New Diagnostic for Electric Field in Atmospheric Pressure Plasmas

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A new non-intrusive laser diagnostic for electric field measurements, picosecond Second Harmonic Generation, has been developed and has been used to measure temporal and spatial distributions of electric field vector components in three different atmospheric pressure plasmas:

- Dielectric Barrier Discharge (DBD) surface plasma actuators powered by AC sine wave and ns pulse voltage waveforms, operated in ambient air (Fig. 1).
- H₂ ns pulsed discharge plasma jet in atmospheric hydrogen diffusion flame (Fig. 2).
- He plasma jet exhausting in ambient air and impinging on liquid water surface (Fig. 3)

Absolute calibration is provided by measuring a known electrostatic electric field. Horizontal and vertical components of the electric field vector are determined by measuring the second harmonic signals with different polarizations. The new diagnostics is simple to use and about two orders of magnitude more sensitive compared to ps four-wave mixing used in our previous work. Since the new diagnostics is species-independent, it can be used for measurements of electric field distributions in plasmas sustained essentially in any high-pressure gas mixture, with high (sub-ns) temporal resolution. The new experimental results provide essential new insight into kinetics of plasma flow control, plasma-assisted combustion, and plasma-liquid interaction. The technique is able to produce extensive sets of data for validation of high-fidelity kinetic models.

Figure 1 – Electric field components in an AC surface plasma actuator in ambient air, 2 mm from the high-voltage electrode and 100 µm above the alumina ceramic dielectric surface.

Figure 2 – Horizontal electric field in ns pulsed discharge in atm. pressure hydrogen diffusion flame.

Figure 3 – Relative vertical electric field in AC atmospheric pressure He plasma jet exhausting into air and impinging on liquid water, 100 µm from surface.
• New diagnostic, ps Second Harmonic Generation, is species-independent.
• Can be used for measurements of electric field vector distributions in plasmas sustained in any gas mixture, with sub-ns temporal resolution.
• Electric field measured in plasmas sustained in helium near liquid water, in hydrogen, and in ambient air, using the same experimental apparatus.
• New insight into kinetics of plasma-liquid interaction and plasma flow control.

- E-field components in AC air plasma

- E-field in atmospheric pressure helium plasma jet, near liquid water surface
Short-Circuit Effect in Low Temperature Plasmas with Finite Electron Gyroradius

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The Simon effect is a well-known phenomenon where a magnetized plasma contained in a vessel with conducting walls is lost much faster than if the walls were insulating [1]. This is due to a short circuit between the walls that intersect the magnetic field and those that are parallel to it. Electrons are lost to the walls that intersect the magnetic-field lines while ions are lost to the walls that are parallel to them since their cross-field diffusion is faster. Thus, instead of ambipolar diffusion limiting plasma wall losses, a current is set up in the walls increasing wall losses.

We recently predicted and demonstrated a different short-circuit effect which can occur in plasmas with a magnetic field and bounded with non-conductive or floating conductive walls. When a gyrating electron counters a wall that is parallel to the magnetic field, if it does not have enough energy to get through the plasma-wall sheath, it is reflected away from the wall. If the sheath is much smaller than the gyro-radius, this reflection is simply a velocity kick, $\Delta v$ (Fig. 1). This kick causes the electron gyro-center to move in the $-e\Delta v \times B$ direction along the wall. As a result of this ‘bouncing’, a current flows along the wall in a layer with a size on the order of an electron gyroradius. The largest effect of this short-circuit should be in a weakly collisional plasma with the electron gyroradius being comparable to the system size. Such conditions can be realized in weakly magnetized plasma sources, magnetized dusty plasmas and probes. In fact, this bouncing effect was first proposed as an explanation for the lack of suppression of the electron current inside of a magnetically insulated baffled probe [2].

Experiments to demonstrate this effect have been performed in a magnetized xenon plasma in a cross-field Penning configuration with density of $10^{12}$ cm$^{-3}$ and an electron temperature of 2 eV [3]. These experiments involved an insulating plate that was placed parallel to the magnetic field with two identical metal collectors at either end with heights around an electron Larmor radius. Each collector measures three different electron currents: the background thermal current, the current from the $E \times B$ drift, and the current due to the bouncing electrons. The latter two were either additive or subtractive depending on the B-field direction. From these measurements, the bouncing current did not exceed 10% of the electron saturation current. Following this first successful demonstration of the bouncing current, we plan to continue theoretical and experimental studies with a focus on scaling, role of collisionality, and possible applications.

References
Electrons ‘bouncing’ off a floating wall parallel to a magnetic field are predicted to cause a net motion and current to flow along the wall.

Relevant to weakly-collisional plasmas with $L \lesssim r_L$ (e.g. microplasmas, probes).

This prediction was validated in experiments using a probe with two collectors on either side of an insulating plate immersed in a magnetized plasma.

The short-circuit current due to bouncing electrons seen as a difference in measured currents between the two sides was ≤ 10% of the total current.

Future studies will address scaling of this effect.

- Schematic showing the bouncing motion and a picture of the probe used in experiments.
- The normalized difference in currents between the two plates was only a few percent; smaller than anticipated.