Invasiveness of high-power ns and ps pulsed laser beams on a ns pulsed N2 atmospheric pressure plasma jet

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Application Note

Invasiveness of high-power ns and ps pulsed laser beams on a ns pulsed N_2 atmospheric pressure plasma jet

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(December 2021))

Introduction

Among the different parameters that characterize a plasma, the electric field gives a multitude of information. It affects, for instance, the electron energy distribution function (EEDF), gas temperature and creation of energetic particles [1]. Better knowledge of the electric field inside a plasma allows for more efficient application of plasmas in different fields. Many techniques exist to determine the electric field, but these are often found lacking when investigating transient plasmas. Common problems are limiting assumptions, poor sensitivity, and invasiveness on the plasma [2].
This work investigates a relatively novel diagnostic technique to determine electric fields, called Electric Field Induced Second Harmonic Generation, or EFISH for short. This technique is considered non-invasive, has high spatiotemporal resolution, and can be applied to both non-transient and transient plasmas.

In an E-FISH measurement, a short high intensity laser pulse is fired at the plasma. Due to the high intensity, the laser pulse reacts non-linearly with the electric field and can create frequency-doubled photons. The intensity of this second harmonic (SH) signal scales with the square of the electric field. Thus, by measuring the SH signal using an appropriate detector, the electric field can be determined.

In recent years, E-FISH has been used to determine the electric field with nanosecond, picosecond, and femtosecond laser pulse durations. Using a nanosecond pulsed laser with pulse duration 16 ns at atmospheric pressure, electric field measurements have been performed on a parallel plate electrode configuration, reaching a sensitivity of about 1.5 kV/cm [3].
However, what is generally lacking is a thorough investigation on the invasiveness of the laser on the plasma. In this work, the invasiveness of pico- and nanosecond lasers on the plasma is investigated. This is done using a nanosecond pulsed N_2 plasma jet operated at atmospheric pressure, and near-infrared laser sources with pulse durations in the nanosecond and picosecond range. The invasiveness is investigated using ICCD camera images of the region where the plasma and laser intersect.

Experimental set-up

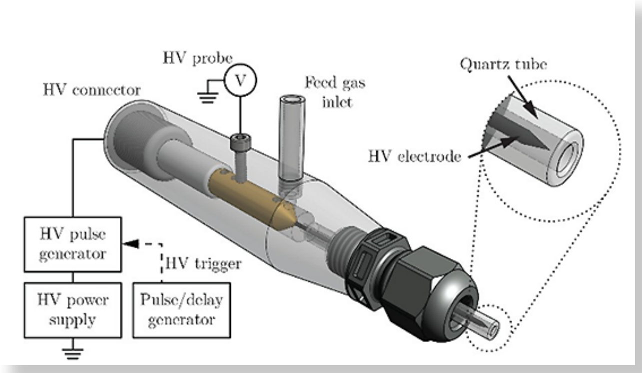

Figure 1: Schematic representation of the plasma source used in the measurements, image from [4].

The used plasma source is shown schematically in Figure 1 and was completely characterized in [4]. Nitrogen is injected through the gas feed inlet at a volumetric and then passes through a quartz tube nozzle into open air. Inside the nozzle there is a concentrically placed tungsten electrode. Using a gated HV power supply, pulsed DC voltages can be delivered to the needle electrode through a brass screw at the back of the casing. The HV pulses are set to be 500 ns wide, with rise and fall times of about 40 ns. The applied voltage is 8 kV at a repetition rate of 3 kHz. The plasma jet generated by using these settings consists of cylindrically symmetric bullets with a radius of 140 μm.

The nanosecond laser we investigate is a Nd:YAG laser (Quantel Q-smart 450), pulsed at a frequency of 20 Hz using the delay generator. The nominal pulse duration at a fundamental wavelength of 1064 nm is about 6 ns. The picosecond laser (Ekspla 312) is also an Nd-YAG laser, but it has a pulse duration of about 150 ps and is pulsed at 10 Hz.

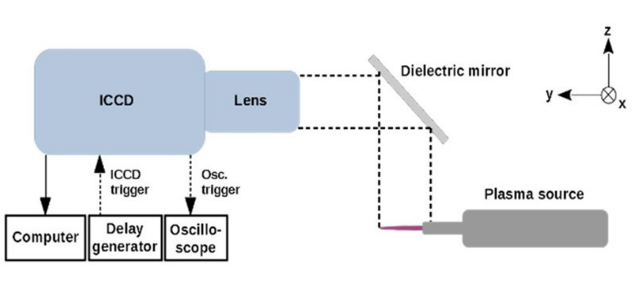

Figure 2: Schematic representation of the set-up used to take the ICCD camera images. The camera is triggered using the delay generator, and it in turn triggers the oscilloscope.

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The plasma jet is imaged using an intensified charge coupled device (ICCD) camera (Andor iStar DH334T-18U-E3), with a minimum exposure time just below 2 ns. Using this camera, the shape of the plasma jet with the laser turned off and on are compared, giving an indication of the invasiveness of the laser beam. A simple diagram of the camera setup is shown in Figure 2. A dielectric mirror is placed above the plasma and the camera is placed at the same height facing this mirror, in such a way that the complete plasma jet can be seen. This results in a top-down view of the plasma where the laser beam crosses the plasma in the x-direction.

Results and discussion

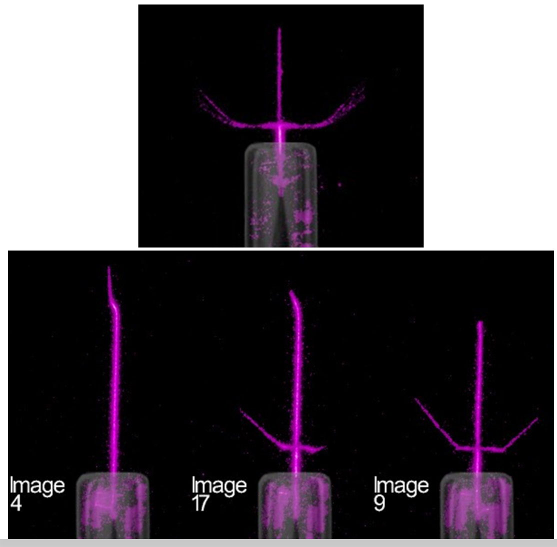

Figure 3: Branching of the plasma jet due to nanosecond (top) and picosecond (bottom) laser effects. The laser beam is travelling from right to left. Long exposure of a single discharge event. The measured plasma radiation is visualized in purple, while an ambient light image of the quartz tube and electrode is superimposed in grayscale,

In figure 3 we can observe that the nanosecond laser indeed has an impact on the plasma jet. Without the laser on, we only observe a straight plasma trail traveling along the jet direction (upwards in the figure). With the laser on, clear branching is visible, exactly along the laser path, although further out the branches start to deviate from this path and follow the electric field. If we now use E-FISH to determine the electric field profile of the jet, we get the result plotted in figure 4.

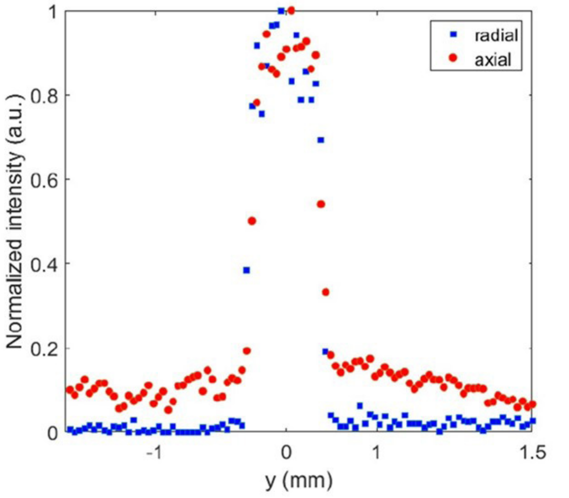

Figure 4: Radial profiles of the radial and axial electric field using the nanosecond laser.

Here we can see that the axial and radial electric field components both show an unexpected top hat profile, instead of the expected gaussian-like shape.
With the picosecond laser, we observe roughly similar branching of the jet, but its effect on the measured profile is hardly visible, as can be seen in figure 5. This indicates that, although the picosecond laser can also lead to branching, it is much less invasive because the E-FISH measurement occurs before the branching significantly affects the field distribution.

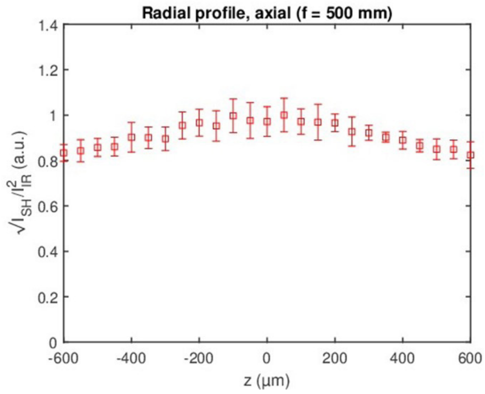

Figure 5: Normalized radial profiles of the axial component of the E-FISH signal using the picosecond laser.

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