CONTROL OF LASER RADIATION PARAMETERS

PACS numbers: 42.65.Re; 42.55.Rz; 07.60.Ly
DOI: 10.1070/QE2009v039n02ABEH013859

Device for enhancing the time contrast of utrashort laser pulses based on a polarisation Mach – Zehnder interferometer

A.V. Gitin

Abstract. **A polarisation Mach – Zehnder interferometer is considered containing identical cells with a nonlinear medium in different arms. A parallel wave beam propagates through one cell and a converging-diverging wave beam propagates through the other. It is shown that the interferometer transmission depends on the power of the laser pulse propagated through it. It is proposed to use this effect to enhance the time contrast of ultrashort and superhigh-power laser pulses, i.e. to suppress side (background) pulses.**

Keywords: *time contrast, ultrashort laser pulses, polarisation Mach – Zehnder interferometer, optical Kerr effect.*

1. Introduction

Since the advent of lasers, their pulse power has been constantly increasing and the achieved duration of pulses generated by using passive mode locking [1, 2] is already comparable with the cycle of light oscillations. The use of chirped pulse amplification (CPA) [3] makes it possible for such ultrashort pulse to achieve petawatt powers and to increase the intensity of the radiation focused on a target to 10^{22} W cm^{-2} [4]. Physical processes proceeding during the interaction of light with matter depend, first of all, on the intensity, i.e. the ratio of the laser beam power F to its section area S:

$$I = F/S. \tag{1}$$

The output pulse of the CPA system usually has a complex shape: its main peak is surrounded with side (leading and trailing) peaks [5] and is located on a pedestal of spontaneous emission noise (Fig. 1). At the high intensity of the main pulse, the leading side pulse, the so-called prepulse, can ionise the target, which distorts the interaction pattern of the laser pulse with the target material. In such studies it is necessary to increase maximally the peak intensity I_S of the main pulse and its intensity with respect to the intensity I_N of side pulses, i.e. to increase the so-called time contrast $K = I_S/I_N$ [5].

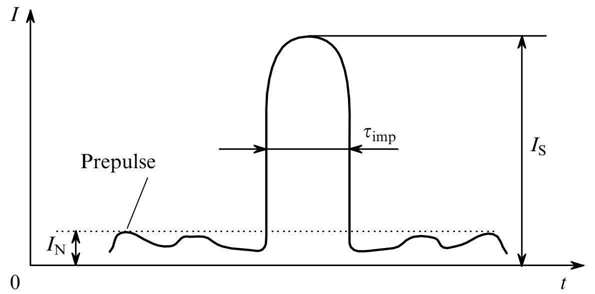

Figure 1. General view of an optical ultrashort pulse.

The 'natural' time contrast of the output pulse from the CPA system does not exceed 10^6 [6], but it is known that it can be increased by placing a passive contrast enhancer (PCE) [8, 9] between a preamplifier and the main amplifier of the two-stage CPA system [7] (where the pulse energy is of the order of millijoules). Such a device should cut off side maxima and transmit the main pulse to the main amplifier without losses. To fabricate a nonselective PCE, either the effect of nonlinear elliptic polarisation rotation [4, 8 – 11] or the effect of generation of cross-polarised waves [12 – 14] or a nonlinear circular Sagnac interferometer [6] are used.

We will show that a PCE for ultrashort and superhigh-power laser pulses can be fabricated based on the scheme of a polarisation Mach – Zehnder interferometer.

2. Polarisation Mach – Zehnder interferometer

The polarisation Mach – Zehnder interferometer [15] (Fig. 2) differs from the conventional interferometer [16] by the fact that it employs polarisation prisms rather than semitransparent mirrors as beamsplitters.

To explain the operating principle of the polarisation interferometer, we will mentally divide it into two units. The first unit contains a polariser, whose principal cross section forms an angle $\theta = 45^\circ$ with the vertical (Fig. 2) and a polarisation divider, whose principal cross section is vertical. This divider splits the linearly polarised laser pulse U into two equal complex amplitudes, $U_v = U \sin 45^\circ = U/\sqrt{2}$, and $U_h = U \cos 45^\circ = U\sqrt{2}$ and separates them to different optical channels. The second unit contains a similar polarisation divider and an analyser, which is oriented perpendicular to the polariser of the first unit, i.e. at an angle $\theta = 45^\circ - 90^\circ = -45^\circ$ to the vertical. In the second unit the polarisation divider combines pulses with complex

A.V. Gitin Max-Born-Institut für Nichtlineare Optik und Kurzzeitspectroskopie, Max-Born-Str. 2A, 12489 Berlin, Germany; web-site: www.mbi-berlin.de; e-mail: andrey.gitin@gmx.de

Received 2 April 2008; revision received 10 July 2008
Kvantovaya Elektronika **39** (2) 154 – 156 (2009)
Translated by I.A. Ulitkin

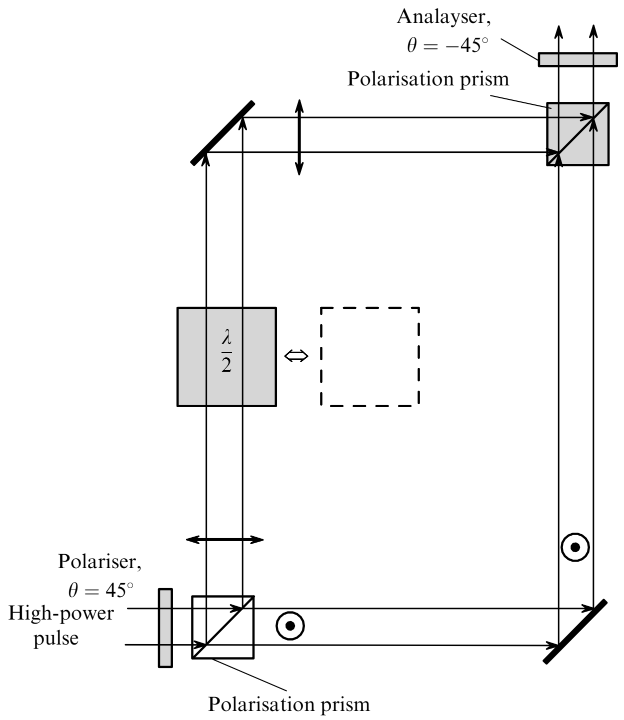

Figure 2. Polarisation Mach – Zehnder interferometer with Glan – Taylor prisms serving as beamsplitters.

amplitudes U_{v} and U_{h} into one pulse. In this case, if the optical lengths of channels from the first polarisation divider to the second one are equal, the combined pulse will have the same linear polarisation as the pulse before the polarisation divider (Fig. 3a) and the analyser will not transmit it. If the optical lengths of these channels differ by $\lambda/2$, the complex amplitude of one of the pulses will change its sign to the opposite one (for example, $U_{\text{v}} \to -U_{\text{v}}$) and, having passed through the second polarisation divider these pulses will be combined into a linearly polarised pulse orthogonal to the pulse polarisation after the polariser (Fig. 3b), which will be transmitted through the analyser without losses. (The $\lambda/2$ plate oriented at 45° to the polarisation plane of incident

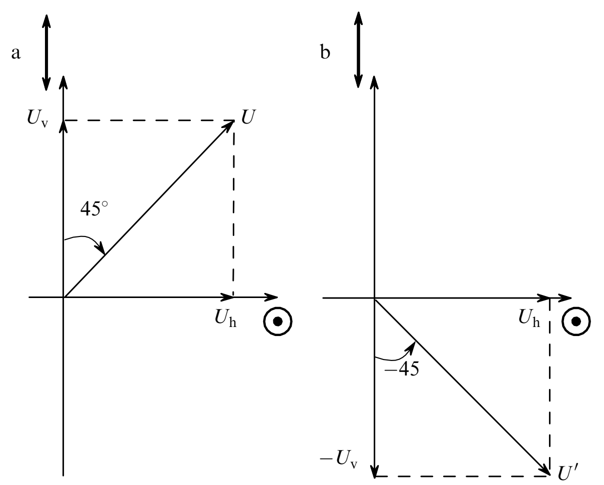

Figure 3. Summation of vertically and horizontally polarised waves with the zero optical path difference (a) and the $\lambda/2$ path difference (b).

radiation has a similar property to rotate the polarisation plane of transmitted linearly polariser radiation by 90° [17]. The advantage of the polarisation Mach – Zehnder interferometer compared to the $\lambda/2$ plate consists in the fact that the orthogonally polarised components of the pulse are separated in it into different optical channels.)

In the general case, the transmission τ of the polarisation Mach – Zehnder interferometer depends on the difference of optical lengths Δ in channels and is calculated for the orthogonal orientation of the polariser and analyser by using expression [18]:

$$\tau(\Delta) = \sin^2\left(\frac{\pi}{\lambda}\Delta\right). \tag{2}$$

3. Optical path length in an optical nonlinear medium

If a high-power laser beam passes through an optically nonlinear medium, the refractive index n of this medium changes due to the optical Kerr effect according to the expression

$$n = n_0 + n_2 I, \tag{3}$$

where n_0 is the refractive index for the low intensity; and n_2 is the nonlinearity coefficient of the refractive index.

The optical path length of the beam consisting of parallel rays (a light beam) is proportional to the geometrical path length multiplied by the refractive index of the medium. Let us compare the optical lengths of collimated and converging-diverging light beams of equal power F, which propagate through completely identical layers of optically nonlinear media of thickness l. According to expressions (1) and (3), the optical path difference

$$\Delta = n_2 \frac{F}{S} \eta l, \tag{4}$$

appears between these pulses. Here, η is the coefficient taking into account differences in the beam geometries. In the particular case of telescopic expanders (Fig. 4) $\eta = 1 - S/s$, where $S = \pi R^2$ and $s = \pi r^2$, but in the general case, instead of telescopic expanders ordinary spherical concave mirrors can be used (Fig. 5). In both cases,

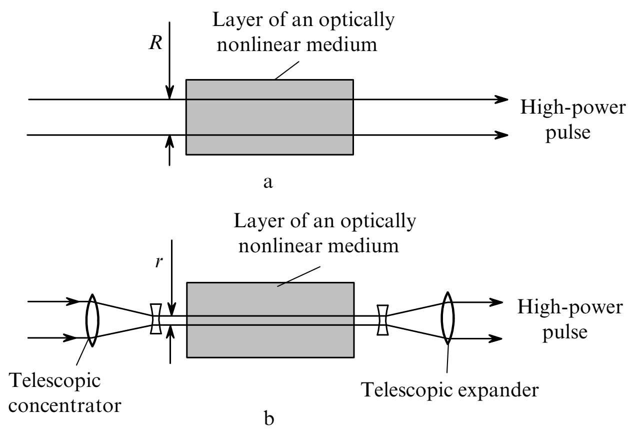

Figure 4. Optical lengths of light beams having different cross sections in optically nonlinear media.

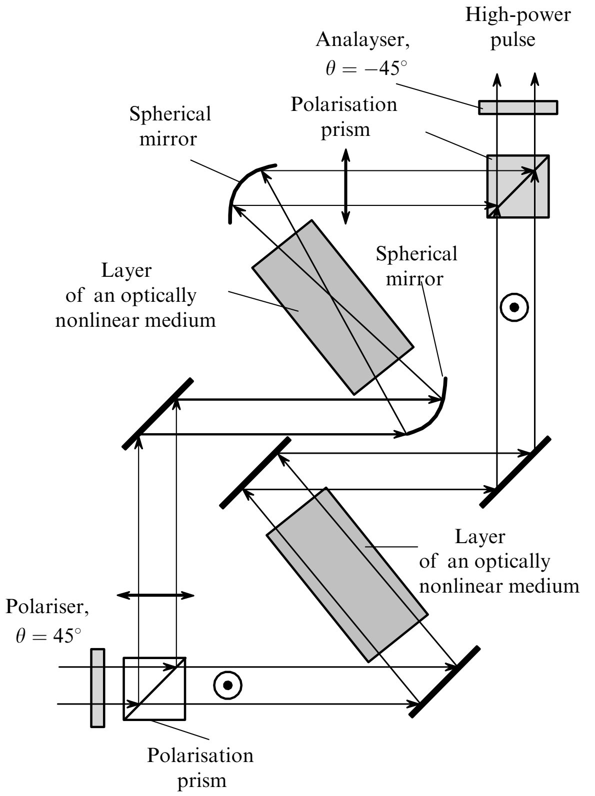

Figure 5. Optical scheme of a device based on a polarisation Mach – Zehnder interferometer.

according to (4) there appears the optical path difference, which is proportional to the radiation power F. Hence, there exists the radiation power F^* for which the optical path difference has the form

$$\frac{\lambda}{2} = n_2 \frac{F^*}{S} \eta l, \tag{5}$$

where λ is the wavelength of a monochromatic wave (central for the pulse spectrum). We will call the quantity F^*, which depends on the beam geometry η, composition and the gas density in the cell as well as on the cell length l, the 'power of the half-wave delay'.

4. Optical scheme of a PCE based on the Kerr effect in a polarisation Mach – Zehnder interferometer

Let us place identical cells with the optically nonlinear medium (for example, gas) in both channels of the polarisation Mach – Zehnder interferometer, but in one channel a pulse in the form of a collimated wave beam will propagate through the cell and in the other channel a pulse in the form of a wave beam focused and defocused by a couple of identical confocal concave spherical mirrors will propagate through the other cell (Fig. 5). The parameters of focusing mirrors, the composition and the gas density in the cells as well as the cell length can be selected so that the power $F_S = U_S^2$ of the main pulse propagated through the cell be equal to the power F^* of the half-wave delay. This pulse will propagate through the interferometer without any losses. The side maxima and spontaneous emission noise (for the time contrast of the pulse equal to $K = 10^6$) have the power $F_N = U_N^2$ inducing the optical path difference so small that the interferometer will not transmit them. Thus, the device under study will relieve the main peak of the pulse from side maxima, which will enhance the time contrast of the ultrashort laser pulses propagated through it.

In the general case, according to expressions (2), (4) and (5) the transmission dependence of the PCE based on the polarisation Mach – Zehnder interferometer on the pulse power has the form:

$$\tau(F) = \sin^2\left(\frac{\pi}{\lambda}\frac{n_2\eta l}{S}F\right). \tag{6}$$

In this case, according to expression (6) half transmission of the PCE corresponds to the half power $F^*/2$ of the half-wave delay.

5. Conclusions

It has been shown that the polarisation Mach – Zehnder interferometer makes it possible to split, without losses in the light beam, the input laser beam into two orthogonally polarised beams, which are spatially separated into two channels containing cells with an optically nonlinear medium. Because in one channel a parallel wave beam propagates through the cell, and in the other channel a converging-diverging beam propagates through the cell, the optical path difference appears between pulses in different interferometer arms and its value depends on the input pulse power. This allows one to remove less powerful side pulses and emission noises, thereby increasing the time contrast.

References

1. Steinmeyer G., Sutter D.H., Gallmann L., Matuschek N., Keller U. *Science*, **286**, 1507 (1999).
2. Steinmeyer G. *J. Opt. A: Pure Appl. Opt.*, **5**, R1 (2003).
3. Mourou G.A. *Appl. Phys. B. Lasers and Optics*, **65**, 205 (1997).
4. Bank S.-W., Rousseau P., Planchon T.A., Chvykov V., Kalintchenko G., Maksimchuk A., Mourou G.A., Yanovsky V. *Appl. Phys. B.*, **80**, 823 (2005).
5. Jullien A., Auge-Rochereau F., Cheriaux G., Chambaret J.-P., d'Oliveira P., Auguste T., Falcoz F. *Opt. Lett.*, **29**, 2184 (2004).
6. Renault A., Auge-Rochereau F., Planchon T., d'Oliveira P., Auguste T., Cheriaux G., Chambaret J.-P. *Opt. Commun.*, **248**, 535 (2005).
7. Kalashnikov M.P., Osvay K. *Proc. SPIE Int. Soc. Opt. Eng.*, **5975**, 125 (2006).
8. Sala K., Richardson M.C. *J. Appl. Phys.*, **49**, 2268 (1978).
9. Homoelle D., Gaeta A.L., Yanovsky V., Mourou G. *Opt. Lett.*, **27**, 1646 (2002).
10. Tapie J.-L., Mourou G. *Opt. Lett.*, **17** (2), 136 (1992).
11. Stolen R.H., Botineau J., Ashkin A. *Opt. Lett.*, **7**, 512 (1982).
12. Petrov G.I., Albert O., Etchepare J., Saltiel S.M. *Opt. Lett.*, **26**, 355 (2001).
13. Minkovski N., Saltiel S.M., Petrov G.I., Albert O., Etchepare J. *Opt. Lett.*, **27**, 2025 (2002).
14. Minkovski N., Saltiel S.M., Petrov G.I., Albert O., Etchepare J. *J. Opt. Soc. Am. B.*, **21**, 1659 (2004).
15. Cotel A., Jullien A., Forget N., Albert O., Cheriaux G., Le Blanc C. *Appl. Phys. B.*, **83**, 7 (2006).
16. Francon M., Mallick S. *Polarization Interferometers* (New York: John Wiley & Sons, 1971).
17. Born M., Wolf E. *Principles Of Optics* (Oxford: Pergamon Press, 1969).
18. Gerrard A., Burch J.M. *Introduction to Matrix Methods in Optics* (New York: John Wiley&Sons, 1975).