The Texas petawatt laser and current experiments

Mikael Martinez, Woosuk Bang, Gilliss Dyer, Xiaoming Wang, Erhard Gaul, Teddy Borger, Martin Ringuette, Michael Spinks, Hernan Quevedo, Aaron Bernstein, Michael Donovan, and Todd Ditmire

Citation: AIP Conference Proceedings **1507**, 874 (2012); doi: 10.1063/1.4773814
View online: http://dx.doi.org/10.1063/1.4773814
View Table of Contents: http://scitation.aip.org/content/aip/proceeding/aipcp/1507?ver=pdfcov
Published by the AIP Publishing

The Texas Petawatt Laser and Current Experiments

Mikael Martinez[a], Woosuk Bang[a], Gilliss Dyer[a], Xiaoming Wang[b] Erhard Gaul[a], Teddy Borger[a], Martin Ringuette[a], Michael Spinks[a], Hernan Quevedo[a], Aaron Bernstein[a], Michael Donovan[a] and Todd Ditmire[a]

[a]*Center for High Energy Density Science, The University of Texas at Austin 1 University Station Austin, TX 78712*
[b]*Laser Plasma Acceleration Group, Department of Physics, The University of Texas at Austin 1 University Station Austin, TX 78712*

Abstract. The Texas Petawatt Laser is operational with experimental campaigns executed in both F/40 and F3 target chambers. Recent improvements have resulted in intensities of >2x10^{21} W/cm^2 on target. Experimental highlights include, accelerated electron energies of >2 GeV, DD fusion ion temperatures >25 keV and isochorically heated solids to 10-50 eV.

Keywords: OPCPA, Mixed Nd:glass, Petawatt, laser-cluster fusion, neutron source, laser wakefield acceleration, warm dense matter, and isochoric heating.
PACS: 42.2.Eq, 42.65.Rc, Ky, 42.70.Hj, Mp, 29.25.Dz, 52.50.Jm, and 25.45. -Z, 36.40.Gk 52.38.Kd, 52.38.Hb

FACILITY DESCRIPTION

The Texas Petawatt Laser Facility (TPW) is an internationally unique research tool located at the University of Texas at Austin's Center for High Energy Density Science. Research conducted in the facility is primarily centered on the field of High Energy Density Science (HED). The TPW operates year around and supports up to 10 experimental campaigns over 200 days and a total shot count of 1,200 shots. The experimental users are composed of UT Physics Faculty, DOE National Laboratories, US academic institutions and international collaborators. A formal User Program organizes the annual shot calendar. The TPW is designed to deliver a wide range of experimental parameters on target. To accomplish this, the User can choose between either a high intensity (>10^{21} W/cm^2) f/3 target chamber or a long focus f/40 geometry. The laser is capable of delivering 180 J pulses in 170 fs at a center wavelength of 1057 nm. See Figure 1 below for a facility layout.

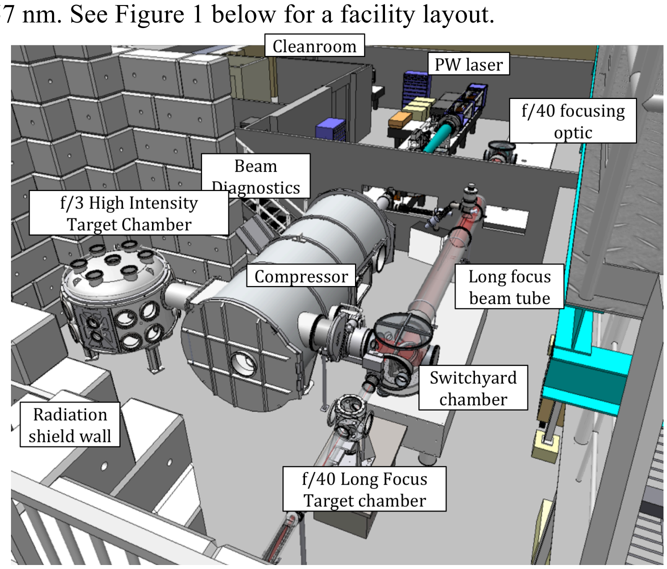


FIGURE 1. The Texas Petawatt Laser Facility provides two experimental chambers to support a wide range of experimental missions.

Advanced Accelerator Concepts
AIP Conf. Proc. 1507, 874-878 (2012); doi: 10.1063/1.4773814

LASER SYSTEM ARCHITECTURE

At 180 J, 170 fs and1 shot/hour, The Texas Petawatt Laser is unique. Typically, petawatt class lasers operate at 30 J, 30 fs, 500 J, 500 fs or 1 kJ, 1 ps [1,2,3]. Currently, however, a whole new class of 10 PW systems are funded and in the design phase [4]. The Texas Petawatt leverages a novel, hybrid approach of Optical Parametric Chirped Pulse Amplification (OPCPA) and mixed Nd:glass amplification [5]. This architecture takes advantage of the high gain (>10^{10}), broad bandwidth (>30 nm) OPCPA as well as the large aperture (>24 cm), high-energy storage, high optical quality characteristics of Nd:glass. Additionally, keeping the net gain in Nd:glass (~400) and using two compositions of Nd:glass (silicate and phosphate), this design mitigates the unwanted effects of gain narrowing. This hybrid approach enables the Texas Petawatt to delivery energies and pulse durations relevant for HED science missions. Figure 2, shown below describes the architecture of the laser system, design parameters of subsystems as well as emission spectra overlap of the mixed Nd:silicate and Nd:phosphate.

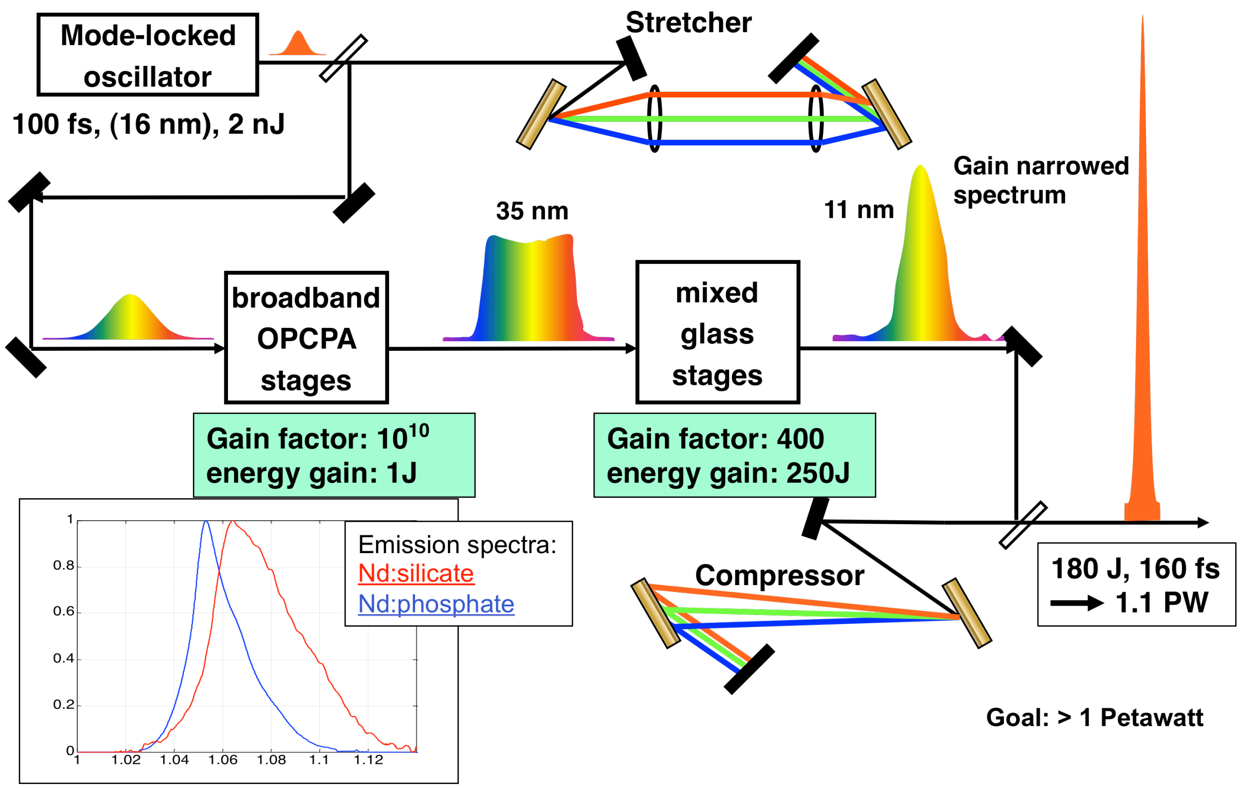
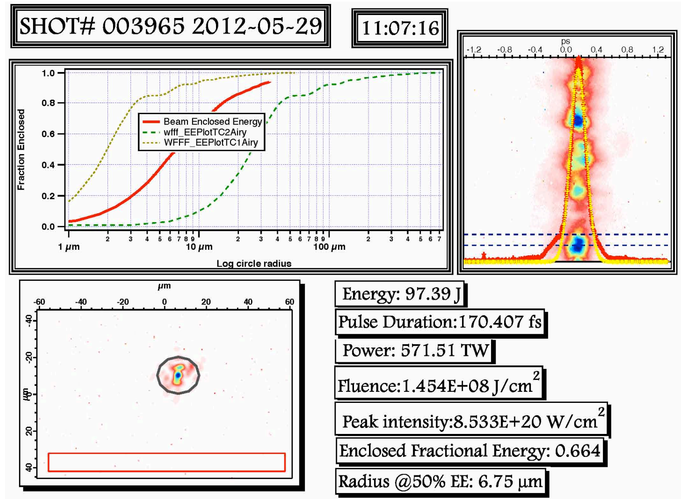


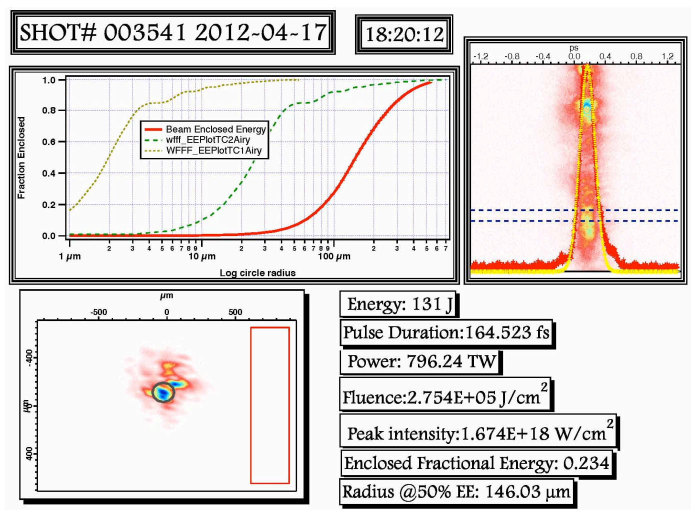
FIGURE 2. The system architecture includes OPCPA, mixed Nd:glass with design performance targets as well as emission spectra of the two Nd:glass compositions used to achieve the bandwidth required to 100 fs pulses.

RECENT LASER SYSTEM PERFORMANCE

Recently, the Texas Petawatt has demonstrated excellent system performance on a number of experimental campaigns. Due to laser damage on the post compression, near normal incidence mirrors, the system has been de-rated to 100 J. Despite the de-rated energy, the system still delivers greater that 1×10^{21} W/cm^2 on 30% or more of the shots in the f/3 target chamber. In the f/40 long focus chamber, the system is delivers 28% of the total energy into a 160 μm spot. Figure 3 shows a shot report that represents the average performance of a shot into the f/3 chamber.



(a)



(b)

FIGURE 3. (a) Shot report representing average laser performance for shots into the f/3 chamber. (b) Shot report representing average laser performance for shots into the f/40 chamber.

TABLE a). This table shows relevant laser parameters taken for 100 shots in the f/3 chamber and 18 shots in the f/40 chamber. Each parameter is measured on every shot.

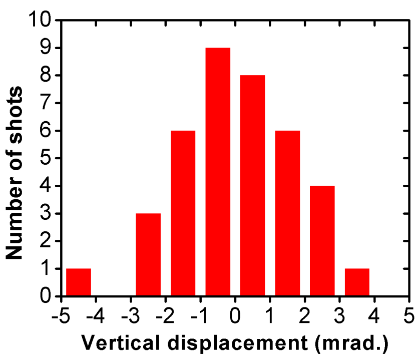
Laser Parameter	f/3 Chamber	f/40 Chamber
Average Energy	97.6 J	132 J
Std. Dev	7.7 J	12 J
Avg. Pulse Duration	167 fs	178 fs
Avg. Enclosed Energy	65 % (10 μm dia.)	28% (160 μm dia.)
Peak Intensity	1.04 x10^{20} W/cm^2 (σ=3.5x10^{20} W/cm^2)	1.04 x10^{18} W/cm^2 (σ=3.5x10^{20} W/cm^2)

RECENT EXPERIMENTAL PROGRESS

The Texas Petawatt facility supports approximately 10 experimental campaigns per year. Each campaign can run from 3-5 weeks with laser maintenance scheduled between runs. Users can submit proposals for consideration to be scheduled. The shot calendar looks 6 – 12 months out. Below are highlights from 3 experiments in 2011-2012.

Laser Wakefield Acceleration

One series of campaigns produced laser wakefield acceleration of quasi monoenergetic electrons to 2.4 GeV in a low electron density ($n_e = 3.3 \times 10^{17}$ cm^{-3}) petawatt driven wakefield and realized electron self-injection at $n_e = 1.0 \times 10^{17}$ cm^{-3} [6]. The self-injected electrons had a low divergence angle less than 0.5 mrad FWHM on individual shots and a pointing stability less than 2.5 mrad. was observed over multiple shots. The electron charge we observed in experiments varied from several tens PC to hundreds PC, which strongly depend on the plasma density and laser power. These experimental results make the single stage, self-injected, multi-GeV electron acceleration with PW lasers at low plasma density ($n_e \sim 10^{17}$ cm^{-3}) very promising.



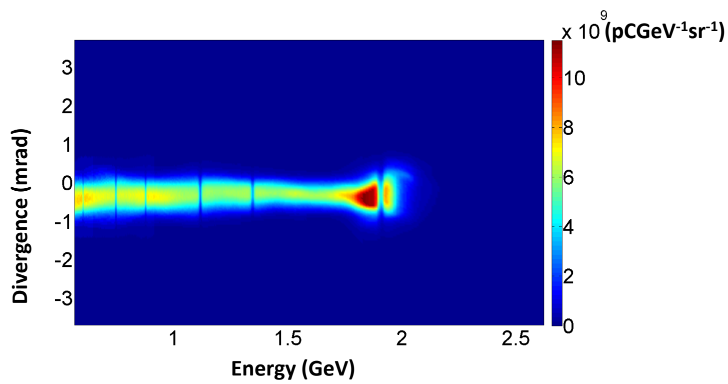


FIGURE 4. (a) Statistical results of the electron beam vertical displacement over multiple system laser shots; (b) Quasi mono energegtic spectrum reaching 2GeV.

Cluster Fusion

In another experimental campaign, we studied interactions of petawatt pulses with two different types of cluster targets: one a mixture of deuterium clusters and ^{3}He gas, and one of deuterated methane clusters and ^{3}He [7]. These interactions produced deuterium ions energetic enough to initiate D-^{3}He nuclear fusion reactions as well as the DD fusion reactions inside the fusion plasma. By comparing the neutron yield from D(D, n)^{3}He reactions with the proton yield from D(^{3}He, p)^{4}He reactions, we successfully measured the ion temperature of fusion plasmas at the time of the fusion reactions. The measurements of ion temperatures with fusion yields were consistent with independently measured ion temperatures from the ion time-of-flight measurements, and the measured temperature of deuterium ions was as high as 25 keV. The following figure illustrates the schematic setup for the mixture cluster fusion experiments along with the relevant fusion reactions.

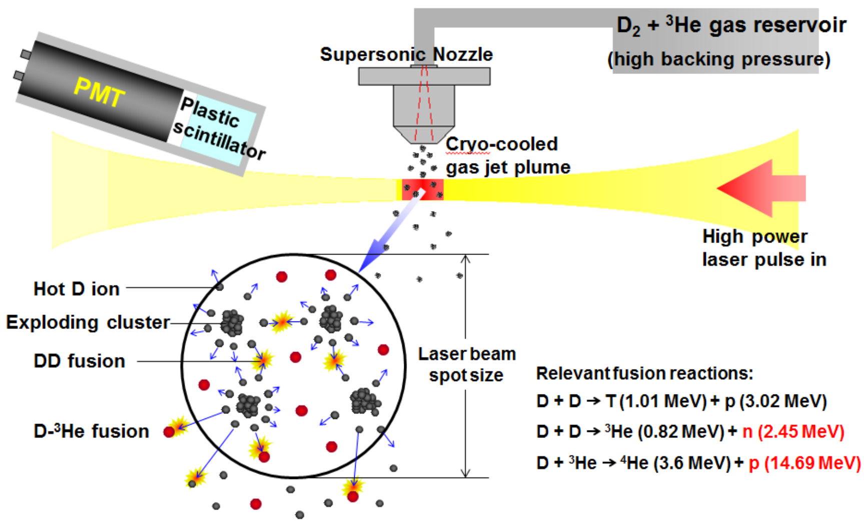


FIGURE 4. Schematic diagram illustrating the laser-cluster interaction.

Warm Dense Matter

Building on earlier proof of principle experiments on other laser systems [8, 9] we have begun a campaign to study the equation of state (EOS) properties of a number of materials of interest in the temperature and density regime known as warm dense matter (WDM). Using a well-characterized, intense proton beam generated by petawatt laser-solid interaction with a source foil, a secondary sample foil is rapidly heated to temperatures of 1 to 100 eV. The heating is isochoric and ultrafast measurement techniques are used to discern the expansion and temperature of the heated sample. Comparing the expansion rate to the thermal emission and using the measured proton spectrum to estimate the energy density, we produce EOS data for conditions that have scarcely been measured and for which theoretical models are difficult to achieve. We have worked with the EOS group at LLNL to determine materials of interest, leading the initial experiments to focus on transition metals. So far we have made several complete measurements on Cu and Ag WDM states with temperatures of up to 65 eV [10].

REFERENCES

1. J. Sung, S. Lee *et al.*, 0.1 Hz 1.0 PW Ti:sapphire Laser, *Optics Letters* **35**, 3021-3023 (2010).
1. J. Schwartz, P. Rambo, M. Geissel *et al.*, *Journal of Physics:Conference Series* **85**, 032020-24 (2008).
2. L. Waxer, M. Guardalben *et al.*, "The OMEGA EP High-Energy, Short-Pulse Laser System" in *High-Energy Short-Pulse Lasers and Technology (JThB)-2008*, Conference on Lasers and Electro-Optics Technologies San Jose, California.
4. J.P. Chambaret, P. Georges *et al.*, "The Extreme Light Infrastructure Project ELI and Its Prototype APOLLON/ILE: "The Associated Laser Bottlenecks" in *High Peak Power Laser Technology I (FMI)-2009*, Frontiers in Optics (FiO) San Jose, California.
5. E. Gaul, M. Martinez, J. Blakeney *et al.*, Applied Optics, **49**, **9**, p1676 ff, (2010).
6. X. Wang, R. Zgadzai, S. A. Yi *et al.*, Phy. of Plasmas, accepted. (2012).
7. W. Bang, G. Dyer, H. Quevedo *et al.*, Phys. Rev. Lett., in preparation. (2012).
8. G. M. Dyer, A. C. Bernstein, *et al.*, Phys. Rev. Lett. **101**, 15002 (2008).
9. A. Mancic, J. Robiche, P. Antici, P. Audebert, C. Blancard, P. Combis, F. Dorchies, G. Faussurier, S. Fourmaux, M. Harmand, R. Kodama, L. Lancia, *et al.*, High Energy Density Physics **6**, 21 (2010).
10. G.M. Dyer in preparation