Approaching the edges of a surfatron microwave plasma by Thomson scattering

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The radial and axial profiles of a cylindrical surfatron plasma created at intermediate pressure in argon were mapped by Thomson scattering. This technique provides accurate, non-perturbing access. The direct imaging capacity of a triple-grating spectrometer equipped with an iCCD camera allows investigating radial and axial profiles. The obtained radial $n_e(r)$ values match a Bessel function, even if the plasma column is strongly contracted. The axial profile is linear, depending on the pressure. However, the end of the plasma column shows a discontinuity at n_e-values of the order of $10^{18}m^{-3}$.

Microwave induced plasmas (MIPs) are used in various applications as deposition, etching and functionalization of surfaces. The widespread use of MIPs originates from their high efficiency in terms of creating high effluxes of radical species compared to the power consumption. In order to enhance the efficiency a mapping of the radicals close to the plasma edge is needed.

The power flow goes along the following chain; First the mw-power is transferred to the electrons $n_e(r,z)$ and consequently to heavier species. That implies that in order to predict e.g. surface fluxes an accurate knowledge of the (temporal-) spatial distribution of $n_e(r,z)$, as the dominant plasma kinetic agent, is necessary.

The method of observation is Thomson Scattering. This scattering of photons by free electrons can be used to measure directly the properties of the electron gas. In the incoherent regime the signal is proportional to n_e, while the spectral broadening gives insight in T_e. Special care has to be taken to suppress the Rayleigh scattered and stray light since these can be orders of magnitude stronger in intensity. That is especially true in the vicinity of the wall, where laser side beams are scattered. For that purpose a specially designed spectrometer is employed. The first two gratings and a mask form a notch filter in order to block the central laser wavelength, while the third spectrometer resolves the actual spectral information. The detection is performed by a 2D-iCCD camera. That allows having spatial resolved TS with a resolution of below 0.1 mm.

The plasma is a surface wave sustained discharge driven by 2.45 GHz microwaves with an input power of about 50 W. The plasma was operated at pressures of $1<p<100$ mbar argon. The plasma confining quartz tube has an inner radius of 3 mm, an outer radius of 4 mm and a length of 50 cm.

Assuming a simple model with a constant ionization along the radius and diffusion of electrons to the wall, we arrive at a profile of $n_e(r)$ which can be described in the cylindrical symmetry by a Bessel function. A shape-fitting of the experimental $n_e(r)$ curves shows good agreement with that Bessel function in the pressure range of 5 to 88 mbar.

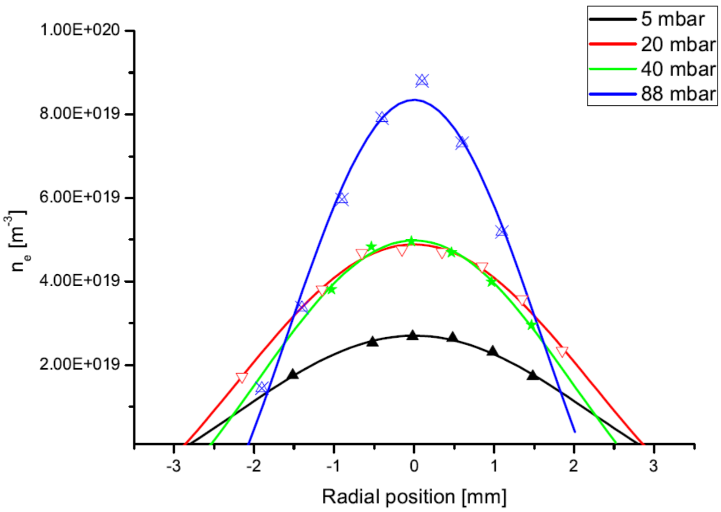

Fig. 1: Radial distribution of n_e with a Bessel function fitting in a surfatron argon plasma at various pressures. The inner tube radius is R=3 mm.

However at higher pressure it is also well known that argon plasmas will be subject to radial contraction [1]. That can be seen in figure 1 as well. Moreover it was shown that at around 10 mbar in argon, volume dissociative recombination by Ar_2^+ becomes the dominant loss mechanism in this plasma source [2]. The shape of $n_e(r)$ is however not directly linked to the loss mechanism as at 20 mbar no contraction could be observed.

As an extension of a previous study we investigate the axial distribution of n_e [3] toward the very end of the plasma column. It is found that $n_e(z)$ decreases linearly from the launcher for pressures of 5 mbar and below. Above that pressure value we observed a non-linear behaviour of $n_e(z)$ due to the non-linear behaviour of the energy needed for creating an electron-ion pair [4]. Along the whole column a steady rise of $T_e(z)$ was found. That behaviour continues till the very last observed frame.

At the very end of the column (EOC) $n_e(z)$ always drops very steeply. That is a very interesting point, since the usual similarity laws break down at the point where the power dissipation cannot be continued. Effectively the region after that critical point can be described as an afterglow, however $n_e(z)$ at the "knee" is still at values of about $n_e=10^{18}$ m^{-3}, so higher than the critical density for power dissipation. (figure 2)

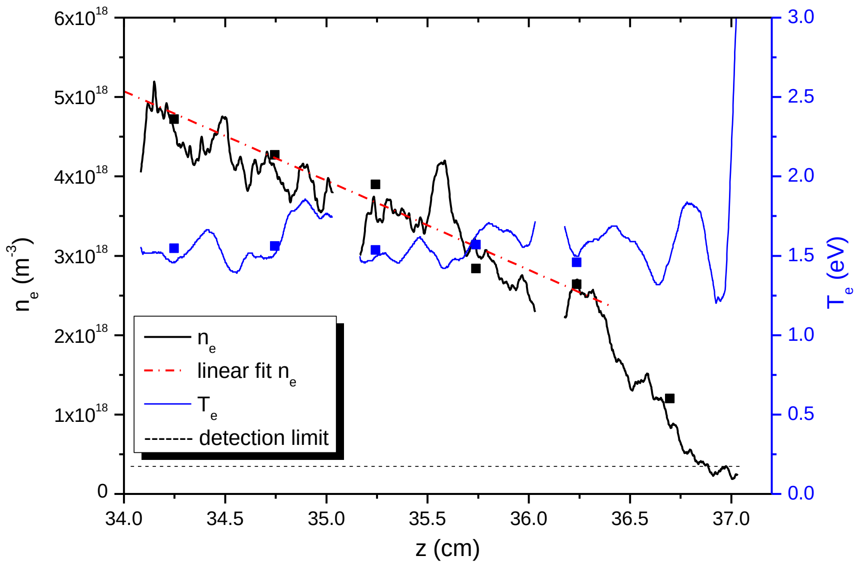

Fig. 2: The n_e and T_e values for 11 mbar obtained at the plasma column end with 3 frames of the iCCD. The symbols are Raman-calibrated TS results with pixel binning, while the curve presents the adjusted raw data. Note the steep drop of n_e in the very last frame, while T_e stays more or less constant at about 1.5 eV. At lower n_e values the low S/N ratio leads to very high (unphysical) values of T_e.

References

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