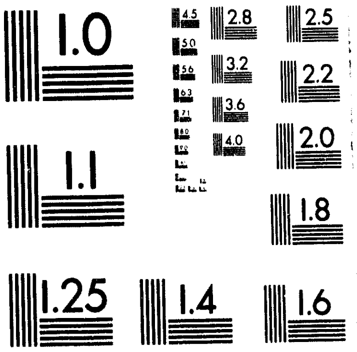
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Conf-931048--10

LA-UR- 94-528

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Submitted to: 11th International Workshop on Laser Interaction and Related Plasma Phenomena
Monterey CA,
October 25-28, 1993

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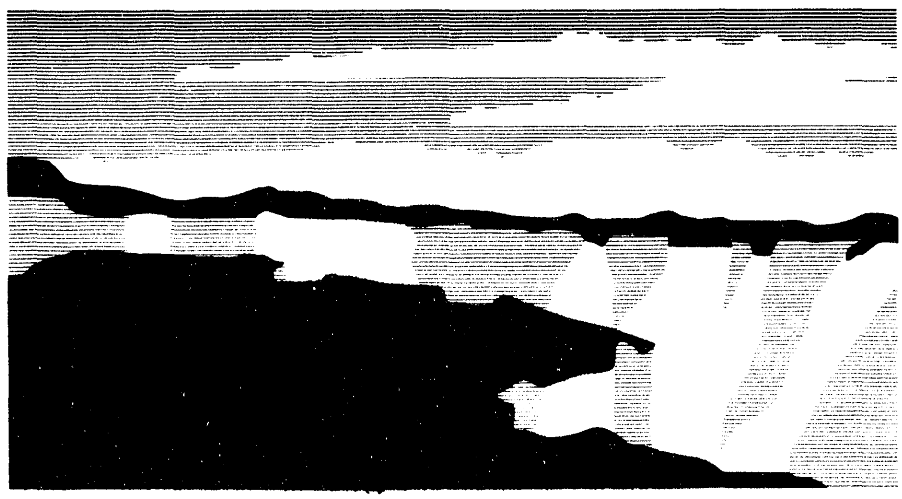

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SHORT-PULSE, HIGH-INTENSITY LASERS AT LOS ALAMOS

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ABSTRACT

We describe two laser systems for high intensity laser interaction experiments: The first is a terawatt system based on amplification of femtosecond pulses in XeCl which yields 250 mJ in 275 fs and routinely produces intensities on target in excess of 10^{18} W/cm^2. The second system is based on chirped pulse amplification of 100-fs pulses in Ti:sapphire.

1. INTRODUCTION

Advances in ultrafast lasers and optical amplifiers have spurred the development of terawatt-class laser systems capable of delivering focal spot intensities approaching 10^{20} W/cm^2. At these extremely high intensities, the optical field strength is more than twenty times larger than the Bohr electric field, permitting investigations of the optical properties of matter in a previously unexplored regime. Applications of such laser systems include the study of multiphoton phenomena in atoms, the production and investigation of picosecond x-ray pulses and the testing of optical pumping strategies for x-ray lasers. We describe here two such laser systems for high intensity laser interaction experiments: one based on ultrashort pulse amplification in XeCl and one based on chirped pulse amplification in Ti:sapphire.

2. XeCl LASER SYSTEM

Amplification in XeCl is the basis of several ultrashort-pulse high-brightness systems worldwide.[1-4] We describe here a terawatt-class laser system based on the amplification of subpicosecond pulses in XeCl discharge amplifiers.

Generation of 308-nm seed pulses is accomplished by frequency-doubling the output of a synchronously-pumped subpicosecond dye oscillator-amplifier system,[5] operating at 616 nm. These uv seed pulses are amplified in a chain consisting of a small-aperture (1-cm^2) XeCl amplifier, a beam-expanding spatial filter and a large aperture (100-cm^2) final amplifier.

The final amplifier[4] consists of two independently pumped discharge regions, each with clear apertures of 10 cm by 10 cm. Simultaneous preionization of the gas mixtures in both gain sections is accomplished with a single 130-keV, 10 mrad/shot x-ray preionizer. The discharges are driven by low-jitter, thyratron-switched pulse modulators employing two-stage magnetic compression. With 10 kV/cm 100 kW/cm^3 discharge pumping and a gas mixture of 2290-Torr Ne, 14-Torr Xe and 1-Torr HCl, the centerline small-signal gain is 0.032 cm^{-1}. Useful gain is available over more than half of the clear aperture. To maintain near-diffraction-limited beam quality at a 1 Hz repetition rate, a gas flow system is employed that maintains nearly laminar flow transverse to the discharge electrodes. After hot gas is cleared from the discharge volume this flow system establishes less than $\lambda/20$ wavefront distortion over 80% of the clear aperture before the next shot is fired.

This laser system generates 250-mJ, 275-fs pulses at 308 nm and operates at a sustained repetition rate of 1 Hz. The ultrashort output pulse lies on a 20-ns, 20-mJ amplified spontaneous emission (ASE) pedestal, but only half of the ASE energy is included in the solid angle subtended by the output beam. Using f/3.7 optics we measure FWHM focal spot dimensions of 3.4 x4.1 μm^2 for the full energy final output beam and therefore demonstrate a focal-volume intensity of 6.5 x 10^{18} W/cm^2.

3. Ti:SAPPHIRE LASER SYSTEM

The large gain bandwidth and high saturation fluence of Ti:sapphire (Ti:Al_2O_3) permit efficient amplification of ultrashort pulses, allowing Ti:sapphire to become the solid state material of choice for producing ultrahigh peak power pulses.[6-8]

Our Ti:sapphire system consists of an oscillator, a chirper, several amplifiers and a pulse compressor. The system is seeded with pulses from a commercial mode-locked

Ti:sapphire laser operating at 810 nm and pumped by the 10 Watts, all-lines output of an Ar^+-ion laser. These 70-fs, 15-nJ pulses have a spectral bandwidth of 9.6 nm. Before amplification, these pulses are temporally stretched using a grating pair pulse-stretcher configured to yield positive group velocity dispersion.(9) Two antiparallel 2000-line/mm gold-coated holographic diffraction gratings are separated by 1.7 m, and a unit magnification telescope using 60-cm-focal-length achromatic lenses is inserted between the gratings. After two passes through the stretcher, the measured pulse duration is 440 ps. Next, the pulses traverse a Faraday isolator. Losses in the beam up to this point (mostly in the stretcher) result in a 5-nJ/pulse energy to seed the amplifier chain.

The Ti:sapphire amplifier chain boosts the energy to 110 mJ and consists of a regenerative amplifier, a double-pass preamplifier and a final amplifier. All amplifiers are pumped using frequency-doubled Nd:glass/Nd:YAG oscillator/amplifier system.(10) The intensity of these 110-ns, 0.53-μm pump pulses are more than an order of magnitude smaller than those obtained from conventional Q-switched Nd:YAG lasers typically used to pump Ti:sapphire amplifiers, making the system more resistant to optical damage from the pump beam. The strategy used to increase the pump pulse duration is to utilize the low gain of Nd:glass in the oscillator to yield long-pulse-duration seed pulses at 1.062 μm, and then use Nd:YAG, with its superior thermal properties, for amplification up to joule-level energies. The laser system, described in detail in Reference 10, consists of a Q-switched glass oscillator, followed by three Nd:YAG amplifiers operating at a 5 Hz repetition rate. Frequency-doubling of the output with conversion efficiencies approaching 50% is achieved in two output arms using a 60-mm-long and a 100-mm-long KD*P crystals.

The first amplifier is a regenerative amplifier using a linear cavity with one flat end mirror and one 3-m focal length end mirror separated by 145 cm to form a stable TEM_{00} mode with a waist size of 1.63 mm located at the flat end mirror. The 7-mm-diameter by 20-mm-long Ti:sapphire crystal with 0.15% Ti doping yields a small signal gain of 4 when pumped with 65 mJ of 532-nm light focused to a diameter of 2.0 mm. The seed beam is input via a Brewster's reflection off of the Ti:sapphire crystal. A combination of two Pockel's cells, a quarter wave plate and a thin film polarizer is used for pulse selection and switch-out. A 5-ns, 3.6-kV pulse from a pulse generator switches the Pockel's cell. A total of 20 round trips in the cavity is required to boost the pulse energy from 5 nJ to 7 mJ.

The pulse is then amplified up to the 60-mJ level in a double pass Ti:sapphire preamplifier. The 7-mm-diameter by 20-mm-long, 0.15% doped, Ti:sapphire rod is pumped with 250 mJ of 532-nm light focused to a 3.0-mm-diameter spot. After the first pass the output energy from the Ti:sapphire beam is 28 mJ, and after the second pass, the double pass gain is 8.6 to yield pulse energies of 60 mJ. At the output of the preamplifier, the diameter of the Ti:sapphire beam is 2.9 mm. In order to improve the spatial quality of the output from the Ti:sapphire preamplifier, a vacuum spatial filter is placed between the preamplifier and the final amplifier. The vacuum spatial filter consists of a 125-μm-diameter diamond pinhole that has a 75% energy throughput efficiency including reflection losses from telescope lenses and vacuum port windows. The output energy after the vacuum spatial filter is 45 mJ. The telescope for the vacuum spatial filter is also used to expand the Ti:sapphire beam diameter to 4.2 mm before seeding the final amplifier.

The final amplifier consists of 12-mm-diameter by 20-mm-long, 0.15% doped, Ti:sapphire rod which is pumped with 400 mJ of green from the second output arm of the 532-nm pump laser. The single pass gain of the final amplifier is 2.6, yielding an output energy of 110 mJ for the Ti:sapphire beam. The beam diameters for the pump and the Ti:sapphire beam at this point are 4.4 mm and 4.2 mm, respectively. Before injecting the amplified Ti:sapphire pulses into the grating compressor, the beam diameter is expanded and collimated to a diameter 9.3 mm with a dual lens telescope in order to minimize any potential for optical damage to the compressor gratings. After the telescope, the Ti:sapphire pulse energy is 95 mJ.

After, the Ti:sapphire amplifier chain, the pulse width is compressed by a factor of 3200 with a parallel grating pair. The compressor consists of a pair of 2000 lines/mm gold-coated holographic gratings separated by 74 cm. Although compressed pulse widths of 110 fs are achievable, day-to-day operation of the system yields a typical compressed pulse width of 125 fs. The throughput energy efficiency of the grating pair compressor is 45%, and the output pulse energy of the compressed beam is 43 mJ. The spectral width of 8.8 nm for the compressed pulse yields a time-bandwidth product of $\Delta\nu\Delta t = 0.443$. Upon measuring the output energy stability at a repetition frequency of 5 Hz, the pulse-to-pulse amplitude stability is within 12%.

4. ACKNOWLEDGEMENTS

We acknowledge the valuable technical assistance of Keith Hosack in the development of the laser systems described here.

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