Currents through a magnetic filter in a low temperature plasma from a Particle-In-Cell Monte Carlo Collisions model

B. Chaudhury, J.P. Boeuf[*], G. Fubiani, J. Claustre

Université de Toulouse; UPS, INPT, CNRS; LAPLACE, F-31062 Toulouse, France.

[(*)] jpb@laplace.univ-tlse.fr

We use a 2D Particle-In-Cell Monte Carlo Collision (PIC MCC) model to describe plasma transport across a magnetic filter in a low temperature hydrogen plasma source in the context of negation ion sources for neutral beam injection in fusion applications. We have shown in recent papers that the presence of walls in the direction perpendicular to diamagnetic and $E\times B$ currents leads to important transport (with a $1/B$ dependence) across the filter field. In this paper we provide more quantitative information deduced from PIC MCC simulations on the electron and ion currents flowing through the filter, and their variations with parameters such as magnetic field intensity, hydrogen pressure, bias voltage, in 1D, 2D periodic, and 2D with walls configurations.

Magnetic field barriers or filters are used in low temperature plasmas for different purpose. In Hall effect thrusters (Fig. 1a) a magnetic barrier perpendicular to the discharge current decreases the electron conductivity leading to the formation of a large plasma electric field that can accelerate ions and provide thrust. In negative ion sources for fusion applications (Fig. 1b), a magnetic filter is used before the negative ion extraction region to lower the electron energy (in order to reduce negative ion detachment by collisions with fast electrons), and to limit the co-extracted electron current. In both cases an electron current must cross the magnetic field region to reach the anode (Hall thruster) or the plasma in the extraction region (negative ion source). The electron current density from cathode to anode or extraction region, $J_{e,x}$ perpendicular to the magnetic field (Fig. 1a), is therefore subject to the Lorentz force which leads to the formation of a current in the direction $J_{e,x}\times B$, perpendicular to $J_{e,x}$ and B. Since the electron current $J_{e,x}$ can be written as the sum of a term proportional to the potential gradient and a term proportional to the electron pressure gradient, the current in the $J_{e,x}\times B$ direction has an $E\times B$ term (the drift current) and a $\nabla\left[nkT_e\right]\times B$ term (the diamagnetic current). In a Hall thruster the potential gradient term in $J_{e,x}$ is dominant in the magnetic field region and therefore the $E\times B$ drift current is the main component of the current in the $J_{e,x}\times B$ direction. The design of a Hall thruster is cylindrically symmetric and the $E\times B$ current (the Hall current) is in the azimutal direction. Therefore the Hall current closes on itself (Hall thrusters are also called “closed drift thrusters”) and does not reach a wall.

In standard negative ion sources the pressure gradient term is the dominant contribution to $J_{e,x}$ in the expansion region. This is because the plasma generated in the driver (inductive RF driver in the ITER negative ion source) expands to the walls and through the magnetic filter (the potential tends to confine electrons in the driver but the pressure gradient pushes them toward the walls and the magnetic filter). Therefore the dominant contribution to the current in the $J_{e,x}\times B$ direction comes from the diamagnetic current proportional to $\nabla\left[nkT_e\right]\times B$. This current is directed to the walls in the design of the ITER negative ion source (Fig. 1b). The plasma potential must therefore adjust itself in order to limit the electron current to the walls and to preserve quasineutrality. One consequence of this redistribution is the non uniformity of the plasma in the direction parallel to the right wall (i.e. parallel to the extraction grid, which is not good for the uniformity of the extracted negative ion beam).

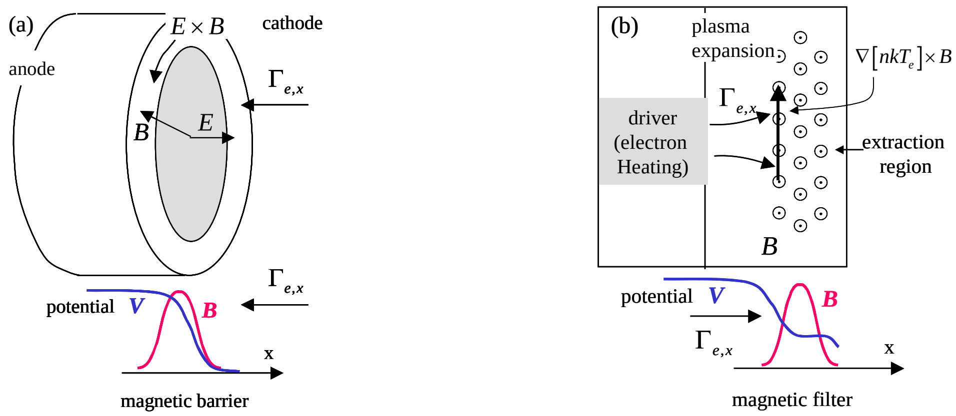

Fig. 1: Transport through a magnetic barrier or filter in low temperature plasma devices; $\Gamma_{e,x}$ is the axial electron flux ($J_{e,x} = -e\Gamma_{e,x}$); (a) closed drift in a Hall effect thruster; (b) negative ion source for fusion applications. A large potential (~300 V) is applied to the anode in (a), while the potential in the driver (~50 V above the chamber walls) in (b) is due to the large electron temperature and the plasma grid on the right wall is biased about 20 V above the chamber walls.

The simulations of a negative ion source in the geometry of Fig. 1b show that this redistribution of the plasma potential leads to a redirection of part of the electron current through the magnetic filter, to the extraction region (see Figs. 2b and Refs [1-3]). When the side walls are removed (top and bottom walls of Fig. 1b) and replaced by periodic boundary conditions (Figs. 2c,d) the diamagnetic component of the electron current (Fig. 2d) is not perturbed by the walls and is much larger than the current through the filter. In this paper we will show how the current through the filter depends on parameters such as magnetic field, pressure, bias voltage (voltage applied to the plasma grid located on the rigth wall). We will also discuss the formation of drift wave instabilities, clearly apparent on the density plot in the periodic case of Fig. 2c, but also present in the bounded case (see the plasma density in Fig. 2a) and address the question of transport through the filter induced by this drift wave.

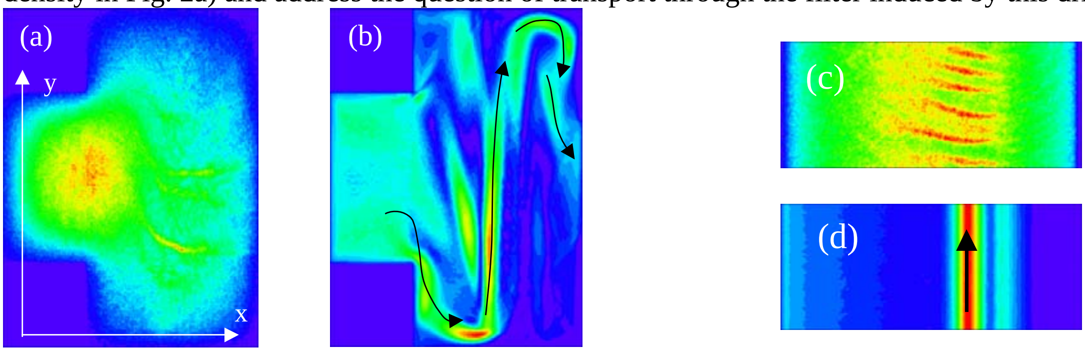

Fig. 2: Plasma density (a), and electron current distribution (b) in a H_2 source with a magnetic filter as in Fig. 1b (maximum at 3 mT); (c), (d) plasma density and electron current for periodic boundary conditions. H_2 density 5 10^{19} cm^{-3}, dimensions (x,y) 24 cm x 32 cm for (a), (b), and 24 cm x 10 cm for (c), (d). The power absorded in the driver region (x<8cm) is 10 W/m. maximum densities are 3 $10^{14} m^{-3}$ for (a) and 4 $10^{14} m^{-3}$ for (c). A scaling up^3 of about 5000 in the density and power must be done to get realistic values for a negative ion source.

Acknowledgments

Work supported by the Fédération nationale de Recherche Fusion par Confinement Magnétique – ITER

References

[1] St. Kolev, G. Hagelaar, G Fubiani and J.P. Boeuf, *Physics of magnetic barrier in low temperature bounded plasmas - insight from particle-in-cell simulations*, to appear in PSST (2012)
[2] G. Hagelaar and N. Oudini, *Plasma transport across magnetic field lines in low-temperature plasma sources*, Plasma Phys. Control. Fusion 53, 124032 (2011)
[3] G. Fubiani, G. Hagelaar, St. Kolev, J.P. Boeuf, *Modeling plasma transport in a high power large volume negative ion source*, to appear in Physics of Plasmas (2012)