High-Sensitivity Time-Resolved Electric Field Measurements at Sub-Torr Pressures Using Homodyne E-FISH

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We report on recent improvements to the Electric Field Induced Second Harmonic generation (E-FISH) diagnostic technique which allows for the measurement of sub 1 V/cm electric fields. Utilizing a combination of homodyne detection and optimization of the optical components the minimum measurable electric field was able to be reduced by over 2-3 orders of magnitude, allowing for the potential of measurements in sub 1 Torr conditions.

1. Introduction

The reduced electric field (E/N) is a key indicator of energy partition in electrical discharges, giving an understanding of the potential for plasma chemistry and reactivity. The strength of the E-FISH signal depends on the electric field strength, gas density, and probed volume length ($I_{E-FISH} \propto E^2N^2L^2$) [1]. Due to these dependencies, any improvements demonstrated in one factor/term can be traded to improve the performance in another factor/term. This property allows for simplification to the testing of improvements, for instance, generating low-magnitude electric fields at atmospheric pressure is relatively easier to implement than generating high electric fields under high vacuum conditions.

Leveraging homodyne detection, a process where the generated signal interferes with a reference signal based on the differences in their phase, and optimizing the optical system, the detection limits of E-FISH can be improved by orders of magnitude allowing the extension of the environments where E-FISH can be seen as a useful diagnostic technique.

2. Methods

A sinusoidal voltage corresponding to electric fields from +35 V/cm to -35 V/cm at 10 MHz was used to generate a sub-breakdown voltage across a set of parallel plate electrodes and generate calibrated electric fields. A 1064 nm 30 picosecond laser is focused between the electrodes to generate the E-FISH signal.

The signal and fundamental beam are propagated to a dichroic mirror which serves two purposes. Firstly, as the fundamental beam interacts with the mirror an additional Second Harmonic (SH) signal is generated, which acts as a local oscillator enabling homodyne detection. Secondly, the dichroic mirror then transmits the majority of the fundamental beam and reflects the SH signals. This stops further stray SH generation from optics in the beam path and allows for the measurement of the signal without over-saturation from the fundamental beam.

The signal is then focused on a photomultiplier tube (PMT). Using a photodiode, voltage probe, and the PMT voltage traces on an oscilloscope, the voltage waveform can be reconstructed in time, allowing for 400 ps time-resolved data.

3. Results and Discussion

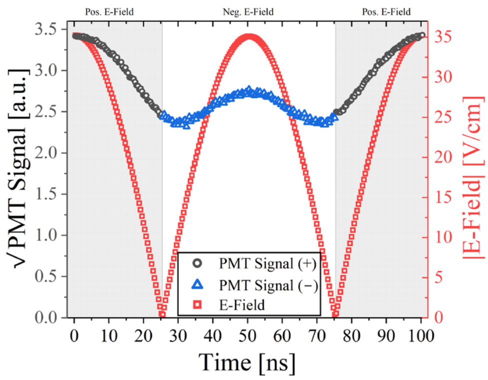

Fig. 1. 400 ps Time resolved sinusoidal electric field measurements ranging over ±35 V/cm. The data in black and blue showcase the difference in signal from positive to negative electric fields.

Figure 1 compares the time-resolved E-FISH measurement with the measured electric field from the voltage probe, here the data is expressed as the $\sqrt{PMT}$ signal vs the $|E - Field|$ to highlight that for the same magnitude of electric fields but with inverted polarity there is a large variation in the magnitude of the measured signal. This arises from constructive interference of the E-FISH signal generated with a positive electric field and the local oscillator increasing the signal. In contrast, the E-FISH signal generated by a negative electric field destructively interferes with the local oscillator decreasing the signal initially, before surpassing the intensity of the local oscillator and therefore increasing the total signal.

4. Conclusion

Utilizing homodyne detection in an optimized E-FISH diagnostic setup the detection limit can be improved by 2-3 orders of magnitude, allowing for the measurement of sub 1 V/cm electric fields and allowing for useful measurements at low pressures, below 1 Torr, where E-FISH has not been previously deployed.

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References

[1] T. L. Chng et al., PSST, **29**, 125002 (2020).