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# A 100-TW Ti:Sapphire Laser System at a Repetition Rate of 0.1 Hz *

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*We demonstrate a 100-TW-class femtosecond Ti:sapphire laser running at a repetition rate of 0.1 Hz based on a 20 TW/10 Hz laser facility (XL-II). Pumping the new stage amplifier with a 25 J green Nd:glass laser, we successfully improve the laser energy to 3.4 J with duration of 29 fs, corresponding to a peak power of 117 TW.*

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With the advent of the chirped-pulse amplification (CPA) technique,[1] remarkable progress on the development of high peak power laser systems on a table-top scale has been achieved. Peak power up to multi-terawatt($10^{12}$ W, TW) based on CPA Ti:sapphire laser has been widely realized by many groups over the world. In particular, petawatt($10^{15}$ W, PW) laser systems were also demonstrated in some large laboratories, for example, 1.5 PW in a 440 fs hybrid Ti:sapphire-Nd:glass laser system was developed in LLNL,[2] 1.1 PW hybrid OPCPA (optical parametrical CPA) Nd:glass laser was developed in Texas,[3] and 0.85 PW in a 33 fs Ti:sapphire laser system was developed in Japan,[4] and high contrast 1.16 PW with a combination of Ti:sapphire laser and OPA was demonstrated in our group.[5] However, these petawatt-class laser facilities work at very low repetition rate, which is limited to few shots per hour or single shot. More recently, Jae Hee Sung *et al.*[6] demonstrated a 1 PW Ti:sapphire laser at 0.1 Hz with multi-stage amplifiers, large space and many pump lasers were employed to support the laser operation. For in depth research on high intense laser matter interaction, it is necessary to accumulate laser shots and to improve the signal-to-noise ratio for experiments.[7] Although we have realized 20 TW laser output at repetition rate of 10 Hz,[8] similar laser facilities have also been reported by domestic and international groups,[9−12] for many applications such as generation of exceedingly short bursts of energetic radiation and particles,[13] peak power of higher than 100 TW running in a repetitive mode is necessary. Therefore, it is still a promising work to develop a compact multi-TW femtosecond laser running at a high repetition rate with low economical cost.

In this Letter, we report a 100 TW Ti:sapphire laser at 0.1 Hz based on 20 TW femtosecond laser at 10 Hz (XL-II laser facility) by adding a stage of amplifier before the compressor. The final amplifier stage is pumped by a 527 nm Nd:glass laser with energy of 25 J at repetition rate of 0.1 Hz, and with optimization of the final amplifier and compressor, the output laser energy up to 3.4 J with pulse duration of 29 fs was obtained, which correspond to a peak power of 117 TW.

The "XL-II" laser facility consists of a home-made femtosecond Ti:sapphire laser oscillator, a pulse stretcher, a regenerative amplifier, a one-stage multi-pass amplifier and a vacuum compressor. It was able to deliver the laser pulses with energy of 600 mJ in 30 fs at a repetition rate of 10 Hz, details are described in Ref. [8]. Based on this 20-TW laser facility, a high energy booster amplifier stage is designed to boost the energy. A commercial 527 nm Nd:glass laser with energy of 25 J at a repetition rate of 0.1 Hz (Thales Inc.) is employed to pump last amplifier stage. To realize over 100 TW at a high repetition rate, some key techniques must be taken in consideration, for example, a homogeneous pump scheme, the thermal effect, the gain narrowing effect, and suppressing parasitic lasing, which are described in the following.

To achieve good beam quality of a compressed beam and to improve the extracting efficiency, the homogeneous pump scheme is very important. Two independent oscillators with a multimode spatial profile are employed in this pump laser. After combination of these two beams into one beam by using a thin film polarizer, and injecting into two independent amplifiers, by accurately compensating for thermally induced birefringence, spatial modulators in amplifier modules, the near field of beams output from the

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pump laser have a flat-top distribution in the spatial domain. By the image relay scheme through a vacuum tube, this near field beam pattern with flat-top distribution is imaged and expanded to 30 mm in diameter on a Ti:sapphire crystal with diameter of 35 mm to obtain a homogeneous pump. This pump scheme can ensure amplified beam quality and improve efficiency. The design of the booster amplifier stage and the spatial profile of the pump laser are shown in Fig. 2. To suppress parasitic lasing in a large diameter crystal, a polymer thermoplastic material is clad around the Ti:sapphire crystal to absorb the reflection at the Ti:sapphire interface. To compensate for the gain narrowing effect and to support more bandwidth spectra, a gain notch filter is employed into the regenerative amplifier to accurately tune the angle in the beam path of the regenerative cavity. The gain narrowing effect is then compensated for. The spectrum bandwidth is enlarged to 32 nm by inserting a gain filter, with comparison of 22 nm without a gain filter. It was demonstrated that the gain narrowing effect was compensated for in the last booster amplifier stage and supports a much wider spectral bandwidth.

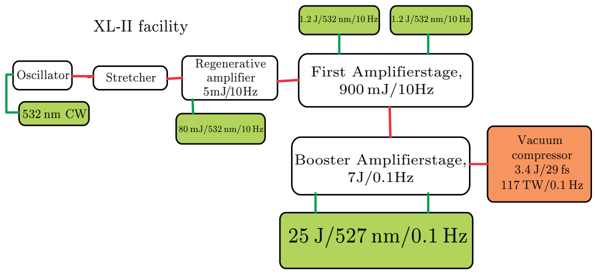


**Fig. 1.** Diagram block of the 117 TW laser system at 0.1 Hz.

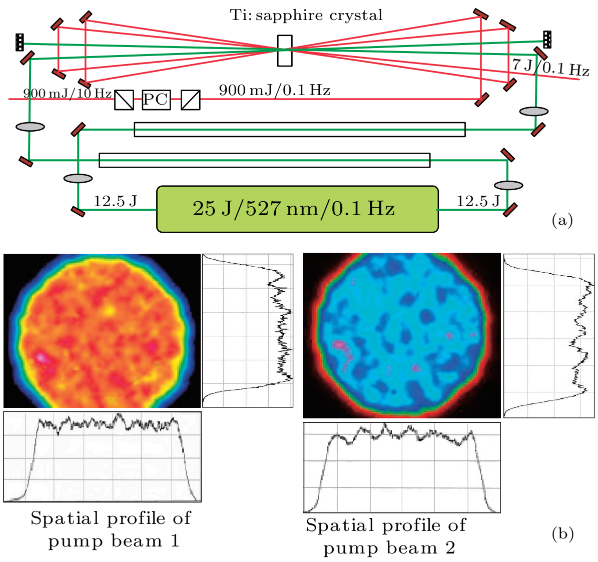


**Fig. 2.** Design of the final booster amplifier (a), and spatial profile of the two pump beams (b) showing flat-top spatial distribution.

A Pockels cell with a diameter of 30 mm is located between the first amplifier stage and booster amplifier stage, the repetition rate of amplified pulses can be switched to 0.1 Hz by using this Pockels cell and synchronizing to the pump laser for the last stage. With fine synchronization and optimized alignment between the pump and the amplified laser beam, we obtain an amplified pulse with energy of 6 J under a pump energy of 21 J, which corresponds to the extract efficiency of 28%. The shot-to-shot energy stability is less than 2%, as shown in Fig. 3.

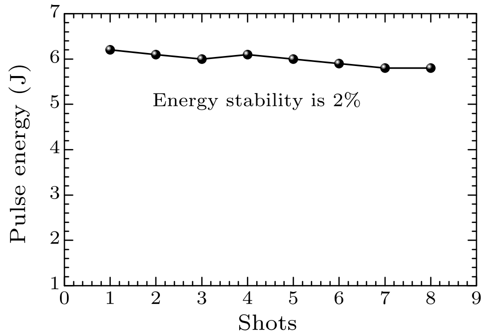


**Fig. 3.** Output energy of the booster amplifier pumped with energy of 21 J.

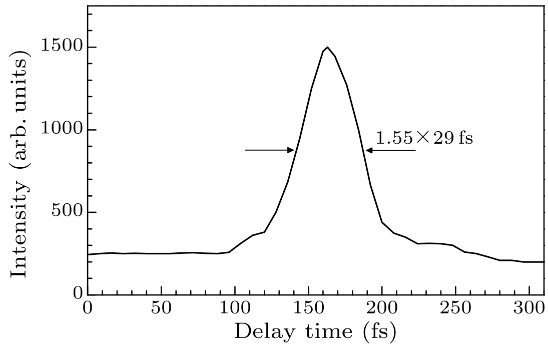


**Fig. 4.** Single-shot autocorrelation trace of the compressed pulse, showing that the pulse duration is 29 fs by calibration.

After the final amplifier, the amplified laser beam is enlarged to 80 mm in diameter by using a telescope, and injected into the vacuum compressor. Following the optimization of dispersion compensation in a compressor, we measured the compressed pulse with a commercial single-shot autocorrelator (Coherent Inc.). By calibration and assuming a Sech$^2$-shaped temporal profile, the calculated pulse duration is 29 fs, as shown in Fig. 4. The energy is 3.4 J after the compressor, corresponding to a peak power of 117 TW. The contrast ratio is around $10^6$–$10^7$ at 1 ns time scale, which was measured by a photodiode with resolution of picosecond. Based on this progress, we plan to replace the front end with a multi-pass amplifier, which has a contrast ratio up to $10^{10}$. Based on the new scheme, we expect that the contrast ratio from last stage will be improved to more than $10^9$.

In conclusion, based on a 20-TW laser (XL-II laser facility), a booster main amplifier has been completed, which is pumped by a green laser with energy of 25 J at 0.1 Hz. Suppressing the parasitic lasing in a Ti:sapphire crystal and employing a homogenous pumping scheme, the amplified energy is boosted to 6 J before the compressor under the pump energy of 21 J, corresponding to an extract efficiency of 28%. Through accurate compensation of the dispersion between the stretcher, amplifier and compressor, and suppressing the gain narrowing effect in the regenerative amplifier to obtain more broader bandwidth, the compressed pulses have durations as short as 29 fs and energy of 3.4 J, which correspond to a peak power of 117 TW. The rms energy stability is 2%. The laser will pave the way to carrying out high-field experimental research in relativistic regimes involving high repetition rates.

## References


[1] Strickland D and Mourou G 1985 *Opt. Commun.* **56** 219

[2] Perry M D, Pennington D, Stuart B C, Tietbohl G, Britten J A, Brown C, Herman S, Golick B, Kartz M, Miller J, Powell H T, Vergino M and Yanovsky V 1999 *Opt. Lett.* **24** 160

[3] Gaul E, Martinez M, Blakeney J, Jochmann A, Ringuette M, Hammond D, Escamilla R, Henderson W, Borger T, Ditmire T 2008 *International Conference on Ultrahigh Intensity Lasers* (Tongli, China 27–31 October 2008) p 3

[4] Aoyama M, Yamakawa K, Akahane Y, Ma J, Inoue N, Ueda H and Kiriyama H 2003 *Opt. Lett.* **28** 1594

[5] Wang Z H, Liu C, Shen Z W, Zhang Q, Teng H and Wei Z Y 2010 *Opt. Lett.* **36** 3194

[6] Sung J H, Lee S K, Yu T J, Jeong T M and Lee J M 2010 *Opt. Lett.* **35** 3021

[7] Mourou G, Tajima T and Bulanov S V 2006 *Rev. Mod. Phys.* **78** 309

[8] Wei Z Y, Wang Z H, Ling W J, Wang P, Zhang J, Suzuki M, Kuroda H 2004 *IOP Conf.* **186** 685

[9] Peng H S, Huang X J, Zhu Q H, Wang X D, Zhou K N, Wei X F, Zeng X M, Liu L Q, Wang X, Guo Y, Lin D H, Xu B, Xu L B, Chu X L and Zhang X M 2006 *Laser Phys.* **16** 244

[10] Liang X Y, Leng Y X, Lin L H, Lu H H, Wang W Y, Jiang Y H, Shuai B, Peng H L, Zhao B Z, Wang C, Zhang W Q, Zhang Z Q, Li R X and Xu Z Z 2006 *Opt. Lasers Engin.* **44** 130

[11] Wei Z Y, Wang Z H, Wang P, Ling W J, Zhu J F, Han H N, and Zhang J 2008 *J. Phys.: Conf. Ser.* **112** 032003

[12] Lozhkarev V V, Freidman G I, Ginzburg V N, Katin E V, Khazanov E A, Kirsanov A V, Luchinin G A, Malshakov A N, Martyanov M A, Palashov O V, Poteomkin A K, Sergeev A M, Shaykin A A and Yakovlev I V 2007 *Laser Phys. Lett.* **4** 421

[13] Mourou G and Tajima T 2011 *Science* **331** 41