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# Time resolved imaging of a dielectric barrier discharge by using pulsed power supply

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**Abstract:** Short exposure images of the Ultraviolet (UV) and both the visible and UV emission from a Xenon/Chlorine Dielectric Barrier Discharge (DBD), have been recorded to investigate the discharge structure for a pulsed power supply for various frequencies. The images from the pulsed discharge have shown that the plasma is essentially concentrated on the active electrode area. From the results obtained, it is indicated that the exciplexes formation area is drastically different, which depends on the power supply waveforms.

**Keywords:** Dielectric barrier discharge, Ultraviolet (UV), exciplexes, light sources.

## 1. Introduction

Ultraviolet (UV) sources have been investigated for many years by numerous researchers [1, 2, 3]. However, in these few years, UV sources have become an essential technology in several industrial sectors involving electronics (plasma display), chemical reactions, multilayer techniques and medical treatments (water and skin treatment). More recently, excilamps have become an attractive technology for the skin treatment through the application of highly intense UV at the wavelength of 308nm. DBD is an efficient method for stimulating ultraviolet emission from excimer or exciplexes and such UV sources are thus commonly called 'Excilamps'. There are many different excimers including rare gas excimers ( $\text{Ar}^*$ ,  $\text{Kr}^*$ ,  $\text{Xe}^*$ , ...) and rare gas halogen exciplexes ( $\text{XeF}^*$ ,  $\text{XeCl}^*$ ,  $\text{XeBr}^*$ ,  $\text{XeI}^*$ , and  $\text{KrCl}^*$ ). When we compare with UV sources using excimer - excitation techniques such as high electron beams, coronas, X-rays, synchrotron radiation and microwave, DBD is the most simple, low cost and easy to maintain. Thus DBD excilamp has a great potential as high power and efficient incoherent UV sources.

Some authors have studied the discharge modes on excilamp with different power supplies [6]. The discharge modes of DBDs can be divided mainly into two kinds: filamentary discharge (or micro discharge) and glow discharge (or diffuse discharge). The filamentary discharge is a typical characteristic of traditional ozone generators [1], but the characteristics of DBDs in some atomic gases such as helium, neon and argon at high pressure are of glow-like diffused discharge [2]. With a total pressure around 150mbar in a Xenon/Chlorine mixture we could see both

of these two kinds of discharge, when the power supply waveform is changed.

## 2. Experimental setup

Fig 1 presents a schematic diagram of a DBD excilamp excited by a pulsed power supply. The excilamp consists of two coaxial quartz tubes, which are the two dielectric barrier layers between outer and inner electrodes. The inner electrode is an aluminum rod connected to a high voltage source and the outer is a grounded wire mesh as displayed in Fig 1. Here, the pulsed power supply generates an unipolar (affected by ringing) voltage pulse with an amplitude about 4kV and in the frequency range between 50kHz and 250kHz. The waveform of this voltage is shown schematically in Fig 2. It consists in a rising front immediately followed by a falling front.

The excilamp is sealed with a mixture of chlorine (lower than 0.5%) and Xe at a total pressure around 150mbar. The high speed imaging experimental setup is presented on figure 1. The lamp is supplied by a pulsed power supply (2). A quartz lens (3) focuses the image of the excilamp on the photocathode of an Intensified CCD camera (4). This latter is a Roper Scientific PI-MAX. The controller (5) of the camera handles the synchronization of the acquisitions with the electrical parameters of the excilamp power supply. The oscilloscope registers these electrical parameters during the acquisition. The images intensified coming from the camera are transferred to the computer (6).

In order to study the development of the pulsed discharges, the frequency of the power supply is changed in the range 60kHz-160kHz. For each value of the frequency, the images of discharge were acquired with and without a low

pass optical filter (3). The resulting acquisitions are UV imaging, in the first case or visible + UV imaging in the second case.

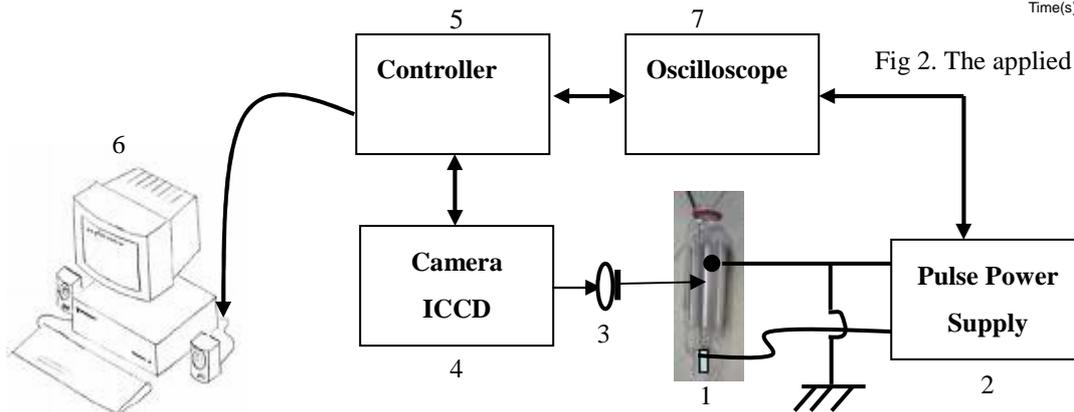


Fig.1 : Schematic diagram of DBD excited excimer experiment

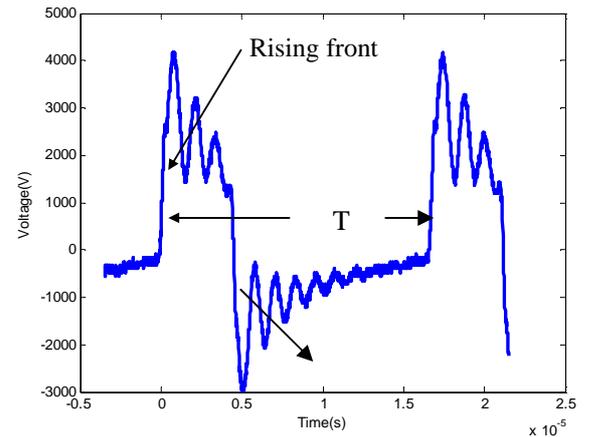


Fig 2. The applied voltage pulse

### 3. Results and discussion

Figures 4 and 5 (a,b) show the images of the emission of the excilamp for one period at the frequency of 60kHz and 120kHz. For these frequencies, Fig 3 and 6 show the synchronous time evolution of, respectively, the UV irradiance, and the UV+visible irradiance. Through the image of pulsed discharge obtained for 2 frequencies, it is indicated that the UV and visible +UV emission are essentially concentrated in the neighborhood of the dielectrics. However, the discharge in most of the case is not homogeneous and varies according to the position at the surface of the electrodes and also the frequency of the power supply.

At the frequency of 60 kHz, when the pulse voltage is rising, some filaments start forming and propagating on the surface of the internal dielectric Fig 4. Thus corresponds to the maximal peak of the irradiance at the time of  $3.0337 \times 10^{-7}$ s. During this process, the electron lose their energy due to the effects of relax ion and recombination, so that the discharge turns off, which corresponds to an irradiance equal to zero.

On the voltage falling front ( $4.49 \times 10^{-6}$ s) a second irradiance peak can be observed, localized this time on the outer tube surface.

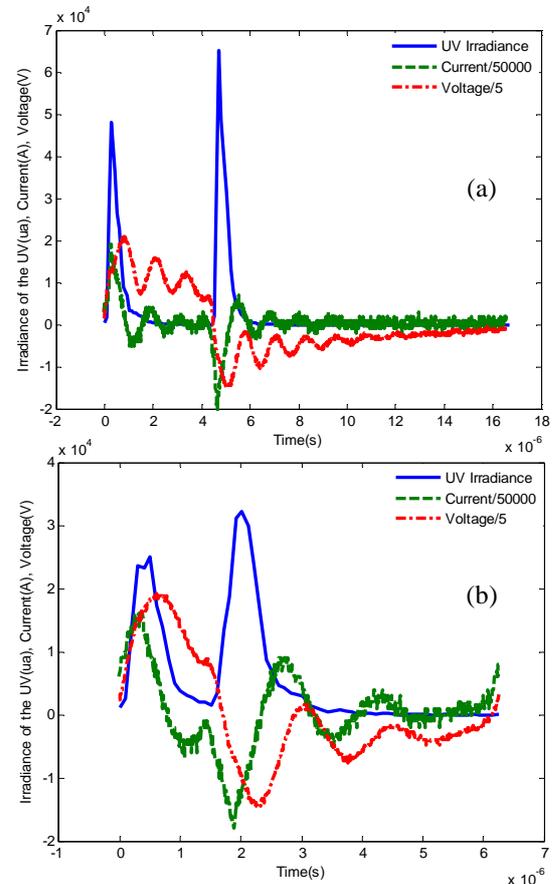


Fig.3. UV irradiance temporal variation of the DBD lamp at 60 kHz (a), 160 kHz (b)

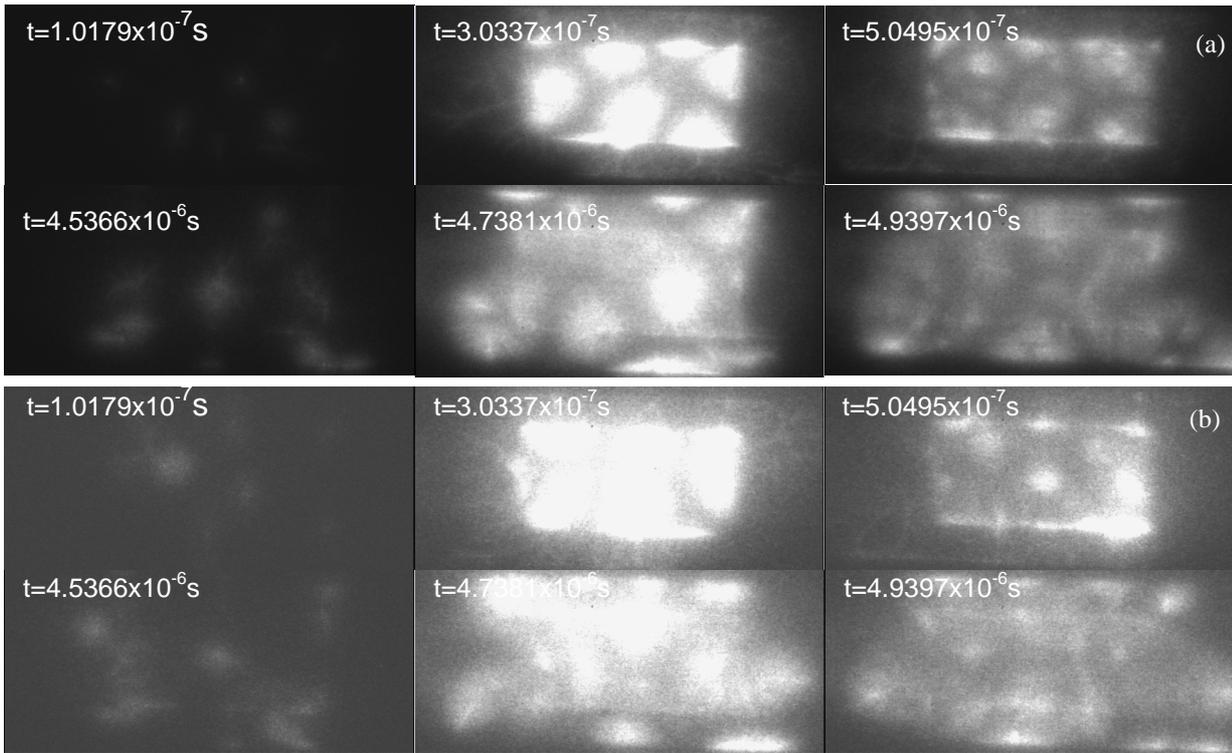


Fig 4: Image of pulsed discharge emission in the visible + UV (a) and only UV (b) at the frequency of 60kHz

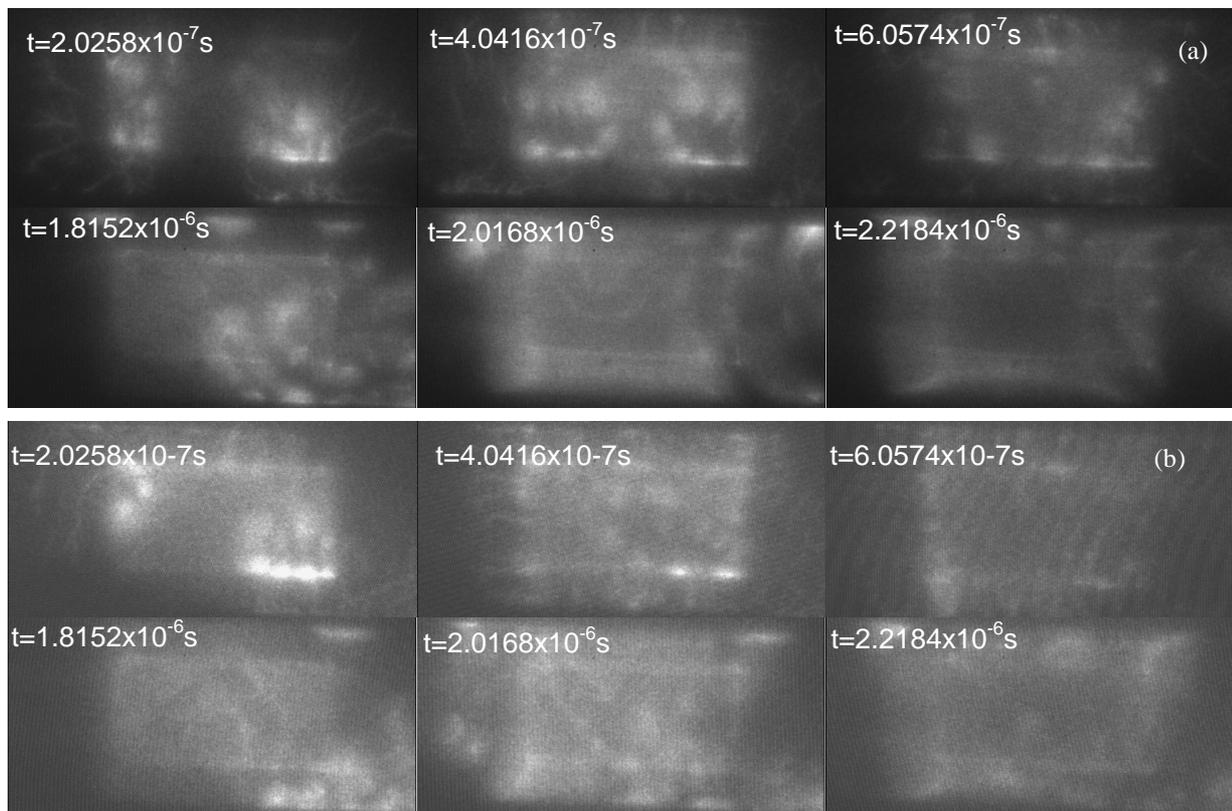
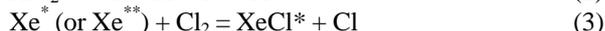
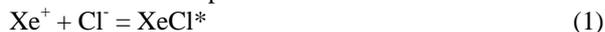


Fig 5 : Image of pulsed discharge emission in the visible + UV (a) and only UV (b) at the frequency of 160kHz

The aspect of this second discharge is more homogeneous than the first one. However, the region of the discharge is longer and expands above the two tips of the inner electrode. Under our experiment conditions, the  $B_{1/2}-X_{1/2}$  transition is the strongest one among various possible transitions between different electron excited states and ground states of the exciplexes  $XeCl^*$ , thus generating the main radiation at 308nm. The key reactions leading to the formation of  $XeCl^*$  exciplexes can be described as follows:



At the high concentration of Xe in the total pressure, the quenching of  $XeCl^*$  is associated with the formation of the tri-atomic species  $Xe_2Cl^*$ :



The generated  $XeCl^*$  and  $Xe_2Cl^*$  exciplexes undergo a spontaneous transition from excited state to weakly bonded ground state and emit UV photon:

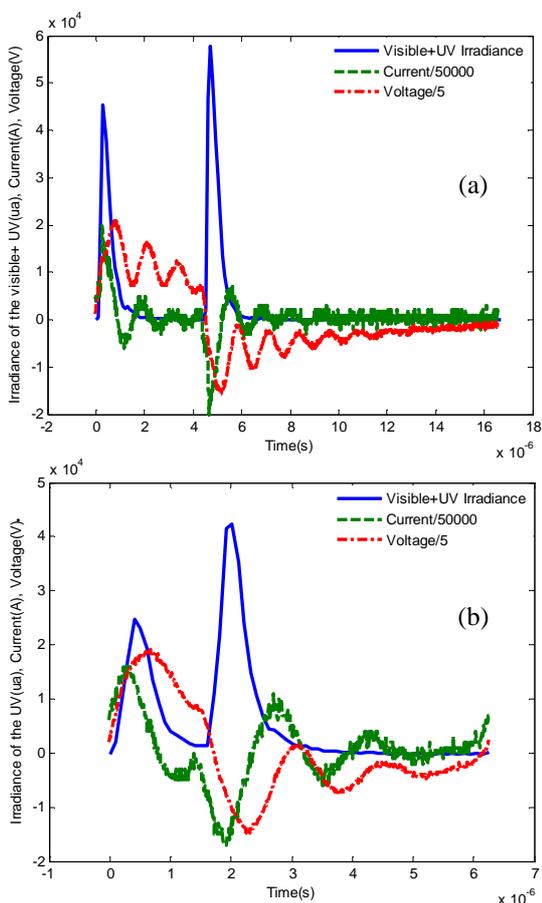
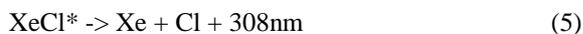


Fig.6. Visible + UV irradiance temporal variation of the DBD lamp at 60 kHz (a), 160 kHz (b)



With the increase of the frequency of the power supply

from 60kHz to 160kHz, the image of the pulsed discharge for both the visible + UV and UV emission have changed from some filaments to a more diffuse discharge as shown in Figure 5 (a,b). Similar to the frequency of 60 kHz, at the falling front of the voltage, the region of the discharge is also expanded above the two tips of the inner electrode.

In the same experimental condition and frequency, the intensity of the visible + UV emission is more intense than the only UV emission. However, when the form of discharge changes from the filament to a more diffuse discharge, the intensity of both the visible +UV and only UV emission decrease considerably because of the discharge diffusion far from the electrodes.

#### 4. Conclusions

In this paper, we have presented an experimental system dedicated to the fast imaging of the irradiative characteristics of DBD lamp. It was used on a Xenon/Chlorine excilamp with a low partial pressure of chlorine (about 0,5%) operated by a pulsed power supply. From the results obtained, it is indicated that the visible+ UV and only UV emission are essentially concentrated on the active electrode area. At the same frequency, the images of visible + UV and only UV emission have been recorded by the camera ICCD, there have not been the difference remarkable in the discharge between two cases. By changing the frequency we could get the difference discharges in filament or almost diffuse (more than 160kHz). It means that the exciplexes formation area depended on the power supply waveform.

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