

Route to 100 TW Ti: Sapphire laser at repetitive mode

Hao Teng¹, Jinglong Ma¹, Zhaohua Wang¹, Yi Zheng¹, Xulei Ge¹, Zhiyi Wei^{1,a},
Yutong Li¹ and Jie Zhang^{1,2}

¹*Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China*

²*Department of Physics, Shanghai Jiaotong University, Shanghai 200240, China*

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

1. INTRODUCTION

With the advent of chirped-pulse amplification (CPA) technique [1], remarkable progress on the development of high peak power laser system on table-top scale is achieved, peak power up to multi-terawatt based on CPA Ti:sapphire laser has been widely realized in many groups in the world. In particular, petawatt laser systems also were demonstrated in some large laboratories, for example, 1.5 PW in 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 33 fs Ti: sapphire laser system was developed in Japan [4]. However, these petawatt-class laser facilities work at very low repetition rate which is limited of few-shot per hour or single shot. More recently, Jae Hee Sung *et al* demonstrated a 1 PW Ti: sapphire laser at 0.1 Hz with multi-stage amplifiers [5], large space and many pump lasers were used to support the laser operation. For a lot of researches on high-intensity laser-matter interaction, it is necessary to accumulate laser shots and improve the signal to noise ratio for experiment [6]. Although we have realized 20 TW laser output at repetition rate of 10 Hz [7], similar laser facilities were also reported by domestic and international groups [8–11], for many applications such as generation of exceedingly short bursts of energetic radiation and particles [12], 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 capable of running at significant repetition rate with economical cost.

In this conference, we report a 100 TW Ti:sapphire laser at 0.1 Hz based on our previous 20 TW femtosecond laser at 10 Hz (XL-II laser facility) by adding a stage of amplifier before the compressor. Pumping the final amplifier by a 527 nm Nd:glass laser at repetition rate of 0.1 Hz and optimizing the compressed pulse duration, an output laser energy up to 3.4 J with pulse duration of 29 fs was obtained, which corresponding to a peak of 117 TW.

2. DESIGN OF BOOSTER AMPLIFIER AND EXPERIMENTAL RESULTS

The “XL-II” laser facility consists of a home-made femtosecond Ti:sapphire laser oscillator, pulse stretcher, a regenerative amplifier, one stage multi-pass amplifier and a vacuum compressor. It was

^ae-mail: zywei@iphy.ac.cn

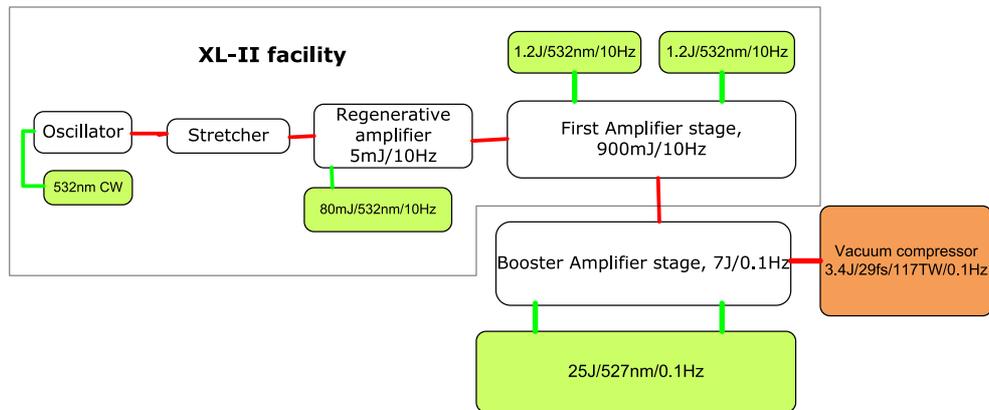


Figure 1. Block diagram of the 117 TW/ 0.1Hz. laser system.

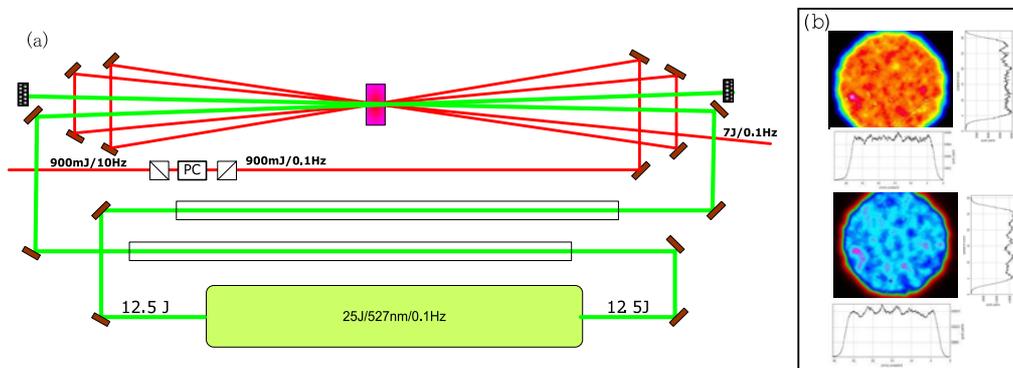


Figure 2. Design of the final booster amplifier (a), spatial profile for the two pump beams (b), which show flat-top spatial distribution.

able to deliver the laser pulses with energy of 600 mJ in 30 fs at repetition rate of 10 Hz, the detail was described in reference [7]. 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 repetition rate of 0.1 Hz (Thales Inc.) is employed for pumping for last amplifier stage, as shown in figure 1. To realize over 100 TW at high repetition rate, some key techniques must be taken in considerations, for example, homogeneous pump scheme, the thermal effect, the gain narrowing effect and to suppress the parasitic lasing etc.

To achieve good beam quality of compressed beam and improve the extracting efficiency, the homogeneous pump scheme is very important. Two independent oscillators with multimode spatial profile are employed in this pump laser. After combination of these two beams into one beam by thin film polarizer, and injected into two independent amplifiers, by accurately compensating for thermally induced birefringence, spatial modulators in amplifier modules, the near field of beams output from the pump laser are flat-top distribution in spatial domain. By image relay scheme through vacuum tube, this near field beam pattern with flat-top distribution is imaged and expanded to 30 mm in diameter on the Ti:sapphire crystal with diameter of 35 mm to produce homogeneous pump, which ensures the amplified beam quality and improves the efficiency. The design of booster amplifier is shown in figure 2.

To suppress the parasitic lasing in larger diameter crystal, a polymer thermoplastic material is cladded around the Ti:sapphire crystal to absorb the reflection at the Ti:sapphire interface.

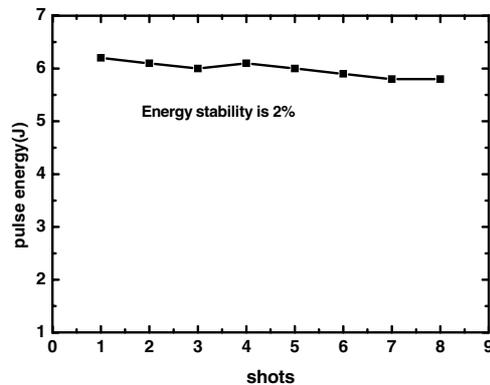


Figure 3. Output energy of booster amplifier pumped with energy of 21 J.

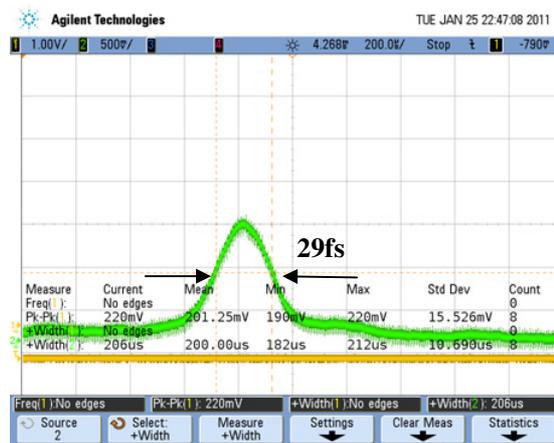


Figure 4. Single shot autocorrelation trace of compressed pulse, which show the pulse duration is 29 fs by calibration.

To compensate the gain narrowing effect and support more bandwidth spectra, a gain notch filter is employed into the regenerative amplifier, with accurately tuning the angle in the beam path of regenerative cavity, the gain narrowing effect will be compensated. The spectrum bandwidth will be enlarged to 32 nm by inserting gain filter, compared to the 22 nm without gain filter. It was demonstrated that the gain narrowing effect will be reduced especially in the last booster amplifier stage and support much wider spectral bandwidth.

A Pockels cell with 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 this pockels cell and synchronized to the pump laser for the last stage. With fine synchronization and optimized alignment between pump and chirped laser pulse, we obtained amplified pulse with energy of 6 J under pump energy of 21 J, which corresponds to an extract efficiency of 28%. The shot-to-shot energy stability is about 2%, as shown in figure 3.

The amplified laser is enlarged to 80 mm in diameter by a telescope, and injected into the vacuum compressor. After optimized dispersion compensation, we measured the compressed pulse with a commercial single-shot autocorrelator (Coherent Inc.), as shown in figure 4. By calibration and assuming Sech^2 -shape temporal profile, the calculated pulse duration is 29 fs. The energy is about 3.4 J after the

compressor, corresponding to a peak power of 117 TW. The contrast ratio is around $10^{6\sim 7}$ at 1 ns time scale, which was measured by a photodiode with picosecond resolution. 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 the contrast ratio from last stage will be improved to more than 10^9 .

3. SUMMARY

In summary, based on our previous 20 TW laser (XL-II laser facility), a booster main amplifier was constructed, which is pumped by a green laser with energy of 25 J at 0.1 Hz. By suppressing the parasitic lasing in Ti: sapphire crystal and employing a homogenous pumping scheme, the amplified energy is boosted to 6 J before compressor under the pump energy of 21 J, corresponding to an extract efficiency is 28%. By accurately compensating dispersion between the stretcher, amplifier and compressor, and suppressing gain narrowing effect in the regenerative amplifier to get more broader bandwidth, the compressed pulses is as short as 29 fs with energy of 3.4 J, which corresponds to peak power of 117 TW. The energy stability is 3%. The laser will pave a way to carry out high field experimental studies at relativistic regime that require repetition rate.

Author thanks for financial support of the National Key Technology R&D Program of the Ministry of Science and Technology under Grant No. 2012BAC23B03, the National Natural Science Foundation of China under Grant No. 11074298 and No.9112608, the National Basic Research Program of China (973 Program) (No. 2007CB815104), the Instrument Developing Project of the Chinese Academy of Sciences Grant No. 2010004.

References

- [1] D. Strickland and G. Mourou, *Opt. Commun.* **56**, 219 (1985)
- [2] M. D. Perry, D. Pennington, B. C. Stuart, G. Tietbohl, J. A. Britten, C. Brown, S. Herman, B. Golick, M. Kartz, J. Miller, H. T. Powell, M. Vergino, and V. Yanovsky, *Opt. Lett.* **24**, 160 (1999)
- [3] Erhard Gaul, M. Martinez, J. Blakeney, A. Jochmann, M. Ringuette, D. Hammond, R. Escamilla, W. Henderson, T. Borger, T. Ditmire, International Conference on Ultrahigh Intensity Lasers-2008, Oct 27–31, 2008, Tongli, China
- [4] M. Aoyama, K. Yamakawa, Y. Akahane, J. Ma, N. Inoue, H. Ueda, and H. Kiriyama, *Opt. Lett.* **28**, 1594 (2003)
- [5] Jae Hee Sung, Seong Ku Lee, Tae Jun Yu, Tae Moon Jeong, and Jongmin Lee, *Opt. Lett.* **35**, 3021 (2010)
- [6] G. Mourou, T. Tajima, S. V. Bulanov, *Rev. Mod. Phys.* **78**, 309 (2006)
- [7] Z.Y. Wei, Z.H. Wang, W.J. Ling, P. Wang, J. Zhang, M. Suzuki, H. Kuroda, X-Ray Lasers 2004, *Inst. Phys. Conf.Ser.No.* **186**, 685 (2004)
- [8] H.S. Peng, W.Y. Zhang, *Journal of the Korean Physical Society* **49**, 305 (2006)
- [9] XY Liang, YX Leng, LH Lin, HH Lu, WY Wang, YH Jiang, B Shuai, HL Peng, BZ Zhao, C Wang, WQ Zhang, ZQ Zhang, RX Li, ZZ Xu, *Opt and Lasers in Engineering* **44**, 1302006 (2006)
- [10] Z.Y. Wei, Z.H. Wang, P. Wang, W.J. Ling, J.F. Zhu, H.N. Han, and J. Zhang, The fifth International Conference on Inertial Fusion Sciences and Applications (IFSA2007), *Journal of Physics: Conference Series* **112**, 032003 (2008)
- [11] V.V. Lozhkarev, G. I. Freidman, V. N. Ginzburg, E. V. Katin, E. A. Khazanov, A. V. Kirsanov, G. A. Luchinin, A. N. Mal'shakov, M. A. Martyanov, O. V. Palashov, A.K. Poteomkin, A.M. Sergeev, A.A. Shaykin, I.V. Yakovlev, *Laser Phys. Lett.* **4**, 421 (2007)
- [12] G. Mourou, T. Tajima, *Science* **331**, 41 (2011)