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THE CHANGE OF LINE RATIO OF OPTICAL EMISSION SPECTRA WITH TIME FOR INDUCTIVE RADIO FREQUENCY ARGON DISCHARGE AT LOW PRESSURE

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ABSTRACT

In this study, inductive radio-frequency (RF) argon (Ar) discharge and afterglow downstream discharge at low pressure were investigated with optical emission spectroscopy (OES). Spectral lines recorded with OES measurements were detected in the wavelength range of 650-900 nm. For all measurements, a spectrum line that remained at approximately the same value was taken as the value of the reference wavelength throughout the study. The changes in the optical emission spectrum ratios of the inductive RF Ar discharge and the afterglow downstream discharge with respect to time were compared. As a result, it was reported that some transitions for both regions were to be increased in time. The transitions in time for some wavelengths (738.39, 751.47, 772.42, 801.48, 810.37 and 842.46 nm) have been approximately improved between 20% and 34% for discharge zone. Also, it can be increased for wavelength of 801.48 nm in afterglow downstream discharge region (32.55%).

Keywords: Discharge in vacuum, Ionization of plasma, Plasma properties, High frequency and RF discharge

1. INTRODUCTION

In recent years, the high-density plasmas can be improved as the inductive coupled RF discharge at low pressure. Inductive coupled plasmas sources have been researched for over a century. Because the inductive RF discharge plasmas (low temperature) at low pressure can be used for the commercial purpose and researches. A coil surrounds the plasma chamber. A radio frequency magnetic flux is generated by the currents in the coil. RF magnetic flux will penetrate the plasma zone. According to Faraday's law, a solenoid RF electric field will be induced by the time-varying magnetic flux density. The free electrons will be accelerated by a solenoid RF electric field and the discharge will be sustained. Non-local thermodynamic equilibrium (non-LTE) plasmas can be produced with inductively coupled plasmas at low pressure [1].

Descoeudre et al examined the effects of the plasma parameters via optical emission spectroscopy (OES) and calculated the plasma temperature and density [2]. Canal et al has used the modified Saha equation in order to obtain the electron temperature of Ar inductive RF discharge at low pressure [3]. Relative intensities of OES lines were used to define the kinetic temperature of electrons, and to specify the number density of particles that emerged in the plasma [4]. When gas is exposed to an electric field under low pressure at room temperature, a plasma can be generated. In this case, some optical properties can be determined with OES from gases in the glow and afterglow downstream discharges [5]. If we look at other study, one of them is that the capacitively coupled RF Ar discharge and afterglow downstream discharge have been analyzed using numerical modelling and the modified Boltzmann method [6]. While the plasma includes very much particles, the afterglow downstream discharge only occurs in stable and metastable particles. Also, the positive ion densities are seldom determined by OES, since ionic emission lines in low temperature plasmas are generally weak. However, OES gives the density of the electrons under certain conditions and in certain plasmas and the density of the electrons are equal to the positive ion density.

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The study is outlined as follows: The introduction part of this study was given in sect. 1, and the experimental setup were expressed in sect. 2. Plasma are determined by the results of spectral analysis in sect. 3. The importance of this study is given in conclusion.

2. EXPERIMENTAL SETUP

First, in this study; the initial test parameters such as gas type, gas flow rate, tube material and size, plasma generation method (capacitive or inductive), RF power, and integration time of spectral measurements were determined. Total measurement period for the experiments was 30 min and the measurements were performed in every five minutes after the first minute.

Ar discharge and afterglow downstream discharge are generated in inductive RF discharge system (Figure 1). The plasma tube is a cylindrical quartz glass vacuum chamber. Its length and diameter are 50 and 6 cm, respectively. This includes stainless steel flanges in 6 arms and it is kept as perpendicular (for high intensity). Pure Ar gas is sent from the top of chamber. The mechanical vacuum pump was operated to evacuate the plasma chamber down to 10^{-4} mbar. Vacuum pump was connected to Edwards RV8 the bottom of tube. The pressure was initially obtained 6.4×10^{-3} mbar. Pressures of the plasma chamber varied from 0.07 mbar to 1.90 mbar during gas inlet. The values of Ar flow rates were adjusted between 0.05 and 0.20 L/min using mass stream flowmeter (M + W instrument).

Advanced Energy RF matching box and Cesar generator are used as power supply in the inductively system. Solenoid with 8 turns at the top of the chamber is connected to power supply. The height and diameter of the solenoid are 8 and 6.5 cm, respectively. Using RF generator with 13.56 MHz and automatic impedance circuit, the discharge was generated at the top of the tube via the coil in the chamber. The pure Ar discharge was generated by RF powers as 100, 160 and 200 W. The integration time for spectra is 5 ms.

Our system consists of two parts. First one is the discharge region containing active neutral particles and the other is the afterglow downstream discharge zone, in which the particle types form or disappear. The measurements of OES for the resulting radiation of discharge and afterglow downstream discharge of pure Ar were realized by Ocean Optics HR2000+. Figure 1 shows a plasma state with large spatial variations. However, the radiations of discharge and afterglow downstream discharge were recorded from A and B points as seen from Figure 1.

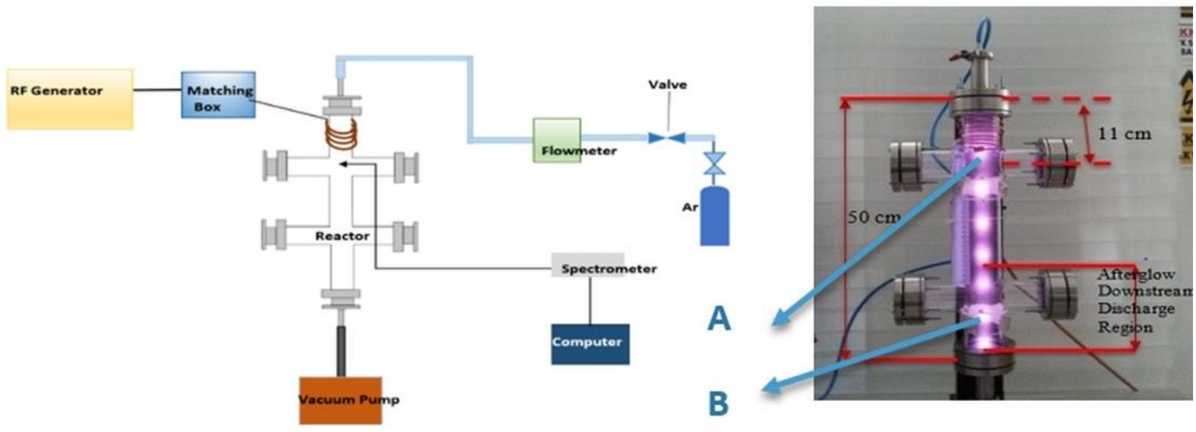


Figure 1. The experimental setup and photograph of discharge and afterglow downstream discharge region in inductive RF vacuum chamber

3. RESULTS AND DISCUSSION

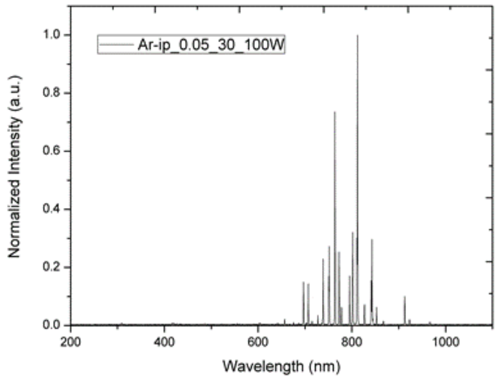
The photograph of the discharge in Figure 1 indicates that the discharge parameters are strongly structured in space. As seen in Figure 1, optical emission spectral measurements have been taken from two points which are closest to regions of the discharge and far away regions of the discharge. These measurements show an axial dependence along the discharge. Therefore, the measurements for two points in the quartz chamber have been compared each other.

Wavelengths of spectral lines for pure Ar discharge are determined from optical emission measurements. In addition, they are found from the standard data of National Institute of Standards and Technology (NIST) for each peak as seen in Table 1. The upper energy levels can be seen in Table 1. As seen from the results of OES measurement, the spectral lines have been recorded in the range 696 - 912 nm. Spectra are normalized as in Figure 2.

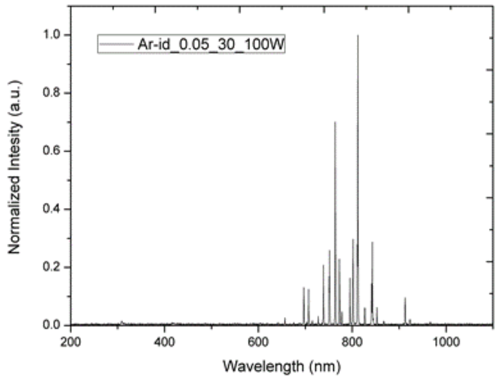
Table 1. Spectral Lines of Ar with OES [7]

Wavelengths (nm)	Ion	E_p (eV)
696.54	Ar I	13.328
706.87	Ar I	14.848
738.39	Ar I	13.302
750.39	Ar I	13.480
751.47	Ar I	13.273
763.51	Ar I	13.172
772.42	Ar I	13.328
794.82	Ar I	13.283
801.48	Ar I	13.095
810.37	Ar I	13.153
811.53	Ar I	13.076
826.45	Ar I	13.328
842.46	Ar I	13.095
852.14	Ar I	13.283
912.30	Ar I	12.907

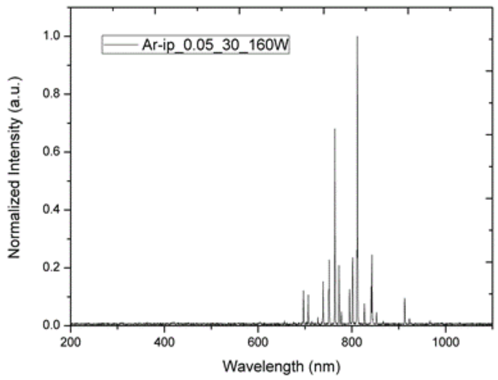
According to the optical emission spectra, the intensity of spectral line at wavelength of 811.53 nm in the discharge and afterglow downstream discharge is higher than other spectral lines. The highest intensity in the spectral lines obtained under different pressure, power and flow belongs to the wavelength of 811.53 nm. It is obvious that the intensity of spectral line of the wavelength of 842.46 nm in the afterglow downstream discharge is reduced. The energy of particles in discharge is transferred each other. This energy increases with the increasing amount of particle. Hence, this situation can cause a decrease in the electron temperature.



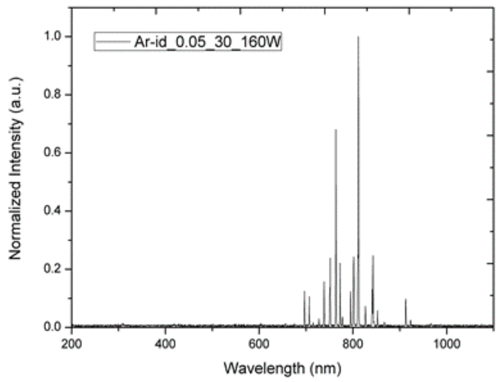
(a)



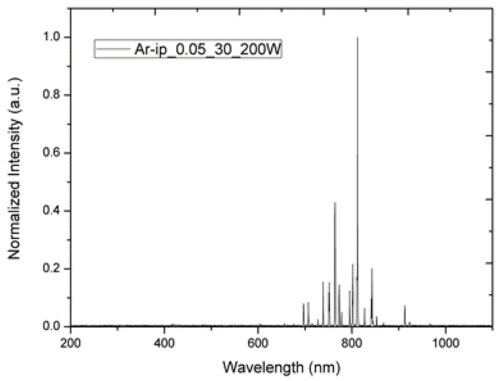
(d)



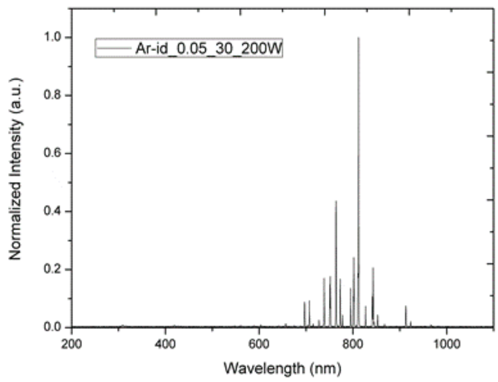
(b)



(e)



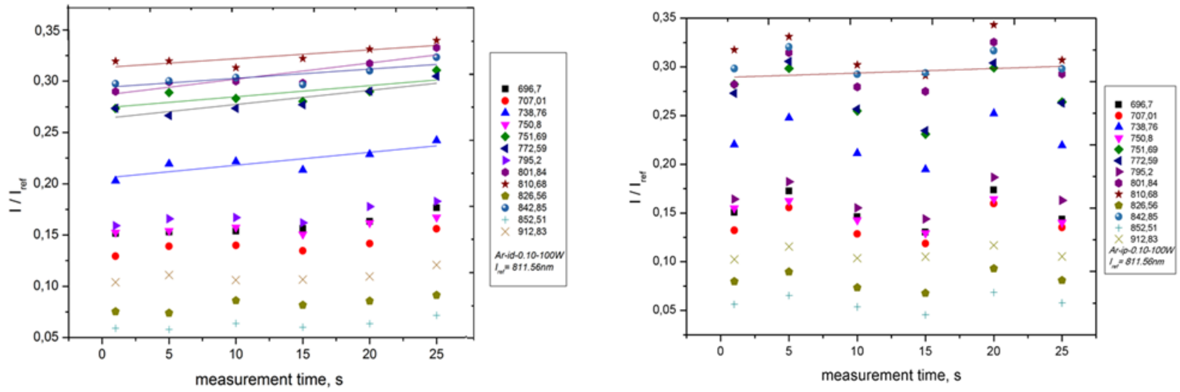
(c)



(f)

Figure 2. Normalized spectra for 0.05 L/min flow rate of inductive Ar discharge at (a) 100 W, (b) 160 W, (c) 200 W and afterglow downstream discharge at (d) 100 W, (e) 160 W (f) 200 W

According to the raw results of OES measurements, in Figure 3, the variation of rate of spectral lines $({}^{I}/_{I_{ref}})$ over measurement times for inductive discharge and afterglow downstream discharge have been compared. In particular, the same flow and power data are restricted to selecting from intensity rates. In this study, the reference wavelength (I_{ref}) is chosen as 811.53 nm (arbitrary reference line). The reason is that the change in wavelength of 811.53 nm remains almost the same for all measurement times. Also, the intensity of this wavelength is almost the highest value in all spectra. According to a reference value, intensity rates ($^{I}/_{I_{ref}}$) versus measurement time (t) is compared for the first time. G. Musa et al reported the M effect in gas mixtures [8]. The changes of different wavelengths in different gas mixtures have been just reported. Also, the optical characteristics for capacitively and inductively helium discharges were also defined by M. Tanışlı and N. Şahin. The electron temperature of capacitively and inductively radio frequency discharges of helium is estimated using the spectral lines obtained from optical emission spectra. It is determined for the first time that the line ratio rates are changing according to the measurement time for helium at low pressure [9]. This study supports a comparison for OES of capacitive and inductive discharges for He in detail and shows the change of line ratio with time. In addition to this, the discharge stability was estimated by monitoring the changes of the CN emission upon the discharge power [10]. This study shows the linearity between the applied voltage and emission intensity. S Siepa et al. shows that the line-ratio method is applicable for pure Ar discharges and the line-ratios are determined in a purely experimental investigation to enhance the accuracy of the method [11].



(a) **(b)**

Figure 3. ($^{I}/_{I_{ref}}$) versus measurement time (a) Discharge (b) Afterglow downstream-discharge (I_{ref} = 811.53 nm, for 0.10 L/min and 100 W)

4. CONCLUSIONS

The inductive RF discharge and afterglow downstream discharge of Ar are investigated by means of OES and their characteristics have been determined. Similarity and differences between the discharge and afterglow downstream discharge regions have been described. According to initial parameters, the optical properties of inductive RF afterglow downstream discharge of pure Ar at low pressure have been obtained in detail. In the literature, there are lots of works on the use of especially the collisional radiative model of the RF Ar discharge at atmospheric pressure. However, there are still unknown parts about the RF Ar discharge at low pressure. The novelty of this study is principally to determine the time change of the line ratio rate for the RF Ar discharge and afterglow downstream discharge at low pressure.

The transitions in time for some wavelengths (738.39, 751.47, 772.42, 801.48, 810.37 and 842.46 nm) have been approximately improved between 20% and 34% for discharge zone. Also, the intensity of the spectral lines at the wavelength of 801.48 nm can increase in the afterglow downstream discharge region (32.55%). These results can indicate a change for discharge type, the time variable parameter (the range of minute) and the relative intensities of the transition. It is seen that some transitions can be intensified over time. The exchange of large results may be obtained in small unobservable changes. Also, the plasma begins to change slowly over time.

The laser wavelength charts show the common types of lasers, and major wavelengths associated with them. According to this list, the wavelengths find here correspond to the region in the specified range. These could be used as a new wavelength laser source. Thus, the new laser types to be added to the table can be produced. A new wavelength that changes in the afterglow downstream region may be considered as a monochromatic laser source. In the discharge zone, the intensity of some peaks, except for certain peaks, tends to increase. For a region just above the visible region, it can be thought as a double or triple-beam laser sources in a single discharge tube.

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