# Generation of UV photons in a surface wave discharge at atmospheric pressure

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## 1. Introduction

In the last years, plasmas operated at atmospheric pressure have been the object of increased attention due to their potential and current use in variosus applications such as excitation for elemental analysis [1] and, more recently, sterilization of medical instruments [2], which consists in destroying or eliminating all forms of life, specially microorganisms. From this last application, direct exposition of the microorganisms to the action of the plasma (or afterglow) species and/or emitted photons is carried out. The agents of sterilization have been extensively studied in recent years, however it is not clear which agent (species or UV photons) plays the main role in sterilization. On one hand, Boudam *et al*. [3] have found a greater capability for inhibition/inactivation of microorganisms by ultraviolet photons emitted by plasma. On the other hand, Dobrynin *et al*. [4] show that the charged species play the main role in inactivation. In this way, the porpouse of this paper is to show the results obtained on the generation of UV radiation from de-excitation of $NO(A^2\Sigma^+)$ specie to the ground state $NO(X^2\Pi)$ and, the emission of the $(A^2\Sigma^+) \rightarrow (X^2\Pi)$ transition from the de-excitation of OH radical by a surface wave discharge at atmospheric pressure (SWD) using different gas mixtures.

## 2. Experimental device

In Figures 1a and 1b a schematic drawing of the devices used to generated the discharge and register the radiation emitted by it is shown. The plasma was created in a quartz tube with one of its end opened to the atmosphere. The inner and outer diameters of the discharge tube were different depending on the mixture used. In this way, several gas mixtures were used, the discharge was always ignited in argon in which small amounts of reactive gases (air, $N_2$, $N_2O$, vapor of $H_2O_2$ and dropplets of $H_2O$) were added. A bubbling system was utilized in order to introduce $H_2O_2$ and $H_2O$ into the discharge (Figure 1a).

The microwave (2.45 GHz) power used to create and maintain the discharge was supplied in a continuous mode by a SAIREM generator (GMP12kT/t) and coupled to the plasma by

means of a surfatron device (Figure 1b) [3]. A stub system was also handled in order to ensure that the reflected power was less than 2% of the incident power. The power values were different depending on the gas mixture used to generate the plasma.

At the end of the plasma, a post-discharge (or afterglow) was also observed. The plasma and the post-discharge lengths were different for each one of the gas mixture used to generate the plasma. In this research, the radiation emitted by it was recorded by an optical fiber and directed to the entrance of a Jobin-Yvon monochromator (1000M, Czerny-Turner type) with 1 m of focal length and a holographic diffraction grating of 2400 lines/mm. A CCD camera was used as radiation detector (Symphony CCD-1024x256-OPEN-STE).

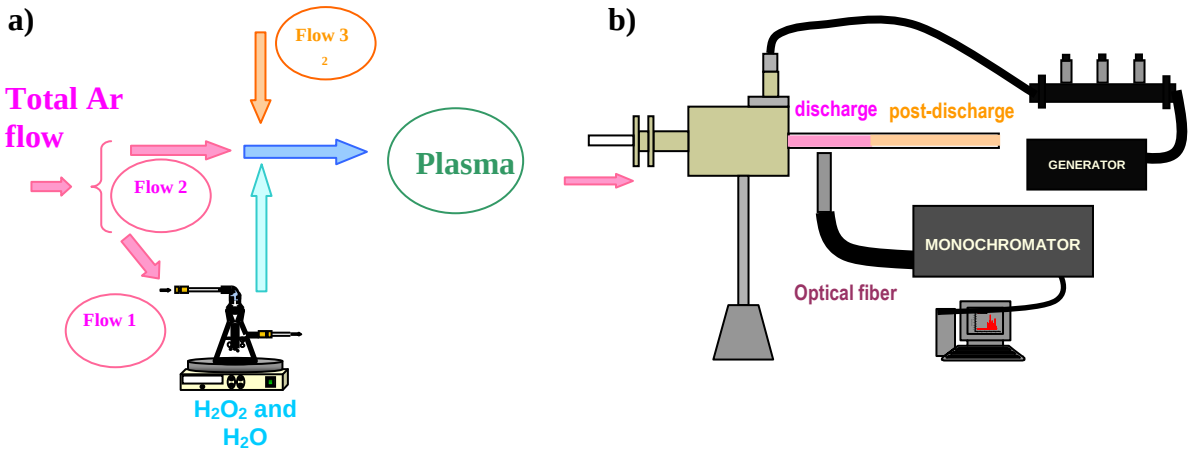


**Figure 1.** Experimental set up: a) bubbling system and b) experimental device used in the experiments

## 3. Results and discussion

In this part of the paper emission of UV radiation using different mixture of gases to generate the discharge is presented. Four different mixtures have been studied. The first one was composed of Ar, $N_2$ and $H_2O_2$ which was introduced using bubbling method. Other one, was a mixture of Ar, $N_2$ and air and the last discharge was created adding $N_2O$ to Ar gas in order to obtain the NO excited specie. As far as emission of OH species, plasma was generated with Ar gas and dropplets of water using a bubbling system.

In the case of $Ar/N_2/H_2O_2$ plasma, the inner and outer diameters of the discharge tube were 2 a 7 mm, respectively. The total gas flow of Ar (400 ml/min) was divided into two parts: one of them (flow 1), with a value of 50 ml/min, was bubbled into the recipient containing $H_2O_2$ to drag its molecules. The resulting mixture (gas and $H_2O_2$) was then joined to a mixture composed of the rest of argon (350 ml/min) (flow2) and a flow of nitrogen (12 ml/min) (flow3). The spectrum registered from emission of this discharge is shown in Figures 2a and 2b, observing a high emission of OH ($A^2\Sigma^+ \rightarrow X^2\Pi$). The range of 220-275 nm was

amplified it can be observed low emission of NO($A^2\Sigma^+ \rightarrow X^2\Pi$) species. This result suggests that the dissociation of $H_2O_2$ molecules by the plasma particules is likely produced by decomposition of $H_2O_2$ into two OH radicals instead of oxygen atom and water molecules.

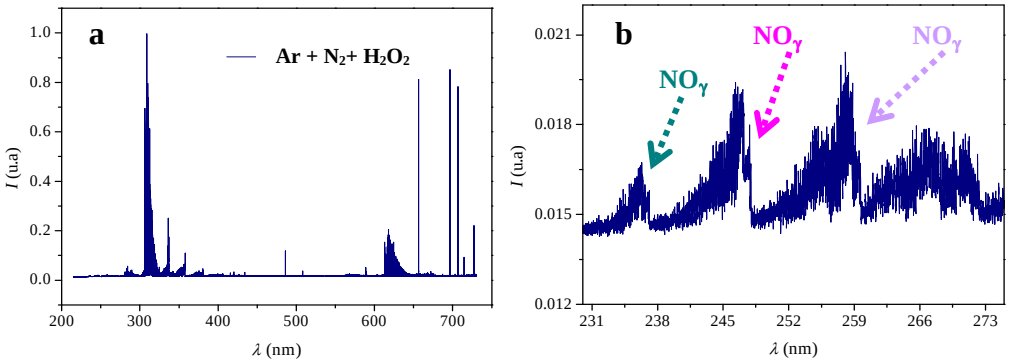


**Figure 2.** Normalized spectrum of $Ar/N_2/H_2O_2$ discharge, a) total spectrum b) amplied range of 220-290 nm

Other mixture, $Ar/N_2$/air plasma, in a quartz tube with 4 and 6 mm of inner and outer diameters, was studied in order to generate UV emission from NO($A^2\Sigma^+ \rightarrow X^2\Pi$) species using flows of 5 l/min, 120 ml/min and 180 ml/min for Ar, $N_2$ and air, respectively. Figures 3a and 3b show the spectrum recorded from this plasma. As it can be seen, $NO_\gamma$ bands present intensities enough to be directly observable in the total registered spectrum.

It was also studied the possibility to obtain UV photons from a plasma generated by the addition of $N_2O$ to Ar as in a quartz tube with 2 and 7 mm of inner and outer diameters, respectively. The flows were of 20 ml/min of $N_2O$ and 400 ml/min of Ar. As it can be shown in Figures 4a and 4b the spectra emitted by $Ar/N_2O$ plasma the intensities of $NO_\gamma$ bands are observed when the region in the interval 200-290 nm is amplified. This result is similar to the one obtained in the case of $Ar/N_2/H_2O_2$ mixture, and the emission of UV photons coming from OH band is smaller in comparison to the first studied mixture.

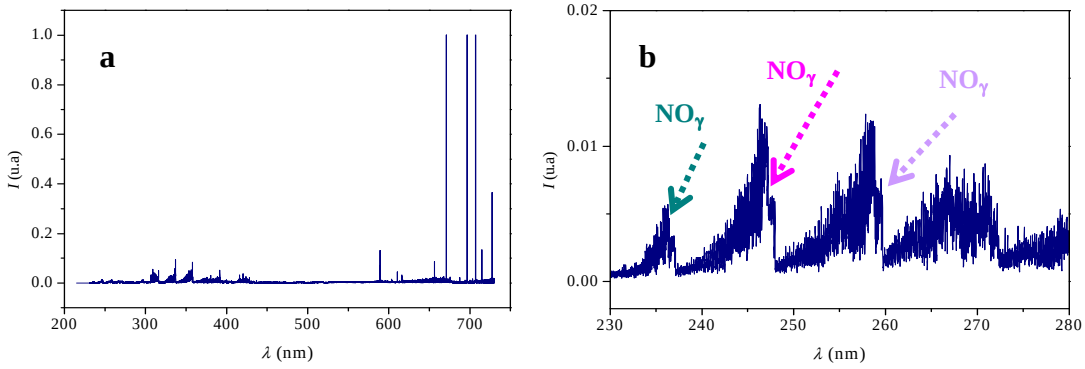


**Figure 3.** Normalized spectrum of $Ar/N_2$/air discharge, a) total spectrum b) amplified range of 220-290 nm

Introducing water into the discharge, high UV emission from de-excitation of OH($A^2\Sigma^+$) was also obtained (Figures 5a and 5b). The total Ar gas flow was 400 ml/min and

50 ml/min of this amount was bubbled into water.

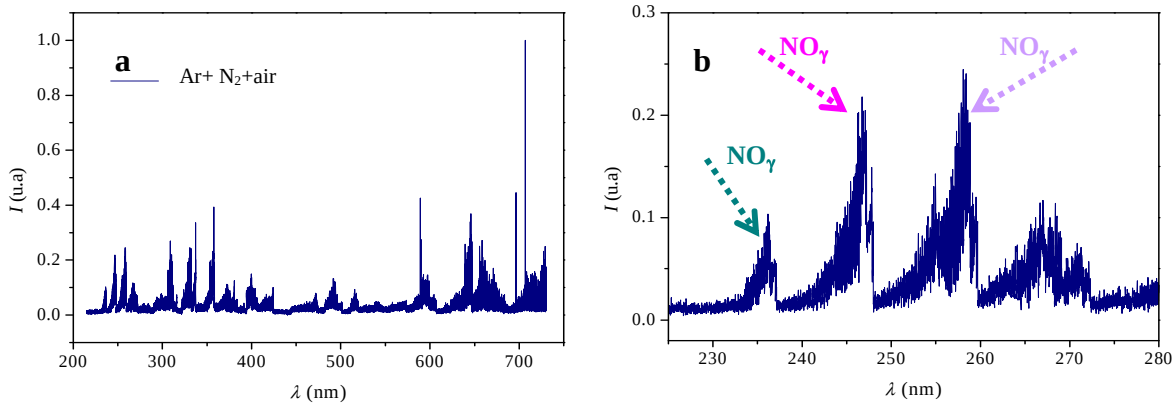


**Figure 4.** Normalized spectrum of $Ar/N_2O$ discharge: a) total spectrum and b) amplified range of 220-290 nm

## 4. Conclusions

Different ways of obtaining UV photons have been presented. Comparing the interval of UV radiation emission (200-400 nm) of studied mixtures, we can obtained the conclusions: a) the intensities of $NO_\gamma$ bands are highest for the $Ar/N_2/Air$ mixture, b) between 300 and 400 nm, the addition of $H_2O_2$ to the $Ar/N_2$ produces the highest intensity of UV radiation corresponding to the emission of OH radical band and c) the mixture containing air, the formation of NO and OH species is observed.

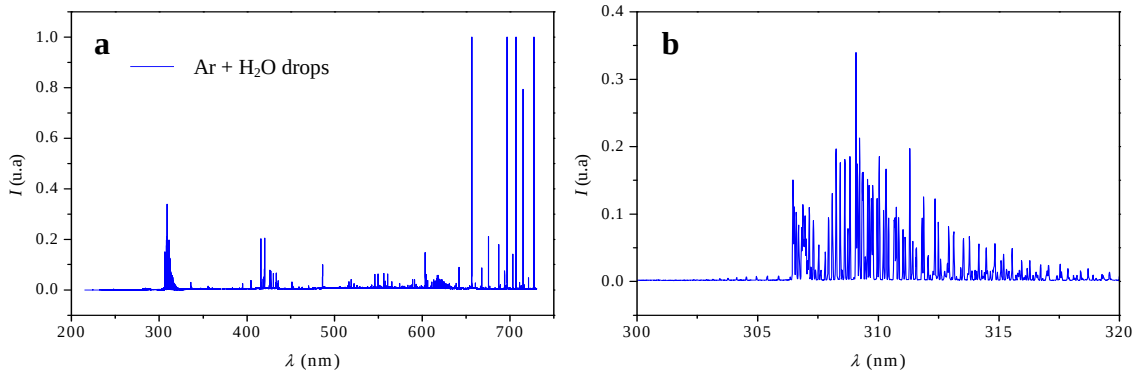


**Figure 5.** Normalized spectrum of $Ar/H_2O$ discharge: a) total spectrum and b) amplified range of 300-320 nm

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