

Improved pulse contrast on the Texas Petawatt Laser

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Abstract. We have completed a pulse contrast upgrade on the Texas Petawatt Laser. This improvement enables the use of thin and reduced mass targets for ion acceleration, and reduces pre-plasma effects on all experiments. The new design starts with two BBO-based OPCPA stages pumped by an optically synchronized 8-ps laser. These stages amplify slightly chirped few ps pulses by six orders of magnitude. Next there are two LBO-based OPCPA stages that are pumped by 4 ns pulses. With much less gain than before, parametric fluorescence has been reduced by about three orders of magnitude. Prior to the upgrade, lenses caused pencil beam prepulses. Since tilting or wedging lenses was not a viable option, we replaced all lenses in the glass amplifiers with off-axis parabolic mirrors. There are still weak prepulses that we attribute to surface scattering. We eliminated thin transmissive optics to avoid post pulses that would result in prepulses by nonlinear (B-integral) conversion. This required us to reduce from eight to four passes in the 64-mm glass amplifier and to add a two-pass 25-mm “booster amplifier.” As a final upgrade we added an Acousto-Optic Programmable Dispersive-Filter (AOPDF) to improve higher order dispersion and steepen the rising edge of the compressed pulse.

1. Motivation for improving contrast

The Texas Petawatt Laser [1] is a university research laser used for a variety of experiments that require ultrahigh electromagnetic fields, extreme laser intensities, and extreme temperatures and pressures. The laser facility has two target chambers: Target Chamber 1 (TC1) that uses fast focus optics ($f/3$ and soon $f/1$ off-axis parabolic mirrors) to achieve maximum intensities, generally for solid targets, and Target Chamber 2 (TC2) that has a slower focus $f/40$ mirror most often used for larger volume interactions with gas targets. Both target chambers have been very productive as high energy particle sources. TC1 produced the brightest ultrashort pulsed neutron source yet measured ($>10^{18}$ n/cm²/s in a sub 50-ps pulse) [2]; the highest measured positron-to-electron ratio pair creation in a solid ($\sim 50\%$ in a Pt rod) [3]; and high energy (~ 45 MeV pre-upgrade) proton yields. TC2 has yielded 2×10^7 fusion neutrons from deuterium clusters [4]; high charge (nC), low divergence (sub-mrad), quasi-monoenergetic high energy (2-3 GeV) laser wakefield accelerated electrons [5]; high brightness betatron x-rays [6]; and $\sim 10^4$ muons from wakefield accelerated electrons hitting a tungsten converter.

All of the results mentioned could potentially benefit from higher laser main-pulse to prepulse contrast, and in fact ion acceleration has already shown improvement in initial experiments after the upgrade. For laser interactions with solid targets, sufficiently intense laser prepulses create preformed surface plasma which can affect the nature of the laser-target interaction. In the case of thin or mass-limited targets, which are known to produce the highest ion energies [7], the target may not even survive the prepulse. For protons and neutrons produced by cluster fusion, the yield can be reduced by



a prepulse destroying the clusters. For wakefield acceleration, the impact of a prepulse on the gas cell is unclear and difficult to account for theoretically.

In 2014-2015, the Defense Advanced Research Project Agency funded a year-long Texas Petawatt Laser upgrade to advance the science and technology of neutron generation for radiography and other applications. With better contrast, the expectation was that ions of laser breakout afterburner ion acceleration [8] at higher energies and fluence create more neutrons from a knock-on target.

2. Pre-upgrade prepulse measurement and analysis

Prior to the upgrade, the Texas Petawatt Laser's chirped, broadband, 1054-nm seed was being amplified via three stages of optical parametric chirped pulse amplification (OPCPA) in BBO and YCOB, follow by 8-pass amplification in a 64 mm silicate Nd:glass rod, followed by 4-pass amplification in a 315 mm phosphate Nd:glass slab amplifier. The laser had typically been operated between 100 J and 180 J pulse energies, with pulse duration FWHM of 150-170 fs.

Parametric fluorescence from the parametric amplifiers showed up in the region ± 4 ns from peak signal (Figure 1) as a pedestal, consistent with having a 4-ns OPA pump pulse. Depending on the amount of saturation and gain in a given stage, the amplitude of the prepulse pedestal could vary, and data to that effect is shown later for the post-upgrade performance. It is important to realize that the OPCPA fluorescence pedestal is not chirped and will not compress—thus the intensity contrast is four orders of magnitude better than the energy contrast seen in the photodiode measurement.

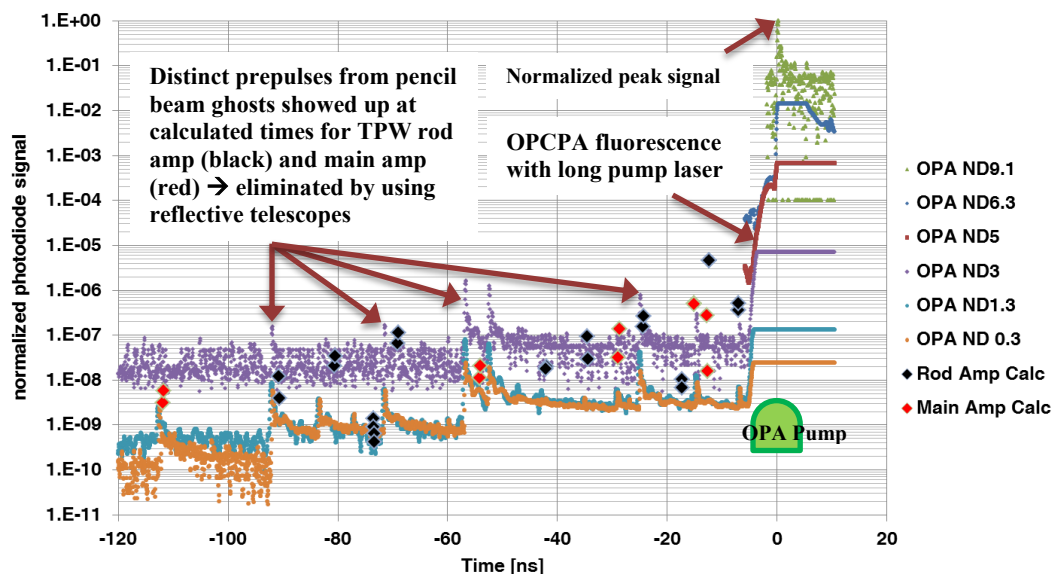


Figure 1. Laser pulse energy versus time as measured by a photodiode placed after the target chamber focus. This measurement was taken with various neutral density filters to get the needed dynamic range. Calculated prepulse arrival time and energy (diamonds) is consistent with the measurement.

The photodiode measurements of Figure 1 show discrete prepulses between the OPCPA fluorescence pedestal (-4 ns) and about -112 ns. These include the prepulses that come from multiple reflections in optics that produce ghost foci and pencil beams [9]. We have calculated the expected arrival time and amplitude of pencil beam prepulses, and can with good accuracy attribute the measured prepulses to a distinct set of reflections. Since the pencil beams are not relay imaged to the target, they will not focus at the target and will have better intensity contrast than the measured energy contrast.

Discrete prepulses can also arise from diffuse surface scattering at just the right location to propagate forward along the beam path; this prepulse source is uncorrected and we believe it to be the source of remaining prepulses. Unlike the main pulse, such a prepulse would fill the aperture of the downstream spatial filters, and thus would have better (higher) intensity contrast than energy contrast.

3. Nanosecond prepulse suppression

To eliminate lenses as a source of prepulses, we replaced all of the lenses beyond the OPCPA stages with off-axis parabolic (OAP) mirrors (Figure 2). Tilting or wedging lenses is not possible in a broadband short pulse system because of unacceptable chromatic aberration and wavefront errors. Removing the relay lens in the 315-mm power amplifier presented some geometrical challenges. We ended up using a 45° OAP reflecting vertically onto a fold mirror in a periscope configuration, which sent the laser pulse into a raised set of horizontal amplifier heads. The vacuum window leading into the main amplifier was optimized in tilt angle and thickness to avoid secondary reflections. We carefully designed mounts as the mirrors are less forgiving of pointing errors than lenses.

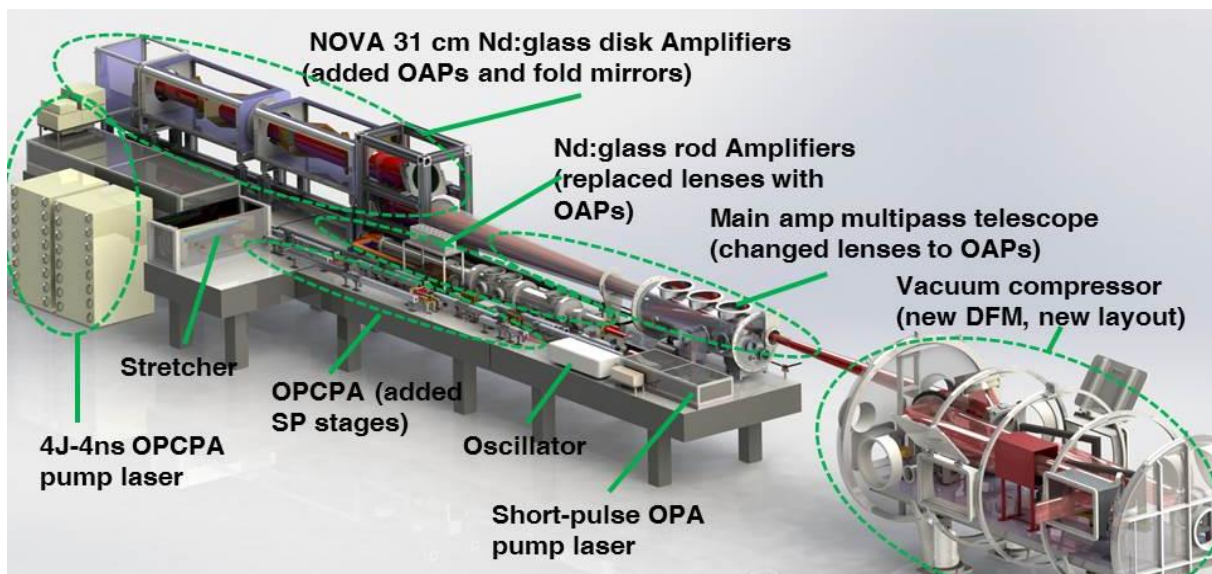


Figure 2. Rendering of the Texas Petawatt Laser upgrades.

4. Sub-nanosecond prepulse pedestal suppression

From -4ns until peak pulse energy we have at issue the parametric fluorescence pedestal and higher order (typically 4th order) uncompensated dispersion. In past experiments amplified spontaneous emission from both glass amplifiers had no effect on 400 nm thick targets and seemed negligible.

We addressed the fluorescence pedestal by implementing two “short-pulse OPCPA” stages using design principles described in [10]. We achieve a total gain of 10^6 in two BBO crystals each pumped by 5mJ, 8ps, 527nm pulses from an optically synchronized Nd:YLF laser (Ekspla). The amplified 8-ps pulse is then stretched to 4 ns and amplified in two LBO-based OPCPA stages. The net result is that the first two OPCPA stages only contribute to a pedestal within 8 ps of the main pulse arrival, and with a stronger seed, the 4-ns OPCPA gain and fluorescence are reduced by three orders of magnitude.

To correct higher order dispersion and steepen the rising edge of the pulse, we added an AOPDF (Dazzler from Fastlite) in the laser chain acting both as a picosecond stretcher and to pre-compensate for the residual spectral phase errors after the final pulse compression. The oscillator pulse is stretched by the AOPDF to approximately 2 ps by adding 60,000 fs² dispersion to the pulse. The fine-tuning of the compression at the end of the laser chain is done employing a closed loop between the AOPDF and a self-referring spectral interferometer (Wizzler-1030 from Fastlite) resolving the spectral phase. To minimize postpulses and nonlinear conversion to prepulses we eliminated all waveplates, minimized all double reflections in transmissive optics and added a booster rod amplifier to compensate the gain.

5. Contrast measurements on the upgraded Texas Petawatt Laser

Photodiode measurements show prepulses at -85 ns and -38.5 ns, which correspond to the round trip times in the main amplifier and rod amplifier, respectively (Figure 3). We believe these prepulses to be due to scattering into the spatial filter pinholes at angles that propagate through the system.

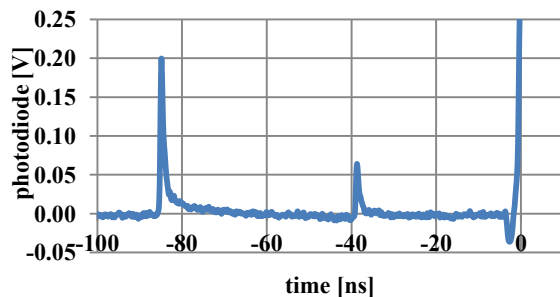


Figure 3. Measured pulse energy at target chamber focus from the upgraded laser as a function of time. The energy contrast is 3×10^8 for the -85 ns pulse. The noise floor is better than 10^{11} , and no other prepulses are evident. The estimated intensity contrast is 10^2 - 10^3 times better than the energy contrast due to different glass dispersion and lack of focusability.

Intensity contrast has been measured with a third-order autocorrelator. Figure 4 shows how the parametric fluorescence pedestal is affected by various levels of OPA saturation, and it shows, not unexpectedly, that the pedestal depends of how hard the crystals are pumped. This set of data was taken prior to optimizing the spectral phase of the laser pulse. Figure 5 shows the final contrast after optimization of the pulse duration, resulting in pedestal contrast of 5×10^8 at hundreds of ps delay, about three orders of magnitude in contrast better than prior to the upgrade.

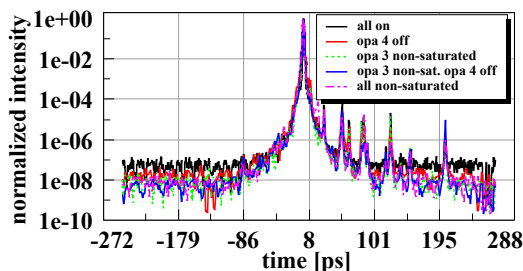


Figure 4. Long pulse OPA saturation affects the pedestal contrast.

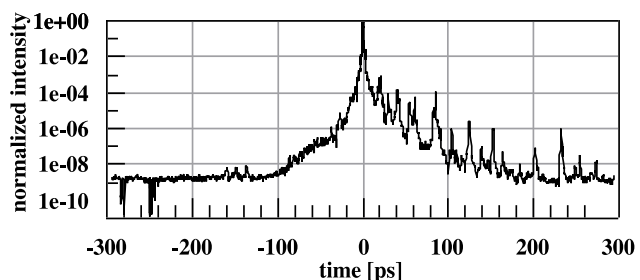


Figure 5. Picosecond intensity contrast is $\sim 5 \times 10^8$. The small prepulses and the post pulses come from the measurement device.

We have added a second deformable mirror which has greatly improved the focus (typical Strehl ratio > 0.6) and improved operations. In June 2016 we will add an f/1 OAP, which we expect to take us to intensities over 10^{22} W/cm² and make the prepulse improvement even more relevant.

Acknowledgements

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