Reaching beyond the surface in plasma treatments

A.H. Shaw[1], G. Shama[2], F. Iza[1]

[1]School of Electronic, Electrical & Systems Engineering, Loughborough University, UK
[2]Department of Chemical Engineering, Loughborough University, UK

Low temperature atmospheric pressure plasmas have emerged in recent years as a new powerful technology for a wide range of biomedical applications. The potential therapeutic value of these plasmas has already been demonstrated for applications ranging from sterilization of medical equipment to new cancer treatments. With animal and clinical trials underway, the hopes for this new technology are high and the field is developing very rapidly.

Helium is often used in these discharges as a background gas because its high thermal conductivity helps limiting the discharge gas temperature and enhances their stability. Discharges operating in pure helium, however, have limited application because their reactivity is low and therefore, admixtures of oxygen and water are typically introduced. These are good precursors of reactive oxygen species (ROS) and the two can be combined to create cocktails of ROS (O, OH, O_3, $^1O_2$, OOH and H_2O_2) of different compositions. Growing number of experimental and computational studies can be found in the literature describing the interesting dynamics and chemical kinetics of these complex discharges. The high reactivity of most of the ROS, however, limits their penetration into a treated sample and therefore plasma treatments are mainly ‘topical’. In many practical scenarios, however, one would wish that the beneficial effects imparted by the plasma could reach beyond the first layer of cells, e.g. in wound healing applications. Encapsulation of the ROS and/or triggering of a secondary chemistry is therefore required for the plasma treatment to reach beyond the first layers of (bio)molecules and deeper into the treated region.

Experimental and computational results indicate that production of ROS in water containing plasmas can be enhanced by the presence of droplets, and a combination of low-temperature plasma with high speed droplets provides an interesting opportunity for the generation and delivery of ROS beyond the surface of a treated sample. Here we report on a ‘plasma injection system’ that, by exploiting the interaction of plasma with high speed droplets, is able to deliver ROS beyond the surface and into a target.

The injection system is designed to fire tiny droplets of water at high speed and these droplets travel then through plasma before reaching and penetrating a skin model (agar). Previous work has shown that penetration of water jets (2.5-6µL of fluid) into actual skin is possible and indeed several needless injections systems have been commercialized in recent years. For this application, however, we are interested in lower volumes of fluid to be injected by a repetitive droplet firing system as this maximizes the surface to volume ratio of the droplets for their interaction with the background plasma. The injection system has been built around a piezo-electric actuator that drives a syringe plunger to fire water droplets out of an orifice with a diameter that ranges between 50µm and 200µm. The high speed droplets travel then between two electrodes that are used to generate an RF plasma. The plasma is time modulated to make sure that the gas temperature remains close to ambient temperature, avoiding undesirable thermal effects on treated samples. The injection system and RF generator are synchronised to ensure that the injected water droplets travel between the electrodes when the plasma is active.

At high input power, the droplets are fully evaporated and if large droplets are used then the injected liquid quenches momentarily the discharge. At lower input power, however, droplets can transit the plasma without being evaporated and undergo reactions with the background plasma, up-taking reactive species such as H_2O_2. The droplets then carry on to the surface of the skin model where they have enough momentum to penetrate, reaching beyond the outer surface to typical depths on the order of millimeters.

This work was supported by the UK Engineering Physical Science Research Council.