Ultra-broadband Optical Parametric Chirped Pulse Amplification
By Two Broadband Pump Beams


INTRODUCTION

Optical parametric chirped-pulse amplification (OPCPA) is suitable for a new approach to few-cycle, high-peak-power laser systems because of its broad gain bandwidth and large single-pass gain while maintaining negligible thermal load in a nonlinear crystal. In order to amplify ultrabroad bandwidth, various types of OPCPA schemes are proposed and demonstrated. Generally, non-collinear OPCPA (NOPCPA) has been used for broad-band amplification. NOPCPA is the way to set the crossing angle of generally over 2 degrees between pump and seed beam in non-linear crystal which is gain media. For example, the calculated phase-matching bandwidth of a Type-I BBO crystal pumped by a monochromatic wavelength of 532 nm at crossing angle of 2.2° is obtained the range of 300 nm. By using the broadband pump pulse from a Ti:sapphire laser, the enhancement of the amplified bandwidth was also obtained at degeneracy [1]. As another approach, OPA pumped by multiple pulses has been proposed and demonstrated [2]. In this scheme, each pump pulse which has a different incidence angle on the nonlinear crystal can achieve phase matching over different signal wavelength regions, respectively.

In this paper, we demonstrated a Degenerate OPCPA with two pump beams. Using two beams, the amplified bandwidth extended more than 350 nm at a center wavelength of 1020 nm. This bandwidth is capable of producing less than 8.1 fs optical pulse duration, corresponding to the 2.5 optical cycles.

EXPERIMENT AND RESULT

The two curves in Fig.1 show the calculated phase matching conditions for the two broadband pump beams. The phase matching bandwidth can be accomplished from 820 nm to over 1220 nm with two phase matching angle $\theta_1$ and $\theta_2$ by using a type-I BBO crystal. The internal crossing angle of $\alpha$ between the signal and pump beams has been set at 1.2°.

Figure 2 shows the experimental setup of ultra-broadband DOPCPA. A seed pulse from the mode-locked Ti:Sapphire oscillator has 400 nm average output power, 80 MHz repetition rate and 1020 nm center wavelength is split into two beams. One is temporally stretched with a 1.2 km long, polarization-maintained single-mode fiber up to ~ 1 ns and then amplified in the cryogenically-cooled Yb:YLF regenerative amplifier [3]. The laser crystal was 20 at.% Yb:YLF with a thickness of 2 mm and a 5 mm x 5 mm cross section. A fiber-coupled laser diode beam with an emission wavelength of 940 nm was focused to 800 µm diameter on the crystal. A maximum output pulse energy of up to 30 mJ was obtained at a LD pump power of 93 W with a pulse duration of 4 ms. The amplified chirped pulse was then compressed by two parallel, gold-coated, 1100 grooves/mm, ruled gratings. The duration of the compressed pulse was 1.4 ps. A fraction of the compressed pulse was down-collimated to a 3 mm diameter by a Galilean telescope. The pulse was then frequency doubled in a 7 mm long, type-I BBO crystal ($\theta$=23.8°) for pumping the parametric amplifier. An output pulse energy of the frequency-doubled pump pulse was measured to be 2.2 mJ at a fundamental laser intensity of 36 GW/cm² which corresponded to an energy conversion efficiency of ~ 40 %. A duration and
bandwidth of the pulse were measured to be 2.4 ps and 3 nm at the full width half maximum (FWHM), respectively. At present the laser system is operated at a 10-Hz repetition rate which is limited by the capability of the LD driver.

Another seed pulse from the oscillator was converted into the white light continuum (WLC) through a photonic crystal fiber (PCF) to use as a signal pulse of DOPCPA. The PCF had a length of 5 cm and core diameter of 4.7 µm with a zero-dispersion wavelength of around 1030 nm. The laser pulse with an energy of 2.8 nJ and duration of 80 fs was focused into the PCF. The generated white light was stretched to ~1ps by the dispersion of PCF. The energy of the white light seed pulse injected into the parametric amplifier was ~ 0.75 nJ. A BBO crystal is cut at 23.8° and arranged type-I collinear phase matching with an internal crossing angle between the seed and pump pulses of 1.2°.

Figure 3 shows the detail around the crystal. Two pump beams led into a BBO crystal with different phase matching angle, 23.64° and 23.49°. The seed pulse was loosely focused to 1.0 mm diameter on the crystal with an intensity of 59 kW/cm². The first and second OPA pump beams were down-collimated to a 1.2 mm and 1.45 mm diameter with an energy and intensity of up to 0.5 mJ and 44 GW/cm² and 0.8 mJ and 49 GW/cm², respectively. Laser energies and power spectra were measured by a thermopile power meter and fiber optic spectrometer, respectively.

The maximum OPA gain of 3.2 x 10⁵ was obtained, corresponding to calculated output energy of 162 µJ. In addition, optical-to-optical conversion efficiency of 12% were obtained. Figure 4 shows the amplified spectrum of DOPCPA. The spectrum ranging from 850 nm to 1200 nm was amplified, corresponding to calculated, transform-limited pulse duration of 8.1 fs (2.5 optical cycles).

CONCLUSION

Using two beams of pump beams from diode-pumped cryogenic-cooled Yb:YLF CPA laser, we have obtained over 350 nm ultra-broadband OPA around degeneracy. The OPA gain of 3.2 x 10⁵ and conversion efficiency of 12% were obtained. It should be noted that it is possible to extend the amplification bandwidth towards octave-spanning spectra by using additional pump beams. Finally, we will obtain the 2 TW peak power for generation of atto second pulse, which has a 13 mJ pulse energy and 6 fs of pulse duration.

REFERENCE(S)


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