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Towards Ultrashort Pulse Generation from Nanosecond Laser Sources for Electric Field Measurements

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1. Introduction

A laser diagnostic based upon the phenomenon of second harmonic generation has been re-developed recently for the purpose of electric field measurements in gas plasmas [1-2]. More commonly known as electric field induced second harmonic generation (E-FISH) [3], the relatively straightforward implementation of this technique has begun to find application in real-life plasma actuators [4-5]. Since the signal generation is intrinsically intensity-driven, this naturally favours short laser pulses on the order of hundreds of picoseconds (ps) or less. The use of high-energy, nanosecond pulses (ns) is in principle possible, but increasing the energy indefinitely is constrained by the occurrence of laser-induced breakdown. Furthermore, ns pulses are limited in time-resolution, which may prove important when diagnosing fields associated with ns type discharges. Unfortunately, ultrashort pulsed laser systems are not easily accessible and costs can often be prohibitive.

In this work, we attempt to use a Pockels cell to ‘slice’ a ubiquitous 1064 nm YAG laser beam into a pulse of shorter duration, with a view to using this shorter pulse for useful E-FISH measurements in ns discharges.

2. Experimental setup

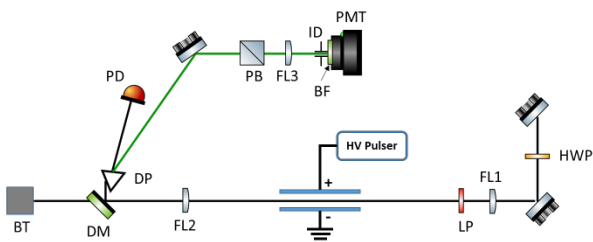


Fig. 1: E-FISH setup

The experimental setup consists of 3 main parts. The high voltage pulses and electrode system used for demonstrating the E-FISH measurements, the optical layout for the pulse-slicing, and that for the E-FISH measurements. An FID model number FPG 12-1NM high-voltage (HV) generator delivers positive polarity, 9.4 kV amplitude voltage waveforms with a rise time of ~ 8 ns and a full width at half maximum (FWHM) of ~ 30 ns at a repetition rate of 10 Hz. This voltage is applied across two rectangular, flat plate electrodes separated by a gap of 4 mm as shown in Fig. 1.

The Pockels cell used in these experiments was supplied by Leysop Ltd and consists of a UV BBO crystal housed in a custom-made casing with electrical leads. Applying a HV pulse to the Pockels cell alters the birefringence of the BBO crystal for the duration of this pulse, effectively rendering the cell as an ‘electronic waveplate’. By placing the Pockels cell between two crossed polarizers and timing it such that it is triggered in coincidence with a laser pulse, a shorter laser pulse may be obtained (see Fig. 2) [6].

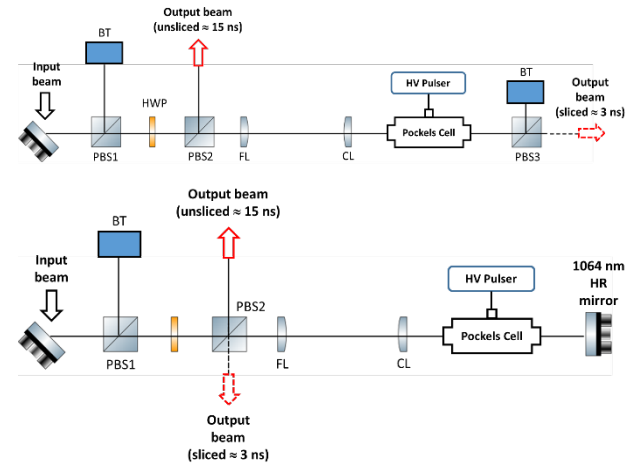


Fig. 2 Pulse slicing optical schematic. Top: Single-pass, Bottom: double-pass.

The energy of the sliced pulse is strongly dependent on the polarization rotation that can be produced by the Pockels cell. As seen in the top schematic of Fig. 2, for a fully transmitting cell, performance is best when half-wave rotation can be effected. Unfortunately, the present cell was designed for 205 nm light and limits the amount of polarization rotation that can be obtained at 1064 nm. Furthermore, the possibility of crystal damage at this off-optimum wavelength also restricts the energy input into the cell. To mitigate this problem, a double-pass arrangement is implemented, results of which are shown in the following section.

The E-FISH setup given in Fig. 1 is essentially similar in principle to that described in [2]. A Quanta-Ray Lab-230 YAG laser system is used as a source of 1064 nm, 50 mJ, ~ 15 ns pulses at repetition rate of 10 Hz. These pulses are reduced to about 2.8 ns and 2 mJ after passing through the double-pass pulse slicing layout given in the bottom panel of Fig. 2. This beam is focused with a 30 cm lens into the

center of the electrode gap and collimated with a 25 cm lens. A dichroic mirror and dispersive prism separate the residual 1064 nm beam and the 532 nm second harmonic (SHG) signal. This 532 nm light is then focused with a 10 cm lens into a photomultiplier with an attached 532 nm bandpass filter. Part of the residual 1064 nm beam is picked off and directed onto a photodiode as a way of monitoring the laser intensity.

The intensity of the 532 nm, E-FISH signal, $I_y^{(2\omega)}$, is given by,

$$I_y^{(2\omega)} \propto [\chi_{yy}^{(3)}(2\omega, 0, \omega, \omega) N E_y I_y^{(\omega)} L]^2 \left[\text{sinc} \left(\frac{L}{L_c} \right) \right]^2 \quad (1)$$

In Eq. (1), E_y is the vertical (y-axis) component of the electric field, $I_y^{(\omega)}$ is the intensity of the vertically polarized 1064 nm laser beam, $\chi_{yy}^{(3)}$ is the third-order nonlinear susceptibility, N is the gas number density, L is the confocal beam parameter, L_c is the coherence length where $L_c = \frac{2}{\Delta k}$ and Δk is the difference between the fundamental and the second harmonic wave vectors.

3. Results and discussion

Fig. 3 shows the results obtained with both the single and double-pass arrangements. The double-pass option produces about 50 times more energy without any detriment to the pulse width. This encouraging result supported the use of this multi-pass configuration for all the results that follow. The overall energy conversion efficiency in this case is estimated to be about 4%.

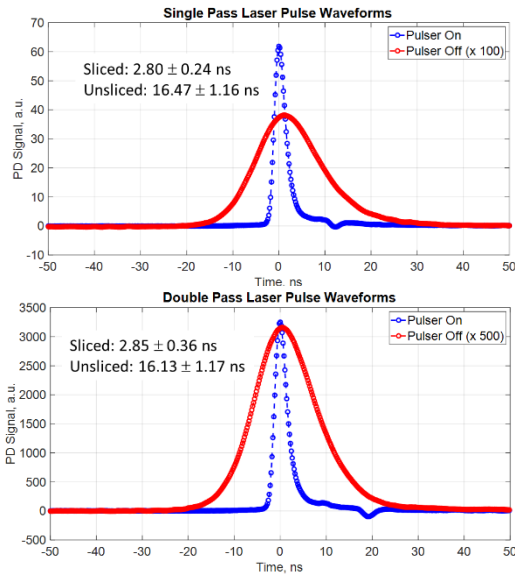


Fig. 3 1064nm laser pulse waveforms obtained with (a) single-pass and (b) double-pass configurations.

To evaluate the viability of these shorter pulses, the E-FISH signal was measured at various time instants in a Laplacian field produced by the HV ns waveforms. This was achieved by stepping through the delay of the main laser

beam relative to the applied HV pulses. **Fig. 4** shows the voltage evolution obtained using the E-FISH technique with the sliced pulses. Measured signals are calibrated against corresponding values measured by a custom-made back current shunt (BCS) installed in the cable connected to the high-voltage electrode. It is clearly seen that these shorter pulses are capable of generating signals which follow the fast rise and fall of the voltage waveforms.

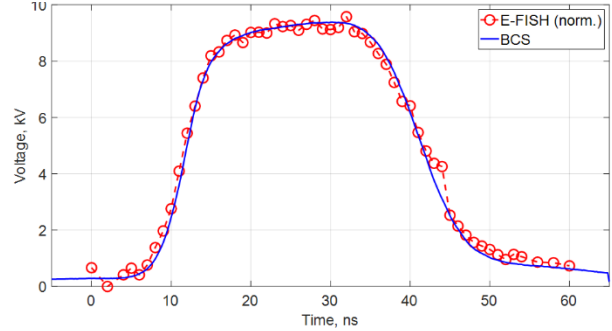


Fig. 4 Laser intensity normalized E-FISH signals plotted against back current shunt data. Dividing these voltages by the interelectrode gap distance gives the electric field strength.

4. Conclusion

The use of an off-optimum design Pockels cell to generate short pulses for electric field measurements has been successfully demonstrated. Significantly shorter and higher energy pulses can be readily achieved with a well-designed, commercial package and at a fraction of the cost of a typical ultrashort pulse laser system. This economical solution may pave the way for performing useful measurements for a variety of laser-based diagnostics.

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