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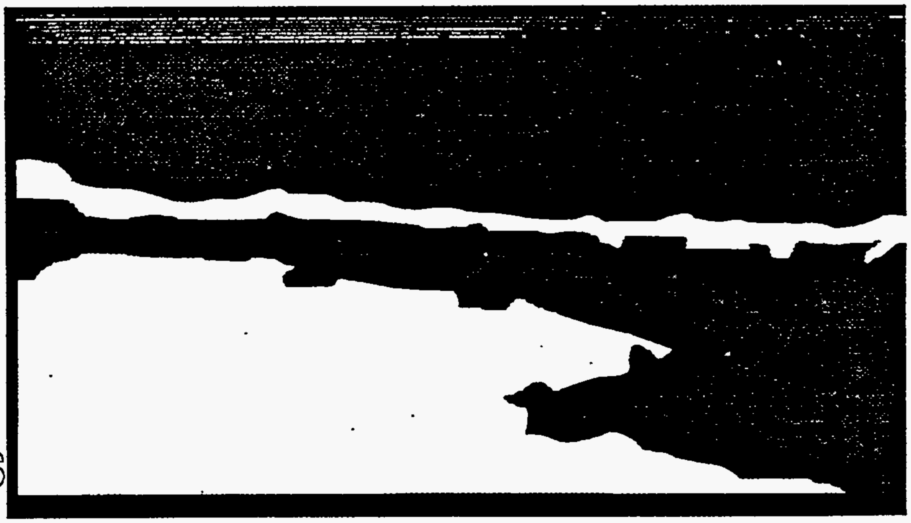

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Trident as an ultrahigh irradiance laser

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ABSTRACT

The Trident Nd:glass ICF laser at Los Alamos may be operated in a mode that produces high energy ultrashort pulses by the chirp/compression method. The 125-ps pulses from a standard mode-locked, Nd:YLF oscillator are first frequency-broadened to 3-nm bandwidth, chirped in a quartz fiber, and then compressed with a grating pair to 1.5 ps. A second quartz fiber then provides nonlinear polarization rotation for background and satellite suppression and to further broaden the spectrum to >7 nm. Pulses are chirped again to 1 ns width with a second grating pair and amplified in a Nd:YAG pumped Ti:sapphire regenerative amplifier. Millijoule-level output is then amplified through the existing phosphate glass Trident amplifier chain before compression to <400 fs.

Energy ≥1 J with excellent beam quality and contrast ratio is routinely produced by compressing after three rod amplifier stages. Higher energies are possible by compression further along the amplifier chain. Simultaneous use of long (~1ns) pulses for plasma formation is also possible.

2. INTRODUCTION

Large fusion laser systems are designed to operate most efficiently with pulses ranging from 100 ps to several nanoseconds. The output of these laser systems with short pulses is limited by intensity induced non-linear effects which can cause beam break-up and damage to optical components.[1,2] This limitation can be partially overcome by using chirped-pulse amplification (CPA) techniques.[3,4] A short pulse is chirped and stretched prior to amplification, amplified at low intensity so that non-linear effects are negligible, and then compressed to produce a high intensity short pulse.

The Trident Nd:glass ICF laser at Los Alamos, originally designed to operate with 100 ps to 2 ns pulses, has been operated in a CPA mode through the 45 mm amplifier stage to produce 400 fs compressed pulses with energy ≥ 1 J. Compressed pulses from Trident have been focused on target with intensities as high as 10^{19}W/cm^2 to study the generation of x-rays and to develop and calibrate fast x-ray diagnostic instruments.

3. DESCRIPTION OF LASER SYSTEM

A schematic of the front end of the CPA system is shown in Fig. 1. A CW mode-locked Nd:YLF oscillator provides a train of 76 MHz, 125 ps pulses which are injected into a 1500 m long, 9 mm core quartz fiber. Self-phase modulation and group velocity dispersion chirp and broaden the bandwidth to 3 nm [Fig. 2(a)] and increase the pulse length to 200 ps. A Faraday isolator prevents feedback of reflections to the oscillator. A 1740 lines/mm grating pair, used in a double pass configuration, compresses the pulses to 1.5 ps.. Spectrally windowing improves the pulse to background amplitude contrast at this point to 10^4:1. A second 4-1/2 m, 4.8 mm fiber between two crossed polarizers, provides nonlinear polarization rotation for background and satellite pulse suppression[5,6], and further broadens the spectrum [Fig. 2(b)]. The chirped pulses are stretched to 500 ps using a four pass stretcher configuration with a single 1740 lines/mm grating, a 1 m focal length lens, and mirrors to direct the beam. The use of only one grating and lens simplifies the alignment of the stretcher and reduces the possibility of a horizontal chirp.

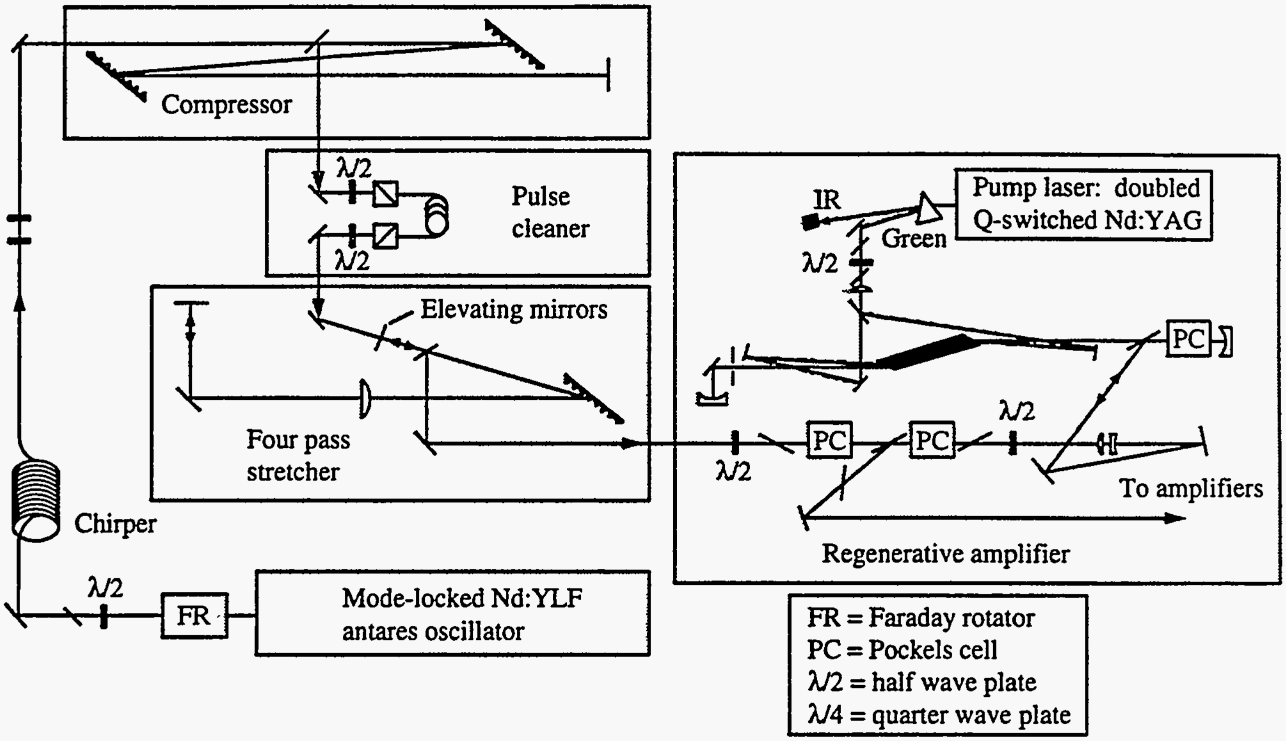

Figure 1. Layout of the front end of the CPA Trident laser.

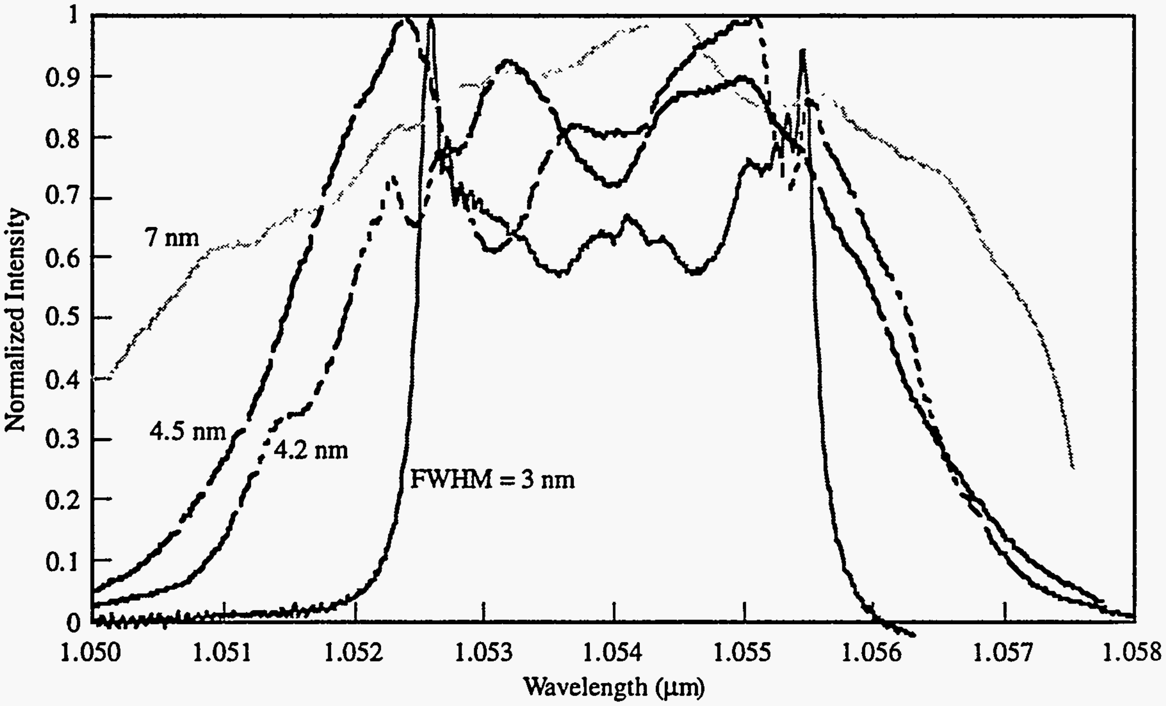

Figure 2.

To avoid spectral narrowing, a Ti:sapphire (Ti:Al_2O_3) regenerative amplifier (RGA) is used to amplify the chirped pulse from the sub-nanojoule level to the millijoule level. The RGA resonator is in a stable configuration with two highly reflective 1.054 mm mirrors, one with 1 m radius of curvature and the other with 0.75 m radius of curvature, separated by 1.5 meters. This configuration provides a small mode size at the Ti:sapphire crystal while maintaining a relatively large mode size at the Pockels cell to protect it from optical damage. A folding mirror with high reflection at 1.054 mm and low reflection at 800 nm, is included in the resonator to suppress gain at 800 nm. A single Pockels cell within the resonator is used to switch pulses in and out of the system, while external Pockels cells further enhance pulse-to-background contrast.

The Ti:sapphire crystal in the RGA is pumped by a frequency-doubled Q-switched Nd:YAG laser (Continuum, Surelite Model No. SL-10). The output of the pump laser passes through a dispersing prism to separate the second harmonic output from the residual fundamental to avoid self seeding of the RGA. The pump beam passes through two polarizers and a half wave plate which provide adjustment of pump level. The beam passes through a 1 m focal length lens, and is split into two beams of equal energy. These beams are then used to pump the Ti:sapphire crystal symmetrically from both ends. Dispersion in the Ti:sapphire allows the pump beams to overlap completely with the resonator mode inside the crystal while maintaining an angular separation externally. The pump beams and the resonator mode are both approximately 0.8 mm diameter at the Ti:sapphire crystal.

The Ti:sapphire crystal is 20 mm long, Brewster cut on both ends and has an absorption at 532 nm of 1.4 cm^{-1}. During typical operation, the crystal is pumped with 15 to 20 mJ on each end (3 to 4 J/cm^2) in a 10 ns pulse of 532 nm light, resulting in a single pass gain of approximately 1.7. Pumping the crystal from both ends produces a much longer effective gain length than single end pumping, and reduces the potential for damage on the crystal surfaces.

A polarizer-Pockels cell combination is used in the RGA to inject, trap, and finally eject the amplified pulse. The Pockels cell crystal is sol-gel coated KD^*P (Cleveland Crystals Model QX 1020 crystal in a MEDOX cell assembly Model 700 KDP) and is driven by a microwave tube pulser (MEDOX Model DR 85-A) which provides a two step high-voltage pulse. The Pockels cell is oriented to provide a quarter wave of static birefringence to inject a pulse into the cavity. The first voltage step adds another quarter wave of birefringence, trapping a pulse in the cavity. After amplification, a second voltage step is applied to the crystal adding an additional quarter wave of birefringence, ejecting the pulse from the resonator.

Two external Pockels cells are used (Fig. 1.) to enhance pulse to background contrast. The first Pockels cell selects a single chirped pulse from the seed beam for injection into the regenerative amplifier. During injection, the second external Pockels cell remains inactive allowing the pulse to propagate through. After the amplified pulse is ejected from the regenerative amplifier, it passes back through this Pockels cell which is then pulsed to switch the pulse into the beamline for further amplification.

During typical operation, the Ti:sapphire RGA produces approximately 2 mJ output with a total of 35 mJ pump (6% efficiency) at a 5 Hz repetition rate. Fig. 3 shows an oscillograph of the intracavity buildup of a pulse in this system. Total roundtrip gain including all losses is measured to be approximately 1.8. The 4.5 nm FWHM spectrum of the stretched pulse input to the RGA is shown in Fig. 2(b). The free running spectrum of the RGA is shown in Fig. 2(c) and is about 7 nm FWHM. This spectrum is limited by the intracavity polarizer and can be tuned by varying the polarizer angle. Fig. 2(d) shows that the spectrum of the pulse after amplification in the RGA has not been narrowed.

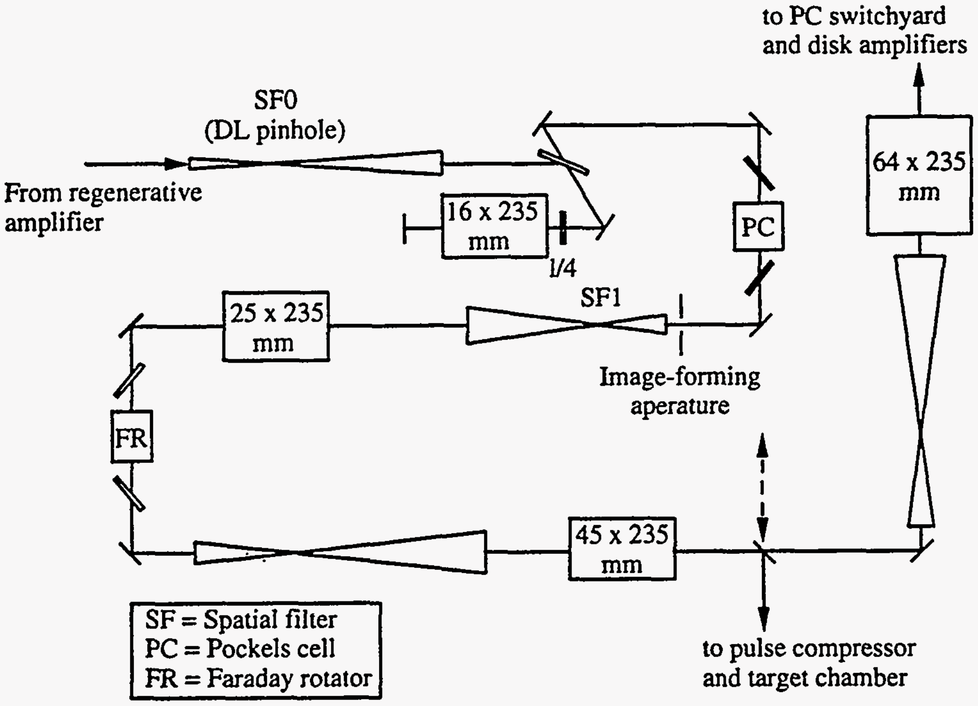

Figure 3. Trident rod amplifiers

The power contrast ratio measurement with our single shot autocorrelator is limited to about a 10^4:1 dynamic range, but third-order correlation measurements on a similar laser system[6] show that with careful alignment, it should be possible to obtain 10^8:1 contrast between the peak of the pulse and the background.

4. AMPLIFIERS

The output of the RGA is injected into the relay imaged, Trident laser amplifier chain (Fig. 4.), which can deliver over 400 J per beam in a 1 ns pulse when amplified through the entire chain. The beam passes through two alignment apertures separated by 1.5 m, then into a diffraction-limited in-air spatial filter to generate a good spatial profile for further amplification. A 16 mm rod amplifier is double passed and operated with an overall gain of 200. A Pockels cell isolates this stage from downstream amplifiers and protects from target reflected energy. A vacuum spatial filter expands the beam from 10 to 20 mm and keeps the spatial profile of the beam clean for amplification by the 25 mm amplifier which has a gain of 20. A permanent magnet Faraday isolator provides 30 db of isolation. The beam is spatial filtered again and expanded to 40 mm. The 45 mm amplifier has a gain of 8, and the beam is extracted at this point and directed to the compressor. At this time, chirped, stretched pulses for compression have been amplified only through the 45 mm rod amplifier, and have been limited to ≤ 2 J to protect the compression gratings from damage.

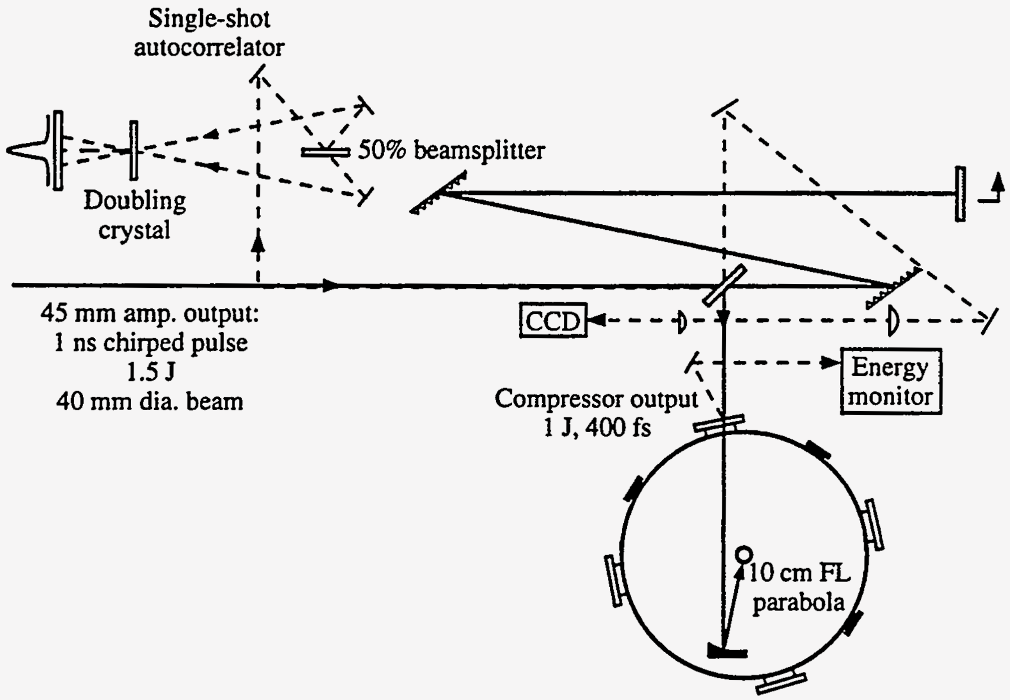

Figure 4. The pulse compressor and beam diagnostic layout

5. COMPRESSION

The amplified pulse is compressed (Fig. 5.) using a pair of identical 220 mm x 165 mm, 1740 lines/mm, gold coated holographic gratings (Instruments, S. A.) separated by 1.28 meters in a double pass configuration.[7,8] The gratings are parallel in a near Littrow angle, matched to the angle of the stretcher grating. The transmission through the compressor is 75% (four grating reflections). Compressed pulse width has been measured with a single pulse autocorrelator[9] (Fig. 6) to be <400 fs FWHM assuming a sech^2 pulse shape.

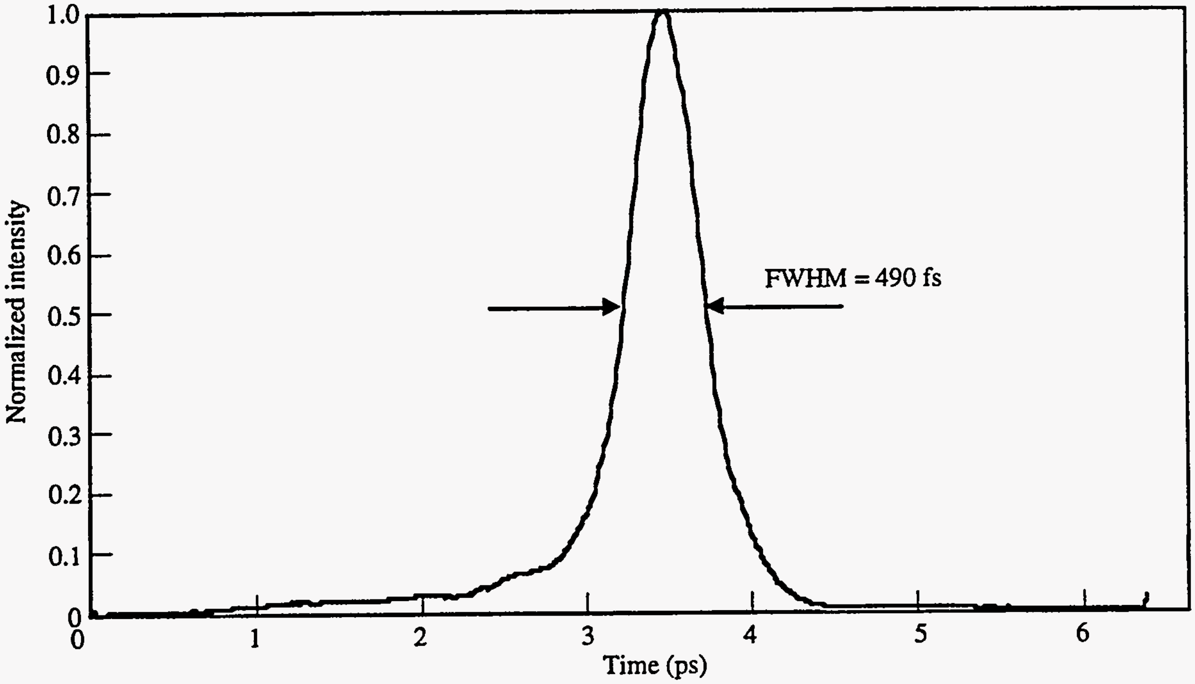

Figure 5. Single shot autocorrelation of a 1 J pulse.

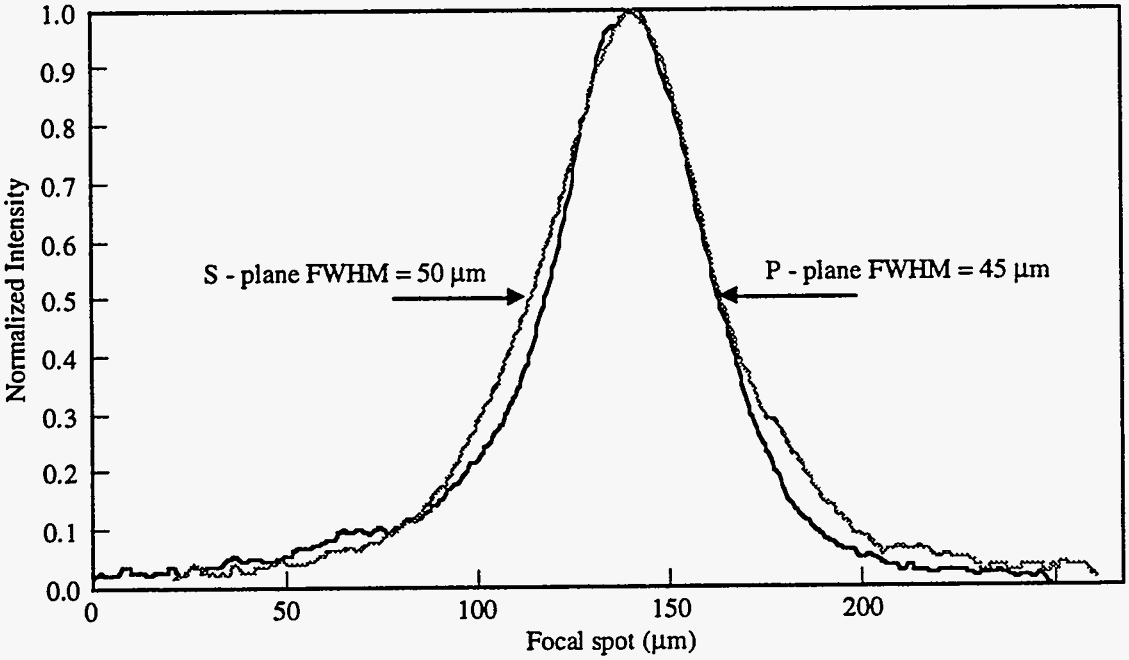

Figure 6. P & S plane equivalent focal distribution of a
1 J pulse through a 1 m lens.

The double pass compressor configuration returns a round, nearly diffraction limited beam. The beam is focused on target with a f/2.5 off axis paraboloid mirror (Fig. 5.) to a spot size < 10 mm diameter. Focal spot size was measured by sampling the high power beam with an uncoated wedged splitter and recording the focal spot at the focus of a 1 meter lens with a microscope objective and a

CCD camera (Fig. 5). Resulting equivalent target plane beam profiles are shown in Fig. 7. In an additional estimate of spot size, over 65% of the beam energy was measured to be transmitted by a 75 mm pinhole at the focus of a 1 meter lens, or the equivalent of 7.5 mm at the target plane. Further confirmation of the focal spot on target was obtained by observing x-ray emission from Au and Al target surfaces. A 5 mm pinhole camera shows x-ray images of 10 - 12 mm diameter (Fig. 8.) before deconvolving the effects of the 5 mm pinhole aperture. Observation of low energy light reflected off the target surface also confirmed this spot size. These measurments indicate a peak irradiance on target of nearly 10^{19}W/cm^{2}.

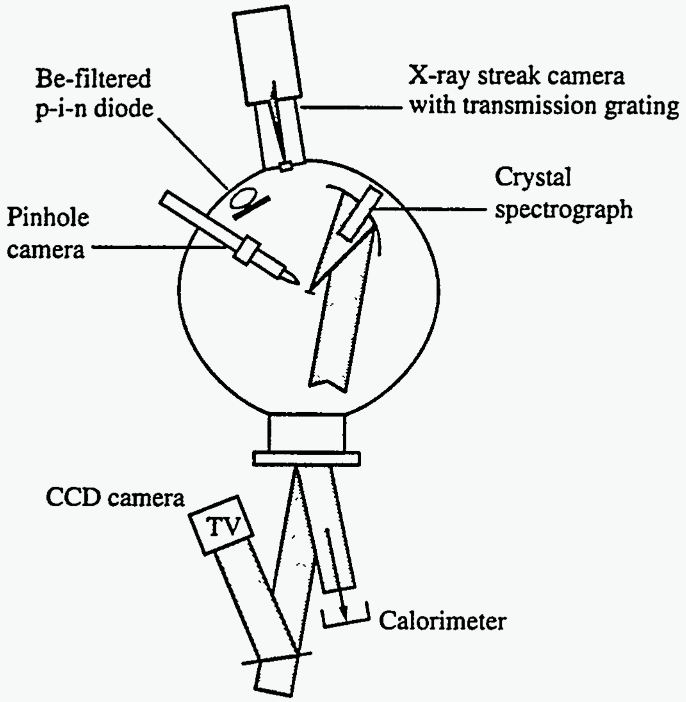

Figure 7. Trident CPA target chamber

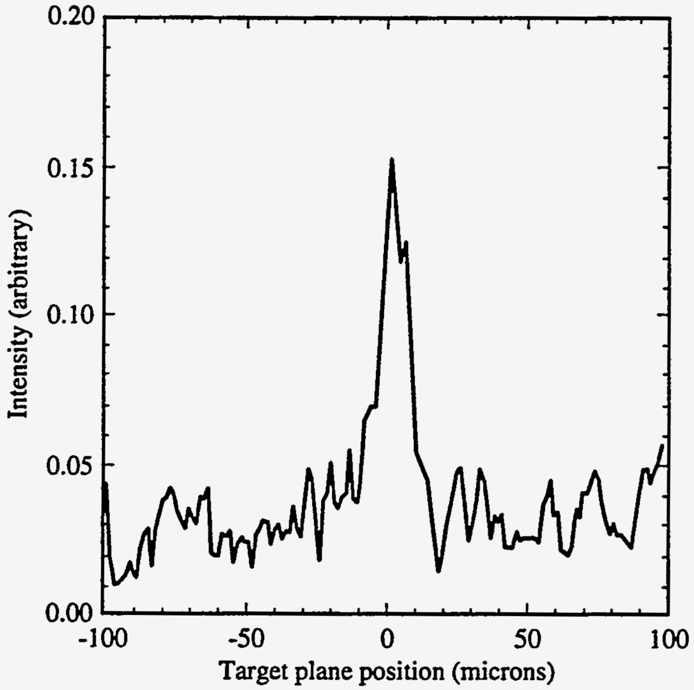

Figure 8. X-ray emission recorded with a 5 µm x-ray pinhole camera shows a 10-12 µm shot

With over 400 J per beam readily available at the 14 cm diameter output amplifiers, irradiance much greater than 10^{19}W/cm^2 is possible with the use of larger, more damage resistance compression gratings. Experiments can be carried out that require precise timing and control of laser parameters. Trident laser has two Nd:YLF regenerative amplifiers which are used for operation with 100ps to 2ns pulses. Pulses from either of these can be injected into the amplifier beam line with the chirped pulse and synchronized to generate conditions such as a preformed plasma at the target.

6. CONCLUSION

Chirped pulse amplification has been added to the Trident laser system at Los Alamos. Pulses with energy ≥ 1 J have been compressed to <400 fs with excellent beam quality and contrast. This energy has been focused on target with intensities near 10^{19}W/cm^2. A target chamber is available with a variety of diagnostics to conduct a variety of high-power short-pulse experiments.

7. ACKNOWLEDGMENT

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