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Thomson scattering at low pressure surfatron induced Ar plasma: axial profiles of n_e and T_e determined.

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1. Introduction and theory

The surface-wave discharges, a special type of Microwave Induced Plasmas, have been studied and investigated systematically, both theoretically and experimentally, over the past decades. Due to their broad range of operating conditions, stability and reproducibility they have received many technological applications. In order to further improve these applications, insight into plasma parameters is needed, which can be achieved by modelling and experimental diagnostics or better by their combination.

The experiments can be based on several different diagnostic techniques classified in probe measurements and spectroscopic methods. The latter category can be further divided into active and passive spectroscopy. The interpretation of the line and continuum radiation in terms of the main plasma properties is far from simple. In general, models are required that take the degree of departure from equilibrium into account.

In the case of low pressure surfatron induced plasma (SIP) the discharge is far away from thermodynamic equilibrium so that models are needed. A good example is the use of a collisional radiative model combined with the absolute line intensity measurements of the argon 4*p* lines [1-3]. Less sensitive to the degree of equilibrium departure is the method of absolute continuum radiation measurements [4]. In [5] we recently published a method based on the simultaneous measurements of line and continuum radiation by which the values of the electron density n_e and electron temperature T_e can be obtained in an iterative way.

Another way to determine n_e and T_e simultaneously is Thomson Scattering (TS). This active spectroscopy method is based on the scattering of laser photons by the free plasma electrons. It can be considered as a direct technique since the interpretation does not need any model that depends on the state of equilibrium departure. Moreover, this technique also gives accurate results of n_e and T_e with high spatial and temporal resolution, and it can be applied over a wide variety of discharges.

In [6], TS was for the first time applied to low-pressure SIPs. The values obtained for n_e and T_e were found to be in the order of $10^{19}\cdot m^{-3}$ and 1.3 eV respectively. The values and the trends were in a reasonable agreement with previous diagnostic techniques and global plasma models. It was proved that for a fixed geometry T_e depends mainly on the pressure while n_e increases sensibly with the microwave power.

However, the main characteristics of a SIP that lies in the axial dependence of plasma properties could not be studied with the setup used at that time.

In this work, we present axial TS measurement preformed for the first time on a low-pressure surfatron plasma. For this purpose, we designed and built a new setup based on the previous one, but improved in such a way that axial measurements could be performed. This allows doing TS measurements at any position of the plasma column.

Thomson scattering, i.e. the scattering of (laser) light on free electrons, can be used to measure the properties of the electron gas. For the relatively low n_e and high T_e observed in the plasma under study, the scattering is incoherent and the intensity of the scattered radiation is directly proportional to the electron density, since the electrons respond individually to the laser photons. Assuming Maxwellian electron energy distribution function, the T_e can be determined from the Gaussian shape of the TS spectrum.

In order to calibrate the TS setup, in intensity, rotational Raman scattering on N_2 is used. For incoherent Thomson scattering, the TS power radiated by the electrons in a combination with the Raman scattering is used to determine the electron density.

2. Experimental setup and results

The experimental setup consists three main parts: the microwave surfatron, the laser setup and the detection system. Most of the essential elements are discussed in detail in [3, 4, 6] so here we confine ourselves to the information that is relevant for this paper. The plasma is created in a quartz tube by a surfatron launcher. Brewster windows are attached on both sides of the tube to minimize laser reflections. The EM waves are generated by a magnetron device (with maximum power of 300 W) at a fixed frequency of 2.46 GHz.

The laser is a Continuum Laser, model Precision II 8000, which is a frequency doubled Nd :YAG laser that produces pulses of 8 ns with a repetition rate of 10 Hz. The maximum energy per pulse is approximately 700 mJ @ 532 nm.

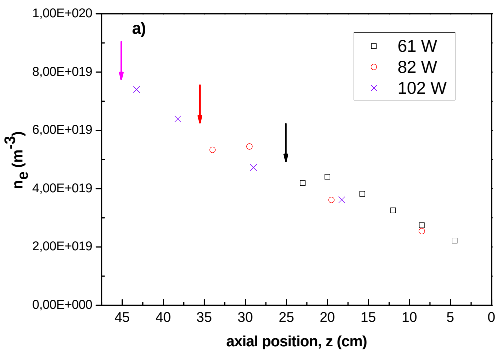
The detection system is a triple grating spectrograph (TGS) designed with purpose to reject the false stray light and the Rayleigh scattered photons, and to disperse and collect the

TS signal. The combination of the first two gratings, form a notch filter whereas the final dispersion is performed by the third grating that sends the dispersed image to an iCCD.

The TS measurements have been performed in the pressure range from 6 to 20 mbar and input power in range from 61 to 102 W.

2.1. Dependence on the input power

Figures 1a and 1b show the axial n_e and T_e profile for increasing microwave powers for the constant pressure of p = 20 mbar. The applied powers were 61 W, 82 W and 102 W, and the corresponding column lengths of 25 cm, 36 cm and 45 cm respectively. Figure 1a shows that the axial n_e profiles do not change in shape as the microwave power increases. When more power is introduced new segments with higher n_e-values are added at the position of the launcher while the old plasma shifts in unaltered form.



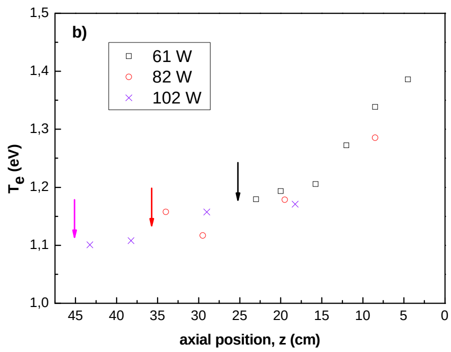


Figure 1. Axial profiles of n_e (a) and T_e (b) for 20 mbar (pa = 4.5Torr·cm) and different microwave power. The points are shown from the end of the column (position z =0 cm). The arrows mark the position of the surfatron launcher for every condition.

Figure 1b shows that in the new added energetic plasma slabs T_e goes down, albeit slowly. An asymptotic tendency is found.

2.2. Dependence on the gas pressure

In figure 2a and 2b, the dependence with the pressure of T_e and n_e profiles is shown. The absorbed microwave power was kept constant at 61 W, and the gas pressures were 20, 10 and 6.5 mbar, the columns lengths were 25 cm, 32.5 cm and 34 cm respectively. The behaviour of the surface wave induced plasmas with pressure has been studied and measured many times in the past and as we observed in figure 2a for a regime of low pressures the columns lengths should increases and the slopes of the density profiles should decreases when the pressure is reduced.

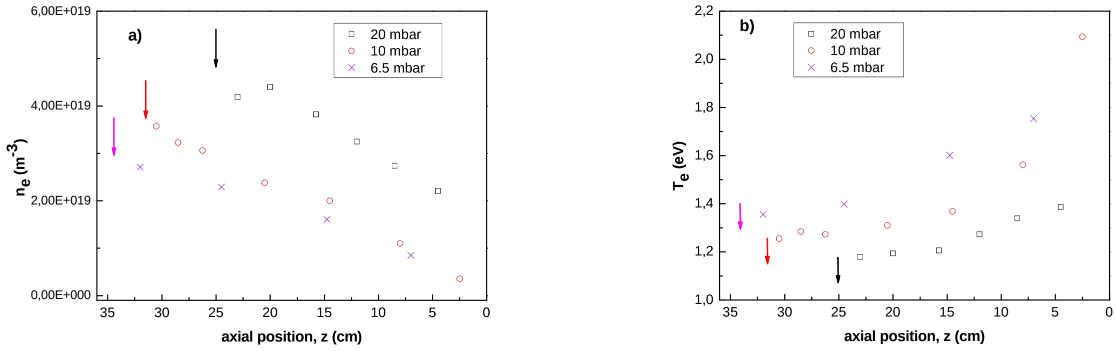


Figure 2. Axial profiles of n_e (a) and T_e (b) for 61 W of microwave power and different pressures. The points are shown from the end of the column (position z =0 cm). The arrows mark the position of the surfatron launcher for every condition.

Figure 2b, again shows that T_e is not constant along the column and approaches a sort of asymptotic value at the launcher. This asymptotic T_e-value increases as the pressure decreases. This can be explained as follows: if the pressure goes down, the losses by diffusion increase and therefore a higher T_e is needed to sustain the discharge.

3. Summary

In this work, for first time axial TS results of low pressure induced argon surfatron plasma have been presented. The measurements were made in pressure range between 6 mbar and 20 mbar for different microwave powers in range between 60 W and 110 W. The n_e and T_e-values were directly obtained from the experimental data. This is a main advantage compared to passive diagnostics, where plasma models are required to give an interpretation of the experimental results. The TS results can be used to calibrate passive diagnostics which are experimentally much easier to use.

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