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Micro-gap DBD Plasma and Its Applications

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Abstract : The Dielectric Barrier Discharge (DBD) is a nonequilibrium gas discharge that is generated in the space between two electrodes, which are separated by an insulating dielectric layer. The dielectric layer can be put on either of the two electrodes or be inserted in the space between two electrodes. If an AC or pulse high voltage is applied to the electrodes that is operated at applied frequency from 50Hz to several MHz and applied voltages from a few to a few tens of kilovolts rms, the breakdown can occur in working gas, resulting in large numbers of micro-discharges across the gap, the gas discharge is the so called DBD. Compared with most other means for nonequilibrium discharges, the main advantage of the DBD is that active species for chemical reaction can be produced at low temperature and atmospheric pressure without the vacuum set up, it also presents many unique physical and chemical process including light, heat, sound and electricity. This has led to a number of important applications such as ozone synthesizing, UV lamp house, CO2 lasers, et al. In recent years, due to its potential applications in plasma chemistry, semiconductor etching, pollution control, nanometer material and large area flat plasma display panels, DBD has received intensive attention from many researchers and is becoming a hot topic in the field of non-thermal plasma.

1. Introduction

The historical roots of the research and application of DBD can trace back to the 1860s, although it has been known and used over 100 years, but detailed investigations into the structure and the properties of DBD were carried out only during recent twenty years. Many investigations showed that DBD can present two modes, “micro-discharge” and “glow discharge”. Although many researchers have presented some research results about the glow discharge mode in a DBD reactor at atmospheric pressure, the glow discharge mode requires a few special operation conditions that can not be fulfilled in most cases. At atmospheric pressure, most applications of DBD operate in this micro-discharge mode, a local micro-discharge is actually a course during which a micro-streamer is formed, developed and extinguished in DBD volume. When the streamer reaches dielectric layer surface,

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electric charges in a micro-discharge does not disappear rather deposit on surface of dielectric layer owing to low conductance rate of the dielectric. Thus a special electric charges layer, which is called interface area plasma, is formed by large numbers of micro-discharges. It can influence physical course and chemical reaction of DBD plasma markedly. In this paper four aspects of the study are presented:

2. Electric charges deposition and the interface area plasma formation

DBD radiation characteristic not only can be used to describe the ionization state of working gases, but also can be employed to observe deposition course of electric charges on dielectric layer surface. Employing a DBD device with a transparent electrode and a side view, the radiation characteristic of micro-gap DBD plasma is studied at atmospheric pressure. Result shows that deposition electric charges and its distribution on dielectric layer surface are brought out by micro-streamer discharges, some factors such as the applied voltage, applied frequency and the configuration of DBD can affect the interface area plasma that is made up of these deposition particles, in turn deposition electric charges can influence micro-streamer evolution; These electric charges on dielectric layer surface mostly are high energy electrons, they can carry out plasma chemical reaction easily on the interface area, thereby the interface area can effectively affect the capability of DBD; For the DBD whose one electrode is covered with dielectric layer strong interface area radiation occurs, and obvious filaments characteristic are presented. For the DBD whose both electrodes are covered with dielectric layer a dispersive homogeneous interface area radiation on surface of two dielectric layers can be produced, and clear pseudo-glow characteristic are presented; Some methods, including the narrow discharge gap and thinner dielectric layer, high-frequency high-voltage power supply, are very effective in increasing the electrical filed strength and power density in discharge gap of DBD, by applying such methods the capability of DBD reactor is enhanced. These are useful means for accomplishing strong ionization discharge at atmosphere pressure.

3. Micro-gap DBD plasma source at atmospheric pressure

DBD capability is restricted by configuration parameter, dielectric materials, performances of power supply, working condition et al. Of all configuration characteristics the width of discharge gap is a key factor for DBD. while the exceeding high voltage isn't needed, the amount of deposition electric charges are obviously increased owing to added micro-streamers; the ideal dielectric materials for DBD reactor requires appropriate dielectric constant, higher insulation intensity, lower energy loss, higher mechanical intensity, and capability of resisting heat or electric impact; the power supply parameters and working condition are very important for DBD. Any factor being mentioned in the front can affect the interface area plasma in DBD reactor. Thereby, capability of the DBD plasma source can be enhanced by optimizing a few factors such as using micro-gap, thinner Al2O3 dielectric layer in the DBD reactor, and applied high frequency power supply, et al.

4. Systematic resonance on the large volume micro-gap DBD plasma source

If the discharges area of DBD reactor is extended, abnormal phenomena that discharge capability declines with the increasing frequency of power supply can be observed in many DBD reactors. In order to solve the problem, the variety of discharge parameters of DBD is studied using charge-voltage measure. Results show that the resonance is caused by the transformer inductance leaking and the equivalent capacitance of the dielectric layers. The resonance not only cause some unconventional variety to discharge parameters such as gap voltage, dielectric layer voltage, gap resistance, et al, but also damages the transformer and insulation of dielectric layers of DBD. Thus decreasing transformer inductance leaking and the equivalent capacitance of dielectric layer is an effective method to solve the resonance problem of DBD device.

5. Some typical applications of micro-gap DBD plasma source at atmospheric pressure

The micro-gap DBD plasma source at

atmospheric pressure basing on the interface area plasma principle has been employed in many fields such as the generation of high concentration ozone and dissolved ozone, treatment of harmful micro-organism in seawater, as well as non-equilibrium plasma chemistry synthesis et al. The highest ozone concentration and its efficiency are 250g/m^3 and 100g/kW·h, respectively, which are much higher than that of a conventional DBD generator, furthermore its volume is reduced to 1/6 that of conventional DBD generators. High concentration ozone is dissolved in water with the mass transfer efficiency of 98.8%, dissolved ozone concentration above 8 g/m^3 is obtained by means of the injector and the dissolved vessel of gas/liquid. Hydroxyl radicals produced from O_2 and H_2O have shown good effect on killing the harmful micro-organism in red tide and ship's ballast water, which provides an ideal, "green", environmental-friendly method for two serious ocean environment problems. The concentration of NH_3 synthesized by the strong ionization discharge reaches 12500ppm, and liquid fuel is gained in plasma chemical production, which is a new method for the non-equilibrium plasma chemistry synthesis at atmospheric pressure.

For the next work, it will be very interest using techniques of Electrophoretic Thick Film Deposition (ETFD) on the metal electrode to generate efficient plasma at atmospheric pressure of ambient air and water bubbles which was researched and developed in the Semiconductor Technology Research Center (STRC) of Myong-Ji University (MJU), Korea, supervised by Prof. D. W. Soh who is an outstanding scientist and Scientific Academician of IHEAS.

6. Application for the killing of invasive species

The bacteria concentration is 2.6×104/mL; the mono-cell algae concentration is 2.0×104/mL; the protozoan concentration is 1.5×104/mL. After the injection of hydroxyl solution, the samples are taken out in five points of A, B, C, D and E respectively with the duration of 0.0s, 1.33s, 2.67s, 5.33s, 8.00s. The effect of hydroxyl duration on the organism concentration is shown in Fig.3. When the ratio concentration is 0.6mg/L, the duration that the hydroxyl radicals kill all of bacteria and protozoan is only 1.33s, the kill efficiencies reach 100%. When the duration is in the range of 1.33~2.67s, the concentration of algae is decreased into 1.1×103/mL and no-test respectively. When the duration is above 2.67s, the kill efficiencies of bacteria, mono-cell algae and protozoan are 100%. The experimental results indicate that all organisms in ballast water could be killed in ship in line.

7. Conclusions

From the DBD plasma application experiment, the treatment of ship's ballast water using OH· radicals is a kind of advanced oxidation method, which realizes Atom Economy, Zero Emission and Zero Pollution in the process of the production of OH·radicals and the kill of organisms of ship's ballast water. Invasive marine species can be killed in ship in the process of the discharge or inputting ballast water.

(1) OH·radicals are dominantly produced from the positive ions O_2^+ reacting with H_2O to form the water cluster ions.

(2) With the 20t/h pilot-scale system for the treatment of ship's ballast water, the kill efficiencies of bacteria, mono-algae, protozoan reach 100% within 2.67s when dissolved OH· concentration is 0.6mg/L.

(3) The contents of chl-a, chl-b, chl-c and carotenoid are decreased to 35%-64% within8.0s further to the lowest limit of test after 5 minutes.The content of phaeophytin is increased to ten times. Hydroxyl radicals make phytoplankton lose its activity finally resulting in all mono-cellalgae to be killed.

(4) The equipment of dissolved hydroxyl radicals has some advantages such as small volume, simple operation and low running cost which is only 1/30 in comparison with the open-ocean-exchange of ship's ballast water.

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