# The Population Densities of Argon Metastable Levels

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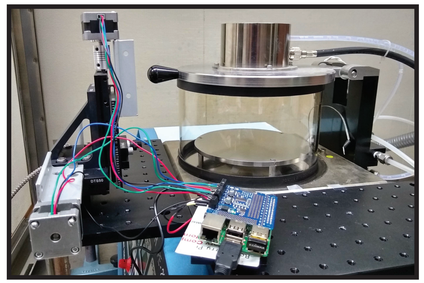
## Introduction

Over the past few decades, the interest in low temperature, non-equilibrium plasmas used for plasma processing has been increasing.
It has been shown that low temperature, high-density plasma sources generated using radio frequency powers can help us understand the most attractive properties for plasma etching and cleaning plasma.

Even though these discharges are widely used, their fundamental properties are still being explored. Therefore, developing models and experiments to improve understanding, performance, and control of these processing plasmas is much needed. Most of the time it is necessary to apply non-intrusive, spectroscopic techniques. In this study, the optical emission spectroscopy (OES) method is used to obtain the main properties of argon plasma. OES is useful only when detecting species that are excited energy levels higher than ground metastable states.

## Experimental Setup

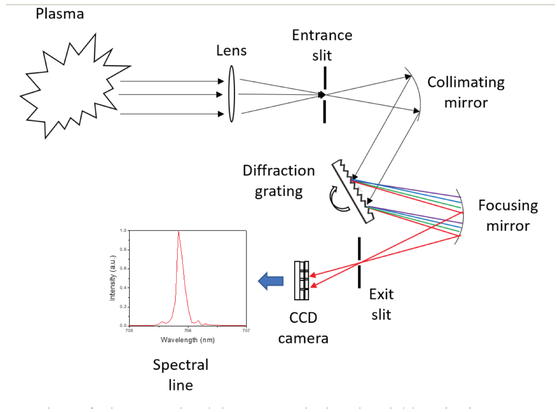
Radio Frequency Argon Plasma



Detection system driven by Raspberry Pi computer

RF frequency – 13.56 MHz
Pressures: 15 – 50 mTorr
Powers: 15 – 100 W

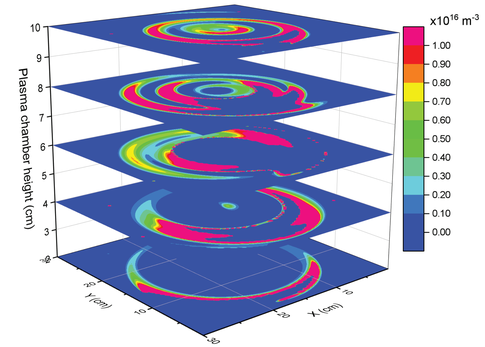
Pressure 30 mTorr
Power 50 W



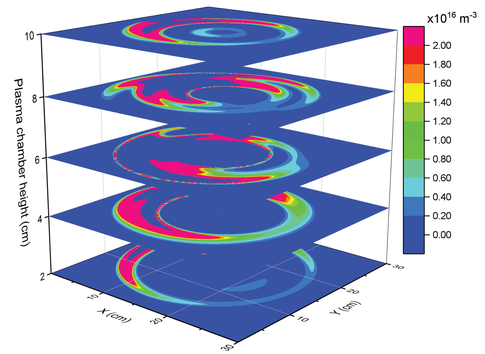

2 stepper motors – submillimeter precision
Avasoft spectrometer – synchronized with the motors

## Results

Spatial distributions of population densities of resonant states $1s_4$ and $1s_5$




$2p_3$ - Population density at 738nm and 706nm




$2p_6$ - Population density at 800nm and 763nm

## Metastable and Resonant Levels

Selection rules: $\Delta J = 0, \pm 1$

Metastable levels: $1S_4$ and $1S_5$

Correction for the reabsorption:

$\Phi$ : Between 0.75 -0.8

$$\Phi = \gamma_{ij} A_{ij} N_i$$

Escape factor: $\gamma_{ij} \approx \frac{2 - e^{-\frac{k_{ij} l}{1000}}}{1 + k_{ij} l}$

Absorption coefficient k (Doppler broadened line):

$$k_{ij} = N_j \left( \frac{\lambda_{ij}^3}{8\pi^{\frac{3}{2}}} \right) \frac{g_i}{g_j} A_{ij} \sqrt{\frac{m}{k_B T_g}} = C_{ij} N_j$$

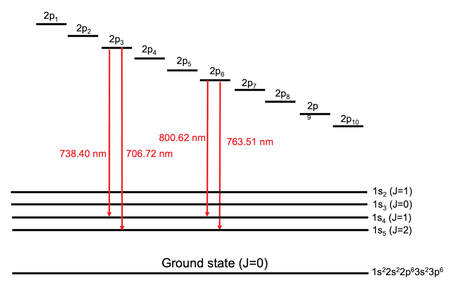
$$C_{ij} = \left( \frac{\lambda_{ij}^3}{8\pi^{\frac{3}{2}}} \right) \frac{g_i}{g_j} A_{ij} \sqrt{\frac{m}{k_B T_g}}$$

Ratio of spectral line intensities:

$$\frac{\Phi_{12}}{\Phi_{13}} = \frac{\gamma_{12} A_{12} N_1}{\gamma_{13} A_{13} N_1} = \frac{\gamma_{12} A_{12}}{\gamma_{13} A_{13}}$$

$$\frac{\Phi_{12}}{\Phi_{13}} = \frac{\frac{2 - e^{-\frac{k_{12} l}{1000}}}{1 + k_{12} l} A_{12}}{\frac{2 - e^{-\frac{k_{13} l}{1000}}}{1 + k_{13} l} A_{13}} = \frac{\frac{2 - e^{-\frac{N_2 C_{12} l}{1000}}}{1 + N_2 C_{12} l} A_{12}}{\frac{2 - e^{-\frac{N_3 C_{13} l}{1000}}}{1 + N_3 C_{13}} A_{13}}$$

Spectral Lines Transitions




## Conclusion

In this experiment, the optical emission spectroscopy (OES) is useful only when detecting species that are higher than the ground and metastable levels.

To calculate the metastable levels, we can use the fact that the population densities depend on the spectral line intensity and photon emission rate (photon flux). We can take the ratio of two sets of spectral lines from photons emitted from two different level upper energy levels to the same two lower energy levels, we'll have a system of two equations with two unknowns. This system has a unique solution and can be solved numerically. We were able to calculate the spatial distributions of population densities of resonant $1s_4$ state and metastable $1s_5$ state using the two $2p_3$ lines at 738 nm and 706 nm and the two $2p_6$ lines at 800 nm and 763 nm.

## References and Acknowledgement

[1] J. B Boffard et al. Plasma Sources Sci. Technol. 18 035017 (2009).
[2] M. P. Freeman and S. Katz, J. Opt. Soc. Am. 53 (1963) 1172.
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