XE-AR AND AR PLASMA DISCHARGES IN A SMALL HALL EFFECT THRUSTER: ELECTRIC AND OPTIC DIAGNOSTIC

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ABSTRACT

Ion energy distribution function (IEDF), current-voltage characteristics are investigated in Xe-Ar and Ar plasmas discharges in a hall effect ion source. The investigations were carried out on a constant Xe mass flow rate and for different Ar flow rates. The comparison between Xe and Xe-Ar discharges were done for evaluation of Ar ionisation probabilities in plasma discharge governed by Xe ions. Two different behaviors were underscored depending on the filling fraction of Ar.
Firstly we have studied a plasma dominated by Xe ion population and it was found that the electron temperature (Te) increases when a small part of argon was injected. Secondly the Xe-Ar plasma dominated by Ar plasma discharges parameters have been also investigated. These measurements coupled to Optical Emission Spectroscopy (OES) and to the ion characterisation by Retarded Field Analyser give a new insight of the discharge properties such as ionization processes, efficiency, and ion current density variation.

1.INTRODUCTION

The electric propulsion for orbit keeping satellites is a mature spatial technology. Two special kind of thrusters are already used in space: the gridded thruster and Hall Effect Thrusters (HET) [1]. In these two configurations, the propulsion is based on the ejection of very fast ions (exhaust velocity of several km/s). The most common propellant is xenon due to his high mass (131a.m.u) and his relatively low ionization potential (12.1 eV).
The technology of HET is demonstrated since 1970 by Russian in the 1 kW power range [2]. Today, high power (5 kW) Hall sources with a Thrust of 300 mN are investigated for the equipment of the human Martian travel. On the other hand, the development of smaller sources in the sub 200 W power range is interesting for the scaling laws and for the equipment of low atmosphere satellites as well as for the development of a laboratory tool.
The physical process inside the source needs to be clarified for optimization namely the question of the dynamic of ionization and acceleration areas [3]. Based on this technology of HET, the GREMI -built PPI (Petit Propulseur Innovant) source is used with a mixture of Argon and Xenon gases as propellant. The ultimate aim is to obtain and characterize an original Argon ion source in the 150 W power range with 1A of current for application in material treatment.
In this contribution, we present the first investigations of Ar-Xe mixture discharge properties. Argon ionization is a crucial problem in this kind of source and doesn't fit exactly to the scaling laws. In order to better understand ionization of argon atom, investigated parameters such as current discharge, potential cathode, mean ion current, divergence are reported as function of the (Ar + Xe)/Xe flow rate ratio. The Ion Energy Distribution Function (IEDFs) are also measured by using Retarding Potential Analyzer (RPA).

2. EXPERIMENT

Fig.1: The PPI thruster in operation in GREMI vacuum chamber

The fig.1 shows the PPI in operation: a gas flow of Argon or xenon is ionized in a ceramic delimited annular channel (inner radius 16mm and outerdiameter 21mm). The plasma is established by a DC magnetized discharge between the anode and an external hollow cathode working only in xenon.
The power of the source varies between 50 and 300 W. The magnetic field is assured by the assembly of small size SmCo permanent magnets and reduced the axial mobility of the electrons leading to a potential drop. The ions are efficiently produced and accelerated by an electric field as high as 10^4V/m. The ion velocityis in the range of 15km/s [4].
The PPI source works in the GREMI vacuum chamber. Three turbomolecular pumps allow pumping speed in xenon around 3000 l/s and give a pressure of 10^{-7} mbar. During thruster operation, chamber pressure is approximately at 3. 10^{-5}Torr for a xenon mass flow rate of 1mg/s.
The used RPA is small enough to avoid plasma perturbation and no differential pumping is necessary. The RPA is mounted either on a translation arm face to the source or on movable arm for angular measurements. The RPA is made up of four grids and a collector. Fig.2 shows the schematic structure of the RPA. The first grid (G_0) is at the floating potential and is used to avoid the disturbance of surrounding plasma properties. The second grid (G_1) is negatively biased (-15V) in the order to repel the electrons of the plasma. The third grid (G_2) corresponding to the discriminator repels ions with total energy lower than the grid bias. The IEDFs can be reconstituted after derivative by varying the applied potential (V_{RPA}) [5].
The last grid (G_3) is also negatively biased (-15V) and serves to repel the secondary electrons coming from the ion bombardment of collector.
The ions charges are collected by a low capacitance shielded coaxial cable. The signal is recorded on a 500 MHz Wavejet LECROY oscilloscope through a resistor of 500 kΩ. The bandwidth of acquisition circuit is about 1MHz.

3. RESULT AND DISCUSSION

The aim of the study is to evaluate argon plasma properties thanks to a comparison of Xe pure plasma and Ar-Xe mixture plasma with a constant Xe mass flow rate (Φ_{Xe}). In the

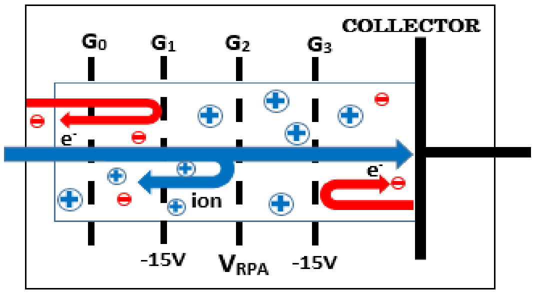

Fig.2: The schematic structure of the Retarding Potential Analyser

following, the Xe mass flow rate is set at 8.2 sccm and mass flow rate of Ar (Φ_{Ar}) varies from 1 to 4 sccm.
Fig.3 illustrates the 542 nm ionized xenon line (XeI) evolution used as reference. The optical spectra are recorded by an AVANTES spectrometer. Its intensity is practically insensitive to the addition of argon. This guarantees that the argon inflow doesn't modify the operation of PPI thruster.
The evolution of mean current discharge with different Φ_{Ar} is illustrated in Fig.4.
The plasma discharge is ignited first exclusively in Xe and the Ar is progressively injected. The typical nominal operating point for a xenon running mode is with a discharge voltage U_d at 220V and a current discharge I_d at 0.85A.

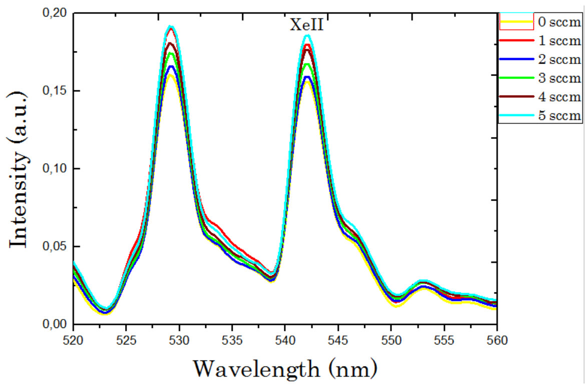

Fig.3: XeII spectra as function of different Ar mass flow rate

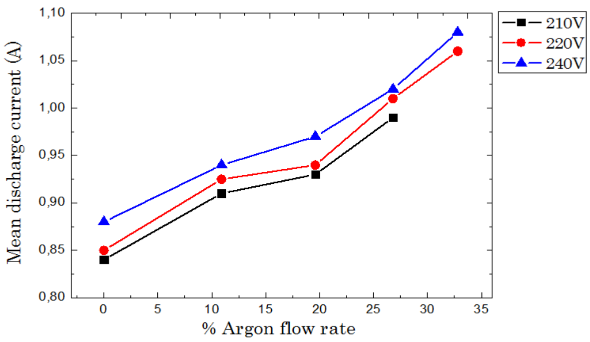

Fig.4: Evolution of mean discharge current as function of different Ar mass flow rate for 3 discharge voltages

The mean current discharge increases with the argon flow increase. This augmentation can be

attributed either to an amount of global ion current (Ar^+ or Xe^+) or to an amount of electronic current coming from the cathode.
Answering this question is of particular interest for the investigation of the Ar working source and further for the optimization.
Equation (1) shows the relation between ion current and the atom mass flow rate.

$$I_{Ar+}\ (A) = \tau_i * q * \Phi_{Ar} \qquad eq.(1)$$

τ_i: ionisation rate

q: elementary charge

Φ_{Ar}: atomic flow (at/s)

If we assume that the increased discharge current correspond to the Ar ionisation, thus the rate can be estimate.
Table (1) shows a comparison between the expected discharge current (theoretical discharge current (I_{dtheo}) calculated by eq.(1) with τ_i equal to 0.9 as for Xe) and the measured discharge current (I_d).

$\dot{m}_{Ar}$(sccm)	1	2	3	4
$\%\ \dot{m}_{Ar}/\dot{m}_T$	10.8%	19.6%	24.6%	32.8%
I_{dtheo} (A)	0.0645	0.129	0.195	0.258
ΔI_d (A)	0.075	0.09	0.16	0.21
$\%\Delta I_d/I_{dT}$	8.8%	10.6%	18.8%	24.7%

Table1: Calculated and measured discharge current for different Ar flow rate in the mixture

$\dot{m}_{Ar}$ = argon mass flow rate
$\dot{m}_T$ = Total mass flow rate (Ar+Xe)
I_d = Total discharge current (Ar+Xe)
ΔI_d=Difference between I_{dT} and discharge current in Xe pure plasma
I_{dtheo} = calculated current

We observed that more the argon filling rate increased more the theoretical current closes to the measured value. That means that the Ar ionization is better for high flow rate. This is the consequence of Te increasing which is evidenced in the following.

<u>1-time oscillation of cathode and discharge current</u>

The current oscillations frequency for Xe pure plasma is at 30 kHz and can be related to the well-known breathing oscillations [6-7]. The burst typical time corresponds to the neutral depletion–filling time of the channel. The oscillations frequency remains around 30 kHz for all of the studied Xe-Ar mixture plasma.
Fig.5 illustrates the cathode potential related to ground by a 500 MHz PP006A LECROY probe. The mean cathode potential increases from -28V in pure Xenon discharge to -18V for a 24% of filling fraction in argon/xenon mixture. Considering the stability in the current electron extraction of the hollow cathode, this

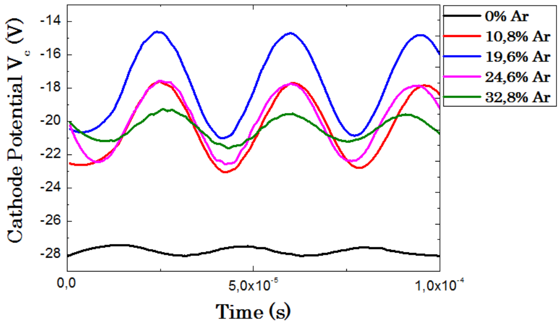

Fig.5: Evolution of the cathode potential as function of different %Ar mass flow rate in the mixture for a discharge voltage at 220V

potential variation is only due to plasma potential variation (+10V) in the near cathode area.
So the plasma potential becoming more positive involves that Te increases when argon atom is injected in the plasma [8].
However at the point, further investigations are necessary to conclude on the nature of the amount of the total ion current.

<u>2-RPA measurement</u>

RPA technique gives a measurement of the total ion current reaching the biased collector. For that the RPA is placed on axis at 40cm from the exhaust plane. We compare the total ion flow of Xe and Xe-Ar mixture discharges with V_{RPA} set at 100V. Fig.6 shows that the total ion current decreases for the lower filling fraction of argon (19% and 24%) whereas the Xe flow rate remains the same. This behavior involves that the argon injection leads to an attenuation of Xe ionization efficiency which contrast to current discharge evolution. It means that the discharge current evolution is due exclusively from electrons coming from cathode which is not probable thanks to magnetic barrier.
Thus two explanations are given in the following. Firstly this decreasing can be linked to the oscillations amplitude of discharge current (fig.6). Secondly, the ion beam can become more divergent. Investigations of ±30° ion current shows that beam shape is not changed by an argon addition.

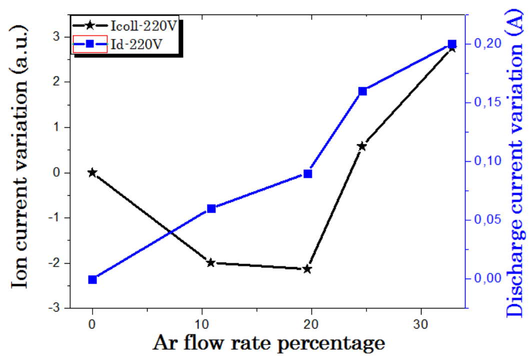

Fig.6: Evolution of total ion flow and discharge current as function of different %Ar mass flow rate in the mixture for 220V

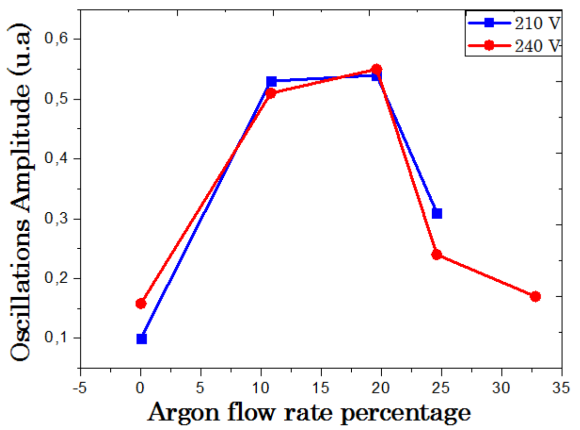

Fig.7: Oscillations amplitude of discharge current as function of different %Ar mass flow rate in the mixture

The Argon pure plasma discharge is done with a mass flow rate at 29sccm, a discharge voltage of 220V and a discharge current of 1.71A. The Ion current densities are measured by RPA at 40 cm from the thruster exit plane. Analysis of Ar and Xe IEDFs shows that the FWHM is smaller for argon (44V) than for the xenon (57V). This means that the ionization zone is less wide in Ar than in Xe and thus the ionization and accelerating regions are better separated in Ar discharge. The mean ion energy is equal to 159 eV and 166 eV respectively for Xe and Ar for the same discharge voltage (fig.8).

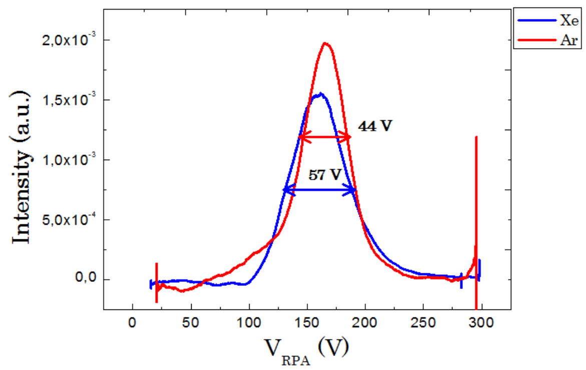

Fig.8: Comparison of Ar and Xe Ion Energy Distribution Function (IEDF)

4. CONCLUSION

We present the first implementation of low-power HET with Ar and Ar-Xe mixture. The source is ignited in pure Xe. The Xe flow is kept constant while Ar is added 1 by 1sccm. The control of the Xe efficiency is assured by the control of the stability of the 542 nm XeII line. The mean discharge current follows the filling fraction of Ar but is not imputed only to an amount of Ar^+. For the lower amount of Ar the mean discharge currents is due to a more oscillating discharge current. In the same time, Te increases giving a better condition for Ar ionization. At this point (36% of Ar and more) the amount of the current is related to the amount of Ar^+. As expected the ionization efficiency is lower for Ar than Xe. This due first to ionization energy (15.7 eV for Ar and 12.1 eV for Xe) but the second reason is the transit time in the channel. It is proportional to the atom mass plasma and thus is 3 times shorter in Ar discharge.
Finally, the velocities of ions (Xe+ and Ar+) will be measured by Laser Induced Fluorescence for different operating conditions and related to the Vp modifications near and inside the channel. On the other way the time-resolved ions current gives some insights on the nature of the channel species in the far field beam. The whole characterization of the source will provide a useful laboratory tool as well as interesting fundamental physics of gas mixture discharges.

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