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HIGH POWER MICROWAVE DISCHARGES AT ATMOSPHERIC PRESSURE IN CAPILLARY TUBES[1])

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An experimental study of high power microwave (2.35 GHz) argon discharges at atmospheric pressure generated by a surfatron is reported. The measurements of a length of a plasma column are performed for long and short capillary tubes. Electron density and collision frequency are determined from a reflection coefficient in an X band waveguide. It is shown that the power dependence of electron temperature for short tubes is saturated; this effect can be used in some technological processes.

ВЫСОКОМОЩНЫЙ СВЧ-РАЗРЯД В КАПИЛЛЯРНЫХ ТРУБКАХ ПРИ АТМОСФЕРНОМ ДАВЛЕНИИ

В работе приводятся результаты экспериментального исследования СВЧ-разрядов (2.35 ГГц) в аргоне при атмосферном давлении, которые генерировались при помощи генератора поверхностных волн. Измерения длины разряда проводились как для длинных, так и для коротких капиллярных трубок. Концентрация электронов и частота соударений определялись по коэффициенту отражения в 3-сантиметровом волноводе. Показано, что зависимость электронной температуры от мощности в случае коротких капилляров имеет насыщение. Этот эффект можно использовать в некоторых технологических процессах.

I. INTRODUCTION

Microwave discharges in capillary tubes are of great importance to plasma chemistry, chemical analysis, spectroscopic studies and are also used in small plasma torches, etc. At a relatively low total absorbed power, a high power density in plasma volume can be achieved and therefore large concentrations of electrons and a wide variety of other active species (neutral, excited and ionized atoms and

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molecules). Long, stable and reproducible plasma columns in capilary tubes can be obtained as a result of the propagation of electromagnetic surface waves [1] at microwave frequencies. Recently various discharges of this kind occurring at pressures in the 10^{-1}—10^{3} Torr range have been described [2—6].

It is the purpose of this paper to present the results of experiments with discharges at atmospheric pressure. The influence of the discharge conditions on the plasma length, the average density of the absorbed power, electron density and temperature has been studied.

II. EXPERIMENTAL SETUP

The plasma is generated in a setup similar to that described previously [5], the experimental arrangement is schematically given in Fig. 1.

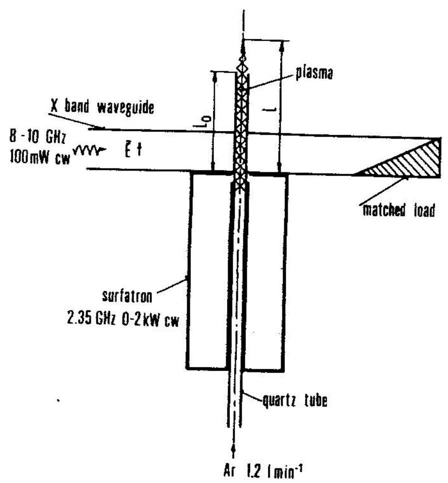

Fig. 1. Schematic diagram of the experimental arrangement.

Argon plasma at atmospheric pressure was generated by a microwave surfatron at a frequency 2.35 GHz in a quartz tube. The tube and the surfatron were cooled by air. For measurements of plasma parameters the tube was very short; the distance L_0 from its end to the aperture of the surfatron was 22 mm. For the absorbed power $P_{abs} > 30$ W the plasma extended beyond the end of the tube. The argon flow in all experiments was kept constant 1.2 l/min. The plasma in the tube passed through the centre of a rectangular X band waveguide for measurements of electron density and effective collision frequency. Measurements of the length of the plasma column were performed without this X band waveguide.

III. RESULTS

Two kinds of experimental situation exist. With a low power (or a long discharge tube) the plasma does not reach the end of the tube and remains inside it. On the other hand, when the power is large (or the tube short) enough, the plasma extends beyond the end of the tube and a jet is formed (see eq. [3]). For a constant flow rate of the gas the length of the jet remains approximately constant. In the first case, the length of the plasma column increases with the growing amount of the microwave power fed into the plasma. On the other hand, once the plasma fills the tube and the jet is formed, the total length of the column is almost independent of the input power.

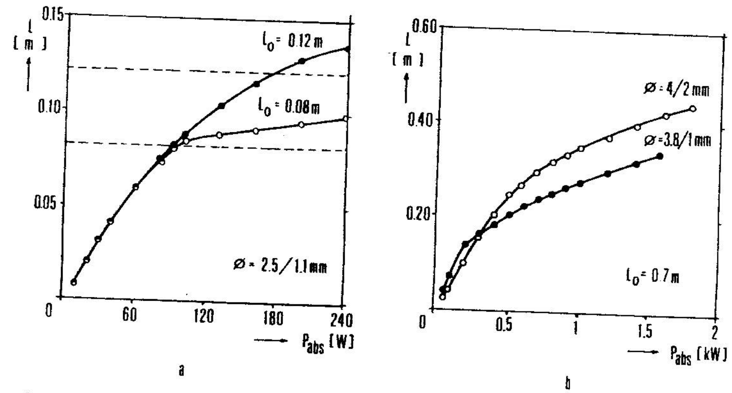

Fig. 2. Experimental dependences of the length L of plasma column on the absorbed microwave power P_{abs}; a) for two lengths L_0 of the capillary tube, b) for two diameters Φ of the capillary tube.

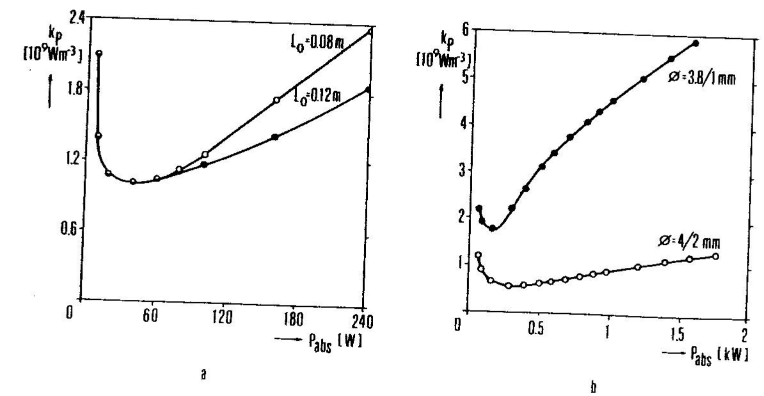

Fig. 3. Experimental dependences of the average density k_p of the absorbed power on the absorbed power P_{abs}; a) for two lengths L_0 of the capillary tube, b) for two diameters Φ of the capillary tube.

The measurements were performed under conditions stated above. In all instances the plasma was macroscopically stable, showing no stratification or filamentation. Also it filled the whole cross-section of the tube.

The effect of saturation of the column length is shown in Fig. 2a. Under otherwise identical discharge conditions, for large powers it is determined by L_0. This accounts for a significant increase of the average value of the absorbed power density, occurring in short tubes, as shown in Fig. 3a.

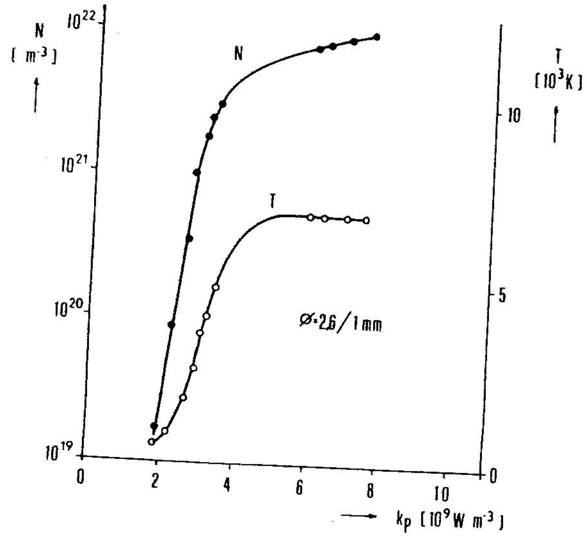

Fig. 4. Experimental dependences of the electron density N and the electron temperature T on the average density k_p of the absorbed power.

The influence of the diameter of the tube on the length of the plasma column generated in a long capillary tube is presented in Fig. 2b. Fig. 3b shows the corresponding dependence of the average density of the absorbed power on the total power entering the column. The average density of the absorbed power is defined as $k_p = P_{abs}/V_P$, where V_P is the volume of the plasma $V_P = \pi r^2 L$, r is the plasma radius. The values of the obtained density are in good agreement with those that can be obtained by inference from experimental results presented elsewhere (Fig. 3 in [4]).

Microwave measurements performed in an experimental setup already described [5] allow to find the dependence of the electron density and effective collision frequency on the power density in plasma. The electron temperature was calculated from experimental data on electron collision frequency. Typical results are presented in Fig. 4. At large power densities the electron temperature saturates

and any increase of the density of absorbed power leads to a further increase of the electron density. It follows from the previous discussion that such a situation can be easily reached in short discharge tubes. This has some practical implications. Let us consider a situation when an open end of the capillary tube extends directly into a reaction chamber, in which some kind of technological process is run, depending on the concentration of the active species. Those are brought into the chamber by the gas flowing from the tube. In such a case their concentration can be controlled by the amount of power delivered to the plasma generator.

The presented results show the influence of the most important discharge conditions on the behaviour of the surface wave plasma columns in the capillary tubes. Unfortunately, there does not exist so far any theoretical description of such columns at atmospheric pressure.

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