THE AXIAL ELECTRIC FIELD STRENGTH AND THE WALL POTENTIAL IN A DC NEON GLOW DISCHARGE AS A FUNCTION OF THE TEMPERATURE

J.F. Behnke, T. Bindemann, H. Deutsch, **M. Tichý*** and K. Becker**

Institute for Physics, Greifswald University, Domstraße 10 A, 17487 Greifswald, Germany.

**Department of Electronics and Vacuum Physics, Faculty of Mathematics and Physics, Charles University, V Holešovičkách 2, 180 00 Prague 8, Czech Republic.*

***Dept. of Physics & Engineering Physics, Stevens Inst. of Tech., Hoboken, NJ 07030, USA.*

e-mails: behnke1@physik.uni-greifswald.de, tichy@mbox.troja.mff.cuni.cz, kbecker@stevens.tech.edu

We report on measurements of the axial and radial potential gradients in the DC glow discharge in neon as a function of the gas and the discharge tube wall temperature at the pressure around 100 Pa. For the study we used two Langmuir probes positioned on the axis of the cylindrical discharge tube separated by 8 cm and a planar probe whose collecting surface was aligned with the inner discharge tube wall, so-called wall probe, see Fig. 1. The external wall probe, also shown in Fig.1, has not been used in the presented measurements. The apparatus has been described in detail in [1], therefore only a brief description will be given here, see Fig. 2. Basically, the discharge tube was placed in an oven and it could be heated up to the temperature of about 300 °C. For the potential gradient measurements the floating potentials of the selected couple of probes were sensed by two voltage followers with extremely high input impedance (5×10^{11} Ω input resistance, approximately 1pF input capacitance) and monitored by a computer-controlled system. For the electron density, the electron temperature (effective temperature) and the electron energy distribution function (EEDF) measurements we used the floating probe computer-controlled circuit that measured the

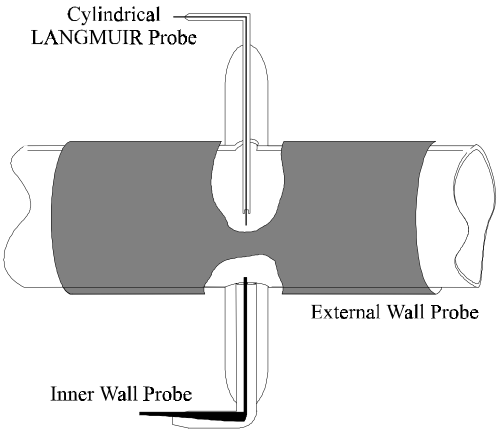

Figure 1. Sample of the used probes.

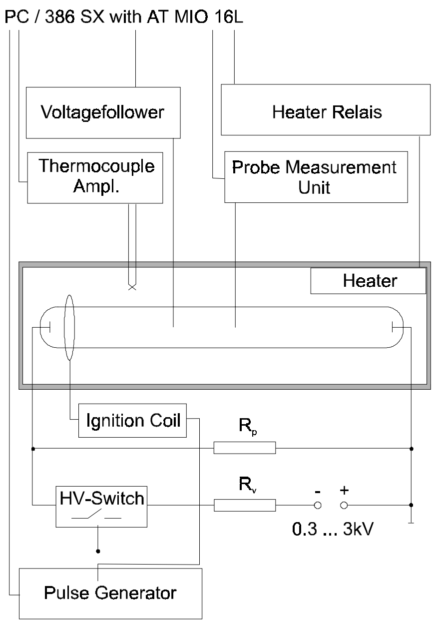

Figure 2. Experimental set-up.

current-voltage characteristic of the Langmuir probe(s). The probe data has been processed off-line using the computer program the theoretical principles of which are described in [2].

The experiments have been done with three discharge tubes made of the two different kinds of glass: Duran and Rasotherm. For the presented results it is of great importance that no impurities are desorbed from the glass in the whole range of applied temperatures. These impurities degrade the measurements, since the impurity ions have usually low recombination energy and hence reduce the measured electric field in the dicharge. The tube made of Duran glass enabled the measurements up to 150 °C, the tube from Rasotherm glass up to 300 °C. The method of preparation of the discharge tubes was standard for both materials namely:

- eddy-current heating of the nickel electrodes to the cherry-red temperature,
- baking the discharge tube while pumping 50 hours at 500 °C,
- ultimate pressure after baking out (at the room temperature) < 5×10^{-9} mbar,
- further outgasing of the electrodes by discharge current 200 mA (max. current used for experiments was 20 mA).

The purity of the gas filling of the discharge tube was checked also during the measurements (at every 50 K change of the temperature) by means of optical spectroscopy.

The presented results of measurements are that in a neon DC discharge at the pressure p_0 = 159 Pa (1.2 Torr), for a discharge tube of radius r_0=1.18 cm consisting of Rasotherm glass. The following typical tendencies of the studied plasma parameters can be inferred from the experimental results:

1) Axial electric field
   - weak dependence on temperature up to 180 °C,
   - steep decay of the electric field for temperatures > 180 °C,
   - qualitative agreement with the simple model of the positive column [3,4].
2) Wall potential (potential difference between the floating potentials at the axis and at the wall of the discharge tube)
   - weak dependence on temperature up to 200 °C,
   - steep decay of the wall potential for temperatures > 200 °C.
3) Electron and ion density
   - slow increase of the carriers density for temperatures < 250 °C,
   - greater plasma density for temperatures > 250°C (current balance satisfied). Comment: Lower density values at T > 250°C and 10 mA were probably caused by the observed instabilities of the discharge (ionisation waves).

4) Electron energy distribution function (EEDF)

- under 280 °C no change of the EEDF with the temperature,
- under 280 °C the EEDF is close to the Druyvesteyn EEDF, i.e. to the distribution given by the formula

$$f_0(U) = A\frac{1}{U_e^{3/2}}\exp\left[-\frac{1}{k}\left(\frac{U}{U_e}\right)^k\right];\ A = \frac{(1/k)^{\frac{(3-2k)}{2k}}}{\Gamma\left(\frac{3}{2k}\right)};\ k \approx 2$$

(Γ is the gamma function, U_e is the so-called effective temperature that is for the Druyvesteyn distribution equal to the electron mean energy <*E*>.

5) The electron mean energy <*E*>.

- no measurable change with the temperature (greater scatter of the values at 300°C is probably due to the changes in the EEDF.

Sample of the experimental results are presented in Figs. 3-6. In Fig. 3 we show the reduced axial electric field strength E/p_0 on the tube axis for various gas temperatures. Open symbols represent measured data and the curves are results from model calculations based on a model of the positive column in a low pressure glow discharge, see [3,4]. The discharge current is a free parameter. The relatively steep decay of the reduced axial electric field strength for gas temperatures above 180 °C was, as far as we know, never measured before. The radial potential gradient V_w (wall potential) in Fig. 4 shows a weak rising dependence on

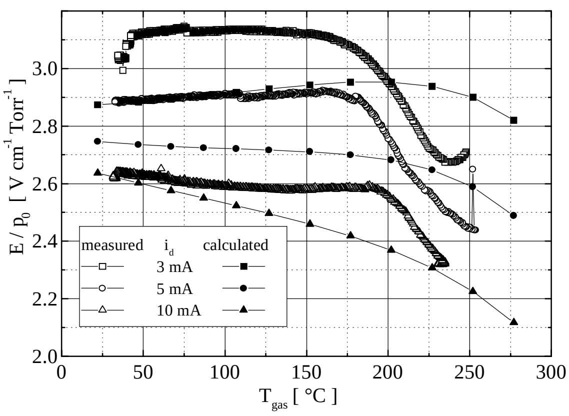

Figure 3. Axial electric field strength.

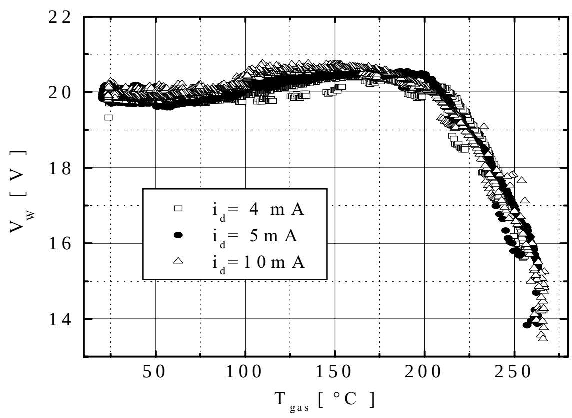

Figure 4. Radial potential gradient (wall potential).

the gas temperature up to 200 °C. For higher temperatures the wall potential shows a steep decay similar to that of the axial electric field strength.

The axial number densities determined from the probe measurements are depicted in Fig. 5 for various gas temperatures with the discharge current as a parameter. The electron densities n_e determined from the integral over the EEDF and the densities of the positive ions n_i determined from the radial motion theory [5,6] are shown. The difference between the electron and positive ion density determined by probe measurements (15% at 2 mA, 20 % at 5 mA, 25 % at 10 mA) is most likely due to collisions of positive ions with neutrals in the probe sheath which are not taken into account in the theory [5,6] and, therefore, it cannot be interpreted as a violation of the quasi-neutrality of the plasma.

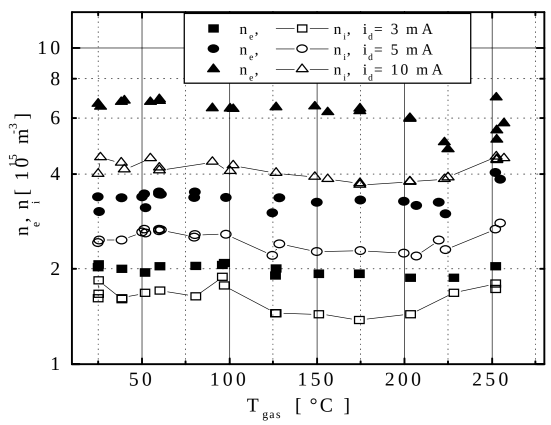

Figure 5. Plasma number densities.

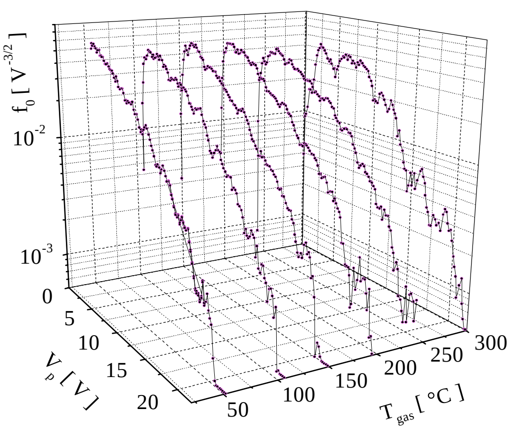

Figure 6. EEDF on the discharge axis.

In Fig. 6 we show the EEDF on the discharge axis as a function of the gas temperature at the discharge current 5 mA. The shape of the EEDF is close to Druyvesteynian and does not change with the gas temperature significantly.

Acknowledgement

The research was supported by DFG SFB 198, GAUK-181/96, 75/98, GAČR-202/97/1011, 202/98/0166, 202/98/P078 and U.S. NSF through grant PHY-9722438.

References

[1] T. Bindemann et al.: Rev. Sci. Instr. **69** (1998) 2037.

[2] M. Tichý, P. Kudrna, J.F. Behnke, C. Csambal, S. Klagge: Journal de Physique IV France **7** (1997) C4-397.

[3] H. Deutsch, A. Rutscher: Beitr. Plasmaphys. **8** (1967) 205.

[4] L.M. Chanin, M.A. Biondi: Phys. Rev. **106** (1957) 473; A.V. Phelps: Phys. Rev. **114** (1959) 1011.

[5] J.E. Allen, R.L.F. Boyd, P. Reynolds: Proc. Phys. Soc. B**70** (1957) 297.

[6] F.F. Chen: Plasma Phys. **7** (1965) 47.