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MEASUREMENTS OF POWER TRANSFER TO OVERDENSE PLASMA IN LOW-PRESSURE MICROWAVE DISCHARGE[1]

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The results of experimental investigation of a stationary microwave (2.45 GHz) discharge in helium at pressures of hundreds of Pa are presented. They are in a good agreement with the analytical model.

The possibility of an effective generation of low pressure overdense plasma with the help of a simple waveguide structure has been shown.

ИЗМЕРЕНИЯ ПЕРЕДАЧИ МОЩНОСТИ СВЕРХПЛОТНОЙ ПЛАЗМЕ В МИКРОВОЛНОВОМ РАЗРЯДЕ ПРИ НИЗКОМ ДАВЛЕНИИ

В работе приведены результаты экспериментального исследования стационарного микроволнового (2,45 ГГц) разряда в гелии при давлении несколько сотен Па, которые находятся в хорошем согласии с аналитической моделью. Описана также возможность эффективного генерирования сверхплотной плазмы при низком давлении с помощью волновода простой формы.

I. INTRODUCTION

A microwave discharge in the rectangular waveguide is convenient both to handle experimentally and to describe analytically. Such a discharge in a matched waveguide has already been described [1, 3]. As far as the balance of microwave power is concerned it is not very efficient because of the losses in the matched load.

It is a purpose of this work to present the possibility of an effective generation of low pressure plasma of an overcritical electron density using a simple waveguide structure.

II. EXPERIMENTAL SET-UP AND PROCEDURE

The stationary microwave discharge was sustained by the wave in a rectangular waveguide (72 mm × 34 mm) at a frequency of 2.45 GHz and power up to 80 W.

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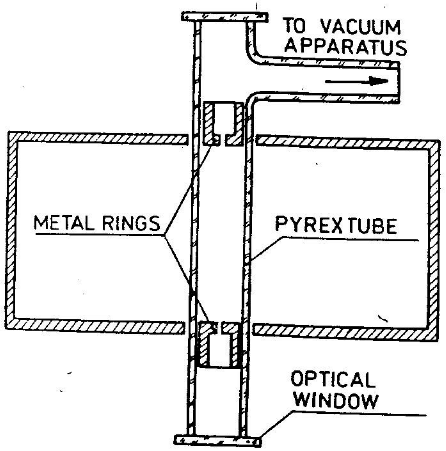
The discharge tube (of 10 mm and 12 mm internal and external diameter, respectively) was placed as in Fig. 1. The metal rings in the tube provide the limiting surface both for the diffusing particles and the electromagnetic field.

The simplified diagram of the external set-up is shown in Fig. 2. The microwave power is fed into a waveguide tract containing the discharge tube and terminated by a movable shorting plunger. The experimental set-up allows a direct recording of the reflected power and the relative light intensity versus position of the plunger.



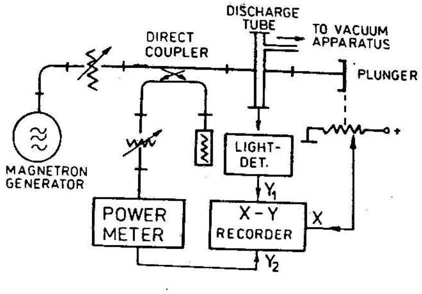


Fig. 1. The cross-section of the waveguide.

Fig. 2. Simplified diagram of experimental set-up.

Following the previous experience [4] it was assumed that the intensity of light was proportional to the electron density in the plasma. The validity of this assumption has been indirectly confirmed during the experiments presented here.

The procedure was as follows. For each value of the neutral gas pressure a series of recordings was made corresponding to various levels of the incident wave in the waveguide. A typical result is shown in Fig. 3. Although the details vary, the general shape of the obtained curves remains unchanged for various discharge conditions.

III. THEORETICAL MODEL

To describe the behaviour of the discharge a simplified analytical model is used. The discharge plasma enveloped in the glass walls is considered to be a local dielectric obstacle in the waveguide. Its influence on the propagation of the wave may be determined if the equivalent circuit of this discontinuity is known. Such an approach has often been used.

The foollwong assumptions are made. The plasma is axially homogeneous and the skin effect may be neglected. Consequently the electric field is uniform throughout the plasma. In this case both the plasma and the tube wall have [5] an equivalent circuit in the form of a single impedance shunting the waveguide in the plane of the axis of the column. Losses in the waveguide walls and in the plunger can be neglected. Thus the power P_I of the incident wave is divided between that absorbed in the plasma, P_A, and that reflected, P_R. Because of the uniformity of the electric field in the plasma, P_A is proportional to the average electron density.

The simplified theory predicts the general dependence of P_R and P_A on the position of the plunger as shown in Fig. 3 (1 — distance from the axis of the column, λ_g — wavelength in the waveguide). For any pressure and any incident power there is a position of the plunger, corresponding to the maximum absorbed power. All the further results refer to that position. Moreover, at each pressure there exists one value of incident power P_I^{OPT} such, that all this power is transferred into the plasma. Let us define for each pressure

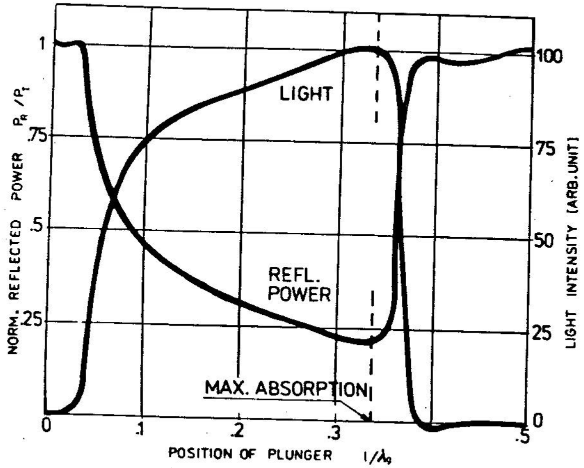


Fig. 3. The dependence of the reflected power and light intensity on the position of the plunger as recorded during the experiment (P_I = const.).

$$p_I = P_I/P_I^{OPT}; \quad p_A = P_A/P_I^{OPT}. \tag{1}$$

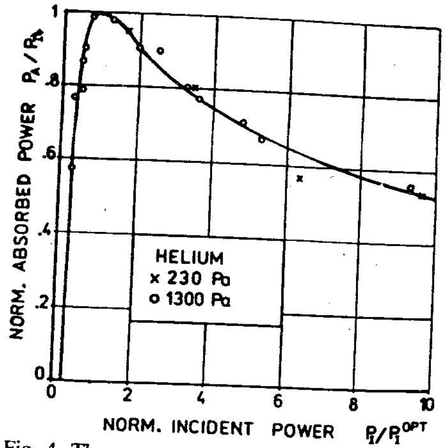
It follows from the theory that at each pressure the absorbed power depends only on the incident power

$$p_A/p_I = P_A/P_I = \frac{2\sqrt{p_I} - 1}{p_I} \tag{2}$$

and

$$n/n^{OPT} = 2\sqrt{p_I} - 1, \tag{3}$$

where n denotes the electron density normalized in respect to its critical value.



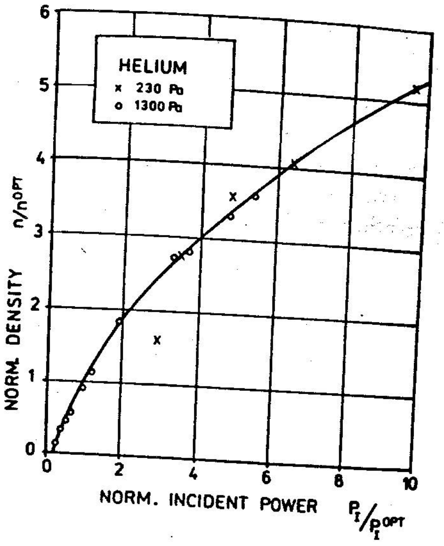


Fig. 4. The measured and calculated (line) normalized absorbed power.

Fig. 5. The measured and calculated (line) normalized electron density.

IV. RESULTS AND DISCUSSION

The results of measurements and of the theory are presented in Fig. 4 and Fig. 5. Each point represents results for the position of the plunger corresponding to the maximum absorbed power. For each pressure the value of P_I^{OPT} was determined providing the best fit of the results.

The proposed theoretical model properly describes the behaviour of the discharge. At each value of gas pressure there exists a value of incident power, P_I^{OPT}, at which all the energy is transferred to the plasma. To sustain the discharge, the incident power has to be larger than $P_I^{OPT}/4$. The simple waveguide structure, with one adjustable element makes an effective generation of overdense plasma possible.

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