Diode laser diagnostics of an atmospheric pressure microhollow cathode discharge

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This work reports on diagnostics of a miniaturized atmospheric hollow cathode discharge using diode laser atomic absorption spectroscopy. The electron density of an Ar microplasma was determined from the broadening of the 811.754 nm Ar line. By extrapolation of the results in different He/Ar mixtures, the electron number density of the discharge operating in He was also estimated. These values are in the range of 10^{15} - 10^{16}/cm^3.

1. Introduction

In the category of non-thermal plasma sources operating close to atmospheric pressure, the microhollow cathode discharge was intensively developed in the last years. Its potential applications are in the field of surface treatment, generation of UV and VUV radiation and molecular decomposition.

Despite the fact that the design is already optimised for different applications, the plasma parameters are not very well known. It is rather difficult to employ diagnostic techniques when the discharge dimensions are in the micrometer range. Emission [1] and diode laser absorption spectroscopy [2] were used for the determination of the excited species density, electron number density as well as gas and electron temperature in the pressure range lower than 500 mbar for plasmas operating in Ar or He.

2. Discharge operation

The discharge is a multilayer system consisting of two Pt electrodes (25 µm thickness) separated by a 200 µm Al_2O_3 insulator. A 100 µm diameter hole is drilled through the structure as it can be seen in Fig.1.

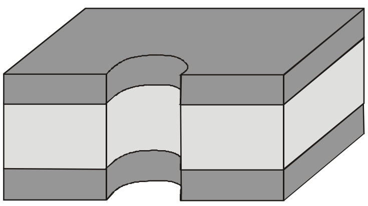

Fig.1 Schematic view of the microstructure

The microdischarge is ignited in the hole between the two metallic layers representing the electrodes. The main advantage of the microhollow cathode discharge is that the current density is higher that in a normal discharge operating at similar parameters and consequently the electron density is higher.

The voltage – current characteristic of the discharge for currents lower than 8 mA shows the normal glow operation with independent gas voltage at the variation of the current. The gas voltage is about 200 V at 1 bar for both Ar and He as filling gases.

3. Experimental set-up

The electron density was determined from the broadening of the line performing line profile analysis. A laser diode tuned to the Ar transition at 811.754 nm corresponding to the $1s_5$-$2p_9$ transition was used. By scanning the diode laser wavelength the absorption line profiles were recorded. Simultaneously the interference fringes from a confocal Fabry-Perot interferometer were used as frequency markers and the wavelength was measured with a wavemeter.

The discharge was operated in Ar and Ar/He mixtures. This method offers the possibility to estimate also the electron density in the He plasma by extrapolating the results obtained in pure Ar and Ar/He mixtures.

4. Results and discussions

The evaluation of the electron density of the Ar and He discharge was performed by measuring the width and the shift of the Ar 811.754 nm line.

In high pressure discharges, the line profiles are mainly broadened and shifted due to the thermal movement of the neutral atoms (Doppler broadening), the frequent collisions between neutrals (pressure or collision broadening) and their interaction with charged particles (Stark broadening). At atmospheric pressure and at high electron number densities in the order of 10^{15} to $10^{16}/cm^3$ the Doppler broadening becomes insignificant in comparison with the other two broadening mechanisms and can be neglected.

The gas temperature of the discharge is ranging between 1500 K and 2000 K[1]. The collision broadening width and shift presented in [3] where corrected for the reported gas discharge temperature.

The total width and shift are given by the sum of the pressure and Stark broadening and pressure and Stark shift, respectively. Therefore, the Stark contribution to the line profile can be calculated from the measured line width or shift of the broadened line subtracting the collision-induced width or shift.

The 811.754 nm line has a strong oscillator strength and as a consequence the $1s_5 - 2p_9$ transition is optically thick due to the high density of atoms on the lower level. Therefore precise evaluation of the line width is difficult to perform in these conditions. In our measurements, independent on the Ar concentration in He when Ar/He mixtures were used, the total width remains almost constant in the range of the experimental errors.

The only parameter which is not influenced by the optically thick transition is the total shift of the line. This is presented in Fig. 2 together with the theoretical data for collision-induced shift. It can be seen that with the increase of the He amount in the discharge the experimental shift is decreasing faster than the theoretical collision-induced shift. Therefore the determined Stark shift is also decreasing at higher He amounts. This leads to the conclusion that the electron density should decrease if the plasma is operated at the same parameters in He.

Using the Stark broadening constants for the shift taken from [4] we obtained an absolute electron density in Ar plasma of $10^{16}/cm^3$ while in pure He this can be extrapolated to about $10^{15}/cm^3$

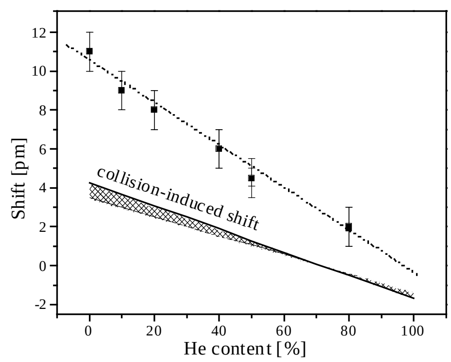

Fig.2 The measured shift (squares) and the collision-induced shift calculated from [3]

The electron number density was already measured in a microhollow cathode discharge in Ar but in the pressure range 50 – 400 mbar [2]. Fig. 3 presents these results and the extrapolation of the values at 1 bar.

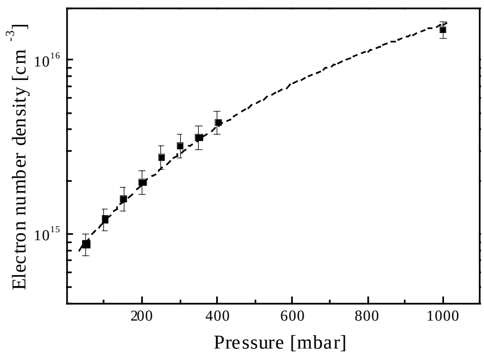

Fig.3 Extrapolation of the electron density results obtained in the pressure range 50 mbar – 400 mbar

5. Conclusions

The study of the miniaturized hollow cathode discharge applying diode laser absorption spectroscopy revealed information about the electron number density in the plasma operating at 1 bar in noble gases. Such parameters are rather difficult to obtain by other plasma diagnostic techniques in these small size discharges.

6. References

[1] I. Petzenhauser, U. Ernst, W. Hartmann, K. Frank, Proc. of the APP Spring Meeting ”Diagnostics of Non-Equilibrium High-Pressure Plasmas”, Bad Honnef, (2001) 217-220.

[2] C. Penache et al., submitted to Plasma Sources Science and Technology (2002).

[3] G. H. Copley, J. Quant. Spectrosc. Radiat. Transfer, **16**, (1976) 377-384.

[4] H. Griem, Phys. Rev. **128** (2), (1962), 515-521.