The electron density and temperature in the Philips QL-lamp

THE ELECTRON DENSITY AND TEMPERATURE IN THE PHILIPS QL-LAMP

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1. INTRODUCTION

There is an increasing interest in electrodeless lamps since reactions between the electrodes and the plasma are avoided which leads to a considerably longer life time and less restrictions to the choice of filling than conventional discharge lamps. One special class of electrodeless lamps is that formed by the inductive fluorescent lamps. For some years commercial lamps of this type have been available: the "QL-lamp" of Philips since 1992 and the "Genura" of General Electric since 1994 [1]. Recently the third major lighting company Osram Sylvania announced the "Endura".

Within the Eindhoven University of Technology a 2D model is being developed which accurately describes the QL-lamp. The electron density and temperature are key-parameters in the description of the plasma. Moreover it appears that due to the relatively high gas temperature (550 to 800 K, depending on the filling pressure) and electron density the mercury ground state atoms are seriously depleted in the most active zone of the discharge.

2. METHODS

The electron density and temperature in the QL-lamp are obtained using two different methods:

1. from the argon $4s^3P_2$ metastable density and the gas temperature which were obtained from radially resolved diode laser absorption measurements [2] and
2. from the electron particle and energy balances.

Each method results in a set two equations with two unknowns (n_e and T_e) which can be solved iteratively. Results are presented for three different argon filling pressures (33, 66 and 133 Pa) and fixed RF power (80 W).

2.1 Absorption measurements

The electron temperature is estimated from the ratio of the argon metastable and ground state densities. A Collisional Radiative Model (CRM) [3,4] is used to correct for the non-equilibrium population. The electron density is obtained from the heavy particle heat balance.

2.2 Size-stabilised plasma theory

A good estimation for the electron temperature can be obtained from the electron particle balance:

$$n_e n_i^{Hg} S_{CRM}^{Hg} \approx \frac{D_a}{\Lambda_{ne}^2} n_e$$

The CRM which is used to calculate the ionisation coefficient S_{CRM}^{Hg} is treated in a different contribution [4]. The gradient length in the electron density profile Λ_{ne}, which dictates the electron temperature, is estimated from the position of the maximum in the gas temperature.
In a similar way the electron energy balance yields a value for the electron density.

3. RESULTS

The results are depicted in Figure 1. The agreement between the temperatures as found by both methods is striking: the differences are much smaller than the error bars (due to various assumptions and inaccuracies in the measurements and the model). Also the electron densities agree fairly well with each other.

For increasing argon filling pressure the losses of charged particles are reduced which results in a lower electron temperature and a higher electron density. It should be noted that apart from the fact that a higher argon pressure obstructs the diffusion, it is also found that the center of the most active zone is situated more to the outside so that (in our simple model) the characteristic size of the plasma Λ_{ne} is larger. Both effects (lower diffusion coefficient D_a and larger Λ_{ne}) benefit the residence time of the charged particles, so that the electron temperature is lower and the density higher.

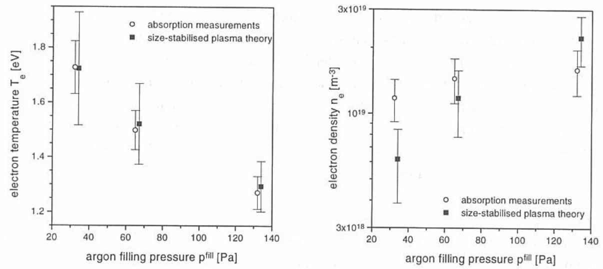

Figure 1: The electron temperature and density as estimated from the two different methods. The error bars stem from the estimated inaccuracies of the measurements, the used assumptions and the CR model. The points at the same argon filling pressure are plotted next to each other, so that the error bars do not interfere.

The combination of the relatively high electron density and gas temperature causes that the density of mercury atoms in the most active part of the lamp (5.7 at 33 and 2.6×10^{19} m^{-3} at 133 Pa) is significantly lower than near the outer wall of lamp (around 9.0×10^{19} m^{-3}).

4. REFERENCES

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