The auto-acquisition of optimum electron saturation current by Langmuir probe with photon detection function

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1. Introduction

Langmuir probe measurements suffer from the problem to find the correct inflection point corresponding to the plasma potential Φ on the characteristic, in particular in plasmas with non-Maxwellian electron distributions. In order to obtain the true value of Φ we have to record the electron saturation current I_{es} in the region beyond Φ. So far the inflection point is found from two ways. One is obtained from the absolute maximum by differentiating the probe current (I_p) to voltage (V_p) curve. Here I_p consists of the electron current I_e and the ion current I_i. An crucial point to notice is that the electron beam component in I_e makes the inflection point before V_p transverses Φ. Second is from the cross point between two tangential lines on V_p-ln$|I_e|$ curve by subtracting the ion saturation current I_{is} from I_p [1]. Both analysis needs the region of I_{es} on the characteristic curve. However, when the electron sheath of the probe collector extends abruptly as an increase of V_p, I_e never saturates [2]. Since the width of the biased sheath is proportional to the Debye length and inversely proportional to the electron temperature, concerning the low density plasma under the high pressure, it is difficult to find I_{es}. As one increases V_p furthermore to find the inflection point, a discharge likes to occur around the Langmuir probe tip. Clearly we see Secondary Plasma Emission (SPE) at the probe collector when V_p is larger beyond Φ, and then $|I_p|$ increases abruptly. So we need a new way to find I_{es}, so that, the thermal electron current I_{th} at Φ. Normally, one likes to get the low I_{es} from the conventional Langmuir probe analysis when V_p becomes larger than Φ so as to induce SPE. It is desire to stop the sweep of V_p at the adequate bias voltage lower than V_{em} after detecting SPE at V_p=V_{em}. Since the beginner to use the Langmuir probe as the tool is not so easy to determine the sweeping of V_p empirically, it would be very great to sweep V_p automatically. Our final goal is of all investigators to be able to determine Φ and subsequently I_{th} as correctly as possible by the Langmuir probe with photon detection function.

2. Experimental procedure

The test plasma is generated by the conventional DC discharge in Ar gas with the relatively low pressure [Fig.1 (a)]. First we confirm that SPE occurs always at the collector of the

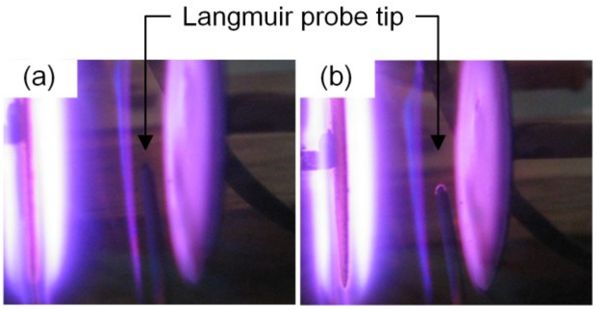

Fig.1 The conventional DC discharge in the symmetric parallel-plate. The distance between cathode and anode is 15 mm and the same diameter in 20 mm. The probe tip position is 5 mm axially from the anode center.

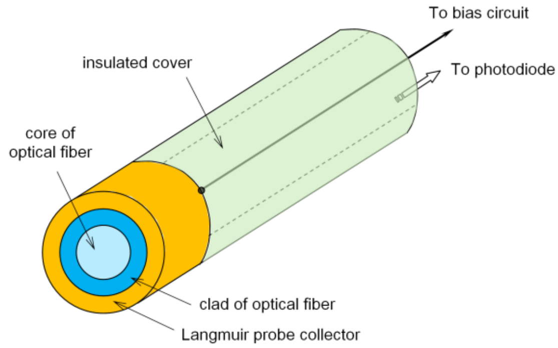

Fig.2 The schematic illustration of the probe tip.

Langmuir probe tip when V_p is larger than Φ as shown in Fig.1 (b). We define the value of V_p where SPE starts as V_{em}. The experiments are performed within the Ar gas pressure range p=10-500 Pa in the range of DC voltage amplitudes $V_{A\text{-}K}$=300-450 V with constant discharge current mode (I_a=29 mA). The plasma parameters are measured with a Langmuir probe. In order to measure SPE, we make the probe tip as shown in Fig.2. The top surface of the probe tip is set so as to suppress the contamination of the sputter particle from the cathode. The relationship between (V_{em}-Φ) and p multiplied by the sheath width is expected to be similar with the Paschen curve in the excited gas.

3. Results and discussion

When V_p is increased manually and slowly, Fig.3 presents the optical emission spectrum, obtained for 266 Pa, $V_{A\text{-}K}$=443 V and I_a=29 mA, at about 0.7 cm from the cathode (the negative glow region). The upper trace shows the normalized spectrum of the bulk plasma at fixed bias voltage V_p =0 V lower than Φ. One can see that the most intense spectral lines are situated around λ=750 nm. Nearly all the lines lie between 650 and 900 nm corresponded to the 4p → 4s transitions for monitoring the argon metastable level population. The middle trace is one subtracted the upper trace from the trace at the larger bias voltage V_p =37 V beyond Φ. The negative difference at 751 nm line appears showing a decrement of the peak strength. This line is characterized as the super-elastic electron collisions leading to metastable state ($Ar^{**} + e \rightarrow Ar^{*} + e$) [3]. It is seemed that the probability of the super-elastic electron collisions decreases. The slow-down electrons, which already release their kinetic energy through the ionization in the first (bulk) plasma, like to interact with Ar** through the super-elastic collision. There may be moderate bias voltage ($\Phi < V_p < V_{em}$) to accelerate and thereby to decrease the slow-down electrons in the localized electric field formed around the probe collector. The bottom trace is also one subtracted the upper trace from the trace for SPE found by eyes at the more larger bias voltage V_p=44 V. This shows that SPE signal is detected obvi-

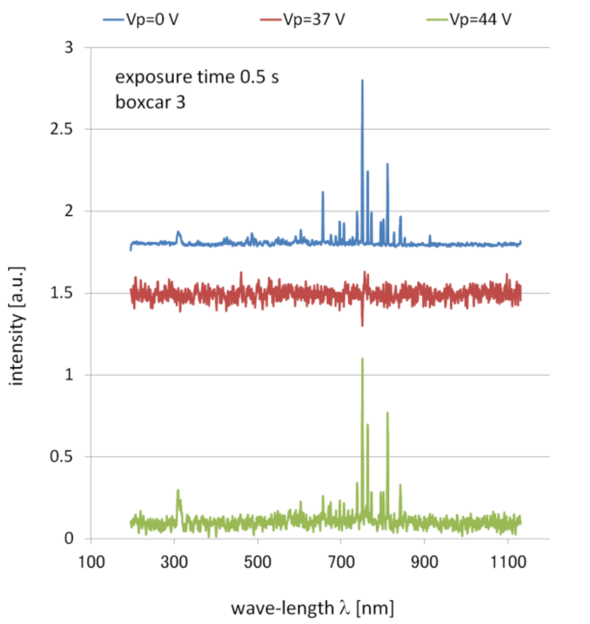

Fig.3 Argon atomic optical emission spectrum, measured in a glow discharge at a current of 60 mA ($V_{A\text{-}K}$=444 V) and a pressure of 35 Pa.

ously and the relative strength of SPE lines is almost the same as that of the bulk plasma. In case that SPE brings about the crucial problem for some plasma applications such as high purity deposition and photon-assisted reaction, the photon signal at 751 nm line through the optical filter could be candidate of the marker to limit the sweeping of V_p.

To determine the upper limit of the sweeping V_p automatically, we make the plasma current and photon acquisition system (Fig.4). The system consists of the high voltage bias circuit, photon detector circuit, and USB interface inclusive of A/D, D/A, and I/O. Each signal is acquired as a function of the bias voltage V_p. The maximum dynamic range of V_p and I_p is ±200 V and ±20 mA, respectively. The bias voltage is amplified by high voltage OP-Amp whose input is connected to D/A converter worked through USB communication. The photodiode is HAMAMATSU's Si PIN S5971, which interface is operational amplifier as integral circuit, the output of which is connected to A/D converter. The discharge noise around the probe tip is suppressed by the optimum circuit design. The spectral response range is 320 to 1060 nm with the peak sensitivity of 900 nm. We can control the waveform of V_p as a trigger of the photon signal with the arbitrary wave-length by employing the eliminative optical filter. In this time, we show the results obtained by the integrated photon signal without the filter.

In case of sweeping V_p, we obtain the repeat time variation of the plasma current I_p and the photon signal I_{ph} (Fig.5). First the program determines the lowest V_p so as to confirm the ion saturation current I_{is}, next V_p is swept beyond the expected Φ. The response of I_{ph} denoted in the orange trace is relatively slow comparing with the voltage drop of V_p denoted in the blue trace because the time constant is relatively large to suppress the emission noise accompanying with the discharge

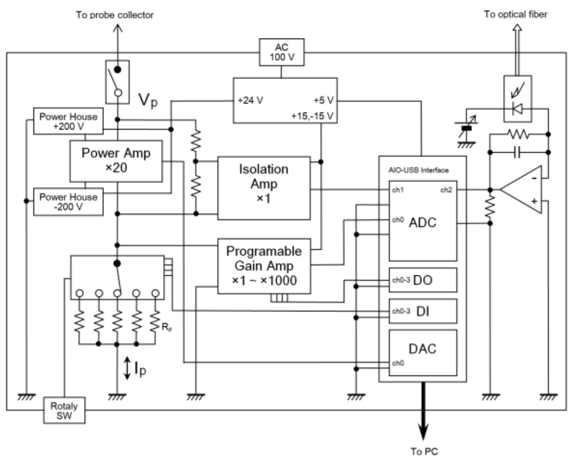

Fig.4 The plasma current and photon acquisition system operated on Windows XP.

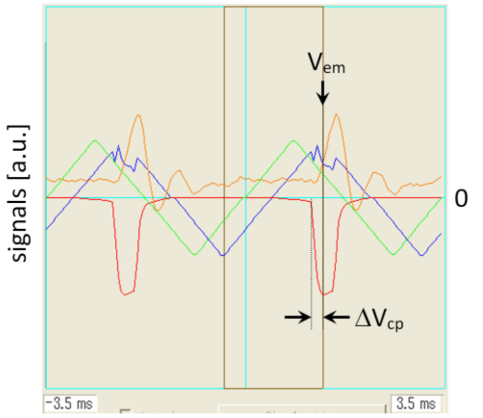

Fig.5 The repeat time variation of V_p (ch1: blue), I_p (ch0: red), and the photon signal I_{ph} (ch2: orange). The period is 3.5 ms.

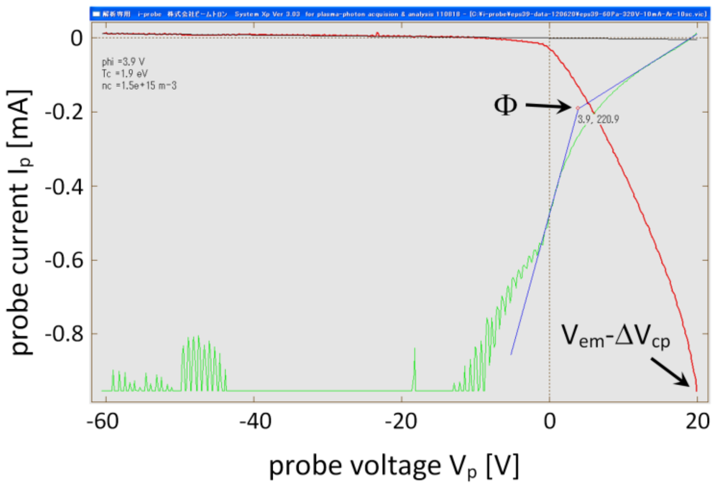

Fig.6 A typical PC screen to analyze the Langmuir probe characteristic obtained by our hard & software system.

at the probe tip. Under auto-bias mode, the maximum of V_p is set at the value lower than V_{em} so as not to induce SPE, so that, not to receive the photon signal. An result with the sweep frequency of 10 Hz is shown in Fig.6. This corresponds to the red trace surrounded by the ocher rectangular in Fig.5. But, no abrupt current of I_p accompanying with the discharge at the probe tip appears as the maximum of V_p is set to V_{em}-ΔV_{cp} after selection of the auto-bias mode. The black straight line on the ion saturation current region of the red trace denotes a tangential line to eliminate I_i. The green trace shows a V_p-$\log_{10}|I_e|$ curve. Two blue lines denote tangential lines on the green trace. It is easy to find the longer region to fit the tangential line on the green trace beyond Φ.

4. Summary

We have investigated the effect of the photon detection on determining the optimum inflection point in the Langmuir probe characteristics. The abruptly increasing current due to the discharge at the probe tip is excluded as the sweeping of V_p is limited just before the discharge emission detected by the optical fiber inside the probe collector. This function can assist to draw optimally a tangential line on I_{es} region. Also by considering the elementary process of the atomic excitation in the localized electron sheath, we could propose another way to determine the inflection point adequately from photon detection at the probe tip, even with no SPE.

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