Active Interrogation of Plasma-Liquid Boundary using 2D Plasma-in-Liquid Apparatus

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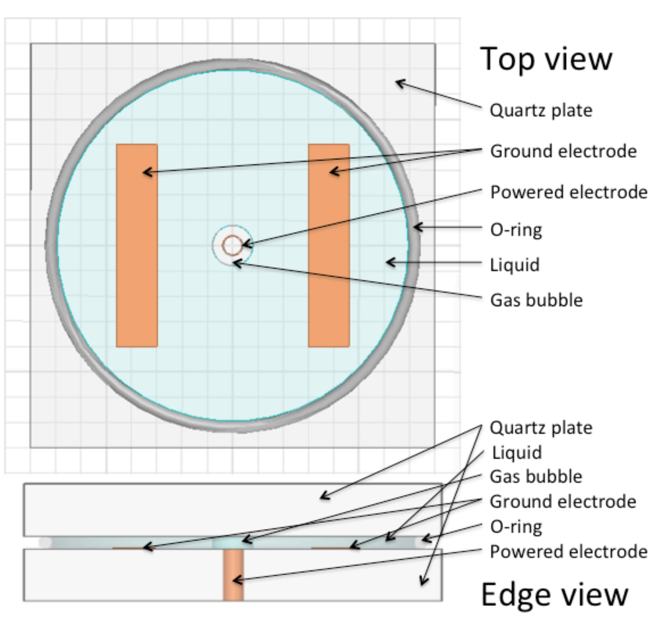
Project Overview

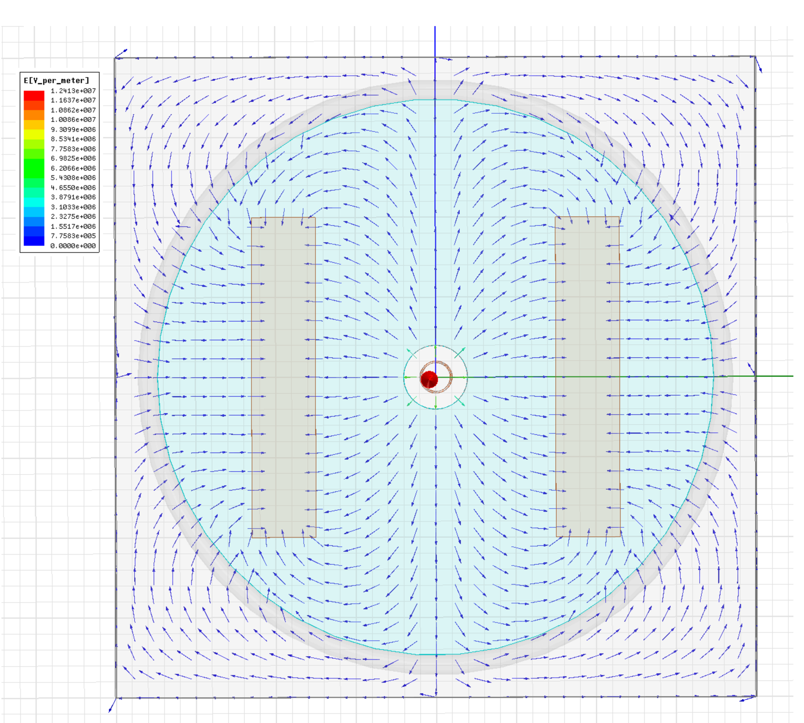
Plasma medicine and plasma-based water purification technologies rely on the production and transport of plasma-derived reaction species into the bulk medium. This interaction takes place at the interface between the gas phase plasma and the liquid medium. A 2-D plasma-in-liquid water apparatus which makes the interface region accessible is implemented. Using colorimetric chemical probes, acidification and oxidation fronts were tracked using microscope compounded imaging and spectroscopy. Observed plasma-induced fluid dynamical effects were also analyzed.

Experiment Set Up



Experiment set up schematics, modeled on Maxwell, showing various components of the set up.

Maxwell Model



3D Maxwell model of the bubble in water, showing the magnitude and directions of the electric field in tap water. Center electrode was excited to 10kV.

Acknowledgements

Work supported by DOE DE-SC0001939 and NSF CBET 1336375.

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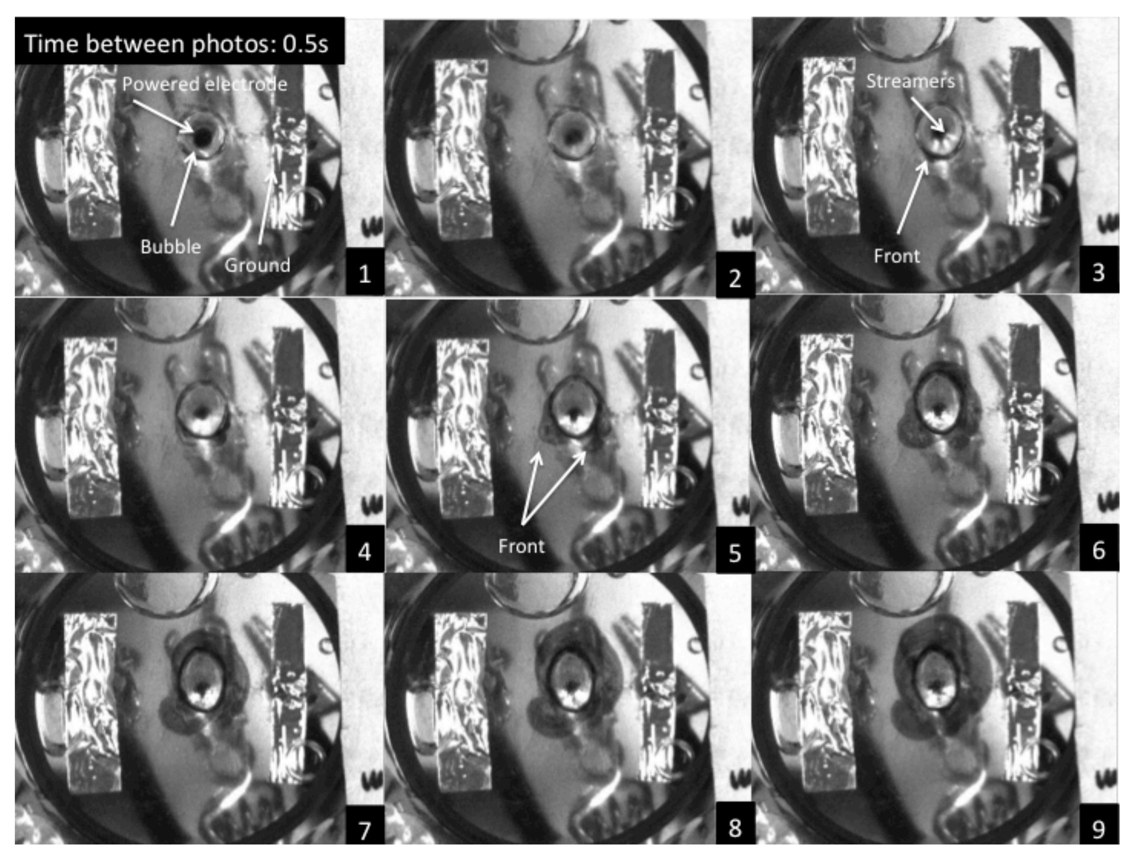
Results

General Results

Two modes of discharges were observed: microdischarges and streamers. Various frequencies were used for excitation, measured to be ranging from ~1-3kHz. Breakdown voltage was measured to be ~4.1kV in microdischarge mode and ~6.9kV in streamer mode. Voltage and current were measured using a Pierson coil and Tektronix high voltage probe.

Chemical Probe: KI + Starch

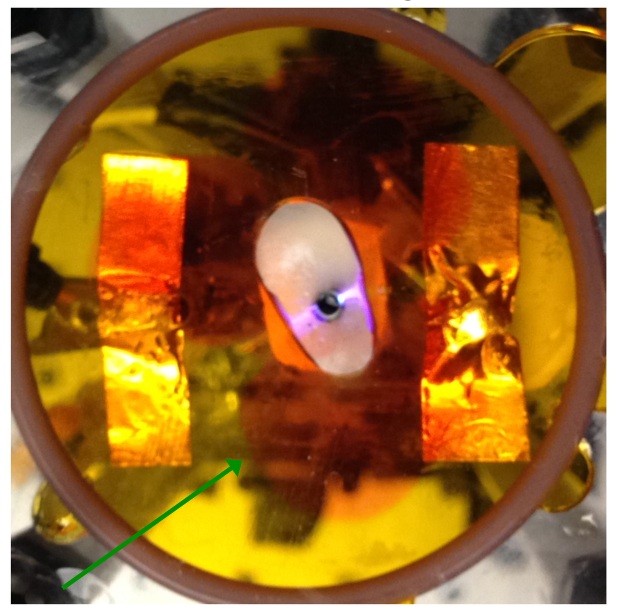
Potassium iodide and starch was used as an indicator of hydrogen peroxide production. Iodide ions reacts with hydrogen ions and hydrogen peroxide generated by the plasma to produce iodine, which then reacts with starch. A drastic color is observed, from changes from translucent to dark blue.



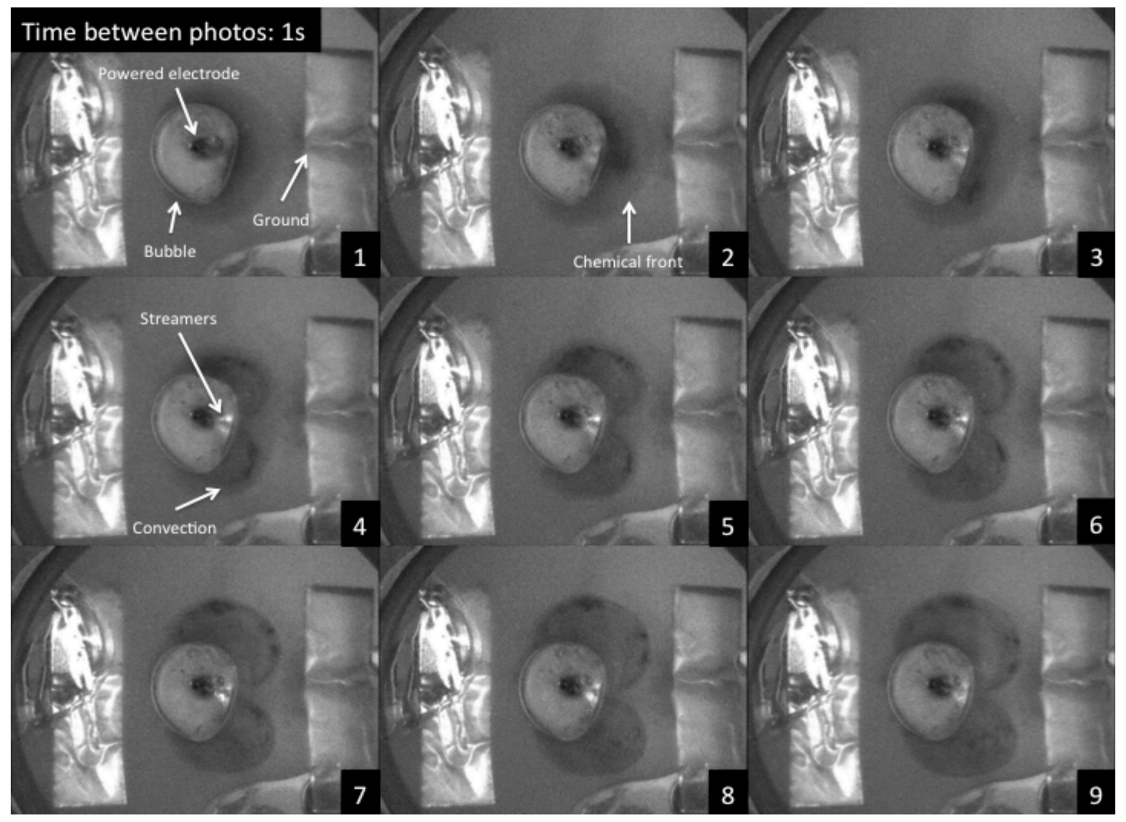
Swirl pattern and chemical front can be seen in the time lapsed photo above.

Chemical Probe: Methyl Orange

Methyl orange was used as a chemical probe to detect production of OH radicals. Color change occurs between pH 3.1-4.4.



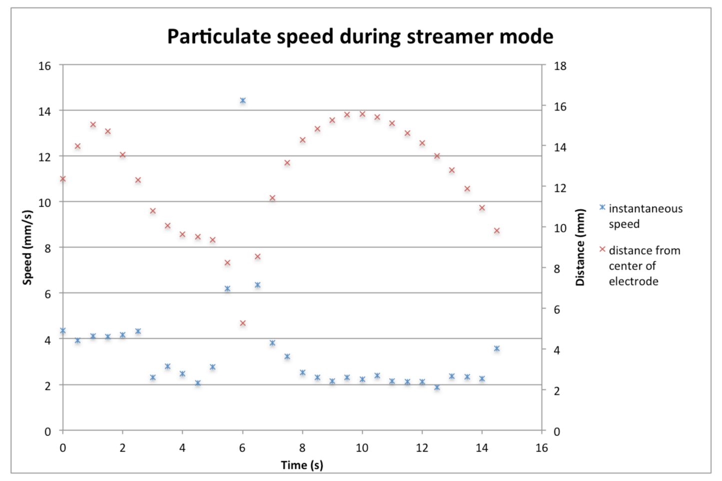
In the photo on the left, purple streamers can be seen inside the bubble. An orange chemical front (green arrow) propagated outward, indicating the production of OH radical. Radicals initiate advanced oxidation processes, oxidizing the methyl orange creating the acidic chemical front.



As seen in the time lapsed photo above, swirl pattern can be seen as the two lobes in darker shades surrounding the air bubble. Particulates formed when processed methyl orange accumulated at the interface and the liquid was heated to steam.

Fluid Flow

In methyl orange tests, solid particle flow was apparent after ~10 minutes as particles crystallize from the bulk. Particles were seen pulled into the interface from the bulk liquid and ejected out into the bulk again after interacting with the streamers.

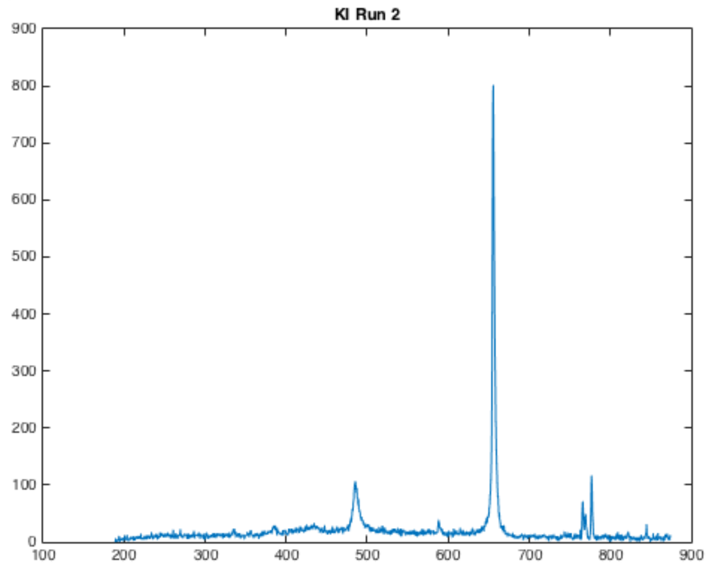


A particle was chosen and its location was tracked in still images taken from the video. Instantaneous speed was calculated and plotted on the left, with corresponding location.

As seen on the plot, the closer the particle was with the interface, the higher its speed was. Right after the particle hit the interface, its instantaneous speed spiked to its peak.

Spectroscopy

Spectroscopy of streamer discharge in KI+starch solution was performed.



A peak was observed at 656nm, corresponding to the alpha hydrogen line. Additional peaks were seen: hydrogen line (486nm) and oxygen line (777nm). This indicates the presence of advanced oxidation processes.

Further Studies

Quantifying Active Species

Fluorescent probes combined with absorption spectroscopy are proposed as a means for identifying and quantifying the production of other active species such as nitrates, nitrites and ozone in the bubble and in the bulk liquid.
Titration kits are also proposed for quantifying the production of hydrogen peroxide.

High Speed Imaging

A high speed camera will be used to investigate fluid flow in the bulk liquid in order to provide insights on plasma-driven interfacial forces, and how active species penetrate the bulk liquid.
High speed imaging will also be used to investigate the initial stages of plasma production to better understand the apparent difference in fluid flow between microdischarge and streamer modes.

Application on Water Purification

Preliminary tests on the effects on plasma on destroying cyanotoxins have been performed. Further test involves optimization of the quantities of active species for the complete elimination of cyanotoxins for water purification purposes. Additional interests include investigating the process of which plasma deactivates cyanotoxins.