High Gain Frequency domain Optical Parametric Amplifier (FOPA) for High Contrast Pulses

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Abstract: 800nm, nJ level pulses are amplified >2.000 times in a single 2mm BBO crystal, pumped by picosecond 400nm pulses. Experiments evidence that the picosecond pulse contrast within the pump window remains unchanged upon amplification.
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1. Introduction

Technological progress yielding ever increasing laser intensities beyond 10^{22}W/cm^2 has established the field of relativistic nonlinear optics [1]. Since the damage threshold for interaction with solid targets lies at intensities below 10^{13}W/cm^2, lasers with a pre-pulses contrast exceeding 10 orders of magnitude are required.

One motivation for FOPA is to overcome the universal dilemma of gain narrowing present in ultrashort laser amplifiers [2]. It rests upon spreading a broad input seed spectrum along the Fourier plane (FP) of a 4f setup [3] where different frequencies can be amplified independently of each other in a parametric process. A proof of concept has recently been introduced at lower gain (15 times) and yielded mJ level sub-two cycle pulses.

These results on high energy amplification (gain of 15) are complemented in the current work by realizing FOPA as high gain stage with > 2000 times amplification from nJ to the µJ level. Such conditions are typical in primary optical parametric chirped pulse amplifier (OPCPA) stages to amplify oscillator pulses. With this work we like to highlight FOPA as a way to amplify high contrast laser pulses with a high gain (up to 12.000) without reduction of ps pulse contrast. Furthermore, FOPA bears the potential to increase the pre-pulse contrast upon amplification *within* the time window of the pump pulse as will be discussed at the conference.

2. Experimental Setup and Results

The experimental setup starts with a mJ level Ti:Sa laser system whose output is sent to two different compressors as shown in figure 1a. The low energy portion (Comp. 1) is compressed to 45fs and its energy is attenuated to about 1nJ representing typical seed pulses from an oscillator. Subsequently, these pulses are sent through a dispersion free

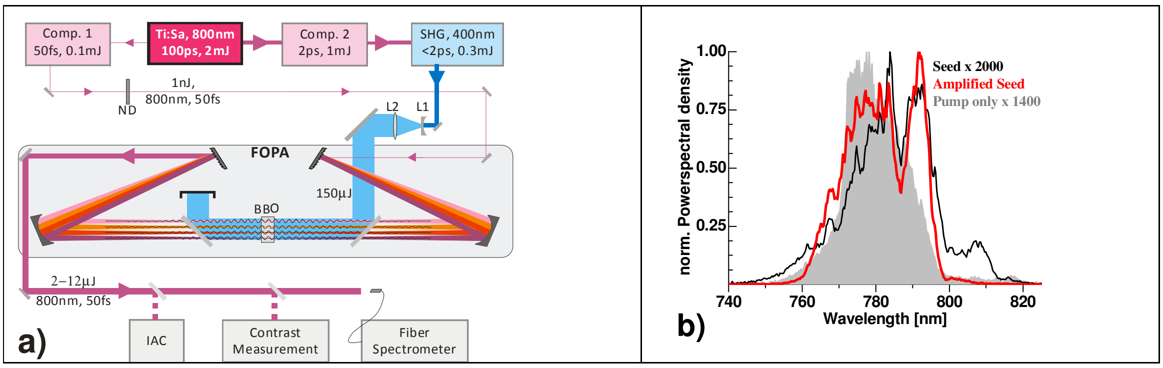

Fig.1 a) Setup showing the seeding of a 4f system with weak nJ level, 50fs pulses at 800nm wavelength pumped by ps frequency doubled 150µJ pulses in the Fourier plane. The pump beam is focused onto a line to amplify the entire spectrum as can be seen from the comparison presented in b) which shows a 2000 fold amplification (red) of the seed spectrum (black). Blocking the seed beam yielded a very low superfluorescence level (shaded gray) of 0.073% of the amplified output.

4f system containing a single type I BBO in the FP. The output was characterized temporally via interferometric autocorrelation (IAC), and spatially and spectrally via a fiber spectrometer.

The majority of about 1mJ is independently compressed to 2ps (Comp. 2) representing typical conditions for pumping an OPCPA. These pulses are frequency doubled in a 0.3 mm thick BBO crystal (30% efficiency) to serve as a pump beam in the parametric process. Unlike in OPCPA where temporally chirped seed pulses interact with ps pump beams in the time domain, in a FOPA, the pulses interact in the frequency domain provided by the 4f setup. This concept has several advantages compared to an OPCPA scheme: (i) The 4f system can provide the same output pulse duration as at the input - no extra stretcher-compressor is required. It has been proven that sub-two cycle pulses remain transform limited after amplification [2]. (ii) The 4f setup intrinsically narrows the spectrum in each focal point in the FP which provides transform limited ps pulses to interact with the pump pulses. Thus, the temporal shape of the pump pulse does not influence the spectrum of the amplified seed like in the case of OPCPA. (iii) The optical Fourier transformation maps the pulse spectrum onto a spatial coordinate in the FP which opens up new design opportunities for parametric amplification. For instance, the pump beam shape can be spatially modulated to tailor the gain function across the seed spectrum [2].

In the present study, the pump energy was limited to about 150µJ in the FP due to the available laser output, the transport optics and uncoated lenses. Its extension in the FP was adjusted by using various combinations of cylindrical lenses (L1 and L2). With a small line in the FP a spectrum of 8nm (FWHM) was amplified 12.000 times (data not shown here). Increasing the pump line to amplify the entire seed spectrum lowered the pump intensity and the corresponding gain factor to 2000, as can be seen by the results of figure 1b. Remarkably, blocking the seed pulses yielded a superfluorescence level of only 0.073% of the maximum amplified signal which is probably lower than any reported value for OPCPA.

Figure 2 shows third order correlation measurements in a transient grating geometry (see for instance Ref [4]) for the seed (shaded gray), amplified (red) and the stretched 800nm pump beam (blue) out of compressor 2 prior to frequency doubling. The different dynamic range for unattenuated seed (10 µJ) and amplified (1µJ) beam are due to their different energy incident on the correlator. Although the noise level of the amplified pulse is only slightly below 10^{-5}, one sees that the seed pulse contrast of about 10^{-5} around ±1ps is not reduced within the pump window.

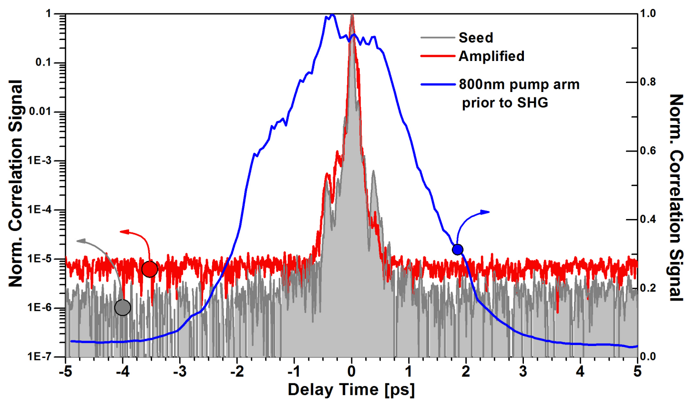

Fig. 2 Evaluating the pulse contrast around ±1ps which is within the pump window (blue curve) shows no reduction of contrast within the dynamic range of the measurement.

In summary, we present the first demonstration of high gain (>2.000) frequency domain optical parametric amplification (FOPA) in a 2mm thick type I BBO crystal around 800nm wavelength with a very low level of superfluorescence (0.073% in the unseeded case) and shows no reduction of pulse contrast within the pump window.

4. References

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