Sub-Ns Electric Field Measurements in Ns Pulse Discharges in Atmospheric Air and Over Liquid Water Surface

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The electric field (E-field) during ns pulse discharge breakdowns in ambient air has been measured by ps four-wave mixing with a temporal resolution of 0.2 ns. The measurements were performed in a diffuse plasma generated in a dielectric barrier discharge having a plane-to-plane geometry. Absolute calibration of the E-field was provided by the Laplacian field measured before breakdown. Sub-ns resolution was obtained using a 150 ps laser pulse, and by monitoring the timing of individual laser shots relative to the voltage pulse, and post-processing four-wave mixing data for each laser shot. The results were compared with the analytic solution for time-resolved electric field in the plasma during pulsed breakdown, showing good agreement on ns time scale. Qualitative interpretation of the data (~0.1-100 ns) illustrates the effects of charge separation and charge accumulation on the dielectric surfaces, electron attachment, and secondary breakdown.

The E-field was also measured in a ns discharge between a razor edge electrode and a distilled water surface for positive and negative pulses having durations of ~10 ns and ~100 ns. In the positive pulse, breakdown occurred at 85 kV/cm, after which the E-field decreases over several ns due to charge separation in the plasma. In the negative pulse, breakdown occurs at a lower E-field, 30 kV/cm, due to a longer pulse, after which the E-field decays over tens of ns and reverses direction when the applied voltage is reduced. For both polarities, the E-field after the pulse decays over many μs due to residual surface charge neutralization by transport of opposite polarity charges from the plasma. Measurements away from the center plane, ~100 μm from the water surface, show that during the voltage rise, horizontal field (E_x) lags in time behind the vertical (E_y). After breakdown, E_y is reduced to near zero and reverses direction. The results provide quantitative insight into charge transport and plasma kinetics near an air plasma–water interface.

Figure 1 – Comparison of E-field measured during the positive discharge with model predictions. Time resolution: 0.2 ns during the pulse (t= -5 to 5 ns), 0.5 ns before and after the pulse.

Figure 2 – E-field on the center plane of the negative ns pulse discharge above a distilled water surface. Discharge gap 1 mm.
SUB-NS ELECTRIC FIELD MEASUREMENTS IN ATMOSPHERIC AIR AND OVER LIQUID WATER

- Electric field is measured in a plane-to-plane ns pulse dielectric barrier discharge in atmospheric air by ps 4-wave mixing, with time resolution of 0.2 ns
- Quantitative insight into kinetics of ns pulse breakdown, charge separation, charge accumulation on the dielectric surfaces, and electron attachment

- Electric field during ns pulse breakdown in air, time resolution 0.2 ns
- Electric field in ns pulse discharge over liquid water surface
Electron Energy Distribution Functions in Lithium-Containing Argon Plasmas

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Lithium containing argon plasmas are of interest both scientifically and technologically. They are encountered in plasma-assisted deposition of solid electrolyte thin films, a technologically important and emerging process for manufacturing lithium-ion batteries, electrochromic windows, and other devices that make use of high mobility of lithium in the solid state. Scientifically, argon-lithium plasmas are interesting because these two elements are at the opposite sides of the periodic table with drastically different electron collision cross sections and energy thresholds.

We have been studying Li/Ar plasmas both experimentally and using modeling and simulations. Recently, we solved the Boltzmann equation to determine the electron energy distribution function (EEDF) in lithium-containing argon plasmas via a Boltzmann solver BOLSIG+.[1] Surprisingly, even very small amounts of lithium in argon plasmas change the EEDF dramatically. Specifically, the high-energy tail of the EEDF is depleted significantly in presence of lithium. For example, Fig. 1 shows a comparison of the EEDFs in a pristine argon plasma and in an argon plasma containing 0.1% Li. EEDFs are shown for different electric field to neutral density ratios (E/N in Td, 1 Td = 10\textsuperscript{-17} V-cm\textsuperscript{2}). When compared at the same E/N, even 0.1% of Li dramatically alters the EEDF, suppressing the electron energy population with energies above \sim 5 eV. The effect is even more pronounced as the lithium concentration is raised (e.g., to a few per cent). We attribute this depletion of high-energy electrons to low ionization energy threshold (5.4 eV) of lithium and the presence of lithium excitations, also with low energy thresholds (i.e., 1.9 eV and 3.9 eV). Cross sections and probabilities of these collisions rise sharply above their thresholds and are surprisingly large. Experimental measurements of the average electron energy using rare gas optical emission actinometry suggests that when lithium is added to an argon plasma, the electric field rises to maintain the effective electron temperature (2/3 of average electron energy) around \sim 3 eV. That is, the plasma makes up for the loss in high-energy electrons, when lithium is present, by increasing the self-sustaining electric field, or more specifically, the self sustaining E/N.

References
ELECTRON ENERGY DISTRIBUTION FUNCTIONS (EEDF) IN LITHIUM CONTAINING ARGON PLASMAS

- EEDF determines the rates of electron impact reactions in Li containing Ar plasmas used for depositing solid electrolytes for Li-ion batteries.
- Boltzmann equation was solved to determine the EEDF in Li/Ar plasmas.
- Even very small amounts of Li changes the EEDF dramatically.

- Comparison of EEDF in pristine Ar plasma with 0.1% Li added at the same electric field (E/N in Td, left) show a dramatic suppression of the high energy tail of the EEDF due to low threshold energies in Li for excitations and ionization.
- Experimental measurements of the average electron energy suggests, however, that the E/N rises in presence of Li to keep the average electron energy the same.