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DETERMINATION OF PLASMA SPACE POTENTIAL FROM A LANGMUIR PROBE BY TIKHONOV'S REGULARIZATION METHOD

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Abstract. An analysis of the accurateness of determining the plasma space potential from the probe current-voltage characteristics have been performed to improve the accurateness of the consequently determining plasma parameters from it. The problem is analyzed as an inverse and ill-posed one. Tikhonov's regularization method was introduced to solve such problem. It was shown that the accurate determination of the plasma potential is the most important for low temperature plasma $< 1eV$. The method was checked in argon plasma created in the double plasma machine. The satisfactory results were obtained.

1. INTRODUCTION

One of the most important and frequently used plasma diagnostic techniques is the Langmuir probe method. This method, which was first introduced by Langmuir more than eighty years ago, allows to provide the most important characteristics such as electron density n , space potentials V_s , average electron energies $< \varepsilon >$(temperatures T_e), electrical fields E, electron energy distribution function (EEDF), drift velocities etc. Knowing these parameters gives a possibility to determine a series of other important characteristics-rates of many non-elastic processes, populations of excited levels of an atom or ion, coefficients of mobility and diffusions and others. One should note that nowadays, namely probe methods produced a great number of quantitative data of plasma characteristics. The main advantage of electrical probes to greatness other methods, is their possibility to measure local values of plasma characteristics. Thus, a great attention is constantly given to developing and accuracy of the probe methods. The starting point in the processing of a probe current-voltage characteristic (CVC) is always determination of the plasma space potentials. The consequently determined plasma parameters highly depend on the accurateness of the determination of the space potential. In this work an analysis of determination of the plasma potential from the CVC is done, considering the problem as an ill-posed one (Tikhonov and Goncharski 1987).

2. METHOD

The fundamental plasma parameters can be determined by placing a small conducting probe into the plasma and observing the current to the probe as a function of the difference between the probe and the plasma space potentials. The plasma space potential is just the potential difference of the plasma volume with respect to the vessel wall (anode). The simplicity of equipment and experiment constitute the advantages of the probe method. The disadvantages lie in complexities of the theory used to extract plasma characteristics from probe measurement data. There is only a limited range of conditions under which the theory is only moderately complicated and does not lead to a considerable probability of obtaining erroneous results and faulty interpretation (Raizer 1987). As it is shown in (Kagan 1970), the electron component of the probe current is given as,

$$i_e = (2e\pi n_e/m^2)S\int_{eV}^{\infty}(\varepsilon - eV)\ f_0(\varepsilon)\ d\varepsilon \tag{1}$$

where are n_e- electron density; e, m- elementary charge and mass of an electron respectively; ε- electron energy; V- a retard potential applied on the probe; S the surface area of the probe, and $f_0(\varepsilon)$- electron energy distribution functions in the unperturbed plasma. With the distribution function known, any quantity characterizing electron gas can in principle be calculated. Twice differentiating the eq. 1, with respect to the probe potentials V gives

$$d^2i_e/dV^2 = (2e^3n_e\pi/m^2)Sf_0(eV) \tag{2}$$

This method, first employed by Druyvesteyn in 1930 (Druyvesteyn 1930), is still used nowadays, with certain improvements. Because of the function $i_e(V)$ is measured with some errors,its direct double differentiation involves considerably errors.For this reason, d^2i_e/dV^2 has to be found by indirect means. Let us analize than, not the eq.2 but eq.1. The given inverse problem is a typical example of so-called ill-posed problem (Tikhonov and Goncharski 1987). The basic characteristic of such problems is its nonstability of the solution in respect to the perturbation of the input information. In our case small errors in the given curve $i_e(V)$ can result in arbitrarily great errors of the asked EEDF $f_0(eV)$.

A. N. Tikhonov found a possibility for obtaining a stable approximate solution $f_0(\varepsilon)$ knowing minimum *a priori* information of the asked solution.

3. RESULTS

Some typical results of our analyses are shown in the Figures below. In order to check applicability of the Tikhonov's method several model tasks were introduced. At the Fig. 1., are shown results obtained in such way: a hypothetical electron component

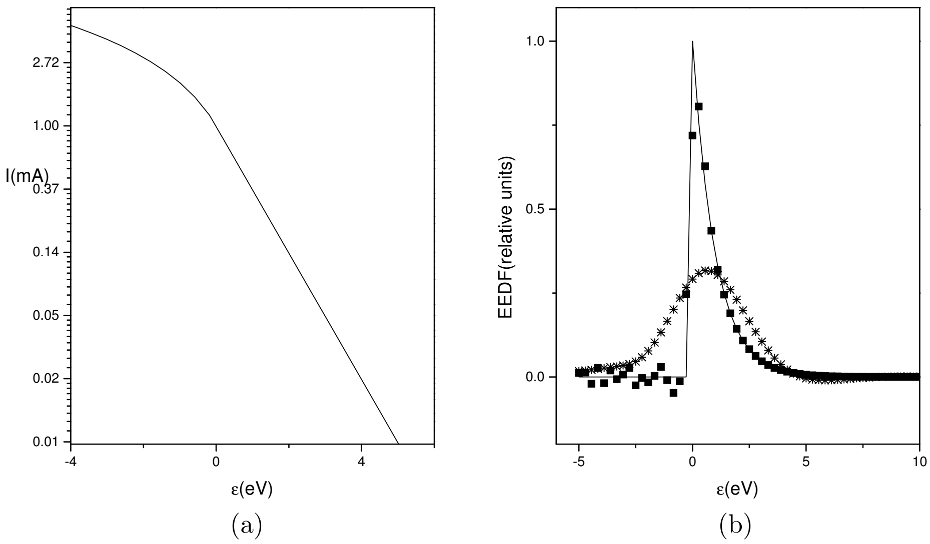

Figure 1: (a) Model probe CVC ; (b) The exact EEDF (solid line); EEDF obtained by the regularization, the simulated absolute maximum errors 0.1% (square); the simulated maximum errors 5% (star).

of a CVC was simulated by solving the direct problem described by eq. 1, in an assumption that EEDF $f_0(\varepsilon)$, is Maxwell's with the electron temperature $T_e = 1eV$. Then, artificial random noises were added to the CVC in order to simulate an experimental CVC. Finally, the inverse problem, i.e., finding $f_0(\varepsilon)$, was solved using Tikhonov's procedure. Only *a priory* information was an estimation (in this case known) of the experimental errors. From the Fig. 1., one can estimate the powerfulness of the method. Extracting information from real experimentally obtained CVCs using Tikhonov's regularization method is shown in Fig. 2. The experimentally CVC were obtained in the double plasma machine in Institute of Ion Physics in Innsbruck.The extracted EEDF from the CVC of the probe is shown in Fig. 3, supposing the experimental errors to be 0.4 %.

4. DISCUSSIONS AND CONCLUSIONS

From the Fig. 1b) one can see the severe dependence of obtaining the plasma potential and EEDF versus the experimental errors. At the knee of the probe CVC (given on semi-logarithmic scale), d^2i/dV^2 reverses its sign and this fact rather facilitates the determination of the bend point of the CVC and of the plasma potential. It is clear from the Fig. 1, that one can not pretend to obtain the plasma potential in better accuracy than 0.5 V , even in very quiescent plasmas. Such deviation is the most important if the plasma temperatures are less than 1 V , due to the great relative error. The situation is more complex when applying this method to the real experimentally probe CVC due to influences of many other factors.

From the Fig. 2 it is clear that EEDF is not Maxwell's one (the CVC on semi-logarithmic scale is not a line) and our method discovered two groups of electrons (see the Fig. 3) like as in (Sternovsky and Robertson 2004). Furthermore the second derivative of the CVC is still reverses sign at (or near) the plasma potential. Thus, it was found that Tikhonov's regularization procedure could be a reasonable effective method to estimate the plasma potentials and EEDF from a probe CVC.

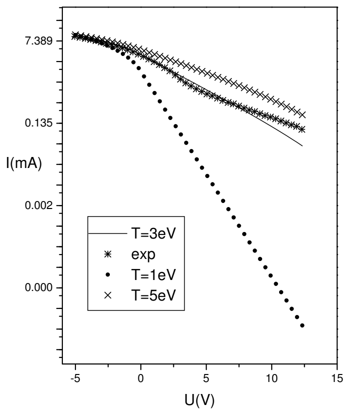

Figure 2: The experimental probe characteristic (*); model probe characteristic for different temperatures.

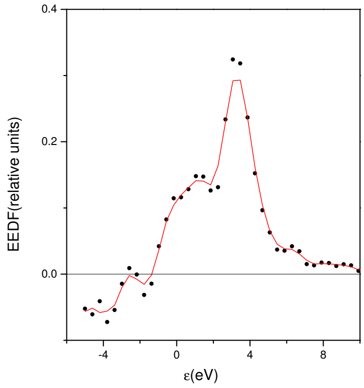

Figure 3: EEDF obtained by regularization method from the experimental CVC.

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