Topic number: 6

MODELING OF NEGATIVE ION SOURCES

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The negative ion source for ITER has been officially chosen to be the radio frequency inductively coupled discharge developed at IPP Garching [1]. This source consists of three parts (see Fig. 1): the cylindrical driver, where the RF coils are coupled to the H_2 gas to generate the plasma, the rectangular expansion region, where the plasma expands into the actual source body, and the extraction region, consisting of three grids, the plasma grid PG, the extraction grid EG and the grounded grid AG. The expansion and extraction regions are separated by a magnetic field parallel to the plasma grid of the order of 5-7 mT, the filter field. In fact, it is generally accepted that most H^- ions are produced in the volume by a two-step process which involves dissociative attachment of slow electrons (T_e<2 eV) to highly vibrationally excited levels of hydrogen molecules H_2 (optimum vibrational level v=4-9 reached at T_e>10 eV). For this reason, the optimum condition for H^- formation is not compatible with that for $H_2^*(v)$ production and a magnetic filter has been introduced to separate the negative ion source into two regions where the electron temperature is optimized for each the two processes. The cooling-down from the expansion region is further assisted by magnets in the EG which are primarily there to deflect the co-extracted electrons. The resulting magnetic fields (filter and deflection) are shown in Fig. 2. In addition to volume production of negative ions, the extraction current density of negative ions is strongly increased by adding Cs and generating a lot of additional negative ions from the Caesiated surfaces.

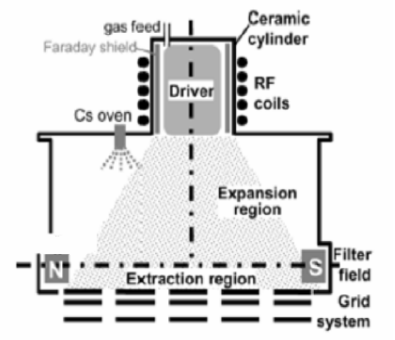


Fig.1: Scheme of the radio frequency inductively coupled negative ion source developed at Max-Planck IPP in Garching.

The separation of this negative ion source in two regions allows the development of two different un-coupled simulations. In order to better understand the formation and destruction of high vibrational levels of hydrogen molecules in the expansion region, a Direct Simulation Monte Carlo (DSMC) model (from the exit plane of the driver to the magnetic filter location) has been performed as first simulation. We consider 16 species of neutral particles [H(n=1s) and $H_2(v=0,..,14)$]. The particle representation allows the self-consistent inclusion of the gas-surface interaction, a very important issue in the vibrational population distribution. Furthermore, it includes also rarefied gas effects, important at low pressures (0.3 Pa). This is a neutral dynamics module preparing and describing the physics in the transition zone between the source and extraction region. This model is only valid for conditions, where a separation of the neutral from plasma dynamics is possible. For hydrogen gas this is usually a good approximation for electron temperatures greater than 5 eV.

The second part of the work represents the continuation of the previous one, where the neutral population was prepared into the expansion region to allow the negative ion production in the subsequent extraction region. In order to obtain negative ion beams with higher efficiency, it is essential not only create but also understand the fundamental transport mechanism of negative ions produced. Plasma parameters in the region next to the plasma grid PG are considered influential to the amount of extractable H^- current from an ion source. In this region, gradients due to plasma sheath and the presence of a magnetic filter and deflection fields create forces strongly affecting the free flight and collisional events. The spatial structure of plasma parameters near the PG is a key point in the transport of negative ions. On the basis of these features it is important to have a self-consistent model of the extraction region. Differently from the treatment done in the expansion region, where the plasma subsystem was considered a fixed background, in the extraction region charged particles dynamic is numerically solved by the Particle-in-Cell technique. The geometry of the two-dimensional slab model used to study the sheath in front of the PG surface and a part of the acceleration region downstream (between plasma and extraction grid EG) is shown in Fig. 2. One extraction hole is considered surrounded by the PG surface, while uniformity is assumed in the transverse coordinate *y* not simulated; periodic boundary conditions in *x* are imposed. In the plasma source layer, electrons and different ion species (H^+,H_2^+,H_3^+,H^- are considered) are created to simulate the flow out of the bulk plasma to the left of the simulation domain.

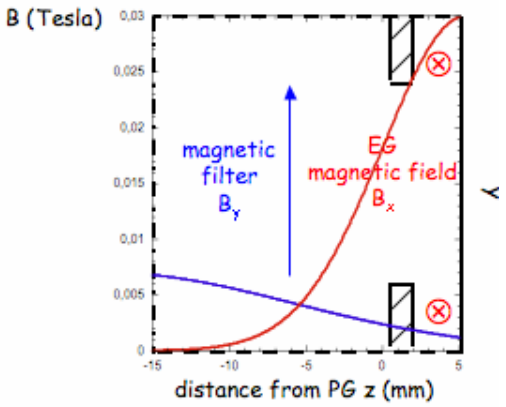


Fig. 2: Sketch of the simulation domain of the extraction region and magnetic fields.

Fig. 3 shows the total population of the vibrational states VDF of molecular hydrogen in the electronic ground state at the end of the expansion region. A strong super-thermal non-Boltzmann distribution with a very long plateau is formed extending up to v=9. The Boltzmann character is restricted to the first two vibrational levels and it is due the competition between direct vibrational excitation induced by electron collision, atomic recombination on walls and wall relaxation processes. Furthermore, due to the high ionization factor (and in particular to the high density of H_2^+ and H_3^+ ions) and high surface to volume ratio of the expansion chamber, the molecular ions neutralization on walls play an important role increasing the density of high vibrational levels.

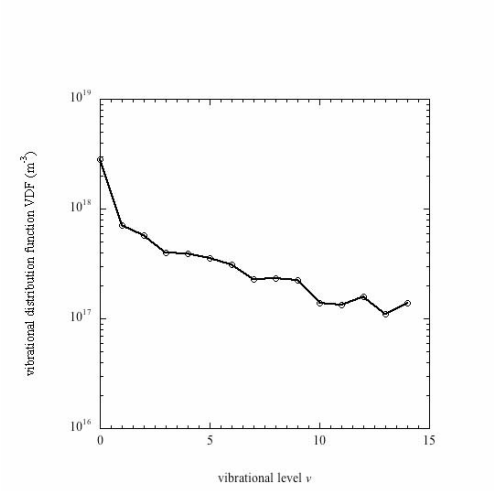
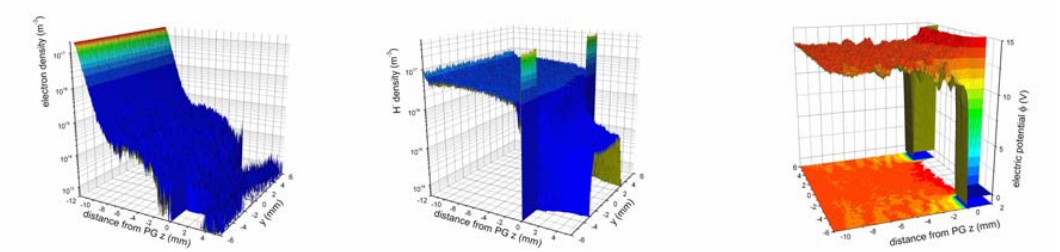


Fig. 3: Total density of vibrational states at the exit of the expansion region (z≈20 cm).

The 2D spatial distribution of electron and H^- density and electric potential in the extraction region are shown on Figs. 4. The electron density distribution shows two different drops corresponding to the magnetic filter and deflection fields influence. The negative ion distribution shows a peak attached to the PG surface corresponding to surface-produced H^-. This peak represents H^- trapped in a potential well formed attached to the PG surface as a consequence of the non-compensation of the H^- produced on the PG surface by a counter-streaming positive ions. In particular, the potential well, located 0.1 mm from PG surface, is due to the neutral conversion which represents the dominant mechanism of surface-produced H^-: 94.6 % against the 5.4% produced on the surface by ionic conversion. As a consequence of this potential barrier in front of the PG surface, the majority of surface-produced H^- is reflected back to the wall and only the 8.3% succeed crossing the extraction aperture. This value is far below the extraction probability of surface-produced H^- calculated by simple Monte Carlo (no self-consistent field is calculated) models [2,3] that gives a value of about 20% depending on the starting energy of surface-produced H^-. Therefore, at the present status, with the processes involved into the model, the population H^- extracted is dominated by volume-produced negative ions: 85.2% against 14.8% of surface-produced. However, it has to be pointed out that the surface contribution coming from the y-direction and some other possible volume mechanism induced by the presence of Cs (decreasing of plasma potential [4], enhancement of vibrational excited H_2 production by charge transfer of H_3^+ with Cs, direct H^- ion formation by dissociative attachment to CsH molecules) and/or surface-

related mechanism induced by the presence of Cs, like near-wall mechanisms (vibrational excitation via molecular ion-neutralization or atomic ion or neutral recombination) are missing into the present model and they could partially explain the relatively low value of the extracted H^- current density computed (through the extraction hole) j_{H^-}=80 A/m^2 against an experimental value larger than 140 A/m^2 measured for a well conditioned ion source [5].



Figs. 4: 2D map of electron and negative ion density and electric potential in the extraction region.

Aknowledgement

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Reference

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