Pressure-Dependent Langmuir Probe Characteristics of DC Gas Discharge Plasmas

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Abstract
In this letter, the behavior of Langmuir probe in dc gas discharge plasma was explored for argon and nitrogen gases via the current-potential characteristics at different gas pressures. It was found that these characteristics apparently depend on the gas pressure and type. In argon discharge, the electron current rapidly increases with positive potential to reach the saturation, while the current decreases with increasing pressure due to collisions. In nitrogen discharge, the curve is distorted at gas pressure of 1 mbar due to the nonlinear space charge layers, and then flattened at 10 mbar due to the dense collisional plasma that reduces the charge transfer efficiency when compared to argon discharge.

Keywords: Langmuir probe; Discharge plasma, Electrical characteristics; Charge collection
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1. Introduction

In Langmuir probe method, the current-potential characteristics of the probe are determined to show that the applied bias voltage (V_B) is swept from a negative to positive potentials. Researchers on experimental plasma physics have quickly realized that construction of the probe and introduction to its current-potential characteristics are much easier than the extraction of accurate values for plasma parameters from the references and published data [1-3]. However, understanding these probe characteristics is somehow difficult due to the fact that the electrons and ions are not mono-energetic and often have different temperatures [4-6]. Therefore, the probe may collect ion current only, electron current only, or sometimes may collect both of them. The full current-potential characteristics of the probe can be easily understood and analyzed by separating the contributions of ion and electron currents from each other [7-9]. The positive ions are continuously collected by the probe until the bias voltage reaches a specific value (V_P), at which ions begin to be repelled by the probe. For $V_B V_P$ product, all positive ions are repelled, and the ion current to the probe vanishes, (I_i= 0) [10,11]. The mathematical treatments of these characteristics can be found in literature [12-14].

2. Experimental Part

Langmuir probe was used to measure the plasma current due to electrons and ions. The probe consisted of a tungsten wire of 2mm diameter and 23cm length to hold high temperatures. In order to protect tungsten wire from plasma, except a short part of exposed tip, the rod was threaded into a thin ceramic tube of 4mm diameter. In addition to the protection, this insulator prevents electrical contact between the tips and conducting wall of torus housing fixed in circular stainless-steel flange. The inner face of this flange had a circular groove for Teflon gasket. Also, the flange had many holes for mounting screws. The end of the tungsten wire was out of the ceramic part for 2mm, which was inserted inside plasma, while the other end was connected to a BNC cable.

In order to use electrical probe to measure plasma parameters, a double probe driving circuit was used. The dual-source of DC 120V is used to supply the probe with suitable positive and negative potentials to reach balance state or floating potential, by adjusting a variable resistor of 50kΩ. The negative – or positive – potential can be employed to collect the electrons' – or ions' – current by the probe or determine the I-V characteristics.

A set of 100Ω, 1kΩ and 10kΩ resistors were used as load balance resistor, so certain values of current and voltage can be recorded on XY-recorder by selecting suitable value of balance resistor. The plasma current was measured by a micro-ammeter connected in series with the probe. The plasma to be studies was generated inside a discharge chamber. Figure (1) shows the experimental setup used in this work.

The discharge chamber consisted of stainless-steel plasma cylinder reactor of 40cm length and 30cm diameter, DC generator, an adjustment system, high-voltage power supply (4kV), milli-ammeter and high-voltage voltmeter to record the dc-discharge current and the discharge voltage, respectively. The discharge chamber was evacuated using rotary and diffusion pumps.

The Langmuir probe was located inside the vacuum chamber and connected to the probe driving circuit. The probe tip was located inside plasma channel. The experimental conditions of plasma generation were initial vacuum pressure of 10^{-4} mbar, working pressure of 0.001-10 mbar, discharge voltage of 1-4kV, discharge current of 4mA, and discharge power of 16W.

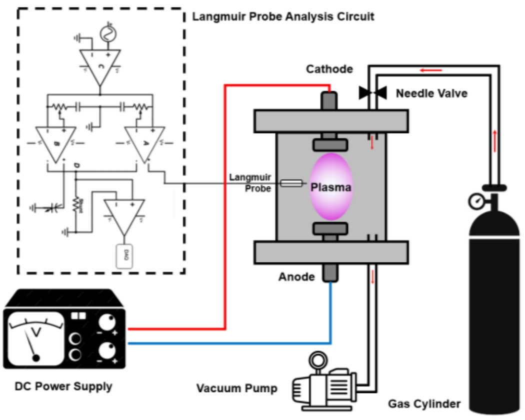

Fig. (1) Schematic diagram of the experimental setup of dc gas discharge plasma system used in this work

3. Results and Discussion

Figure (2) shows the current-potential (I-V) characteristics of the gas discharge plasma using argon (Fig. 2a) and nitrogen (Fig. 2b). These characteristics apparently depend on the gas pressure due to different collision and transport mechanisms in each gas. In Fig. (2a), the characteristics are typical for argon discharge plasma as the probe current rapidly increases with positive potential to reach an electronic saturation state at relatively high potentials, whereas in the negative potential region, the ionic saturation is smaller. As the gas pressure is increased from 1 to 10 mbar, a major change occurs as the ability of electrons to reach the probe is reduced due to increasing frequency of collisions with neutral gas molecules, which leads to decrease the saturated electron current as well as the slope of the transition region between plasma and turn-off potentials.

In nitrogen gas discharge, some different behavior is observed. At low pressures (0.01-0.1 mbar), the saturated electron current is lower than that of argon gas discharge at the same potential values. This is attributed to the difference in the effective collisional cross-section and the molecular mass as nitrogen molecule is diatomic and loosing energy much more effectively throughout the vibrational and rotational excitation. At gas pressure of 1 mbar, a clear distortion in the positive half of the curve is observed, which may be attributed to the formation of nonlinear space charge layers or attachment processes forming negative ions. This reduces the overall current when compared to argon gas discharge. At gas pressure of 10 mbar, the curve is approximately flat that refers to a dense collisional plasma in which it is difficult for electrons to acquire sufficient energy for gas ionization, and hence both electron and ion currents are reasonably maintained.

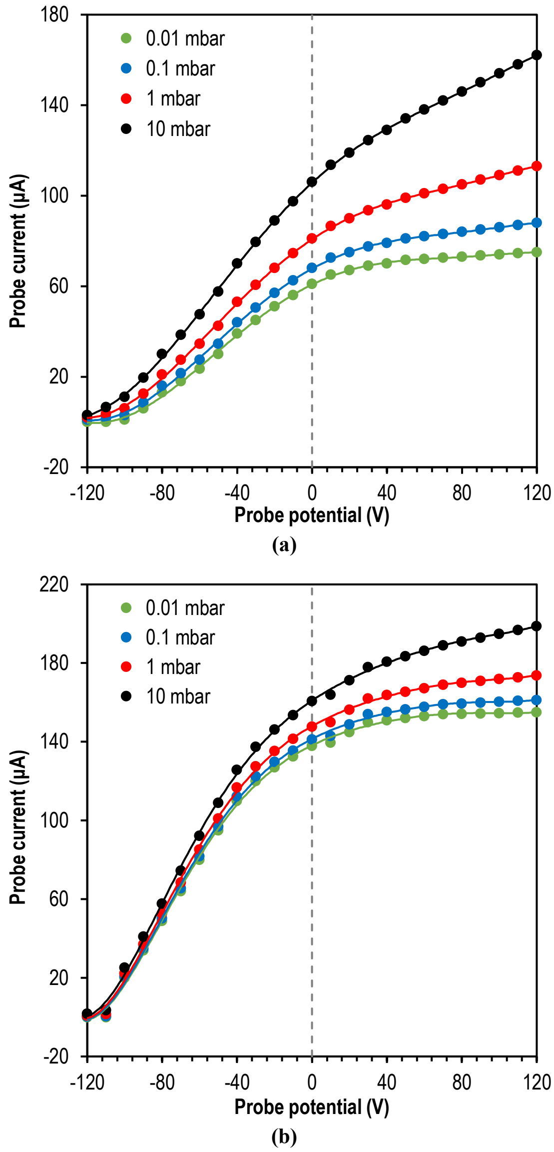

Fig. (2) The I-V characteristics of Langmuir probe for (a) Ar discharge plasma and (b) for N_2 discharge plasma

The comparison between the two gases declares that the characteristics of argon discharge plasma shows higher stability and current at the same pressure values since no channels are available to lose the vibrational or rotational energy. This makes argon gas mostly suitable for discharge applications at moderate pressures. On the other hand, nitrogen show higher sensitivity to the variation in pressure leading to lower current and reduced charge transfer efficiency with increasing pressure. It is important to notice that the plasma potential converts into higher values in nitrogen at low pressures, which indicate differences in ionization energy as well as energy loss via inelastic collisions.

4. Conclusion

In concluding remarks, argon showed higher stability and larger current at the same pressure values, which make it much more suitable for the applications of moderate gas pressure discharges. Nitrogen – on the other hand – shows higher sensitivity to the change in gas pressure with smaller current and lower charge transfer efficiency with increasing pressure. The plasma potential converted into higher values in nitrogen discharge at low pressures, which explain the differences in the ionization energy and energy loss via inelastic collisions.

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