Use of emission spectroscopy for real-time assessment of relative wall erosion rate of BHT-200 hall thruster for various regimes of operation

Use of Emission Spectroscopy for Real-Time Assessment of Relative Wall Erosion Rate of BHT-200 Hall Thruster for Various Regimes of Operation

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Abstract

Radiation emission due to Boron atoms sputtered from the Boron-Nitride ceramic walls of a BHT-200 Hall thruster was measured as a diagnostic for real time assessment of thruster wall erosion and to determine the effects of various operation conditions on thruster lifetime. Boron neutral 249.677 and 249.773nm lines were measured using a high resolution spectrometer. Spectral measurement results and the accompanying analysis and discussion are presented in this study. From the spectral measurements it was observed that the Boron emission intensity significantly increases for increased discharge voltage pointing to a large increase in the thruster wall erosion rate. Additionally, the measurements show that for the nominal discharge voltage and the applied magnetic field intensity, there is an optimum propellant flow rate for minimum Boron emission, thus minimum wall erosion rate. The variation in the current to the magnet coils showed that the Boron emission intensity increases for increased magnetic field and the Boron emission intensity shows similar behavior to that of the Xenon single ion emission line intensity at 248.911nm. The findings of the study show that emission spectroscopy can be used in determining the optimum operational parameters for minimum wall erosion for SPT type Hall thrusters.

Key words:
Plasma; Hall thruster; Spectroscopic measurement; Electric propulsion; Erosion

1. Introduction

Due to their high specific impulse and more controllable thrust levels, electric propulsion devices such as Hall thrusters provide an attractive alternative to traditional chemical thrusters for many in-space propulsive applications[1]. Stationary Plasma Thrusters (SPTs) are Hall effect thrusters that have concentric annular walls made of dielectric ceramic material. Erosion of these ceramic walls due to impact of high-energy ions is one of the major life limiting factors for these thrusters[2, 3].

The impulse obtained from a Hall thruster is provided by the acceleration of the ionized propellant due to the potential drop between the anode located at the end of the annular acceleration channel and the cathode located outside the thruster. The ion flux directed out of the annular channel produces the thrust. However, some of the high-energy ions hit the channel walls causing the sputtering of the ceramic insulator material[4]. Removal of the wall material this way, eventually causes the underlying magnetic yoke to be exposed[2, 5].

Erosion of the thruster ceramic walls results in plasma impurities in the discharge and the plume regions due to the eroded products entering the plasma. The detection of radiation emission due to these erosion products and correlation of the emission data to the actual wall erosion rate is a promising method in determining the erosion rate of the thruster components, and subsequently of the thruster operational lifetime.

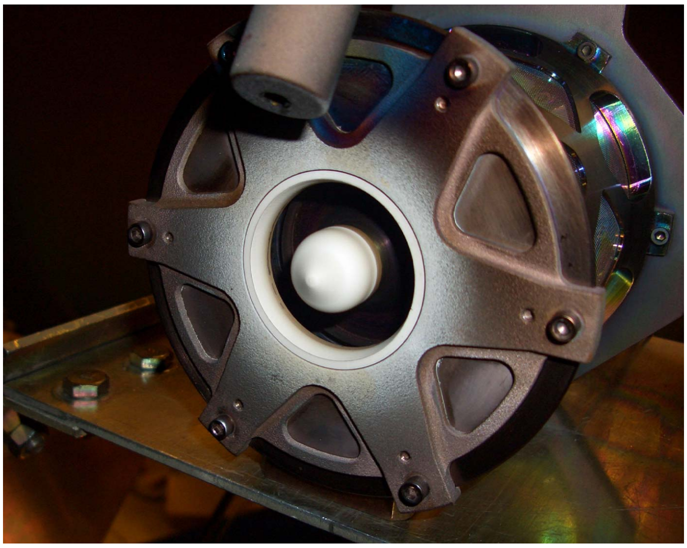

Figure 1: BHT-200 Hall thruster ceramic annular walls made of Boron-Nitride

The BHT-200 Hall thruster is an SPT type Hall thruster that runs on Xenon propellant. It has insulator ceramic annular walls made of Boron-Nitride (BN). A picture of the BHT-200 Hall thruster annular channel is shown in Figure 1. Radiation emission due to excited Boron atoms is detected in the

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BHT-200 Hall thruster plume plasma because of ions sputtering off the thruster BN channel walls. In this study, Boron neutral emission lines at 249.677 nm and 249.773 nm are measured for varying thruster operational parameters. Even though an absolute material loss correlation to the emission data is difficult to obtain, the spectral measurements of these Boron neutral lines are used to identify the regimes of operation that cause high thruster wall erosion. The measurements showed that the use of emission spectroscopy can provide a real-time, non intrusive method to assess the relative thruster erosion rate as the various operational parameters are changed.

According to the study by Rubin et al.[5] where the sputter yield measurements, by quartz crystal microbalance, of Boron-Nitride due to bombardment by Xenon ions of relevant energies are presented, the sputtering predominantly occurs as atoms of B and N, but not so much as BN or other B_xN_y. Thus, measurements of Boron neutral emission would provide a good measure of the relative total erosion rate of the Hall thruster channels.

Determination of the ceramic erosion rate is traditionally done by operating the thruster for long durations (several weeks to months) inside a vacuum chamber, and measuring the change in the wall thickness before and after the testing. However, such experiments are time consuming and expensive, and often require the destruction of the thruster[6, 7]. Also, the analysis of the findings is difficult due to the uncertainty in the deposition rates and other vacuum tank effects, as well as the difficulties in establishing a non-varying reference for surface geometry measurements. In addition, such experiments are conducted without changing the operational parameters, and thus does not provide information about different operation conditions.

There have been a few computational models developed to simulate the erosion of the Hall thruster ceramic walls[2, 3, 8, 9]. Most relevantly, Cheng[2] modeled the erosion of the ceramic nose cone of the BHT-200 Hall thruster using a hybrid particle-in-cell Hall thruster discharge plasma simulation code. The models use experimental and analytical sputtering coefficients for Xenon ions hitting Boron-Nitride walls. However, an accurate modeling of the erosion is difficult due to the uncertainties in predicting the plasma properties, electric field strengths (or sheath potential drops), and wall thermal conditions inside the Hall thruster discharge channel.

In previous studies, optical emission spectroscopy has been proposed as a means to diagnose the erosion rate of the ceramic walls of Hall thrusters[10, 11, 12, 13, 14, 15]. In Hall thrusters, optical emission spectroscopy provides emission lines due to mainly the propellant plasma particles such as Xenon neutrals and single ions. Measurements of line emission due to the Xenon double ions are also reported [10]. In addition, radiation emission lines due to the thruster ceramic wall materials such as Boron or Silicon were also detected [11, 12, 13, 15]. In experiments by Karabadzhak et al.[13], the Boron neutral (BI) lines at 249.68 and 249.77 were identified as the lines to be analyzed for BN ceramic wall erosion.

In a paper by Pagnon et al.[11], the emission by the propellant plasma (Xe, Xe^+) and the BN-SiO_2 ceramic erosion products (B and Si) have been used to analyze the wall erosion of an SPT type Hall thruster. Bugrova et al.[16], proposed the use of a simple corona model to deduce the Boron number density from the measured emission intensity of Boron emission line at 249.77nm.

In the most relevant study, Hargus et al.[12] looked at the ceramic erosion rate of the BHT-200 Hall thruster by measuring emission of the Boron neutral resonant line at 137.9 nm in the vacuum ultraviolet (VUV) portion of the spectrum. In that study, the optics were focused on the Boron-Nitride ceramic nose cone of the BHT-200 Hall thruster center pole and the effects of various operating conditions on the Boron emission intensity were studied.

In this study, spectral measurements were conducted in the ~ 250 nm portion of the UV spectrum due to the limitations of doing vacuum UV measurements[17]. Yet, the measured Boron lines are resonant lines to the ground state.

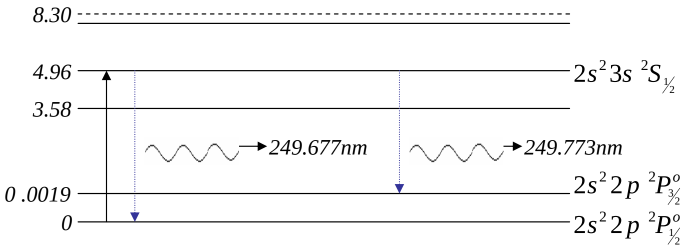

Figure 2: Illustration of the neutral Boron energy levels and the 249.677 and 249.773 nm resonant emission lines

Boron has a doublet transition at 249.677 nm and 249.773 nm. These are the longest wavelength resonant transitions for Boron [18]. The 249.677 nm line corresponds to the transition between the energy levels $2s^22p\ ^2P^0_{1/2}$ at ground state (0 eV) and $2s^23s\ ^2S_{1/2}$ at 4.964 eV, and the 249.773 nm line corresponds to the transition between the energy levels $2s^22p\ ^2P^0_{3/2}$ at 0.00189 eV and $2s^23s\ ^2S_{1/2}$ at 4.964 eV. The excited state lifetimes are ~ 8 ns and ~ 4 ns respectively, due to large oscillator strengths of the transitions [18, 19]. Figure 2 shows the graphic illustration of the Boron atomic energy levels, in eV, and the 249.677 nm and 249.773 nm resonant emission lines.

Detailed collisional-radiative (CR) models are generally required to relate plasma optical emission signals to species concentrations. Under appropriate conditions corona assumptions can be employed to simplify the analysis; however, even in such cases the task of relating measured emission signals to the corresponding overall species concentration is not straightforward as the excited state fractions depend on electron number density and electron temperature. Additionally, determining the actual wall erosion rate from the the number density of the erosion products presents another challenge.

However, if one assumes that both the eroded species and the propellant species (i.e., Xe, Xe^+, Xe^{++}) are excited only by electron impact collisions, the variations in emission intensity can be related to the variations in the species densities by taking into account the relevant cross section and spatial/temporal plasma electron temperature and density values. For optically thin plasma, assuming corona equilibrium, the intensity, I_{ij}, of an emission line λ_{ij} corresponding to a radiative transition from the energy level j to level i will be given by:

$$I_{ij} = \frac{A_{ij}}{\sum_{k<j} A_{kj}} n_e n_1 < \sigma v_e >_{1j} \quad (1)$$

where n_e is the electron density, n_1 is the ground state atom density, A_{ij} is the spontaneous emission transition coefficient from level j to level i, $\sum_{k<j} A_{kj}$ is the reciprocal of the lifetime, τ, of level j, and $< \sigma v_e >_{1j}$ is the electron impact excitation collision rate from the ground state to level j. The values of electron temperature and density can be obtained from other intrusive diagnostics measurements such as Langmuir probe measurements. Analytical formulas such as Gryzinski's formula [20] can be used to calculate the electron excitation cross section from the ground state to the 4.964 eV energy state. If the absolute emission intensities can be obtained, the 249.677 nm and 249.773 nm Boron lines could be used to determine the Boron number density in the region of observation. The obtained Boron number density can then be used to calculate the wall erosion rate. However, such analysis, quantitatively linking the optical emission to the Boron concentration and further linking the Boron concentration to the actual wall erosion rate, is beyond the scope of this study. This paper aims to show that the high-resolution spectral measurements of the two mentioned resonant Boron lines can be an effective method to assess the relative wall erosion for various regimes of operation for BHT-200 Hall thruster and other thrusters with same type of ceramic wall material. The findings of the current study show that emission spectroscopy can be used in determining the optimum operational parameters for minimum wall erosion for SPT type Hall thrusters within thrusters' other design limitations.

2. Experimental Setup and Procedure

The spectral measurements to study the effects of various operational parameters on the erosion of the ceramic walls of the BHT-200 Hall thruster were performed at MIT Space Propulsion Laboratory (SPL). The thruster was operated inside the MIT-SPL vacuum chamber which is 1.5 m in diameter and 1.6 m in length. The chamber is equipped with a mechanical roughing pump and two cryogenic pumps. The total pumping capacity is 7000 L/s for Xenon [21]. The base pressure was 7.8×10^{-8} Torr before the thruster operation began. The chamber pressure during the testing was 3.57×10^{-5} Torr for the nominal operational flow rates for the thruster. The pressure inside the vacuum chamber was monitored by a thermocouple gauge for down to 10^{-3} Torr. A cold cathode pressure gauge was used for measuring lower pressures (accuracy down to 10^{-9} Torr). The BHT-200 thruster was mounted on top of a metal stand inside the chamber. The thruster was run on Xenon propellant.

For the spectral measurements, the radiation emitted by the thruster plasma as well as the erosion products was collected by a collimating lens located inside the vacuum chamber, and transmitted to the entrance slit of a spectrometer through UV-rated optical fibers. A schematic of the experimental setup is shown in Figure 3. A picture of the thruster and the collimating lens is shown in Figure 4.

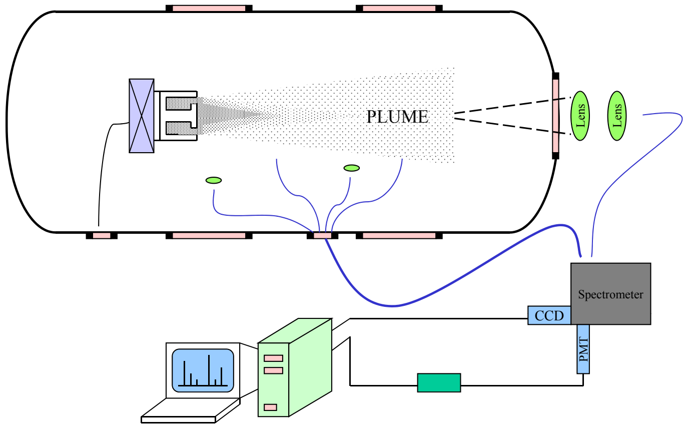

Figure 3: Schematic of the Thruster Erosion Rate Spectral Measurement Setup

2.1. Radiation Collection and Transmission

A collimating lens was used to collect the light from the plasma region of interest. The collimating lens, Ocean Optics UV-74, is 5 mm in diameter and has a focal length of 10 mm. It has an SMA connector on the focused-end where the optical fiber cable is attached. The lens has good transmissivity in the UV wavelength range.

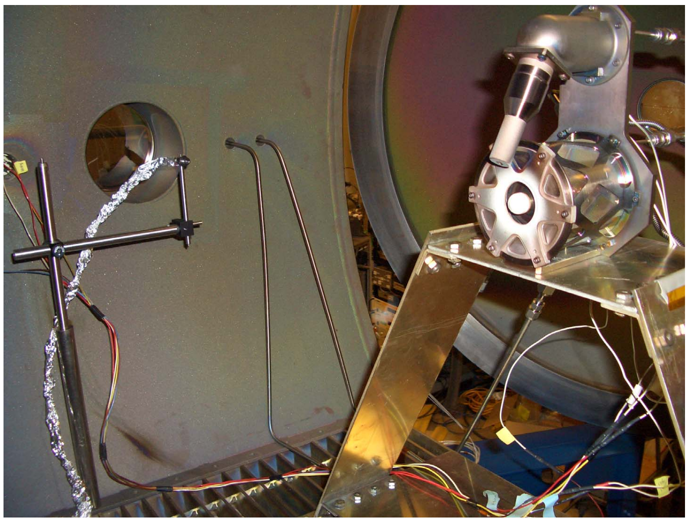

Figure 4: Picture of the BHT-200 Hall thruster and the collimating lens/fiber system inside the vacuum chamber

The collected signal was transmitted from inside the chamber to the outside through a four-channel vacuum-fiber feedthrough. This vacuum feedthrough has four 200 μm diameter UV rated fiber cables. The fiber ends were attached to a 3 m long Acton Research LG-456-020 fiber bundle using an SMA mating adaptor outside of the vacuum tank. The fiber bundle carried the collected signal to the entrance slit of the spectrometer.

2.2. Radiation Dispersion and Detection

An Acton Research SpectraPro-750i spectrometer was used as the dispersive instrument. This 750 mm focal length, f/6.5

aperture Czerny-Turner type spectrometer provides a resolution of ∼ 0.01 nm at 435 nm using 1800 g/mm grating. The inlet port was equipped with an adjustable slit assembly. The spectrometer has a triple-grating turret, and was equipped with three different diffraction gratings. The grating with 300 grooves/mm blazed at 500 nm was used to obtain broader range spectrum. The second grating at 1800 grooves/mm blazed at 500 nm was widely used due to its better wavelength range with relatively good resolution. The high-resolution UV optimized holographic grating of 3600 grooves/mm provided a high resolution spectrum, ∼ 0.007 nm with small wavelength range of only ∼ 3 nm.

A CCD camera, Roper Scientific Photometrics K4, was attached to the axial exit port of the spectrometer. The CCD has 2048×2048 pixels with a pixel size of 7.4 × 7.4-μm. This thermoelectric cooled detector has good quantum efficiency in the visible wavelength range as well as in the UV portion of the spectrum.

2.3. Spectral Measurement Procedure

Unless specified otherwise, the BHT-200 Hall thruster was run at the operational parameters of 250 V discharge potential, 8.0 sccm Xenon propellant flow rate to the anode and 1.0 A of current to the thruster magnet coils. For the various scans, only one of these three operational parameters was varied at a time. The cathode Xenon propellant flow rate was kept constant at 1.0sccm for all runs. These baseline operating parameters are tabulated in Table 1.

Table 1: Baseline operating parameters of BHT-200 Hall thruster

Discharge voltage	250 V
Anode current	0.8 A
Anode propellant flow rate	8.0 sccm (Xe)
Cathode propellant flow rate	1.0 sccm (Xe)
Magnet coil current	1.0 A
Cathode keeper current	0.5 A
Cathode heater current	0 A*

* *no heater current is needed once the cathode is turned on. ∼7.5 A current to heater is required to turn on the cathode.*

The collimating lens, located inside the vacuum chamber, was pointed at the nose cone of the thruster. When a laser pointer is shone into the fiber cable end on the outside the vacuum chamber, the collimating lens projects the light beam on the nose cone of the thruster as a ∼ 1 cm diameter red dot, indicating the cylindrical region of radiation collection for the spectral measurements. For the measurement results presented in this paper, the 1800 g/mm grating blazed at 500 nm was used. The spectral resolution in the region of observation was 0.012 nm. For all the measurements presented in this paper, an exposure time of 250 seconds was used.

3. Results and Discussions

The wavelength region between 245-255 nm has the two strong Boron neutral emission lines at 249.677 nm and 249.773 nm as discussed earlier. Thus this wavelength region was chosen for the spectral measurements. Figure 5 shows the measured spectrum in 245-255 nm region for nominal operating conditions of the thruster. The two mentioned Boron neutral emission lines are identified in the figure.

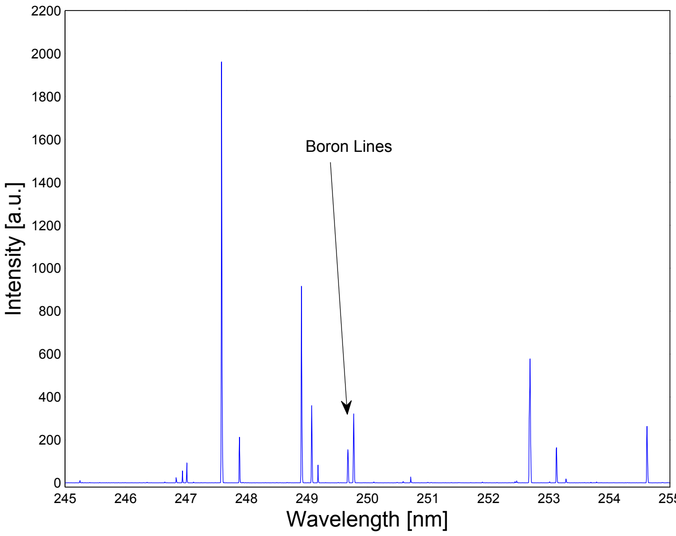

Figure 5: BHT-200 Hall thruster measured spectrum of 245-255 nm wavelength region

Figure 6 shows the measured spectrum of the 247-250 nm region where all the detected lines are labeled. As seen in this figure, the region contains emission lines of Xenon single ion and Boron neutral. According to the NIST database[19], The Boron line at 249.677 nm has a spontaneous emission transition coefficient of $1.2 \times 10^8\ s^{-1}$ and the line at 249.773 nm has a spontaneous emission transition coefficient of $2.4{\times}10^8\ s^{-1}$. The observed line ratio for these two transitions from the same, $3s^2\ S_{1/2}$, energy level at 4.964 eV shows the validity of Equation 1. Thus, if the local electron temperature and density are known, and if the absolute emission intensity can be determined, the integrated area under these two lines could be used to obtain the local Boron neutral density.

3.1. Voltage Scan

In order to observe the variation in the emission intensity of the Boron lines, the thruster discharge voltage was varied from 175 V to 350 V with 25 V increments and the emission spectra in the 245-255 nm wavelength region were measured. Figure 7 shows the variation in the integrated emission intensity for the two Boron lines and the 248.911 nm Xenon single ion line for varying discharge voltage. As the discharge current does not show significant variation for the scanned voltage range, the variation of the integrated emission intensity of the Boron lines as a function of thruster power show a similar trend.

From Figure 7, it is observed that as the discharge voltage is increased the Boron emission intensity increases. The increase is more significant for higher discharge voltages. Thus, assuming the emission intensity is linearly proportional to the Boron density, the observation indicates that the erosion rate increases

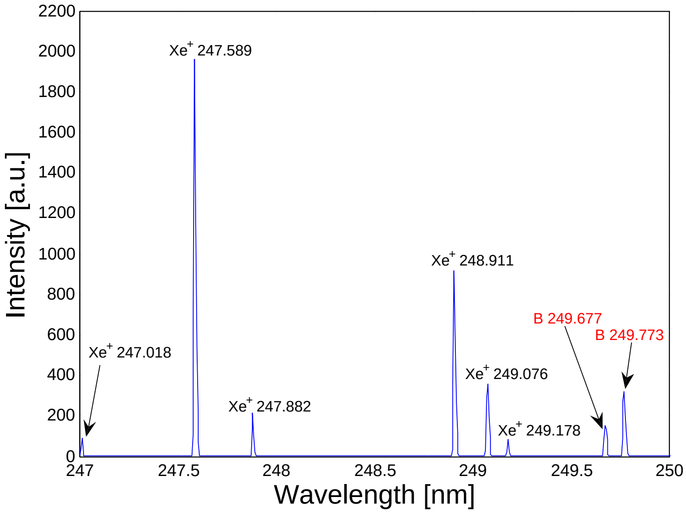

Figure 6: BHT-200 Hall thruster measured spectrum of 247-250 nm wavelength region

for increasing discharge voltage. The figure shows that in comparison to the change in the Boron emission intensity, the single ion emission intensity is much smaller.

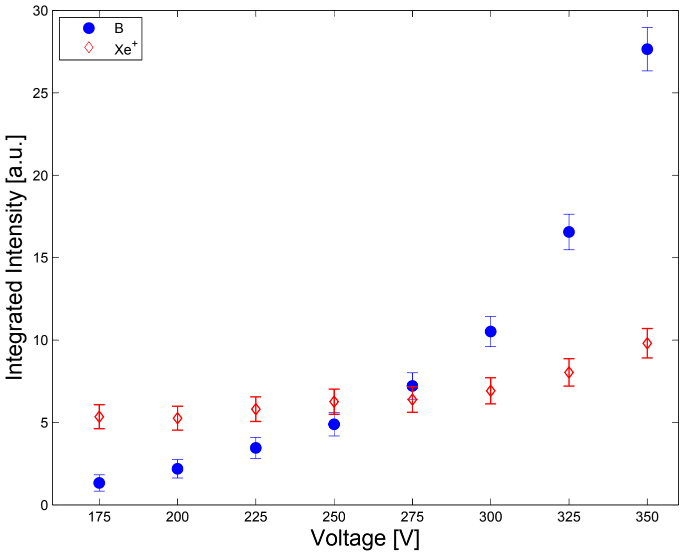

Figure 7: Comparison of neutral Boron and singly-charged ion emission lines total integrated intensities for varying discharge voltage

One explanation for the dramatic increase in the Boron erosion rate for increased discharge voltage is that the ions impacting the thruster ceramic walls have much higher energies for high-voltage cases. Experiments of Boron Nitride bombarded by Xe^+ show that sputtering yield increases as the ion energy impinging on the surface increases[5, 22, 23, 24].In addition, it is expected that the plasma temperature increases as the discharge voltage is increased.Such an increase in plasma temperature would increase the electron induced excitation collision rate, thus the emission intensity. In addition, increased plasma temperature would result in an increase in the wall temperature. This could be an additional factor for the increased Boron emission intensity.

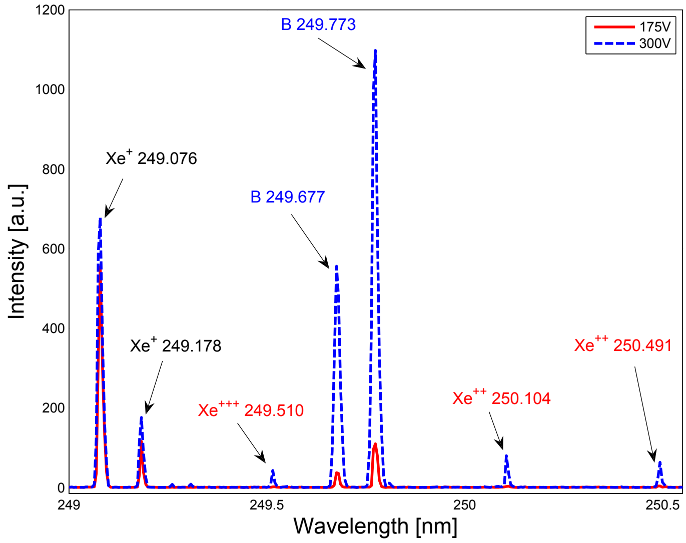

Figure 8: BHT-200 Hall thruster measured spectra comparison for the 175 V and 300 V discharge voltages in the 249.0-250.55 nm wavelength region

When the thruster is operated at high discharge voltages, emission from the Xe^{++} and Xe^{+++} species are also observed. Figure 8 shows the comparison of the emission spectra for the 175 V and 300 V discharge voltage cases in the 249.0 nm to 250.55 nm wavelength region. For the 175 V case, the discharge current was 0.75 A and for the 300 V case the discharge current was 0.85 A.

As observed from Figure 8, for the 175 V discharge voltage case, the Xe^{++} and Xe^{+++} lines are not visible. However, for the 300 V case, emission lines from these species are clearly observed. In addition, in comparison to the 175 V case, the 300 V case has significantly higher Boron line emission intensities. As seen from the presented portion of the spectrum, for the 300 V case, the Boron emission lines become the dominant lines, which suggests a large increase in the Boron number density in the region of radiation collection, thus pointing to a significant increase in wall erosion rate. One other observation is that the intensities of the Xe^+ emission lines do not show significant variation as the discharge voltage is varied from 175 V to 300 V as discussed earlier in this section.

The significant increase in the Boron erosion rate for increased discharge voltage can also be attributed to the increase in the number of double ions. According to Cheng[2], double ions could have significant effect in the sputtering of the thruster ceramic walls. Since double ions have roughly twice the energy compared to the single ions, even a small increase in the double ion fraction results in a significant increase in the sputtering rate[2]. Figure 9 shows the variation in the integrated emission intensity of the 250.104 nm Xenon double ion line for varying discharge voltage. As seen from the figure, the double ion emission intensity sharply increases for increasing discharge voltage above 250 V pointing to an increase in the double ion density. As observed from the figure, the double ion emission trend shows similarities to that of the Boron emission intensity.

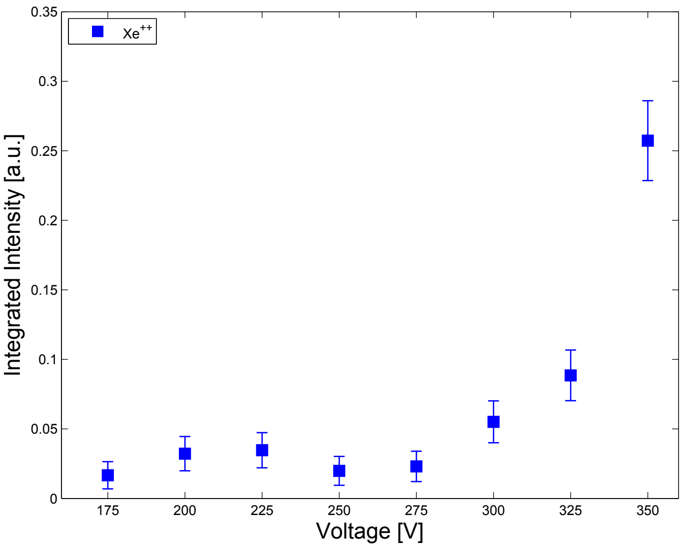

Figure 9: Xe^{++} 250.104 nm emission line total integrated intensity for varying discharge voltage

3.2. Anode Propellant Flow Rate Scan

In order to observe the variation in the emission intensity of the Boron lines, the anode propellant flow rate was varied from 7.5 sccm to 10.0 sccm with 0.5 sccm increments and the emission spectra in the 245-255 nm wavelength region were measured. Figure 10 shows the variation in the integrated emission intensity for the two Boron lines and 248.911 nm Xenon single ion line for varying Xenon propellant flow rate to the anode. As seen from the figure, for the given thruster operational parameters, the Boron emission intensity first drops sharply as the anode flow rate is increased from 7.5 sccm to 8.5 sccm. The minimum emission intensity occurs at 8.5 sccm. Then, as the flow rate is increased the Boron emission intensity linearly increases with the increased propellant flow rate. Thus, the measurement results show that wall erosion is lowest at the nominal flow with increasing erosion at both higher and lower flows. This observation differs from the observations reported by Hargus et al.[12], where a linear increase in the Boron line emission is reported for increased flow rate.

As seen in Figure 10, the Boron neutral and Xenon single ion emission line intensities vary in a similar fashion as the flow rate is varied. Similar to the Boron intensity, the Xenon single ion emission intensity is minimum for an anode flow rate of 8.5 sccm. Furthermore, the ratio of the Xenon ion and Boron emission line intensities shown in Figure 10 remains constant to within 5%.

The reduction in the ion emission intensity in the region of observation around the thruster ceramic nose cone can explain the reduction in the Boron emission lines. Since the ion emission intensity is proportional to the ion density in the nose cone

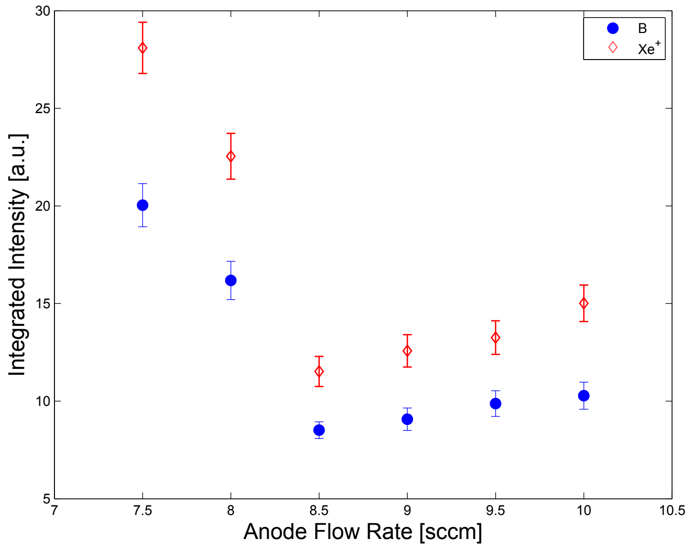

Figure 10: Comparison of neutral Boron and singly charged Xenon ion emission lines total integrated intensities for varying anode propellant flowrate

region, a reduction in ion emission implies a reduction in ion density in the nose cone region, thus a reduction in the number of ions causing the sputtering of Boron-Nitride ceramic material, and a reduction in the Boron emission intensity. However, the ion emission intensity also depends on the local electron temperature, thus the effects of the anode propellant flow rate on the plasma electron temperature need to be better understood.

One possible explanation, for the observation of minimum line emission in the nose cone region occurring for 8.5 sccm flow rate, lies with the fact that the magnetic field profile for this thruster is optimized for 8.5 sccm anode flow rate. At this flow rate, it is likely that the thruster ions move more axially and thus less ions hit the nose cone. Another observation is that for low flow rates, the thruster operation is less stable and flickering is observed. When the flow rate is reduced below 7.0 sccm, the thruster shuts off. Even at a flow rate of 7.5 sccm, strong flickering is observed in the discharge. This might also be a possible explanation for the significant increase in the emission intensity at this flow rate as flickering might cause more ions to move towards the nose cone region.

3.3. Magnet Coil Current Scan

In order to observe the dependence of the Boron emission intensity on the magnetic field intensity, the current to the thruster magnet coils was varied from 0.75 A to 1.25 A with 0.05 A increments and the emission spectra in the 245-255 nm wavelength region were measured. The radial magnetic field varies approximately linearly with magnet current[12]. Figure 11 shows the variation in the integrated emission intensity for the two Boron lines and 248.911 nm Xenon single ion line for varying magnet current. As seen from the figure, for the given thruster operational parameters, the Boron emission intensity increases with increased magnetic field intensity. This observation is different from the one observed by Hargus et al.[12]. In that study[12], it is reported that the minimum Boron emission is measured for the nominal (1.0 A) magnet current. According to Hargus et al.[12], the magnetic field is optimized for particular conditions for this thruster and variation in magnetic field intensity would lead towards increased erosion. However, in this study, the measurements showed that the minimum Boron emission intensity occurs for the lowest magnetic field case. From Figure 11, it is observed that the Boron neutral and Xenon single ion emission line intensities vary in a similar fashion for varying magnetic field. Thus, for the set magnetic field profile, the number density of ions in the nose-cone region determines the density of the sputtered Boron atoms, thus the erosion rate. One possible explanation, for the reduction in Xenon ion density in the nose cone region for the reduced magnetic field intensity, would be that lower magnetic field causes a reduction in the ionization rate as the electrons may not be well magnetized to have sufficient time to cause enough ionizing collisions before being lost to the anode. Another possible explanation is that varying magnet current would change the magnetic profile in addition to changing its intensity and thus would alter the location of the ionization region.

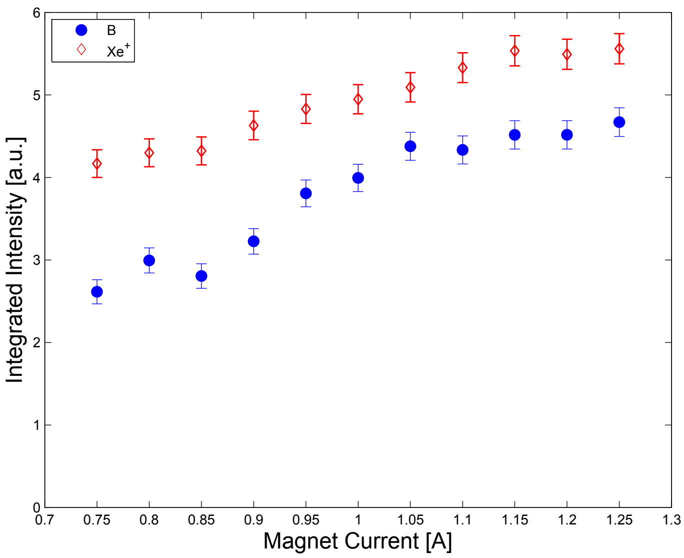

Figure 11: Comparison of neutral Boron and singly charged Xenon ion emission lines total integrated intensities for varying magnet current

4. Summary and Conclusion

The BHT-200 Hall thruster has insulator annular walls made of Boron-Nitride (BN) ceramic material. The erosion of the walls is a major life limiting factor for Hall effect thrusters. In order to assess the effect of the BHT-200 Hall thruster operational parameters on the ceramic wall erosion rate, spectral measurements of the neutral Boron atom emission lines at 249.677 nm and 249.773 nm are conducted. The measured spectra in the 245-255 nm wavelength region are presented.

The thruster discharge voltage was varied and the emission intensity of the Boron lines were recorded. The trends showed that for increased discharge voltage the Boron emission line intensity increases. Especially for higher voltages than the nominal operational voltage of 250 V, the erosion rate seems to increase significantly. This could be due to the higher energy ions hitting the the thruster wall as a result of the increased potential drop between the anode and the cathode. The increase in the double ionization fraction is another major factor for the increased erosion rate for higher voltage cases. The effect of increased wall temperature can also be a factor for high erosion for high voltage operational regime.

In addition, the thruster anode propellant flow rate was varied. The results show that the Boron emission intensity is lowest for an anode flow rate of 8.5 sccm. For lower flow rates the Boron emission intensity increased sharply. The reasons for this behavior is not well understood. However, one possible explanation lies with the fact that the magnetic field profile for this thruster is optimized for 8.5 sccm anode flow rate. In the region of observation around the thruster nose cone, the Xenon single ion emission intensity showed similar behavior to the Boron emission intensity for the flow rate variation. The Boron line behavior is therefore clearly driven by that of the Xe^{+} population.

The effect of the magnetic field on the Boron emission intensity was also studied. The spectral measurements showed that increased magnetic field intensity results in an increase in the Boron emission intensity. Boron emission intensity shows very similar behavior to the Xenon single ion emission intensity as the magnetic field is varied.

The spectral measurements showed that Boron 249.677 nm and 249.773 nm lines can be used to monitor the relative erosion rates for various regimes of operation in SPT type Hall thrusters.

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