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Research Article

Research on Flat Panel Ultrovilet Lamps

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Abstract: Flat panel ultraviolet Lamps were made of ITO glass and bonded aluminum with porous anodic alumina on the surface. The mixture of argon and nitrogen is introduced as the working gas. The UV radiation power density is tested at different optimization conditions. The results show that the lamp with about 20 W/m^2 UV radiation can be obtained when the lamp with 3 mm thick glass and 0.7 mm gas gap distance work at 5% nitrogen and 95% argon at 250 torr. The influence factors are investigated and discussed.

Keywords: Electron temperature, vacuum ultraviolet radition, ultroviolet lamps

INTRODUCTION

Dielectric Barrier Discharge (DBD) also referred to as barrier discharges or silent discharges have found a number of interesting industrial applications of plasma (Wang *et al*., 2009a; Li *et al*., 2011) in addition to the historical ozone generation. Dielectric barrier discharge is important in that it can easily produce non-thermal plasma in an easy way. Most of all, it has been used widely in the PDP production. Argon and nitrogen mixture is good for ultraviolet emission. Ultraviolet (UV) and Vacuum Ultraviolet (VUV) radiation are important applications (Midren and Carman 2001; Wang *et al*., 2009b; Zhou *et al*., 2008; Heikkilä *et al*., 2009; Anandan and Ketchum, 1994). Usually the UV lamps are tube sources. The flat panel UV lamps are seldom designed and referred (Li *et al*., 2012; Klausch *et al*., 2012; Anne, 1995).

In our work, a flat panel UV lamp was fabricated by using ITO glass as the transparent electrode and dielectric, bonded aluminum with porous anodic alumina (AA, Fig. 1) acts as the other electrode. The properties of the discharge are investigated. With nitrogen concentration increasing from 0.5 to 20 percent, the UV radiation decreases at the same voltage. However, the UV emission properties in the total emission dropped meanwhile. The spectra of the lamp were also taken and analyzed. The structures of the UV flat panel lamps are optimized.

EXPERIMENT

Figure 2 shows the flat panel UV lamp. The ITO glass (thickness: 0.7 mm, 1.8 mm and 3.0 mm) acts as the front electrode and the dielectric of the UV lamp.The rear electrode is made of bonded aluminum with porous AA on the surface. The distances between the front and rear electrode are 0.5 mm, 0.7 mm and 1.0 mm. The aluminum thickness is 50 μm and the porous AA, which is produced by anodizing in the oxalic acid, is 20 μm. After anodizing, the porous AA is eroded by voltage drop till the voltage is 3 V to increase the AA bottom thickness. Pore widening in 0.1M H3PO4 solution is carried out afterwards. Nickel pigmented the AA in the end to increase the alumina thickness.

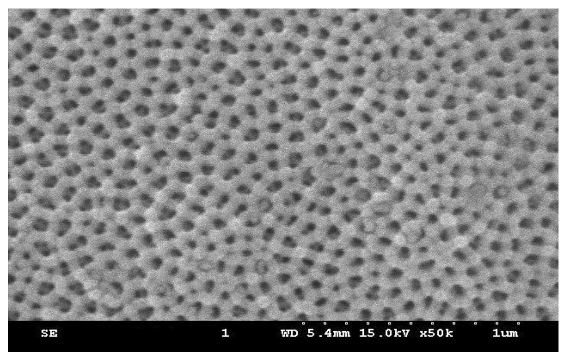

Fig. 1: SEM of porous alumina

The UV lamp was filled up with argon-nitrogen mixture after the lamp was vacuumed till 10-7torr. In discharge, the gas mixture is excited in a pulsed transverse power supply. The power supply frequency is 20-40 kHz and the peak voltage is 1.0-1.8 kv. The spectra were taken in the course of the discharge.

The power density was tested by a power meter with and without the SRG-610 filter. The Power Meter

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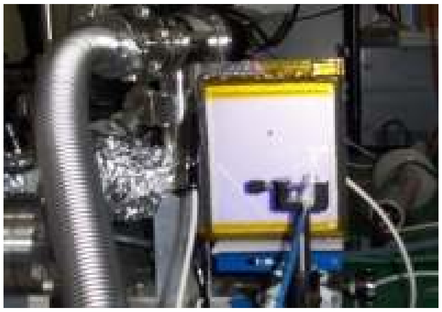

Fig. 2: Flat panel UV lamps

is 2832-C Dual-Channel Power Meter (produced by Newport Company). SRG-610 filter can separate the emission into two parts: 200-610 nm and 610-1000 nm. So we can test the total emission power density without SRG-610 filter and the near IR emission (610-1000 nm) power density with the filter. Therefore, the UV emission power density can be attained by subtracting the near IR emission power density from total one.

RESULT AND DISCUSSION

In argon-nitrogen mixture discharge, when nitrogen is of small quantity, the excited species are mainly argon ions (Ar+), electrons (e-) and the excited argon species in radiative or metastable states. It was believed that the argon metastables (Arm) is the common energy source for all the species emitting Ultraviolet (UV) and Vacuum Ultraviolet (VUV). Nitrogen can get energy and turn it into active species and give out UV emission (Fang *et al*., 2004).

Argon alone can only give out near IR emission in the lamps. Because of the lower concentration, nitrogen cannot have an appreciable influence on the argon metastable states processes populating. However, it can efficiently depopulate these states in the reaction:

$$Ar^m + N_2 \rightarrow N_2^* + Ar,$$

where, N2* represent all possible molecular excited states, which can give out UV emission.

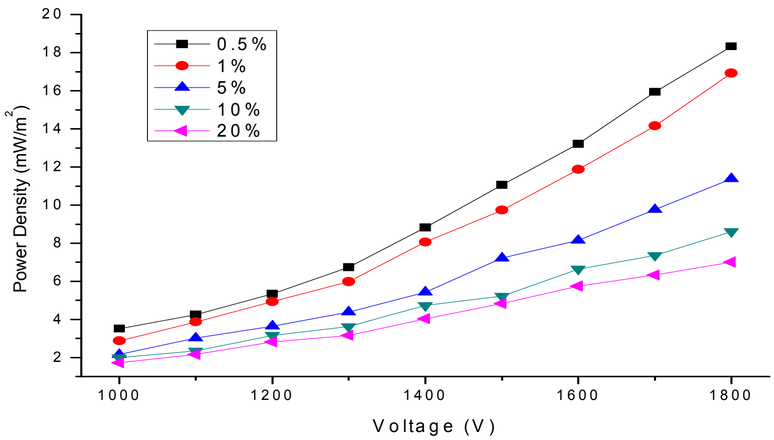

Fig. 3: Power density versus voltage at different N2 concentrations

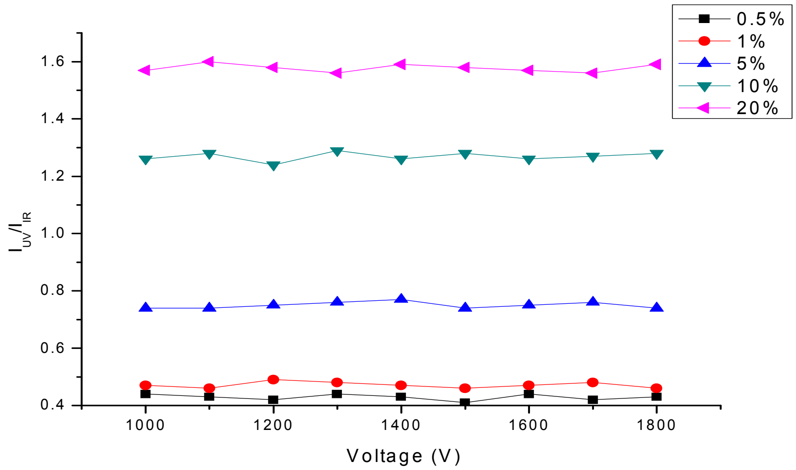

Fig. 4: UV concentration in radiation versus voltage at different nitrogen concentrations

The UV Power and Nitrogen concentration: Figure 3 shows the curve of the UV power density versus voltage at different nitrogen concentration. The testing condition is: 0.5 to 20% nitrogen in the mixture, total pressure 200 torr, the power supply repetition 40 kHz. With the nitrogen concentration increasing, at the same voltage, the UV emission will decrease and the UV emission proportion in the total emission will increase.

In the working gas, the Arm concentration drops with nitrogen concentration increase (Ian and Jun-Ying, 2001; Shanshan *et al*., 2005; Jun-Ying *et al*., 2000; Wei *et al*., 20011). As the nitrogen is lower, the quantity of argon met stable states is enough to excite the nitrogen molecules to give out UV. So Arm can excite the nitrogen molecules more effectively. More UV emission will be given out.

Figure 4 shows the UV concentration in radiation versus voltage at different nitrogen concentrations. With nitrogen concentration increasing, the IUV/IIR increases. Meanwhile, lower nitrogen concentration will result in more argon relative species, which give out higher near IR emission. The UV emission in the total emission dropped with nitrogen concentration increasing. This can be proven in the lamp spectra, which is shown in Fig. 5.

Figure 5 shows the spectra of the UV lamp. There are mainly two parts of spectra lines which locates at UV region and near IR region. They are nitrogen related species and argon related species respectively. The near IR emission power density at 1 percent nitrogen is more intense than that at 5 percent. When a pulsed discharge of a short duration excites the mixture of argon and a small amount of nitrogen, the excited species in the plasma are mainly argon related species. Argon met stables (Arm), which has longer lifetime, act as the energy source of the UV and VUV emission (Kenji, 2006; Isaac *et al*., 2007; Portela *et al*., 2011). In our experiment, the UV emission acceptors are mainly nitrogen molecules. Arm also provides energy to the other argon related species and gives out near IR emission. So a competition occurs between argon and nitrogen species. When nitrogen concentration increases, more nitrogen molecules existing in the mixture will cause higher UV emission power proportion. However, as argon concentration dropping, Arm concentration drops. The total UV power density decreases at the mean time.

The UV power and pressure: Figure 6 shows the experimental curves of UV power density versus voltage at different pressures. The pulsed power supply repetition is 40 kHz. The UV lamp performs better when the pressure is at 200 and 300 torr. From 200 to 400 torr, the UV power density emission performance becomes worse, which is similar to that of 100 torr.

In argon-nitrogen discharge, the UV emission performance rests on the quantities excited nitrogen. Excited nitrogen molecules get energy from Arm by collisions. Therefore, nitrogen molecules and Arm concentration is the key to UV emission performance

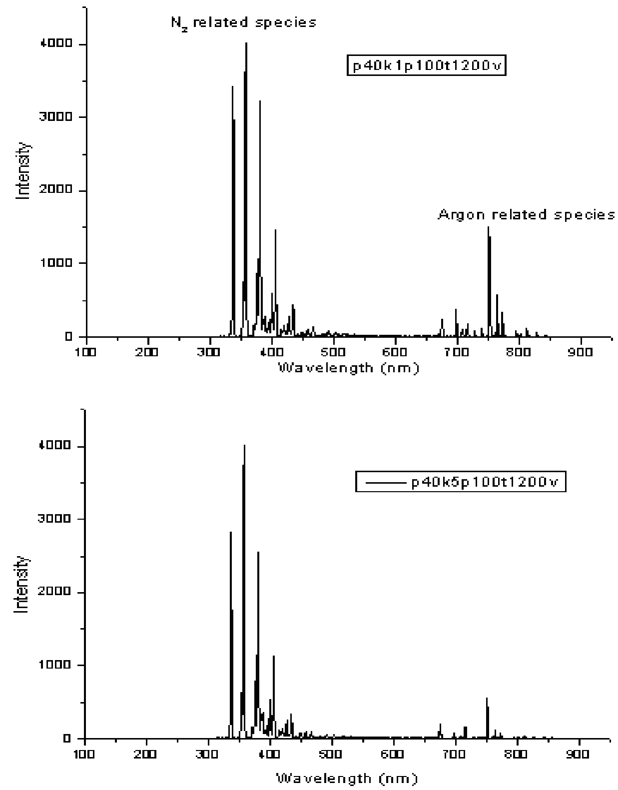

Fig. 5: The UV lamp spectra: 1 and 5 percent nitrogen in the argon-nitrogen: 100torr; 1200v, 40 kHz

(Yu and Boyd, 2007). At 100 torr or lower pressure, there are not enough nitrogen molecules colliding with Arm, so that more argon related species are excited and give out more near IR emission. At 200-300 torr, the nitrogen molecules are just suitable and the lamp will give out more UV emission and less near IR emission than at 100 torr.

From the spectra100 and 300 torr, more IR emission produced at 100torr than that of 300 torr. Therefore, we can conclude the nitrogen molecules absolute concentration at 300 torr is more suitable for the collisions between nitrogen molecules and Arm than that at 100 torr. More UV emission is produced at 300 torr. If the pressure goes on increasing, the plasma properties will change: the electron free path will shorten and the number of the excited species will reduce. So the lamp will perform worse when the pressure gets to 400 torr or above.

The UV power at different gas gap distances: Figure 7 show the dependence of the power density on voltage at different gap distances (0.5, 0.7 and 1.0 mm, respectively) in the flat panel UV lamps. It is found that the lamp with the 0.7 mm-gap-distance has the highest power density 18.6 m W/m^2.

The proper gas gap distance is favorable for the energy transferred between molecules and electrons, which lead to more radicals and the higher power density. If the gas gap distance is too large, the

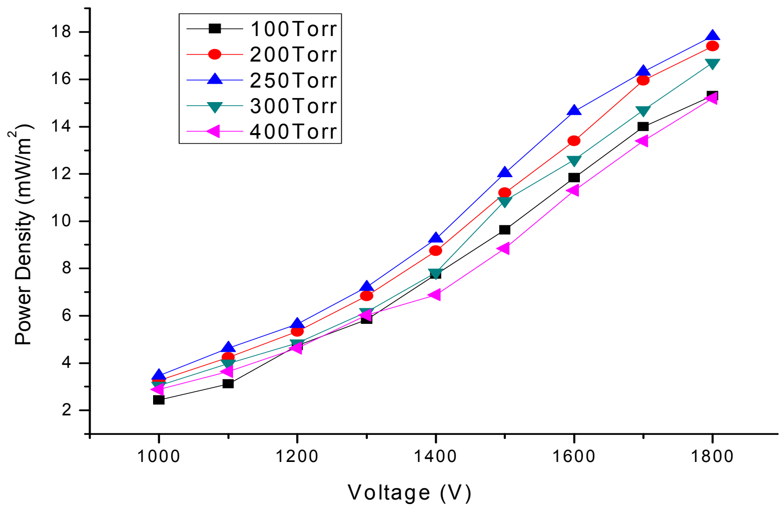

Fig. 6: Power density versus voltage at different N2 concentrations

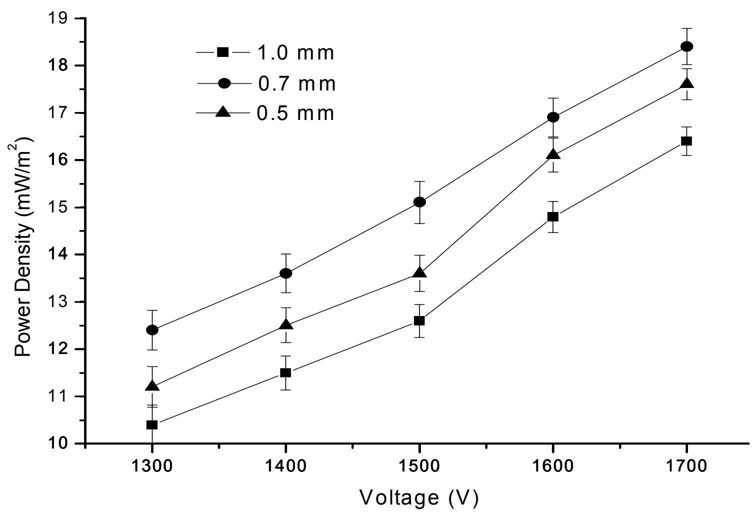

Fig. 7: Dependences of power density on voltage for different gas gap distances: 1.0 mm, 0.7 mm, 0.5 mm

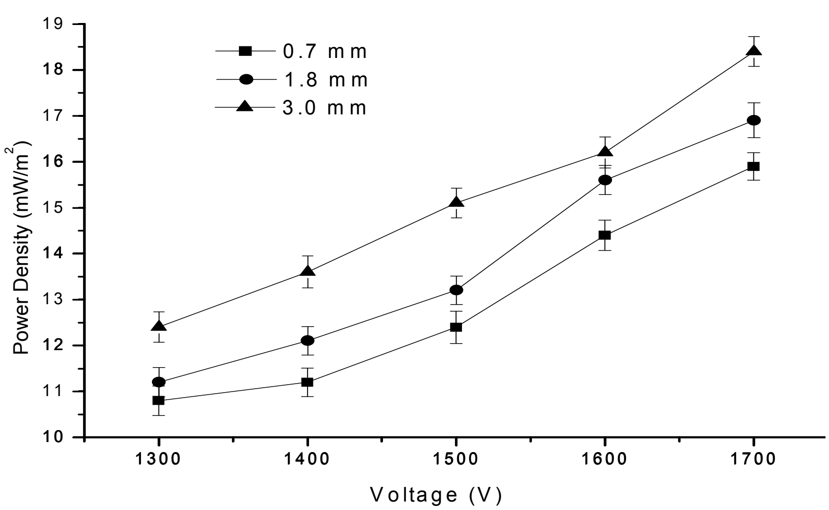

Fig. 8: Dependences of power density on voltage for different glass thicknesses: 0.7 mm, 1.8 mm, 3.0 mm

decreased electrical field causes lower electron density and less radiation. The large gas gap distance provides more chances of the UV photons caught by the molecules. Therefore, the power density would decrease. If the gas gap distance is too small, the electrons have not enough mean free paths to accelerate and excite molecules, which would cause less radicals and the lower power density.

The UV power at different glass thicknesses: Figure 8 shows the dependence of the lamps power density on the voltage in lamps at different front glass thickness (0.7, 1.8 and 3.0 mm, respectively). The gas gap distance and the pressure were kept at 0.7 mm and 250 torr. The front glass panel thickness has much influence on the lamps power density and the lamp with 3.0 mm thick glass performed the best in our experiment.

From the point view of circuit, the UV lamp can be taken as a parallel load composed of a resistance and a capacitance (Klausch *et al*., 2012). The lamp was made of two flat glass panels. The front panel was usually a glass with ITO layer on the outside surface. Therefore, the capacitance of the lamp is the sum of what of the front glass and the working gases. When the lamp works, the gas will turn into plasma which can be taken as a conductor. The capacitance of the front glass was the main factor to the lamp. In the three samples, the 3.0 mm thick glass has the lowest capacitance. It leads to the lowest invalid power in the circuits which leads to the highest power density.

CONCLUSION

Flat panel UV lamp with a size of 125×80 mm and a power density of about 20 mW/m^2 UV emissions is obtained by optimizing the gas compositions, the pressures, the gas gap distance and the front glass thickness. It is found that the lamp can emit intense UV emission by vehicle of argon-nitrogen discharge. At 200-300 torr and less than 5% nitrogen in argon-nitrogen mixture discharge, the lamps UV emission performance is much better than those at the other conditions. The results show that the proper gas pressure and gas composition could increase the power density.

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