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Loop-shaped ultraviolet lamp with high uniformity distribution by applying a poly-phase ac discharge/plasma in a multi-pole magnetic field

磁場中多相交流放電ﾌﾟﾗｽﾞﾏを応用した高一様性分布のﾙｰﾌﾟ状紫外線ﾗﾝﾌﾟ

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An ultraviolet (UV) glow lamp in the shape of a loop has been devised to improve characteristics of spatial uniformity of irradiating distribution and emitting intensity of brightness. The lamp is capable of photo-curing a hard-coat layer even in the atmosphere containing oxygen gas with very small irradiation energy compared with the case of curing by conventional high-intensity mercury lamps. It is distinctive that the lamp is driven by a poly-phase ac discharge/plasma confined in a multi-pole magnetic field and is filled with a mixed molecular gas consisting of oxygen and nitrogen gases at a pressure of about 50Pa.

1. Introduction

Recently, the energy problem and global environmental issues have become a great concern both at home and abroad. As one of these is the use of high intensity UV mercury lamps that have been widely used for photo-curing of hard coats on wooden floorings and resinous automobile-parts. Those UV lamps driven by arc discharge consume large amount of electric energy and contain a lot of mercury hazardous to the environment. Development of a new lamp is desired in terms of energy saving and mercury removal.

An UV glow discharge lamp available to the photo-curing had been proposed by us, which consumed more than ten times smaller electric energy compared with conventional lamps and contained no mercury but molecular gases such as oxygen and nitrogen [1]. From our lamp two UV components are irradiated. The one component with shorter wavelength suppresses the photo-curing inhibition by oxygen dissolved into coating layers, which causes an effective photo-curing by the other UV with very small irradiation energy.

The purpose of present study is to improve characteristics of our previous UV lamp with a straight shape, and to complete it as a practical lamp useful in various industries.

2. Fundamental structure of our UV emitter

Figure 1 shows a conceptual 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 covered with a dielectric and confined by multi-pole magnetic fields formed by permanent magnets. A poly-phase ac power source is connected to electrodes [2].

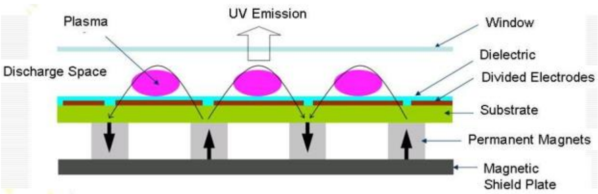

Fig.1 Cross section of UV emission device, where a symmetric poly-phase ac power source is connected to divided electrodes.

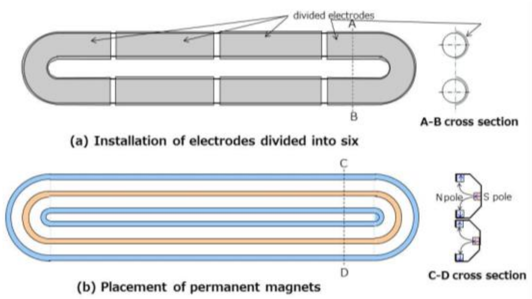

Fig.2 Schematic drawing of a new UV lamp in the shape of a loop, driven by a six-phase ac glow discharge/plasma, where arrangements of six-divided electrodes and permanent magnets are shown in (a) and (b), respectively.

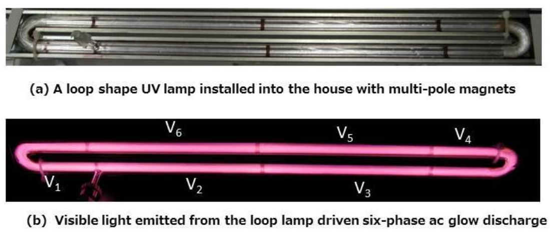

Fig.3 Photographs of a loop shape lamp actually made, where lamp housing with magnets and real light emission are shown in (a) and (b), respectively.

3. Experimental method and results

We devised a loop shape UV lamp that has improved characteristics both about spatial uniformity of irradiating distribution and emitting intensity of brightness compared with the previous straight one, whose schematic drawing is shown in figure 2. Figure 3 shows photographs of the loop shape lamp installed in a housing with magnets in (a) and the light emission driven by a six-phase ac discharge/plasma in (b), where the lamp's length is ~400mm and diameter is 11mm, a molecular gas mixed nitrogen with oxygen is filled with at the pressure of 0.5Torr, frequency of the discharge is 156kHz and average discharge power is ~50W.

Figure 4 indicates spatial intensity distributions of the light emission shown in Fig. 3(b), where the light is decomposed into three primary color components by image processing technique. It is found along the lamp shape that fairly uniform emission profile is obtained.

For comparison, characteristics in the case of the previous straight lamp are shown in Fig.5 and Fig. 6, where experimental conditions are almost the same with the case of Fig.3.The distribution is considerably non-uniform, especially at both ends.

A typical spectrum irradiated from our ramps is shown in figure 7, where a mixed gas consisting of nitrogen (90%) and oxygen (10%) gases is filled. The spectrum is divided into three regions with respect to the wavelength: UV I ranging over 220-280nm, UV II over 280-380nm and Visible region over 510-780nm. The UV I with shorter wavelength suppresses the photo-curing inhibition by dissolved oxygen, making a thin barrier layer very close to coating surface. The UV II with longer wavelength plays a main role in photo-curing.

Figure 8 shows experimental results in the case of the loop shape lamp, where irradiant flux densities for three regions are plotted as a function of ac discharge power. When we applied an ac voltage of 1kV (amplitude), which is practical maximum voltage, to the straight lamp, the ac discharge power was about 50W. In the case of the loop shape lamp under the same voltage, however, the ac discharge power was increased to 75W. This increase in the incident power led to the increase in brightness.

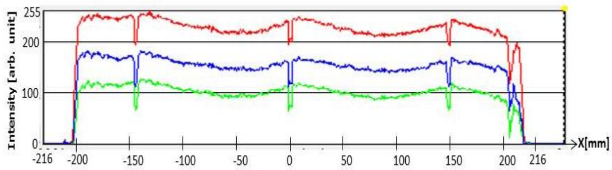

Fig.4 Spatial intensity distribution of light emitted from the loop shape lamp, where images recorded by a video camera are decomposed into red, blue and green components.

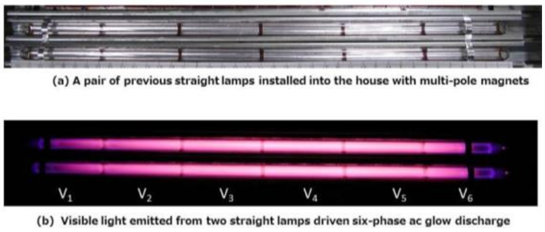

Fig.5 Photographs in the case of a pair of previous straight lamp

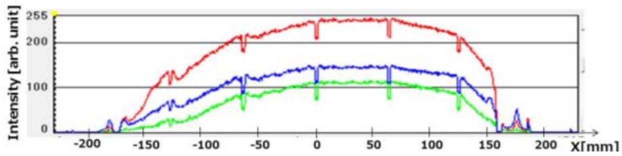

Fig.6 Spatial intensity distribution in the case of a pair of the straight lamp

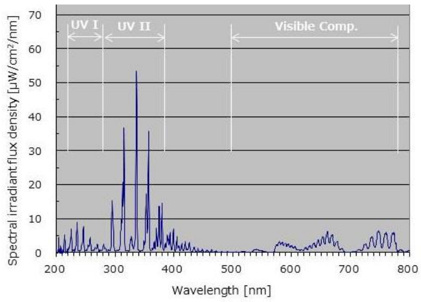

Fig.7 Typical spectral irradiant flux density emitted from our UV lamp filled with N_2(90%) and O_2(10%) gases

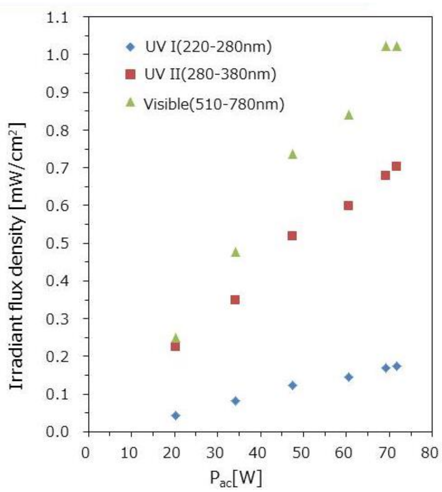

Fig.8 Experimental results about the loop shape lamp, where irradiant flux densities for three wavelength regions are plotted versus ac discharge power.

References

[1] K. Matsumoto, S. Oda, H. Uchida, K. Shimizu, N. Nojima, M. Kato and K. Hoshino: *Proc. ICRP-8/SPP-31, Fukuoka, 2014,* 4P-PM-S11-P37.

[2] K. Matsumoto and Y. Taira: J. Plasma Fusion Res. SERIES, **8**(2009) 1304.