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OPTICAL EMISSION SPECTROSCOPY MEASUREMENTS ON A SPT-20 HALL EFFECT THRUSTER ON THE KHAI GROUND TEST FACILITY

The plasma plume of a SPT-20 has been analysed by Optical Emission Spectroscopy in order to analyse the emission of XeI, XeII and Al I emitted from the Al_2O_2 ceramic walls.

satellite, electric propulsion, optical emission spectroscopy, erosion

Introduction

In the frame of the international spacecraft ATEX project (Advanced Technology EXperiments), the Research Group (GdR) on Plasma Propulsion CNRS / CNES / SNECMA / Universities and the Kharkov Aviation Institute (KhAI) are studying the KhAI SPT-20 Hall effect thruster on the Khai test facility by means of Optical Emission Spectroscopy (OES).

The ATEX project intend to develop a spacecraft platform for scientific and technological advanced experiments. Two Stationary Plasma Thrusters (SPT-20) manufactured by KhAI will be used to communicate an acceleration to the spacecraft and the french propulsion GdR plans to fit out the spacecraft with a minispectrometer to analyse the ligth emitted by the plasma of the SPT-20 thrusters.

Light emitted by the plasma plume gives, after spectroscopic analysis, informations about neutral, ionized and double ionized xenon.

A study of the difference between ground and in-flight optical emission of the plasma will indicates how the environmental pressure and temperature act on the thruster working.

The second stakes of this OES experiment is to control the erosion of the channel ceramic wall of the SPT-20 thruster. Previous measurements on SPT100-ML, PPS1350 and PPS-X000-ML [1, 3] have shown the possibility to control the ceramic erosion by emission spectroscopy of the ceramic lines, boron and silicon lines for BN-SiO_2. For the KhAI SPT-20, the ceramics are made of Al_2O_3, and the line to be detected is an alumina line. First emission spectroscopy on Al_2O_3 has been performed in LPGP with a small magnetron which has a Al_2O_3 target. Results are that the Al I (396 nm) alumina line is high enough to be used to control SPT-20 erosion, and that the spectrometer resolution had to be 0,6 nm.

The main aim of this paper is to present the first Optical Emission Spectroscopy (OES) measurements on the SPT-20 KhAI thruster carried out in 2005 on the KhAI test facility.

The standard mini-spectrometer used for these OES first measurements had a bad resolution, but the feasibility has been demonstrated for a new minispectrometer with a suitable resolution.

These first OES results shown the evolution of the lines emitted by the xenon plasma (Xe and Xe+) and by the Al2O3 ceramic (Al lines) which were used in conjunction with coronal model and actinometric hypothesis in order to obtain the relative ceramic sputtering density versus discharge voltage (in the 170-270 V range), mass flow rate (in the 0,25 – 0,33 mg/s range) or coil current (2,5 – 3 A) .

A second campaign has been performed in July 2006 with a new mini-spectrometer HR2000 having a suitable resolution on an optimized SPT-20 operating with a discharge voltage in the range 200 V to 300 V, a mass flow rate from 0,20 to 0,25 mg/s and coil current from 1,8 to 2,5 A. We only present in this paper three recorded spectra (AlI, XeI and XeII) for a comparison of the two spectrometers. The detailled results will be shown in a next paper.

1. Ground test feasibility OES experiment

In order to test the feasibility of the ATEX spectroscopy experiment a standard mini-spectrometer was first used during two days in the KhAI laboratory. This USB2000 standard spectrometer manufactured by Ocean Optics is very compact (15×11×5 cm), very light (600 g), and has a low power comsumption (100 mA@5 VDC). Recently, a second mini-spectrometer with a better resolution (HR2000 Ocean Optics) was used.

1.1. Ground test feasibility set-up. The Optical Emission Spectroscopy experimental set-up analysing the Khai-SPT20 plasma on the KhAI ground test facility (9,2 10 – 5 Torr) is shown on the Fig. 1.

The light emitted by the plasma of the KhAI-SPT20 passing through a quartz flange was collected by a 10 cm focal quartz lens and focalised at one end of a 1 mm diameter optical fiber. The other end of the fiber was connected via a SMA connector to the USB2000 spectrometer entrance slit.

The distance between the plasma and the lens was about 80 cm. With a focal of 10 cm for the lens, the magnification was about 9. With an optical fiber of 1 mm diameter, the spatial resolution was about 9 mm diameter. So, a large part of the plasma inside the thruster channel and outside the exit plane of the thruster was covered by the optical set-up.

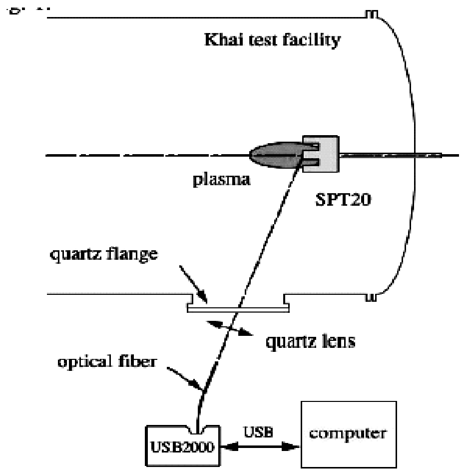

Fig. 1. Experimental set-up with USB2000 spectrometer analysing Khai-SPT20 plasma

The light entering the spectrometer is diffracted by a fixed grating towards a 2048-element linear array CCD detector. So, in one shot, this spectrometer provides a large 200-1100 nm wavelength range spectrum but with only 2 nm resolution.

The spectrometer is connected to a lap top computer by USB interface. Software reads programmed datas and a graphical interface produces on-screen spectrum which can be recorded on a .text file.

1.2. Ground test feasibility OES results. In this section are presented a parametrical study of the plasma emission where the discharge voltage is varying while mass flow rate and coil current are fixed. Values for the four parametrical OES measures are reported in Table1.

Typical spectrums are shown on Fig. 2 on which 823 and 828 nm neutral xenon lines, 394 and 396 nm neutral aluminium lines are marked. The line group between 450 and 550 nm is principally ionized xenon lines among which 460, 484, 529, and 542 nm XeII lines here used (Fig. 3).

Details from the spectrum Fig. 2 are reported on Fig. 3, 4, and 5. The neutral xenon lines part is well resolved (Fig. 4), the ionized xenon lines are also resolved (Fig.3), but the neutral aluminium lines (Fig. 5) are mixed with 395 nm ionized xenon lines.

Table 1
Discharge voltage, mass flow rate and coil current values for the 4 OES parametrical measures

Coil current	2,5 A		3,0 A	
Mass flow rate	0,25 mg/s	0,30 mg/s	0,30 mg/s	0,30 mg/s
	/	/	/	168V
	/	180V	/	182V
	/	190V	190V	190V
	200V	200V	202V	200V
	210V	210V	212V	210V
Discharge voltage	220V	220V	220V	220V
	230V	230V	230V	230V
	240V	240V	240V	240V
	250V	250V	250V	250V
	260V	/	260V	/
	270V	/	/	/

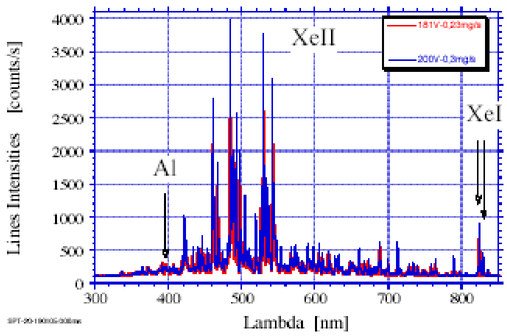

Fig. 2. Spectrum of the ligth emitted by the plasma

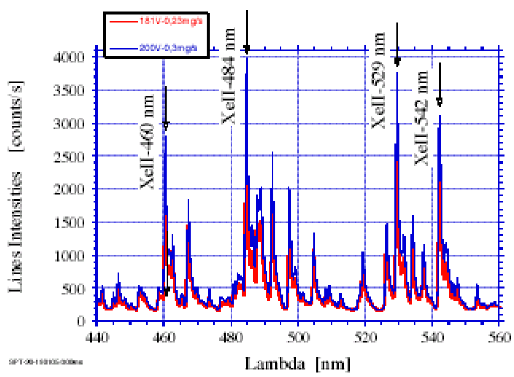

Fig. 3. Ion xenon line emission

Intensities of neutral xenon lines have been obtained by surface integration and averaging 2 lines (XeI-823,16 nm and 828,01 nm), intensities of ionized xenon lines with 3 lines (XeII-484 nm, XeII-529 nm and XeII-542 nm) and intensities of neutral aluminium line by surface integration of AlI-396,15 nm.

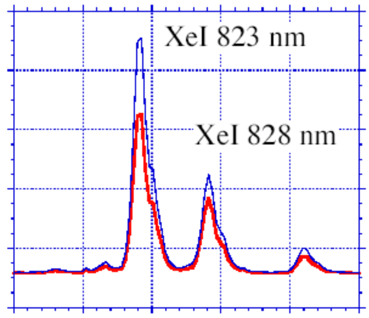

Fig. 4. Neutral xenon line emission

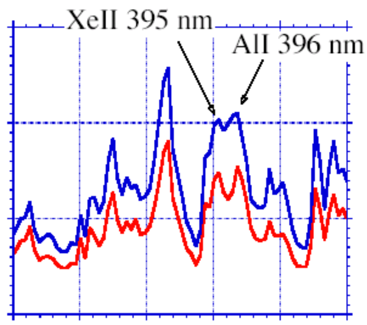

Fig. 5. Neutral alumina line emission

Evolution of neutral xenon and aluminium, and ionized xenon intensities are reported in Fig. 6, 7 and 8. First, the evolution of the three species (XeI, XeII, AlI) with discharge voltage is the same for both 2,5 and 3 A coil current and 30 mg/s mass flow rate. This indicates that the influence of the magnetic field is weak for such coil current variation. For the same discharge voltage the variation of the three species is principally due to the mass flow rate variations.

Both neutral and ionized xenon lines intensities are decreasing with discharge voltage, and increasing with mass flow rate. The decrease of the neutral xenon with discharge voltage is due to the increase of the ionization. The decrease of the ionized xenon with discharge voltage is probably due to the increase of the ion energy which for the same ion flow rate decrease the ion density. The increase of both neutral and ionized xenon with mass flow rate is due to the increase of neutral density.

Evolution of neutral aluminium is difficult to interpreted because aluminium and xenon lines are mixed and aluminium line is not resolved. Nevertheless, the intensity of the aluminium line at 260 V discharge voltage is 4 times the value at 200 V while xenon lines are decreasing. This indicates that the erosion is strongly increasing with discharge voltage. A better spectrometer resolution as the HR2000 is neaded to obtain better accurancy.

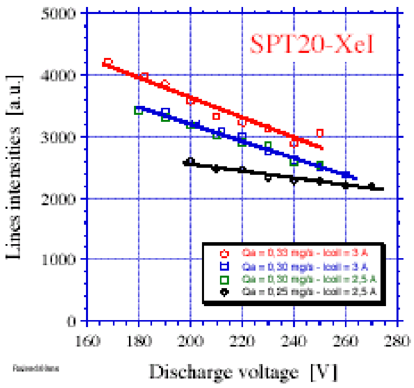

Fig. 6. Neutral xenon line intensities versus discharge voltage

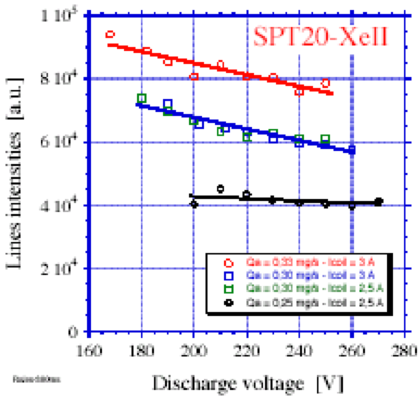

Fig. 7. Ionized xenon line intensities versus discharge voltage

In the frame of the Groupement de Recherche CNRS / CNES / Snecma / Universités «Propulsion spatiale à plasma» (GdR n°2759), the Laboratoire de Physique des Gaz et des Plasmas (LPGP) had improved a method to measure the ceramic erosion of Hall effet thrusters by Optical Emission Spectroscopy. Results on ceramic erosion have been published for various thrusters SPT100-ML [1], PPS1350G [2], and PPSX000 [3]. Method and hypothesis (coronal model and actinometry) have been discussed in these articles. With these hypothesis, the ceramic erosion is obtain by the ratio between neutral ceramic line (here AlI-396 nm), neutral xenon line and ionized xenon line:

$$Erosion = \frac{I(Al396nm)\,x\,I(XeI828nm)}{I(XeII484nm)}.$$

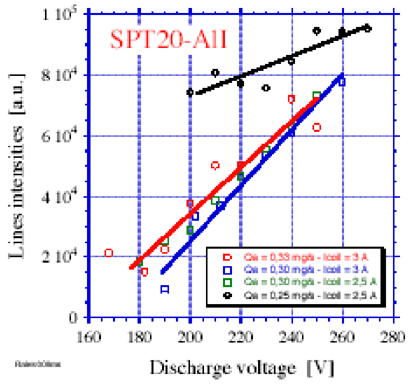

Fig. 8. Neutral alumina line intensity versus discharge voltage

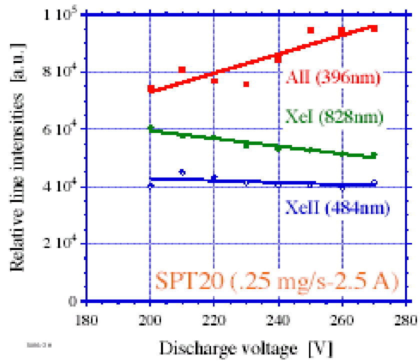

Fig. 9. Aluminium and xenon line intensities versus discharge voltage. Mass flow rate = 0,25 mg/s. Coil current = 2,5 A.

In the Fig. 10, 11, 12 are shown the evolution of aluminium (Al 396nm) and xenon line (XeI 828nm, XeII 484nm) intensities versus discharge voltage for different mass flow rates.

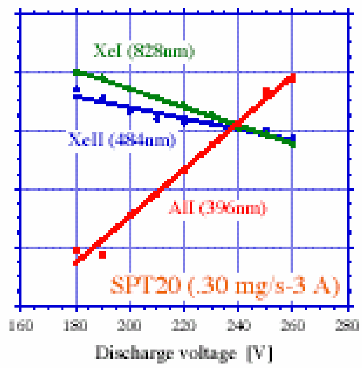

Fig. 10. Aluminium and xenon line intensities versus discharge voltage. Mass flow rate = 0,30 mg/s. Coil current = 3,0 A

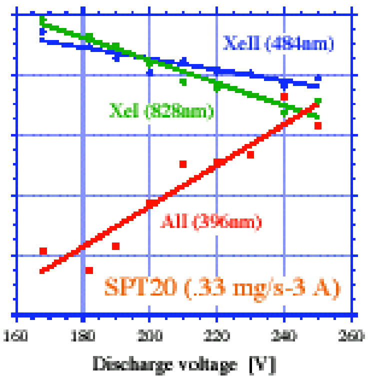

Fig. 11. Aluminium and xenon line intensities versus discharge voltage. Mass flow rate = 0,33 mg/s. Coil current = 3,0 A.

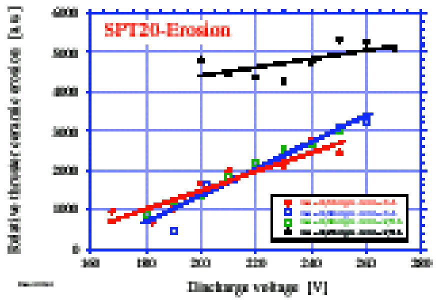

Fig. 12. Thruster ceramic erosion versus discharge voltage

The above ratio of these line intensities leads to the ceramic erosion shown in the Fig. 12. With great caution due to the lack of accuracy on the aluminium line intensity, it is obvious that the ceramic erosion is strongly increasing with the discharge voltage (about a 4 factor for the two mass flow rates, 0,30 and 0,33 mg/s). Ceramic erosion values obtained for 0,25 mg/s mass flow rate are about two times those of higher mass flow rates and needed to be confirmed with the new spectrometer (HR2000).

2. July 2006 new OES campaign

A new spectrometer (HR2000 Ocean Optics) was used during a new campaign in KhAI in July 2006. Using this new spectrometer with a reduce spectral range (380- 830 nm) and a better resolution of about .6 nm allows a satisfying separation of the Alumina lines and will be proposed for on-board experiments.

The SPT-20 (model 5) is optimized for a mass flow rate lower than model 3 one's and the pressure in the vacuum chamber is 6,5 10^{-5} Torr (9,2 10^{-5} with the model 3).

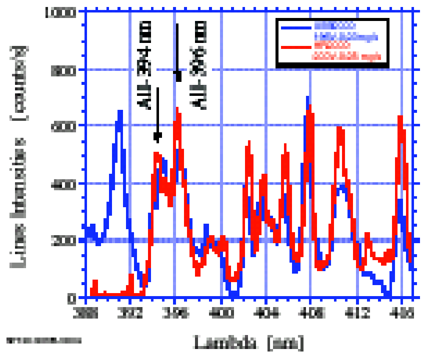

Fig. 13. Comparison between USB2000 and HR2000 in the alumina spectral range

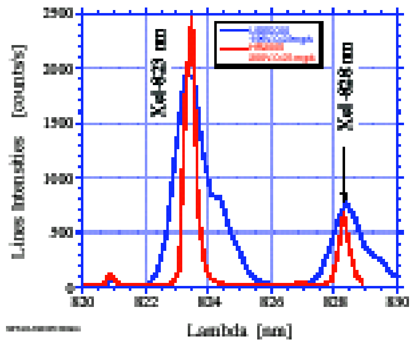

Fig. 14. Comparison between USB2000 and HR2000 in the neutral xenon spectral range

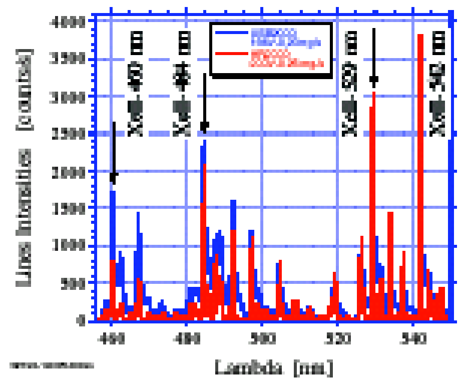

Fig. 15. Comparison between USB2000 and HR2000 in the ion xenon spectral range

The figure 13 presents Al-394 nm and Al-396 nm lines recorded with USB2000 and HR2000 spectrometers. This figure clearly shows the advantage of the second spectrometer. Figures 14 and 15 present the acquired spectrums in the XeI and XeII spectral ranges.

3. ATEX on-board OES experience

The ATEX project intends to use two Stationary Plasma Thrusters (SPT-20) manufactured by KhAI to communicate an acceleration to the spacecraft. These thrusters have been studied by means of OES in ground test facility and the ATEX project equiped with a minispectrometer allows to compare in-fligth thruster working to ground one's.

A schematic set-up is shown in Fig. 16. In order to obtain a better resolution than the USB2000 spectrometer one's used on KhAI ground test facility, the new spectrometer (HR2000) with a 0,6 nm resolution and 390 – 830 nm wavelength range will be used on ATEX satellite.

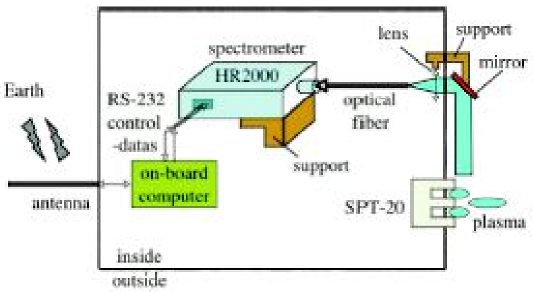

Fig. 16. Experimental set-up with HR2000 spectrometer on-board ATEX satellite

This spectrometer will be connected to the on-board computer by means of RS-232 interface. Only a mirror will be outfitted outside the satellite in order to collect the light emitted by the plasma of the SPT-20 thruster towards an inside lens. An optical fiber transferts the light to the HR2000 spectrometer. Datas and control of the spectrometer will be transmitted to the Earth by the on-board computer through the antenna.

Conclusion

The feasibility to obtain spectroscopic informations on the plasma of a thruster has been demonstrated using the KhAI ground test facility equipped with the KhAI SPT-20 thruster. Neutral and ionized xenon lines bring some valuable informations about how the thruster is running. Neutral aluminium line can be used to quantify the amount of thruster ceramic sputterised, and specially the evolution of the sputtering during the two or three years time of flight.

The in-flight OES measurements will allow investigations on the temperature and pressure influence on the thruster working compared to the ground test one's.

This research has been performed in the frame of the French Research Group GdR 2759 - CNRS, CNES, SNECMA, Universities, «Propulsion Spatiale à Plasma» and STCU 1936 «Investigation of electric propulsion system hollow thruster for control of geo-stationary spacecraft orientation dynamic characteristic».

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