A novel optical parametric chirped pulse amplification source as seed for a 10PW laser

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Introduction

Optical parametric chirped pulse amplification (OPCPA) has enormous potential for generating laser pulses of extreme power [1-4]. An OPCPA scheme based on KD*P in a non-collinear geometry has been shown to have sufficient bandwidth to amplify ultrashort pulses of duration down to 10 fs [5,6], and can yield amplified energies in the kilojoule range [7]. Our current programme is aimed at the development of a 10 PW system, and this letter describes the design and development of a new OPCPA driver source using a 400 nm pump wavelength and generating an idler at ~910 nm with a bandwidth in excess of 160 nm.

To meet the amplified background noise (ASE) specification for the 10 PW system, a principal requirement of the source is that its ASE pulse must be narrower than ~1ps after the final compressor, and that its energy must exceed a few tens of µJ. This ensures that the longer timescale ASE generated by the subsequent amplifiers remains below a threshold level of 10^{10} W/cm^2.

We initially considered two non-collinear geometries for this OPCPA driver source, one using a broadband pump requiring an angularly dispersed signal and the other a narrowband pump requiring no angular dispersion of the signal [8,9]. Both could be operated with pump pulses around 1ps (giving 1 ps duration for the ASE), but in both cases it would be necessary to compensate for the angularly dispersed idler.

The third approach considered, a collinear chirp-compensation scheme [10], was chosen for investigation. In this scheme the broadband pump and signal, propagating collinearly, are chirped in a carefully tailored way to ensure that their instantaneous wavelengths are phase matched at all times. No angular spectral dispersion is now necessary. For the scheme to work, sufficient pump bandwidth must be available, and the pump laser must be able to operate efficiently at a suitable pulse duration. Both conditions could be met in this scheme by using LBO as the OPA since the required bandwidth and pulse duration of the pump laser were approximately 20 nm and 10 ps respectively to deliver a 160 nm bandwidth idler. If the pump is linearly-chirped, the signal must have a significant nonlinear chirp (figure 1) to ensure phase matching over as long a time period as possible. Fortunately this could be achieved by using a prism stretcher and adjusting the nonlinear chirp by selection of the type of glass.

Since the signal and idler bandwidths are large and the crystal was of sufficient thickness to give high OPA gain, the effect of group velocity dispersion on OPCPA performance was significant. Therefore computer modelling was needed to properly assess and optimise the scheme. The basis of the code was described in [11] although some modifications were needed to accommodate the chirp-compensation scheme. An example of a simulation is shown in figure 1. A linearly chirped pump is mixed with a signal having optimised linear and quadratic chirps. With suitable adjustment of their intensities figure 1 demonstrates the potential for an idler bandwidth of 230 nm (compressible to 9.8 fs) and a pump depletion of 50%.

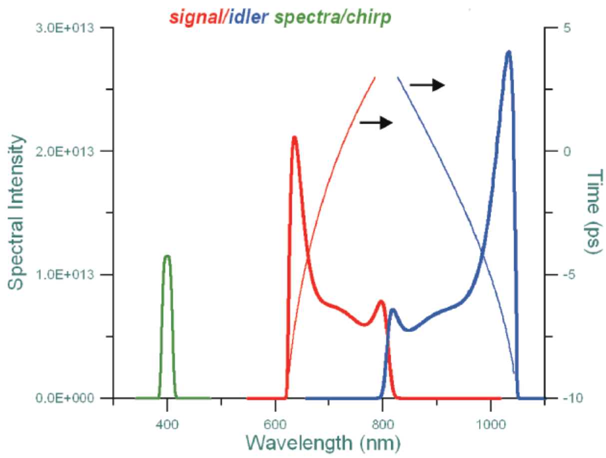

Figure 1. Simulation example. Pump (divided by 10), signal and idler spectra after the OPA. Fine lines denote the required nonlinear chirps on signal and idler for a linearly chirped signal.

An additional feature of the chirp-compensation scheme relates to the ASE. At a given point in the chirped pump pulse, the parametric gain bandwidth is limited by phase-matching at the instantaneous pump wavelength; this yields an ASE with limited bandwidth (in our case 15 nm at the idler wavelength), which sweeps over a wide bandwidth as the pump wavelength changes. This sweep follows the chirp of the signal and idler, and is consequently partially compressible when the idler is finally compressed. The degree of compressibility is

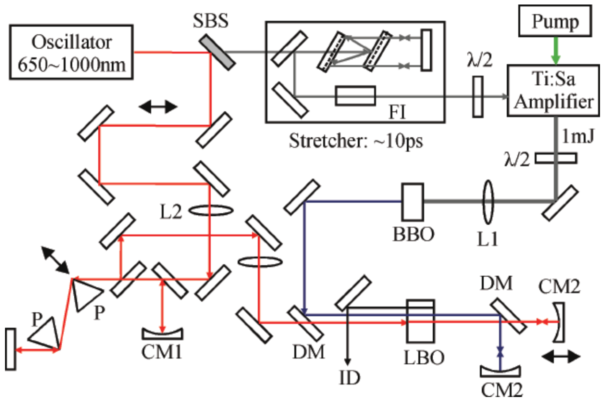

Figure 2. Schematic of Chirp Compensated Collinear OPA amplifier, where SBS is the spectral beam splitter; DM the dichroic mirror; P the SF10 prism; CM the curved mirror.

determined by the ratio of the time-integrated to the instantaneous ASE bandwidth. In the system under investigation, the ratio is approximately 10, which indicates that the ASE can be compressed down to a duration of ~10 ps÷10 or 1 ps.

Experimental results

The experimental design is based on a double-pass collinear LBO OPCPA amplifier, pumped at 400 nm with seed signal at 714 nm, and generating an ultra-broadband idler laser pulse centered at 910 nm. A schematic of the system was shown in figure 2.

A commercial Ti:sapphire oscillator (FemtoLasers ‘Rainbow’) with a ultra-broad spectrum extending from 650 nm to ~1000 nm was used as the common oscillator to provide both signal and pump pulses for the OPCPA. The oscillator output spectrum was divided by a spectral beam splitter, the reflected short wavelength section being used as the signal pulse for the OPCPA, and the transmitted long wavelength section as the pump seed. Figure 3 shows the oscillator spectrum, and the spectrally-split signal and pump seed pulses, respectively. This technique provided very robust optical synchronization between the signal and pump pulses in the OPCPA that resulted in a highly stable amplification for picosecond pulses. The ability to use

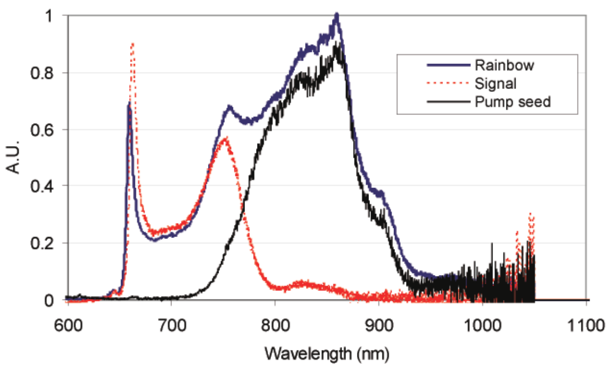

Figure 3. Spectra of the Rainbow oscillator, the signal and pump seed.

small diffraction-limited beams in the driver OPCPA allows the generation of a clean idler centred at ~910 nm with little phase aberration.

A compact grating stretcher in a negative GVD configuration stretched the pump seed pulses with a linear chirp of ~2 nm/ps. These chirped pulses seeded a commercial multi-pass Ti:sapphire amplifier (FemtoLasers ‘Compact Pro’), which delivered ~1 mJ infrared (IR) laser pulses centred at ~800 nm at a 1 kHz repetition rate. These were frequency doubled in a ~200 µm BBO crystal to provide suitable pump pulses (at ~400 nm and chirped at ~1 nm/ps) for the OPCPA system. Gain narrowing can severely limit the bandwidth of the output pulse from the amplifier, and hence the duration of the chirped second harmonic pulses, and ultimately limits the bandwidth of the OPCPA signal and idler pulses because the OPA bandwidth is directly proportional to the bandwidth of pump pulses in this chirp-compensation scheme. To overcome this, a birefringent filter of ~40 nm free spectral range was inserted between the seed stretcher and the TiS amplifier to increase the effective bandwidth of the pump seed beam by suppressing the peak of the spectrum. Figure 4 shows spectra after amplification both with and without a birefringent filter. A fundamental bandwidth of ~28nm was recorded with the birefringent filter, significantly wider than without the filter. Using a 200 µm BBO crystal, a second harmonic bandwidth of ~6.8 nm (FWHM) was achieved at a conversion efficiency of ~14% and pulse energy of ~110 µJ limited by the pump laser. This was used as pump for the collinear chirp-compensation OPCPA amplifier.

The signal pulse at ~714 nm was stretched by a prism stretcher, which introduced nonlinear as well as linear chirp to optimise phase-matching across a wider bandwidth. To demonstrate the principle of collinear chirp-compensated OPCPA, a pair of readily available equilateral SF10 prisms was used in a 4-pass configuration with a prism separation distance of ~800 mm. Both the air length and the glass length in the stretcher were adjusted to obtain the correct linear (18 nm/ps) and nonlinear chirps necessary to match the pump pulse chirp of 1 nm/ps. The stretched signal pulse was then injected into an 8 mm LBO crystal through a dichroic pump steering mirror, and the pump was focused to a fluence of ~0.3 J/cm^2 corresponding to an intensity of ~40 GW/cm^2. In order to separate the amplified signal and idler pulses, the signal and pump beams were inclined at a small angle of less than 3mrad, which should not affect the collinear amplification. Since the spatial slippage of the beams in LBO is small, longer crystals may be used for a higher amplification gain. To maximize the energy extraction efficiency, the amplified signal and residual pump pulses after the 1st pass amplification were imaged back into the same LBO crystal via high resolution translation stages and with a small transverse spatial displacement with respect of the 1st pass beam. This provided a precisely timed second pass at similar pump intensity.

By carefully tuning the LBO phase matching angle in combination with scanning the timing between the signal and pump pulse and adjusting the chirp of the prism stretcher, broadband collinear chirp-compensated OPCPA

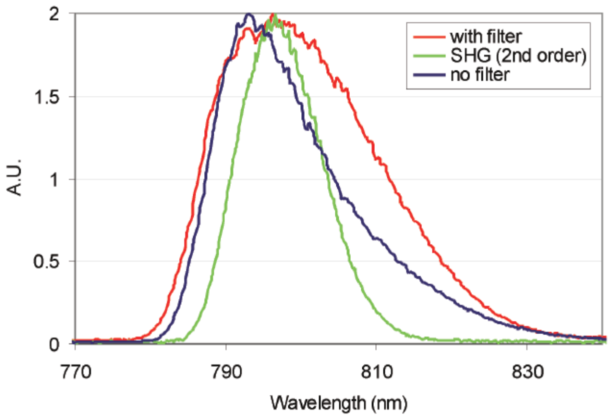

Figure 4. Spectra of the IR pump pulse with/without filter, and SHG pulse (plotted on wavelength scale ×2).

was successfully achieved. Figure 5 a) shows that an idler pulse spectral bandwidth in excess of 165 nm (full width) was obtained after both the 1st and 2nd pass amplification. This was sufficient to support a transform-limited pulse duration of ~14.5 fs. Figure 5a) also shows that good agreement was achieved with a simulation using the values of parameters used. Under these conditions, an idler pulse energy of ~7 μJ was obtained. Figure 5c) shows the amplified idler pulse spatial profile measured at a distance of ~600 mm from the LBO crystal. This beam was close to the diffraction limit and unlike the more conventional broadband non-collinear OPA (NOPA), it was clearly observed that the idler had no residual spatial dispersion. Consequently, the output idler pulse could be directly used to seed subsequent OPCPA amplifiers without the need for angular dispersion compensation.

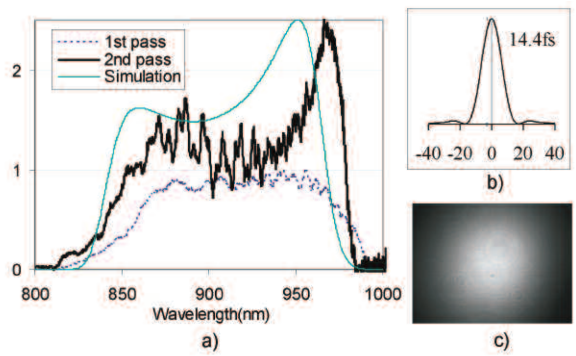

Figure 5. a) Single pass, double pass and simulated idler spectra, b) Transform-limited pulse profile, and c) amplified idler beam profile.

Conclusions

In conclusion, we have successfully demonstrated for the first time a broadband collinear chirp-compensation OPCPA source in a 2-pass configuration amplifier.

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).
3. O. V. Chekhlov, J. L. Collier, I. N. Ross, P. K. Bates, M. Notley, C. Hernandez-Gomez, W. Shaikh, C. N. Danson, D. Neely, P. Matousek and S. Hancock, *Opt. Lett.* **31**, 3665 (2006).
4. V. V. Lozhkarev, G. I. Freidman, V. N. Ginzburg, E. V. Katin, E. A. Khazanov, A. V. Kirsanov, G. A. Luchinin, A. N. Mal'shakov, M. A. Martyanov, O. V. Palashov, A. K. Poteomkin, A. M. Sergeev, A. A. Shaykin and I. V. Yakovlev, *Laser Phys. Lett*. **4**, 421 (2007).
5. V. V. Lozhkarev, G. I. Freidman, V. N. Ginzburg, E. A. Khazanov, O. V. Palashov, A. M. Sergeev and I. V. Yakovlev, *Laser Phys*. **15**, 1319 (2005).
6. G. Freidman, N. Andreev, V. Bespalov, V. Bredikhin, V. Ginzburg, E. Katin, E. Khazanov, A. Kortin, V. Lozhkarev, O. Palashov, A. Poteomkin, A. Sergeev and I. Yakovlev, *Proc. SPIE* **4972**, 90 (2003).
7. I. M. Pritula, M. I. Kolybayeva, V. I. Salo and V. M. Puzikov, *Opt. Materials*, **30**, 98 (2007).
8. G. Arisholm, J. Biegert, P. Schlup, C. P. Hauri and V. Keller, *Opt. Exp*. **12**, 518 (2004).
9. G. M. Gale, M. Cavallari, T. J. Driscoll and F. Hache, *Opt. Lett*. **20**, 1562 (1995).
10. K. Osvay and I. N. Ross, *J. Opt. Soc. Am. B*, **13**, 1431 (1996).
11. E. J. Grace, C. L. Tsangaris and G. H. C. New, *Opt. Commun*. **261**, 225 (2006).