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Transport in low-temperature magnetized plasma With significant ionization rate

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Introduction and background

In low-temperature plasma discharges, the ionization fraction usually remains sufficiently small (10^{-4}) so that neutral density stays uniform in the reactor. However, the development of high electronic density plasma sources such as Inductively-Coupled Plasmas (ICP's) or helicon plasmas [1], in which the ionization fraction may reach a percent, has raised new problems in the field of plasma transport. Recent theoretical works [2-3] have shown that when the electronic pressure $n_e\, k_B\, T_e$ is in the same range as the neutral pressure $n_n\, k_B\, T_n$, the neutral dynamics can play a significant role. It was shown that neutral gas density is depleted in the reactor center leading to enhanced plasma transport via non-linear diffusion. The influence of a static magnetic field has also recently been addressed in this situation [4]. On the experimental side, neutral gas depletion in the center of the discharge has been investigated by laser induced fluorescence (LIF) of excited and ground neutral states [5-6]. In particular, Aanesland *et al.* [6] have measured this neutral depletion effect in a helicon reactor on the ground state xenon atom.

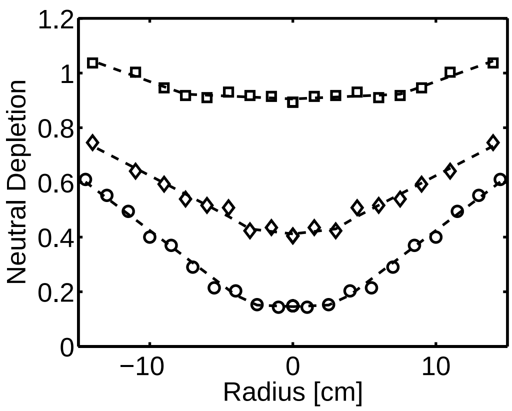

Figure 1 *Radial variation of the neutral gaz density in an helicon reactor for different magnetic field amplitude. This figure has been published in [6].*

Figure 1 is extracted from ref. [6]. It shows the spatial variation of the neutral gas density for different magnetic field amplitudes (respectively 0, 9.5 mT and 15 mT). Without magnetic field, the density profile remains almost flat. With a magnetic field, two phenomena appear. Firstly, we observe the depleted neutral gas profile, which is well explained by the existing theory, i.e. the high electronic pressure pushes the neutral gas toward the edges. Secondly, the overall gas density decreases and we observe in particular that the neutral gas density at the reactor wall is only 60% of that when the plasma is switched off. This second phenomenon is not explained by the theory.

In this paper, we present time resolved LIF measurements performed to understand the dynamics of the neutral gas and attempt to explain the above results. In addition, we also performed temperature measurements made by LIF on argon metastables, as it was shown that neutral gas heating is also playing a role in the neutral depletion effect [7].

Results on the neutral gas dynamics

The ignition and the afterglow of were studied, using time and space resolved measurements of Xenon ground state atom densities with a two photon absorption light induced fluorescence (TALIF) technique [9,10]. The measurements have been obtained by pulsing the plasma at the very low frequency of 0.25 Hz, with 50% duty cycle. This frequency was chosen to let the system reach the steady state, both at ignition and in the afterglow. The match box was set to obtain the fastest possible ignition of the plasma. In figure 2 and 3, we display the time evolution of the neutral gas density at the reactor wall, i.e. 14 cm away from the discharge center. We see that either at ignition or in the afterglow, the density relaxes to the steady state in a very long time scale (of about 2 seconds), much longer than typical diffusion times. However, at ignition, we observe an overshoot of the neutral gas density in short time scales (the maximum is reached in a few millisecond) which is followed by a slow decay to reach a steady state density at about 70% of the density without plasma. The fast increase corresponds to the effect described by the theory, that is the fast raise in plasma pressure pushes the neutral gas towards the wall.

We attribute the slow decay to an increase in the pumping speed when the magnetized plasma column is present. The exact reason for this enhanced pumping is not yet understood. We observe on figure 2 that the relaxation time to equilibrium after the plasma is switched off is about the same order. This time, the pumping speed is reduced after the plasma is off such as the reactor is slowly filled with neutral gas until the new equilibrium is reached.

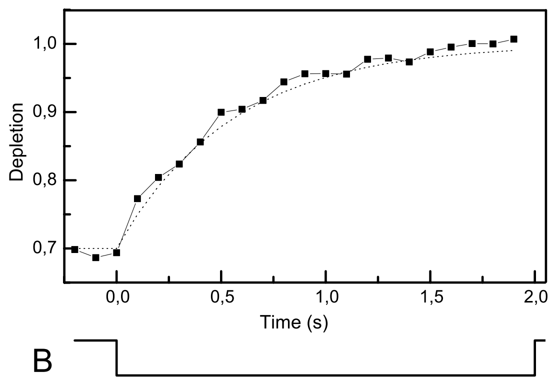

Figure 2 *Neutral depletion as a function of time during the afterglow at 14 cm from the center of the discharge.*

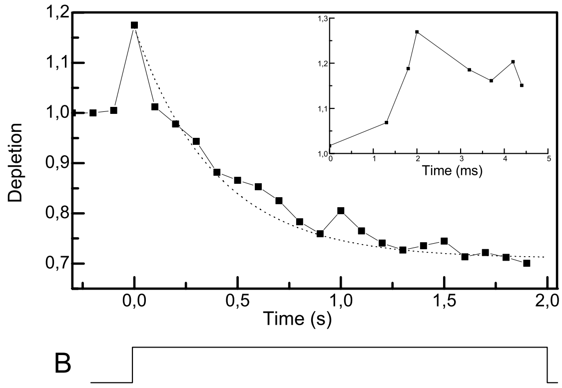

Figure 3 *Neutral depletion has a function of time during the ignition of the plasma, at 14 cm from the center of the plasma.*

Finally, time-resolved measurements of the neutral gas temperature were not obtained but the steady-state temperature was measured at about 500 K for 500 Watts and 10 mTorr.

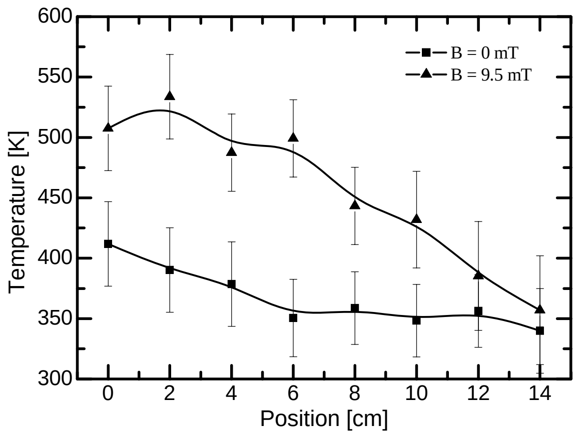

Figure 4 ***Spatial variation of neutral temperature (Argon metastable) in the helicon reactor, with 500W, 10mTorr and different magnetic fields.***

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