J. Phys. IV France **133** (2006) 713–715

DOI: 10.1051/jp4:2006133144

Nonlinear temporal pulse cleaning for high-energy petawatt-class lasers

A. Cotel[1], A. Jullien[2], N. Forget[1], O. Albert[2], C. Le Blanc[1], J. Etchepare[2], G. Chériaux[2], N. Minkovski[3] and S.M. Saltiel[3]

[1] *Laboratoire pour l´Utilisation des Lasers Intenses, UMR 7605 CNRS, CEA, Université Paris VI, École Polytechnique, 91128 Palaiseau, France*
[2] *Laboratoire d´Optique Appliquée, UMR 7639 CNRS, ENSTA, École Polytechnique, Chemin de la Hunière, 91761 Palaiseau, France*
[3] *University of Sofia, 5. J. Bourchier Bd., 1164 Sofia, Bulgaria*

Abstract. We present a new nonlinear solid-state technique for temporal femtosecond pulses cleaning. The contrast reaches 10^{-10} for millijoule input pulse. Efficiency is demonstrated at 800 nm and 1 μm. The method is reliable enough to solve the contrast issue for Petawatt class lasers.

1. INTRODUCTION

One of the last major difficulties in development of ultra-intense and ultra-short laser systems is the ability to produce pulses with a high temporal contrast. High peak-power petawatt-class laser systems require background-to-peak intensity contrast ratios above 10^{-10} to avoid ionization of the target before the arrival of the high peak-power pulse. A typical high-power Ti:Sapphire lasers configuration, based on a chirped pulse amplification (CPA) scheme, generates not only a femtosecond pulse but also an amplified spontaneous emission (ASE) nanosecond background and short prepulses and postpulses that limits the temporal contrast to 10^{-7}. In an optical parametric chirped pulse amplification (OPCPA) system [1], the temporal contrast is expected to be higher than 10^{-7} and exempt of ASE and pre-pulses. Nevertheless, a parametric fluorescence effect can occur during the pulse amplification and can give a temporal pedestal on the compressed pulses.

Some techniques to improve temporal contrast have already been proposed, as femtosecond preamplification [2], plasma mirror [3], nonlinear Sagnac interferometer [4], nonlinear elliptical polarization rotation (NER) [5], and cross-polarized wave generation (XPW) [6]. Among these techniques, XPW present the most advantages and has proved to be a simple, efficient and reliable pulse cleaner operating in the millijoule level. We present the experimental XPW pulse filtering using a nonlinear crystal (BaF_2) in two different petawatt front end lasers : a Ti:Sapphire amplifier at 800 nm and an OPCPA at 1057 nm.

2. XPW PRINCIPLE AND EXPERIMENTAL SETUP

XPW generation is a four-wave mixing process governed by the anisotropy of the real part of the crystal third-order nonlinearity tensor ($\chi^{(3)}$) [7]. Because this process is highly nonlinear with the input intensity and varies as the cubic power of the intensity of the wave, XPW generation may be used to discriminate low intensity level parts of a sub-picosecond pulse (e.g. prepulses, pulse background, time-dependant wings) from the pulse peak. When used between crossed-polarizers, XPW generation allows to reject the low-intensity parts of the pulse and therefore to improve the temporal constrast of the intense laser pulse. Barium fluoride (BaF_2) nonlinear crystal is especially well-adapted to XPW generation. As this crystal is isotropic with respect to its linear optical properties, the process is characterized by a perfect phase and group velocity matching of the two orthogonally polarized waves propagating along the z axis. Another advantage of BaF_2 is its transmission from the ultraviolet to the infrared.

Experiments are performed firstly with a Ti:Sapphire CPA laser including regenerative and multipass amplifiers. It produces 42 fs, 800 nm, 2 mJ maximal energy pulses, at 1 kHz repetition rate. In that case, the energy converted from the input pulse to the XPW signal is about 10% without excessive self-phase modulation [6]. The second laser system is an OPCPA which provides 260 fs, 750 μJ pulses at a repetition rate of 10 Hz with a spectrum centered at 1057 nm. With this system and a two BaF_2 crystals filter, an efficiency of 20% is measured considering a gaussian spatial profile and a single-pass configuration.

3. NONLINEAR FILTERING EXPERIMENTS

The XPW filter cleans the pulse both temporally and spatially. We estimate the temporal pulse contrast improvement by using a high-dynamic range third-order cross-correlator. For the Ti:Sa laser system, the pulse contrast enhancement is illustrated by Fig. 1, where temporal profiles of non-filtered and filtered pulses are measured [6].

The ASE intensity level of the input pulse is six orders of magnitude below the peak intensity of the main pulse. As the XPW generated pulse intensity profile presents a cubic dependence on the input one, the pulse pedestal is drastically reduced. The 10^{-10} remaining ASE pedestal corresponds to a leakage of the incoming pulse pedestal through the analyzer. The spectral behaviour of XPW process results on no spectral modulations and no spectral distorsions.

Because of the nonlinear filter is positionned near the focal plan, XPW generation also acts as a spatial filter that improves the spatial profile. Therefore, the spatial beam quality is enhanced (Fig. 2).

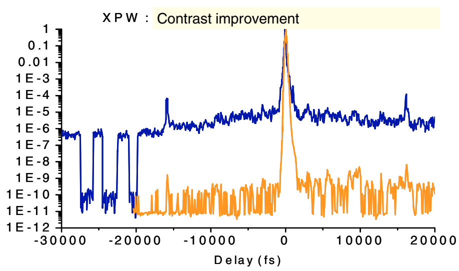

Figure 1. Third order correlation curves before at 800 nm (blue curve) and after (orange curve) filtering. For these measurements, the energy seeded in the correlator is 120 μJ. For this energy level, the correlator noise is 10^{-11}.

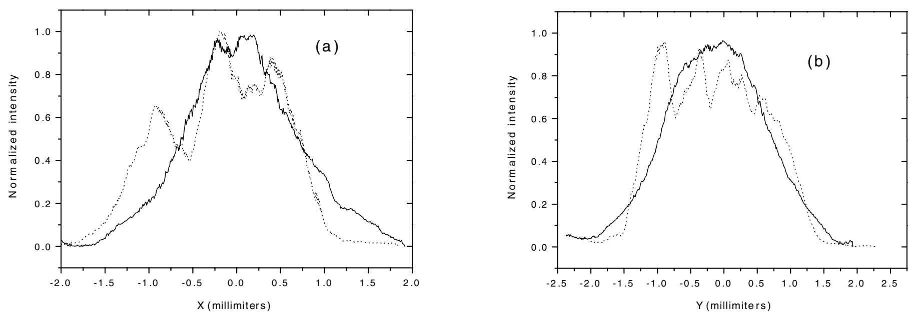

Figure 2. Horizontal (a) and vertical (b) spatial distribution before (dotted curves) and after (solid curves) filtering. The input energy is 1.2 mJ and the conversion efficiency is 10%.

We also demonstrate that XPW technique can be fully transposed at 1μm with pulse duration of several hundred femtoseconds, which is the pulse duration domain relevant to Nd:glass petawatt-class lasers. XPW filter is implemented after an OPCPA laser which delivers 260 fs, 750 μJ pulses. Beyond efficiency greater than 20% with two BaF_2 crystals, the pulse contrast is enhanced by three orders of magnitude, only limited by the polarizer extinction ratio (Fig. 3a). In that case, the nonlinear filter steepens the pulse front and decrease both the picosecond pedestal and the nanosecond background. A significant reduction of the pulse duration during the filtering process is also measured with a single shot second-order autocorrelator (Fig. 3b).

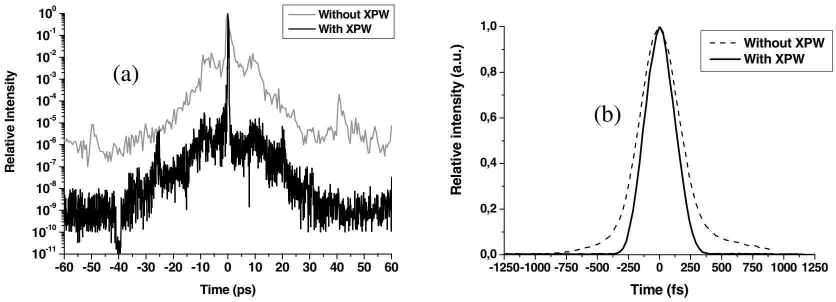

Figure 3. (a). Third-order cross-correlation at 1057 nm without XPW filter (lighter curve) and with XPW filter (darker curve). (b) Second-order autocorrelations at 1057 nm measured without XPW filter (dashed curve) and with XPW filter (solid curve). The deconvolved pulse full widths at half maximum are respectively 260 fs and 215 fs.

4. CONCLUSION

In conclusion, we have demonstrated the XPW generation technique at 800 nm and 1057 nm with pulses of respectively 42 fs and 260 fs and reached a transmission efficiency as high as 20% in a single-pass configuration. Four orders of magnitude contrast enhancement to 10^{-10} limited by the extinction ratio of the polarizer set was demonstrated. Such favourable results show that, at the cost of a double CPA architecture, XPW generation is a pulse cleaning technique fully compatible with high peak-power pulse laser chains and able to meet the requirements for extreme pulse contrast.

Acknowledgement

This work is performed under the auspices of the European SHARP contract.

References

[1] Dubietis, G. Jonusauskas, and A. Piskarskas, Opt. Comm. **88**, 437 (1992).
[2] J. Itatani, J. Faure, M. Nantel, G. Mourou, and S. Watanabe, Opt. Comm. **148**, 70 (1998).
[3] G. Doumy, F. Quéré, O. Gobert, M. Perdrix, P. Martin, P. Audebert, J.-C. Gauthier, J.-P. Geindre, and T. Wittman, Phys. Rev. E **69**, 026402-1 (2004).
[4] A. Renault, F. Augé-Rochereau, T. Planchon, P. D'Oliveira, T. Auguste, G. Chériaux, and J.-P. Chambaret, Opt. Comm. **248**, 535 (2005).
[5] M. P. Kalashnikov, E. Risse, H. Schönnagel, and W. Sandner, Opt. Lett. **30**, 923 (2005).
[6] A. Jullien, O. Albert, F. Burgy, G. Hamoniaux, J.-P. Rousseau, J.-P. Chambaret, F. Augé-Rochereau, G. Chériaux, J. Etchepare, N. Minkovski, and S. M. Saltiel, Opt. Lett. **30**, 920 (2005).
[7] N. Minkovski, G. I. Petrov, S. M. Saltiel, O. Albert, and J. Etchepare, J. Opt. Soc. Am. B**21**, 1659 (2004).