IOPscience iopscience.iop.org

Home Search Collections Journals About Contact us My IOPscience

# A single-shot autocorrelator for UV femtosecond pulses

This content has been downloaded from IOPscience. Please scroll down to see the full text.

1990 Meas. Sci. Technol. 1 637

(http://iopscience.iop.org/0957-0233/1/7/017)

View the table of contents for this issue, or go to the journal homepage for more

Download details:

IP Address: 134.76.223.157
This content was downloaded on 05/01/2017 at 13:37

Please note that terms and conditions apply.

You may also be interested in:

KrF gain module for short-pulse off-axis amplification
G Kovacs and S Szatmari

Soft x-ray brilliance of femtosecond and picosecond laser-plasmas
D Altenbernd, U Teubner, P Gibbon et al.

Single-shot characterization of ultrashort light pulses
A Brun, P Georges, G Le Saux et al.

Single-shot measurement of femtosecond pulses using the optical Kerr effect
H -S Albrecht, P Heist, J Kleinschmidt et al.

The generation of ultrashort laser pulses
P M W French

Longitudinally pumped quenched dye laser
J Klebniczki, S Szatmari and F P Schafer

On-line diagnostic tool for measurement of the time delay between two ultrashort light pulses
V Tenishev, V Avdeichikov, A Persson et al.

Low jitter rail-gap switch triggered by sub-picosecond KrF laser pulses
G Kovacs, S Szatmari and F P Schafer

Microprocessor-based system for measurement of the characteristics of ultra-short laser pulses
F Krausz, T Juhasz, J S Bakos et al.

Meas. Sci. Technol. 1 (1990) 637–639. Printed in the UK

# A single-shot autocorrelator for UV femtosecond pulses

**Peter Simon†§, Harald Gerhardt† and Sandor Szatmári‡||**
† Laser-Laboratorium Göttingen, Im Hassel 21, D-3400 Göttingen,
Federal Republic of Germany
‡ Max-Planck-Institut für biophysikalische Chemie, Am Faßberg, D-3400 Göttingen,
Federal Republic of Germany

Received 30 October 1989, accepted for publication 27 February 1990

**Abstract.** A single-shot autocorrelator for UV pulses is presented. It uses a tilted pulse-front geometry and three-photon fluorescence of XeF as a non-linear detector. The readout system consists of a CCD camera and an oscilloscope. The resolution of the device is a few femtoseconds.

## 1. Introduction

Recently considerable effort has been concentrated on the development of short-pulse high-power KrF laser systems [1–4]. When operating these high-brightness systems, a simple shot-to-shot control of the pulse duration is important. A commonly used technique for the measurement of the pulse length at 248 nm is the multiple-shot autocorrelation technique, based on two-photon ionisation of NO [5–7]. However, for the recording of a multiple-shot trace, $10^2$–$10^3$ shots have to be accumulated, obviously limiting the feasibility of this measurement. Very recently single-shot methods have been introduced for temporal measurement of UV pulses based on two-photon fluorescence of $Xe_2$ [8], three-photon fluorescence of XeF [9], and two-photon ionisation of gases [10, 11].

According to references [8–10] the temporal resolution of the autocorrelator is limited by the spatial resolution of the non-linear detector since a counter-propagating pulse-geometry is used. This imposes severe conditions, in addition, for the alignment of the set-up. In this respect a considerable improvement is achieved with the use of slightly tilted pulse-fronts [12] instead of counter-propagating beams, allowing easy alignment and high temporal resolution. On the other hand the detection of the spatial distribution of the ions needs a special electronic device. In reference [9] a non-linear spatial detector based on three-photon fluorescence of XeF is introduced where the spatial distribution of the visible fluorescence can be detected by commercial devices.

In this paper we present a single-shot UV autocorrelator, developed as the combination of the three-photon fluorescence method [9] and an optical arrangement using slightly tilted pulse-fronts [11]. The present device is capable of measuring pulse durations with femtosecond accuracy using a simple detection system consisting of a CCD camera and an oscilloscope.

## 2. Experimental procedure

The principle of a single-shot autocorrelator using tilted pulse-fronts (figure 1) was first reported in 1977 [12]. It can be realised by using two co-linear beams in which at least one of the pulse-fronts is tilted by a dispersive element [13, 14]. Another way is to split the beam of the short pulse into two which are then combined at an angle

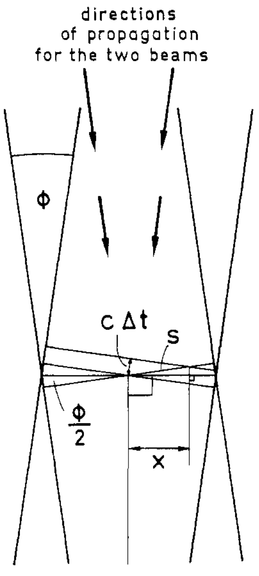


**Figure 1.** Scheme of the tilted pulse-front geometry for single-shot autocorrelators.

---

Permanent address:
§ JATE University, Department of Experimental Physics, Dóm Tér 9, H-6720 Szeged, Hungary.
|| JATE University, Research Group on Laser Physics of the Hungarian Academy of Sciences, Dóm Tér 9, H-6720 Szeged, Hungary.

0957-0233/90/070637+03 $03.50 © 1990 IOP Publishing Ltd

$\varphi$ in a non-linear medium [15, 16]. It was shown that using these configurations the spatial distribution of the response of the non-linear medium displays the autocorrelation function of the pulses along the bisector of the pulse-fronts. The required time scale can be set by proper choice of the angle $\varphi$. The advantage of the multiphoton fluorescence and ionisation technique in combination with the tilted pulse geometry is that the time window of the measurement can be changed continuously by changing the angle between the two beams [11]. In order to find the relationship between the spatial width of the observed pattern and the temporal width of the autocorrelation function, let us assume a delay of $\Delta t$ introduced into one arm. Then the maximum of the spatial pattern shifts by an amount $x$ (figure 1).

From figure 1

$$x = s \cos \varphi/2 \tag{1}$$

and

$$\frac{c\Delta t}{s} = \sin \varphi. \tag{2}$$

Substituting equation (2) into (1) yields

$$x = \frac{c}{2 \sin \varphi/2} \Delta t. \tag{3}$$

When using XeF as a non-linear medium a cubic dependence of the XeF C–A visible fluorescence signal on the laser intensity is observed when the power density of the 248 nm pulse is in the range of 1 TW cm$^{-2}$ [9]. Our laser pulses are taken from a DFDL-based KrF laser system [1] delivering sub-picosecond pulses of $\approx 8$ mJ energy. An area of the beam, $6 \times 16$ mm$^2$, is selected carrying 3 mJ energy. Over this area the intensity is practically flat-topped, which is essential for the measurement. The estimated divergence of the beam is $\varphi \leqslant 0.4$ mrad. If the beam is focused with a cylindrical lens of $f = 150$ mm along the smaller axis, one obtains a focal area of $16 \times 0.06$ mm$^2$. Since the expected pulse duration is about 300 fs this corresponds to a power density of $\approx 1\, TW$(cm$^2$). This is just in the intensity range where generation of three-photon fluorescence in XeF is expected.

When a short pulse, large aperture UV beam is passed through a lens, temporal front distortion occurs [17, 18] resulting in a stretched pulse duration in the focus. The magnitude of this effect ($\Delta T$) can be estimated by

$$\Delta T = \frac{\lambda}{c} \frac{b^2}{8} \frac{1}{r} \frac{\mathrm{d}n}{\mathrm{d}\lambda} \tag{4}$$

where $\lambda$ is the wavelength, $c$ is the speed of light, $b$ is the smaller size of the beam at the lens, $r$ is the radius of the curved surface of the planoconvex lens and $\mathrm{d}n/\mathrm{d}\lambda$ is the dispersion of the lens material (fused silica in the experiment) [17]. In our case, equation (4) yields 27 fs. This is less than 10% of the expected pulse duration and hence an error that is of the order of the uncertainty of the pulse-width measurement. The relative contribution of the lens effects to the pulse duration does not increase even in the case of the measurement of the compressed pulses of our laser system [1]. Although the pulse duration decreases by a factor of 3–4, an increase by almost the same factor is expected in peak power. This would make possible the use of a lens of proportionally larger focal length resulting in correspondingly less pulse-front distortion (see equation (4)).

A scheme of the single-shot autocorrelator device is shown in figure 2. The $16 \times 6$ mm$^2$ input beam is split by a 50% beam splitter. The transmitted beam is sent through a variable delay line and is directed into the XeF cell. The reflected beam is also directed into the XeF cell at an angle of $\varphi = 2.8°$ with respect to the other beam. Both beams are focused by the same cylindrical lens of $f = 150$ mm. Focusing is done along the smaller dimension of the beams. The cell contains 100 kPa of Xe, 85 kPa of $F_2$ (5%) in He, and 215 kPa of argon as in reference [9]. The fluorescence from the focal line is observed from the side by a CCD camera (Kappa CF3). The camera-lens system serves as a UV cut filter thus selecting only the visible fluorescence from the C–A transition of XeF.

A typical image taken by the camera is shown in figure 3(*a*), obtained using a Sony UP-104 video graphic printer. The fluorescence intensity distribution is read

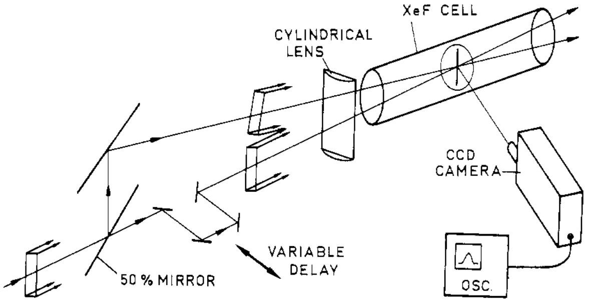
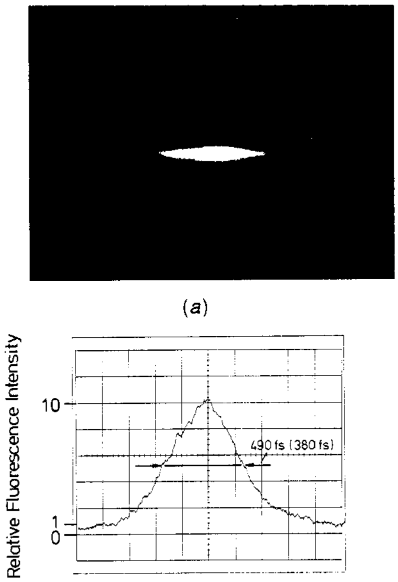


**Figure 2.** Experimental set-up of the autocorrelation device.



(*a*)

(*b*)

**Figure 3.** (*a*) Typical image seen by the CCD camera of the autocorrelator; (*b*) horizontal intensity distribution of the picture: autocorrelation function.

from a digital oscilloscope (Gould 4072) which is set to sweep along one selected line of the video frame where the intensity is the highest. A typical trace is shown in figure 3(*b*). The apparent peak-to-background ratio is close to the theoretical expectation of 10:1 supposing a third-order process for autocorrelation [19]. As the variable delay is changed the peak of the fluorescence shifts. This provides direct calibration of the time scale and leads to the same result as obtained in equation (3). The autocorrelation width of the pulses was typically 490 fs. The corresponding pulse duration supposing a $\mathrm{sech}^2(t)$ shape [9] is 380 fs.

## 3. Conclusion

In conclusion, we constructed a single-shot autocorrelator for UV pulses. The device combines tilted pulse-front geometry and the use of XeF as a third-order detector. Data are collected using simple commercial equipment, CCD camera and oscilloscope, easily accessible for many laboratories. The temporal resolution of the device is a few femtoseconds. Measurement of 380 fs pulses was demonstrated.

## Acknowledgment

The authors wish to thank Professor F P Schäfer for his useful comments and critical reading of the manuscript.

## References

[1] Szatmári S and Schäfer F P 1988 Simplified laser system for the generation of 60 fs pulses at 248 nm *Opt. Commun.* **69** 196

[2] Roberts J P, Taylor A J, Lee P H Y and Gibson R B 1988 High irradiance 248 nm laser system *Opt. Lett.* **13** 734

[3] Barr J M, Everall N J, Hooker C J, Ross I N, Shaw M J and Toner W T 1988 High energy amplification of picosecond pulses at 248 nm *Opt. Commun.* **66** 127

[4] Watanabe M, Endoh A, Sarukura N and Watanabe S 1989 Subpicosecond UV pulse generation for a multiterawatt KrF laser *Appl. Phys.* B **48** 417

[5] Morita N and Yajima T 1982 A nonlinear correlation method using multiphoton ionization for the measurement of UV ultrashort pulses *Appl. Phys.* B **28** 25

[6] Rayner D M, Hackett P A and Willis C 1982 Ultraviolet laser, short pulse-width measurement by multiphoton ionization autcorrelation *Rev. Sci. Instrum.* **53** 537

[7] Glownia J H, Misewich J and Sorokin P P 1986 Ultrafast ultraviolet pump-probe apparatus *J. Opt. Soc. Am.* B **3** 1573

[8] Hutchinson M H R, McIntyre I A, Gibson G N and Rhodes C K 1987 Measurement of 248 nm, subpicosecond pulse durations by two-photon fluorescence of xenon excimers *Opt. Lett.* **12** 102

[9] Sarukura N, Watanabe M, Endoh A and Watanabe S 1988 Single-shot measurement of subpicosecond KrF pulse width by three-photon fluorescence of the XeF visible transition *Opt. Lett.* **13** 996

[10 Bourne O L and Alcock A J 1986 Ultraviolet and visible single-shot autocorrelator based on multiphoton ionization *Rev. Sci. Instrum.* **57** 2979

[11] Szatmári S, Schäfer F P and Jetwa J 1990 A single-shot autocorrelator for the ultraviolet with a variable time window *Rev. Sci. Instrum.* (submitted)

[12] Jansky J, Corradi G and Gyuzalian R N 1977 On a possibility of analysing the temporal characteristics of short light pulses *Opt. Commun.* **23** 293

[13] Wyatt R and Marinero E E 1981 Versatile single-shot background-free pulse duration measurement technique, for pulses of subnanosecond to picosecond duration *Appl. Phys.* **25** 297

[14] Szabó G, Bor Z and Müller A 1988 Phase-sensitive single-pulse autocorrelator for ultrashort laser pulses *Opt. Lett.* **13** 746

[15] Ishida Y, Yajima T and Watanabe A 1985 A simple monitoring system for single subpicosecond laser pulses using an SH spatial autocorrelation method and a CCD image sensor *Opt. Commun.* **56** 57

[16] Salin F, Georges P, Roger G and Brun A 1987 Single-shot measurement of a 52-fs pulse *Appl. Opt.* **26** 4528

[17] Szatmári S and Kühnle G 1988 Pulse front and pulse duration distortion in refractive optics, and its compensation *Opt. Commun.* **69** 60

[18] Bor Z 1988 Distortion of femtosecond laser pulses in lenses and lens systems *J. Mod. Opt.* **35** 1907

[19] Auston D H 1971 Higher order intensity correlations of optical pulses *IEEE J. Quantum Electron.* **QE-7** 465