LASER WAKEFIELD ACCELERATION EXPERIMENT AT KERI*

G. H. Kim, C. Kim, J. U. Kim, H. J. Lee, H. Suk
Center for Advanced Accelerators, Korea Electrotechnology Research Institute (KERI),
Changwon 641-120, Republic of Korea

Abstract

Laser wakefield have been well-known as a method to accelerate particles, including electrons, ions, and even photons. At KERI in Korea, a TW Ti:sapphire/Nd:glass hybrid laser system is established recently. In this paper, the performance of the TW laser system will be presented. And the experimental topics scheduled at KERI will be presented.

1 INTRODUCTION

The studies on intense laser-plasma interactions have been an interesting research subject after the development of the CPA (chirped pulse amplification) technology [1]. Multi-TW laser pulse can be focused to intensities of $I \geq 10^{18}$ W/cm^2, that is strong enough to cause nonlinearity in even unbound (free) electrons. Acceleration of electrons by a plasma wakefield showed the possibility of application to small-scale accelerators because the acceleration gradient of a plasma wakefield is much larger by three or four orders of magnitede than that of conventional RF linacs. Several methods to generate ultra-high field were proposed, including the plasma wakefield accelerator, the plasma beam-wave accelerator (PBWA), the laser wakefield accelerator (LWFA), and the self-modulated laser wakefield accelerator (SM-LWFA) and so on [2]. With the development of the laser technology LWFA and SM-LWFA attract much attention.

All-optical acceleration schemes with self-injection of electrons becomes an important issue since it does not need any external accelerator or lasers for electron injection and we need not to worry about timing problems [3-5]. Recently Suk *et al* proposed a new self-injection scheme that background plasma electrons are self-injected and trapped by a plasma wakefield when an electron beam passes through an underdense plasma with a sharp downward density transition [5]. Similar results were observed in the 2-D PIC simulations with the OSIRIS code when an electron beam is replaced by an intense laser pulse [6]. We are going to verify this scheme experimentally. As a preliminary step, in this paper, we report the installation of TW laser system at KERI, Korea. In Sec. 2, the TW laser system is described in detail. Future experiment plans will be presented in Sec. 3.

2 TW LASER SYSTEM

Figure 1 and 2 are the picture and layout of the TW laser system of Ti:sapphire/Nd:glass hybrid type installed in KERI, respectively. According to CPA technology, the system consists of four parts mainly: oscillator, stretcher, amplifier, and compressor. A diode-pumped solid-state Nd:glass laser (model GLX-200) is used as oscillator. Figure 3 shows the performance of the TW laser system at each step, including the pulse energy, pulse repetition rate, pulse temporal width, pulse spectral width and average power. The laser produce a train of mode-locked, transform-limited femtosecond pulses at the center wavelengths ranging from1050 nm to 1070 nm. To achieve rock-solid ultrafast pulses, the laser relies on diode pumping of the laser crystal and the use of a semiconductor saturable absorber mirror (SESAM) to start and stabilize the pulse-forming process. A beam cutter is used to tune the center wavelength of the laser and is fixed to the wavelength of 1054 nm with the average power of 220 mW (equal to the pulse energy of 3 nJ) and pulse repetition rate of 76 MHz. In a pulse stretcher, the input beam is incident on a single diffraction grating that is multi-passed to reduce complexity. And the beam passes the grating four-times to ensure that the stretched laser beam is spatially reconstructed. The pulse is stretched to 1.4 ns.

The amplifier system consists of two parts depending on the laser crystals: a regenerative amplifier using a Ti:sapphire laser rod and multi-step linear amplifier using

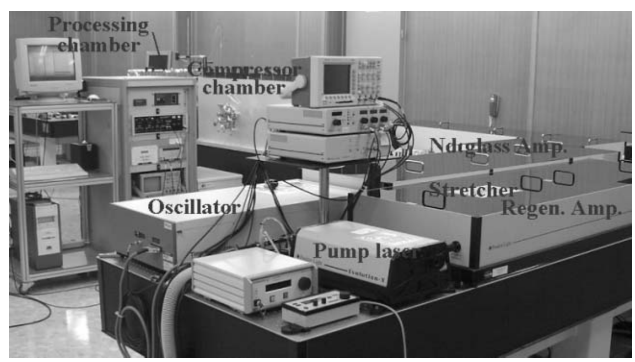
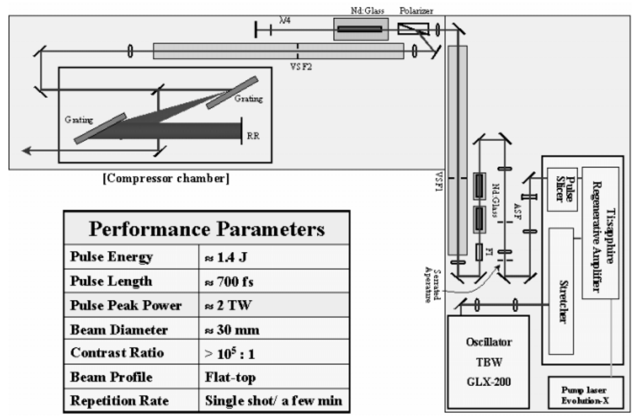
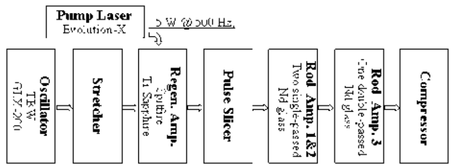


Figure 1: TW laser system at KERI



Performance Parameters	
Pulse Energy	≈ 1.4 J
Pulse Length	≈ 700 fs
Pulse Peak Power	≈ 2 TW
Beam Diameter	≈ 30 mm
Contrast Ratio	> 10^5 : 1
Beam Profile	Flat-top
Repetition Rate	Single shot/ a few min

Figure 2: Layout of TW laser system at KERI



Pulse Energy	3 nJ	-	-	0.4 mJ	24 mJ	2 J	1.4 J
Pulse Repetition Rate	76 MHz	76 MHz	500 Hz	500 Hz	single	single	single
Pulse Temporal Width	~350 fs	-	-	1.4 ns	-	-	700 fs
Pulse Spectral Width	4.7 nm	-	Unseeded:9.7 nm Seeded: 4.1 nm		-	-	-
Average Power	220 mW	-	-	200 mW	-	-	-

Figure 3: Performance of TW laser system

Nd:glass laser rods. Optical excitation of the regenerative amplifier is achieved by pumping with a frequency doubled Q-switched Nd:YLF laser with the pulse repetition of 500 Hz and pulse energy of 10 mJ at the wavelength of 527 nm. After a number of round trips, the pulse is ejected by activating Pockels cells with the pulse repetition rate of 500 Hz and pulse energy of 0.4 mJ (gain $> 10^5$). A synchronization and delay generator is used between the mode-locked oscillator and the regenerative amplifier in order to fire Pockels cells in the regenerative amplifier and the pulse slicer. The generator also serves as a protection device to the amplifier system by disabling the triggers to the Pockels cells in the event that the spectrum collapses due to failure of the mode-locked laser or clipping of the spectrum by adapting the bandwidth detection.

At any individual amplifier stage, the maximum energy is limited by the damage threshold of the optical elements. In order to extract the maximum possible energy, it is desirable to fill the rod with the laser beam in case of side pumping. But, diffraction can cause rings and strong intensity modulation (hot spots in some cases) that can cause optical damage. So, before sending to Nd:glass amplifiers, the beam is incident on the serrated aperture with the inner diameter of 3.5 mm and outer diameter of 4.0 mm to cut the edge part of a Gaussian beam. The beam size at the serrated aperture is adjusted to produce a spatial profile that compensates for the radial gain profile of the Nd:glass rods in the linear amplifiers. This insures a flat-top profile at the output of the laser system.

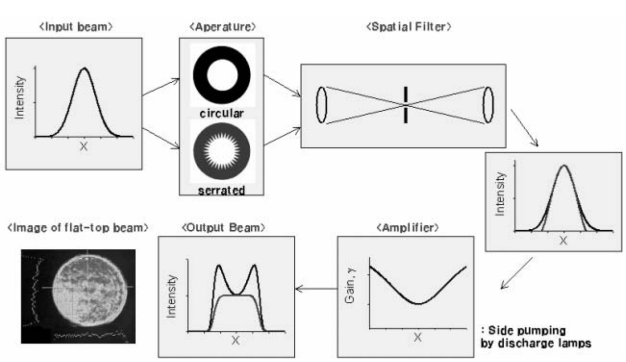


Figure 4: Relay imaging in Nd:glass amplifiers

Figure 4 shows the principle of this relay imaging technique in rod amplifier system. There is some energy loss at the serrated aperture due to the clipping. This is not a problem because there is sufficient gain in the amplifiers to make up for this loss. Following the serrated aperture the beam is transmitted through a spatial filter with the pinhole of 10 times the diffraction limit of the focused spot size, where the overall flat-top bema profile will be retained. However, any high spatial frequencies from the aperture, or from diffraction rings in the beam, are filtered. Then, the beam is transmitted through two laser rods as a pair in series with the dimensions of 9.5 mm × 115 mm and single-passed. The gain of two rods is around 100 when pumped at ~2.5kV. Each rod is pumped by four discharge lamps with the maximum pump energy of 500 J. Following the 9.5 mm amplifiers there is a Faraday isolator. A vacuum spatial filter is used to relay the first image located after the second 9.5 mm amplifier to the next image plane located just after the 1” amplifier double pass. The pulse energy after this vacuum spatial filter is 24 mJ. The vacuum system for this and another vacuum spatial filter in the system is a dry type scroll pump capable of pumping down to ~300 mTorr. The final double-pass laser rod has the dimensions of 25.4 mm × 304.8 mm and produces a gain of ~80 when pumped at ~7kV. The rod is pumped by eight discharge lamps with the maximum energy of 12 kJ. Another vacuum spatial filter is used to relay the second image plane just after the 25.4 mm amplifier to the first grating in the compressor chamber. The pinhole size is approximately 10 times diffraction limited at 1.2 mm diameter. The beam is expanded to the diameter of 30 mm after the vacuum spatial filters to limit the beam energy to 125 mJ/cm^2 that is lower than the damage threshold of the compressor gratings of 250 mJ/cm^2. Finally the beam is transmitted to the compressor chamber. Compressor consists of two diffraction gratings (1740 lines/mm) and one retro-reflecting mirror assembly. It is designed to compress pulses from the Nd:glass amplifier chain to 700 fs with the efficiency of 70 %. Compressor is placed inside a vacuum chamber with the dimensions of 60”×27”×20”. Figure 5 shows the autocorrelation measurement of the compressed pulse with the pulse width of 700 fs.

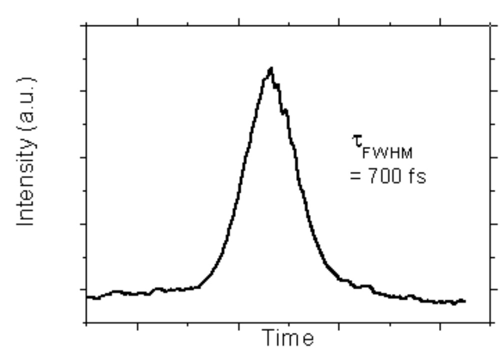


Figure 5: Autocorrelation measurement

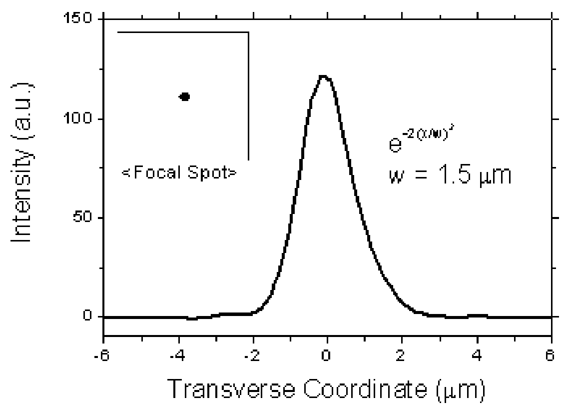


Figure 6: Focal spot measurement.

And then, the beam is transmitted to the interaction chamber that is coupled with the compressor chamber to study the laser-plasma interactions. The beam is focused to a focal spot just above a gas nozzle using an off-axis parabolic mirror. An energy analyser to obtain energy distribution of accelerated electron beam is installed inside the interaction chamber. The charge of the electron beam is measured with the ICT beam charge monitor (Bergoz).

All required electronics to synchronize lasers, operate and fire laser amplifiers, and provide the laser cooling are contained in the 19" rack.

3 FUTURE EXPERIMENT PLAN

Before main experiments, we checked the beam quality of focused beam using an off-axis parabolic mirror with the focal length of 50 mm. An objective lens with the magnification of 60 times was used. In order to avoid the damage of the objective lens the pulse energy was attenuated with anti-reflecting mirrors and neutral density filters. Figure 6 shows the beam profile of focal spot and the inset shows the two-dimensional image of focal spot. It shows that the beam quality of focal spot is very good with the beam diameter of 3 μm.

We are now considering two approaches to achieve local density transition to verify Suk's self-injection scheme [6]. One is the density transition produced using thin wires. Characterization of density distribution after a thin wire above the gas nozzle is under study using an interferometer. The other is the density transition at the boundary of plasma channel. This will be discussed in details in another paper [7].

4 SUMMARY

TW laser system of Ti:sapphire/Nd:glass hybrid type is installed at KERI successfully. TW laser pulses are with the pulse energy of 1.4 J, pulse length of 700 fs, and then the peak power is 2 TW. Experiments of the particle acceleration are scheduled on various scheme, e.g. gas jet with density transition and so on.

REFERENCES

[1] T. Tajima and J. M. Dawson, Phys. Rev. Lett. **43**, 267 (1979).

[2] E. Esarey, P. Sprangle, J. Krall, and A. Ting, IEEE Trans. Plasma Sci. **24**, 252 (1996).

[3] S. Bulanov, N. Naumova, F. Pegoraro, and J. Sakai, Phys. Rev. E **58**, R5257 (1998).

[4] K. Nakajima et al., Phys. Rev. Lett. **74**, 4428 (1995).

[5] H. Suk, N. Barov, J. B. Rosezweig, and E. Esarey, Phys. Rev. Lett. **86**, 1011 (2001).

[6] H. Suk, C. Kim, G. H. Kim, J. U. Kim, H. J. Lee, and W. B. Mori, in *Advanced Accelerator Concepts: Tenth Workshop*, AIP Conf. Proc. No. 647 (AIP, New York, 2002), pp. 710-716.

[7] J. U. Kim, C. Kim, G. H. Kim, H. J. Lee, N. Hafz, H. Suk, to be appeared in *Proceedings of the 2003 Particle Accelerator Conference*.