Control of Plasma-Biointeractions by Tuning Plasma Chemistry

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Recently, it has been demonstrated that cold atmospheric plasmas (CAPs) have considerable potential for wound disinfection and healing.[1] CAPs used in plasma medicine produce a cocktail of radicals, ions, UV radiation and electric fields all contributing not only to wound disinfection but also stimulate cell regeneration. In-vitro cell treatments by plasmas made to investigate the safety and effect of plasma treatment are always made in a liquid medium. It has been show that the liquid medium strongly influences the plasma induced effects. Several important chemical pathways leading to plasma-biointeraction have been proposed by different groups around the world. The goal of the research is to investigate the link between gas phase chemistry and induced liquid phase chemistry. This knowledge will allow us to develop control strategies for inducing the desired reactive chemistry in liquids for medical applications.

A thoroughly characterized atmospheric pressure plasma jet (APPJ) [2-4] has been used to assess the chemical reaction mechanisms impacting mammalian cell viability in cell medium. The plasma induced chemistry has been changed drastically by admixing O_2, H_2O and air in an RF Ar APPJ. The inactivation of cell viability correlates in most conditions with the concentration of H_2O_2 produced in the liquid. This is confirmed by the addition catalase, a selective scavenger of H_2O_2, which eliminates the plasma induced cell viability reduction. A distinctive case has been found for Ar–O_2 mixtures leading to a 100% cell viability reduction, not affected by adding catalase. The strong dependence on distance eliminates O_3 as the main active component. The biological effect is proposed to be initiated by the exceptional high O density in the effluent for this plasma condition. (See Fig. 1.) This new mechanism is currently under further investigation.

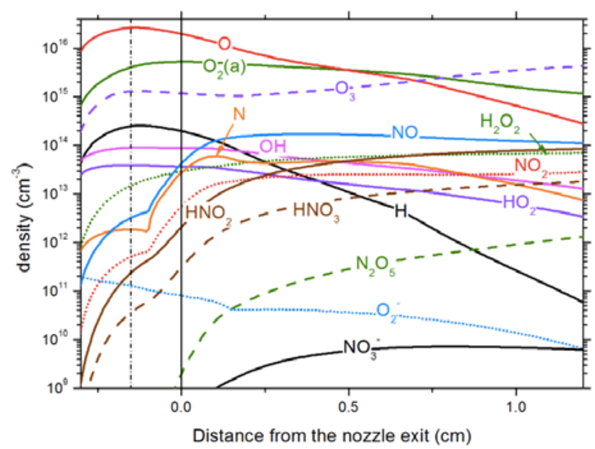


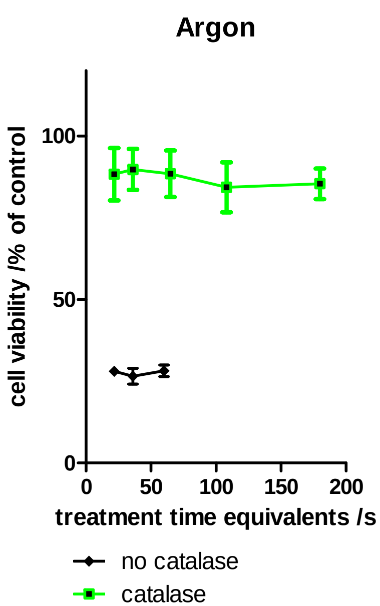
Figure 1 – Reactive species in the effluent of the Ar-O_2 cold atmospheric pressure plasma jet as used for the cell interaction study. (GlobalKin, Kushner and co-workers)

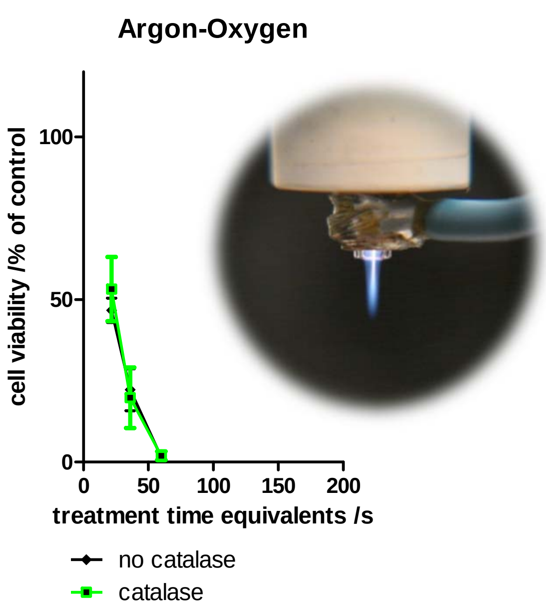
References

[1] D.B. Graves, *J. Phys. D: Appl. Phys.* **45** 263001 (2012).
[2] A.F.H. van Gessel, R. Brandenburg and P. Bruggeman, *Appl. Phys. Lett.* **103** (6) 064103 (2013).
[3] W. van Gaens, P.J. Bruggeman and A. Bogaerts, *New J. Phys.*, **16** 063054 (2014).
[4] B.T.J. van Ham, S. Hofmann, R. Brandenburg and P.J. Bruggeman, *J. Phys. D: Appl. Phys.* **47** 224013 (2014).

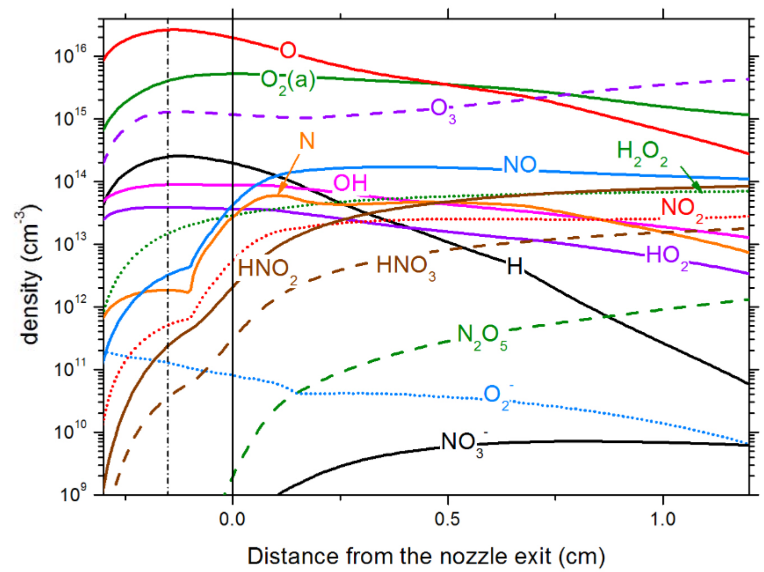
CONTROL OF PLASMA-BIOINTERACTIONS BY TUNING PLASMA CHEMISTRY

- **Tuning plasma induced liquid phase chemistry by different gas compositions.**
- **For most conditions, cell viability is impacted by H_2O_2 generated in solution. 100% viability reduction is found for Ar-O_2 mixtures. Catalase, a scavenger of H_2O_2, does not counter the plasma induced effect in this case.**
- **The effect is not caused by O_3. A new mechanism is believed to be responsible initiated by an exceptional high O density for this plasma condition.**





- **Cell viability and effect of adding H_2O_2 scavenger**



- **Bio-active species in gas phase**

HIGHLIGHT

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Controlling Fluences of Plasma Induced Liquid Reactivity With Dielectric Barrier Discharges

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The field of plasma medicine is investigating many different types of plasmas sources for the treatment of human tissue – and wounds in particular. The tissue being treated is very often covered with a thin liquid layer, many 100s μm to 1 mm thick, composed of water with dissolved gases and proteins. Plasma produced activation energy and radicals generated in the air must penetrate through the liquid layer to reach the tissue. The liquid transforms the plasma produced radicals and ions into other species prior to reaching the tissue. Since the liquid layers are thin, there is not significant mixing between different lateral locations – transport is primarily downward through the layer. The uniformity of plasma treatment therefore impacts the uniformity and composition of fluences of reactive species through the liquid layer to the tissue below..

This highlight reports on computational investigations of dielectric-barrier-discharges (DBD) sustained in humid air interacting with thin water layers. Two scenarios were investigated. The first is when the DBD streamer intersects at the same location on the liquid layer for many pulses. The second is when the DBD streamer intersects the water layer at random locations. Densities are shown in Fig. 1 of plasma produced RONS (reactive oxygen and nitrogen species) in the liquid after 100 pulses at 100 Hz with the streamer striking the same location. There are two classes of precursors – species produced directly by the streamer and species generated by additional reactions in the gas phase and which accumulate over many pulses. Ions and UV photons are produced directly by the streamer and are delivered to the liquid in large part where the streamer hits. This species lead to production of OH_{aq} directly under the streamer, which then rapidly produces H_2O_{2aq}. NO and O_3 are produced over many pulses and enter the liquid over a diffusion limited range which is much broader than the width of the streamer. $NO_3^-{}_{aq}$ and O_{3aq} are fairly uniformly distributed. On this basis, NO_{aq} should be uniformly distributed, but is depleted at the site of the streamer where OH_{aq} is produced. NO_{aq} will, however, reach the tissue elsewhere. When the streamer randomly strikes the liquid, the NO_{aq} and OH_{aq} react along the entire boundary, and so dramatically reduce the fluence of NO_{aq} to the underlying tissue.

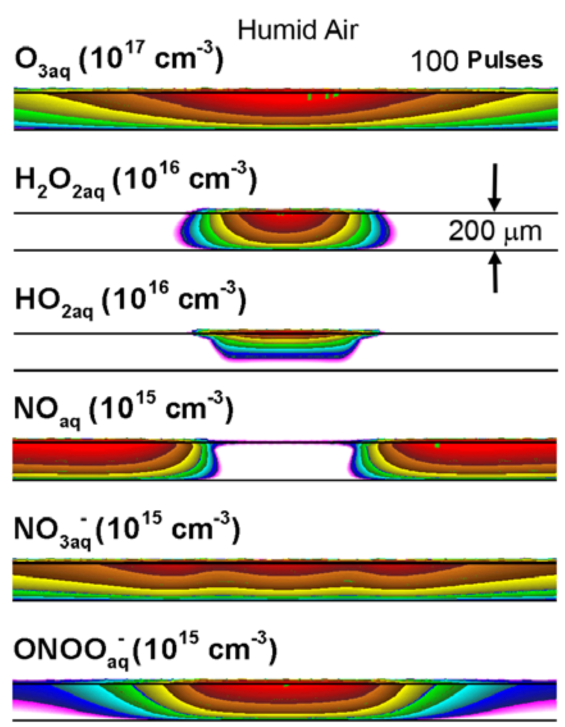

Figure 1 – Densities in a thin water layer after 100 pulses of a DBD operating at 100 Hz with the streamer striking the same location.

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Highlight

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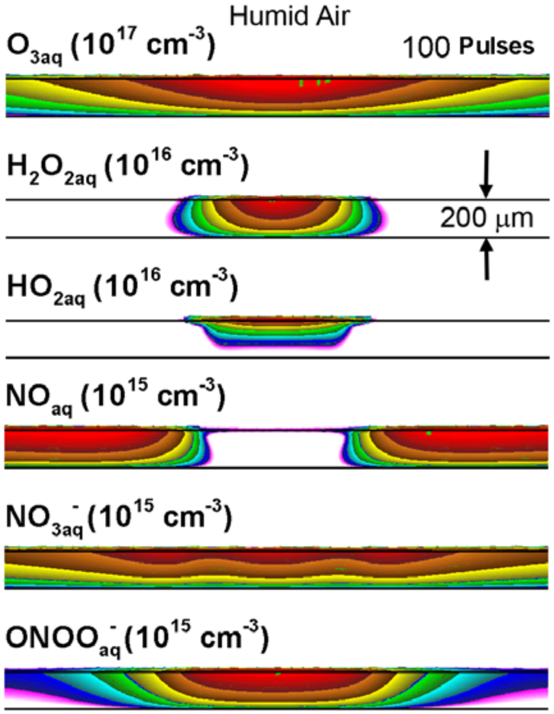
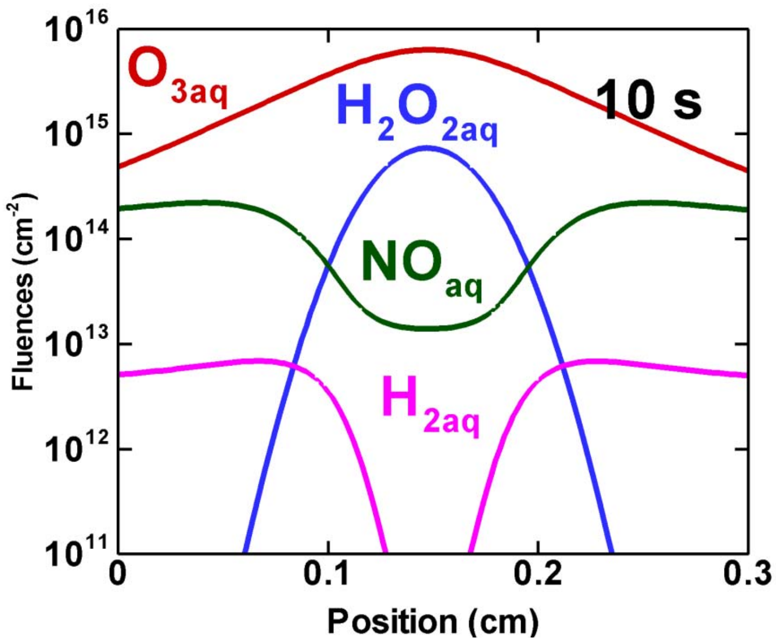
CONTROLLING FLUENCES OF PLASMA INDUCED LIQUID REACTIVITY WITH DIELECTRIC BARRIER DISCHARGES

- Dielectric barrier discharges (DBDs) treat wounds covered by thin liquid layers. The pattern of streamers striking the surface affects fluences to the tissue.
- With a streamer repeatedly striking the same location, NO_{aq} is depleted by reactions with OH_{aq} where the streamer hits, but leaks through elsewhere. With randomly striking streamers, no NO_{aq} reaches the tissue.



- Reactive species in water after 100 humid air DBD pulses hitting same place.



- Fluences reaching tissue under liquid after 10s (and 100 pulses).

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