100 TW CPA Nd:GLASS LASER FOR FAST IGNITION RESEARCH

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Abstract

A 100 TW chirped pulse amplification (CPA) Nd:glass laser has been developed to investigate the fast ignition concept. The ultrashort-pulse (60 TW, 42 J, 0.7 ps) was focused on plane targets, plane targets with preformed plasma, and high density compressed plasmas produced by the GEKKO-XII (12 beam, 20 kJ) laser. Focus intensity of $>10^{19}$ W/ cm^2 has been achieved.

1. INTRODUCTION

Recently, intense ultrashort-pulse lasers were developed all over the world. One of the applications was fast heating of a compressed core plasma of inertial confinement fusion (fast ignition concept)[1]. A simulation study shows that, in order to achieve fast ignition, 2 - 3 kJ energy is required to heat a part of a compressed fuel with the density of ρ=400 g/cm^3 to a temperature of 10 keV over the region of ρR=0.6 g/cm^2, with a resultant core gain of 2,000 [2]. Although the coupling efficiency (the fraction of the heating laser energy coupled to the compressed core) is a main subject to be investigated, a short pulse laser with the energy of over 10 kJ is required for future ignition/burn experiments. For the present experiment, the typical parameters of the plasma core produced by the GEKKO-XII are: diameter of a few 10 μm, life time of a few 10 ps, and core energy of a few 100 J. Therefore the requirements to the laser for fast ignition experiments are: focus spot diameter of 10 μm, pointing accuracy of 10 μm, pulse width of less than 10 ps, synchronization of better than 10 ps, and output energy of approximately 100 J. Furthermore, high intensity of $>10^{19}$ W/cm^2 is required for generation of high energy electrons and for penetration of the laser beam through over dense plasma close to the plasma core. We have developed an ultrashort-pulse laser of less than 1 ps duration with 50 J energy, with which focus intensity of $>10^{19}$ W/ cm^2 has been achieved[3].

2. SYSTEM LAYOUT

Layout of the 100 TW system is shown in Fig. 1. An LD-pumped mode-locked Nd:glass laser is used as an oscillator, where a newly developed solid state saturable absorber is adopted as a fast modulator[4]. The short pulses from the oscillator are stretched to 1.5 ns by a 4-pass grating stretcher, and amplified to a few mJ by a Ti:sapphire regenerative amplifier. Single pulse from the regenerative amplifier is amplified to a few Joule with a 4-pass glass rod amplifier and another single-pass 5-cm glass rod amplifier.

The final amplifier consists of four disk amplifiers with 350 mm aperture in Cassegrain 3-pass geometry. The pulse compressor is composed of 2 gratings of 1480 lines /mm and 40 cm in diameter with parallel double-pass configuration. The beam diameter is limited to 20 cm due to the grating size. The size and the damage threshold of the gratings limited the output from the compressor to 50 J in 0.5 ps. Since the laser amplifier can deliver 1 kJ in 300 ps, larger diffraction gratings would generate a beam of more than 1 PW. After compression, the beam is directed to the target chamber and focused onto a target by an on-axis parabolic mirror of 65 cm focal length. The optical paths after the compressor are in vacuum. Focal spot of 30 μm in diameter has been obtained by precisely adjusting the parabolic mirror. The intensity on target is $> 10^{19}$ W/ cm^2.

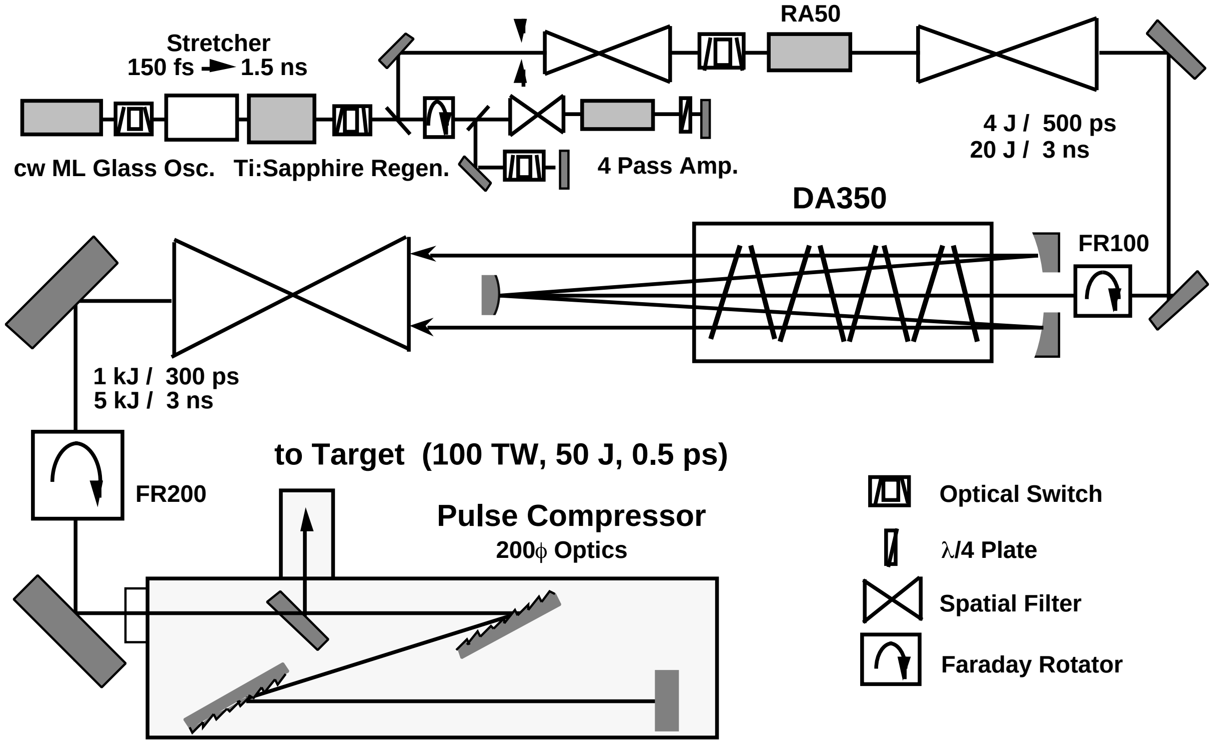

FIG. 1. System layout of the 100 TW CPA Nd:glass laser

3. EXPERIMENTAL RESULTS

This 100-TW system was synchronized with the GEKKO-XII system. A real-time control unit adjusted the cavity length of the mode-locked oscillator so that the mode-locked pulses were synchronized to the 50 MHz standard signal, which controlled an acoustic optical modulator of the oscillator for GEKKO-XII system. The synchronization between the two laser systems was less than 100 ps. To realize the synchronization of a few ps, a new front end system of GEKKO-XII is under designing. The waveform of the oscillator output fitted well to $sech^2$ function with the minimum pulse width of 151 fs. The spectral width of the oscillator output is 8.7 nm (2.6 THz) with the pulsewidth-bandwidth product (Δt x $\Delta \nu$) of 0.39 showing the nearly transform limited pulse shape. The operation stability was tested for 6.5 hours. The fluctuation of oscillation wavelength was +/- 0.15 nm, which is much smaller comparing with gain spectrum of the Nd:glass laser. The output power and pulse width were quite stable during testing period.

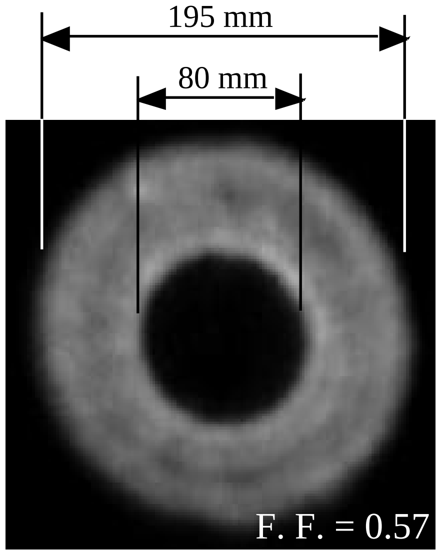

FIG. 2. Near field pattern of output beam

Each disk amplifier module of the main amplifier has two LHG-80 disks (694 x 380 x 45 mm). The measured small signal gain was 1.88 and the pumping efficiency was 1.2 %. The total gain of the 3-pass amplifier was approximately 2000. The flow path of the coolant nitrogen gas was carefully designed, in order to remove the thermal distortion in the laser disks within 60 minutes. The image relay has provided uniform spatial beam profile. The filling factor was 57 % at the laser energy of 52 J as shown in Fig. 2.

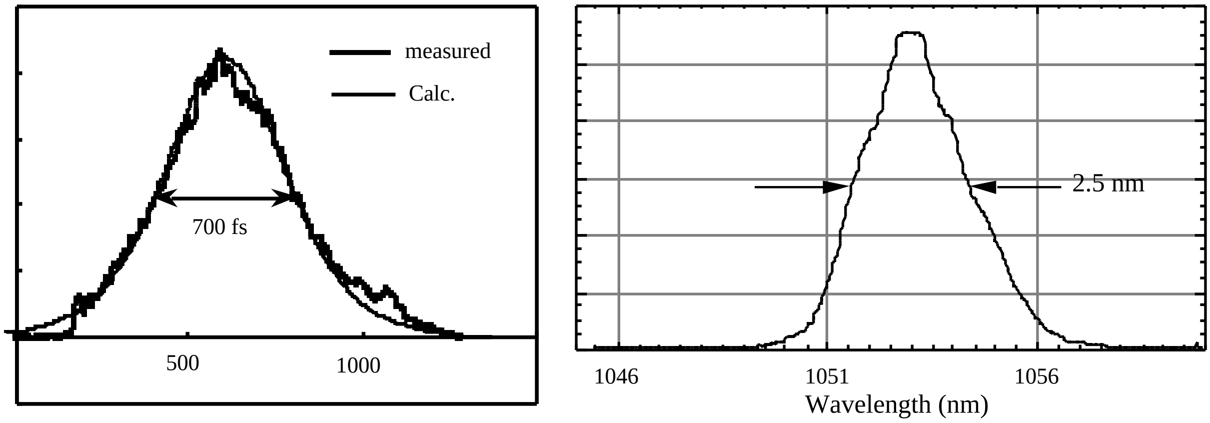

FIG. 3. Second order autocorrelation and spectrum of output pulse at 52 J. The fitting curve is sech2 with FWHM of 700 fs.

A part of compressed pulse (1 %) was splitted to measure the laser parameters. The pulse width of 700 fs was measured by the second order auto-correlation as shown in Fig. 3. The measured spectral width was also described in the figure. The spectral width of 8.0 nm at the oscillator decreased to 2.5 nm at the compressor due to amplification narrowing in the amplifier chain. The pulse width was slightly longer than the estimation from the measured spectral width. The pulsewidth-bandwidth product (Δt x $\Delta\nu$) was about 0.52 due to imperfect adjustment of the compressor. The measured pulse width and spectral width are summarized in Tabel 1 including the pulse width of Fourier transfer limit.

4. SYSTEM ANALYSIS

System analysis was performed using a glass laser amplification code (GLAMP) including 2D beam propagation. The amplification is based on Lowdermilk and Murray model with the lower level relaxation[5]. Recently, it was found that the life time of the lower laser level was sub nanosecond for phosphate glass[6]. Full relaxation of the lower level should be considered for multi-pass amplification. The evaluated maximum output energies for CPA pulse and 3 ns narrow band pulse were 1 kJ and 5 kJ, respectively. The Cassegrain 3-pass geometry is tested as an amplification scheme for future high energy laser system.

Image relay was adopted to obtain uniform spatial beam profile. Image of a hard aperture installed at exit of the 4 pass amplifier was relayed by spatial filters. Filling factor at entrance of the pulse compressor was calculated to be 60 %, while measured one was 57 %. It was shown by simulation that the filling factor increases up to 70 % using an optimized serrated aperture at the starting point of image relay.

TABLE I. SUMMARY OF THE PULSE WIRTH AND SPECTRAL WIDTH

Position	$\Delta\nu$ (measured) nm	Δt (measured) fs	Δt (Fourier transfer limit) fs
Oscillator	8.0	150	141
After Compressor			
Regen.	6.7	262	173
Rod Amp.	2.8	650	413
Disk Amp.	2.5	700	452

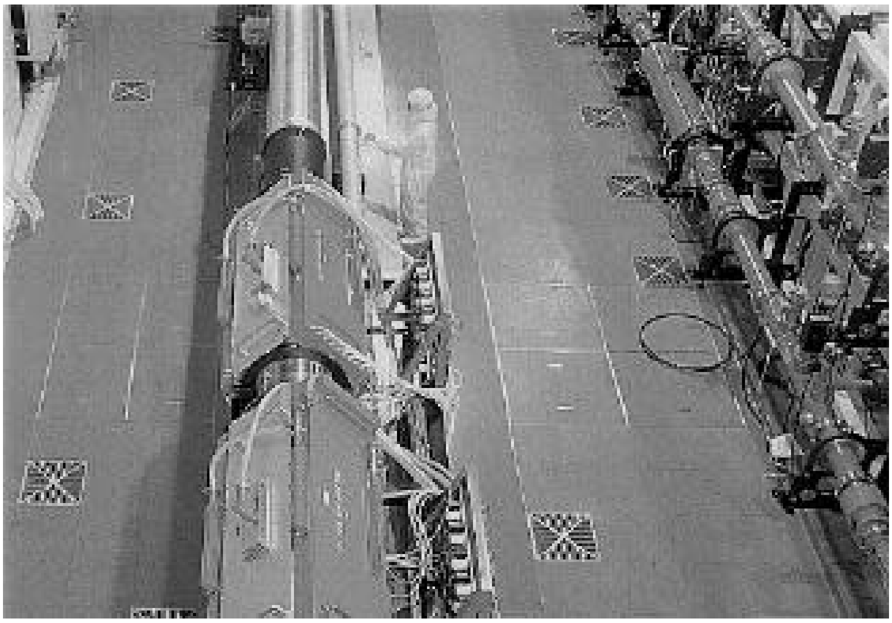

FIG. 4. Photograph of 100 TW CPA Nd:glass laser system

5. SUMMARY

We have developed 100 TW CPA Nd:glass laser system (shown in Fig. 4). The laser system delivered 42 J in 700 fs (FWHM) on target in synchronization with GEKKO XII laser. Parasitic oscillation and wavefront degradation over the whole system are acceptable level. The power and intensity on target are 60 TW and > 10^{19} W/cm^2.

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