AN ELECTRONICAL INSTRUMENT FOR FAST PERFORMANCE AND EVALUATION OF DOUBLE-PROBE MEASUREMENTS

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ABSTRACT

An electronical instrument is described in the paper which has been developed for the easy and fast analysis of data obtained from double probe characteristics of electrodeless low pressure plasmas. The electronic analyzer computes the electron temperature from 10^4 to 10^6 K and density from 10^{11} to $10^{13}/cm^3$ with an accuracy of about 15%. The theory, the electronic lay-out, and the experimental results are considered in the paper.

1. INTRODUCTION

Since several years, radio-frequency ion sources are developed and studied at the First Institute of Physics of the University of Giessen. The ion sources are used as well for space application in rf-ion thrusters as for terrestrical applications like ion etching, sputtering, etc. For the successful development of these ion sources with discharge chamber diameters from 4 to 35 cm, the knowledge of the plasma parameters, electron temperature and density, and their radial and axial distribution is very important.

In our case of a low-pressure, non-thermal plasma, one can obtain informations about the plasma properties by probe measurements immersing small probes into the plasma. Since we have electrodeless plasmas, generated in the rf-field of an induction coil, double probes must be used which technique had been developed by Malter and Johnson (1) at first.

Applying a variable DC-voltage to the probe, one gets probe characteristics from which the plasma parameters can be deduced.

However, the acquisition and evaluation of double probe characteristics are very time-consuming, especially when changing the discharge parameters, as there are the discharge pressure and the discharge power, or the probe location, respectively. For this reason, we decided to develop an instrument for laboratory use which indicates the electron temperature and density with a reasonable accuracy by evaluating the probe signal and calculating the data.

After a short theoretical description of the double probe method, the electronical solution of the problem will be explained. Some experimental data obtained from Xenon plasmas compare the conventional evaluation with the result of our instrument and demonstrate the range of application.

2. DOUBLE PROBE THEORY

Immersing a double probe into a plasma and applying a DC voltage to the probe, one obtains the well known probe characteristic which is shown in Fig. 1. The characteristic follows the hyperbolic tangent function and is described by the formula (2,3):

$$J = J_s \cdot \tanh\left(- \frac{e_o U_p}{2kT_e}\right) \qquad (1)$$

with U_p = probe voltage, J = probe current, J_s = ion saturation current, T_e = electron temperature

This double probe characteristic contains the informations about the plasma parameter that we need, namely, the slope of the characteristic not far of zero is proportional to the electrom temperature and the probe saturation current which is carried by ions only is proportional to the carrier density or electron density, respectively.

Developing equation (1) as a Taylor-progression, the linear term gives the slope near zero, namely:

$$\left[\frac{dJ_p}{dU_p}\right]_{U_p = 0} = J_s \cdot \frac{e_o}{2kT_e} \qquad (2)$$

From this relation the electron temperature is calculated as:

$$T_e = \frac{e_o \cdot J_s}{2\,k} \cdot R_p \qquad (3)$$

with R_p as equivalent probe resistance.

Deducing the carrier density, one has to consider the potential distribution of a negative probe (4,5) which is rather complicated and should not be discussed here in detail. The theory yields for the carrier or ion density n_i:

$$n_i = \sqrt{\frac{m_i}{k}} \cdot \frac{J_s}{e_o \cdot A_p} \frac{1}{\sqrt{T_e}} \cdot e^{1/2} \qquad (4)$$

with m_i = mass of ions, A_p = probe surface.

From equation (2) and (4) the plasma parameters will be calculated by measuring the ion saturation current J_s and the equivalent probe resistance $dU_p/dJ_p \approx \Delta U_p/\Delta J_p$.

3. ELECTRONIC LAYOUT

In order to obtain these both basic values, we decided to apply a sinusoidal voltage of 50 Hz to the probe. The currents caused by the positive and the negative peak voltage are measured by a sample and hold circuitry. The averaged values give the ion saturation current.

The equivalent probe resistance is won from the slope of the probe characteristic near zero. At zero voltage a time constant is released after which the probe current is measured whereas the belonging to probe voltage can be calculated from the course of the sine.

The process of the calculation is demonstrated in the flow chart Fig. 2. The modified equations which have to be evaluated are now for the electron temperature (6):

$$T_e = C_1 \cdot U_{i,R} \cdot \frac{1}{\Delta U_R} \qquad (5)$$

and for the plasma density:

$$n_i = C_2 \cdot \sqrt{U_{i,R}} \sqrt{\Delta U_R} \qquad (6)$$

where C_1, C_2 are constants to be determined, $U_{i,R}$ is the voltage drop at the measuring resistance proportional to the ion saturation current, and ΔU_R the voltage drop proportional ΔJ_i in a small time interval.

The positive and negative peak values of the amplified probe signal are measured and stored delivering the constants C_1 and C_2 as well as the ion saturation current J_s which is metered. Furthermore, the probe signal is led to a zero crossing switch which triggers the delay and the sample and hold circuits.

With the logarithms of the measured values the mathematical operations can be performed easily. The antilogarithms give then the electron temperature and plasma density. Exceeding of the measuring ranges is indicated by overflow signals.

4. EXPERIMENTAL RESULTS

In order to test our instrument, probe measurements in a Xenon plasma were performed evaluating the probe characteristics manually as well as with the electronic analyzer. A comparison of the results is shown in Fig. 3 where the electron temperature and plasma density are depicted versus the probe location using a double probe which could be moved in radial direction.

One can recognize in Fig. 3 that both results are in a rather good agreement. Other experiments varying the discharge pressure or the discharge power which are not presented here demonstrated a similar good agreement of manual and electronic evaluation.

An estimation of the accuracy of the electronic analyzer results in a total accuracy of about 15% consisting of a 5% uncertainty in the calculation of the slope dJ/dU and further 1% to 2% uncertainty in the following stages. Of course, the accuracy of the probe theory itself is not considered here.

5. ACKNOWLEDGEMENT

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6. REFERENCES

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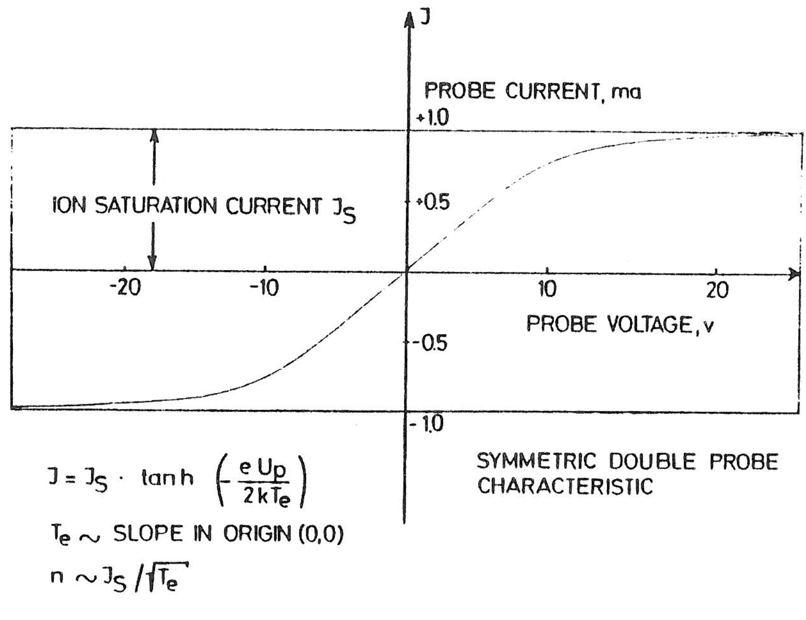

Fig. 1: Double probe characteristic

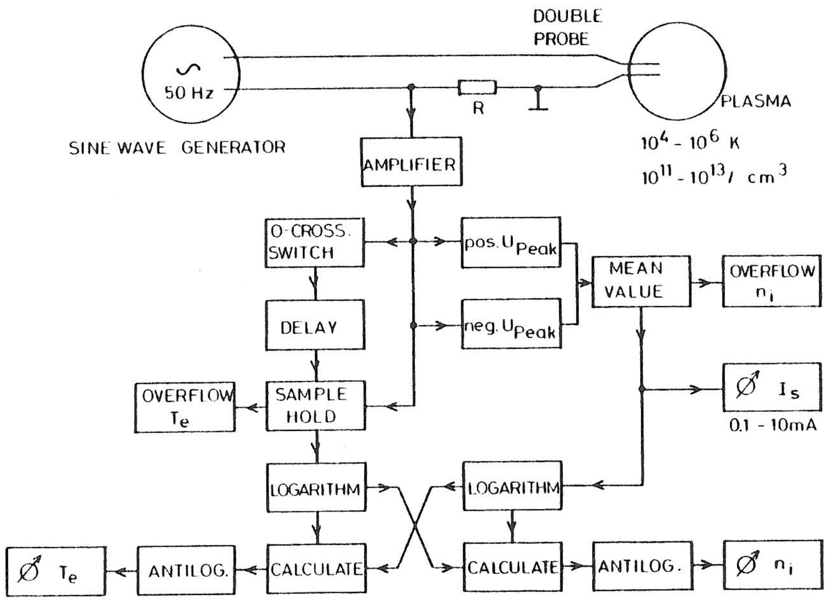

Fig. 2: Block diagram of the electronic analyzer

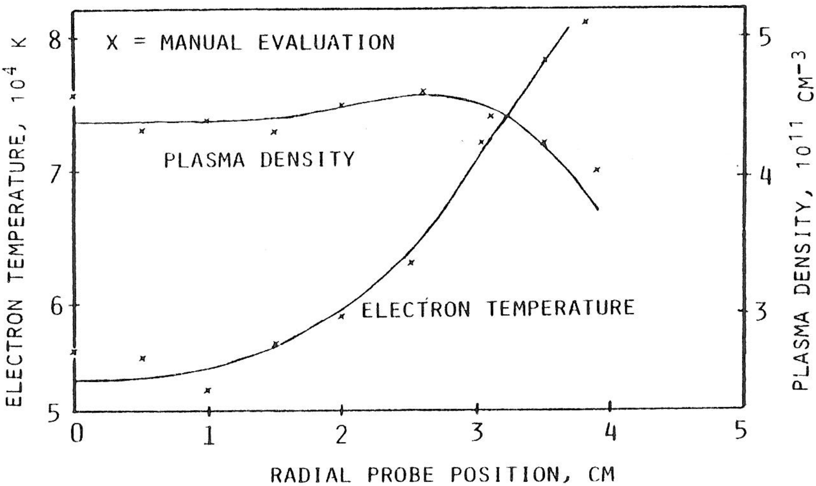

Fig. 3: Plasma density and electron temperature as a function of the probe position comparing manual and electronic evaluation