Multi-Aperture Two-Electrode Extraction System of an 1 mN Ion Thruster

G.M. Sandonato, J.J. Barroso
Laboratório Associado de Plasma - LAP
Instituto Nacional de Pesquisas Espaciais - INPE
12201–970 - São José dos Campos, SP - Brazil

1 Introduction

In this work a multi-aperture two-electrode extraction system has been studied in order to produce a low divergence ion beam for an 1 mN ion thruster. The conceptual modeling has been done by using analytical expressions derived from the spherical diode concept and by numerical simulation using an adapted version of SLAC code [1] named IGUN [2]. The conceptual modeling has been developed taking into account both the electrical and geometrical constraints on the multi-aperture two-electrode extraction system.

2 Theoretical Model

When an ion beam is produced from a plasma the characteristics of the space charge sheath (ion emitting surface) can be described in the same way as for a solid emitter. The parameters describing the space charge sheath can be derived from the spherical diode concept. The curvature radius of the emitting surface is given, then, by [3] :

$$R_\Sigma = 1.6 l_g \left(\frac{P_o}{P_o - P_j} \right) \tag{1}$$

where the perveances are given by :

$$P_j = \frac{j_\Sigma}{U_T^{3/2}} \tag{2}$$

and

$$P_o = \frac{5.5 \times 10^{-12}}{l_g^2} \left(\frac{e}{m_i} \right)^{1/2} \tag{3}$$

where $j_\Sigma = j_o/\phi_o$ is the Bohm density of current and $j_o = (q/2mU_T)^{1/2} F/A_o$ is the ion beam current density related to a thrust F and a total applied potential U_T, for a given ionized gas with a mass m and charge q (A_o is the beam cross section). The electrode transparency can be estimated by : $\phi_o = N_A\left(\frac{r_E}{r_o}\right)^2$ where r_E is the extraction aperture radius and r_o is the ion beam radius.

Equation (2) reveals that the ion emitting surface will be concave ($R_\Sigma > 0$) if $P_j > P_o$, convex ($R_\Sigma < 0$) if $P_j < P_o$ and plane ($R_\Sigma \to \infty$) if $P_j = P_o$. Using the expression for the Bohm density of current, the curvature radius can be given now in practical units by [2] :

$$R_\Sigma = \frac{1.6 l_g}{1 - 4.05 \times 10^{10} \frac{F}{\phi_o}(\frac{l_g}{r_o U_T})^2} \quad [\mathrm{mm}] \tag{4}$$

The emitting surface has a thickness (distance from the extraction electrode) given by [2] :

$$\delta = 4.97 \times 10^{-3} \left(\frac{U_T^{1/2} \Delta U_G^{3/2} \phi_o r_o^2}{F}\right)^{1/2} \quad [\mathrm{mm}] \tag{5}$$

The divergence angle of the ion beam, as function of the emitting surface radius, is given by [2] :

$$\alpha = 0.25 \frac{d_E}{l_g}\left[0.67 - 2.67 \frac{(l_g/d_E)}{(R_\Sigma/d_E)}\right] \quad [\mathrm{rad}] \tag{6}$$

where $d_E = 2r_E$ is the extraction aperture diameter and l_g is the spacing between electrodes. Note that the curvature radius, sheath thickness and divergence angle are all independent of the ion mass if the thrust is specified.

The electrical parameters are all related by the factor R_V which is given by [4] :

$$R_V = \frac{U_N}{U_T} = \frac{V_D + \Delta U_G + U_E}{U_N + |U_A|} \tag{7}$$

where U_N e U_T are the effective and total voltage factors, respectively, V_D is the discharge voltage, and U_E and U_A are the applied voltage across the extraction and acceleration electrodes, respectively.

The spherical diode model has been adopted here and by other authors [3] due to good results that have been obtained. In Fig.(1) the theoretical [2] and experimental [4] equipotential are compared, thus showing excellent agreement.

It has been observed that the ion optics of a multi-aperture electrode system can be described by the ion optics of a couple of aperture [5]. Therefore, the characteristics of the ion emitting surface can be introduced in the IGUN numerical code [2] in order for Poisson and motion equations to be solved for an ion beam consistent with electrical and geometrical parameters of a multi-aperture two-electrode system.

3 Theoretical Results

By using the specified values of $r_o = 2.5\,\mathrm{cm}$, $d_e = 1.7\,\mathrm{mm}$ and $N_A = 499$, it has been estimated that $\phi_o = 0.60$, and by using $F = 1\,\mathrm{mN}$, $U_T = 1000\,\mathrm{V}$ in Eq.(5) it has been obtained that $\alpha = 0\,\mathrm{rad}$ for $l_g/d_E = 1.386$ ($l_g = 1.1\,\mathrm{mm}$) and $R_\Sigma = 3.81\,\mathrm{mm}$.

It has been observed [4] that $R_{V'} = 0.9$ is the best value for producing a low divergence ion beam. As the potential difference between the emitting surface and the extraction electrode is not known by analytical expressions, but only experimentally, values in $5 - 20\,\mathrm{V}$ range have been assumed forΔU_G (values considered to be typical in electron impact ion sources). Finally, using the estimated geometrical parameters and the specified electrical parameters in the IGUN code, the ion beam shown in Fig.2(a) has been obtained . As shown in Fig.2(b) the variation in ΔU_g does not produce any significant effect on the beam divergence angle. The maximum variation observed was 3^o for a discharge voltage of 50 V.

The low divergence ion beam was obtained by using all the electrical and geometrical parameters as shown in Table (1) for the multi-aperture two-electrode system. These parameters can be used either for argon or xenon, because both the curvature radius of emitting surface and the ion beam divergence angle do not depend on the ion mass.

4 Conclusions

Excellent agreement was found between the theoretical and experimental values for the curvature radius of the emitting surface.

The ion beam divergence angle has shown to be quite insensitive to ΔU_G variations.

Both the theoretical and experimental [6] values for the ion beam divergence angle are in close agreement.

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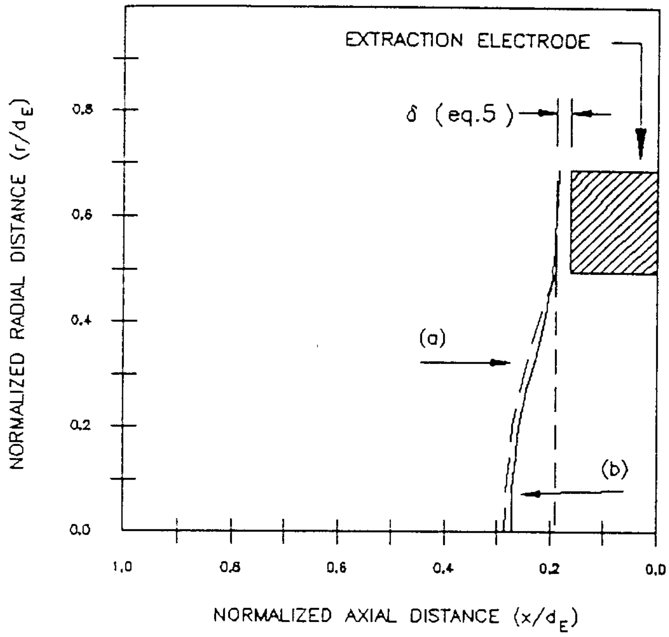
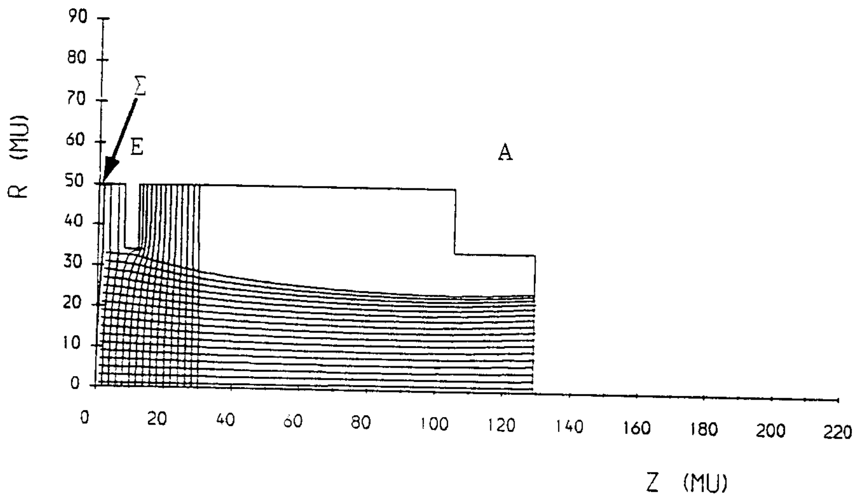


Figure 1. Emitting surface : as calculated in the present model (a) and experimental [4] (b).

Table 1. Geometrical and electrical parameters for the multi-aperture two-electrode system.

Ion beam radius (r_o)	25 mm
Number of apertures per electrode (N_A)	499
Diameter of a single extraction aperture (d_E)	1,7 mm
Extraction electrode thickness (t_E)	0,1 mm
Diameter ratio (d_A/d_E)	1,0
Diameter of a single acceleration aperture (d_A)	1,7 mm
Acceleration electrode thickness (t_A)	0,6 mm
Electrodes separation (l_g)	1,1 mm
Voltage ratio (R_V)	0,9
Total voltage (U_T)	1000 V
Ion beam density of current (j_o)	
(Argon)	17,6 A/m^2
(Xenon)	9,7 A/m^2
Thrust (F)	1 mN

(a)



(b)

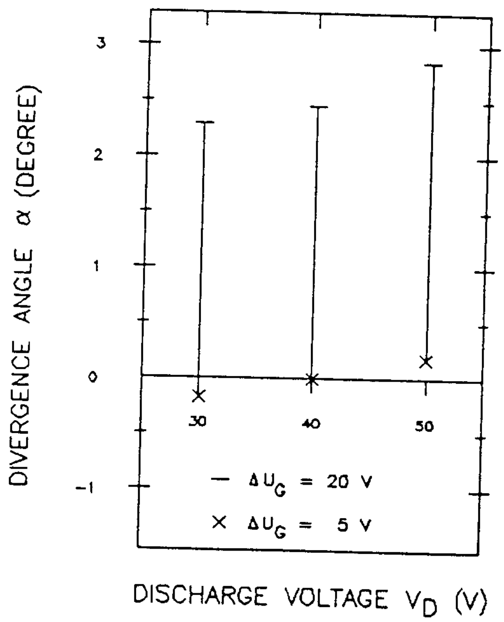


Figure 2. Ion beam (a) (Σ : emitting surface, E : extraction electrode (V_E = 830 V), A : extraction electrode (V_A = −100 V)) and divergence angle variation due the adopted values for ΔU_G (b).

LIF-MEASUREMENTS OF TEMPERATURE PROFILES OF SPUTTERED TITANIUM ATOMS IN A D.C. ARGON GLOW DISCHARGE

Vladimir Henrique Baggio Scheid[1], Bernd Schweer, Eduard Hintz

Institut fuer Plasmaphysik, Forschungszentrum Juelich GmbH, Association EURATOM-KFA, P.O. Box 1913, D-5170 Juelich, Fed. Rep. Germany

Abstract

In this work the population distribution in the groundstate sublevels of the titanium atoms has been measured by means of the laser induced fluorescence (LIF). From this distributions the Ti-temperature profiles in the discharge axis have been determined with a spatial resolution of 1.5 mm. The measurements were made in a d.c. argon glow discharge operated in the abnormal range. In the negative glow a nearly constant temperature of about 350 K has been found. Towards the cathode a temperature rise up to 410 K at 0.5 kV (0.2 mb) and up to 540 K at 2.1 kV (0.1 mb) has been observed.

Introduction

The interest in studing glow discharge is related with the several technological applications, e.g., light sources, surface treatment, etching and deposition processes [1].

In the last time, the laser induced fluorescence and the optogalvanic spectroscopy have given an important contribution in understanding many of the complex processes (e.g. excitation, ionization and charge exchange collisions and sputtering of the cathode material) which take place in the cathode region [2,3]. The laser induced fluorescence is an active spectroscopic technique, which has been sucssesfull used to make selective, non-disturbing and local measurements of particle densities in glow discharges [4-7].

In this work results for the temperature profiles of sputtered titanium atoms in an abnormal argon glow discharge are given, which were obtained by means of the laser induced fluorescence.

Titanium was chosen as cathode material because of its technological significance. The noble gas argon was taken because of its high sputtering yield.

Experimental Arrangement

The measurements were made in the cathode region (cathode fall and negative glow) of a d.c. argon glow discharge. The electrodes consist of a titanium cathode and a copper anode with 6 cm diameter and separated by a fixed distance of 10 cm. They were mounted in a movable system, which allows for axial shifts up to 10 cm inside of a stainless steel UHV-chamber with a diameter of 30 cm and a length of 46 cm.

For the measurements of the particle densities with help of the laser induced fluorescence a dye laser pumped with two flash lamps was used. The laser was operated with rhodamine 590 perchlorate (max. output at 590 nm) solved in ethanol. An interference filter (λ_{max} = 620 nm) and a Fabry-Perot-etalon (d = 0.15 mm, R = 85%) positioned in the laser resonator were used to reduce the line-width. Each wavelength was first adjusted in the visible range with help of a grid spectrometer (accuracy of $\Delta\lambda/\lambda = 2 \times 10^{-6}$). The fine adjustment was thus made with the Fabry-Perot-etalon until a maximal fluorescence signal was achieved. The frequency was duplicated by a temperature stabilized ADA cristal of 50 mm length. With this system a tipical value for the laser spectral power density of 20 W cm^{-2} pm^{-1} was achieved in the UV ($\lambda \approx 300$ nm, $\Delta\lambda \approx$ 12 pm). The laser beam was incident parallel to the cathode surface. The fluorescence light was observed by a photomultiplier after being separated from most of the background plasma radiation by a grid monochromator (1180 groove/mm, focal length = 500 mm and disperssion = 1.6 nm/mm). The observation was made in a perpendicular direction with respect to the laser beam in order to obtain a well defined observation volume. A UV-photodiode was used to monitore the fluctuations in the laser power. The photomultiplier signal and the UV-photodiode signal were integrated and digitized in a fast charge sensitive ADC. After one measurement the

[1] on leave from Instituto de Estudos Avançados, CTA, CEP 12231-970 S. J. dos Campos, SP, Brazil