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Temporal Contrast of Tunable Ultrashort Pulses Generated in the Near Infrared

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Abstract: A laser source delivering ultrashort pulses (50-100 fs) tunable from 820 nm to 1200 nm has been recently developed. It is based on the filtering of a continuum in the Fourier plane of a zero dispersion line without any phase compensator. In the manuscript, we investigate how the temporal contrast from the pump is transferred to the tunable ultra-short pulses. We demonstrate that in addition to the wide tunability, this method allows to enhance the temporal contrast by at least two orders of magnitude. This enhancement at relativement long time is efficient for the complete tunable range but it depends strongly on the spectral bandwidth of each pulse. We also show that the filter profile has a weak impact on the temporal contrast at long time (few ps). Hence, the spectral filtering can be achieved directly in a stretcher (or a compressor) with hard cuts. This new approach can be of great interest for laser-matter interaction experiments in the strong field when it is combined with optical parametric amplifiers.

Keywords: Ultra-short pulse generation, Near infrared, Continuum, Temporal contrast.

1. Introduction

Tunable ultrashort pulses in the near infrared is of great interest for many applications as in nonlinear spectroscopy [1], optical coherence tomography [2] or sensing and imaging [3]. For laser-matter interaction experiment in the strong field physics, the energy of the ultra-short pulse is increased in several amplifiers, as in optical parametric amplifier (OPA) allowing large tunability [4]. However, during a strong interaction of the intense pulse with the matter, a very high temporal contrast is required such as any pre-pulse or noise background do not modify the interaction before the arrival of the main pulse. Even if many investigations have been achieved in OPA to enhance or preserve the temporal contrast during the amplification process [5-8], the injected seed must have a clean background to guarantee excellent contrast through the laser chain. Several methods exist to clean the temporal contrast but they usually require high energy pulse. For example, the well-known techniques are based on a plasma mirror [9-10] or the nonlinear rotation of the polarization as in nonlinear ellipse rotation [11] or cross-polarized wave generation [12]. Recently, a novel approach for temporal contrast enhancement has been proposed for energetic laser pulse by filtering a spectrum that has been broadened in an Argon filled hollow core fiber [13]. In the manuscript, we aim to generate the near infrared pulse at low energy (nJ level) with an enhanced temporal contrast.

Recently, we have presented a new method and developed a laser source delivering ultrashort pulses (50-100 fs) tunable from 820 nm to 1200 nm. It is based on the filtering of a continuum in the Fourier plane of a zero dispersion line without any phase

compensator [14-15]. In the paper, we investigate in detail the impact and the enhancement of the temporal contrast during the generation of the tunable ultra-short pulse. We demonstrate that in addition to the wide tunability, this method allows a temporal contrast enhancement by at least two orders of magnitude. This enhancement is efficient for the complete tunable range but it depends strongly on the spectral bandwidth of each pulse. This new approach can be of great interest for laser-matter interaction experiments in the strong field when it is combined with optical parametric amplifiers.

2. Generation of Tunable Ultra-short Pulses

We have recently investigated the generation of tunable ultra-short pulse in the near infrared [14-15]. Briefly, an ultra-short pulse with a duration of 80 fs and a bandwidth of 20 nm (at full width half maximum-FWHM) at 1030 nm has been injected in an all normal dispersion fiber pumped by an average power of 410 mW. The repetition rate is 76 MHz. A coherent continuum has been generated in a 3.5 cm long fiber and it extends from 800 nm to 1200 nm mainly due to the combination of SPM and OWB [16] (Fig. 1). The continuum is then filtered in the Fourier plane of a zero dispersive line or with spectral filters without any phase compensator. A qualitative agreement with the experimental results have been obtained [15]. With this method, we experimentally and numerically demonstrate the possibility to generate ultra-short pulse in the near infrared (800-1200 nm) with a duration ranging from 40 to 100 fs.

3. Temporal Contrast of the Generated Tunable Pulses

3.1. Input Conditions

In the following, we numerically investigate the temporal contrast of the generated tunable pulse. Particularly, we study how the contrast of the input pulse is transferred to the generated one. Numerical simulations are done by integrating the nonlinear Schrödinger equation along the propagation with the same conditions as in [15] and solving with the standard split-step Fourier with the same fiber (from NKT supplier). The length equals to 3.5 cm. As previously, the tunable pulse is obtained by selecting part of the continuum with a spectral filter. Then, we measure the contrast at different time: at short (-1 ps), intermediate (-4 ps) and long time (-8 ps) from the maximum of the generated pulse. The contrast is calculated by integrating the mean power at these timing in a temporal window of 100 fs. Even if we focus the work on the noise or prepulse in front of the main pulse, similar results should be obtained for positive times (the tail of the pulse). In this investigation, we intentionnaly add to the input pulse (at 1030 nm) a noise background.

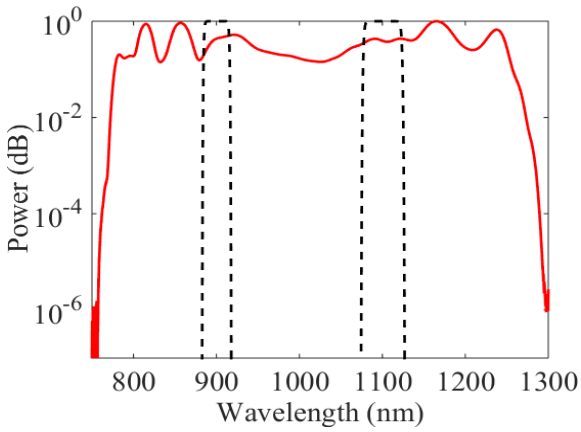
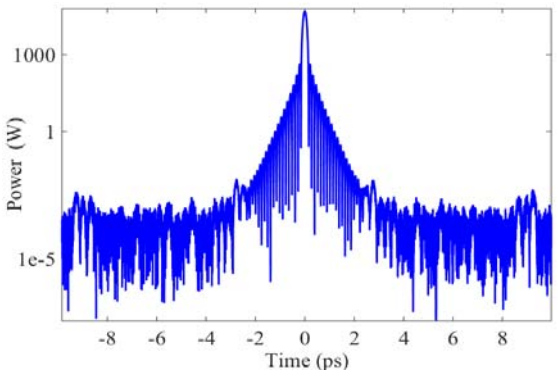
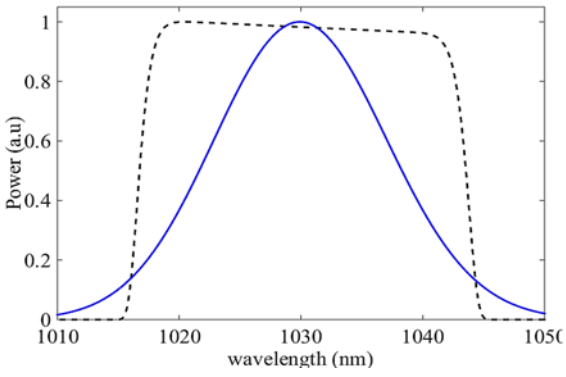


Fig. 1. Simulated continuum (red line) at 410 mW L=3.5 cm. The dashed black lines correspond to the bandpass filters.

Prepulses and postpulses are introduced with a spectral modulation applied to a Gaussian spectral shape. In addition, a high order super Gaussian filter is modelled to represent a hard cut of a stretcher at 1015 and 1045 nm (Fig. 2(b)).



(a)



(b)

Fig. 2. a) Temporal profile of the injected pulse at 1030 nm. b) Gaussian spectrum of the injected pulse (blue line) and the filter used to model the stretcher.

3.2. Temporal Contrast of Tunable Pulses

At the output of the fiber, the continuum is selected with a filter owing a high order super Gaussian shape. The spectral bandwidth is 5.6 THz at FWHM in all cases. For example, the filtered spectrum at different wavelength (900 nm, 1030 nm and 1100 nm) is shown in Fig. 3(a-b-c) (on a logarithmic scale). For 900 nm and 1100 nm (see filters in Fig. 1), the dynamics of the filtered pulse (Fig. 3(d-e-f)) is better than the one of the input pulse (blue line) at relative long time (>2 ps). This is because there is no overlap between the incident spectrum and the weak background of the initial pulse which does not generate any spectrally shifted signal. At shorter time, the contrast is similar to the one at 1030 nm and is due to the hard cut of the filter applied at the input or at the output of the fiber. As the opposite, the temporal contrast at 1050 nm (Fig. 3(e)) is similar to the one of the injected pulse (at 1030 nm). It is conserved around the initial spectrum and no enhancement is possible.

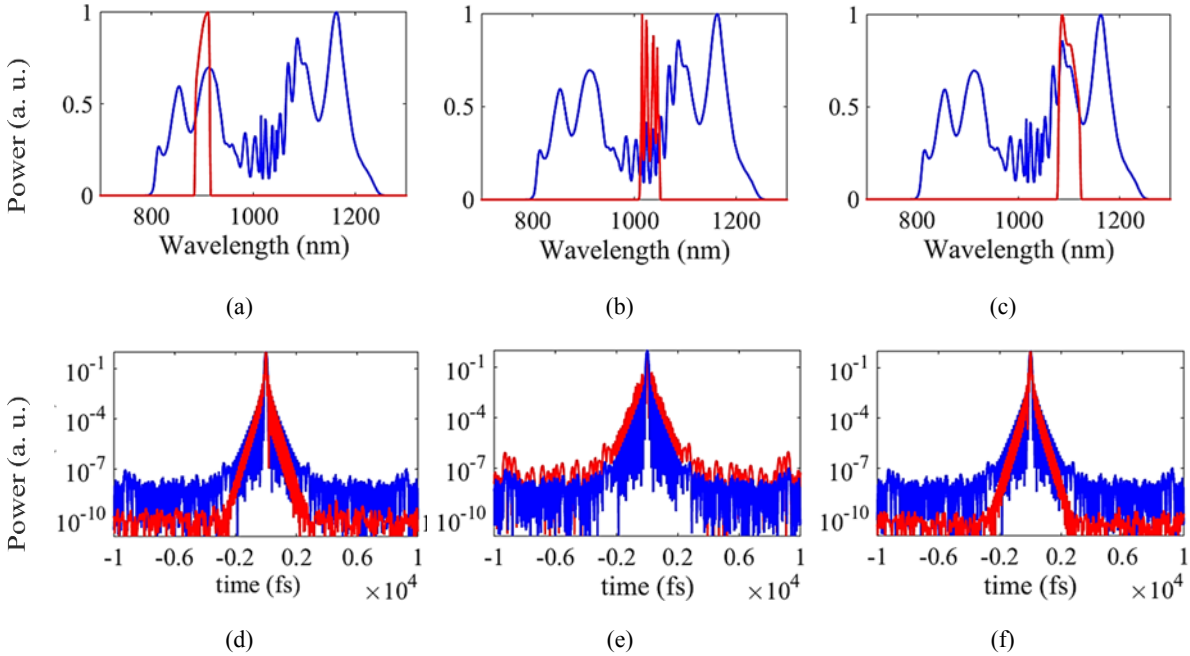


Fig. 3. (a-b-c) Filtered continuum at 900, 1030 and 1100 nm (red line). The blue line shows the continuum. (d-e-f) Temporal profile of the filtered continuum (red lines). The blue line is the input pulse at 1030 nm.

Similarly, Fig. 4 shows the evolution of the temporal contrast at -1 ps, -4 ps and -8 ps as a function of the wavelength. The contrast is clearly improved by approximatively 2 orders of magnitude when the spectrum is away from the input spectrum [13].

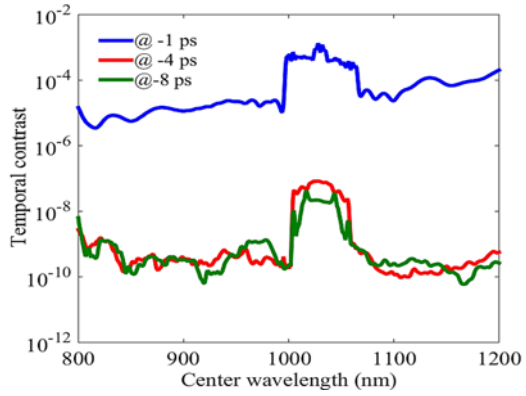


Fig. 4. Temporal contrast when the center wavelength of the filter is tuned. The spectral bandwidth is 5.6 THz (FWHM).

At shorter time, the contrast is worse by ~40 dB compared to the one at long time. This is mainly due to the spectral filters creating pedestal in the temporal domain.

3.3. Role of the Bandwidth Filter

In this section, we investigate the role of the filter bandwidth when it is tuned from 5 nm to 100 nm (Fig. 5). The center wavelength is 900 nm (blue line), 950 nm (green line) 1050 nm (red line) or 1100 nm (blue line). As expected from the previous observations, the contrast is worse at 1030 nm and decrease when the bandwidth increases since the pedestal contribution are weaker for shorter pulse, i.e. for broader bandwidth.

The contrast enhancement can be increased considerably when the pulse is tuned away from the wavelength near 1030 nm (at 1050 nm-red line). For example, the contrast can be enhanced by six orders of magnitude at short time for 950 nm (green line) and a bandwidth of ~60 nm (Fig. 5(a)). This effect is weaker at longer time. Similar behavior is observed when we

consider the Fourier transform limited pulses (dashed line, Fig. 5). Consequently, the pedestals deteriorating the contrast are not due to the uncompensated phase but is originated from the spectral modulation and the input background. For high bandwidth, the spectrum begins to overlap with the input one (at 1030 nm). Therefore, the temporal contrast increases suddenly and reach the value obtained at 1050 nm.

3.4. Role of the Filter Profile

In order to understand the role of the filter profile, we measured the temporal contrast as a function of the wavelength when the spectral filter has a Gaussian (red line, Fig. 6), a 4th order super-Gaussian (green line, Fig. 6) or a 20th order super-Gaussian shape (blue line, Fig. 6) with the same bandwidth (at FWHM) as in Fig. 4. The temporal contrast at short time is clearly impacted by the filter profile (Fig. 6(a)) since it creates the pedestals. The low order Gaussian shape leads to a better contrast for wavelength away from the input spectrum.

The temporal contrast is better by four orders of magnitude compared to the case in which the profile has a high order Gaussian shape. For longer time, the temporal contrast is identical in the three cases and the profile has only a weak influence on the contrast. Hence, the spectral filtering can be achieved directly in a stretcher (or a compressor) with hard cuts.

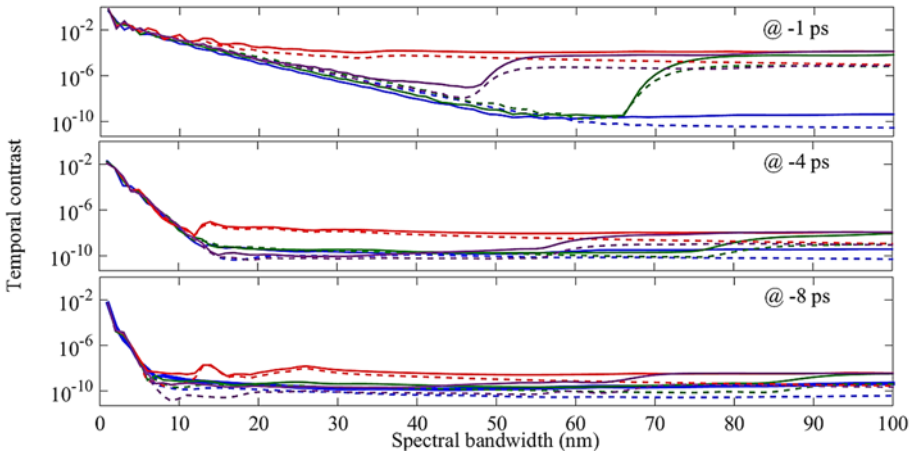


Fig. 5. Temporal contrast when the spectral bandwidth is tuned for three selected time. The blue, green, red and violet solid lines correspond to the center wavelenth of 900, 950, 1050 and 1100 nm respectively. The dashed lines display the evolution of the contrast when the pulse duration is limited by the Fourier transform.

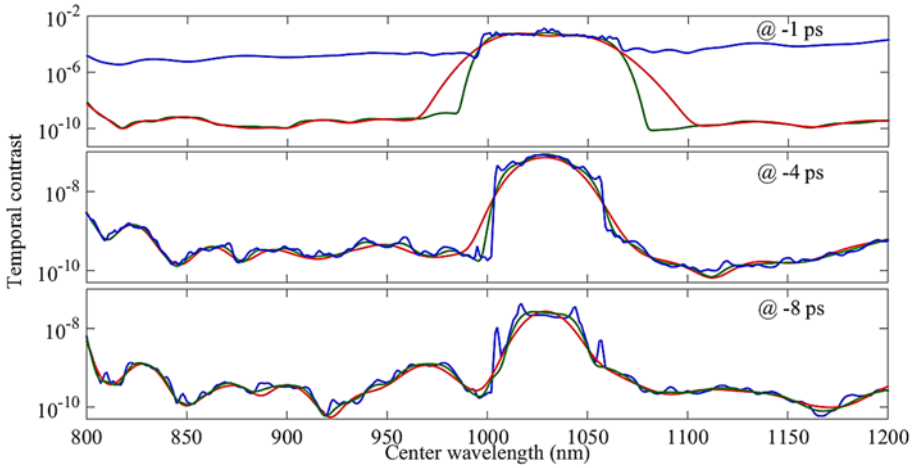


Fig. 6. Temporal contrast when the center wavelength of the filter is tuned with three type of bandpass filter with a Gaussian (red line), a 4th order super-Gaussian (green line) or a 20th order super-Gaussian profile (blue line). The spectral bandwidth is 5.6 THz (FWHM).

4. Conclusion

We investigated the temporal contrast of tunable ultra-short pulses in the near infrared when the generated continuum in a short fiber is filtered. We studied how the temporal contrast from the pump is transferred to the tunable ultra-short pulses. We demonstrated that in addition to the wide tunability, this method allows to enhance the temporal contrast by at least two orders of magnitude. This enhancement

depends significantly on the spectral bandwidth but weakly with center wavelength. We also showed that the filter profile has a low impact on the temporal contrast at few ps. Hence, this technique can be easily implemented in an optical parametric chirp pulse amplifier in which a stretcher can act as a filter with hard cuts. This new approach can be of great interest for laser-matter interaction experiments in the strong field regime when it is combined with such amplifiers. In a future work, the generated ultra-short pulse will be injected in a fiber optical parametric amplifier [17-18] to combine both a high gain and an excellent contrast.

Acknowledgements

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