DIFFUSION COOLING IN NEON STATIONARY AFTERGLOW

J. Rusz, P. Kudrna, M. Tichý and V. Hrachová

Department of Electronics and Vacuum Physics, Charles University,
V Holešovičkách 2, 180 00 Prague 8, Czech Republic
e-mails: jan.rusz@mff.cuni.cz, pavel.kudrna@mff.cuni.cz,
tichy@mbox.troja.mff.cuni.cz, hrachova@mbox.troja.mff.cuni.cz

1. Introduction

We describe the measurements of the ambipolar diffusion coefficients of the Ne^+ atomic ions with electrons in neon afterglow plasma, under the conditions when the ambipolar diffusion was the dominant loss mechanism for the charged particles. For the observation of diffusion cooling of electrons we used the single Langmuir probe technique. The phenomenon of diffusion cooling was evident as a decrease of measured electron temperature and as a reduction of the parameter $D_a p_0$ below the pressure invariant value $D_a p_0$ measured under conditions without the diffusion cooling [1].

When the electron mobility exceeds the ion mobility in the diffusing plasma, the space charge field is established at the plasma boundary. It means, that the electrons with sufficient energy to overcome this field barrier can escape to the walls. This process results in the reduction of the higher energy part of the electron energy distribution and hence in lowering of the mean energy of the remaining electrons. The transfer of energy to electrons by means of collisions between electrons and neutral species or ions partly balances the decrease of electron mean energy. If such collisional transfer of energy does not completely compensate for the diffusive loss of energy, the new equilibrium of electron temperature is reached. When the dominant electron energy transfer process are the collisions with neutral species, then there exists a pressure p_c above which the diffusion cooling is not significant and below which it is.

In plasma consisting of electrons and of one type of positive ions the ambipolar diffusion coefficient D_a, is related to the ion and the electron free diffusion coefficients D_+, D_-, via the well-known relationship

$$D_a = \frac{D_+ \mu_- + D_- \mu_+}{\mu_+ + \mu_-} \,. \qquad (1)$$

In this expression, the symbols μ_+, μ_- represent the ion and the electron mobilities. Assuming that the electron mobility is very much greater than the ion mobility, that the energy distribution of charged species is Maxwellian with temperatures T_i and T_e respectively and that the neutral atoms and the ions have the same temperature (T_e=T_g) we can write

$$D_a = D_+ \left[1 + \frac{T_e}{T_i} \right] \qquad (2)$$

In the plasma, where the charged species are lost only by the fundamental mode of ambipolar diffusion and where the electron temperature is constant, the density of charged particles n at a particular place decreases according to the relation

$$n = n_0 \exp(-\lambda t) \, . \qquad (3)$$

The decay constant λ is given by relationship

$$D_a p = \Lambda^2 \lambda p \, . \qquad (4)$$

Λ is the fundamental mode characteristic diffusion length of the vessel containing the plasma. The product of ambipolar diffusion coefficient with working pressure $D_a p_0$ is under normal diffusion conditions independent of the pressure and size or shape of the vessel. From Eq. (2) we can see, that $D_a p_0$ is depends on T_e/T_i . For $T_e=T_i$ it is to be expected that $D_a=2D_+$ and for the zero value of T_e (limit of the diffusion cooling) the value of D_a approaches the value of D_+.

2. Experimental Apparatus

Plasma was produced in pure Neon by 10 microseconds long pulses of radio-frequency power coupled capacitively to the gas by means of two external electrodes [2]. The pulse repetition frequency was 25 Hz. The plasma was contained in a cylindrical tube 20 cm long with 9.3 cm internal diameter (Λ^2 = 3.42 cm^2). Single Langmuir probe method was used for measurement of the electron temperature and density. The electron density was obtained from the electron acceleration region of the probe characteristic (I^2 vs. V plot), the electron temperature from the slope of the probe characteristic in the electron retarding regime plotted in semilogarithmic scale. The probe was located at the centre of the discharge vessel and the data in dependence on the afterglow time were acquired using the computer-controlled system with the time resolution of 10 μs.

3. Results

The electron temperature was determined from the electron retarding region of probe characteristic. This part of characteristic plotted in semilogarithmic scale was generally linear, see Fig. 1. This is an indication that the distribution of electron energies was close to Maxwellian. For all working pressures the electron temperature decreased after a period of several milliseconds to an equilibrium temperature value. At pressures greater than p_c, T_e

cooled to the wall temperature of 300 K. For the pressures below p_c the electron temperature cooled to the value below the wall temperature, see Fig. 2,3. The lowest recorded temperature was 80 K at working pressure of 6 Pa. It was the lowest gas pressure for which a repetitive discharge could be ignited. The critical pressure p_c, at which diffusion cooling became apparent was approximately 0.2 torr.

The electron density was derived from the electron acceleration region of the probe characteristic. The semilogarithmic plot of the electron density versus afterglow time shows us, that the decay of electron density is not exactly exponential. We could observe the transitions from the higher diffusion modes to the fundamental mode one and to the free diffusion in the density decay. The decay constant λ was determined from the middle part of the decay curve, where the loss of charge was supposedly only via the fundamental diffusion mode. The measured data are presented in Fig. 4 in form of $\Lambda^2\lambda p$ versus p plot. We can see that for the lowest pressures the value of $\Lambda^2\lambda p$ decreases under the values in the region of medium pressures. This is interpreted as a manifestation of diffusion cooling.

4. Conclusion

The measurements presented in this paper show, that the effect of diffusion cooling of electrons in neon afterglow plasma is measurable as a reduction in a electron temperature below the gas temperature. The same effect is also demonstrated by a reduction of the ambipolar diffusion coefficient below the value appropriate to the case where $T_e=T_g$. The values obtained from measurements are within estimated experimental error in agreement with the results published in [3].

Acknowledgements

This work was partially financially supported by the Grant Agency of Czech Republic, Grant No. 202/95/1011, 202/97/P078 and 202/98/0116 and by the Grant Agency of Charles University, Grant No. 181/96, 75/98.

References

[1] Biondi, M.A.: Phys. Rev. **93** (1954) 1136.

[2] Chudáček, O., Kudrna, P., Miler, H., Brzobohatý, M. and Tichý, M.: *Proc. 17th Symposium on Plasma Physics and Technology*, Prague (Czech Republic), J. Píchal, Ed., June, 13-16, 1995, page 221.

[3] Smith, D., Dean, A.G., Adams, N.G.: Z. Physik **253** (1972) 191.

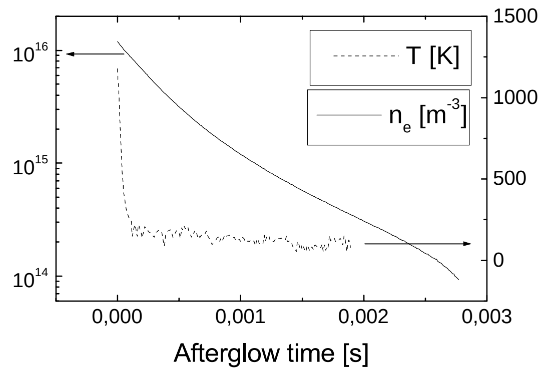

Fig. 1. The decay of the electron density (solid line) and temperature (dashed line) in the neon stationary afterglow

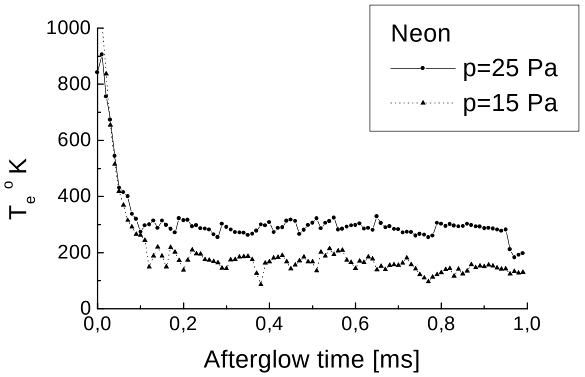

Fig. 2. The electron temperature as a function of afterglow time in neon with the diffusion cooling (pressure 15 Pa) and without the diffusion cooling (pressure 25 Pa)

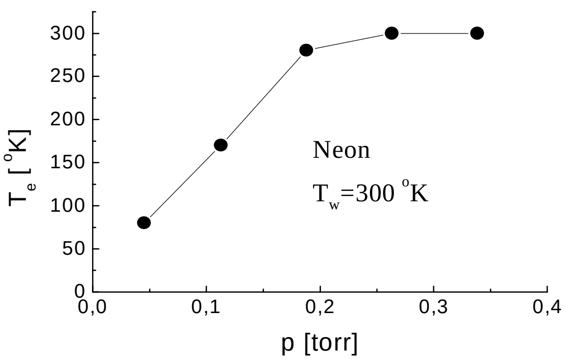

Fig. 3. The equilibrium electron temperature as a function of gas pressure in neon. The wall temperature was T_w= 300 ^{o}K.

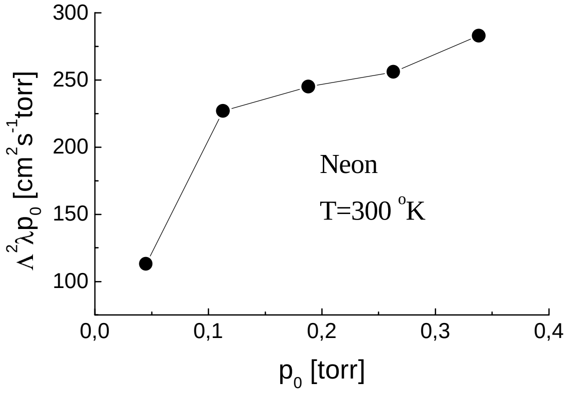

Fig. 4. The measured variation of $\Lambda^2\lambda p$ with pressure from electron density decay in neon.