

# Research of hundred picosecond microjoule pump laser system

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Received April 28, 2012; accepted June 25, 2012; posted online December 20, 2012

A master-oscillator power amplifier (MOPA) system based on Nd glass laser with output intensity of 5 GW/cm<sup>2</sup> is described. The laser operates at 1 Hz with pulse energy up to more than 4 mJ. The spatial profile is near top hat and the diameter is 1 mm, the temporal pulse shape is Gaussian and pulse width is about hundred picosecond. Frequency doubling efficiency is 37.5% with 3-mm-long BBO crystal, the pulse of microjoule output energy and 527-nm wavelength is achieved and used as the pump pulse in the short pulse optical parametric amplification, decreasing the parametric fluorescence influence to contrast of optical parametric chirped pulse (OPCPA) system.

OCIS codes: 140.3280, 140.3515, 190.4970.

doi: 10.3788/COL201210.S21416.

Ultra-short and ultra-intense laser system generate intensities at focus as high as  $10^{18}$ – $10^{21}$  W/cm<sup>2</sup> for a variety of relativistic and high-energy-density physics experiments. Detrimental modifications of a solid target via preplasma formation can happen at intensities as low as  $10^8$ – $10^{11}$  W/cm<sup>2</sup>. One of the main bottlenecks for applications in high-intensity laser-matter interaction is the temporal contrast of pulse. The temporal contrast of a laser pulse, defined as the ratio of the peak intensity of the main pulse to the intensity of the light in some predetermined temporal range before the main pulse, must be at least 10 orders of magnitude in the tens of picosecond region to restrict destructive pre-plasma dynamics<sup>[1–2]</sup>. Optical parametric chirped pulse amplification (OPCPA) is traditional chirped pulse amplification (CPA) combined with optical parametric amplification, it has many attractive properties, such as high single-pass gain, no amplified spontaneous emission (ASE) accumulation, lower thermal load on nonlinear crystals, and ultrabroad-gain bandwidth, so this technique is becoming increasingly popular as preamplifiers for seeding laser systems and as potential amplifiers for extremely high peak power system<sup>[3–6]</sup>. The noise mainly originates from high gain preamplifier, the main source of contrast degradation of OPCPA includes parametric fluorescence (PF), originates from a quantum effect during parametric amplification. As parametric amplification and fluorescence rely on an instantaneous and directional interaction, PF occurs within the window defined by pump pulse, like ASE, PF is added to the main chirped seed and gives rise, after compression, to a flat pedestal surrounding the amplified short pulse<sup>[7–10]</sup>. So a picosecond time domain OPCPA as a preamplifier instead of nanosecond time domain OPCPA is used to generate high-energy high-contrast clean pulses to seed the subsequent amplifier chain, it has a number of advantages: 1) limiting the pump pulse duration to picosecond will limit the duration of the PF generated in this stage to picoseconds as well; 2) in the picosecond regime, high peak intensities can lead to high small-signal gain and high efficiencies,

which can also contribute to limiting the PF. The key technique of this short pulse OPCPA is the generation of high intensity, good beam quality, and good output stability short pump pulse. In this letter, we report a master-oscillator power amplifier system (MOPA) based Nd glass laser system, the pulse width is 100 ps, output intensity is more than 1 mJ after frequency doubling.

The short pump pulse system consists of four major components, an oscillator, a regenerative amplifier, power amplifier, and frequency doubling, shown as Fig. 1.

The oscillator for this short pump system is modeled after the shenguang II (SGII) oscillator. It is an all-fiber-based system with components as shown in Fig. 2(a). A 10-mW continuous wave (CW) signal-frequency fiber oscillator is injected into an (acous-to-optic) AO modulator that carves out a 30-ns pulse, and then injected into a fiber amplifier and amplified to about 10 nJ. The 10-nJ pulse is injected into a two-channel amplitude modulator as described in Ref. [11]. One channel of the modulator is driven by a 1-ns pulse generator that creates a 5-V square pulse, the other channel is driven by an aperture-coupled strip line (ACSL), that generates a 5-V linear ramp voltage about 100-ps. The resultant light pulse exiting the last fiber amplifier is a 1-Hz Gaussian

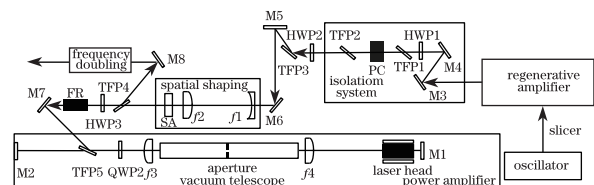


Fig. 1. Schematic layout of the hundred picosecond microjoule pump laser system. M1–M2: 0° high reflector; M3–M8: 45° high reflector; HWP: half wave plate; TFP: thin film polarizer; QWP: quarter wave plate; PC: quarter-wave voltage pulse-slicing Pockels cell; FR: Faraday rotator; f1:  $f=-250$  mm plano-concave lens; f2:  $f=500$  mm plano-convex lens; SA: serrated aperture; f3, f4:  $f=486.5$  mm plano-convex lens.

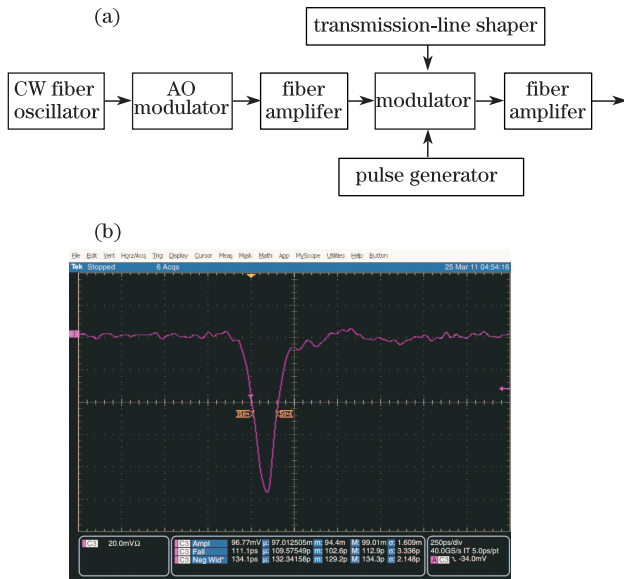


Fig. 2. (a) Schematic of the all-fiber-based master oscillator; (b) oscillator output pulse shape.

shaped pulse of 100-ps width and 100-pJ energy as shown in Fig. 2(b), which is measured with 14-GHz bandwidth high-speed PIN diode and 4-GHz bandwidth Tektronix oscilloscope.

The diode-pumped injection-seed Nd glass regenerative amplifier is the simple modified-Z-shaped oscillator cavity, which is 5.4-m long and allows for easy injection and extraction of pulses with widths up to 10 ns. The gain is provided by side-pump Nd glass rod, which is 4 mm in diameter, has a gain length of 66 mm. The laser head is pumped by five 5-bar diode arrays arranged in pentagonal symmetry and is cooled with clean circulated water. The 100-pJ signal pulse exits the single-mode fiber and is mode-matched to the regenerative amplifier cavity. To ensure the security of optical components and avoid the nonlinear effect, the injected oscillator pulse is trapped in the regenerative amplifier cavity using a FastPulse 5046E pulse slicer and amplified to 0.5 mJ. There are a lot of pre-pulses because of finite extinction of polarizer in the regenerative amplifier. The isolation system, shown as Fig. 1, consists of HWP1, TFP1, PC, TFP2, and it is designed to eliminate these pre-pulses before the main pulse and enhance the pulse contrast.

The power amplifier is four-pass amplifier as shown in Fig. 1. The amplifier head is similar to the regenerative amplifier and the small signal gain is 2.46, the pump diodes (for the regenerative amplifier and for the power amplifier) are pulsed for 450  $\mu$ s. The vacuum telescope has a signal  $f=486.5$  mm plano-convex lens on each end ( $f3$  and  $f4$ ), the aperture with 20 diffraction limit size is located at the focus of the vacuum telescope to eliminate parasitic oscillation and reduce diffraction effects. The relay planes are not in the laser head but at the end mirrors M1 and M2, which can achieve four passes relays.

The beam exits the isolation system and is expanded twice by the  $f1$  and  $f2$  lenses. The beam is spatially shaped to a rounded top hat by a 3-mm diameter serrated aperture (SA) for the purpose of increasing energy conversion efficiency from the power amplifier. The serrated aperture plane becomes the reference plane relay-

imaged onto M1, back to M2, back again to M1, and finally onto M8, with similar distance to TFP8 as SA. The quarter wave plate (QWP2) near the M2 allows the user to select two-pass or four-pass amplification.

The system normally runs at 1 Hz. The output energy of power amplifier is 4.4 mJ in the situation of 0.1-mJ input energy, the pulse-to-pulse energy stability is <3% because the power amplifier runs in the saturation state, 4% single-pass loss makes the 85% transmission efficiency in four-pass cavity. The net gain of power amplifier is 51.76, and the single-pass small signal gain is 2.68. What is more, another laser head located between M2 and polarizer TFP5 can bring 16-mJ output energy without parasitic oscillation. Near-field beam image and pulse shape measurements are separately monitored. As Fig. 3 shown, near-field output beam image from power amplifier is measured with charge-coupled device (CCD) at an output relay plane (near M8 location), the two dimensions intensity distribution profiles is top hat which is accord with the shaped spatial shape. The temporal pulse shape is shown in Fig. 4(a) measured with 12-GHz bandwidth phototube and 4-GHz bandwidth Tektronix oscilloscope. The pulse duration (full-width at half-maximum, FWHM) is 184 ps, wider than the input pulse duration of 100 ps as shown in Fig. 2(b), due to gain narrow effect in regenerative amplifier and power amplifier.

The beam diameter of pulse from power amplifier is demagnified trebly to 1 mm to enhance the intensity of inputting the beta barium borate (BBO) frequency doubling crystal, which is more than 5 GW/cm<sup>2</sup>. The efficiency can reach to 37.5%, finally we can get 1.5-mJ energy, 527-nm wavelength pump pulse, and the pulse width is 240 ps as shown in Fig. 4(b), which is wider than the input pulse because of the thickness of attenuation before the detection, the relatively long tails of the pulse shape are artifacts of the detector and the long cable length to the oscilloscope.

In conclusion, we demonstrate the operation of a pump laser based on generating 4-mJ 1053-nm pulse at 1 Hz with an intensity more than 5 GW/cm<sup>2</sup>. The MOPA integrates more than 100-pJ fiber-based oscillator with a

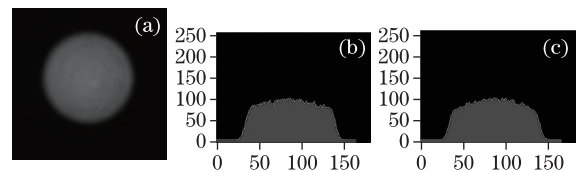


Fig. 3. (a) Near-field beam image of the power amplifier beam; (b) horizontal ( $x$ ) intensity distribution profile; (c) vertical ( $y$ ) intensity distribution profile.

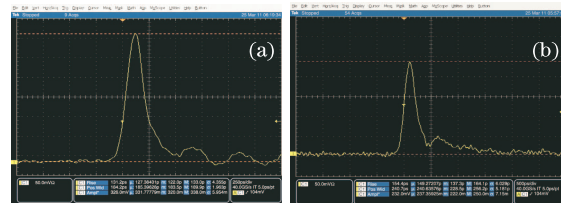


Fig. 4. Temporal pulse shape after (a) power amplifier and (b) frequency doubling.

0.5-mJ regenerative amplifier and a relay-imaged 4-pass diode-pump Nd glass amplifier to generate a 1-Hz top hat spatial beam and about 100-ps temporal Gaussian pulse with <3% pulse-to-pulse energy stability. The pump pulse of 1.5-mJ output energy and 527-nm wavelength is achieved after frequency doubling. When another laser head is added in the power amplifier, the more energy can be achieved and the frequency doubling efficiency can be more than 50%, which is limited by B-integral concern. We generate the more short pulse width (sub-picosecond) and more intensity pump system experiments with the same MOPA structure, and the results will be reported in the near future.

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