Evolution of electron temperature and negative ion density through a magnetic barrier

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In this paper an ion-ion source, where the ion-ion plasma is formed in a magnetic barrier, has been investigated. The plasma is excited by an ICP source and coupled to a magnetic barrier. SF_6 is used as the electronegative gas. The I-V characteristics, obtained by a Langmuir probe, are symmetrical at the maximum and downstream the magnetic barrier. Surprisingly this indicates that an ion-ion plasma is created at the maximum of the magnetic field. The electronegativity has been deduced from the plasma parameters calculated from the EEPF.

The efficiency of negative ion production is determined by the control of the electron temperature (T_e) because of the attachment rate, which increases when T_e decreases [1, 2]. In low-pressure plasmas, the electron temperature depends on the gas pressure and the plasma size. Another usual way to control T_e for a given source geometry, is to use a magnetic field barrier. Many experiments use such a magnetic configuration but it is usually coupled with an expansion, therefore the measured decrease of T_e depend on the magnetic barrier and the plasma expansion [3, 4].

The ion-ion source studied here is shown in Fig. 1 and has been presented previously [5]. Briefly, the plasma is created by an ICP flat antenna enhanced with a ferrite and excited at RadioFrequency (4 MHz). The magnetic barrier is obtained by permanent magnets providing a Gaussian magnetic field, with the maximum at 7.5 cm and a strength of 245 G. The gases used are Argon and SF_6 with a pressure range from 1 to 100 mTorr and an applied power from 50 to 250 W. The measurements are done through the source along the x-axis with a thin Langmuir probe. The probe tips are 50 μm in diameter and 6 mm long, made of platinum-iridium to resist etching in SF_6. The probe holder is 1.7 mm in diameter to create minimal perturbations to the plasma. This probe is driven by the VGPS probe system®.

The source has been studied in Ar and it was shown that the electron temperature decreases through the magnetic barrier [5]. The more important result is that the decreasing of T_e only occurs in the positive gradient of the magnetic barrier. Downstream of the magnetic barrier, T_e remains constant. The fact that the minimum of T_e is reached at the maximum magnetic barrier is not yet understood. A structure on T_e, corresponding to a light increase, in the location of the maximum of the magnetic barrier, along the magnetic field lines (z-axis) of about 1 cm large (x-axis) is observed, measurements shows that T_e increases in this region.

For the following experiment, Argon is replaced by SF_6, which is an electronegative gas, to create an ion-ion plasma. This plasma is studied in the same way as for Argon meanwhile in an ion-ion plasma the electrons are usually considered negligible. However, we assume that between the positive and negative saturation currents electrons are measured even if the I-V characteristics are symmetrical. The EEPF, according to the Druyvestein method, measures the electron temperature and density from the I-V characteristics. With these measurements, $\alpha = n_i/n_e$ is calculated and compare to a well known method from Chabert et al. [3]. The two methods are in good agreement. According to the EEPF method shown in Fig. 2, $\alpha \sim 4$ upstream of the magnetic barrier. The symmetrical I-V characteristics are observed at 7 cm, which means that, according to our results, for $\alpha > 30$ the plasma is considered as an ion-ion plasma. The maximum electronegativity is reached for the maximum of the magnetic barrier ($x = 7.5$ cm). Downstream of the magnetic barrier, α decreases from 80 to 40. From the measurements of α, the densities of positive and negative ions can be deduced from the electron density measured and are shown in Fig. 3. The density of negative ions upstream of the magnetic field is high probably due to two reasons. First, F^- has a high cross section of formation at high electronic temperature [2]. Then the plasma potential decreases from the excitation coil to the exit, therefore SF_5^-, which is created at the maximum magnetic field (minimum T_e) [2], diffuses to the excitation coil. For these experiments, a discharge power of 120 W is transferred to the plasma, and positive and negative ion densities near the excitation coil are about 5.10^{17} m^{-3}. The ion densities decrease by a factor of two in the barrier while the electron density drops by two orders of magnitude. The maximum ion-ion plasma density is about 1.10^{17}.

The ion-ion plasma source presented here has been investigated with a Langmuir probe. The effect of the magnetic barrier, decorrelated from an expansion, on an Argon plasma show that T_e decreases in the positive gradient only. For an electronegative plasma, the barrier increases the attachment rate and allows the formation of an ion-ion plasma. The minimum temperature in Argon is at the maximum of the magnetic barrier, which interestingly is also where the ion-ion plasma is created.

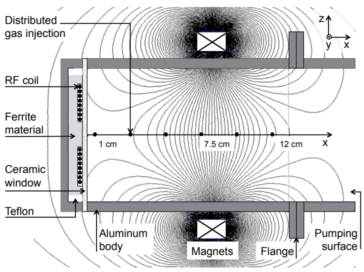

Fig. 1: Schematic diagram of the rectangular ferrite enhanced ICP source with the magnetic field lines

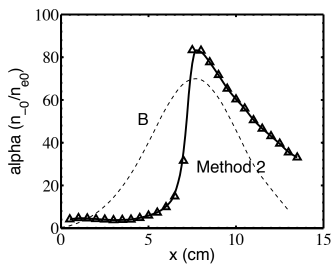

Fig. 2: Alpha calculated along the x-axis and the magnetic field (dotted lines).

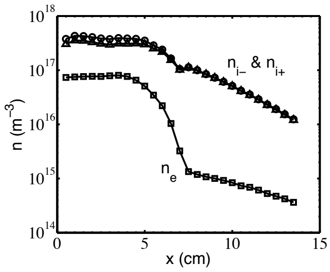

Fig. 3: Plasma densities calculated and the magnetic field measured along the reactor.

Acknowledgment

We are grateful for the expert technical assistance by J. Guillon and M. Baudier. This work is part of the PEGASES project funded by EADS Astrium and the EPIC-ANR blanc project ANR-11-BS09-040. V. Godyaks work was supported in part by the DOE OFES (Contract No DE-SC0001939).

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