High-Energy Parametric Amplification of Spectrally Incoherent Broadband Pulses

C. Dorrer, E. M. Hill, and J. D. Zuegel

Laboratory for Laser Energetics, University of Rochester

Large-aperture Nd:glass amplifiers that are the basis for solid-state, ignition-class laser drivers are intrinsically limited in terms of their amplification bandwidth.[1,2] Spectral gain narrowing typically reduces the optical bandwidth to a few nanometers at a central wavelength of 1053 nm (1ω), mere tenths of a percent in terms of fractional bandwidth $\Delta\omega/\omega_0$. This relatively narrow optical bandwidth limits the performance of beam-smoothing techniques used to generate a smooth, time-averaged focal spot on target. Larger fractional bandwidth of the order of 1% would decrease the asymptotic smoothing time and mitigate laser–plasma instabilities.[3] Simulations show that this bandwidth promises to vastly improve the performance of both direct- and indirect-drive inertial confinement fusion. A new broadband laser driver concept based on optical parametric amplifiers (OPA's) is being designed at LLE to deliver 3ω pulses with a fractional bandwidth greater than 1% and support experiments on the OMEGA laser. Concepts for broadband amplification and frequency conversion of spectrally incoherent pulses are being tested and compared to models.

Optical parametric amplifiers, based on a three-wave nonlinear interaction, can efficiently amplify signals over extremely large bandwidths when the wavelength-dependent phase mismatch between the high-energy pump pulse, signal to be amplified, and resulting idler wave remains small during propagation in the nonlinear crystal.[4] These amplifiers are typically used to amplify a spectrally coherent signal for which spectral components have a well-defined phase relationship, e.g., with a chirped signal in optical parametric chirped-pulse amplification (OPCPA).[5] Smoothing techniques are, however, more effective when the temporal variations of the instantaneous optical frequency are much faster than the overall pulse duration. This can be achieved, for example, with spectrally incoherent pulses originating from a random process such as amplified spontaneous emission. While these signals are effectively used in large-scale, high-energy excimer (gas) lasers,[6] demonstrating their broadband amplification in OPA's pumped by frequency-doubled lasers based on Nd-doped materials opens the path to a new generation of broadband, high-energy, ignition-class drivers based on existing solid-state laser technology and large-aperture nonlinear crystals.

We demonstrate, for the first time to our knowledge, efficient high-energy parametric amplification of broadband spectrally incoherent pulses. Because of the spatial coherence resulting from signal generation in a front end based on single-mode fibers, the amplification process is similar to what is observed with monochromatic signals. Experiments performed with the existing Multi-Terawatt laser's OPA stages, originally designed for OPCPA,[7] demonstrate the generation of spectrally incoherent waves around 1053 nm (1ω) with ~60-nm bandwidth at energies of several hundred millijoules. The large bandwidth and high conversion efficiency from the pump at 526.5 nm (2ω) to 1ω waves are the results of a collinear interaction geometry in the last OPA and generation of the seed signal at a central wavelength below 1053 nm by the fiber front end. In these conditions, the idler wave generated in the last OPA co-propagates with the signal wave and has a spectrum that is spectrally symmetric relative to the signal's spectrum with respect to 1053 nm, effectively increasing the available energy and optical bandwidth at 1ω.

Figure 1 displays the output 1ω energy after the power amplifier as a function of the 2ω pump energy. Similar amplification behavior is observed when the seed signal is a spectrally incoherent broadband signal, with the spectrum centered at 1030 nm, and a narrowband coherent signal at 1030 nm [Fig. 1(a)]. The energy in the combined signal and idler waves resulting from power-

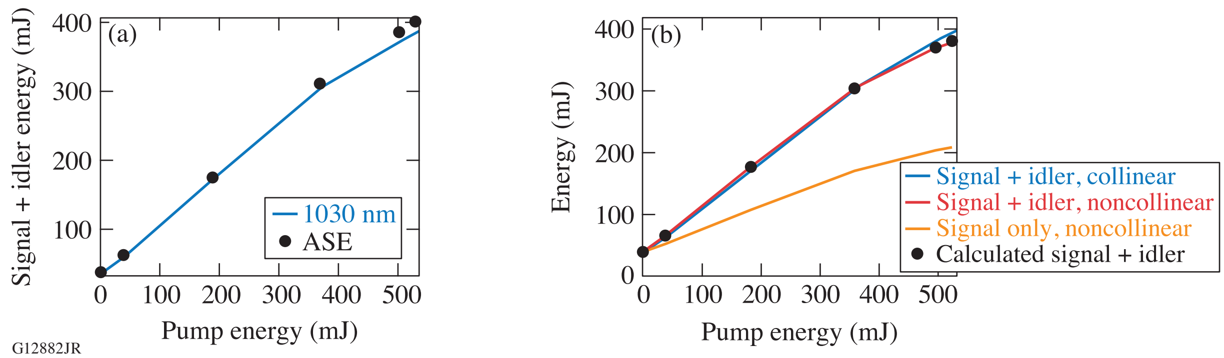

Figure 1
Amplified output energy after the power amplifier. (a) The curve corresponds to a monochromatic seed at 1030 nm and the solid black circles correspond to a spectrally broadband amplified spontaneous emission (ASE) seed. (b) The measured power-amplifier output energy is plotted for the combined signal and idler in collinear and noncollinear geometries (solid blue and red curves, respectively) and for the signal in a noncollinear geometry (solid orange curve). The energy of the combined signal and idler calculated from the signal energy is plotted with solid black circles.

amplifier operation at 530 mJ is 400 mJ, demonstrating a 70% conversion efficiency from the 2ω pump to 1ω waves considering the 30-mJ, 1ω input energy for this amplifier. Operation of the power amplifier in a collinear or slightly noncollinear geometry yields similar output energies for the combined signal and idler pulses [Fig. 1(b)]. The energy of the combined signal and idler waves calculated using the signal energy measured in a noncollinear geometry is in excellent agreement with the experimentally measured energy, showing that parasitic processes such as second-harmonic generation are not significant.[8]

The spectrum of the parametric fluorescence resulting from operation of the fully pumped OPA stages without a seed signal is shown in Fig. 2(a). The measured bandwidth, ~100 nm, is indicative of the large bandwidth that can be obtained for amplification around 1ω. Figure 2(b) shows the spectrum of the input seed signal and the spectrum of the combined signal and idler waves at the output. Because of energy conservation in the OPA pumped at 526.5 nm, amplification of signal photons at wavelengths below 1053 nm leads to the generation of idler photons at wavelengths above 1053 nm. The resulting waves have a spectral density extending over more than 60 nm, i.e., corresponding to a fractional bandwidth larger than 5% at 1ω.

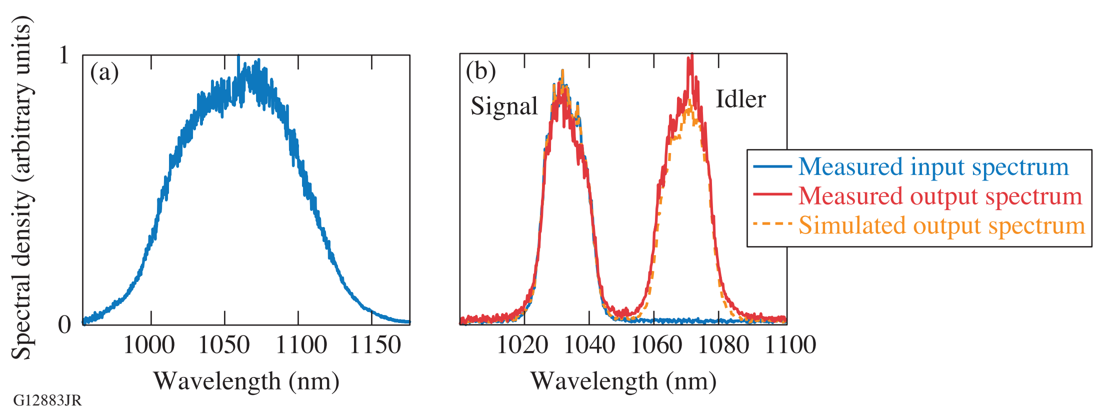

Figure 2
(a) Measured parametric fluorescence at the power-amplifier output in the absence of seed in the preamplifier; (b) input and output spectra of the power amplifier and simulated output spectrum for the ASE seed.

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