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High-beam-quality optical parametric chirped-pulse amplification in periodically-poled $KTiOPO_4$

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Abstract: We have demonstrated a high-gain optical parametric chirped-pulse amplifier for Nd:glass-based short-pulse laser systems based on periodically poled potassium-titanyl-phosphate. Our amplifier produced high single-pass gain, broad bandwidth, excellent beam quality and stability.

OCIS codes: (190.4410) Nonlinear optics, parametric processes; (190.4970) Parametric oscillators and amplifiers

1. Introduction

Optical parametric chirped pulse amplification (OPCPA) [1] has received much attention in recent years due to its superior characteristics when used for broadband amplification at wavelengths near 1 μm. It offers increased bandwidth over amplification in Nd:glass, while its gain is superior to that of Ti:sapphire at 1 μm, eliminating the need for regenerative amplification. Additionally, OPCPA exhibits high prepulse contrast as a result of cavityless amplification, which is of great importance for use in front ends of high peak power lasers. Other favorable characteristics of OPCPA include peak power scalability through large-aperture potassium dihydrogen phosphate (KDP) crystals [2] and potential high average power scalability due to negligible thermal deposition. A double-crystal beta-barium borate (BBO) high-gain preamplifier for front end of a Nd:glass high peak power laser has been previously demonstrated [3], producing broad bandwidth ~1-mJ pulses when pumped by a commercial Q-switched pump laser. However, poor conversion efficiency (~1%) and beam ellipticity were primarily a consequence of relatively large birefringent walk-off compared to the beam diameter in crystal. This effect sets the lower peak power limit for efficient OPCPA in bulk nonlinear crystals, resulting in poor prospects for efficient high average power OPCPA with low pump pulse energy.

OPCPA used in conjunction with quasi-phase-matching (QPM) is not limited by birefringent walk-off and utilizes the large nonlinear coupling coefficients of materials such as lithium niobate and potassium-titanyl phosphate (KTP). Nondegenerate OPCPA in periodically-poled KTP (PPKTP) has been previously demonstrated at a wavelength of 1.573 μm, pumped by a Nd:YAG laser [4]. Here we present, to our knowledge, the first demonstration of broadband, efficient, nearly degenerate OPCPA in PPKTP at a wavelength of 1053 nm, with a potential to replace bulk crystals in the front end of Petawatt-class Nd:glass lasers.

2. Experimental setup

Our experimental setup is shown in Fig. 1. Our seed pulse at a center wavelength of 1053 nm with spectral bandwidth of 7 nm FWHM is generated by a Time-Bandwidth-Product GLX-200 Nd:glass oscillator. A single pulse is selected from the oscillator pulse train and injected into the pulse expander. The resulting 800-pJ seed pulse is stretched to 1.2 ns and resized to 1-mm diameter, with a Gaussian mode. Our 10-Hz pump pulse is provided by a commercial, Q-switched, frequency-doubled pump laser (Continuum Powerlite Plus) operating in a single longitudinal mode. The pump pulses are 6 ns FWHM long and exhibit a spatio-temporal buildup characteristic for an unstable resonator. The supergaussian pump beam is resized to 0.6-mm diameter and imaged onto OPA crystal.

Our optical parametric amplifier is a 5x1x15 mm^3-PPKTP crystal, used in ZZZ-coupling configuration with an effective nonlinear coefficient d_{eff}=8.7 pm/V and a QPM period of 9.04 μm. It is temperature controlled using a crystal oven, with an optimal temperature of 36.0° C. Seed and pump beams are coupled into the PPKTP crystal using a dichroic beamsplitter, and the seed pulse overfills the pump pulse, so that ~50% of the seed energy is contained in the area defined by the pump pulse.

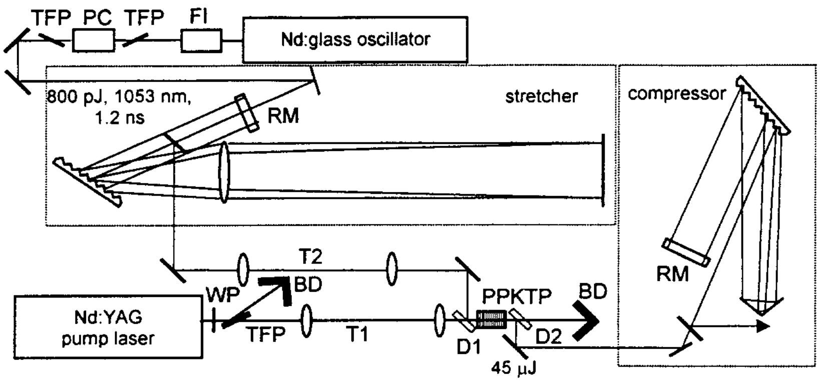

Fig. 1. Experimental setup for OPCPA in PPKTP. λ/2 – half-waveplate, TFP – thin film polarizer, DICH – dichroic mirror.

3. Results

Up to 700 μJ of 532-nm pump energy was incident on the PPKTP crystal, with a peak intensity of ~30 MW/cm^2. We measured a maximum output signal energy to signal of 45 μJ, for a conversion efficiency of 13% to signal and idler, or 65% of the theoretically maximum conversion efficiency based on the spatiotemporal overlap of seed and pump pulse (the seed and pump pulse have an estimated spatio-temporal overlap of 20%). The output signal beam profile (Fig. 2) is circular and we estimate it to be very close to transform-limited beam quality. The amplified spectrum (Fig. 3) exhibits broadening to 8 nm FWHM as a result of operation in strong pump depletion regime. The calculated spectral bandwidth of 15-mm long PPKTP is 50 nm, with a potential of supporting sub-20-fs pulses. Spectral broadening has been previously observed in OPCPA [3] and is the result of nonuniform conversion over the signal spectrum.

We measured the pulse-to-pulse stability of our system over 3000 shots to be 2.7% rms (Fig. 4). Several ~20% variations in output energy are the result of large temporal jitter of the pump laser of ~3 ns. Stability of the system is greatly enhanced by operation in pump-depletion regime. We measured the angular sensitivity of OPCPA in PPKTP (Fig. 5) and determined it to be ±2°, which is an improvement over type-I OPA in BBO of over 10^2. Large angular insensitivity opens up a possibility of pumping with low beam quality or poorly collimated beams.

We compressed the output signal pulses using a gold-grating pulse compressor with 50% efficiency. The autocorrelation trace is shown in Fig. 6. Deconvolution of the autocorrelation trace using our measured spectrum yields the pulse width of 30-fs, which is 1.9 times longer than the transform-limit pulse width based on our measured signal spectrum. Imperfect pulse compression is the result of uncompensated phase between the compressor and the expander and aberrations in the expander which contains a plano-convex lens.

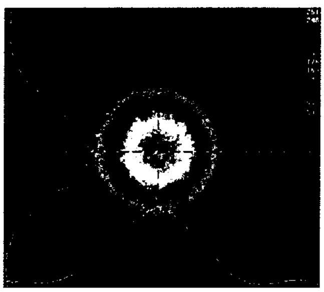

Fig. 2. Amplified pulse transverse intensity profile

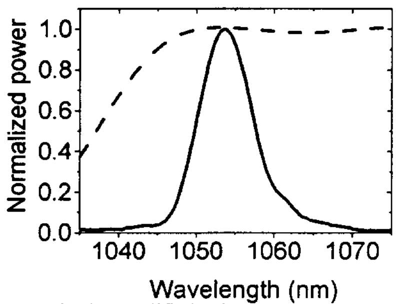

Fig. 3. Amplified pulse spectrum. FWHM is 8 nm. Dashed line is the calculated spectral bandwidth of a 15-mm long PPKTP amplifier.

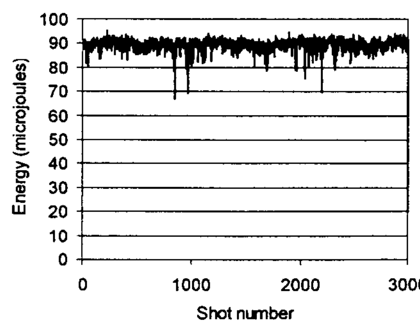

Fig. 4. Experimental stability of OPCPA in PPKTP over 5 minutes. Large fluctuations represent the temporal drift of the pump laser.

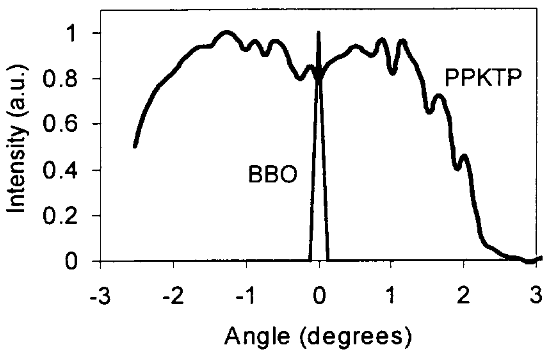

Fig. 5. Comparison of angular acceptance of BBO and PPKTP

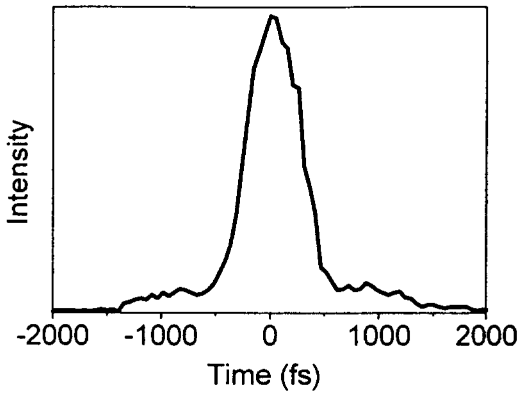

Fig. 6. Intensity autocorrelation of the recompressed pulse. Deconvolved pulse width is 200 fs FWHM.

4. Conclusion

In conclusion, we have demonstrated, to our knowledge, the first OPCPA high-gain preamplifier at 1053 nm in PPKTP. We demonstrated a gain of 1.1×10^5, with a conversion efficiency of 13% to signal and idler, or 65% of the theoretical maximum of this configuration. The obtained beam profile is closest to the diffraction limit of all OPCPA outputs reported to date. We have measured the angular acceptance bandwidth of our crystal and determined it to be two orders of magnitude broader than the acceptance bandwidth of a bulk crystal such as BBO. We have not observed any grey-tracking degradation of the PPKTP crystal during ~24 hours of operation. Several improvements are suggested to increase the output energy of the PPKTP preamplifier. The use of broad bandwidth (16 nm) oscillator should allow greater stretching ratio. A shorter PPKTP crystal would allow us to operate at an intensity of 100 MW/cm^2, which has been previously reported as the limit for safe operation without crystal damage or degradation, which would increase the output pulse energy by a factor of ~3. Finally, periodic poling of KTP to larger apertures (~3 mm) would allow scaling of this device to millijoule energies. Beam quality, spectral characteristics, and simplicity make OPCPA in PPKTP a desirable choice as a part of the front end of short-pulse Nd:glass laser. High conversion efficiency opens up a possibility of use of OPCPA in PPKTP for scaling of short pulses to high average power.

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5. References

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