Pramāṇa, Vol. 5, No. 6, 1975, pp. 349–353. © Printed in India.

A pulsed Langmuir probe for plasma diagnosis

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MS received 14 April 1975; after revision 14 August 1975

Abstract. A pulse technique has been presented for generating a complete Langmuir probe characteristic curve in a short time interval which can be varied from 1 sec to 1 millisec. The method has been applied successfully to different plasma systems of our laboratory. Several examples have been given for indicating the type of diagnostic studies being carried out with this pulsed probe.

Keywords. Langmuir probe; plasma diagnosis

1. Introduction

The application of electrical probes for evaluating the parameters of a gaseous plasma is well known for many years. Since these probes owe much for their development to the pioneering work of Langmuir and co-workers (1923, 1928, 1929), they are commonly called Langmuir probes. The quantities usually measured with a d.c. type of probe are the electron temperature (T_e), electron and ion densities (n_e, n_i) and the space and floating or wall potentials (V_s, V_f) of an enclosed plasma. The probe has the advantage that it provides local values of the plasma parameters so that their space distributions, which are often required in plasma investigations, can be determined. Although the d.c. probe method is very simple and used widely in experimental plasma studies, one needs to take extreme care in recording and interpreting its data because errors due to a number of defects may easily creep in at any stage in this method. One of these defects is that the time required for recording one set of characteristic data is inconveniently large (several minutes) with a usual d.c. probe such that the properties of either the plasma or the probe may get changed during the process of measurement.

In order to shorten the recording time, several investigators (Waymouth 1959, Chapuk *et al* 1963, Chen 1964, Friedman 1971, Derby 1971) have adopted the pulsed operation of Langmuir type of probes. We have also developed a similar pulsed probe technique in our laboratory and applied it to a number of plasma situations. We present in this paper a brief description of our method and some of the results obtained with it.

2. Experimental method

A schematic diagram of our experimental set up with a pulsed Langmuir probe applied to a hot cathode glow discharge is shown in figure 1. The probe is initially kept at its maximum negative bias where it collects the ion saturation current.

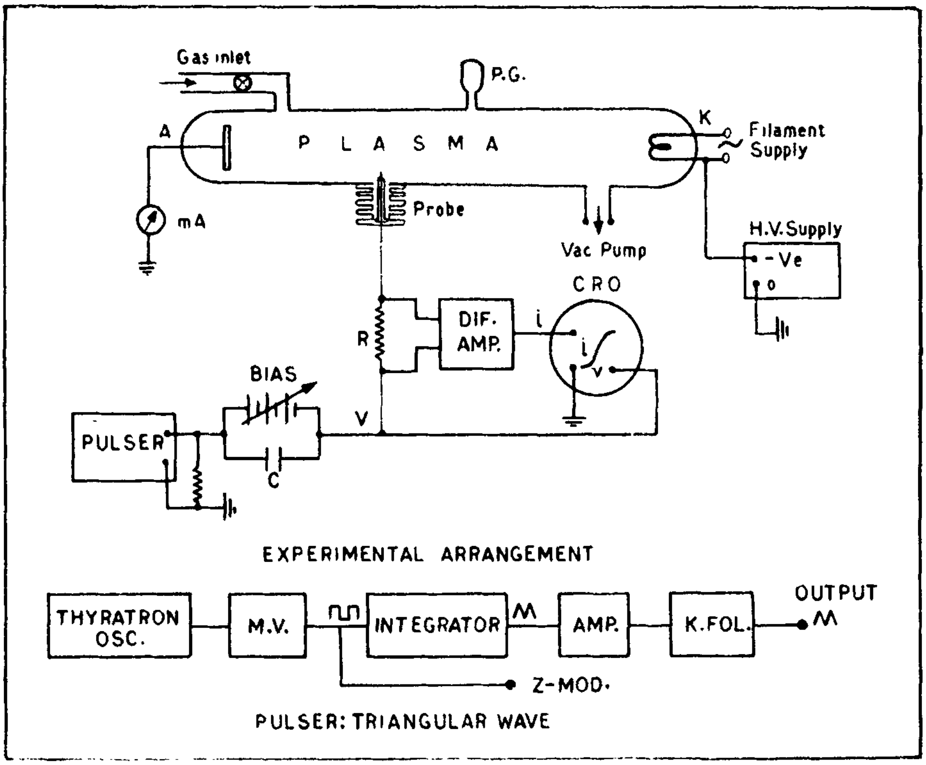

Figure 1. Schematic diagram of the experimental setup.

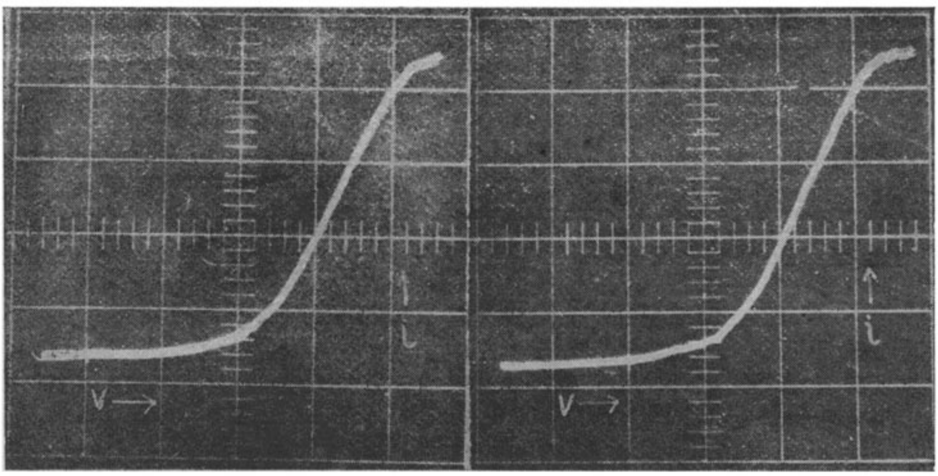

Figure 2. Examples of '$V - i$' characteristics as recorded on the CRO screen.

It is then swept by a linear positive voltage signal to the space potential of the plasma or to a potential a few volts positive with respect to the plasma. The corresponding values of the probe current are found by recording the difference of potentials across the resistance R with the help of the difference amplifier. The output of the difference amplifier, which is proportional to the probe current i, is then fed to the y-amplifier of the CRO. The x-amplifier of the CRO is operated by a part of the initial voltage signal V which drives the probe. In this way we get the complete current-voltage characteristic curve of the probe directly on the CRO screen. The photographs in figure 2 give two examples of such oscilloscope record of probe characteristic curves observed by us. For each i vs V curve thus obtained a corresponding curve of ln i vs. V is plotted. With the help of these two types of curves the values of the plasma parameters are then evaluated, using the known relations in the probe theory as given in the literature, particularly in the book by Loeb (1961).

The pulser constructed by us consists of a thyratron oscillator, a multivibrator giving square waves driven by the thyratron, an integrator converting square waves to triangular waves, an amplifier and a cathode follower. A block diagram of the pulser is given in the lower part of figure 1. The Z-modulation of oscilloscope produced by a synchronous signal from the multivibrator makes either the forward or the backward trace blank so that any measurement inconvenience due to incomplete overlapping of the two traces is removed. The pulser has the maximum output voltage 100 V and current 40 ma and has the repetition rate variable in the range 1 Hz – 1 KHz, *i.e.*, the recording time of a characteristic curve varies from 1 sec to 1 millisec. Due to this variation, the pulser can be used in both steady state and time varying plasmas.

3. Application of the method

The pulsed probe developed by us is being used in different plasma systems of our laboratory, such as, the hot cathode glow Philips Ionization Gauge (PIG) and duoplasmatron devices. Using this method we have been able to measure charged particle densities in the region 10^{10}–10^{12} cm^{-3} and electron temperatures in the range 1–20 eV. We are also using this pulse method for determining the space distributions of the plasma parameters. In figures 3 and 4 are shown several examples of radial distributions of T_e, n_i and V_f as measured in our PIG device. A schematic diagram of the PIG plasma system can be seen in our earlier publication (Chatterjee *et al.* 1969). Using this device a steady plasma column of length

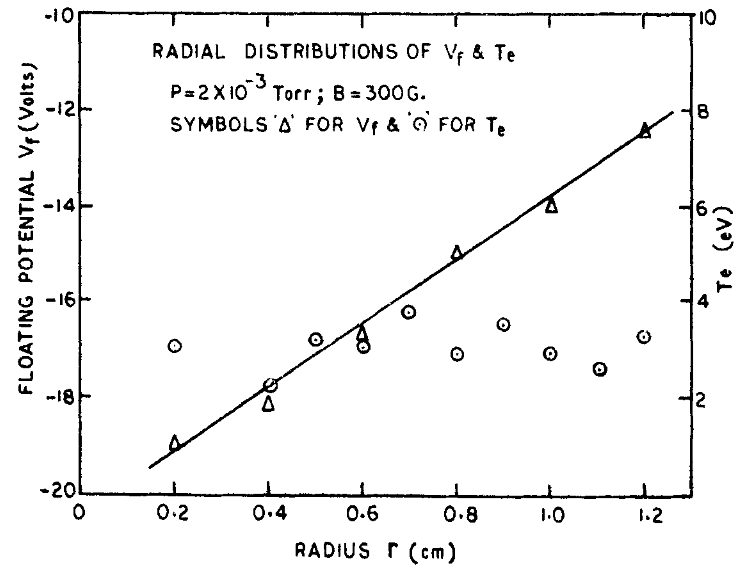

Figure 3. T_e and V_f distributions at pressure 2×10^{-3} Torr and magnetic field 300 G.

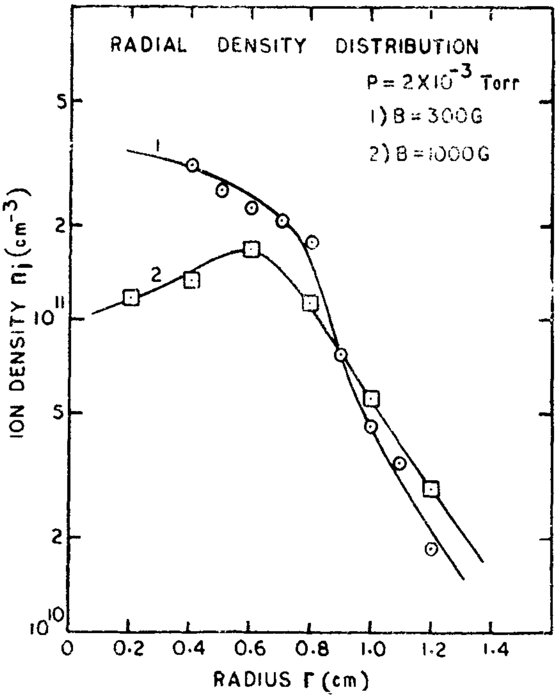

Figure 4. Two examples of ion density, n_i, distributions at pressure 2×10^{-3} Torr and magnetic fields 300 G and 1000 G.

50 cm was produced in the presence of a longitudinal magnetic field. A small area Langmuir probe (1 mm long × 0·25 mm dia.) placed in the middle region of the plasma column scanned the plasma by means of the signals from the pulser. The values of the plasma parameters at different radial distance were determined by moving the probe radially with the help of screw movement fitted with a sylphon bellow. The T_e and V_f distributions at pressure 2×10^{-3} Torr and magnetic field 300 G, as given in figure 3, indicate that the electron temperature has no radial dependence and there is a uniform radial electric field in the plasma in this case. In figure 4 are shown two radial density distribution curves at the same pressure (2×10^{-3} Torr) and two different magnetic fields (300 G and 1000 G). There exists a marked difference between the two curves. The depression of density near the axial region in curve 2 taken at 1000 G indicates that the plasma in this case has made a transition to an enhanced diffusion mode.

4. Discussion

As we have mentioned in the introduction, a rapid recording of probe data is necessary for avoiding two defects, *viz.*, contamination of probe by the deposition of impurities and change of plasma parameters during measurements. In many of the previous investigations the authors designed probe circuits such that the first defect is removed while the second one remains. These methods are suitable for analysis of steady plasmas. For example Waymouth (1959) and Derby (1971) used circuits with repetition frequency of 1/60 and 10 sec., respectively, and therefore, their methods are unsuitable for plasmas where the parameters are changing more rapidly. On the other hand, some investigators (Friedman 1971) devised probes operated by higher frequency signals for use in transient plasmas. In these circuits apparently no provision was made for removing probe contamination. In our method we have tried to avoid both the above defects. Firstly, our probe remains clean due to ion bombardment by a large negative d.c. bias at the start of each sweeping cycle and secondly, our pulser has a considerable range of repetition frequency (1 Hz – 1 KHz) so that one can work in both d.c. and time varying plasmas.

Our measurements so far have shown that the pulsed probe developed by us is a very effective plasma diagnostic tool. With the help of this technique detailed studies of plasma parameters are in progress in our laboratory.

Acknowledgement

The authors wish to express their gratitude to D N Kundu and B D Nagchaudhuri for their keen interest in the present work.

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