Singlet delta oxygen production by RF and ns-plasmas: An electrical study

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Abstract: In this work, we present the effect of different electrical excitations on production of molecular singlet delta oxygen ($^1O_2$). RF excitation as well as nano-second (ns) pulsed excitation are used to ignite a capacitively coupled plasma jet at atmospheric pressure. $^1O_2$ production is monitored by calibrated far infrared (FIR) emission spectroscopy.

1. Introduction

In recent years, non-thermal (NT) plasmas have been investigated for their anti-cancer effect. Reactive oxygen and nitrogen species (RONS) produced by NT plasmas play a key role in cell communication and are thought to be the base of the selectivity properties of NT-plasmas. While the chemistry and signaling pathways for this selectivity are still poorly understood, it has been suggested that singlet molecular oxygen ($O_2(a^1\Delta_g)$ or short, $^1O_2$) plays an important role. $^1O_2$ can be a relevant factor for inactivation of membrane-bound catalase in cancerous cells [1]. The inactivation of said enzyme could lead to further production of RONS and OH radicals, triggering different signaling pathways and leading to apoptotic cell death. These hypotheses showcase the selectivity potential of non-thermal plasma and the importance of a well-defined understanding of $^1O_2$ production mechanisms.

In this work, we use FIR emission spectroscopy and different electrical excitations to respectively monitor and maximize $^1O_2$ quantities in RF and ns-pulsed driven plasma's effluent.

2. Methods

A capacitively coupled atmospheric pressure plasma jet composed of two rectangular stainless-steel electrodes of 100 mm length separated by a 1 mm gap is powered by a 13.56 MHz RF signal or a ns-pulser. Helium flows through the inlet of the jet at 5 standard liter per minute with a 0 to 2% O_2 admixture. The effluent of the plasma jet is collected and directed by a glass tube to a glass cell, where FIR emission spectroscopy is conducted by an InGaAs photodiode mounted on a narrow bandpass filter centered at 1270 nm [2]. The acquired signal is amplified by an operational amplifier before the signal is measured with an oscilloscope. This signal is calibrated to absolute concentrations of $^1O_2$ by a conversion factor determined through a previously conducted ray-tracing Monte Carlo simulation of the transmission and reflection properties of a glass cell.

The electric excitations are measured by a high voltage probe (Cal Test–CT4028). The shape of the pulse is simulated and compared with experimental results by VI-VIEW [3], a tool allowing users to simulate ns-pulse propagation in coaxial cables depending on the load circuit and probe location yielding better understanding of the "truly seen pulse" by the plasma.

The He-O_2 plasma chemistry is modelled with a reduced set of reactions in a plasma chemistry simulation with a Boltzmann solver and a 0D chemical reaction model. $^1O_2$ concentration in the effluent of the plasma is calculated based on the validated reduced electric measured at the electrode.

3. Results and Discussion

The model calculations show a good agreement of the measured electric field with the simulated signals. Figure 1 shows a non-dimensional simulated voltage pulse with a 20 ns width excitation, at the probe's location and spark gap. The chemical model reflects the qualitative development of the $^1O_2$ concentrations for variation of oxygen admixture and plasma deposited power. We show the effect of different electric excitation on plasma homogeneity and $^1O_2$ production efficiency.

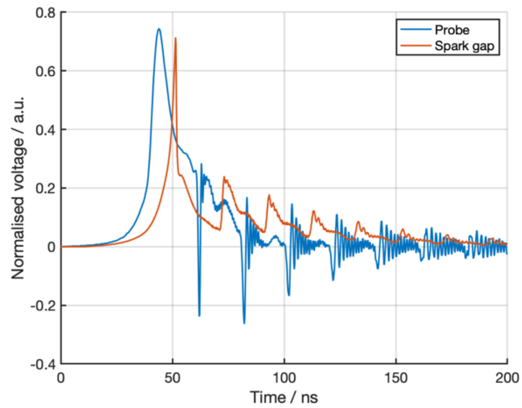

Fig 1: Simulated voltage as a function of time for a ns-pulse at the probe and electrode location. Created with VI-View [3]

4. Conclusion

Modifying the electric pulse shape parameters and oxygen admixture concentration in a helium atmospheric pressure discharge yields maximum production of $^1O_2$. Better understanding of ns-pulse propagation allows accurate simple modelling of He-O_2 chemistry in the plasma effluent and is in good agreement with the experimental results.

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References

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