Novel Ultra-fast broadband laser source at 910nm for Vulcan 10 PW OPCPA laser system

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Introduction

A broadband laser source (~180nm) centered at ~910nm is needed to seed the OPCPA amplifiers for development of the Vulcan 10PW OPCPA laser system [1]. This is required by the optimum gain profile of KD*P that will be used as the high pulse energy OPA amplifier medium, up to a few hundred Joules. To the best of our knowledge, there is no such commercial laser system available to meet the spectral bandwidth requirement at the desired wavelength. Consequently, a high gain (~10^7 small signal) and broadband laser pulse amplifier (pre-amplification stage) is currently being designed and developed, initially based on non-collinear OPA amplification scheme. In this amplifier, an ultra-short broadband laser pulse at ~714nm will be stretched to ~1ps. This will then be amplified in a non-linear optical crystal using a narrow band pump source of similar pulse duration, delivering broadband pulse energy of sub-mJ at the repetition rate of 1kHz. The angular dispersion compensated broadband idler pulse produced at ~910nm will then be used to seed the subsequent multi-stage OPA amplifiers that will be further amplified to J level in phase I of the Vulcan 10 PW OPCPA project.

System description

The schematic of this novel ultra-broadband laser source at ~910nm is shown below in Fig.1.

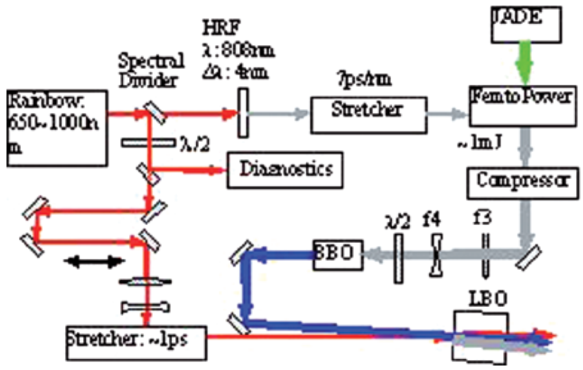

Figure 1. Schematic of OPCPA pre-amplifier stage.

In this laser system, a commercial Ti:Sapphire passively mode-locked ultra-broadband oscillator (Rainbow, ~350nm) is used to provide the seed pulse for both OPA amplifier and its pump laser source. The pump laser source was provided by a commercial laser system consisting of a grating stretcher, multi-pass Ti:sapphire amplifier (Compact Pro) pumped by a Q-switching green laser (Jade) and grating compressor. This pump laser is capable of delivering sub-mJ (~600µJ) narrow or broadband pulses centered at ~800nm at 1 kHz after re-compression, depending on the spectrum bandwidth of seed pulses.

The shorter wavelength section with a spectrum bandwidth of ~150nm centered at ~714nm was separated from the common oscillator pulse spectrum by a spectral divider. This ultra-short signal was stretched to ~1ps by a glass block window, and then the beam profile was collimated and decreased to a desired spot size through a telescope. It was then injected into LBO non-linear crystal at a small angle with respect to the pump beam. A single-axis micrometer translation stage was placed in the signal beam path to provide accurate time delay tuning for precise timing between the pump and signal pulses.

The remaining of the common oscillator pulse spectrum after the spectral divider was further reduced to 3.5nm FWHM centered at ~808nm by a narrow band high transmission filter, and used to seed the pump laser source. The output of pump laser was accordingly decreased by ~25% due to weak seeds, compared with that of broadband seeds. And then this IR pulse was subsequently frequency doubled in BBO crystal at a SHG conversion efficiency of ~40% to provide pump pulses at ~400nm for OPA amplification.

Since the same oscillator is used to provide the seed pulses for both pump source and OPA amplifier, this provides a very robust optical synchronization between the signal and pump pulse in the OPA amplifier that results in reliable and stable temporal overlapping between the pump and signal pulses for ultrafast OPA amplification in the sub-picosecond domain. This optical synchronisation is vital for ultrafast OPA amplification in the picosecond time domain as ordinary electronic synchronization generally causes time jittering greater than 1ps.

Results and Discussion

Fig.2 shows the full spectrum of broadband oscillator, signal spectrum (upper left) and pump laser seed spectrum (right) split through a spectral divider.

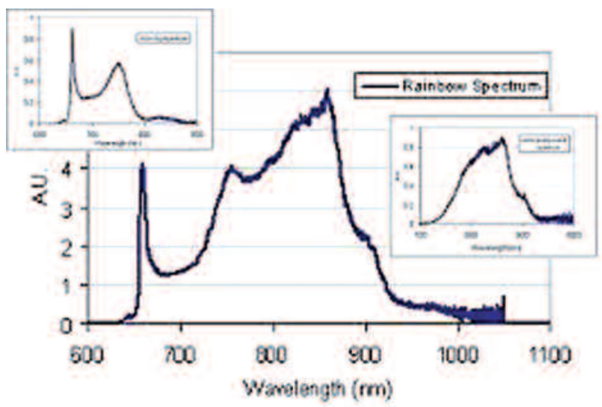

Figure 2. Spectrum of oscillator, signal and pump seed.

The non-collinear angle between the signal and pump beam is very important to the optimum spectral bandwidth amplification, and was set at 2.4º. This was predicted initially through theoretic calculation and simulation, and may need to be further optimised experimentally for optimum spectral bandwidth. In order to maintain the spatial overlapping between the pump and signal beam, a relatively short LBO crystal of 4mm was used. The pump pulse duration was estimated at ~300fs without GVD dispersion. The signal pulse was initially stretched to ~1.6 ps by 16mm long SF10 glass block window. The timing between the signal and pump pulse was preset within an accuracy of ~±30 ps using ultra-fast photodetecter. Under those conditions, single pass OPA amplification was obtained with a gain factor of ~ 10^4 in a LBO crystal at pump fluence of ~0.07J/cm^2 through careful fine tuning the timing between the pump and signal. Further increase in the OPA amplification gain could be envisaged by implementation of a 2nd pass of the LBO crystal. As the pump pulse was shorter than the chirped signal pulse, only part of the signal spectrum within the pump pulse time window was amplified under this circumstance. By tuning the timing between signal and pump, while the rest of experimental condition remains the same, an overlapped image of the idler spectrum of OPA amplification at different timings indicated that full idler spectrum of ~150nm centered at ~910nm could be achieved in this OPA amplifier. Then a 12.7mm BK7 glass block window was used to stretch the signal pulse to ~360fs to match the pump pulse duration. Ultra-fast OPA amplification was successfully obtained in sub-ps domain at a similar gain factor of ~10^4 with a highly angularly dispersed idler, which manifested itself as a very wide spatial spectrum line due to broad bandwidth. The idler, without proper angular dispersion compensation, was diffused at the image plane of short focus length lens and measured by a spectrometer (USB4000, Ocean optics). The full spectrum of idler was shown in Fig.3. Fig.4 shows a transform limited idler pulse duration of ~11fs corresponding to the measured broadband idler spectrum. The Idler pulse energy was measured at ~4μJ, corresponding to a signal pulse energy of ~5μJ compared with the input signal of sub-nJ.

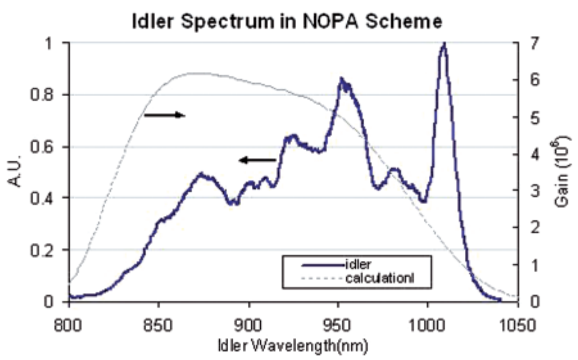

Figure 3. Measured idler spectrum and calculated small signal gain.

The group delay mismatching between the pump and signal pulse is about ~410fs in 4mm LBO, which is longer than either the pump or signal pulse duration. This indicates a temporal slippage between the signal and pump pulse when propagated through the non-linear crystal, resulting in inefficient OPA amplification. As the signal pulse shifted away from the pump pulse during the interaction due to group delay mismatching, the original signal spectrum shape may not be maintained because of uneven and partial amplification across the signal spectrum range. Therefore, both pump and signal pulse duration need to be much larger than the group delay mismatching between them for efficient and optimum OPA amplification. However this is currently limited by the pump pulse energy, and will be shortly addressed.

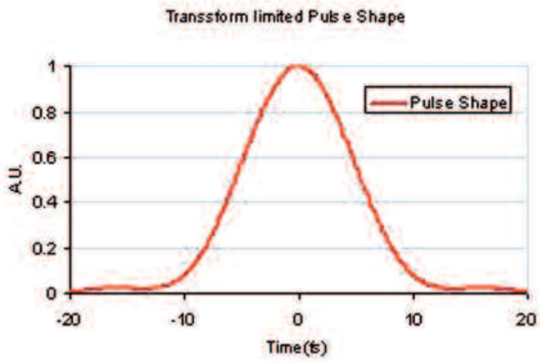

Figure 4. Transform limited idler pulse shape.

The idler angular dispersion needs to be properly compensated before seeding the subsequent OPA amplifier. For narrow band pumping non-collinear OPA amplification, the idler angle δ_{id} with respect to the pump beam is given by:

$$\delta_{id} = \arcsin\left(\frac{k_s \sin\alpha}{\sqrt{k_p^2 + k_s^2 - 2k_p k_s \cos\alpha}}\right) \qquad (1)$$

while the angular dispersion is given by:

$$\frac{d\delta_{id}}{d\lambda_{id}} = \frac{2\pi k_p \sin\alpha}{\lambda_{id}\left(k_p^2 + k_s^2 - 2k_p k_s \cos\alpha\right)} \times \left(\frac{n(\lambda_s)}{\lambda_{id}} - \frac{\lambda_s}{\lambda_{id}}\frac{dn(\lambda_s)}{d\lambda_s}\right) \qquad (2)$$

where a is the non-collinear angle between the pump and signal beam, k_p and k_s are the wave vectors of pump and signal respectively, λ_s and λ_{id} the signal and idler wavelength respectively, and $n(\lambda_s)$ the refractive index at the signal wavelength. Fig. 5 shows the calculated idler

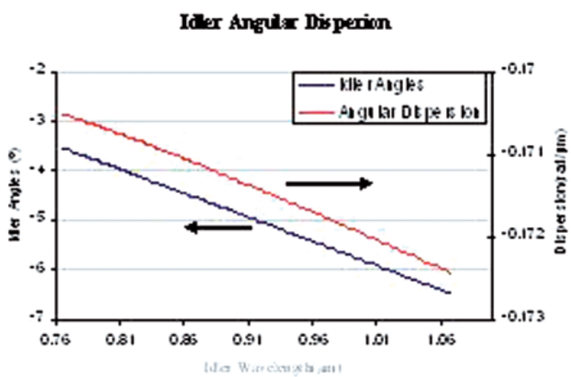

Figure 5. Calculated Idler angular dispersion.

angle and angular dispersion as the function of idler wavelength over desired spectrum range.

As seen, the idler angle almost varies with the idler wavelength linearly at angular dispersion of ~0.1715mrad/nm. The nonlinearity of idler angular dispersion is only $\sim 8\times 10^{-6}$ mrad/nm^2, which is rather small and could be compensated by a properly designed grating.

Conclusions

We have demonstrated ultrafast non-collinear OPA amplification in the sub-ps time domain for the generation of a broadband source at ~910nm for Vulcan 10 PW OPCPA development. Single pass OPA amplification gain of $\sim 10^4$ and an idler spectrum bandwidth of ~200nm were successfully obtained, sufficient to support ~11fs pulse.

References

1. I. N. Ross, P. Matousek, M. Towrie, A. J. Langley and J. L. Collier, *Opt. Commun.* **144**, 125 (1997).
2. A. Dubietis, G. Jonusaukas and Piskarskas, *Opt. Commun,* **88**, 437 (1992).