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LANGMUIR PROBE AND SPECTROSCOPIC STUDIES OF THE MAGNETICALLY CONFINED PLASMA COLUMN IN DUOPLASMATRON ION SOURCE[1]

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Experiments have been carried out to further characterize the magnetically confined hollow cathode duoplasmatron. The plasma column constricted by magnetic field between intermediate electrode and anode is investigated by the Langmuir probe and optical emission spectroscopy. The electron temperature, electron and ion density and plasma potential were measured as a function of source discharge current and argon pressure. In the discharge current range of 25–150 mA used in this expriment, electron temperature increased with an increase in discharge current and also with the reduction in argon pressure. The electron density showed an order of magnitude increase in this discharge current range for fixed gas pressure. The electron temperatures measured by both methods are reasonably consistent. Thereby indicating the usefulness of emission spectroscopy as a simple and reliable technique to measure electron temperature without disturbing the plasma.

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1 Introduction

The hollow cathode duoplasmatron [1] is the mainly applied ion source at PINSTECH low energy ion accelerator since 1994. It has low gas consumption and can deliver mA of singly charge ion current. As opposed to the conventional high power duoplasmatrons [2,3], with this source the stable discharge can be obtained at a discharge power as low as 10 W with a few hundred μA beam current at an extraction voltage as low as 4 keV. The source has been in use on the average 5 hours a day without much degradation of its performance. One of the important regions in a duoplasmatron ion source is between Intermediate Electrode (IE) and Anode (A), here plasma is constricted by strong inhomogeneous axial magnetic field, whose poles are usually IE and A. We studied this constricted plasma by langmuir probe and spectroscopic methods. The investigation of the discharge properties of this confined plasma region was required to understand the on going physical processes that can affect the performance of the ion source. Earlier, Lejeune [4]

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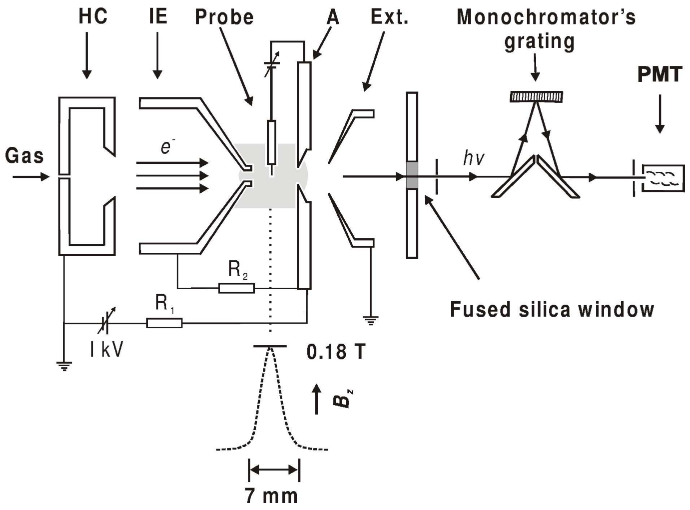

Fig. 1. Layout of the experiment for probe and spectroscopic measurements of magnetically confined plasma column in dopasmatran ion source. HC is the Hollow Cathode, R_1 and R_2 are resistors of 2.4 and 5 kΩ respectively, which are used to stabilize the discharge current.

and Oztarhan [5] investigated the IE-A region of duoplasmatron ion sources. However, their studies differ from ours in the following points:

1. The source is operated in arc discharge region with relatively high discharge current I_d and magnetic field $B_{z,max}$ i.e. 5 A and 0.5 T, respectively. While we operated our ion source in glow discharge region with I_d= 25 – 150 mA and $B_{z,max} = 0.18$ T.

2. They measured the radial distribution of T_e and n_e for fixed I_d and gas pressure p_g, while we determined the value of T_e and n_e as a function of I_d and p_g.

3. During spectroscopic investigation of the ion source Lejeune [4] used Local Thermodynamic Equilibrium model (LTE) to evaluate T_e whereas we used Corona model since our source operates in low plasma density region.

2 Experimental Setup

The magnetically confined hollow cathode duoplasmatron is explained and discussed in detail elsewhere [1,6]. It operates in the glow discharge regime at fairly low power ($\leq$ 100 W) and gas pressure p_g and yet provides stable and sizable ion beam currents ($\leq$ 5 mA). It has two distinct plasmas i.e. between cathode-to-intermediate electrode and intermediate electrode-to-anode. The former plasma acts as an electron source for the latter, from where extraction of the ions takes place. Four ring shaped permanent magnets are used to produce the axial magnetic field, its maximum ($B_{z,max}$ = 0.18 T) lies in the center of intermediate electrode and anode (see Fig. 1). IE is the magnetic field free region but electric field between Hollow Cathode (HC) and IE ensures electron flow up to the IE-A region. The distance between the IE and A is 7 mm. A cylindrical tungsten probe of 0.4 mm in diameter and 2 mm of length was inserted in

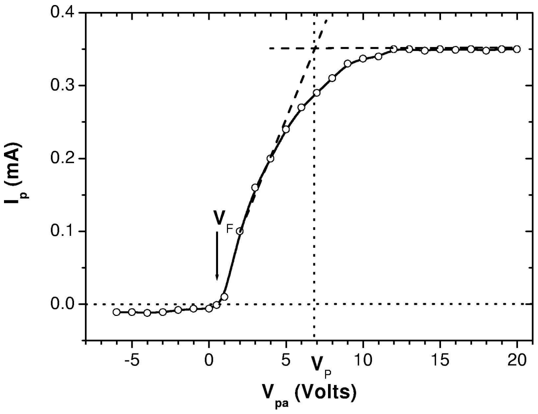

Fig. 2. The I-V characteristics of the Langmuir probe obtained at the discharge current $I_d = 125$ mA. V_p and V_{pa} are the plasma potentials and V_f the floating potential.

the IE-A region right inside the main emissive plasma region. The probe position was chosen to coincide with the maximum $B_{z,max}$ in the IE-A region (see Fig. 1). A variable output DC power supply was used to provide ±50 V bias to the probe with respect to the anode. In spectroscopic measurements, the spectral analyses were performed by a Jobin Yvon H20 monochromator in the 250–600 nm range through a fused silica window, positioned at 0.5 mm hole in the anode. The grating of the monochromator was rotated by a stepper motor controlled by a computer through the General Purpose Interphase Bus (GPIB). The light was detected with a photomultiplier tube (PMT).

3 Results and discussion

A typical current-voltage characteristics obtained with the Langmuir probe in the IE-A region right at the point of maximum magnetic field intensity ($B_{z,max} = 0.18$ T) for the $I_d = 125$ mA and $p_g = 5 \times 10^{-3}$ mbar, are shown in Fig. 2. At the positive plasma voltages (V_{pa}) with respect to the anode ($V_{pa} > 7$ V), electrons are accelerated towards the probe and ions are repelled. An excess of negative charge build up around the probe creates electron sheath. Electron current to the probe is governed by random thermal motion. The area of the sheath is fairly constant with increase in voltage; this explains the fairly constant electron saturation current $V_{pa} > 7$ V. As the probe is made less positive, a point V$_p$ is reached where the sheath disappears, called the plasma potential. At this point there are no electric fields within the plasma and the current is therefore controlled by the relative thermal velocities of the ions and electrons. Since electrons are much more faster due to their smaller mass, the current which the probe collects is still predominantly an electron current. For the probe voltage less than the plasma potential a transition region is reached where electron are beginning to be repelled. In this voltage region an equilibrium point V$_F$ occurs where the electron and ion currents to the probe are equal, which is called floating potential of the probe. At higher negative voltage an ion sheath is formed around the probe and

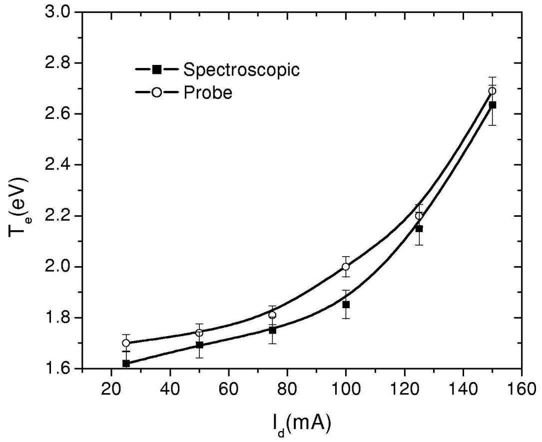

Fig. 3. Langmuir probe and spectroscopic measurements of the temperature of electrons T_e for various ion source discharge currents I_d.

it is saturated with the ion current. The saturation current measured by the probe at positive bias is about 35 times higher than that collected at negative voltage, which is due to the much larger electron velocities as compared to the ions. The plasma potential in this case is about 6.8 V, whereas it was 6–7 V for the measured range of I_d and p_g. The plasma potential was determined from the $\ln(I_p - V_{pa})$ plot; it was taken as a point where the $\ln(I_p - V_{pa})$ plot started to deviate from linearity.

The electron temperature calculated from the slope of the $\ln(I_p - V_{pa})$ plots as a function of I_d and p_g is shown in Figs. 3 and 4, respectively. The ion density n_i was determined from the probe ion saturation current obtained by extrapolating the ion saturation curve to the plasma potential. The ion current is given by [5]:

$$I_i = cn_i e\sqrt{\frac{2kT_e}{m_i}}A_s, \tag{1}$$

where c=0.4 for cylindrical probe and $A_s =$ sheath area $\cong$ probe area. The measured ion densities, at the point of maximum magnetic field intensity, were found to be in the range of 4×10^{10}–1.5×10^{11} cm^{-3} for varying discharge current from 25–150 mA. This also gives an estimate of the electron density, since discharge cannot support large excesses of one charge carrier.

The density of electrons measured by the Langmuir probe are of the order of 10^{10} cm^{-3} therefore, confine the region where plasma is in the Corona equilibrium. The Corona model is applicable for plasmas with low electronic density and atomic densities sufficiently low as to eliminate the possibility of collision among the atoms themselves. Here, excitation occurs by electron impact and de-excitation by radiative decay. The electron temperature can be determined from the intensity ratio of emission lines for transition between levels $i - x$ in the excited singly-

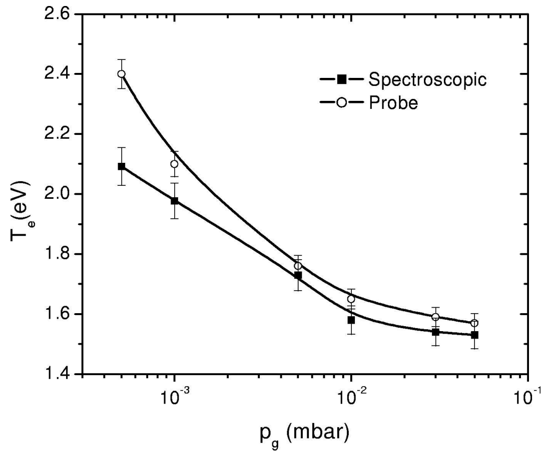

Fig. 4. Langmuir probe and spectroscopic measurements of the temperature of electrons T_e as a function of argon pressure p_g in the ion source.

charged ion ($I^+_{i,x}$) and $p - y$ in the excited atom ($I^o_{p,y}$) using the following expression [7]:

$$\frac{I^+_{i,x}}{I^o_{p,y}} = CT_e^{0.75} \exp\left(\frac{E_{p,g} - E_{i,g} - E_g}{kT_e}\right), \tag{2}$$

where C is a constant, which depends on oscillator strengths and transition probabilities of the involved transitions $i - x$ and $p - y$, $E_{p,g}$ the excitation energy of atom from ground state to level p, $E_{i,g}$ is the excitation energy of the singly charged ion from its ground state g to level i, E_g the ionization potential of atom and k is the Boltzmann constant. The values of oscillator strengths and transition probabilities are taken from Wiese et al. [8] and Griem [9]. Selecting suitable atomic and ionic transitions of argon, and knowing their line intensity ratios and all other constants, equation (2) can be solved to obtain the temperature of electrons T_e.

The temperature of electrons T_e was measured using emission intensities of three atomic argon spectral lines at 419.8, 425.9, 489.4 nm and three ionic spectral lines at 309.3, 324.4 and 330.7 nm. In order to improve the accuracy, different pair of lines, one from each atomic and ionic spectral lines was selected. For each pair, the temperature of electrons T_e was evaluated separately and all the temperatures were averaged. The variation of the temperature of electrons T_e, as a function of the discharge current I_d and the gas pressure p_g is shown in Figs. 3 and 4, respectively. The probe as well as the spectroscopic measurement shows that the temperature of electrons T_e increases with increasing of the discharge current I_d (see Fig. 3). Furthermore as it can be seen in Fig. 4, the temperature of electrons T_e show a pressure dependence with the higher values corresponding to lower gas pressures p_g, which is due to the reduction in collision losses [10]. The probe measurements consistently give slightly higher values of T_e (see Figs. 3 and 4) than the spectroscopic technique because the probe measured in a small-localized area of intense discharge obtained by constriction of the magnetic field at this position, while the spectroscopic measurements give an average value of T_e over the line of sight of the monochromator.

The experimental results presented here suggest that the electron temperatures measured with the Langmuir probe and spectroscopic methods in the magnetically confined plasma column in Duopasmatran ion source are reasonably consistent. Thereby indicating the usefulness of emission spectroscopy as a simple and reliable technique to measure electron temperature without disturbing the plasma. Additionally, these results will help us to improve the performance of our ion source.

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