Optical Spectra of Oxygen, Nitrogen, and Argon Gases Using the NL-ATS RF Atom Source

Optical spectra of the NL-ATS60 RF Atom Source were systematically recorded for various process gases, with parameters including gas flow rates and RF power levels varied across multiple test conditions. These measurements enabled detailed characterization of plasma behavior and emission characteristics of the source for different gases under varying operational conditions. The spectra were analyzed to understand the influence of gas composition, flow rates, and RF power on the source's performance and emission profile, providing critical insights into optimizing source efficiency and stability.

Experimental Conditions

The measurements were conducted using a standard NL-ATS60 RF Atom Source, equipped with a 37 x 0.5 mm hole quartz plate for plasma generation and optical emission. An Ocean Optics USB2000 optical spectrometer was deployed for spectral acquisition, mounted at the back view port of the source to capture emission data across a wide spectral range. All experiments were performed within a sealed box chamber under a base pressure of 5×10^{-6} mbar, ensuring minimal contamination and a controlled vacuum environment. This setup provided a stable and reproducible platform for evaluating the optical spectra of different gases under varying operational conditions.

Results

Optical emission spectra for Oxygen, Nitrogen, and Argon gases, recorded at varying gas flows and RF power levels, are presented in Figure 1. The observed spectral peaks correspond to characteristic emission lines resulting from processes such as ionization, dissociation, and recombination of the gas molecules. Detailed theoretical models and literature data on ionization optical peaks for these gases are available from the NIST Atomic Spectra Database.

1. For oxygen, the most intense spectral line at 777 nm exceeds the saturation limit of the diode detector

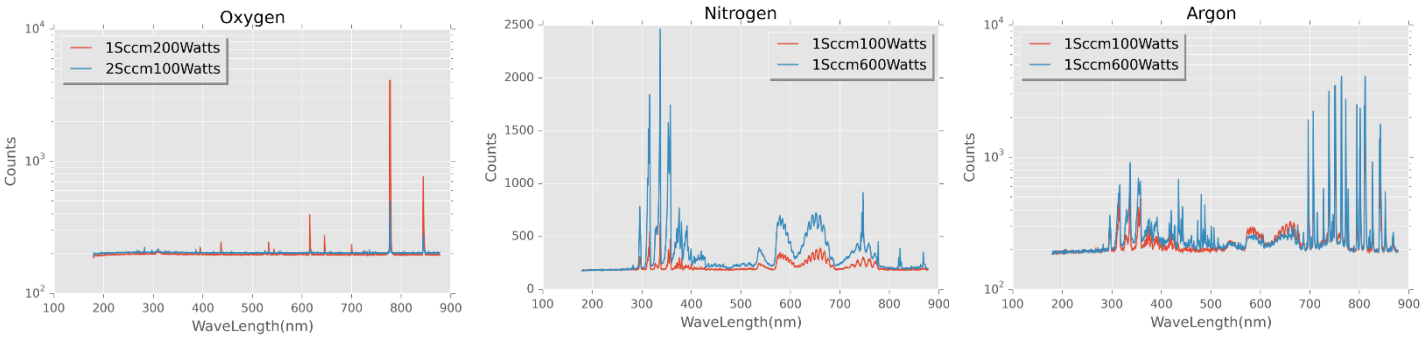

Figure 1 : Optical spectrum of Oxygen, Nitrogen , Argon at different gas flows and power RF Forward Power

in the Ocean Optics USB2000 spectrometer, indicating strong emission. A comparison of the oxygen spectrum with theoretical values from the NIST database reveals that these peaks are predominantly due to the formation and recombination of oxygen radicals (O)—an excited state of the O_2 molecule—which consists of neutral single O atoms rather than the diatomic O_2 molecules. The intensity variation of the oxygen peaks at 645 nm and 845 nm with different gas flow rates and RF power settings is shown in Figure 2. At low gas flow rates (below 20 sccm), the intensity fluctuates randomly, whereas at higher gas flows (above 20 sccm), a decrease in intensity is observed with increasing gas flow and a corresponding increase with higher RF power.

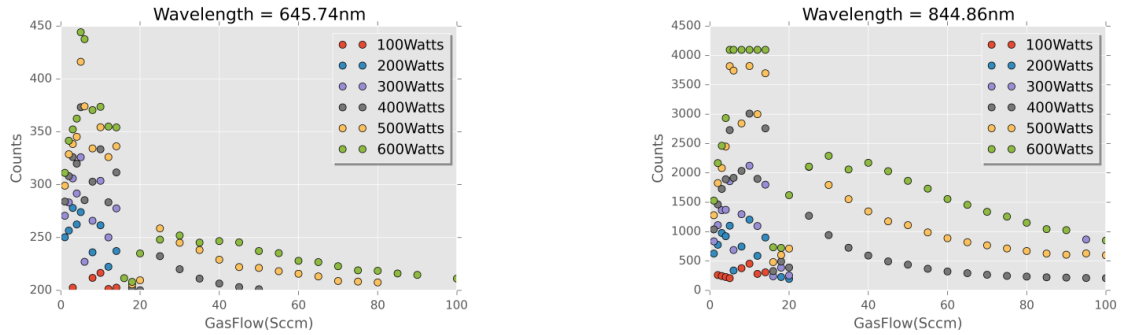

Figure 2 : Change in the intensity of the peak at 645nm (left) and 844nm (right) for Oxygen at different gas flows and power

2. For nitrogen, comparison of the optical peaks in the NL-ATS60 RF Atom Source nitrogen spectrum with the NIST theoretical values indicates that most of the observed peaks correspond to single-charged nitrogen ions (N^+), particularly those from the second excited state. Peaks above 600 nm are attributed to the first excited state of nitrogen. The intensity variation of the nitrogen peaks at 315 nm and 356 nm with respect to changing gas flow and RF power is presented in Figure 3. At low gas flows (below 20 sccm), the intensity decreases as the gas flow increases but shows an increase with higher power. At higher gas flows (greater than 20 sccm), both gas flow and RF power increase the intensity, demonstrating enhanced ionization at these conditions.

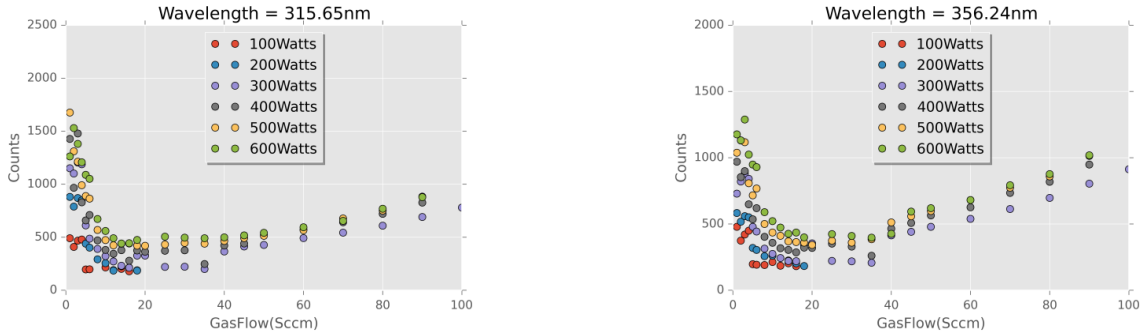

Figure 3 : Change in the intensity of the peak at 315nm (left) and 356nm (right) for Nitrogen at different gas flows and power

3. For argon, analysis of the NL-ATS60 RF Atom Source argon spectrum against theoretical peak positions from the literature indicates that the majority of the observed peaks are attributed to the first excited state of argon. The intensity variation of the argon peaks at 336 nm and 707 nm with varying gas flow and RF power is shown in Figure 4. At low gas flow rates (below 20 sccm), the intensity decreases with increasing gas flow and increases with RF power. At higher gas flows (greater than 20 sccm), a plasma strike across the entire chamber is observed, leading to a significant increase in intensity.

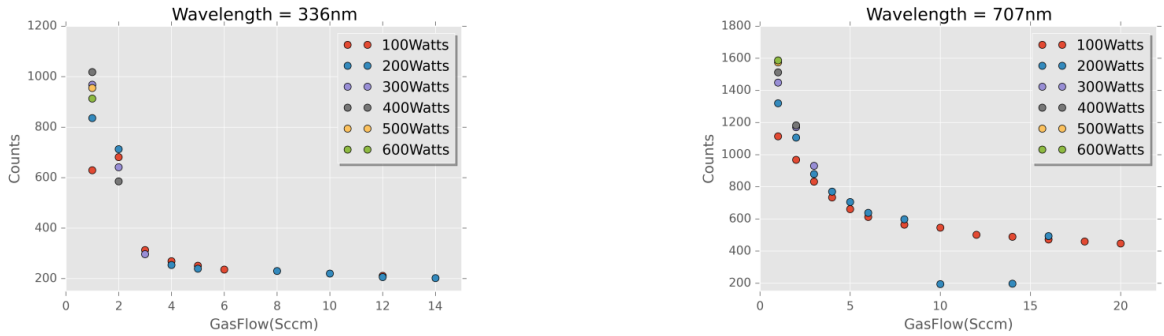

Figure 4 : Change in the intensity of the peak at 336nm (left) and 707nm (right) for Argon at different gas flows and power

The ratio of emission intensities between neutral atoms (first excited state) and single positively charged ions (second excited state) is highly dependent on both gas flow and RF power, as evidenced by the varying trends across different gases.

Conclusion

The optical emission spectra recorded for Oxygen, Nitrogen, and Argon gases under varying gas flows and RF power settings demonstrate distinct emission characteristics that are heavily influenced by the underlying plasma processes, including ionization, dissociation, and recombination.

i. For oxygen, the prominent peaks at 777 nm, exceeding the detector saturation limit, indicate significant emission due to oxygen radical recombination. The observed intensity variations, with a marked decrease at higher gas flows and increase at higher RF powers, suggest the importance of optimizing both parameters to maintain stable plasma conditions.
ii. In the case of nitrogen, the spectral peaks in the 315 nm and 356 nm ranges can be attributed primarily to single-charged nitrogen ions (N^+) in the second excited state, with intensity changes following similar trends to oxygen—decreasing at lower gas flows and increasing with both higher gas flow and RF power, especially at flows exceeding 20 sccm.
iii. For argon, the emission peaks in the 336 nm and 707 nm regions predominantly arise from first-excited argon atoms. At lower flow rates, the intensity decreases with increasing gas flow, while the intensity increases with power. Notably, at higher gas flows (greater than 20 sccm), a full plasma strike across the chamber occurs, resulting in a dramatic increase in emission intensity.

The emission intensity ratios between neutral atoms (first excited state) and ionized species (second excited state) exhibit clear dependencies on both gas flow and RF power, underscoring the importance of precise control over these parameters for optimal plasma generation and source performance.

In summary, these findings provide crucial insights into the plasma dynamics of oxygen, nitrogen, and argon gases under varying experimental conditions, aiding in the optimization of the NL-ATS60 RF Atom Source for diverse material processing applications. Further investigation into plasma stability and ionization efficiency at extended flow ranges will be essential for refining source performance and expanding the operational envelope of RF-driven atom sources.