Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy 117 (2014) 535–540

Contents lists available at ScienceDirect

Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy

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

The influencing factors of nanosecond pulse homogeneous dielectric barrier discharge in air

Shuai Zhang, Li Jia, Wen-chun Wang *, De-zheng Yang, Kai Tang, Zhi-jie Liu

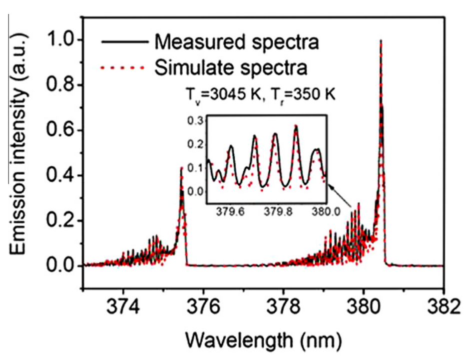
Key Lab of Materials Modification, Dalian University of Technology, Ministry of Education, Dalian 116024, China

HIGHLIGHTS

- Bipolar nanosecond pulse voltage was used to generate homogenous discharge.
- Using electrical and optical methods to diagnose the discharge plasma.
- The T_{rot} and T_{vib} were determined at $T_{rot} = 350 \pm 5$ K and $T_{vib} = 3045$ K.
- The effects of discharge parameters on the HNPDBDs were investigated.

GRAPHICAL ABSTRACT

Homogenous dielectric barrier discharges were obtained in different conditions and the rotational and vibrational temperatures (T_{rot} and T_{vib}) are determined at $T_{rot} = 350 \pm 5$ K and $T_{vib} = 3045$ K.



ARTICLE INFO

Article history:
Received 11 April 2013
Received in revised form 4 August 2013
Accepted 14 August 2013
Available online 24 August 2013

Keywords:
Homogeneous dielectric barrier discharge
Nanosecond pulse
Air discharge
Electrical and optical measurements
Atmospheric pressure

ABSTRACT

In this paper, a bipolar nanosecond high pulse voltage with 20 ns rising time was employed to generate homogeneous dielectric barrier discharges using the plate–plate electrode configuration in air at atmospheric pressure. The effects of pulse peak voltage, gas discharge gap, and dielectric plates made by different materials or thicknesses on the discharge homogeneity, voltage–current waveform, and optical emission spectra were investigated. Results show that aforementioned parameters have a strongly impact on the discharge homogeneity and the optical emission spectra, but it is hard to identify definitely their influences on the discharge voltage–current waveform. Homogeneous discharges were easily observed when using low permittivity dielectric plate and the emission intensity of N_2 ($C^3\Pi_u \rightarrow B^3\Pi_g$, 0–0, 337.1 nm) increases with the rising of pulse peak voltage and the permittivity of dielectric material but decreases with the increasing of gas discharge gap and the dielectric plate thickness. The rotational and vibrational temperatures (T_{rot} and T_{vib}) were determined at $T_{rot} = 350 \pm 5$ K and $T_{vib} = 3045$ K via fitting the simulative spectra of N_2 ($C^3\Pi_u \rightarrow B^3\Pi_g$, 0–2) with the measured one.

Introduction

Homogeneous discharge, also called glow-like discharge, characterized by its advantages of the moderate power density, the uniform energy distribution, high conversion efficiency of active ingredients, and so on [1–4], has been widely applied to thin-film deposition [5,6], surface modifications of polymers [7–9], and biological and chemical decontamination of media [10,11]. In the past two decades, homogeneous discharge was mostly generated by direct current (DC) or alternating current (AC), etc., [5,9,10]. However, these kinds of discharges have the disadvantages of high gas temperature, high energy consumption, and requiring harsh conditions, etc. which limit its industrial applications to a great extent.

* Corresponding author. Tel.: +86 15714066718; fax: +86 411 84709304.
E-mail address: wangwenc@dlut.edu.cn (W.-c. Wang).

1386-1425/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.saa.2013.08.051

Nanosecond high-voltage pulse discharge (NHVPD) is characterized by fast rising time of pulse voltage, the electrical energy delivered in plasma discharge is mainly deposited in the energetic electrons instead of heating the heavy particles [11], therefore NHVPD exhibits many unique advantages over other discharge types, such as very high energy efficiency in production of active species and very low plasma gas temperature etc. [12,13]. On the other hand, NHVPD is an effective method to prevent glow-to-arc transition (GAT) with optimizing the ionization efficiency at AP [14]. Hence a high pulse voltage with short rising and duration time can be employed in producing glow discharge plasma even when the current density is above the threshold for GAT [15,16]. Osculating the advantages of uniform discharge and NHVPD, the homogeneous nanosecond pulse discharge has been studied by many researchers in non-thermal plasma area [17–28].

As an effective way to generate uniform NHVPD, nanosecond pulsed dielectric barrier discharge (NPDBD) has been successfully obtained in air at atmospheric pressure (AP). Table 1 show the parameters of homogeneous nanosecond pulsed discharges that have been reported. It can be found that homogeneous nanosecond pulsed discharge can be generated in wide range of pulse peak voltage, pulse repetition rate, gas discharge gap, pulse rising time, pulse width, et al. with different electrode configurations [19–28]. However, those researches just pay attention to the diagnosis or application investigations of the homogeneous nanosecond pulsed discharge [19–21,25–28], or influence of few of the parameters on the performance of the discharge [22–24]. Hence, a comprehensive and exhaustive investigation on the effects of those parameters on the characteristics of nanosecond pulse discharge is imperative.

In this paper, a bipolar nanosecond voltage pulse with 20 ns rising time is employed to generate low gas temperature homogeneous dielectric barrier discharge in air at AP. The methods of discharge image, electrical measurement and spectral measurement were employed to characterize the discharges, respectively. Then the effects of dielectric material, dielectric thickness, pulse peak voltage, and gas discharge gap between electrodes on the characteristics of the discharges were investigated, respectively.

Experimental apparatus

The experimental apparatus is illustrated schematically in Fig. 1. It is composed of a bipolar pulsed power supply, a discharge reactor, a gas distributing system, an electrical measurement system, and an optical detection system. Switched by rotary spark discharge gaps and with the pulsed capacitors (C_p) repeatedly charged by the storage capacitors (C), the bipolar pulse power supply can provide high voltage pulse with a rising time of about 10 ns, a pulse width of about 30 ns, and an adjustable repetition rate in range of 0–400 Hz. A cylindrical stainless steel discharge reactor was used to control experiment conditions. The homogeneous discharge plasma was generated between two parallel plate electrodes, with both of them covered by dielectric plates that made by aluminum oxide ceramic, quartz glass, epoxy, or polytetrafluoroethylene (PTFE). The discharge voltage and discharge current were measured with a 1:1000 high-voltage probe (Tektronix P6015A 1000 × 3.0 pF 100 MΩ) and a current probe (Tektronix TCP312 Bandwidth 100 MHz), respectively, and both the waveforms were recorded by an oscilloscope (Tektronix TDS5054 500 MHz). The head of optical fiber was placed parallel to the electrode surface and can be adjustable in the lengthwise direction. The optical emission spectra from the discharge region was collected by a Solis-750 grating monochromator (grating groove is 2400 lines/mm, blaze wavelength is 300 nm). After the diffraction of the grating, the output spectral light can be converted into an electrical signal by CCD (Newton DU940P-BV, with a resolution of 2048 × 512 pixels and a pixel size of 13.5 × 13.5 μm) and stored by a computer according to experiment requirement. In order to reduce the interferences of discharge pulses on the detection system and other instruments, both the high-voltage pulse power supply and the measurement system are placed in a two-layer shielding box. Before the working gas is filled, the reactor is pumped to about 3 Pa by vacuum pump. Then high pure nitrogen (99.999%) and oxygen (99.999%) with fixed percentage are filled to atmospheric pressure. Gas flow is used when the experiment carried on and the total gas flow ($N_2 + O_2$) is kept at 200 ml/min for all the measurement.

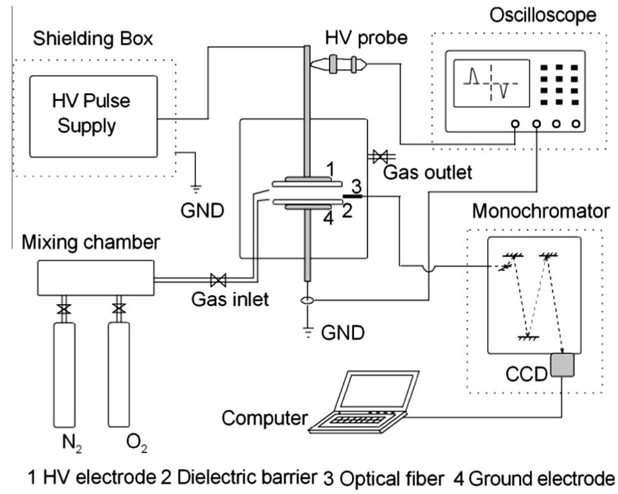


Fig. 1. Schematic of the experimental apparatus.

Results and discussion

Images and typical electrical characteristic of the HNPDBD

Homogeneous dielectric barrier discharge can be acquired in air at AP using nanosecond pulse power supply, and Fig. 2 shows images of HNPDBD captured by a commercial digital camera with exposure time of 500 ms using 1 mm thick ceramic plates under the condition of the pulse peak voltage of 30 kV, the pulse repetition rate of 150 Hz, and the gas discharge gap of 3 mm. As shown in Fig. 2a, the discharge is uniform and no filaments can be observed by naked eye. To distinguish the filament which may be obscured due to the average in the long time exposure, a single

Table 1
The parameters of reported homogeneous nanosecond pulsed discharges in air at AP.

Electrode configuration	PRT (ns)	Duration (ns)	U (kV)	F (Hz)	Gap (mm)	Dielectric material	Thickness (mm)	Refs.
Plate–plate	5	20	13	120	0.5	Quartz	0.66	Ayan [20]
Plate–plate	15	30	35	1 k	2	PTFE	2	Shao [22]
Plate–plate	10	65	4.4	5 k	1	Ceramic	2	Walsh [24]
Plate–plate	20	60	26–32	150	3.5	Ceramic	1	Yang [25]
Needle–plate	20	60	26–32	150	7	Quartz	1	Yang [26]
Wires-plate	20	60	28	150	3	Quartz	1	Zhang [27]
Surface DBD	20	30	15	600	2	–	–	Williamson [28]