Ultra-intensity 4 PW laser and its applications

Seong Ku Lee [a,b*], Jae Hee Sung [a,b], Hwang Woon Lee [a], Jin Woo Yoon [a,b], Je Yoon Yoo [a], and Chang Hee Nam [a,c]

[a]*Center for Relativistic Laser Science, Institute for Basic Science, Gwangju 61005, Korea*
[b]*Ultraintense Laser Laboratory, Advanced Photonics Research Institute, GIST, Gwangju 61005, Korea*
[c]*Department of Physics and Photon Science, GIST, Gwangju 61005, Korea*
lsk@gist.ac.kr

1. Introduction

Ultra-high intensity lasers based on a chirped-pulse amplification (CPA) technique provide great opportunities to explore laser-matter interactions in a new regime. Currently, the multi-PW lasers have been constructed or planed from several research projects, accelerating the research on laser-matter interactions [1-3]. The Center for Relativistic Laser Science (CoReLS) of Institute for Basic Science (IBS) has developed PW lasers [4, 5] and explored laser-matter interactions [6, 7]. In this talk, 4 PW upgrade and application plan at CoReLS is presented.

2. Ultra-intensity PW laser

The upgrade of the 4 PW laser has been made by increasing the pulse energy of the current 1.5-PW laser [5], while decreasing the pulse duration. All laser parameters were calculated and optimized using a newly developed laser simulator. Figure 1 shows the block schematic diagram of the 4 PW laser. Red-line blocks represent the four parts to be added or modified in the 1.5 PW beamline for the 4 PW upgrade.

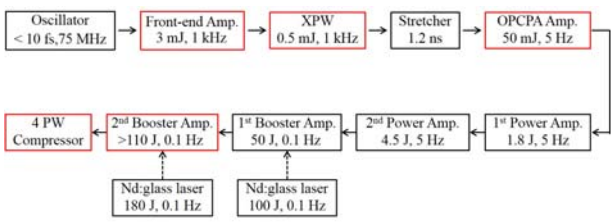
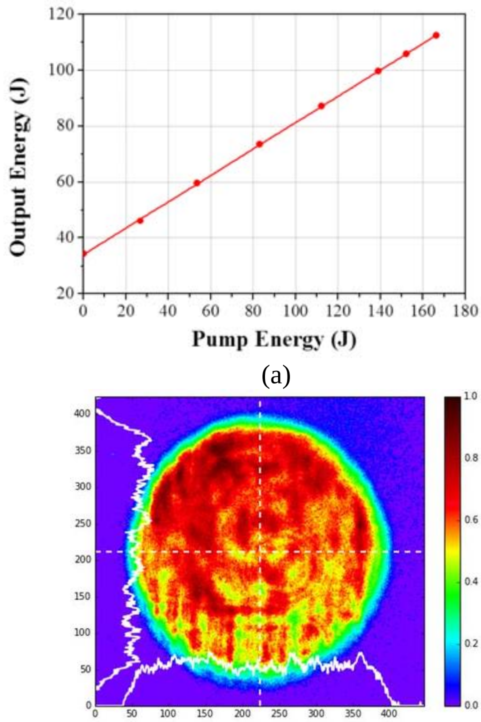


Fig. 1. Block schematic diagram of a 0.1-Hz 4.2-PW Ti:sapphire laser

Firstly, an 1 mJ front-end was replaced with a 3 mJ laser for the stable generation of a high contrast and broadband seed pulse with > 400-uJ energy from Cross polarized Wave (XPW) stage. The XPW technique was employed to enhance the temporal contrast ratio and broaden the spectral width.

Secondly, the Optical Parametric Chirped Pulse Amplifier (OPCPA) was installed instead of the previous a Ti:sapphire pre-amplifier to maintain the broad spectrum width of 120 nm. The 4 PW laser was designed to produce the short pulse duration below 20 fs. This pulse duration has not been achieved yet in the multi-PW lasers because the laser spectrum becomes seriously narrow due to the strong gain depletion and gain narrowing as the number of the amplifier increases. The gain depletion effect is especially strong in the high energy amplifier due to the high extraction efficiency. To avoid the spectrum narrowing by the gain depletion, the spectrum modulation of the seed pulse is required. The spectrum modulation with the Acousto-Optic Programmable Dispersive Filters (AOPDF) is however limited to overcome the whole gain depletion effect from the amplifiers. The OPCPA technique was thus used to shape the spectrum of the seed beam.



(a)

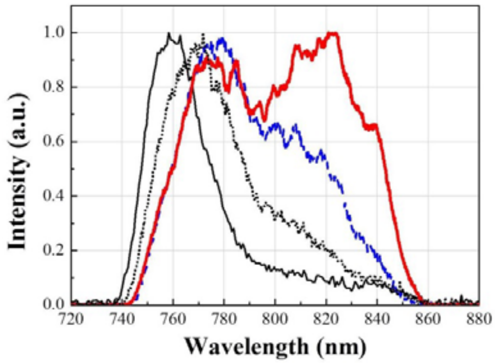
(b)

Fig. 2. (a) Output energy versus the pump energy and (b) beam profile in the final booster amplifier.

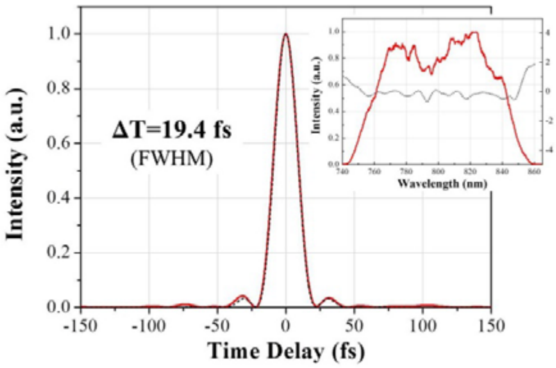
Thirdly, a new booster amplifier was established after the 1.5 PW amplifier. The six Nd:glass pump lasers with the 0.1 Hz rep. rate were installed to deliver the 180 J energy to the Ti:sapphire crystal. Figure 2 (a) and (b) shows the output energy and the beam profile in the final booster amplifier, respectively. The laser pulse was amplified to the energy of 112 J, giving an amplification efficiency of 47%.

Finally, a compressor chamber was modified and new large gratings were installed to compress a 30 cm dia. laser beam temporally. Figure 3 (a) and (b) shows the spectra of amplifiers and the temporal pulse profile.

Consequently 4.2 PW laser pulses with 19.4 fs duration and 83-J energy were generated at 0.1-Hz repetition rate.



(a)



(b)

Fig. 3. (a) Output spectra of amplifiers Laser spectra after the OPCPA amplifier (thin solid line), the 2nd power amplifier (dotted line), the 1st booster amplifier (dashed line), and the 2nd booster amplifier (thick solid line). (b) Reconstructed temporal profile of the 4.2 PW laser pulse.

The wavefront of the laser pulse was corrected with two adaptive optics (AO) systems before and after the pulse compressor. Each AO system is composed of a wavefront sensor, a deformable mirror (DM), and a feedback loop software. The first DM with the diameter of 100 mm was installed between the final booster amplifier and the final beam expander. After the wavefront correction, the rms value for the residual wavefront aberration was less than 0.04 µm. The second large aperture DM with the diameter of 320 mm was installed after the pulse compressor. From the preliminary wavefront correction using both AO systems, the energy concentration over 60% inside the Airy disk was achieved

3. Applications

The 4.2-PW laser is commissioning now. After the beam parameters are optimized and characterized, the laser wakefield electron acceleration (LWFA) toward 10 GeV will be firstly carried out, followed by the nonlinear Compton scattering experiments using both 1-PW and 4.2-PW beamlines. We will also pursue to achieve the laser intensity I >10^{22} W/cm^2, giving users the opportunities to explore relativistic laser-matter interactions in a new regime. And then the proton energy scaling of radiation pressure acceleration, being one of a promising way to enhance ion energy, will be explored in the intensity region of > 10^{22}W/cm^2.

3. Conclusion

We developed a high-contrast 4.2-PW Ti:sapphire laser with a 0.1-Hz repetition rate. To achieve the 4.2-PW peak power, a high energy booster amplifier was added while adopting XPW and OPCPA techniques in the frontend to broaden the spectral width of the seed laser pulse to amplifiers. The final spectral width was maximized by modulating the OPCPA output spectral amplitude for the compensation of the gain depletion effect during amplification. Furthermore, the final spectral phase was optimized with the AOPDF, resulting in 19.4-fs duration, which is the shortest duration in multi-PW Ti:sapphire lasers to the best of our knowledge. The experimental campaigns in the unprecedented intensity regime will be carried out using the 4.2 PW laser.

REFERENCES

[1] http://www.eli-beams.eu/science/lasers/.
[2] J.P. Zou, C. Le Blanc, D.N. Papadopoulos, G. Chériaux, P. Georges, G. Mennerat, F. Druon, L. Lecherbourg, A. Pellegrina, P. Ramirez, F. Giambruno, A. Fréneaux, F. Leconte, D. Badarau, J.M. Boudenne, D. Fournet, T. Valloton, J.L. Paillard, J.L.Veray, M. Pina, P. Monot, J.P. Chambaret, P. Martin, F. Mathieu, P. Audebert and F. Amiranoff, "Design and current progress of the Apollon 10 PW project," High Power Laser Science and Engineering, 3, e2 (2015).
[3] Y. Chu, Z. Gan, X. Liang, L. Yu, X. Lu, C. Wang, X. Wang, L. Xu, H. Lu, D. Yin, Y. Leng, R. Li, and Z. Xu, "High-energy large-aperture Ti:sapphire amplifier for 5 PW laser pulses," Opt. Lett. **40**, 5011-5014 (2015).
[4] Jae Hee Sung, Seong Ku Lee, Tae Jun Yu, Tae Moon Jeong, and Jongmin Lee, "0.1 Hz 1.0 PW Ti:sapphire laser," Opt. Lett. **35**, 3012-3023 (2010).
[5] T. J. Yu, S. K. Lee, J. H. Sung, J. W. Yoon, T. M. Jeong, and J. Lee, "Generation of high-contrast 30 fs 1.5 PW laser pulses from chirped-pulse amplification Ti:sapphire laser," Opt. Express **20**, 10807-10815 (2012).
[6] H. T. Kim, K. H. Pae, H. J. Cha, I J. Kim, T. J. Yu, J. H. Sung, S. K. Lee, T. M. Jeong, and J. Lee, "Enhancement of electron energy to multi-GeV regime by a dual-stage laser-wakefield accelerator pumped by petawatt laser pulses," Phys. Rev. Lett. **111**, 165002 (2013).
[7] I J. Kim, K. H. Pae, C. M. Kim, H. T. Kim, J. H. Sung, S. K. Lee, T. J. Yu, I. W. Choi, C. Lee, K. H. Nam, P. V. Nickles, T. M. Jeong, and J. Lee, "Transition of proton energy scaling using ultrathin target irradiated by linearly polarized femtosecond laser pulses," Phys. Rev. Lett. **111**, 165003 (2013)