Quantifying Atmospheric Pressure Plasma Evolution Utilizing Ultrafast Lasers

Ed Barnat and Andy Fierro
Sandia National Laboratories (evbarna@sandia.gov)

The field of low temperature plasma physics is experiencing an expanding interest in higher pressure, higher collisionality plasmas for their strong promise in a broad range of applications. As the perceived landscape of low-temperature plasma science evolves and challenges become more complex (high densities, shorter lifetimes, more reaction pathways), appropriate diagnostic capabilities are needed to provide a sufficiently complete picture of the plasma. This becomes particularly true for the near-surface region participating with the plasma, as the success of many potential plasma based applications depend on controlling plasma-surface interactions. In this highlight, we describe continued efforts to further the state-of-the-art in plasma diagnostics with particular emphasis placed on capabilities that provide access to the challenging near-surface region.

As described in an earlier update and recently published in an invited fast-track communication [1], the laser-collision-induced fluorescence (LCIF) method was developed to interrogate spatial and temporal evolution of electron densities present in an atmospheric pressure helium plasma (Fig. 1a). The diagnostic technique was applied to study plasma forming and spreading along a dielectric surface (Fig. 1b). The plasma first contacts the dielectric surface ~35 ns after application of a high voltage pulse on the anode. The plasma then rapidly spreads across the surface at a speed of ~5 cm/μs and achieves a final structure pictured at 150 ns. Multiple structures are clearly observed in the spatial distribution of electrons in a thin (<200 μm) layer above the surface. While yet to be confirmed, such structures are anticipated to be analogous with double layers formed in lower-pressure counterparts and likely regulate the plasma-surface interaction.

References
Recently developed atmospheric pressure (640 Torr) laser-collision induced fluorescence is utilized to quantify plasma generation and propagation.

- Laser-collision induced fluorescence (LCIF) capable of assessing electron densities ($n_e$) and reduced electric fields (E/N).
- Diagnostics quantify electron densities at near-surface region of plasma as ionization wave spreads across dielectric surface.

- LCIF scheme
- Setup
- 2D profiles of electron densities
Observation of Plasma Induced Microscale Fluid Pumping Action in a 2-D bubble apparatus

Janis Lai and John E. Foster
University of Michigan (jefoster@umich.edu)

The interactions of plasmas with liquid water lie at the heart of many society impacting applications such as plasma medicine and water purification. At the plasma-liquid interface, gas-phase plasma generated reactants (charged and neutral) diffuse or drift into the surface which in turn drive reactions at the interface. Just below the interface electric fields analogous to double layers control ion flow. These processes can be spatially non-uniform, giving rise to gradients that in turn impact species uptake and subsequent transport. Fluid dynamic processes driven by plasma interactions at the surface can drive reactive species at rates much faster than diffusion alone.

Here we discuss results for plasma-induced interfacial transport of reactivity from the interface into the bulk solution in a 2-dimensional apparatus using optical diagnostics and chemical probes. Previous work has shown that streamers are responsible for Marangoni-like flows emanating at the interface [1]. Here we show streamer-induced flows in liquid water doped with a thymol blue indicator which changes structure based on pH which in turn changes color. Sharp boundaries were observed during streamer action on the interface as shown in Fig. 1a [2]. Plasma-induced convection was observed to pull in untreated fluid (dark regions) towards the bubble boundary on the opposite side of the plasma. This occurs as the solution is exposed to advanced oxidation driven by the local plasma. These processed parcels of liquid are injected back into the bulk fluid under Marangoni forces. Parcels cycle between untreated regions and the plasma interface until fully treated.

The circulation patterns were observed in argon gas environments as well, as shown in Fig. 1b. Here we observe large-scale argon plasma at the interface but the flow pattern and general behavior persist. Untreated solution is pumped along a well-defined boundary, driven circumferentially around the bubble and exposed to the argon plasma. The untreated solution changes color as it passes through the plasma region. Acidification likely occurs due to charge exchange between water and argon ions producing hydroxonium. The mechanisms behind this pumping action are not well-understood. Perhaps local plasma heating produces gradients in surface tension which then drive circumferential flow.

References

Figure 1 – Pumping action and reactivity initiated by streamers at the interface with water. (top) Air plasma. (bottom) Argon plasma.

DOE Center for Control of Plasma Kinetics

Highlight
OBSERVATION OF PLASMA INDUCED MICROSCALE FLUID PUMPING AND TREATMENT

- Plasma-liquid (water) interactions investigated in 2-D test cell.
- Thymol blue is used as a pH indicator to track acidification processes driven by plasma produced reactants and forces acting on the interface.
- Under plasma action, untreated solution (dark green) is pumped toward interface and circumferentially driven past plasma attachment where its treated (yellow). Acidification observed for both argon and air plasmas.
- Plasma produced circulation of reactants is being investigated.