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UV Emission from N_2/O_2 Pulse Microwave Plasma

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Abstract

The emission spectrum from pulse microwave discharge of N_2/O_2 gas mixture in the UV range (from 200 – 400 nm) was studied in a cylindrical quartz tube aiming to apply it as a mercury free UV light source. The UV light in the 200-280 nm range has germicidal effect which can be used for water purification. In our previous work we used continuous microwave power to produce UV emission from N_2/O_2 discharge. In the present work we used pulse microwave power instead of continuous microwave power. We studied the dependence of pulse width and pulse interval on the intensity of the UV emission from N_2/O_2 discharge. Experimental results showed that the UV emission intensity emitted from N_2/O_2 gas discharge in 200- 400 nm region does not vary with pulse width and pulse interval but depends on applied average power.

1. Introduction

Energetic UV radiations have many applications in biological, physical and chemical processes; such as disinfection of drinking water [1], sterilization of medical equipments [2], photochemical synthesis [3] and photo-enhanced chemical vapor deposition [4]. Presently, UV irradiation of water has been established as a mature alternative to chlorination for disinfection of drinking water. UV light within the germicidal region from 200 nm to 280 nm results in the inactivation of the microorganisms of microbiological system by photochemically altering the DNA in the cell [5].

Mercury which is used today as filling element in the UV light source is highly toxic and potentially carcinogenic. These dangers, even in very small quantities, can eventually lead to neurological system and brain damage in humans. Along with other harmful elements, such as lead, cadmium, and hexavalent chromium, environmental groups worldwide are calling for limit on

the use of mercury in electrical and electronic equipment. European Union's RoHS (Restriction of Hazardous Substances) has already banned the use of lead, mercury, cadmium, chromium, polybrominated biphenyls and polybrominated diphenyl ethers from electronics sold in EU member states beginning 1 July 2006. So the replacement of mercury in conventional UV lamps by other components is highly desirable for environmental reasons. Uhrlandt et al. demonstrated low pressure mercury free plasma light source using rare gas mixture [6].

Microwave plasma light source has advantages over conventional light source. In conventional source, the electrode absorbs gas and causes chemical reaction with them which decreases the life time of the source. So the demand for microwave plasma light source is increasing day-by-day for many applications. Al- Shamma et al. developed a low power microwave plasma Hg UV lamp for water purification and ozone applications [5]. Kono et al. observed VUV emission from Ar and Xe using microwave excitation aiming to apply it as VUV excimer light source [7]. Fozza et al. investigated the VUV to near infrared emissions from molecular gas–noble gas mixtures (H_2–Ar and O_2–Ar) to obtain very intense VUV emissions [8]. Rahman et al. measured the optical emission spectra in the 110–400 nm regions from RF-driven (13.56 MHz) hollow slot micro plasmas operating in open air at atmospheric pressure and they compared the intensity with commercial UV mercury lamp [9].

In our previous work we used continuous microwave power to produce N_2 /O_2 discharge. In the present work we have used pulse microwave power to observe the effect of pulse width and pulse interval on the intensity of the emission spectra.

2. Experimental Set-up

The schematic diagram of the experimental setup is shown in figure 1. The microwave source used in the experiment was a magnetron power source operating at 2.45 GHz with power rating of up to 1.5 kWatts. A microwave applicator constructed from aluminum alloy was used in the experiment.

Figure 2 shows the detail structure of the discharge tube and microwave applicator. The power to the applicator was fed through a rectangular waveguide from the microwave source. A quartz tube with 15 mm outer diameter and 450 mm length was used in the experiment as the discharge tube. One side of the tube was closed with a gauge port-adaptor and the other side was connected to a vacuum system. Rotary pump was used to evacuate the system.

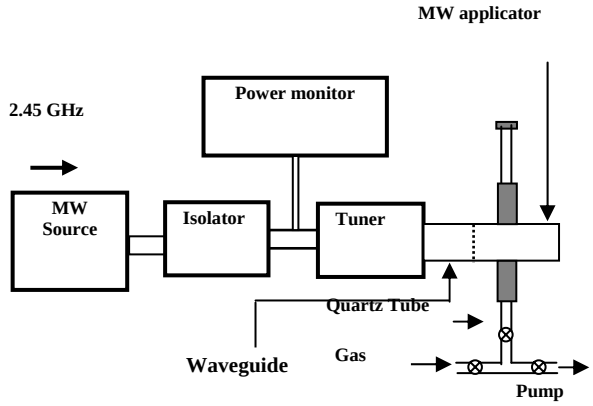

Fig.1 Schematic diagram of the experimental apparatus

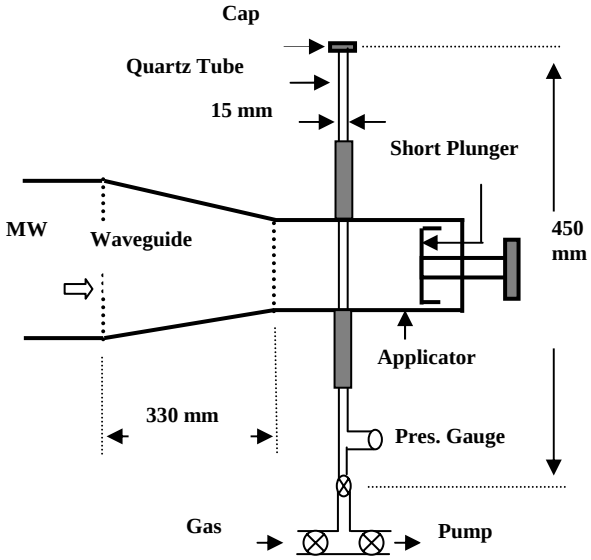

Fig. 2 Detail structure of discharge tube and microwave applicator

The quartz tube was filled with different concentration of N_2 and O_2 gas (both N_2 and O_2 were 99.99995% pure) at various pressure and then microwave excited discharge was produced. Tesler coil was used for ignition. The total pressure in the tube was measured by Baratron pressure gauge (Type 626). Emission spectroscopy was carried out using 2 sets of fiber coupled spectrometer, for UV (HR- 4000, Ocean Optics) and for visible (USB- 4000, Ocean Optics) through a window on the side wall of the microwave applicator. The optical emission from the central part of the discharge tube was monitored. The spectrometers with quartz fiber were calibrated with standard Xe lamp (L7810-02, Hamamatsu Photonics, K.K)

3. Results and Discussion

Figures 3(a) and 3(b) show the emission spectra from continuous wave (CW) microwave N_2 /O_2 (N_2 80%, O_2 20%, total pressure 500 Pa, power 150 W) discharge and pulse microwave N_2 /O_2 (N_2 80%, O_2 20%, total pressure 500 Pa, frequency 100 Hz, duty 50%, power 150 W) discharge respectively.

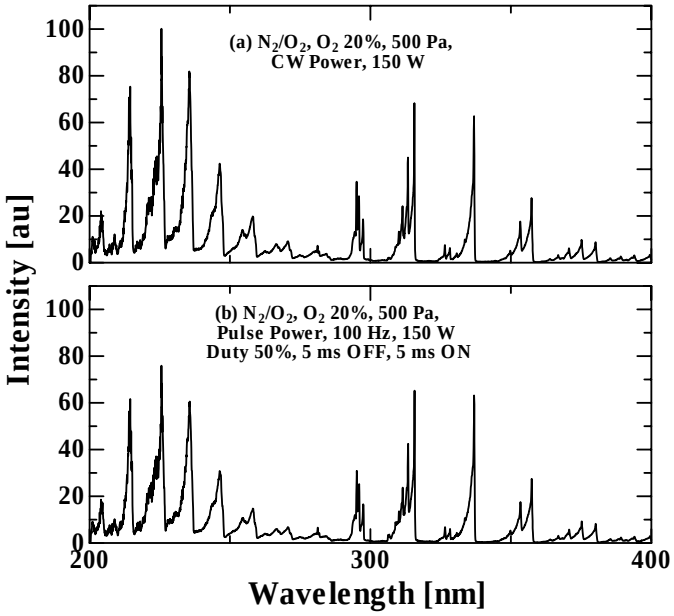

Fig.3. Emission spectra from (a) CW microwave N_2/O_2 discharge and (b) pulse microwave N_2 /O_2 discharge

Table 1 Pulse power with different pulse width and pulse interval

Pulse power			
Different pulse width		**Different pulse interval**	
1.	ON time = 20 ms, OFF time = 5 ms Frequency = 40 Hz, Duty = 80%	1.	OFF time = 30 ms, ON time=5 ms Frequency = 29 Hz, Duty = 14%
2.	ON time = 15 ms, OFF time = 5 ms Frequency = 50 Hz, Duty = 75%	2.	OFF time = 20 ms, ON time= 5 ms Frequency = 40 Hz, Duty = 20%
3.	ON time = 10 ms, OFF time = 5 ms Frequency = 67 Hz, Duty = 67%	3.	OFF time = 15 ms, ON time= 5 ms Frequency = 50 Hz, Duty = 25%
4.	ON time = 8 ms, OFF time = 5 ms Frequency = 77 Hz, Duty = 62%	4.	OFF time = 10 ms, ON time= 5 ms Frequency = 67 Hz, Duty = 33%
5.	ON time = 6 ms, OFF time = 5 ms Frequency = 91 Hz, Duty = 55%	5.	OFF time = 8 ms, ON time = 5 ms Frequency = 77 Hz, Duty = 38%
6.	ON time = 5 ms, OFF time = 5 ms Frequency = 100 Hz, Duty = 50%	6.	OFF time = 6 ms, ON time = 5 ms Frequency = 91 Hz, Duty = 45%
7.	ON time = 4 ms, OFF time = 5 ms Frequency = 111 Hz, Duty = 45%	7.	OFF time = 5 ms, ON time = 5 ms Frequency = 100 Hz, Duty = 50%
8.	ON time = 3 ms, OFF time = 5 ms Frequency = 125 Hz, Duty = 38%	8.	OFF time = 4 ms, ON time = 5 ms Frequency = 111 Hz, Duty = 55%
9.	ON time = 2 ms, OFF time = 5 ms Frequency = 143 Hz, Duty = 30%	9.	OFF time = 3 ms, ON time = 5 ms Frequency = 125 Hz, Duty = 62%
10.	ON time = 1 ms, OFF time = 5 ms Frequency = 167 Hz, Duty = 17%	10.	OFF time = 2 ms, ON time = 5 ms Frequency = 143 Hz, Duty = 70%
11.	ON time = 0.7 ms,OFF time = 5 ms Frequency = 175 Hz, Duty = 12%	11.	OFF time = 1 ms, ON time = 5 ms Frequency = 167 Hz, Duty = 83%
12.	ON time =0. 5 ms, OFF time= 5 ms Frequency = 181 Hz, Duty = 9%		
13.	ON time =0.3 ms, OFF time = 5 ms Frequency = 189 Hz, Duty = 6%		

In both the case, the spectra have similar shape and all the peaks appeared at same wavelengths. The peaks appeared at 214, 225, 236 and 246 nm in the 200-280 nm region are from NO γ and/or NO δ systems, corresponding to $(A^2\sum^+ - X^2\Pi)$ and/or $(C^2\sum^+ - X^2\Pi)$ transition [10]. On the other hand the peaks appeared at 295, 311, 313, 316, 337,353 and 357 nm in the 280- 400 nm range are attributed to the 2nd positive systems of N_2 through $(C^3\Pi_u - B^3\Pi_g)$

transition [10]. The CW discharge has a higher intensity in 200 -280 nm region than the Pulse discharge however, in 280 -400 nm region the intensity is almost similar.

Pulse power of different pulse width and pulse interval which was used in the experiment is shown in Table 1. The dependence of pulse interval on emission intensity is shown in figure 4. From figure 4(a), it can be seen that intensity decreases with the increase of interval. This happens because with the increase of pulse interval, the duty decreases and hence the applied power. With the decrease of applied power, the intensity also decreases. Figure 4 (b) shows the interval ~intensity [normalized with power] graph. From figure 4(b) it is clear that emission intensity does not depend on pulse interval but depends on applied average power.

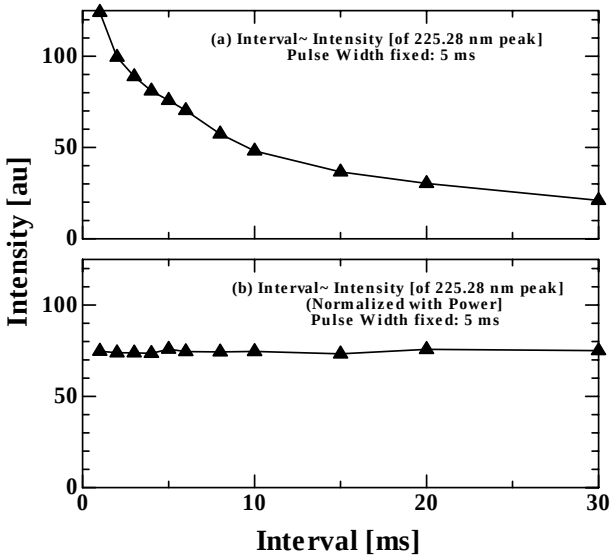

Fig.4. Dependence of pulse interval on emission intensity of N_2/O_2 discharge (a) interval ~ intensity and (b) interval ~intensity [normalized with power]

Fig. 5 shows the effect of pulse width on emission intensity. It is observed from Fig. 5(a) that intensity increases when pulse width is increased. This happens because duty increases with the increase of pulse width and so the power. The intensity also increases with the increase of power. From Fig.5(b) it is seen that the emission intensity completely depends on average applied power but not on pulse width.

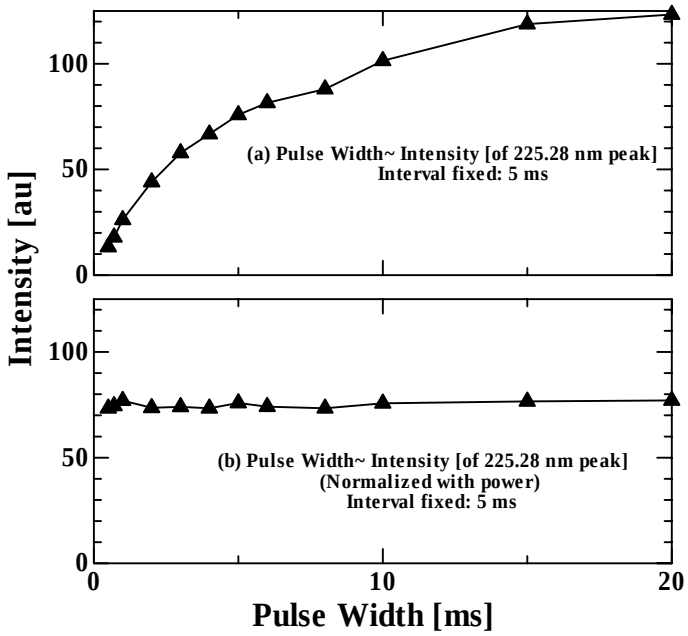

Fig.5. Dependence of pulse width on emission intensity of N_2/O_2 discharge (a) pulse width ~ intensity and (b) pulse width ~intensity [normalized with power]

4. Conclusion

Both continuous and pulse microwave N_2/O_2 mixture discharge emits intensive UV light in the 200 to 280 nm region through NO $\gamma(A^2\sum^+ - X^2\Pi)$ and/or NO $\delta(C^2\sum^+ - X^2\Pi)$ systems. The emission spectra produced from both continuous and pulse microwave N_2/O_2 mixture discharge have similar shape and all the peaks appeared at same wavelengths. The intensity ratio of NO peaks to N_2 peaks in CW discharge is greater than the intensity ratio of NO peaks to N_2 peaks in pulse microwave discharge.

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