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# SPECTRALLY CLIPPED PULSES ANALYSIS IN A CPA LASER SYSTEM

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*Este prezentată o analiză a pulsurilor scurtate spectral în cadrul unui sistem optic stretcher-compresor. Dispozitivul optic, ce include un stretcher optic, un amplificator şi un compresor, are la baza principiul Chirped Pulse Amplification (amplificare de pulsuri modulate). S-a folosit tehnica de producere de pulsuri cu forma controlată pasiv în domeniul spectral prin introducerea unui element absorbant in stretcher. S-au determinat duratele pulsurilor şi contrastul acestora în funcţie de diverşi parametri. Sistemul propus va fi utilizat pentru generarea de pulsuri cu forma controlată în cadrul unor aplicaţii experimentale cum sunt producerea de plasmă şi analiza acesteia.*

*An analysis of spectrally clipped pulses in an optical stretcher-compressor system is presented. The optical system which includes an optical stretcher, an amplifier and a compressor, is based on Chirped Pulse Amplification principle. Passive pulse shaping technique in the spectral domain was used by introducing an absorbing baffle in the stretcher. Pulse durations and pulse contrast were determined as a function of various parameters. The system will be used experimentally for shaping of pulses used in applications such as plasma generation and probing.*

**Keywords:** Chirped Pulse Amplification, ray-tracing, pulse shaping

## 1. Introduction

The chirped pulse amplification (CPA) technique was developed in 1985 at the University of Rochester [1] as a way to simultaneously accommodate the very large beam fluence necessary for energy extraction in superior storage materials while keeping the nonlinear effects and intensity to a suitable level. The ultrashort pulses cannot be amplified in the classical amplifier systems based on direct amplification without producing unwanted nonlinear effects. For minimizing such effects, the CPA technique stretches first the pulse several orders of magnitude, lowering the intensity accordingly without changing the input fluence, then amplifies it to the desired energy level, by a factor of $10^6$-$10^{12}$ and

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finally compresses the pulse back to almost its original duration. In this way, a high-intensity pulse is created [2].

Today, the CPA laser systems can produce terawatt and even petawatt pulses, using high-power Ti-Sapphire-based systems. At the present, CPA technique is incorporated in all the ultrashort and ultra intense laser systems around the world and its applications in laser physics were extended from atomic and condensed-matter studies to plasma physics, life sciences, nuclear and high-energy physics, general relativity and cosmology physics beyond the standard model [2].

An important technique for CPA systems is “the pulse-shaping method” which allows control over amplitude, phase, frequency or inter-pulse separation. It covers a wide area of applications in photonics, optical communication systems, generation of multiple pulses, dispersion compensation, space-time conversions, biomedical applications, phase control in femtosecond amplifiers, bandpass filtering, control of quantum dynamics and nonlinear optics [3].

In the studies of laser produced plasmas, the contrast of the pulses plays an important role. The contrast (ratio between the peak emission intensities and background) can be modified using pulse shaping methods. The usual pulse shaping and multiple pulses generation methods for pump probe experiments are expensive and complicated to implement. We propose in this paper an alternative inexpensive method for pulse shaping which is based on a numerical simulation using Rayica, a package for Mathematica, which uses a numerical ray-tracing model to extract the wavelength-dependent phase for each ray. The pulse shaping technique consists in placing an absorbing element (baffle) after the first stretcher pass. The numerical results obtained after ray-tracing are Fourier analyzed in Mathematica to reconstruct the pulse shape.

## 2. Optical Stretcher-Compressor design

We have investigated a CPA system that was designed to work together with a femtosecond laser system as an oscillator. The laser seed pulses have about 4.4 nm spectral bandwidth, about 200 femtosecond pulses duration and the central wavelength of 775 nm.

Figure 1 shows a schematic of our optical stretcher design. A diffraction grating with 1200 lines/mm and 110x110x16 mm dimensions was used. The spherical mirror with 6 inch diameter has the focal length of 1200 mm and it is placed about 780 mm away from the diffraction grating. The rectangular flat mirrors are used to build the all-reflective, folded, one-to-one telescope of the stretcher and the roof mirror ensures the double passing of the optical system. The pulse is stretched by introducing different optical paths at different wavelengths in the lasing range. At the roof mirror of the stretcher, a spatial chirp is achieved, the blue spectral components having longer optical paths than the red ones. The pulse duration after the stretcher reaches a duration of about 25 ps.

The absorbing element (baffle) is placed 40 mm away from the roof mirror and can be shifted along an axis perpendicular to the direction of the beam in a horizontal plane, for producing the desired spectral clipping. The baffle always obscures a part of the spectrum, the “blue” one or the “red” one. We refer to these situations as red-clipping and blue-clipping. We define the position of the baffle by the corresponding edge position. The central position, b=0 mm, corresponds to the spectral cut at the central wavelength of the laser, 775 nm. As each position corresponds to a wavelength, one can specify the baffle position directly using the wavelength at the cutting edge of the baffle. This convention will be used further in this paper.

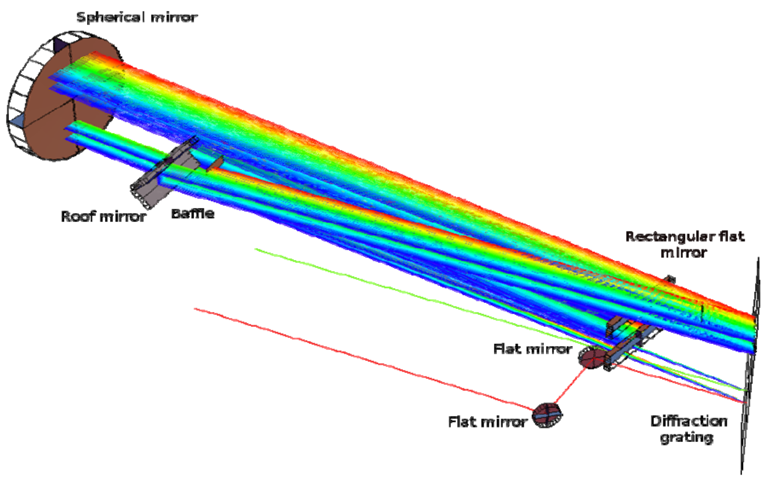


Fig. 1. Color coded ray-tracing using Rayica for the optical stretcher including the baffle. All spectral components for 30 nm bandwidth are included at the entrance in the stretcher so the clipping effect can be visualized at the baffle.

After the amplification, the output pulse is guided through the optical compressor, where it is recompressed back to the original pulse duration. In this system we use only one diffraction grating for both stretcher and compressor, as in ref. [4]. The compressor includes two roof mirrors to compensate for the optical paths introduced by the stretcher. The total length of the stretcher and compressor is about 14 m. The position of the first roof mirror in the compressor can be modified along the beam path. In this way, the optical paths difference between the red and blue parts of the laser pulse can be varied. At the reference position

D=0 for this roof mirror, the compressor completely compensates for the optical paths differences introduced by the stretcher. In this case, the pulses can reach again a duration of about 200 fs. The compressor uses the same incident angle as the stretcher.

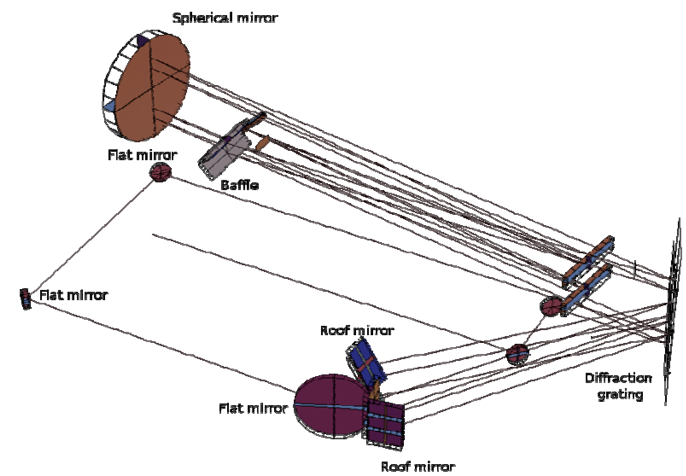


Fig. 2. Rayica ray-tracing of the stretcher-compressor system having only one diffraction grating; it includes the baffle for the spectral clipping in front of the roof mirror in the stretcher

## 3. Clipped pulses analysis

By placing the baffle into the stretcher one produces the spectral clipping which has, as a result, a significant influence on the pulse shape.

For a given compressor length and cutoff wavelength one obtains wavelength-dependent optical paths of the rays. From the optical path one can extract the spectral phase information for the given pulse. Using the clipped amplitude and the phase information one applies numerical Fourier transform in order to produce the temporal intensity profile of the pulses. We used $2^{15}$ sample points with a 4 fs temporal resolution.

A typical result is presented in fig. 3. Figure 3a shows the clipped spectrum at 775 nm (central wavelength) obtained after the baffle placement on the right side of the beam (red clipping). Taking a temporal window of 8 ps, the corresponding normalized intensity of the pulse is illustrated in fig. 3b. The characteristic modulations on the right side of the main peak corresponds to the incomplete compensation of the phase of the stretcher after the pass through the compressor, in the third order, as it is an asymmetric effect. A contrast evaluation is shown in fig. 3c, where the normalized intensity is represented in logarithmic scale . The same temporal profile as in fig. 1b. is obtained in the case of blue-clipping at D=0 mm and cutoff wavelength 775 nm.

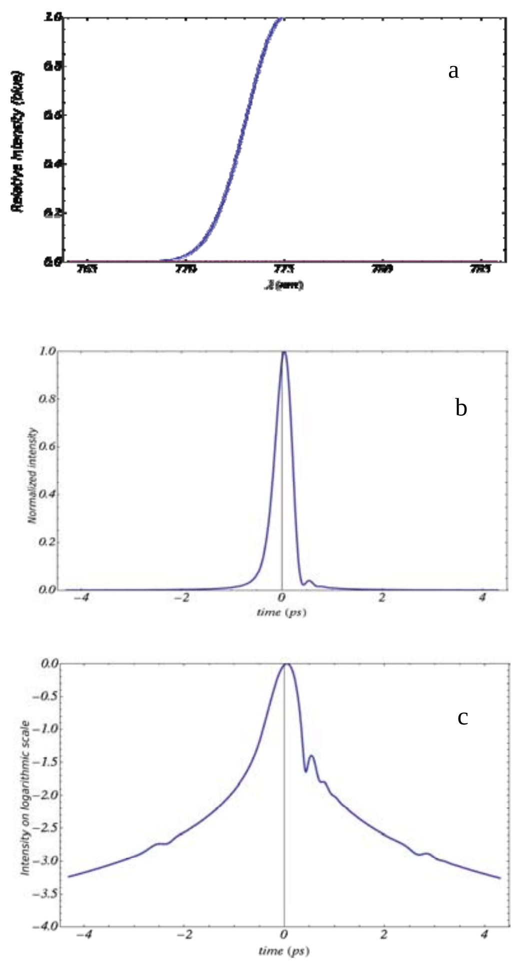


Fig. 3. a) Spectrum of the clipped pulse introduced by the absorbing element; b) normalized time-dependent intensity of the corresponding pulse; c) contrast evaluation at best compression in a 8 ps temporal window

The contrast evaluation, with clipping at the 775 nm (central wavelength) at a compressor detuning of D=4 mm (corresponding to 550 fs with full spectrum) is represented in fig. 4. In the fig. 4 a., it can be observed that the steeper part of the pulse comes first in the blue clipping case while, for the red clipping case, represented in fig. 4 b, the steeper part of the pulse comes after the main peak. This is due to the fact that the pulse has a small temporal chirp so that the red part of the spectrum would came first and the blue part comes at the end in the case of a full spectrum pulse. In this case the spectral clipping corresponds to a temporal clipping.

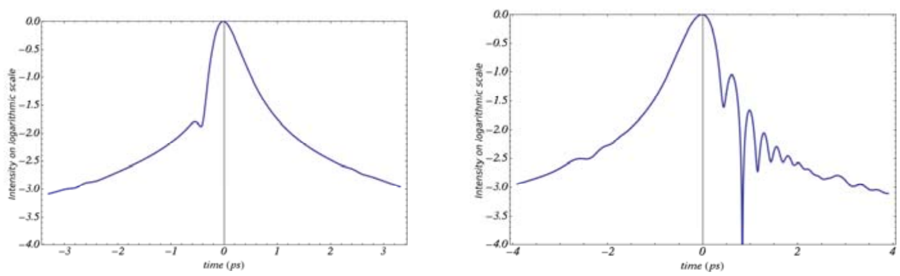


Fig. 4. Clip at the 775 nm (central wavelength) at a compressor detuning of D=4 mm corresponding to 550 fs with full spectrum: a) blue clipping and b) red clipping

Further, we focus on the representation of the pulse duration change as function of the cutoff wavelength for different compressor lengths. We present in fig. 5 the curves for the following D parameters: -5.8, -3.8, -1.8, 0, 2.2, 4.2, 6.2 mm. The detuning of the compressor towards positive and negative lengths D with the same amount produces asymmetric results in the pulse duration. In the left region of the plot, one can see the influence of the compressor detuning only on the pulse duration, while almost full spectrum is used. There are multiple modulations in the central region of the cutoff wavelength (775 nm) given by the spectral clipping. The most significant influence given by the clipping process on the spectrum can be seen on the right region of the figure where almost the full spectrum is obscured by the absorbing element (baffle) and the contrast quality decreases with almost one order of magnitude. It can be observed that there are two effects of the spectral clipping on the pulse duration. On one side, if the pulse is close to best compression, the spectral clipping reduces the available spectrum and, as a consequence, the pulse duration can only increase. On the other side, if the compressor is increasingly detuned, the spectral clipping produces first a shortening of the pulse and only with a significant reduction of the spectrum the pulse duration increases again. This correlates well with the previous observation from fig. 4 where it was shown that the spectral clipping might correspond to a temporal clipping of the pulse.

Another remark can be made regarding the behaviour of the pulse duration at large cutoff wavelengths for positive and negative detuning of the compressor in fig. 5. The pulse duration is significantly different for the same absolute value of the detuning D when this value is taken with positive and with negative sign. This effect can be used for the compressor alignment and characterisation in experiments to fine tune the positive and negative chirp of the stretcher-compressor system.

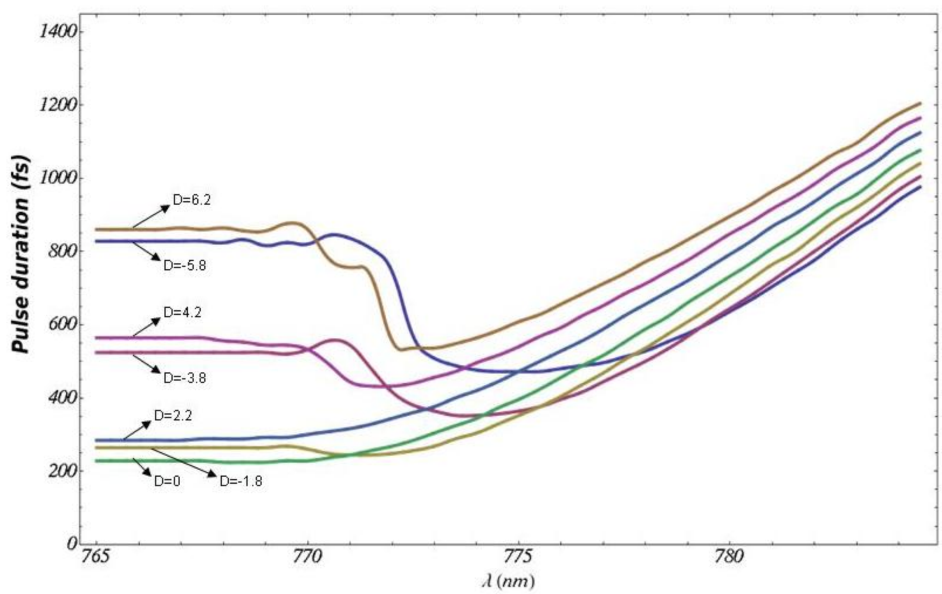


Fig. 5. The pulse duration as a function of the cutoff wavelengths, for different compressor lengths

## 4. Conclusions

This method was elaborated to complement other pulse shaping techniques. It is very flexible in terms of pulse intensity adjustment, compact, simple to implement and inexpensive.

In this study, short time scale contrast modifications were analyzed and it was shown that the pulse duration varies in a non trivial way by varying the compressor length. It also was demonstrated that the contrast of the pulse in the case of a detuned compressor depends on the type of the clipping: red clipping or blue clipping.

Having the information concerning the pulse contrast and duration, the system is suitable for experiments related to plasma generation with ultrashort pulses. The optical system described in this paper is under construction at INFLPR. This work was supported by the projects PNCDI2-People-RP-6, PNCDI2-Partnerships-METALASER and FP7-Extreme Light Infrastructure.

## R E F E R E N C E S

[1] *D. Strickland and G. A Mourou,* 1985 Opt. Commun. 56, 219
[2*] G.A. Mourou, T. Tajima, S.V. Bulanov,* Optics in the relativistic regime, 2006 Reviews of Modern Physics 78 (2)
[3] *A M Weiner,* Femtosecond pulse shaping using spatial light modulators, 2000 – Rev. Sci. Instrum., Vol. 71, No.5, May
[4] *D. Javorkova,* The CPA system for the PW peak intensity at PHELIX, 2007 - Dissertation Thesis, Bratislava