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RAPID COMMUNICATION

VUV emission from a novel DBD-based radiation source

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Abstract

In all previous works on the dielectric barrier discharge (DBD), the authors used two electrodes separated by one or more dielectric layers and a gas-filled gap between them. In this work a new DBD design is investigated, using ring electrodes (two or four) on the outside of a dielectric tube. The discharge inside the tube occurs as a result of the application of RF power (13.56 MHz). The VUV emission under high-pressure conditions for different gas mixtures is studied.

VUV emission at 130.3 and 121.5 nm (Lyman- α) is obtained by using an argon–oxygen mixture, and an argon (or neon)–hydrogen mixture, respectively. The emission spectra, the power density, the total power, the lifetime and the stability will be discussed.

1. Introduction

The dielectric barrier discharge (DBD) is very attractive for various industrial applications because it can provide non-equilibrium plasma conditions at about atmospheric pressure [1]. The dielectric layers covering the electrodes act as current limiters and prevent the transition to an arc discharge [2]. Typical dielectric materials used are glass, quartz, ceramics or polymers. The most interesting property of DBD is that the breakdown is initiated in a large number of independent current filaments with nanosecond duration.

For high pressure, and large diameters (few millimetres), the discharge operates in a streamer regime. In the streamer regime, the volume between the dielectric layers is filled with randomly distributed transient streamers. In this type of DBD, the plasma profile is Gaussian but it is difficult to form a homogeneous steady state plasma because the breakdown process itself is filamentary.

Hodoroaba *et al* [3] studied the effect of hydrogen in an argon glow discharge. He found that when the hydrogen is present even in small quantities in argon, not only are there significant changes in the emission line intensities, but also new spectral features such as emission bands of new compounds (hydrides of sputtered sample constituents). Also the discharge current was found to decrease with increasing hydrogen concentration [4]. Also when he added hydrogen

to argon the excitation of the hydrogen continuum appears to quench the population of the argon meta-stables (11.55 and 11.72 eV).

In this work, the DBD consists of a quartz or alumina tube and two ring electrodes wrapped around the tube [5]. We used argon–oxygen mixture or neon–hydrogen mixture in flow-through conditions. The DBD discharge works as a dynamic gas flow that means we have gas flow at the same time as the discharge act [6].

2. Experimental set-up

Figure 1 shows the schematic diagram for the DBD system used to study the VUV emission. The system consists of a vacuum

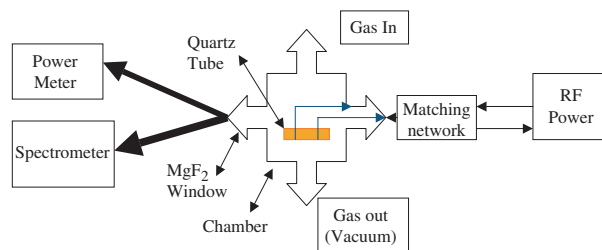


Figure 1. Schematic diagram for the DBD system.

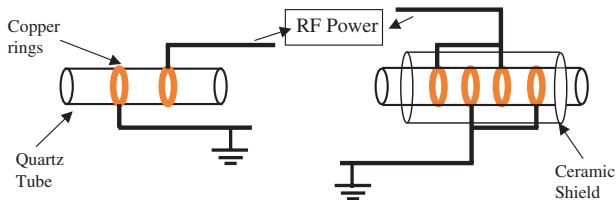


Figure 2. Schematic diagram of the DBD design.

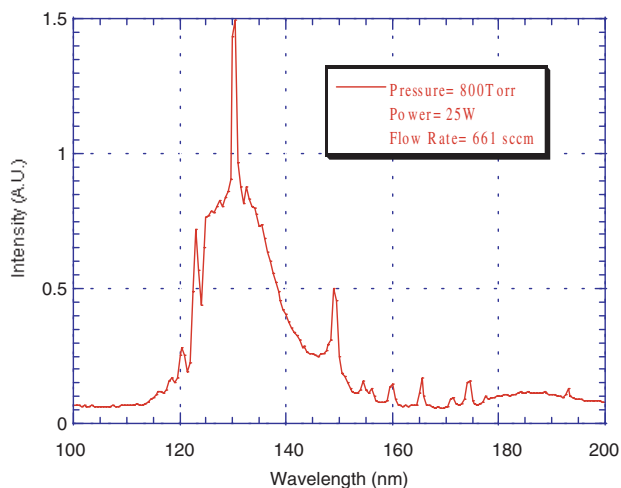


Figure 3. Spectra of argon gas.

chamber with one inlet and one outlet for gas, two windows (one is a MgF_2 window and the other is a glass window), one RF feed-through and a quartz (dielectric) tube connected to the RF feed-through by copper strip rings (two or four rings).

The chamber is connected to an RF generator (13.56 MHz) via a tuning matching network. The emission spectra are measured by a 0.2 m McPherson spectrometer (model 302) with 600 gmm^{-1} grating. The scanning step of the spectrometer is 0.1 nm. A semiconductor diode detector (model SXUV-100, from International Radiation Detector Inc.) is used to measure the emitted VUV power. A narrow band pass filter between the detector and the emission source was used. The transmittance of the filter is 15% for 121.5 nm (Lyman- α) and 18% for 130.3 nm.

Various inner diameters (2, 4, 5 mm) are used. One of the electrodes (copper sheet) is connected to the RF power supply and the other electrode is connected to ground. Figure 2 shows a schematic diagram [12] of the design used here.

The ring electrodes are isolated by ceramic material (the maximum temperature is 2500°F). The tube and the electrode are also covered by ceramic material to avoid generating a discharge outside the tube. A 13.56 MHz, 0–600 W RF power supply (model RF 5S) was used.

3. Results and discussion

In this work we will illustrate the emitted VUV spectra for argon–oxygen and neon–hydrogen mixtures at different pressures and RF powers.

The spectra of the radiation emitted by an argon discharge, measured here showed a small peak at 130.3 nm on the top of the second excimer continuum of argon. By adding the oxygen,

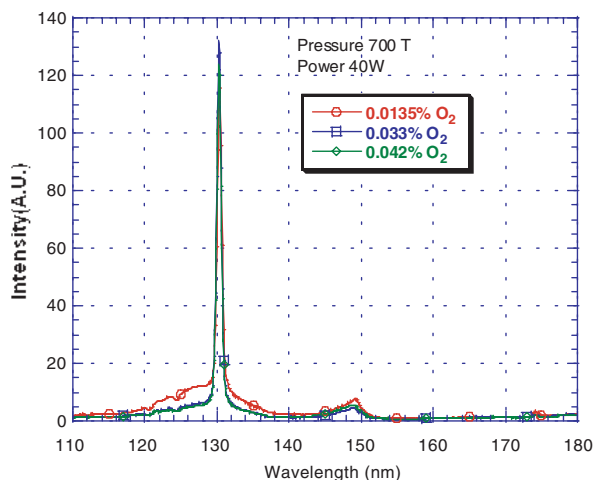


Figure 4. Emission spectra for argon–oxygen mixture at different ratios of O_2 .

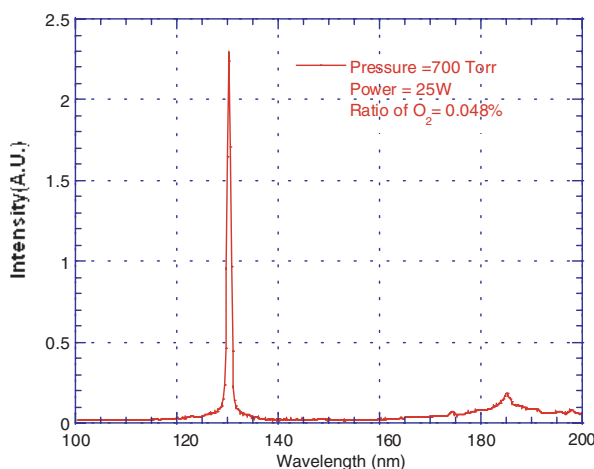


Figure 5. Argon–oxygen spectra at 0.045%.

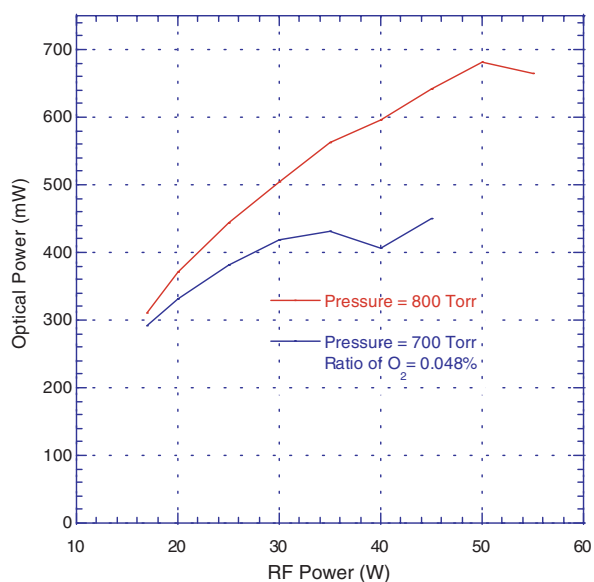


Figure 6. RF Power vs optical power.

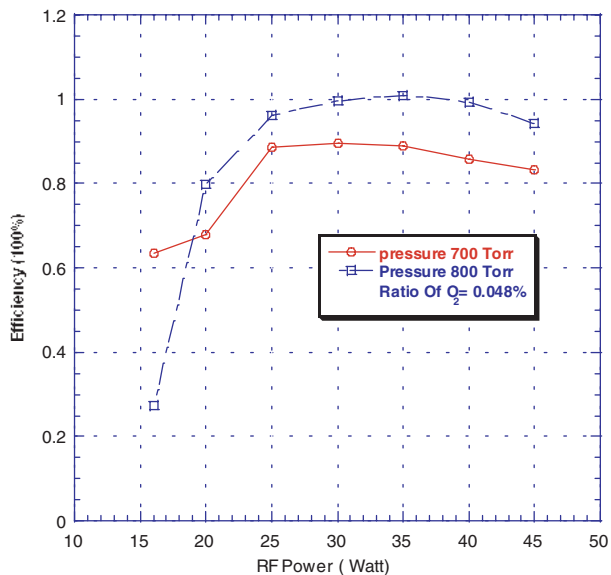


Figure 7. Efficiency vs RF power at 130.3 nm.

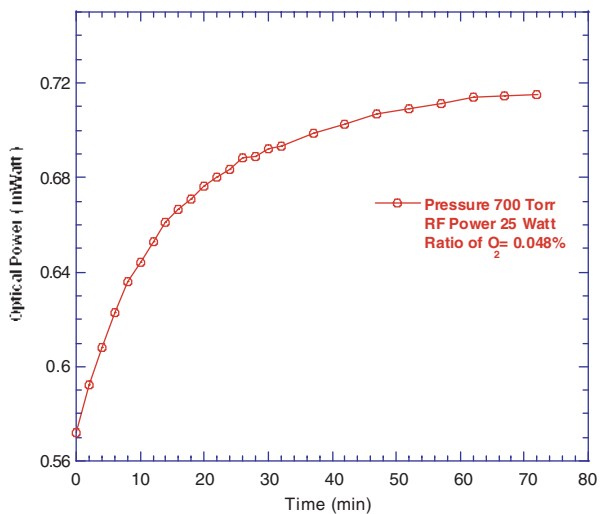


Figure 8. Stability of 130.3 nm.

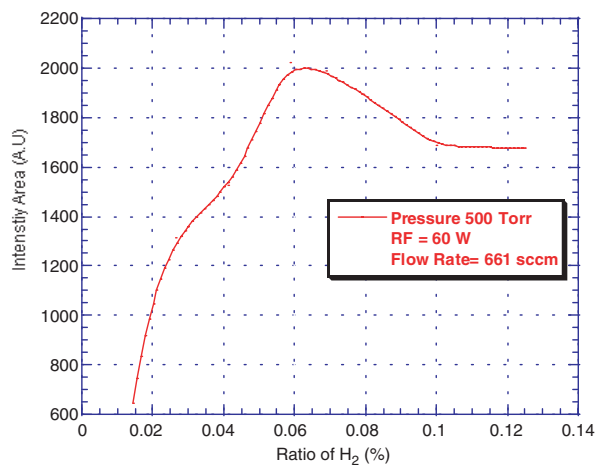


Figure 9. Intensity of Lyman- α line vs the ratio of H_2 .

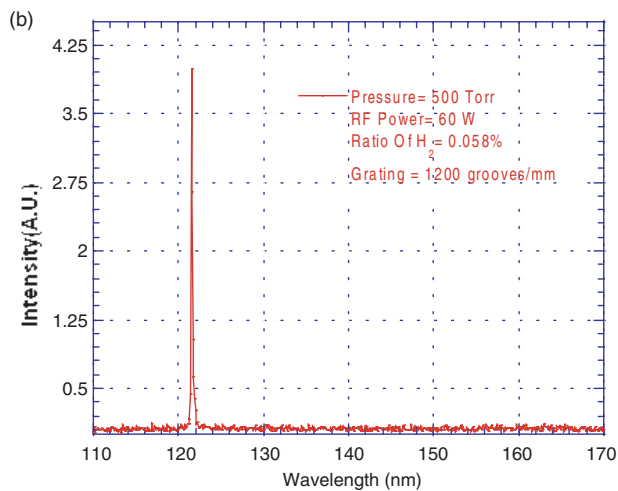
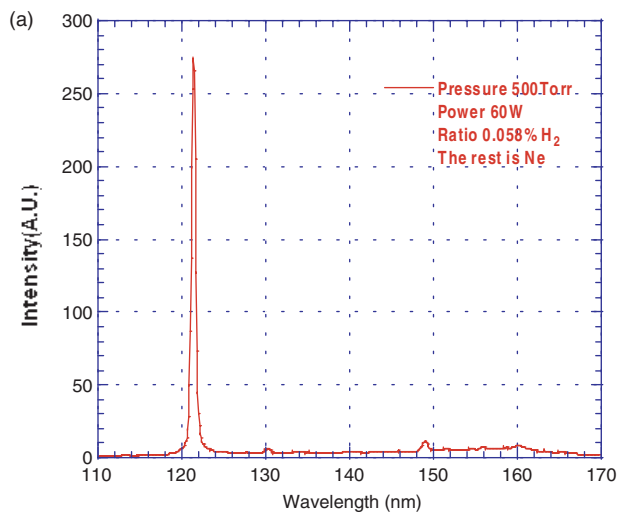


Figure 10. Emission spectra of the Lyman- α line.

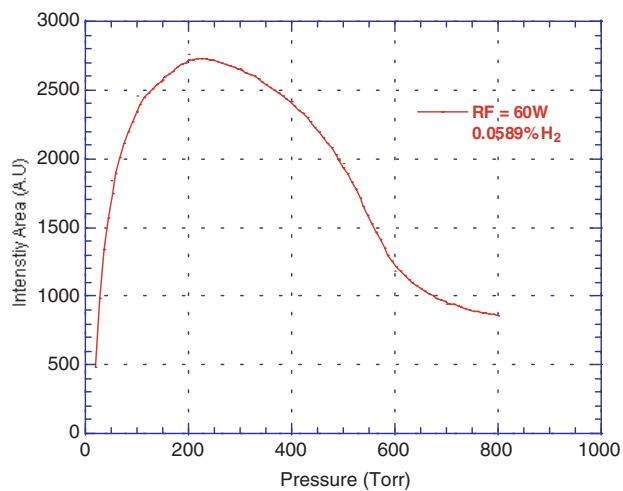


Figure 11. Intensity of the Lyman- α line vs pressure.

we noticed that the intensity of the peak at 130.3 nm increased while the second excimer continuum of argon disappeared gradually.

The spectrum of figure 3 clearly shows the second excimer continuum of argon where the peak at 130.3 nm is overlapping with it. By adding a small ratio of oxygen the intensity of the 130.3 nm line was found to increase while that of the second excimer continuum of argon was found to decrease and eventually disappears. The second excimer continuum of argon, in figure 4, changed to a narrow emission centred at 130.3 nm. This emission results from atomic oxygen O-I. In reality it results from a triplet which is not resolved in our measurement [9].

This behaviour might be attributed to the possible energy transfer [9] from the excited Ar to the atomic oxygen O-I in a resonance process yielding the increase in the 130.3 nm atomic oxygen O-I and the decrease in the second excimer continuum of argon in the range 120–140 nm. Increasing the ratio of the oxygen, the excimer energy will transfer more rapidly to the atomic oxygen O-I yielding the resonance line at

130.3 nm. The mechanism of the energy transfer from the second excimer continuum of argon to the atomic oxygen O-I has been discussed before by Moselhy *et al* [9]. At a certain amount of oxygen (0.042% O₂) the excimer energy will transfer all its energy to the resonance line of oxygen and consequently no second excimer continuum of argon will occur. This behaviour is clearly seen in figure 5 for the argon–oxygen mixture at 0.045%. The effect of applied RF power, and gas pressure on the obtained output power is given in figure 6 up to 700 mW. According to our data, the highest power for the 130.3 nm O₂ line (700 mW) was obtained at RF power = 60 W and gas pressure = 800 Torr. Moreover, for an applied RF power of 50 W, the real optical power (over 4π) was calculated from the power measured by the detector and was found to be 1.6 W yielding an efficiency of about 2.1%. The variation of the efficiency for different RF powers and gas pressures is given in figure 7.

It was found here that the power of the 130.3 nm line becomes more stable after 30 min. After 80 min we noticed that there was no change in the temperature of the lamp

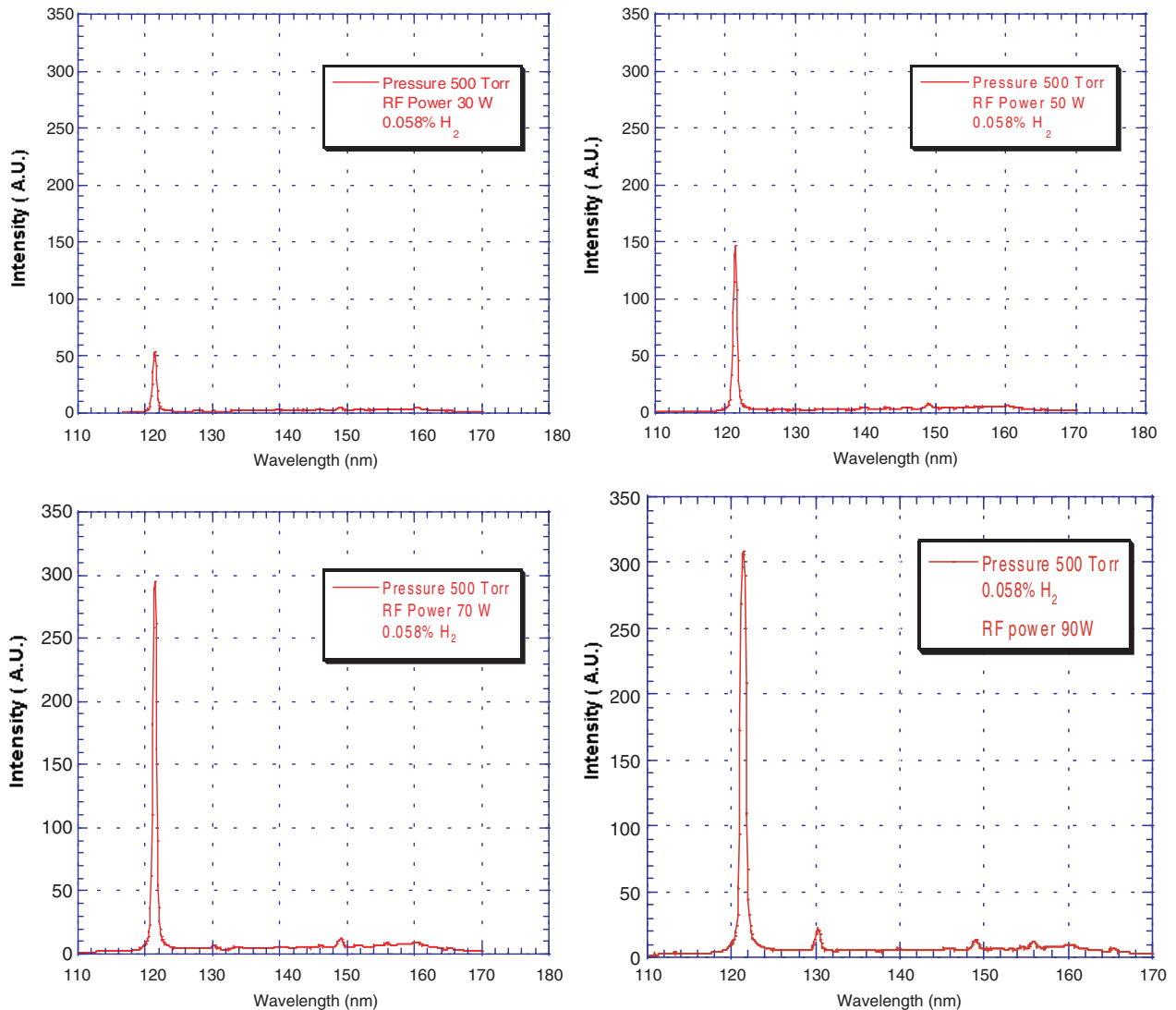


Figure 12. Emission spectra for different RF powers.

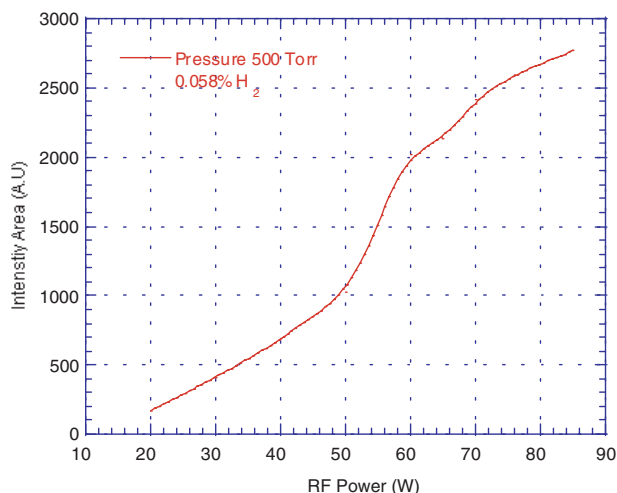


Figure 13. Intensity of the Lyman- α line vs RF power.

(room temperature, 27°C) and no fluctuations in the power of the atomic oxygen O-I at 130.3 nm. Figure 8 shows the stability of the 130.3 nm atomic oxygen O-I.

3.1. Study of the Lyman- α (121.5 nm) emission

To study the emission of the Lyman- α we used a mixture of Ne-H₂. To determine the suitable hydrogen mixture ratio we varied the hydrogen ratio in the range 1%. For a ratio greater than 0.2%, the discharge was found to be unstable under high-pressure conditions. The optimum ratio was found to be about 0.05%. Under this condition, the discharge was stable at a pressure of around one atmosphere, and the Lyman- α emission line dominated the emission spectra. Figure 9 illustrates these results.

The spectra in figure 10 clearly show Lyman- α radiation of atomic hydrogen with ratio 0.058% H₂ and a pressure of 500 Torr. In neon with traces of hydrogen it is formed by energy transfer from neon excimers radiating at 80–88 nm [7], which is not resolved in our measurements. The mechanism of such energy transfer has been discussed by Wieser *et al* [13] and Kurunczi *et al* [7]. Figure 11 shows the intensity of Lyman- α radiation of atomic hydrogen as a function of pressure, for an RF power of 60 W and a hydrogen mixture ratio of 0.058%. Under these conditions, the Lyman- α radiation exhibits the highest intensity when the operating pressure is in the range 200–400 Torr. For pressures greater than 400 Torr the Lyman- α peak was found to decrease but is still prominent and dominates the emission spectra.

Figure 12 shows several emission spectra for various RF powers indicating the increase in the intensity of the Lyman- α radiation with the increase in the applied RF power. This is further illustrated in figure 13. The total (4π) emitted power at 121.6 nm was calculated to be 1.5 W for an applied RF power of 60 W. The efficiency under these conditions is 2.5%.

To study the stability of our source we operated the discharge continuously for 24 h. We measured the spectra every 30 min. After 24 h, we calculated the peak point for the Lyman- α line of each spectrum. Figure 14 shows that after a transient time of about 6 h the intensity of the Lyman- α radiation reaches a steady state, during which a variation of less

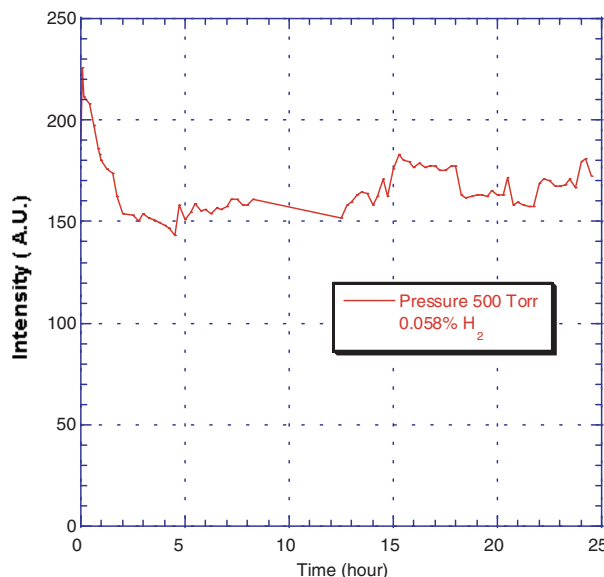


Figure 14. Stability of Lyman- α .

than 2% was observed. Also, we noticed that the temperature of the lamp increased from 26°C to 45°C within the first four hours, after that it became stable without any remarkable changes.

4. Conclusion

From the above experimental results we illustrated in this paper that our novel VUV source could achieve the following performance: (i) in argon–oxygen mixture an optical power of 1.6 W at RF power 40 W is reached at the emission of the atomic oxygen O-I 130.3 nm. The efficiency in this case was found to about 2.1%. The intensity of the 130.3 nm radiation became stable after 30 min. The temperature of the lamp did not change with time. The emitted beam profile was found to be Gaussian; (ii) for a neon–hydrogen (0.05%), the Lyman- α radiation was observed, an optical power of about 1.4 W at RF power 60 W and efficiency 2.5% was achieved. Also the intensity of the 121.5 nm radiation became stable after 6 h. The temperature of the lamp became stable after 4 h. The emitted beam profile was also found to be Gaussian.

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