A 10 Terawatt femtosecond laser plasma facility

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ABSTRACT

The availability of ultrashort (100 fs) high intensity lasers capable of producing focused intensities in excess of 10^{18} W/cm^2 provides many new opportunities in studying the interaction of radiation with matter. We describe a new laser plasma facility constructed around a Cr: LiSAF laser system currently capable of output energies of ~1J in times of ~100 fs. This facility will be directed initially towards basic studies of the interaction of intense ultrashort laser pulses with dense plasmas, and the generation and application of intense hard x-ray point sources.

The laser system we have developed for this facility,[1] uses the new solid-state laser material, Cr:LiSAF. This material has many advantages for the generation of intense ultrashort laser pulses. The spectral gain bandwidth is sufficiently broad for the amplification of pulses shorter than 100 fs in duration. Its florescence lifetime is long enough to permit the use of conventional flashlamp pumping, and its emission cross-section is such that it provides a small signal gains high enough to allow its use in a high powered chirped pulsed amplification laser architectures. The material can now be fabricated into laser rods up to 25 mm in diameter with low scattering losses its and Cr concentrations can be varied to optimize the small signal gain for specific pump cavities. These factors taken together allow the design of a 100 fs high intensity oscillator-laser system that is simpler in architecture than those based on Ti:sapphire or KrF. Moreover the use of Cr:LiSAF laser crystal elements should enable the generation of much higher powers. In principle as high as 1 PW should be achievable with a laboratory with this approach.[2]

Modifications currently being implemented onto our Cr:LiSAF laser system include improvements to pulse contrast, energy extraction, beam uniformity and focusability. The system will soon be incorporated with a 52-port precision target chamber that will be equipped with a broad array of x-ray and plasma diagnostics. Several research programs are being designed around this facility. Two of these programs, those relating to the use of hard x-rays for the analysis of shock phenomena in solids and the general physics of extremely high magnetic fields will be presented.

1. INTRODUCTION

Over the coarse of the last few years developments in broadband laser materials have lead to the creation of compact laser systems capable of delivering energies of up to a Joule in times of less than 100 fs. Focused to spot sizes of ~ 10 microns these small laser systems, by inertial confinement fusion (ICF) standards are capable of generating intensities in excess of 10^{19} W/cm^2. This enormous energy density can generate rich opportunities for the investigations in a number of fields including particle acceleration, coherent x-ray generation, and the behavior of matter under extremely high electric and magnetic fields. Specific to the development of laser systems for ICF femtosecond TW laser systems play a varied, but important role. Investigations

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of laser self-channeling in dense plasmas will provide insight to the Igniter concept of fusion ignition currently being pursued in several laboratories. The interaction of intense femtosecond radiation with dense plasmas results in the generation of energetic electrons. The generation of these electrons in the femtosecond regime will also be important to the Igniter concept. These electrons can also be used to create an extremely bright hard x-ray source. These sources may be of value in ICF studies as backlighting x-ray sources for point projection imaging and spectroscopy. Finally, these femtosecond optical and x-ray sources can also be used as convenient low cost calibration sources for instrumentation deployed on ICF installations.

In this paper we describe the TW laser system we have constructed at CREOL, and the laser plasma facility being built around it. This facility will be used for the investigation of matter under extreme energy densities, and the development of techniques utilizing 100 fs point x-ray sources.

The development of the chirped pulse amplification (CPA) technique[3,4] made it possible to develop table-top solid-state laser systems producing ultrashort pulses with peak powers in the Terawatt range. The first CPA systems were based on Nd:Glass amplifiers[5,6] which generate today peak powers in excess of 30 TW,[7-10] and in the future will generate powers approaching 1 PW. The generation of intense laser pulses with durations of 100 fs or less is currently centered on using broadband band laser media, the primary solid-state materials being Ti:Sapphire and Cr:LiSAF. Ti:sapphire based systems, however, require a frequency-doubled Q-switched Nd:YAG laser as a pump source that increases the cost and complexity of these systems. Cr-doped LiSAF ($LiSrAlF_6:Cr^{3+}$) is a relatively new laser material[11,12] which does not suffer these handicaps and has gained attention as a candidate for femtosecond pulse amplification to the Terawatt level. Cr-doped LiSAF has many attractive characteristics for the generation of high intensity radiation arising from its very broad spectral bandwidth (180 nm)[13] and its relatively long upperstate lifetime (67 ms). The broad spectral bandwidth and the efficient flashlamp pumping furthermore allow the development of compact laboratory sized, low cost femtosecond CPA laser systems. In the past two years considerable efforts have been put into the development of high-intensity femtosecond Cr:LiSAF CPA laser systems by ourselves at CREOL and by another group at Lawrence Livermore National Laboratory. Both these systems are now able to generate pulses of peak power of ~ 10 TW in pulses of ~ 100 fs.[2,14]

2. PROPERTIES OF CR:LISAF

Growth of single crystals of Cr:LiSAF is best fabricated by the Czochralski pulling technique. Other crystal growth techniques, such as the horizontal zone-melting technique and the vertical Bridgeman approach have so far not been successful in producing large crystals with high optical quality. Because Cr:LiSAF has a negative thermal expansion coefficient along the c-axis, great care has to be taken with the Czochralski method to produce good crystals. Crystal boules having outside diameters of ~ 3 cm and overall lengths of 13-14 cm can now be grown. In the past few years the optical spectroscopic data,[11,12] the crystallographic structure,[15,16] the thermo-mechanical and thermo-optical properties,[17,18] the optical damage limits[17] and gain properties[13, 19-21] of Cr:LiSAF have been well assessed.

The primary laser parameters of Cr:LiSAF are summarized in Table.1 and compared with those of Ti:sapphire, Nd:Glass (LHG-8) and Nd:YAG. The gain bandwidth of Cr:LiSAF is nearly as large as that of Ti:sapphire which makes this material likewise very attractive for the amplification of ultrashort optical pulses. Whereas its gain is approximately one order of magnitude lower than that of Ti:sapphire, Cr:LiSAF has a long enough lifetime of 67 ms to permit flashlamp pumping fairly efficiently.[11,22] The optical loss of Czochralski grown Cr:LiSAF has continuously improved during the past years and material with losses of ~0.002

	Cr:LiSAF	Ti:sapphire[39]	Nd:Glass[39]	Nd:YAG[39]
Peak wavelength (λ) [nm]	850[11]	790	1054	1064
Linewidth ($\Delta\lambda$) [nm]	180[11]	230	20	0.45
Emission cross section [10^{-19} cm^2]	0.5[11]	4.1	0.42	6.5
Fluorescence lifetime (τ) [msec]	67[11]	3.2	315	230
Refractive Index (n)	1.41[40]	1.76	1.53	1.82
Scat. loss (α) [cm^{-1}]	0.002[23]	0	0	0.002

Table 1: Laser properties of LiSAF, Ti:sapphire, Nd:Glass and Nd:YAG.

cm^{-1} are now commercially available.[23] The peak emission wavelength of Cr:LiSAF is 850 nm, overlapping well that of a mode-locked femtosecond Ti:sapphire laser which at present is the most reliable femtosecond pulse source in this spectral region. Thus a mode-locked Ti:sapphire laser can be used as a pulse source for a Cr:LiSAF CPA laser system.

The gain of Cr:LiSAF is moderate, strongly polarized and affected by excited state absorption (ESA) and upconversion.[13,19-21,24] ESA reduces the gain for the p-polarization by ~30% and approximately cancels that for s-polarization.[13,19-21] The effective gain cross sections for both polarizations and the unpolarized ESA cross section are shown in Fig. 1.

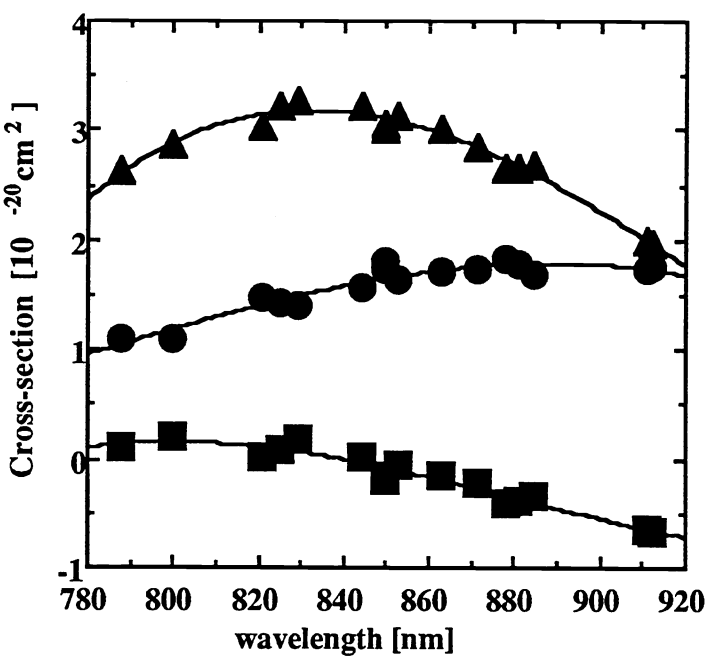

Fig. 1: Wavelength dependence of the ESA cross section (circles) and of the effective gain cross-sections for p (triangles) and s polarization (squares) of Cr:LiSAF.

At first sight ESA could be simply overcome by increasing the pump energy. However, at increasing pump levels the upconversion process becomes detrimental owing to its square dependence on the population of the upper laser level.[20,24] The consequence is, that it is nearly impossible to reach exponential gain using Cr:LiSAF. As a rule relatively large pump densities are required to overcome the drawback of ESA, and to reduce the effect of upconversion the use of long rods must be preferred. The strong polarization of the small-signal gain observed for Cr:LiSAF has strong implications for the design of high power oscillator-amplifier systems. In these systems amplifiers are configured in such a way as to maximize their energy extraction, and minimize ASE and the amplification of retro-reflected laser light. In many amplifier system designs, this involves utilizing the gain properties of both polarizations.

Bulk damage thresholds of 160 - 500 GW/cm^2 for low doped Cr:LiSAF (at 1064 nm with a 47 ps long pulse) have been measured.[17] The relatively low nonlinear refractive index of Cr:LiSAF (5.5×10^{-17} cm^2/W)[17] is an important advantage for the design of high intensity laser systems since it allows higher energy extraction avoiding the detrimental influence of small-scale self-focusing to the focusability of the output beam.

3. 10 TW CR:LISAF LASER FACILITY

The experimental configuration of the laser system is shown in Fig.2. The initial femtosecond pulse source is a Kerr lens modelocked Ti:sapphire laser.[25] The output pulses of this laser are expanded in an anti-parallel grating-pair pulse stretcher and injected into a regenerative amplifier. Pulse slicers used before and after the regenerative amplifier select a single pulse out of the pulse train. This single pulse is then further amplified in three double pass amplifiers with increasing aperture up to 25mm and finally recompressed in a grating-pair pulse compressor.

The Ti:sapphire laser is pumped with 8W of an Argon-Ion laser (Laser Ionics, Model 1400 15A). This laser is configured in an X-type cavity, uses a 7.5 mm long Ti:sapphire crystal and contains two SF10 prisms for group velocity dispersion compensation, a thick one-plate Lyot-filter for wavelength tuning and a variable slit acting as a saturable absorber. With the mid-range mirror set the Ti:sapphire laser produces 300 - 500 mW, <100 fs pulses tunable from 780 to 900 nm. These pulses are expanded ~2000 times to 170 ps by four passes through a single grating pulse stretcher corresponding to a double pass through an anti-parallel grating-pair configuration.[26] The gratings are 1800 grooves/mm, gold coated holographic diffraction gratings. The achromatic telescope lens with a focal lens of 40 cm is placed at a distance of 20 cm from the grating resulting in an effective grating separation of 40 cm. The incident and diffracted angles are 60° and 41.6°, respectively, and the diffraction efficiency is ~90%.

A single stretched pulse is selected by a double quarter-wave Pockels-cell optical gate and injected into the regenerative amplifier having at this point an energy of ~1 nJ. The regenerative amplifier is configured in a linear cavity using a flat 60% output coupler and a 5 m radius high reflective end mirror and contains a thin film broad-bandwidth polarizer, a zero order quarter-wave plate and a quarter-wave Pockels-cell. The 4. mm dia x 65 mm rod is pumped at 6 Hz in a dual flashlamp laser head (Continuum, SF 606-04) with an effective pump length of 56 mm and with a maximum (electrical) pump energy of 50 J. The flashlamp pulse duration is 130 msec, sufficiently short to pump the Cr:LiSAF crystal fairly efficiently. Shorter flashlamp pulse duration would limit flashlamp lifetime. The dopant concentration of the Cr:LiSAF rod is 2% (CrF_3 replacing AlF_3). An iris pinhole of ~2 mm near the output coupler is used as an intra-cavity aperture. The single chirped input pulse is injected into the regenerative amplifier through the thin film polarizer. A digital logic circuit combined with a photodiode which detects the output pulse train of the Ti:sapphire laser is used to synchronize both the optical gate and the Q-switch with the Ti:sapphire oscillator.

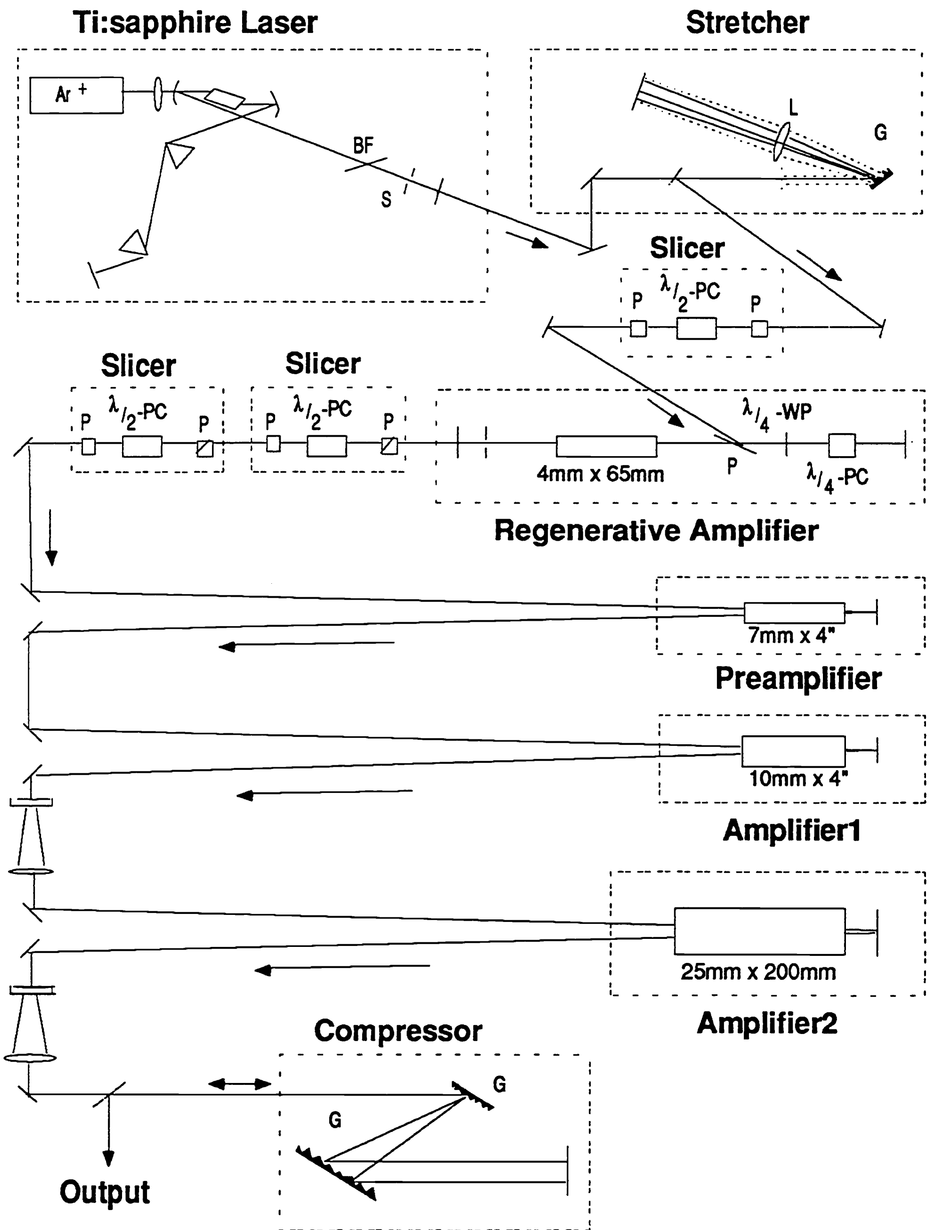

Fig. 2: Experimental set-up: BF: birefringent filter, S: slit, G: grating, L: lens, P: polarizer, PC: Pockels-cell, WP: waveplate.

Two pulse slicers are used in series to select a single pulse from the pulse train produced by the regenerative amplifier. These ensure pre-pulse suppression of the pulse train by approximately a factor of 10^9. The selected pulse is then amplified by two double-pass amplifiers (Laser Modules Inc.) operating at a repetition rate of 1 Hz. The amplifier rods have dimensions of 7 mm dia. x 105 mm and 10 mm dia. x 105 mm, successively. The Cr-concentration in these rods is 1.4%. Both amplifiers (Laser Modules Inc.) have two flashlamps (arc length of 3.5") in close coupled laser heads with 300 J maximum pump energy and ~140 ms pump pulse duration. After this stage of amplification the beam is expanded through a telescope to a beam diameter ($1/e^2$) of 12 mm and double passed through the 25 mm amplifier. This final 25 mm amplifier is a 8 flashlamps, close coupled laser head with an arc length of 200 mm. The maximum input energy to the flashlamps is 5 kJ in a 300 ms long pulse. This amplifier (Continuum, SF 320-25) requires laser rods of >200 mm length. Since the maximum length of the 25 mm Cr:LiSAF rods is 120 mm, a glass tube with 26 mm inner diameter is installed into the laser head.[27] This arrangement allows us to insert two Cr:LiSAF rods lying end to end in the glass tube, at the expense of the repetition rate of the amplifier. Since the rods are not cooled in this configuration we are currently firing this amplifier once every 10 minutes. The rods are of good optical quality. Each rod has scattering losses of ~0.01 cm^{-1} and a total wave distortion of less than a $\lambda/2$ wave rms measured across the full aperture. The actual Cr concentration is 0.6% resulting in a uniform gain distribution.

After this final amplifier the beam is magnified to a beam diameter ($1/e^2$) of ~40 mm and the pulses are recompressed with two gratings in the standard parallel double pass configuration.[28] These grating are identical to those used in the pulse stretcher and have a size of 110 x 110 mm and 110 x 135 mm, respectively. The transmission efficiency of the grating compressor is approximately 55%. For future experiments we are planning to place the compressor stage and the output beam in a vacuum environment to avoid spatial and temporal deterioration of the recompressed pulse owing to the nonlinear refractive index of the air and of the entrance window to the target chamber. In the present experimental setup a fraction of the beam is selected close (~30 cm) to the output grating to perform a single shot autocorrelation measurement of the output pulse by minimizing the contribution of nonlinear pulse propagation in air to the measured pulse duration.

3.1 Current Laser Performance

The Ti:sapphire laser produces nearly Fourier-transform $sech^2$ pulses when operated at pulse durations of 100 fs or longer. Increasing the amount of prism material in the laser cavity leads to somewhat shorter pulses, but significantly increases the time-bandwidth product due to the rather large third order dispersion when using SF10 prisms in a Kerr lens mode locked Ti:sapphire laser.[29] Shorter pulses as short as 10 to 20 fs can be - if necessary - obtained by replacing our prisms by prisms made of Quartz or LaKl21.[29-32] However, we typically operate the Ti:sapphire laser at a pulse duration of ~80 fs. The pulse spectrum has a width of 12.6 nm resulting in a time bandwidth product of 0.42. The pulse wavelength is matched to the center wavelength of the spectrum of the Q-switched regenerative amplifier which typically lies around 850 - 855 nm.

The regenerative amplifier needs 37 roundtrips to reach gain saturation producing a pulse train approximately 70 ns long from which a single pulse is selected at its peak. The spectrum of the regenerative amplifier output pulse is ~8.5 nm which is significantly narrower than the injected spectrum. Due to the narrower pulse spectrum the duration of the uncompressed pulse leaving the regenerative amplifier is estimated to be ~115 ps when including the material dispersion of the amplifier. The energy of the single pulse selected by the pulse slicers at the output of the regenerative amplifier is ~5 mJ with a stability of better than +/-5%. When directly recompressed the pulse energy is 2.7 mJ. The pulse width is measured with a single shot autocorrelator using a 300 mm thin KDP crystal.[33] After first alignment of the pulse compressor the autocorrelation typically shows extended pulse wings and satellites and has a width of typically longer than 200 fs. These satellites are due to residual higher order dispersion introduced in the stretcher/compressor as soon dispersive elements are placed between the stretcher and compressor even if the gratings are perfectly aligned. However, adjustment of the gratings and mirrors of the pulse stretcher and the gratings of the compressor results in pulse durations of typically 90 to 100 fs corresponding to a time-bandwidth product of 0.32 to 0.35 which is close to 0.315, the Fourier-transform limit of a $sech^2$ pulse. A multishot autocorrelation trace is shown in Fig. 3 in logarithmic scale. The dynamic range of $3x10^4$ is limited by scattered second harmonic signal that is produced by each arm of the autocorrelator rather than by the

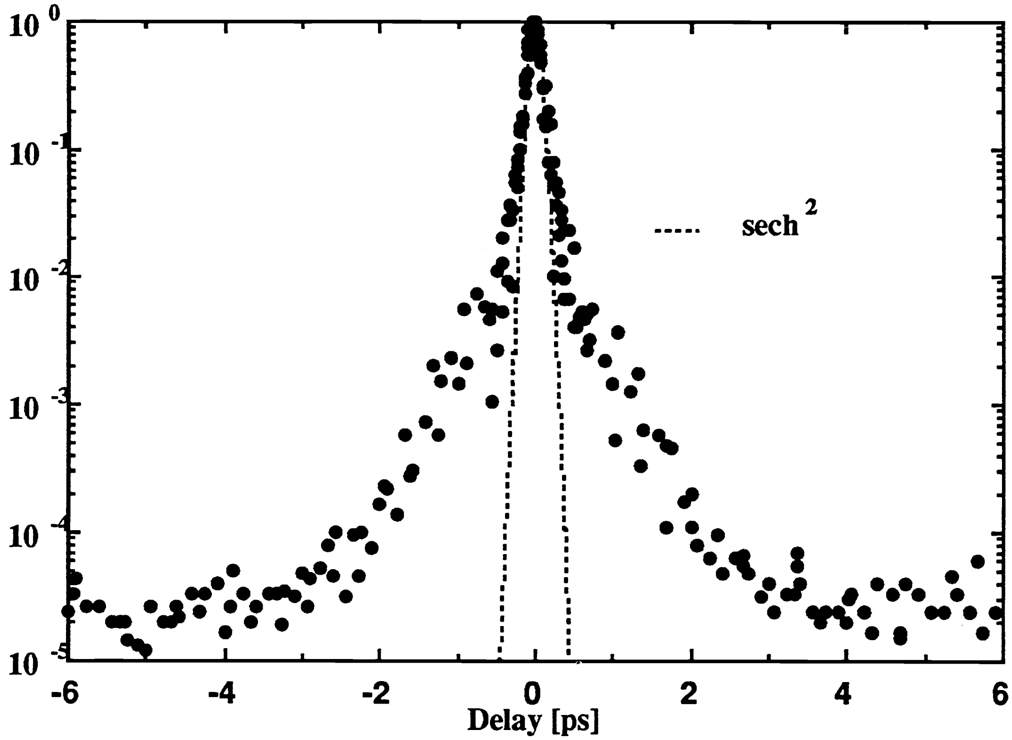

Fig. 3: Multiple shot autocorrelation trace of the recompressed regenerative amplifier output pulses shown in logarithmic scale.

dynamic range of the photomultiplier tube. Although a shoulder is present in the signal no satellite pulses are present and the data points closely fit to a $sech^2$ pulse over nearly two orders of magnitudes. These shoulders are due to residual third order dispersion not compensated in our CPA system.

3.2 Amplifier performance

The 7 mm preamplifier has a small signal gain of ~6.3 for an electrical pump energy of 300 J. and amplifies the pulse to an energy of 75 mJ. The single pass gain of the 10 mm amplifier is 2.7 at a pump energy of 300 J. The scattering losses of this rod is ~0.015 cm^{-1} resulting in a double pass gain of 5.3. After double passing this amplifier we measure a pulse energy of 280 mJ. The final 25 mm amplifier has a single pass gain of 3.8 at an electrical pump energy of 5 kJ when inserting two rods into the laser head. The Cr-concentration in these rods is 0.6% resulting in a homogeneous radial gain profile, see fig 4. Two passes through the 25 mm final amplifier results in 1.45J pulse energy in a single shot mode (1 shot/10 min.). We are currently making modifications to the design of this system that will lead to further increases in the output of this system. Replacement of the amplifier crystals with low-loss Cr:LiSAF and by AR coating all the amplifier rods will increase the available gain by a factor of 7. We also anticipate optimizing further the pump conditions for 25mm diameter amplifiers by shortening the relatively long pump pulse which is currently 300 msec.

The energy density at the first compressor grating is approximately 120 mJ/cm^2. No optical damage to the grating has been observed at this intensity. After recompression the pulse energy

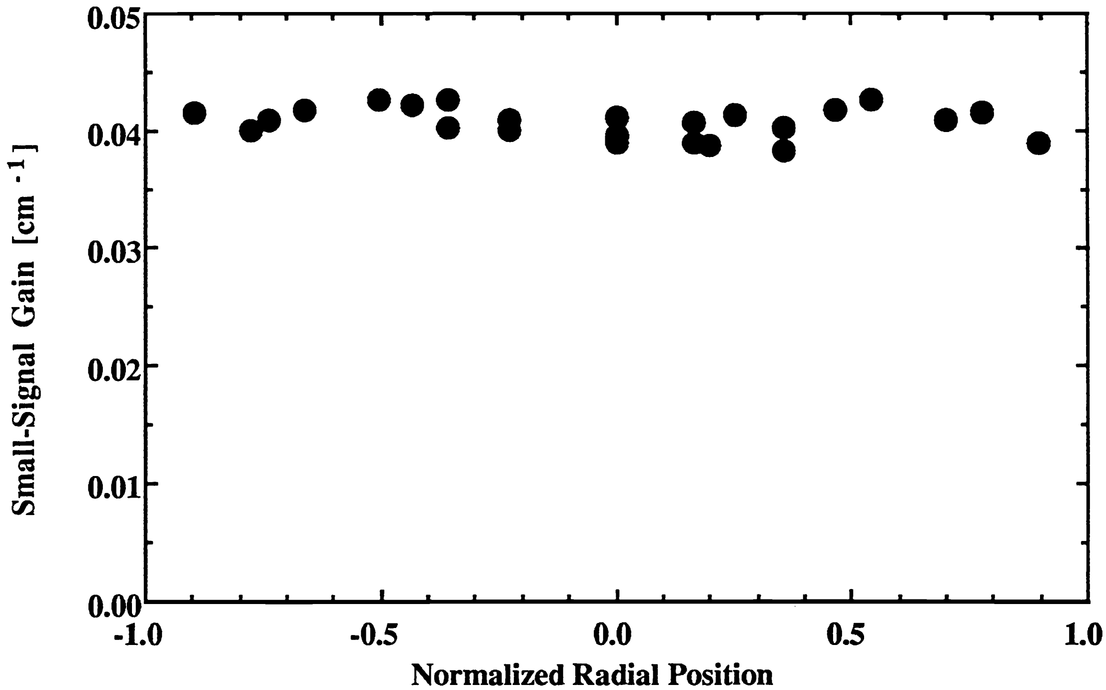

Fig. 4. Radial gain distribution of the final 25 mm amplifier (2.25 kJ).

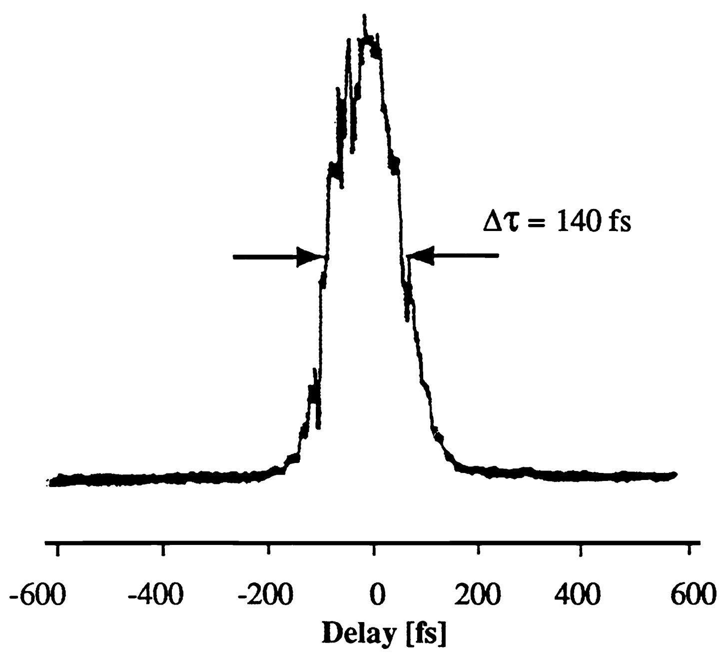

Fig 5 Single-shot autocorrelation trace of the output of the system.

is 750 mJ. We have measured the pulse duration when operating the amplifier system at full energy. A single shot autocorrelation of these pulses is shown in Fig. 5. The measured (FWHM) width is 140 fs which corresponds to a pulse duration of 90 fs assuming a $sech^2$ pulse shape.

3.3 Spatial beam quality

An important requirement of all high intensity lasers is their focusing capability. We have used a CCD camera and a Spiricon LBA-100A beam analyzer to diagnose the near and far field profiles at various points in the system to ensure optimum pulse propagation. We determined B-integral[34] values of 0.2, 0.3 and 1.7 for the 7, 10 and 25 mm amplifiers. Although the B-integral of the final amplifier is rather high, the overall B-integral of the amplifier chain of 2.2 is still smaller than 3, the limit for stable beam propagation.[35] Furthermore we do not observe any intensity dependent changes of the beam profile. The output of the regenerative amplifier is diffraction limited ($M^2 = 1\pm0.1$). A diffraction limited beam is also maintained in the 7mm-preamplifier. The focused output from the 25 mm amplifier when focused with a 1.5 m lens is shown in fig.6. The beam waist has a width of 280 mm ($FW^1/_{e2}M$) corresponding to that of a ~2 times diffraction limited beam. The central peak contains >65 % of the total energy. We believe that part of the energy loss from the far field central peak is due to diffraction from within the 25 mm diameter laser crystals we are currently using.

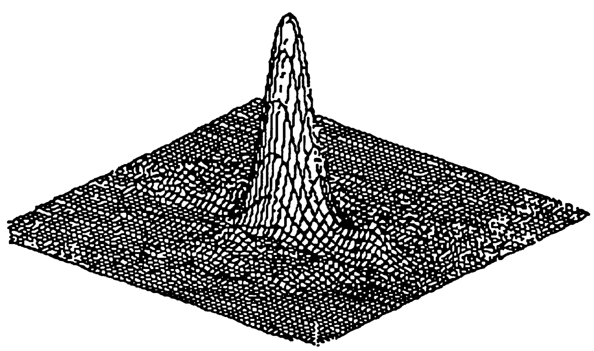

Fig. 6. Far field measurements of the output beam of the 25 mm amplifier when focused with a 1.5 m lens.

We expect to make further improvements to the output beam focusability in the near future. Replacement of some of the amplifier crystals with low-loss Cr:LiSAF will lead to an improvement in focusability and an output beam less than 2x diffraction limited should be achievable operating this system at the 1 Joule level (10 TW). This would imply that when the output beam of the system is focused with a 5 cm focal length focusing element, spot sizes of <5 μm diameter are obtainable, resulting in peak intensities of $>5\times10^{19}$ W/cm^2.

4. HIGHER POWERS TOWARDS 1 PETAWATT

The technology that we have employed in the development of this laser has potential for the achievement of much higher power levels. In principle this technology can make possible the construction of a laboratory-size femtosecond pulse laser operating at the Petawatt level. Such a laser might be expected to have a focused spot intensity of $> 10^{21}$ W/cm^2. The demonstration of focused intensities of this order in a laboratory environment would have a major impact on several fields, particularly those involving high field physics. In this section we describe the measures we are currently taking to extend the output of this system up to the 100 TW level, and discuss the technology involved and the improvements that would necessary to upgrade this system to the 1 Petawatt level.

4.1 20-fs 100 TW laser

We are currently modifying our Ti:sapphire laser to produce pulses of ~20fs duration at a center wavelength of 850 nm.[31,32] Reflective optics in the expansion stage can be used to minimize The design of the regenerative amplifier is based on a cavity-dumped system. Cavity dumping of the regenerative amplifier may become necessary to reduce the number of roundtrip passes in the resonator in order to preserve the larger spectral bandwidth of the 20 fs pulses.

Modifications to the current amplifier chain will both increase the gain per unit length in the amplifier units and reduce the optical path length in the LiSAF rods, thereby significantly decrease the B-integral value since the full aperture of the rods can be used. A single pass gain of 10 from a 10 mm Cr:LiSAF rod pumped with 600J electrical input energy from 4 flashlamps has been demonstrated by Ditmire and Perry.[36] An amplifier head designed for our 25 mm Cr:LiSAF rods should allow a single pass gain of approximately 5. The use of lower-loss AR coated Cr:LiSAF rods in these amplifiers will allow the generation of compressed pulse energies of ~2J.

To achieve recompression of 20 fs pulses it will be necessary to compensate for dispersion up to the fifth order. Although this can be achieved by careful design of the system, an exact knowledge and very precise alignment of all the optical elements in the pulse stretcher and compressor will be required without any possibility to fine tune 3rd and higher order dispersion if once the system design is set. For this reason we are currently investigating the possibility of using additional elements which may allow simultaneous fine alignment of both 2nd and 3rd order dispersion. Such an element might consist in an additional prism pair inside the regenerative amplifier cavity. Simultaneously changing the amount of prism material and the separation of the compressor gratings would allow one to tune the third order dispersion.

4.2. Cr:LiSAF disk amplifier

The assumption that energies in the range 1-5 J can be extracted from rod amplifiers of 25 mm diameter, places a practical power limit of ~ 200 TW for the current system architecture. To achieve significantly higher peak powers on the assumptions of rod technology and the current limits of crystal growth would imply the use of multiple beamlines. To achieve higher powers in a single beam would imply the need to develop alternative amplifier approaches. to increase the beam aperture beyond 25 mm would involve the use of disc amplifier technology. Given that current LiSAF crystal techniques limit the size of available laser material to ~ 25, a LiSAF disc amplifier of larger diameter will need the development spatially matrixed crystal disc amplifiers. Two forms of such amplifier are illustrated in Fig. 7. Both of these involve the use of large aperture discs fabricated as a spatial matrix of crystals. In the first several of these discs would be assembled so as to be face-pumped by conventional linear flashlamps. This approach is now the pump architecture of choice for large high power pulsed fusion lasers.[37] The use of matrixed crystal discs will require precision optical fabrication of the individual crystal components. It may well be necessary to encapsulate them in a transparent optical frame to ensure stability. Another amplifier approach would use the so-called "active mirror" amplifier.[37] This amplifier module would incorporate double pass amplification in a crystal matrix disc at an angle of close to normal incidence. The rear side of the disc would be coated with a high reflectivity broadband dielectric mirror centered at the laser wavelength, but narrow enough to allow efficient pumping from an array of close-coupled linear flashlamps. The Cr doping in the LiSAF and its thickness would be adjusted for uniform optical pumping and the production of high optical gain in the amplifier. This could possibly be increased with the use of a dichroic mirror on the front surface

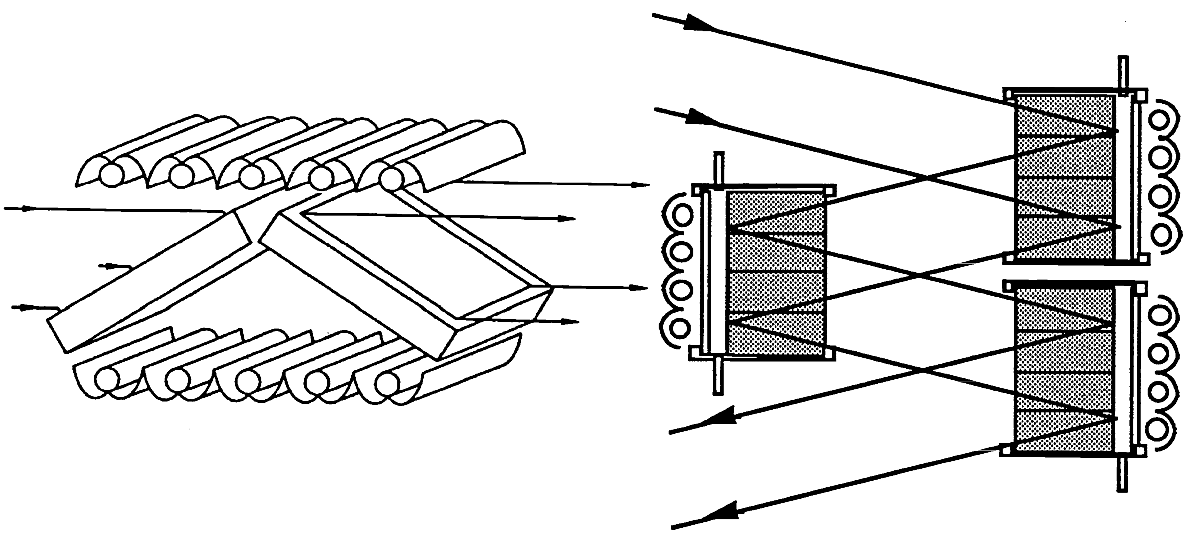

Fig.7. Two possible pumping configurations for spatially matrixed crystal amplifiers.

for the disc that reflected flashlamp pump light but was an anti-reflector for the laser wavelength, as was adopted when this approach was used for Nd:Glass.[38] The primary technical barrier to the use of either of these two amplifier approaches at present in the development of matrix crystal disc arrays. However this approach has been successfully implemented for large harmonic crystals used to convert the wavelength of large diameter fusion laser beams.[38] Its extension to laser crystal arrays is not expected to be insurmountable.

5. SUMMARY

In this paper we have described the development of a new approach to ultrashort ultrahigh power laser pulse generation that is dependent on a new solid state laser material, Cr:LiSAF. This material possesses unique properties ideally suited to the deployment of conventional oscillator-amplifier technology in a high intensity system. After making a detailed study of this material's optical and physical properties, we have successfully incorporated it in a ~ 8 TW, 90fs high power laser system. This system incorporates chirped pulse and regenerative amplification techniques, but otherwise uses pumping and laser technologies that have been in use for many years. Already the current femtosecond laser capability provides many new opportunities for fundamental research in several exciting fields, including high field physics, x-ray lasers, x-ray generation and particle acceleration. However, it is our view that the approach to ultrashort high power pulse generation that we have described can sustain considerably more development. We believe it can provide a path toward the demonstration of laboratory-size laser systems capable of providing ultrashort pulses with powers in the Petawatt range, and repetition-rates high enough to allow productive research.

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