New Coherent Techniques for Ultrafast Diagnostics in Plasmas

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Research groups at Ohio State [1] and Sandia National Laboratories [2] have recently demonstrated the feasibility of highly spatially-resolved electric field measurements in electrical discharges using electric field-induced second harmonic (E-FISH) generation with two probe beams in a noncollinear phase matching geometry. However, they both reported orders of magnitude decrease of the measured signal with the increase of the angle between the probe beams, therefore limiting any further gain in spatial resolution following the crossing of the probe beams.

We have developed an ultrasensitive E-FISH experimental setup showcasing a detection limit about 3 orders of magnitude lower than that of E-FISH setups from the literature. Figure 1-a highlights sample E-FISH waveforms measured with a photomultiplier tube. The waveforms were averaged over a thousand laser pulses for different sub-breakdown DC voltages applied across a pair of parallel plate copper electrodes in atmospheric pressure air as depicted in Figure 1-b.

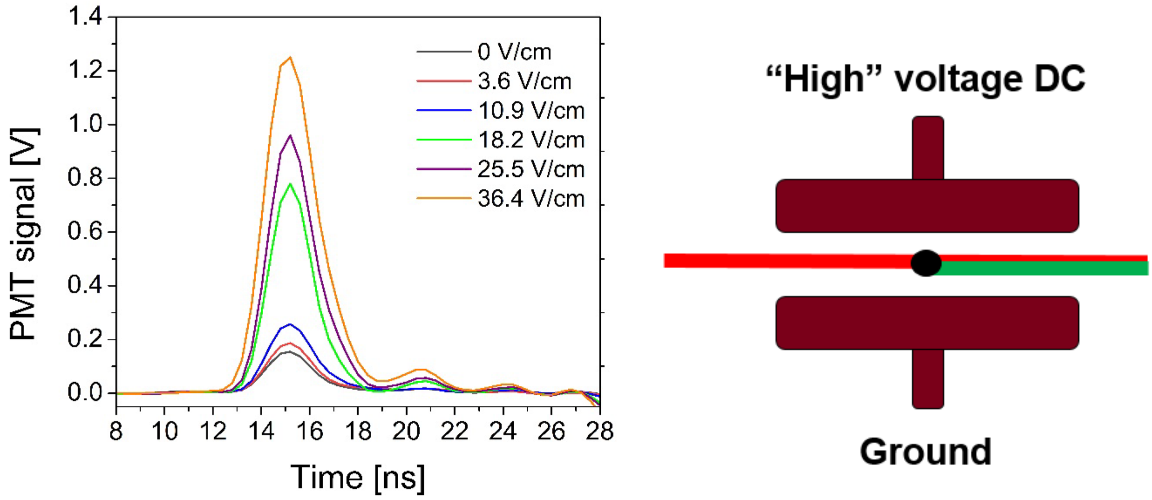

Fig. 1: (a) Sample E-FISH waveforms for different sub-breakdown DC electric field values. (b) Electrode contraption

From Figure 1-a it is readily apparent that electric field magnitudes as low as 4 V/cm can be detected using our novel approach. Furthermore, the measured PMT signal increases with the increase of the externally applied electric field between 4 and 36 V/cm. We expect to be able to further push the capabilities of our system to reach measurement thresholds as low as 0.1 V/cm at atmospheric pressure. Such improved sensitivity at atmospheric pressure holds great promise for deploying E-FISH under low gas-pressure environments.

Now turning our attention to density measurements in plasmas, we have recently reported the observation of three-wave mixing (TWM) in the gas phase [3], a process normally forbidden in centrosymmetric media under the electric dipole paradigm. The experimental setup for this diagnostic is shown in Figure 2-a. Briefly, light generation at 355 nm is observed when mixing the fundamental (at 1064 nm) and the second harmonic (at 532 nm) beams of a picosecond Nd:YAG laser in collinear phase-matching geometry. Figure 2-b displays the relative TWM signals from 5 different gases: He, N_2,

O_2, Ar, and Kr as a function of the gas pressure. Remarkably, the measured signals appear to grow monotonically with the test cell gas pressure. Besides that, PMT signals for species with higher nonlinear susceptibilities [4,5] appear to be stronger.

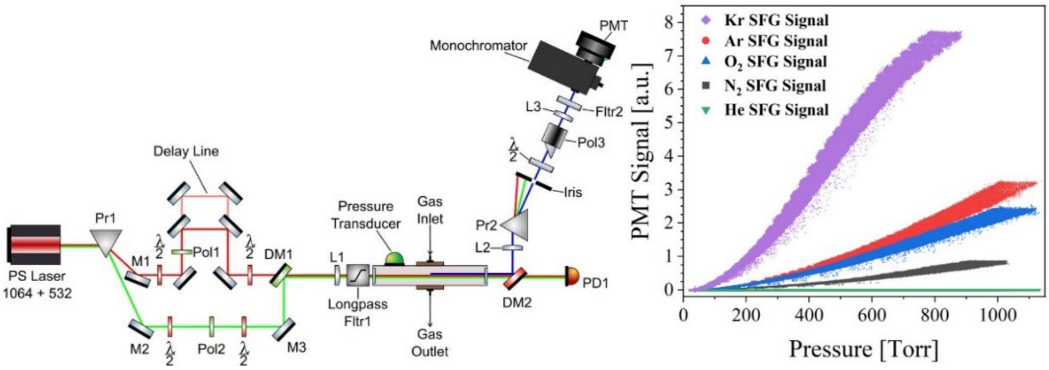

Fig. 2: (a) Schematic of the three-wave mixing experimental setup. (b) Three-Wave Mixing signal at 355 nm for 5 different gases VS Gas pressure

Such observations make the case for leveraging three-wave mixing as a novel technique for density measurements. This would greatly complement CARS (Coherent Anti-Stokes Raman Scattering), which is limited to Raman-active molecules while TWM applies in principle to both atomic and molecular species.

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