raimbault, Phys. Plasmas **20**, 103506 (2013).
[Sva09] P. Svarnas, B. M. Annaratone, S. Béchu, J. Pelletier, and M. Bacal, Plasma Sources Sci. Technol., 10, 045010 (2009)
[Fuk92] O. Fukumasa, M. Hosoda, and H. Naitou, Rev. Sci. Instrum. 63, 042696 (1992)