A Highly Efficient, 10-J Output Signal Amplifier for Ultra-Intense All-OPCPA Systems

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The highest-energy beams and the shortest pulses are always in the mainstream of laser science and engineering to create peta- and exawatt lasers.[1] Optical parametric chirped-pulse–amplification (OPCPA) systems, pumped by high-energy Nd:glass lasers, have the potential to produce ultra-intense pulses (>10^{23} W/cm^2). Existing large-scale glass lasers could be used to pump a large all-OPCPA system.[2] While front-end OPCPA stages are mainly focused on spectral, temporal, and phase characteristics of beams, the final OPCPA stages additionally need to be energy efficient. We report on the performance of the final high-efficiency amplifier in an OPCPA system based on large-aperture (63 × 63-mm^2), partially deuterated potassium dihydrogen phosphate (DKDP) crystals.

The experiment was performed on the Multi-Terawatt (MTW) Laser System, which is a hybrid OPCPA and Nd:glass laser. For all-OPCPA,[2] the MTW laser was switched to a narrowband mode at 1053 nm with energy up to 60 J and pulse-length variation from 1.2 to 1.6 ns. This radiation was converted to 526 nm using second-harmonic generation with an efficiency of 70%. The "green" beam at 526 nm travels by way of two large-scale periscopes into the next room through a series of vacuum spatial filters to maintain high beam quality. Finally, this 45-mm × 45-mm beam pumps a 48-mm or 52-mm-long DKDP crystal on the final stage synchronously with the seed beam. The chirped seed beam (τ = 1.5 ns, E = 240 mJ, $\Delta\lambda$ from 830 to 1010 nm) was created using a sequence of four lower-energy amplifiers seeded by a white-light continuum. The 11.8-J output signal was compressed to 19 fs.

The maximum pump-to-signal conversion efficiency of 37% was achieved with a 52-mm-long DKDP crystal (deuteration level of 70%) and 40 J of pump energy at 527 nm due to the flattop super-Gaussian pump beam profile and flat-in-time pulse. The seed and the pump were precisely synchronized in time. The shape of the 1.6-ns pump pulse was precompensated in the front end to reach a top-flat shape on the final amplifier. The input pump pulse and the residual pump pulse are shown in Fig. 1(a). The resulting hole in the residual pulse corresponds to the place where the seed pulse is located. It also demonstrates how deeply the pump pulse is depleted.

A deep saturation regime in the 52-mm-long crystal smooths output intensity modulation of the seed beam. Figure 1(b) shows a much better output signal spectrum at higher pump energies, even with a moderate quality of the initial seed spectrum. Figure 2 shows saturation of amplification with much better quality of the signal beam (d) than the seed beam (a) and deep depletion of the residual beam at 2ω (b) compared to the pump beam (c).

The maximum conversion efficiency from the pump beam into a signal of 37% (Fig. 3) was achieved with the 52-mm-long DKDP crystal (70% deuteration level) and pulse duration of 1.2 ns (FWHM).

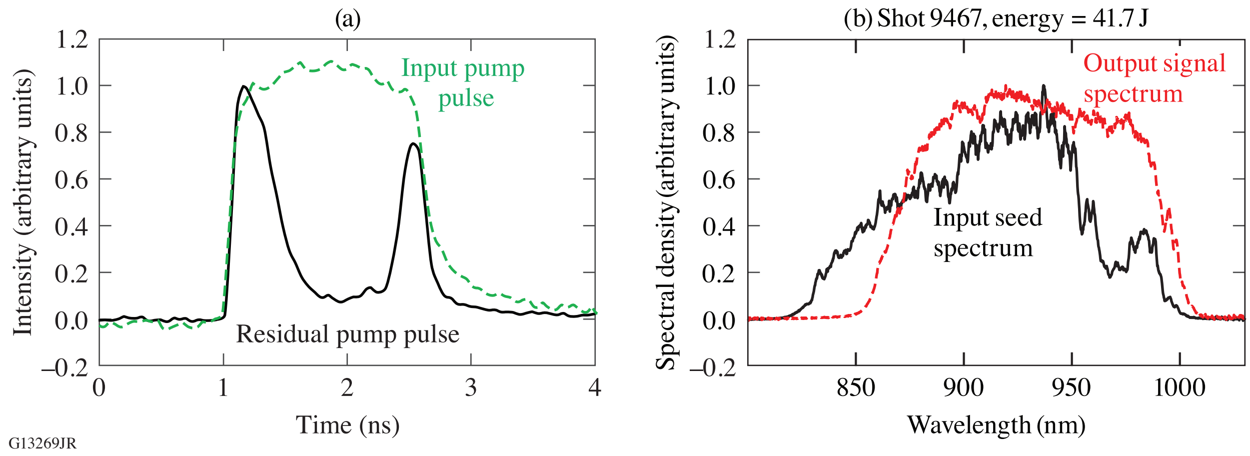

Figure 1
(a) An oscillogram with the input pump pulse and output residual pump pulse, both at 526 nm; (b) spectrum of the input seed beam (black curves) and the output signal beam (red curves) at the maximum pump beam energy.

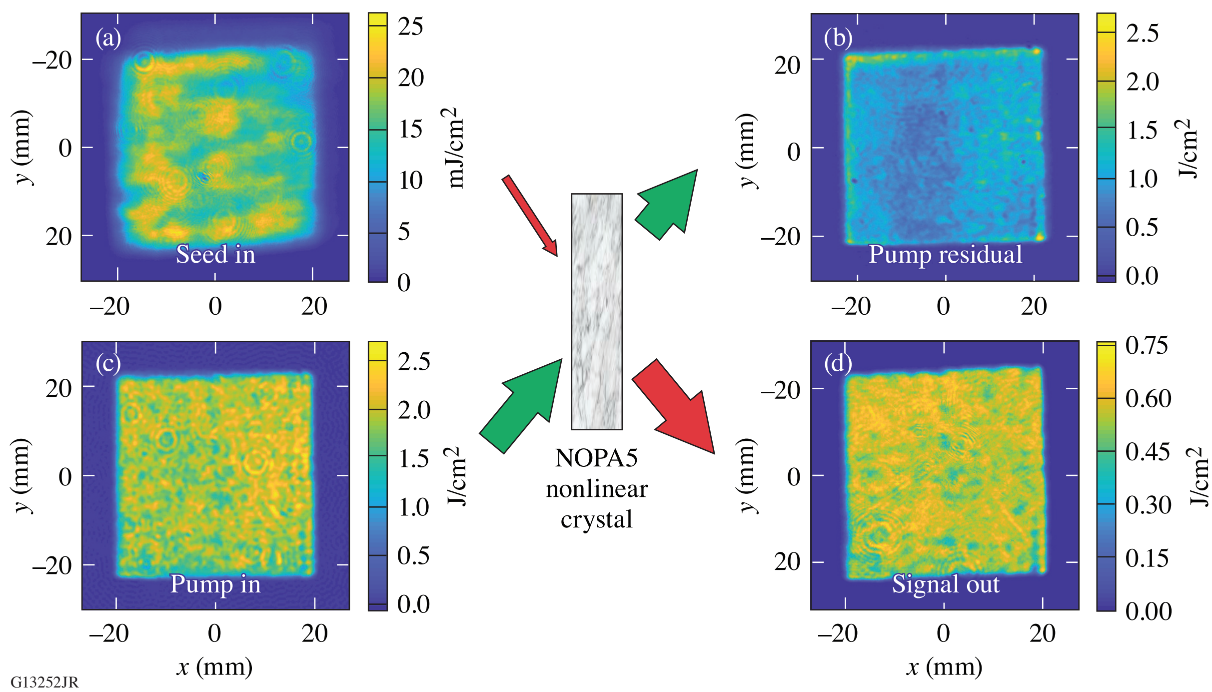

Figure 2
Images of typical interaction beams in the 52-mm-long DKDP: (a) the input seed beam, (b) the residual pump beam at 2ω, (c) the input pump beam, and (d) the output signal beam. NOPA: noncollinear optical parametric amplifier.

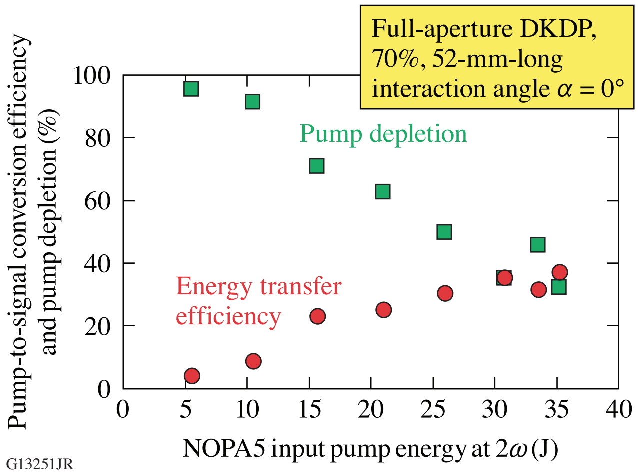

Figure 3
Maximum pump-to-signal conversion efficiency and depletion of the pump energy for the 1.2-ns pump pulse.

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1. C. N. Danson *et al*., High Power Laser Sci. Eng. **7**, e54 (2019).
2. J. Bromage *et al*., High Power Laser Sci. Eng. **7**, e4 (2019).