A Front End for Ultra-Intense Optical Parametric Chirped-Pulse Amplification

Introduction

Ultra-intense laser systems are being developed that will use the full potential of deuterated potassium dihydrogen phosphate (DKDP) crystals for high-energy optical parametric chirped-pulse amplification (OPCPA).[1,2] Noncollinear pumping of DKDP produces broadband gain for supporting pulses as short as 10 fs. Large DKDP crystals (>400 × 400 mm) enable one to use Nd:glass lasers as kilojoule pump sources. The front ends for these systems must provide broadband pulses centered at ~910 nm to match the gain of DKDP noncollinear optical parametric amplifiers (NOPA's) when pumped at 527 nm. The amplified pulses must be compressible and focusable to maximize the on-target intensity, and the temporal prepulse contrast must be high enough to avoid perturbing the target. Previous front-end demonstrations used the idler from the first amplifier stage to seed subsequent amplifiers in either an angularly dispersed geometry[1] or a chirped collinear geometry.[2] An alternate approach, based on white-light–continuum (WLC) generation in a YAG plate,[3] is described in this article.

Development of a Mid-Scale, All-OPCPA System

Figure 129.35 shows the three phases of development of a 7.5-J, 15-fs optical parametric amplifier line (OPAL) that uses technologies scalable to kilojoule energies. Phase 1 has been completed, Phase 2 is in construction, and Phase 3 is being designed. In Phase 1, the first stages of a prototype front end

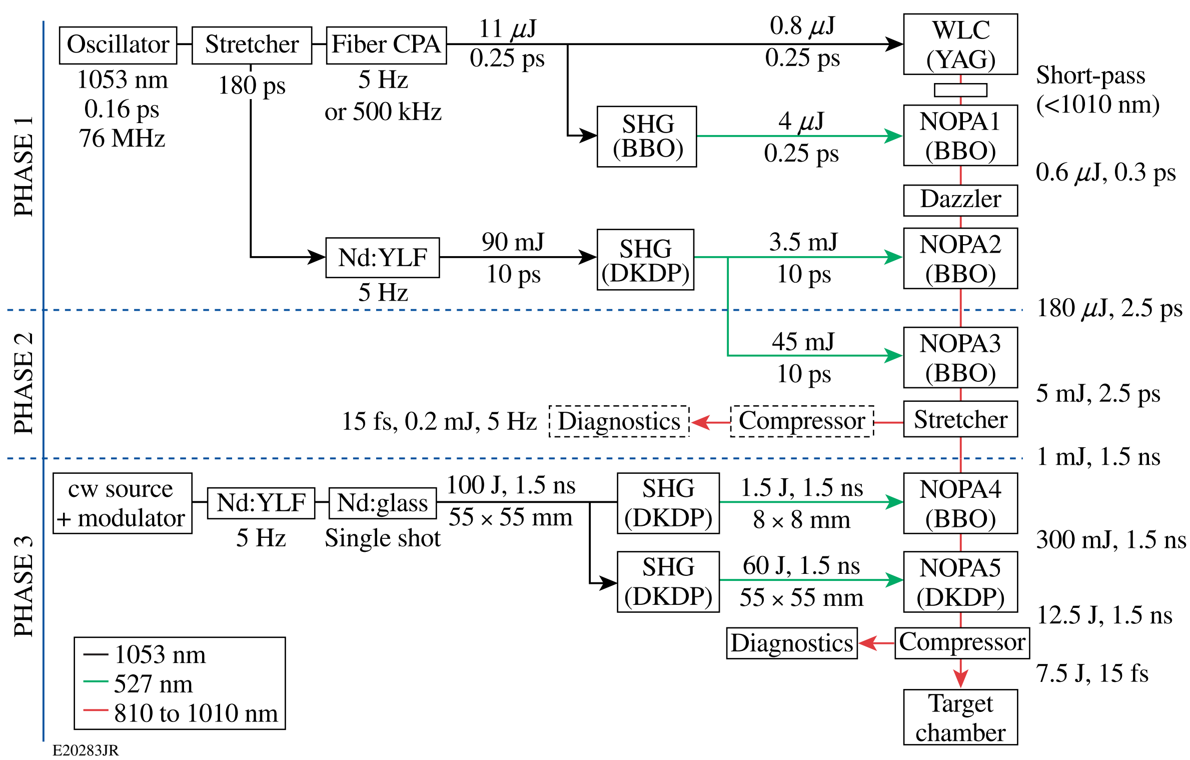

Figure 129.35
Schematic overview of a mid-scale optical parametric amplifier line (OPAL) that is in development. Phase 1 is completed, Phase 2 is in construction, and Phase 3 is being designed.

were developed to produce 180-μJ pulses with 200 nm of spectral support [160-nm full width at half maximum (FWHM)] centered at 910 nm (Fig. 129.36). Seeding the amplifiers with WLC simplifies the requirements for the seed oscillator and pump lasers and removes the need to eliminate the angular dispersion of the idler[1] or precisely set the spectral chirp of the pump.[2] Spectrum and spectral phase measurements made after recompression using a simple prism pair showed that the amplified white-light continuum was compressible to <13 fs, as expected [Fig. 129.36(b)].

Figure 129.37(a) shows a schematic of the nondegenerate NOPA-based cross-correlator[4] that was developed to measure the temporal contrast of the first NOPA stage. Measurements show a detection-limited prepulse contrast of greater than 120 dB up to −10 ps before the pulse [Fig. 129.37(b)].

Determining whether discrete peaks are real prepulses or artifacts caused by gate or pump postpulses is a problem common to all cross-correlators. For a NOPA-based device, however, the value of the peak can be determined from its scaling with the intensity of the pump.[4] By varying the pump-pulse energy before the cross-correlator and measuring the relative magnitudes of each peak, it was determined that all prepulses were caused by pump postpulses.

The second phase of OPAL is under construction. A pulse stretcher for the prototype front end has been developed based

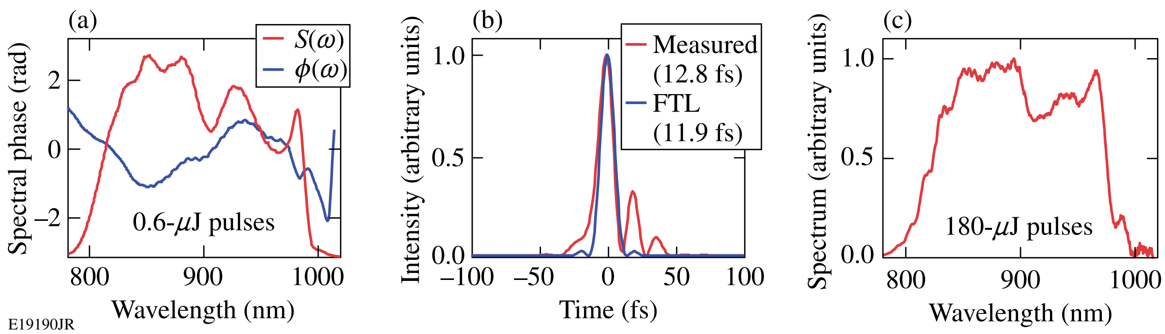

Figure 129.36
(a) Spectrum and spectral phase measurements after prism compression of NOPA1. (b) Calculations of the corresponding temporal intensity. (c) Spectrum after amplification to 180 μJ. FTL: Fourier transform limit.

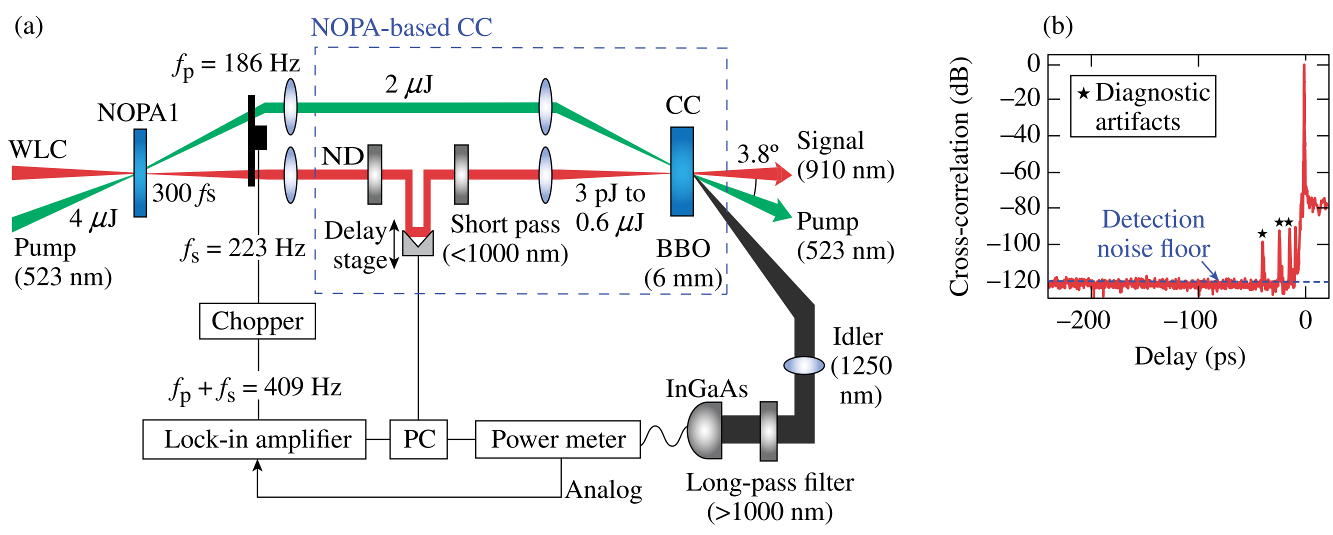

Figure 129.37
(a) Schematic of the NOPA-based cross-correlator for broadband (160-nm), high-sensitivity (39-dB gain), high-dynamic-range (120-dB) measurements of the prepulse contrast. (b) Temporal contrast measurements of the output of NOPA1 (before prism compression). BBO: beta-barium borate; CC: cross-correlator; InGaAs: indium gallium arsenide detector.

on a cylindrical Öffner design that has benefits beyond those originally proposed by Itatani *et al.*[5] Pulse stretchers with stretch ratios large enough for kilojoule systems (~10^5) must introduce minimal chromatic aberrations to ensure a high Strehl ratio at the laser focus.[6] They must permit preamplification using short-pulse–pumped parametric amplifiers to the millijoule level before stretching to improve temporal contrast.[7] Contrast degradation from their optical surface roughness imprinting on the spectral phase of the pulse must be minimized.[8] A cylindrical Öffner stretcher (COS) built to meet these requirements is being tested (Fig. 129.38). Modeling results in Fig. 129.38(b) show that a stretcher with cylindrical Öffner mirrors and two gratings (one at the center of curvature of the two Öffner mirrors) gives significantly better performance in these three areas than the standard spherical Öffner stretcher (SOS) with the same size optics and only one grating. Simulations predict that the mirror-limited temporal contrast is 30 dB better for the COS than a comparable-scale, single-grating SOS with similar surface quality because of the 50×-larger beam size on the secondary mirror.

In the third phase, the front end will seed a mid-scale optical parametric amplifier line (OPAL), which will be constructed next to LLE's Multi-Terawatt (MTW) laser.[9] Narrowband pulses from the MTW Nd:glass amplifier will be frequency doubled to provide up to 65 J for pumping the final beta-barium borate and DKDP amplifiers. OPAL will deliver 15-fs, 7.5-J pulses to an experimental target chamber at a rate of 1 shot/20 min. One stipulation for this system is that all technologies must be scalable to a full-kilojoule-scale OPAL, pumped by OMEGA EP's[10] four long-pulse beamlines, which could deliver 12 kJ of OPCPA pump energy at 527 nm.

Conclusion

OPAL provides a platform for addressing a number of technological challenges for ultra-intense lasers, many of which are shared with other ongoing projects. Areas that will be addressed include developing DKDP amplifiers and broadband and dichroic coatings with high damage thresholds; controlling spatial and spectral phases; relaying and up-collimating broadband, high-fluence beams; attaining high temporal contrast; and diagnosing the laser's single-shot performance.

ACKNOWLEDGMENT

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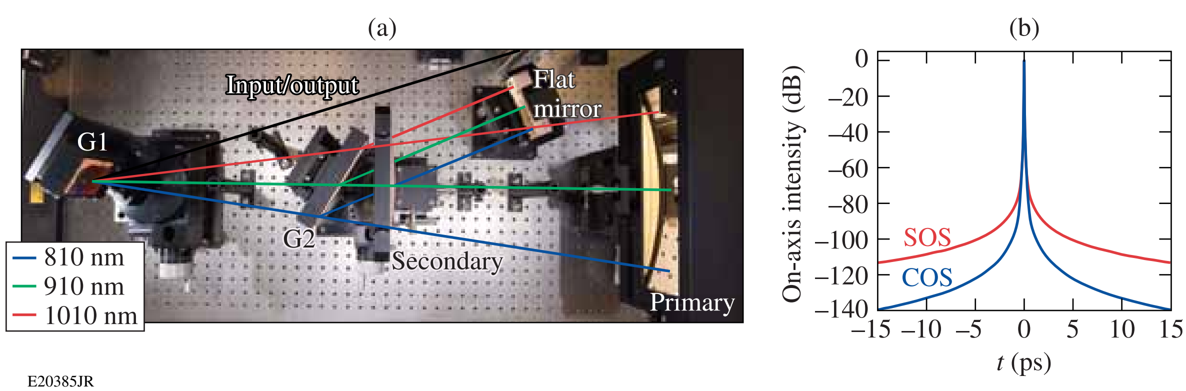

Figure 129.38
(a) Photograph of the cylindrical Öffner stretcher (COS) with an overlaid ray trace. (b) Calculated mirror-limited temporal contrast for the COS and a comparable-scale, single-grating spherical Öffner stretcher (SOS) with similar optical surface quality.

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