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AN INVESTIGATION OF A FLOWING AFTERGLOW PLASMA BY THE LANGMUIR PROBE[1]

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An experimental study of the loss process of charged particles in the flowing afterglow argon plasmas is reported. The measurements are made in the flowing afterglow apparatus with an axially movable cylindrical Langmuir probe in the diffusion controlled region. The plasma flow velocity and the arrival time are measured by a pulse modulation of the discharge in the plasma source. By measuring the decay of the ion concentration the values of the product $D \cdot p$ for different pressures are obtained. The results indicate the presence of the ion mixture, the metastables and the non-thermalized electron gas in the afterglow plasma.

ИССЛЕДОВАНИЕ ПЛАЗМЫ ПОСЛЕСВЕЧЕНИЯ В ПОТОКЕ ПРИ ПОМОЩИ ЗОНДА ЛЕНГМЮРА

В работе сообщается об экспериментальном исследовании процесса потери заряжённых частиц в аргонной плазме послесвечения в потоке. Измерения сделаны при помощи аппаратуры послесвечения в потоке с аксиально подвижным цилиндрическим зондом ленгмюра в области регулируемой диффузией. При помощи импульсной модуляции разряда в источнике плазмы измерены скорость потока плазмы и время поступления. На основе измерения распада концентрации ионов получены значения произведения $D \cdot p$ для различных давлений. Полученные результаты указывают на присутствие смеси ионов, метастабилов и нетермализованного электронного газа в плазме послесвечения.

I. EXPERIMENTAL DETAILS

The classical flowing afterglow apparatus was used [1] with an axially movable cylindrical Langmuir probe. The flow tube is a one metre long glass tube of a 5.6 cm internal diameter pumped by a fast mechanical Roots pump. The plasma is produced by a discharge source in the carrier gas (Ar). The cathode is placed in

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the side arm of the tube, a cylindrical ring anode is placed in the upstream end of the tube (Fig. 1). The metal body of the pumping unit (downstream end of the flow tube) and the anode are electrically connected and grounded and thus there is no external field inside the flow tube. The discharge current is electronically stabilized and can be regulated in the range of 0—30 mA. The measurements are made in the current range where plasma oscillations are suppressed. In the described arrangement of the electrodes the discharge is very stable.

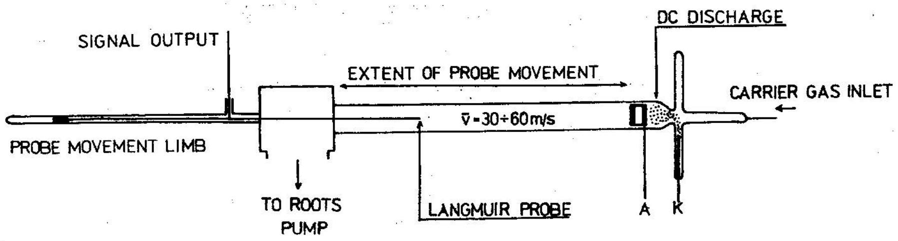


Fig. 1. Experimental arrangement.

The cylindrical Langmuir probe (4 mm long, 40 μm diameter) is placed in the axis of the flow tube and is moving from the downstream end of the flow tube and thus the disturbance of the flow of the carrier gas in the place of the probe is negligible.

The plasma concentration N is determined from the ion part of the probe characteristics using double logarithmic extrapolation [2]. The electron temperature T_e is determined from the slope of the plot of log I_e against V_p (I_e is the electron part of the probe current, V_p is the probe potential) using the correction

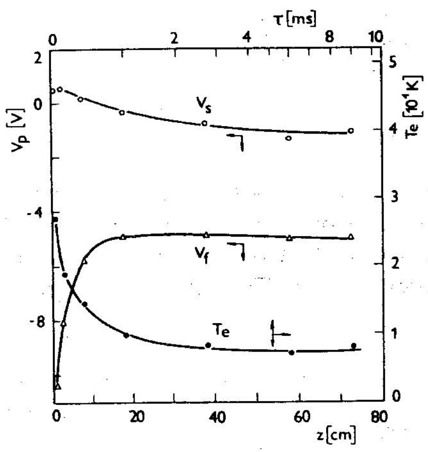


Fig. 2. Variation of plasma potential V_s, floating potential V_f and electron temperature T_e along the flow tube for the pressure of 60 Pa and 8 mA discharge current.

for the ion current following from the double logarithmic extrapolation [2]. This determination of T_e is valid only when the electron distribution function is Maxwellian and in our case it is preliminary and gives only rough information about temperature behaviour. The plasma potential V_s is determined from the probe characteristics [3]. The examples of the variations of the plasma potential V_s, the floating potential V_f and the electron temperature T_e along the low tube are presented in Figure 2.

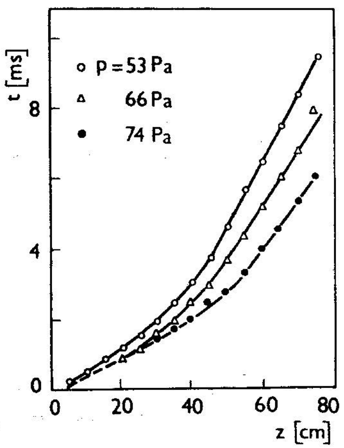


Fig. 3. Dependence of the arrival time t of the pulse response on the probe on its position z for different pressures.

II. MEASUREMENTS OF THE PLASMA VELOCITY IN THE FLOW TUBE

In order to interpret the processes in the flowing afterglow plasmas it is essential to understand the neutral gas and plasma flow dynamics. For the range of the carrier gas (Ar) throughputs and pressures used in this work, the flow is viscous with bulk neutral gas velocity 30—60 ms^{-1}. Since the plasma velocity is not directly proportional to the gas bulk velocity [4], an afterglow time τ is directly measured. The afterglow time τ is measured by a pulse modulation of the discharge and the measuring of an arrival time t of a pulse response on the probe in position z. The plots of a variation of t against z for a series of pressures are illustrated in Fig. 3. These plots clearly show that the plasma velocity in the downstream part of the flow tube is constant for a given pressure. Deviation from linearity in the upstream part of the tube indicates an inoreased plasma velocity in this region. This is attributed to a disturbance of the plasma and a neutral gas flow in the region of the anode, where the plasma is produced.

III. DIFFUSION

An analysis of the measurements is based on the solution of the continuity equation. For a fundamental-mode diffusion and neglecting the axial diffusion and

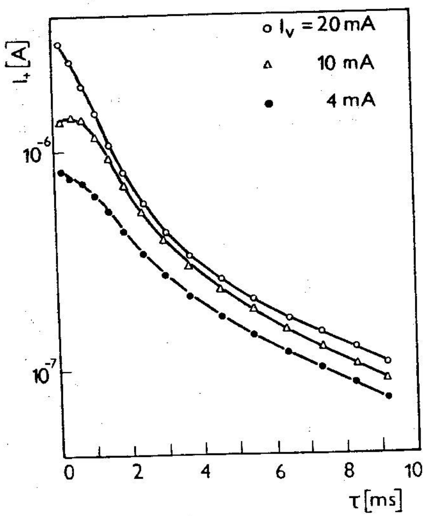


Fig. 4. Dependence of the ion current I_+ on the probe with afterglow time τ for the pressure 52 Pa and various discharge currents.

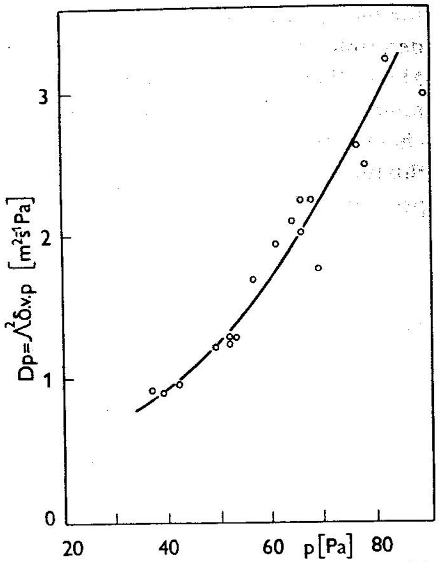


Fig. 5. Experimentally obtained value of the product $D \cdot p$ for different pressures of the carrier gas in the flowing tube.

recombination the decrease of ion concentration N_+ is given by the equation (see [5]):

$$N_+(\tau) = N_+(0) \exp\left(-\frac{D}{\Lambda^2}\tau\right), \qquad (1)$$

where D is the diffusion coefficient, Λ is the characteristic diffusion length, τ is the afterglow time. From (1) the diffucion coefficient can be calculated

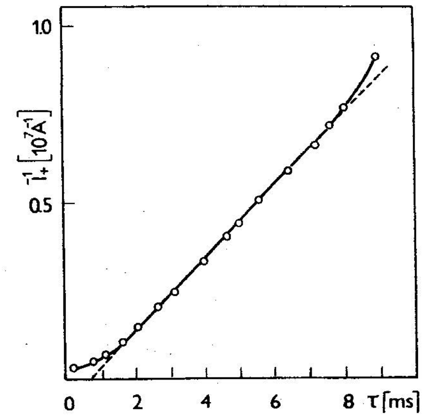
$$D = \Lambda^2 \frac{\Delta(\ln N_+)}{\Delta\tau}. \qquad (2)$$

The analysis of the dependence of the saturated ion current I_+ on the ion concentration showed that under the condition used the saturated ion current at a fixed and sufficiently large negative probe-to plasma voltage is directly proportional to the ion concentration N_+. With respect to this result the diffusion coefficients are determined from the equation:

$$D = \Lambda^2 \frac{\Delta(\ln I_+)}{\Delta\tau}, \qquad (3)$$

where the ion current I_+ is measured at a fixed probe voltage (−30 V). The

Fig. 6. Dependence of reciprocal value of ion current I_+^{-1} against the afterglow time τ for the pressure 52 Pa and 20 mA discharge current.



examples of the measured variations of the ion current I_+ with the afterglow time τ for the pressure a 52 Pa and various discharge currents are given in Figure 4. In the downstream part of the flow tube for $\tau \geq 6$ ms the plots of log I_+ against τ are linear, which indicates that the diffusion is the main loss process in this region [5]. In the upstream end of the flow tube for $\tau = 0$—2 ms the influence of the gas flow and plasma source disturbances are seen.

From the linear parts of the dependences of log I_+ against τ for various pressures p in the flow tube the diffusion coefficients D describing the diffusion in the flowing afterglow in the presence of the discharge plasma source are determined. Figure 5 shows the experimentally obtained dependence of the product $D \cdot p$ on the pressure p. The nonlinear part of the plot in Fig. 4 (for $\tau = 2$—6 ms) indicates that diffusion is not the dominant loss process in this region. Linearity of the plot $1/I_+$ against τ (see Fig. 6) confirms that recombination prevails in this region [5].

IV. DISCUSSION

The experimental data presented in Fig. 5 for the product $D \cdot p$ for various pressures describe the diffusion process in the Ar carrier gas in the flowing afterglow plasmas in the presence of a discharge in the plasma source upstream of the flowing tube.

The obtained values of the diffusion coefficients differ from the known value for the diffusion of Ar^+ in Ar. The difference exists because the described density loss process is not simply the diffusion of Ar^+ in Ar. The diffusion process in our experimental conditions is influenced by the presence of different types of ions in the discharge (Ar^+, Ar_2^+, Ar^{2+} ... etc.) and a non-thermalized electrons. The electron gas in the flowing afterglow plasma is heated by the present metastables of Ar, by a thermal conduction and the photons from the plasma source. The same is valid for the dependence of $D \cdot p$ op p where conditions in source and Ar metastables concentration are changed with the pressure in the flowing tube.

The experiments described here are being extended in order to measure the electron distribution function and to study the presence and the influence of metastables in flowing aterglow plasmas.

REFERENCES

[1] Šícha, M., Tichý, M., Glosík, J.: *The 7th Conf. of czechoslovak physicists*, Part II/C3-27, Fyzikální věd. sekce JČSMF, Praha 24.—28. 8. 1981.

[2] Nuhn, B., Peter, G.: *Comparison of classical and numerical evaluation of Langmuir probe characteristics at low plasma densities.* Proc XIII ICPIG Berlin 1977, Contr. paper p. 97.

[3] Swift, J.: Schwar, D.: *Electrical probe for plasma diagnostic.* Iliffe Books Ltd., 42 Russel Square, London 1970.

[4] Adams, N. G., Church, M. J., Smith, D.: J. Phys. D.: Appl. Phys. *8* (1975), 1409.

[5] McDaniel, E. W.: *Collision phenomena in ionized gasses.* John Wiley and Sons, Inc. New York 1964.

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