Journal of Electrostatics 83 (2016) 16–21

Contents lists available at ScienceDirect

Journal of Electrostatics

journal homepage: www.elsevier.com/locate/elstat

Electrical and spectral characteristics of a tube-to-plate helium plasma generated using dielectric barrier discharge in water

Junnan Liu [a], Jing Pan [a], Jinhai Niu [a], Yangyang He [a], Jing Zhang [a], Dapeng Dong [a],
Yi Hong [a, *], Zhenhua Bi [a], Weiyuan Ni [a], Jie Li [b], Yan Wu [b]

[a] School of Physics and Materials Engineering, Dalian Nationalities University, Dalian, 116600, People's Republic of China
[b] Institute of Electrostatics and Special Power, Dalian University of Technology, Dalian, 116024, People's Republic of China

ARTICLE INFO

Article history:
Received 14 April 2016
Received in revised form
6 July 2016
Accepted 9 July 2016

Keywords:
Dielectric barrier discharge
Optical emission spectrum
Electron temperature
Electron density

ABSTRACT

A tube–to-plate dielectric barrier discharge He plasma was directly generated in water by 8 kHz sinusoidal excitation voltage. It was found that the average power, rotational temperature of OH, electronic excitation temperature, electron temperature, and electron density increased linearly with the increase of applied voltage and with the value in the range of 3.65–11.13 W, 427–529 K, 4355–4533 K, 1.15–1.96 eV, and 2.56×10^{14}–5.76×10^{14} cm^{-3}, respectively. Furthermore, the optical emission spectrum indicated that active He*, O*, N_2*, N_2^+*, and OH* species existed in He plasma.

1. Introduction

In the past decades, dielectric barrier discharges (DBDs) have attracted growing attention in organic pollutants removal from water [1–5]. It is demonstrated that electrical discharges of DBD applied in water could directly or indirectly cause organic compound degradation by physical and chemical effects. Physical effects include the contribution of ultraviolet light and shock waves produced by plasma discharges which depend on their intensity [5–7]. Chemical effects include direct formation of reactive species such as OH*, O*, H*, H_2O_2 and O_3, which are able to react readily with a large group of organic chemicals to form more oxidized intermediate products [5–7]. Furthermore, the DBDs are stable, which can not only prevent spark formation, eliminate electrode etching and corrosion, but also lead to an uniform discharge distribution over the entire electrode area compared with other discharges including electrohydraulic discharge, corona discharge, arc discharge, and spark discharge [8].

Currently, the electrical discharge of DBD in water used to remove organic contaminants could be divided into two main groups, namely electrical discharge inside the reactor immersed in water and direct electrical discharge in water. The plasmas need to transfer a section of distance before reacting with organic pollutants for the electrical discharge inside the reactors which are immersed in water [9–12], leading to disappear of short lifetime active species before chemical reactions. It could seriously affect the degradation efficiency of organic pollutants in water, because the short lifetime active species such as OH* and O* play an important role for organic pollutants removal. On the other hand, the direct electrical discharge in water could avoid this problem. Those active species produced by directly electrical discharge in water could sufficiently react with organic pollutants before disappearing, which is very beneficial for organic pollutants degradation. However, the report related to direct electrical discharge of DBD in water is rare to see.

H. Wu et al. generated DBD plasma by a needle-to-plate electrodes in water to investigate the feasibility of aniline degradation in water [13]. Since the discharge was ignited without pre-existing gas bubbles, a large fraction of energy was converted to heat for producing gas bubbles which were subsequently ionized by a large electric field. It is generally accepted that the electrical discharge in water is initiated in the gas phase-bubbles [14]. If the bubbles are preformed by injecting a gas into water, the energy balance could be improved with more energy used to generate chemically active species and the breakdown field strength could be obviously reduced [15]. B. G. Rodríguez-Méndez et al. generated pulse DBD

---

* Corresponding author.
E-mail address: hongyi@dlnu.edu.cn (Y. Hong).

http://dx.doi.org/10.1016/j.elstat.2016.07.002

plasma by a wire-to-cylinder electrodes under pre-existing gas bubbles in water [16], but the applied voltage was as high as about 25 kV. Moreover, the discharge ignited by alternating current power supply requires higher applied voltage for this kind of device, because it does not inject large energy into bubbles in a short duration time (nano to microseconds) to accelerate electrons which ionize gas molecules to produce plasma.

For these reason, a DBD He plasma was generated using a tube-to-plate electrodes in water and powered by a sinusoidal excitation voltage at 8 kHz. The discharge was ignited with a low applied voltage in water, because the seed charge was generated in the quartz glass tube in advance and transferred by electrical force into bubbles which were preformed through injecting He gas into water before discharge. Thus, the discharge path was easily formed in water. The aim of this work is to analyze the discharge characteristics of DBD He plasma in water. The conduction current, displacement current and average power were determined by electrical diagnosis, and the rotational temperature of OH, electron excitation temperature, electron temperature and electron density were obtained by optical emission spectroscopy.

2. Experimental setup

Fig. 1 shows the schematic diagram of experimental apparatus and discharge photograph. The power electrode is a stainless steel tube, 2 mm in outer diameter, 1.8 mm in inner diameter, and 250 mm in length. In order to generate seed charge in gas phase in advance and prevent contacting with water, the power electrode is tightly inserted into quartz glass tube and the open end is placed in the distance of 3 mm away from the exit of quartz glass tube. The quartz glass tube owns an inner diameter of 2 mm, an outer diameter of 3 mm, and a length of 200 mm and it is vertically immersed in water at a depth of 30 mm. The tap water is held in a transparent quartz glass vessel which consists of a quartz glass plate and a cylindrical quartz glass tube. The cylindrical quartz glass tube is 32 mm in outer diameter, 30 mm in inner diameter, and 70 mm in length. The quartz glass plate is 50 mm length, 50 mm width, and 1 mm thickness. Distance between the open end of power electrode and the bottom of quartz glass vessel is 10 mm. A copper foil is tightly attached on the outside surface of quartz plate as a ground electrode which is 40 mm length, 40 mm width, and 0.2 mm thickness.

The gas bubbles were formed between the power and ground electrodes by injecting working gas of He (99.999%) into water which was controlled by mass flow controller at flow rate of 2 L/min. The applied voltages and currents were measured by a high voltage probe (Tektronix P6015A) and a 20 Ω resistor in series with the ground electrode, and the electrical signals were recorded via a digital oscilloscope (Tektronix MDO3012). An optical fiber was used to collect the optical emission of DBD plasma and located in the position which was 2 and 3 mm away from the cylindrical quartz glass tube and the quartz glass plate respectively. The spectral intensities were recorded by a spectrometer (Acton Research Spectrapro-2500i) with 300 grooves/mm gratings (spectral lines, 300–900 nm) and 2400 grooves/mm gratings (OH line, 306–312 nm and H_α line, 656.3 nm). The resolution and slit width of spectrometer were 0.02 nm and 20 μm, respectively. The discharge images were obtained by a Canon digital camera EOS 5D Mark III.

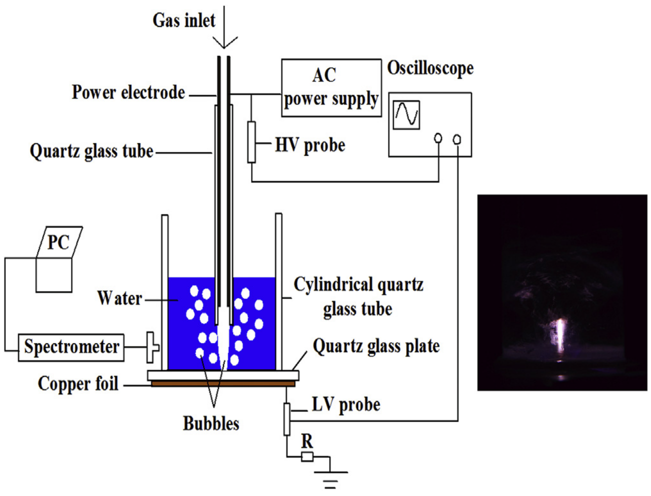

Fig. 1. Schematic diagram of experimental setup and discharge photograph at a peak applied voltage of 8.2 kV and Ar flow rate of 2 L/min.

3. Experiment results and discussions

3.1. Electrical discharge characteristics

Fig. 2 shows a typical waveforms of applied voltage $U_{\text{tot}}(t)$, total current $I_{\text{tot}}(t)$, conduction current $I_{\text{dc}}(t)$, and displacement current $I_{\text{dp}}(t)$ at the peak applied voltage of 8.2 kV. The measurement methods of conduction and displacement currents have been reported in detail in the previous studies [17,18]. In Fig. 2, the phase difference between total current and applied voltage waveforms is almost 90°, which indicates that the impedance of DBD device is capacitive. The amplitude of displace current is much smaller than that of conduction current, in other words the conduction current takes up a large proportion in total current. It is indicated that the

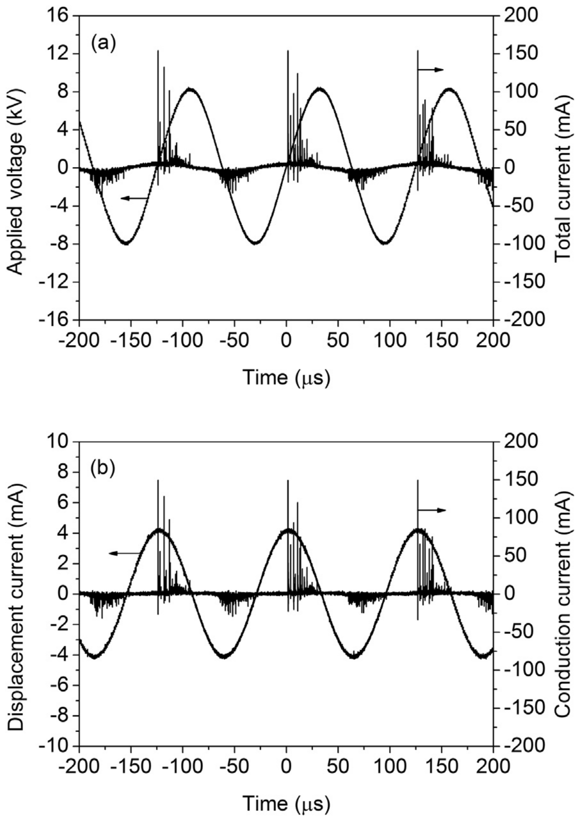

Fig. 2. Applied voltage and total current waveforms (a) and displacement and conduction currents waveforms (b) at a peak applied voltage of 8.2 kV.