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UV-Emission from Poly-Phase Molecular Discharge/Plasma Confined by Multi-Pole Magnetic Field

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We have investigated fundamentally an effect of a multi-pole magnetic field on UV-emission from molecular gases excited by a poly-phase ac discharge/plasma. It was found that when a nitric oxide gas NO mixed with a nitrogen molecular gas was used, an intense ultra-violet (UV) irradiation ranging from 200nm to 300nm was emitted from magnetically confined regions. We have examined the dependence of UV emission on the concentration ratio of NO to N_2. Maximum UV emission was observed around 10% concentration ratio. We have compared with UV intensity in NO/N_2 present experiment and that in Hg/Ar previous experiment. The UV intensity for the NO/N_2 case turned out to be 1.4 times stronger than that for the Hg/Ar case. A multi-channel spectroscope with an optical fiber was employed to detect the emission. A deuterium calibrated light-source was used to obtain the absolute value of the spectral radiant flux density.

Keywords: UV emission, molecular gas, nitrogen poly-phase, ac discharge/plasma, multi-pole magnetic field.

1. Introduction

As environmental issues have become serious, the need for mercury-free lamps has become an important subject for light source manufacturers. Many studies had been carried out to develop mercury-free light sources, especially using a xenon rare gas [1-4]. The research of molecular radiators as a candidate for mercury-free lamps also had been started [5]. Recently, experimental results by using nitrogen gas as a ultra-violet (UV) emitter has been reported [6,7].

The current purpose of our study is to find a new molecular gas and improve its UV-emission performance by applying of two techniques. One is the application of plasma confinement by an advanced multi-pole magnetic field. Another is that of plasma production by a poly-phase ac discharge [8], which had been originally proposed by one (K. M.) of the authors.

The final propose is to develop a UV discharge/plasma lamp in a molecular gas, which is utilized for sterilizing foods, medicines and perfumes, especially powdered ones extracted from natural materials. It is not suitable to sterilize these by conventional high temperature wet steam or a toxic gas [9,10] such like an ethylene oxide gas. Because, powders become firm or include residues. Sterilization by irradiation from radioactive elements [9] is one of promising candidates. But its use is prohibited legally in Japan.

Therefore, present study and its development of a UV lamp for sterilization without mercury or expensive rare gases are very significant.

2. A model of UV light-source

Figure 1 shows a model of our UV emitter driven by a poly-phase ac discharge/plasma, where the cross section is drawn schematically. Discharges/plasmas are produced among divided electrodes whose surfaces are covered with a dielectric, which are confined by multi-pole magnetic fields formed by permanent magnets. Intense light emissions are irradiated from excited gases in confined regions.

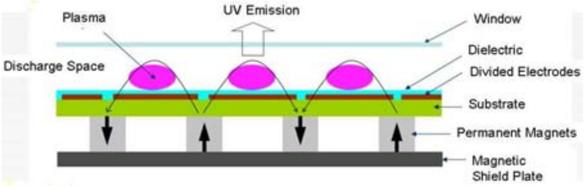

Fig. 1 Cross section of Ultra-Violet emission device, where a symmetric poly-phase ac power source is connected to divided electrodes and plasmas generated among electrodes are confined by multi-pole magnetic fields.

This UV lamp is expected to have the following characteristics:

- High Intensity & efficient emission by magnetic confinement
- Uniform emission from divided electrodes with flexible shape
- Emission with no temperature dependence
- Filament-less & rapid emission
- No electrical noise by canceling out symmetrical poly-phase ac discharges

3. Experimental setup

Figure 2 shows an experimental setup, where a flat electrode divided into twelve is for (a) and a twelve-phase ac power source for (b). The outputs are connected to electrodes in order. The electrodes are made on a

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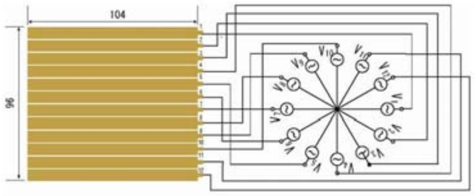


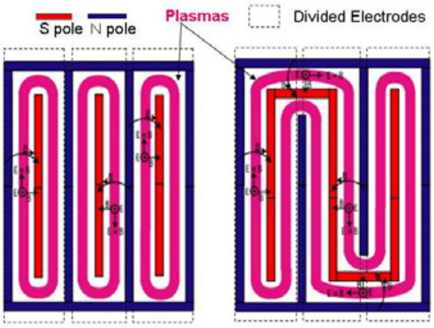
(a) Twelve Divided Plane- Electrodes (b) Twelve-phase AC Power Source (Inverter Type)

Fig. 2 Schematic electrical connection between a twelve-phase ac power source and twelve divided electrodes, where six unit-inverters are employed to compose the source.

polyimide substrate of thickness 50μm, whose surfaces are covered with a thin glass of thickness 50μm. The size of each electrode is 7mm in width and 104mm in length and 35μm in thickness.

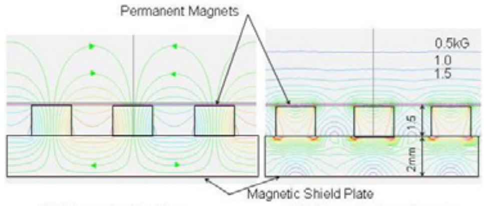
A symmetrical twelve-phase ac power source is consist of six unit-inverters whose on-off switching timings are different of a 1/12 period between adjacent components. The driving frequency of invertors is 40kHz. Twelve outputs have almost sinusoidal waveforms.

Figure 3 shows two types of arrangement of permanent magnets that generate multi-pole magnetic fields, where rectangles drawn by dashed lines indicate divided electrodes. A conventional race-truck shape is shown in Fig. 3(a) and a modified interdigital-transducer one in Fig. 3(b). Both magnetic fields can confine discharge/plasmas without any open-end. In this experiment, the former arrangement was adopted and was installed just behind the electrodes.



(a) Race-truck shape (b) interdigital-transducer shape

Fig. 3 Two types of arrangement of permanent magnets that generate multi-pole magnetic fields; conventional race-truck shape for (a), modified interdigital-transducer one for (b), where rectangles drawn by dashed lines indicate divided electrodes.



(a) Magnetic flux line (b) Magnetic flux density

Fig. 4 Multi-pole magnetic field distributions; magnetic flux lines for (a), magnetic flux densities for (b), where a two dimensional simulator is employed, the size of a magnet is 2mm in width and 1.5mm in height, residual magnetic flux density is 10kG.

Figure 4 shows simulation results of multi-pole magnetic field distributions, where magnetic flux line is for (a) and magnetic flux density for (b). The cross-section size of a magnet is 2mm in width and 1.5mm in height. The residual magnetic flux density is 10kG that is almost equal to the strength of a Samarium Cobalt magnet. The height of a magnetic shield plate is 2mm. Under these conditions, the experiments described in the next chapter were performed.

The simulation result shown in Fig. 4(a) exhibits that arches are formed by magnetic flux lines between adjacent magnets that have different polarities, in which discharges/plasmas are confined. Magnetic rear fields are well shield by a soft-iron plate. The result in Fig. 4(b) indicates that magnitude of magnetic flux density decreases rapidly with the distance apart from the surface. Its value is 0.5kG at ~3mm.

Figure 5 shows a method measuring UV emissions by using a multi-channel spectroscope, where emissions through a window are collected by an optical fiber. The spectrum is obtained by analysis with a personal computer. A deuterium calibrated light-source was used to calibrate the absolute value of the spectral radiant flux density ranging from 200nm to 350nm. A halogen calibrated lamp was also used for visible spectra.

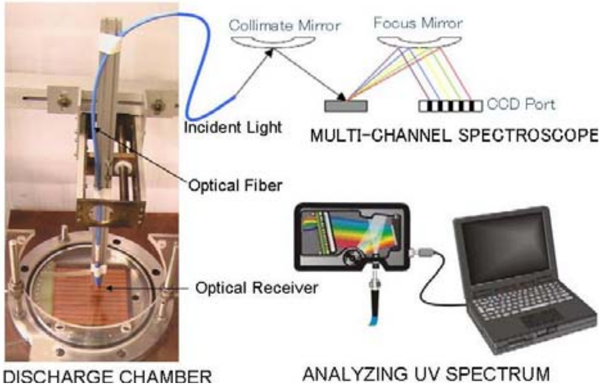


Fig. 5 Emission measurement by multi-channel spectroscope and spectrum analyzing by personal computer

4. Results and discussions

Figure 6 shows three emission-spectra that are typically observed for three kinds of gases, where a nitrogen molecule gas N_2 for (a), a nitric oxide gas NO (10%) mixed with N_2 gas for (b) and NO gas for (c). The total gas pressure is 0.3Torr, the dc input power for inverters forming the twelve-phase ac power source is 30W.

The race-truck shape magnets are installed just behind the electrodes.

It should be noted that an intense UV emission ranging from 200nm to 400nm is irradiated when NO gas is used. This result is believed to be found for the first time.

The reason why the authors selected NO gas as a molecular gas is that NO gas seemed to have a similar character to a carbon monoxide gas CO which is known [7] to emit a UV irradiation with wavelength less than 200nm. Both gases are obtained from chemically very stable gases, NO_2 and CO_2 gases, which are important to emit a light-wave with higher photon energy. The CO gas is easily dissociated into a carbon atom by discharge/plasma and dark deposition is produced on a window, which is a serious problem. However, a nitrogen atom dissociated from NO hardly produce depositions.

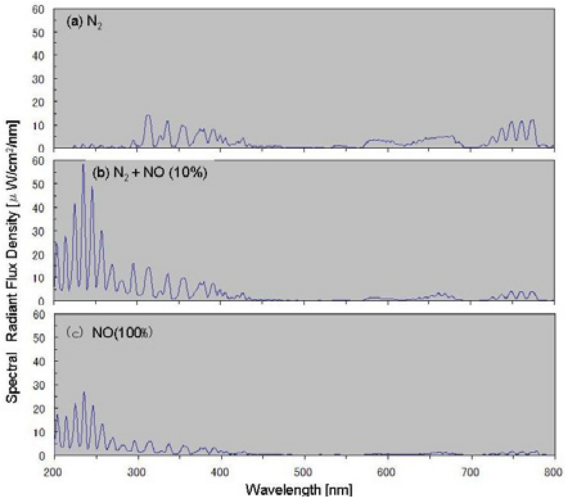


Fig. 6 Spectral radiant flux densities ranging from 200nm to 800nm observed in three kinds of gas; pure nitrogen molecular gas N_2 for (a), nitric oxide gas NO mixed with N_2 for (b), pure NO gas for (c)

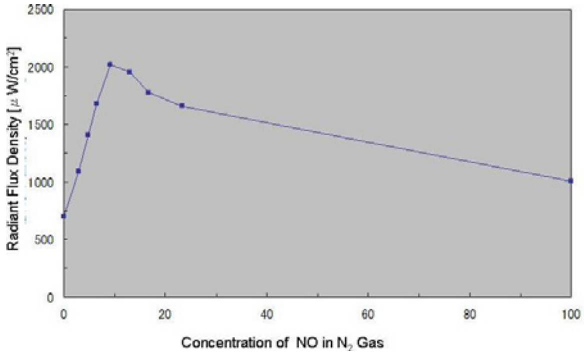


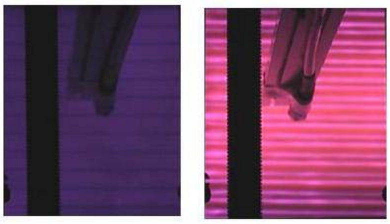
Fig. 7 Dependence of radiant flux density on concentration ration of nitric oxide gas to nitrogen molecular gas; the densities are computed by integrating spectral radiant flux densities from 200nm to 380nm.

Figure 7 shows dependence of a radiant flux density on the concentration ration of NO component to N_2 gas, where data of densities are computed by integrating spectral radiant flux densities from 200nm to 380nm. The experimental result indicates that maximum UV emission is obtained around 10% concentration of NO gas. Argon gas was also used instead of N_2 gas. But, the UV emission was fairly weak compared with the N_2 case. One (K. M.) of the authors is now studying about a physical mechanism of the above emission.

Figure 8 shows two photographs taken by a usual visible camera, where the optical fiber and its support bars are taken together. There is no magnetic field in (a) and the race-truck shape multi-pole magnetic fields in (b). The pressure of a mixture of NO (10%) and N_2 gases is 0.3Torr and dc input power for inverters is 30W.

It is found that visible optical emission is remarkably enhanced by the addition of magnetic fields. This result suggests that UV emission should also highly increase with magnetic fields.

Figure 9 shows spectral radiant flux densities ranging from 200nm to 800nm that were observed in two cases corresponding to Fig. 8(a) and 8(b), respectively.



(a) Without ***B*** (b) With ***B***

Fig. 8 Photographs taken by a usual visible camera; without magnetic field ***B*** for (a), with multi-pole magnetic fields of a race-truck shape for (b)

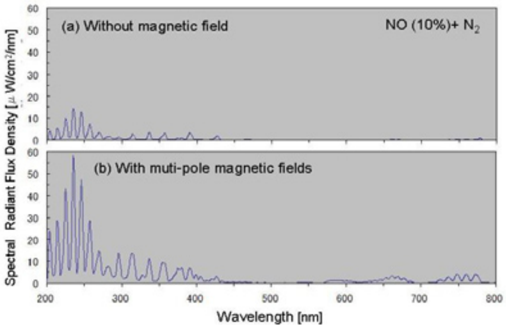
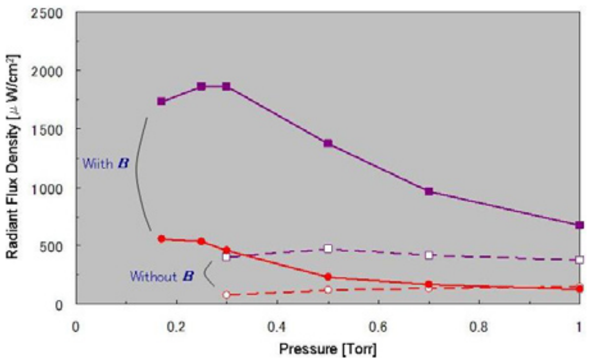


Fig. 9 Spectral radiant flux densities ranging from 200nm to 800nm, observed in two cases corresponding to figure 8(a) and 8(b), respectively.

Figure 10 shows variation of UV and visible radiant flux densities with total pressure of a mixture of NO (10%) and N_2 gases, for two cases without and with magnetic fields. The visible component is obtained by numerically integrating spectral radiant flux densities from 380nm to 780nm. The dc input power for inverters is 30W.



(a) Without ***B*** (b) With ***B***

Fig. 10 Variation of UV and visible radiant flux densities with total gas pressure, where upper two solid curves are for the case with magnetic fields ***B***, lower broken curves for the case without ***B***

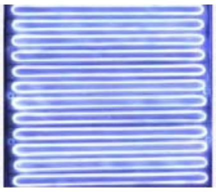


Fig. 11 Visible photograph in Hg/Ar discharge/plasma in previous experiment

Experimental results indicate that when there is no magnetic field, both intensities of UV and visible components do not change so much with the variation of pressure. However, for the case with magnetic fields, those two components increase considerably as the total pressure decreases.

In general, magnetic confinement effect on plasma is improved with the decrease of gas pressure since electron cyclotron-motion is not interrupted by collisions with neutral atoms/molecules [11]. In this experiment, the mean electron-N_2 collision frequency is $0.3\sim6.7\times10^9$Hz for N_2 gas pressure of 0.3~1.0Torr and electron temperature of 3eV and electron cyclotron frequency is $0.1\sim4.2\times10^9$Hz for magnetic field strength of 0.05~1.5kG. Therefore, magnetic confinement becomes effective at a pressure lower than 0.5Torr.

Figure 11 shows a visible photograph of Hg/Ar discharge in previous similar experiment, where total gas pressure is 0.07Torr, Hg partial pressure is 0.03Torr at chamber's temperature of 60 degrees Celsius, race-truck shape magnets are installed behind the electrodes and dc input power for inverters is 20W. The magnitude observed radiant flux density at 253.7nm was ~0.95mW/cm^2 just on the same window. If we extrapolate this value for the condition of dc input power of 30W, it becomes to be 1.4 mW/cm^2. In the present experiment, maximum UV intensity is ~2.0 mW/cm^2 as shown in Fig. 10. This value turns out to be 1.4 times stronger than that for the Hg/Ar case.

4. Conclusions

We applied the poly-phase ac discharge/plasma generation technique, confined into multi-pole magnetic fields, to UV emission from molecular gases. It was found that when a nitric oxide gas NO mixed with a nitrogen molecular gas N_2 was used, an intense UV irradiation ranging from 200nm to 300nm was emitted from a magnetically confined discharge/plasma regions. Maximum emission was observed around 10% concentration of NO in N_2, whose intensity was 1.4 times stronger than that obtained in Hg/Ar previous experiment.

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References

[1] D. Uhrlandt, R. Bussiahn, S. Gortchakov, H. Lange and D. Loffhagen, Proceedings of the 10th International Symposium on the Science and Technology of Light Sources, Toulouse, 15(2004).

[2] T. Shiga, T. Yoshikawa, S. Mikoshiba and M. Yasuda, Journal of Illuminating Engineering Institute of Japan, **88**, 517(2004); Journal of Physics D, **36**, 512(2003).

[3] H. Noguchi, H. Yano, H. Motomura M. Jinno and M. Aono, Journal of Illuminating Engineering Institute of Japan, **87**, 98(2003); Journal of Illuminating Engineering Institute of Japan, **86**, 535(2002).

[4] M. Jinno, K. Toryu, T. Murakami, H. Motomura, K. H. Loo and M. Aono; Proceedings of the 10th International Symposium on the Science and Technology of Light Sources, Toulouse, 145(2004).

[5] R. Hilbig, A. Koerber, J. Baier and R. Scholl, Proceedings of the 10th International Symposium on the Science and Technology of Light Sources, Toulouse, 75(2004).

[6] M. Jinno, S. Takubo, Y. Hazata, S. Kitsinelis and H. Motomura, J. Physics D **38**, 3312(2005).

[7] A. Hatta, Proceedings of the 37th annual meeting of The Illuminating Engineering Institute of Japan, **34**, 75(2001).

[8] K. Matsumoto, Plasma Sources Science and Technology **5**, 245 (1996); K. Matsumoto, T. Yamamoto, S. Oda and S. Yamazaki, Proceedings of the XXV International Conference on Phenomena in Ionized Gases, Nagoya, Vol.**1** 263(2001).

[9] H. Kobayashi, *Infection Control* (Health Publisher, Tokyo, 2000).

[10] S. Nakada, INFLECTION CONTROL **8**, 32(1999).

[11] M. A. Lieberman and A. J. Lichtenberg, *Principles of plasma discharges and materials processing* (John Wiley & Sons, Inc., New York, 1994) p.140.