LA-UR -86-1499

RECEIVED BY OSTI JUN 06 1986

CONF-860620--3

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

TITLE: SUBPICOSECOND HIGH-BRIGHTNESS UV LASER SYSTEM

LA-UR--86-1499

DE86 011271

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SUBMITTED TO SPIE Meeting on
High-Intensity Laser Processes
Quebec City, Quebec, Canada

June 2-6, 1986

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Subpicosecond high-brightness uv laser system

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Abstract

A laser system that produces intense subpicosecond pulses of 248 nm light is under development. Ultrashort pulses are generated in the visible in a synchronously-pumped mode-locked dye oscillator, heterodyned into the uv by two KDP crystals, and amplified in a chain of KrF* amplifiers. Front end output of 5 μ J is amplified to 20 mJ and focused to peak intensities of order 10^{17} W cm $^{-2}$. Additional amplification is expected to permit experiments at intensities $>10^{20}$ W cm $^{-2}$.

Introduction

The interaction of intense radiation fields with matter represents a new and fertile field of study. Ultrashort (~ 1 ps) ultraviolet optical pulses can be amplified to power levels of 10^{10} - 10^{12} watts by commercially available discharge-pumped excimer amplifiers or by electron-beam pumped amplifiers of modest aperture (of order 10^2 cm 2). Drawing from experience with large-aperture KrF* lasers in the inertial fusion program, an effort is underway at Los Alamos to develop high-brightness uv lasers capable of providing focal spot intensities $\sim 10^{20}$ W cm $^{-2}$. Such lasers will be used to study the effect of intense external oscillating fields ($\sim 10^1$ - 10^3 V/Bohr radius) on atoms, properties of highly charged ions and non-equilibrium plasmas, relativistic photon-electron interactions, and x-ray generation processes.

The basic approach being taken to this type of laser system is diagrammed in Figure 1. The system consists of a "front end" that generates subpicosecond 248 nm pulses at the microjoule energy level. Pulses from the front end are amplified in a chain of KrF* stages. Discharge-pumped amplifiers are employed as far as possible with electron-beam pumped amplifiers used for the final stage(s).

The basic design philosophy dictates use of well-developed commercial components wherever possible in the front-end and low-level amplifiers to minimize device development time and maximize reliability. Then e-beam pumping is employed to obtain maximum aperture size and medium uniformity in the final amplifier stage(s).

Figure 1. Block diagram of subpicosecond high-brightness uv laser system.

Ultrashort uv pulse generation

A block diagram of the front-end is shown in Figure 2. The basic scheme follows that of Bucksbaum et al.¹ Heart of the front end is a folded cavity synchronously-pumped mode-locked dye oscillator tuned to 648.5 nm by a single-plate birefringent filter (Coherent 702-1). DCM dissolved in a mixture of benzyl alcohol and ethylene glycol is the lasing medium with DTDCI dissolved in methanol and ethylene glycol the saturable absorber. The dye is pumped by the frequency-doubled output of an actively mode-locked cw Nd:YAG oscillator (Quantronix 416). PRF is 75 MHz. Autocorrelation width of the oscillator output is 1.0 ps FWHM, indicating a pulsewidth of 650 fs, assuming a sech 2 pulse shape out of the oscillator.

Figure 2. Subpicosecond 248 nm pulse generator. Nominal pulse parameters are shown at each stage.

A single pulse from the mode-locked output train of the dye oscillator is amplified in a three-stage flowing-dye amplifier (Lambda-Physik FL 2003). DCM is again used as the gain dye. It is dissolved in dimethyl sulfoxide (DMSO). All dye amplifier stages are pumped by a XeCl discharge oscillator (Lambda-Physik EMP 101 MSC). Gain of the dye follows closely the temporal shape of the pumping pulse, which is only long enough (15 ns FWHM) to encompass one pulse from the oscillator output train. The 648 nm pulse is single-passed through the first two dye cells and is double-passed through the final cell. ASE is suppressed by a 2 mm thickness of Schott RG695 glass inserted between the second and third stages serving as a saturable absorber. Total ASE output of the dye amplifier is 25-30 mJ.

A 6 mm thick KDP crystal cut at 54.5° to the optical axis frequency doubles the output of the dye amplifier to 324 nm with >10% efficiency.

A unique regenerative Nd:YAG amplifier² provides 1064 nm injection to the mixing crystal. This amplifier employs a single intracavity Pockels cell biased by a simple switched charge line to perform input pulse selection, cavity Q switching, and cavity dumping functions. An optical schematic diagram is shown in Figure 3. Operation involves five sequential states: quiescent, pulse trapping, pulse amplification, cavity dumping, and quiescent again.

In the initial quiescent state, cavity oscillation is prevented by the crossed polarizers. Pulses, coupled into the cavity by P1 pass through P2, are reflected by M1, and exit the cavity via P1, counterpropagating along the input path. A pulse is trapped in the cavity by applying bias voltage to the Pockels cell after the pulse has made one pass through it. Then the pulse returning from M1 will pass through to the amplifier, M2, and back. As long as PC remains biased, the pulse will propagate straight through P1 and P2, remain in the cavity, and be amplified. Meanwhile, additional pulses entering the cavity at P1 will be rotated by PC and rejected from the cavity by P2. The amplified pulse is dumped from the cavity by removing the bias voltage from PC after the pulse has passed through it toward the Nd:YAG rod. After another round trip through the rod, the amplified pulse is rejected from the cavity by P2. The cavity is again in its quiescent state.

Figure 3. Single-pulse regenerative Nd:YAG amplifier. PC, Pockels cell; P1 and P2, crossed polarizing cube beam splitters; M1 and M2, total reflectors. L_1 and L_2 are 25 and 53 cm, respectively, and M2 has a radius of curvature of 400 cm.

The Nd:YAG rod is 7.6 cm long and 6 mm in diameter. It is single-side pumped by a xenon flashlamp. The selected input pulse from the oscillator is amplified from 100 nJ to 5 mJ in 8 round trips through the laser rod. Total energy of all unamplified pulses rejected from P2 is 6 μ J.

1064 nm output of this amplifier is combined on a dichroic mirror with the 324 nm output of the doubling crystal and the two wavelengths are focused together in a 1 m FL lens into a second 6 mm KDP crystal (cut at 64.5°) to mix and produce the 248 nm front end output pulse.

The front end system described, though complex, has proven to be highly reliable in operation at repetition rates up to 50 Hz.

Further reductions in pulse length are expected with the addition of a fiber-grating pulse compressor after the Nd:YAG oscillator. This should shorten the output pulse length of the dye oscillator.^{3,4} Peak power increases at the output of both amplifiers is expected to partially offset the reduced conversion efficiency of the shorter crystals required with shorter pulses.

Ultrashort uv pulse amplification

The 5 μ J output pulse from the front end is expanded spatially and then amplified to 20 mJ in a single pass through a Lambda Physik EMG 201E double-discharge laser in which the rear reflecting mirror has been replaced by a MgF_2 window and both cavity windows have been canted 10° to reduce feedback and ASE. Total ASE output accompanying the amplified pulse is approximately 60 mJ.

Focusing the 20 GW output of this stage to spot sizes ≤ 4 mm across permits experiments to be conducted at intensities of 10^{17} W cm⁻².

Four techniques offer promise in increasing peak powers. First, pulses can be further shortened to the bandwidth limit of KrF*, approximately 150 fs. Second, gas mix and pumping conditions can be optimized for short pulse amplification. Third, aperture size can be increased. And fourth, multiple pulses can be temporally multiplexed through the amplifier, as is done with excimer ICF drivers. The most likely approach to pulse shortening has already been discussed. Optimization of pump kinetics is best done with the flexibility afforded by e-beam pumped amplifiers which have already been scaled to apertures of 1 m.⁵

In apertures sizes larger than a few cm², both discharge and e-beam pumped excimer lasers have temporal gain times of tens of nanoseconds, very long compared to the storage time of KrF*. This suggests increasing peak powers by extracting energy from the amplifying medium more than once.⁶ The temporal multiplexing concept is illustrated in Figure 4. The gain medium is pumped to some appreciable fraction of its

maximum gain. Then a saturating optical pulse extracts the stored energy. After the depleted inversion is repumped, a second pulse extracts energy again and so on. Repumping times for KrF* are of order 5 ns. Minimum convenient electrical pump pulse widths for large amplifiers are 20-50 ns. Advantage can be taken of the long electrical pumping times by amplifying 4-10 pulses instead of one.

As illustrated in Figure 5, each pulse follows an angularly distinct path through the amplifier and a separate path to the target. Path lengths are usually adjusted so all pulses arrive on target simultaneously for maximum peak intensity. Of course, this technique lends itself easily to traveling-wave target excitation schemes, which could be important for pumping laboratory x-ray lasers.

Figure 4. Gain history of a temporally multiplexed laser amplifier. Energy is extracted at intervals roughly equal to the repumping time of the gain medium.

Figure 5. Angularly multiplexed amplifier. First pulse through medium follows longer path to target. Path lengths are normally adjusted so all pulses reach target simultaneously.

Acknowledgments

The author acknowledges with appreciation the contributions to this work of Jeffrey P. Roberts, Norman P. Barnes, T. David Nichols, Reed J. Jensen, and many other colleagues at Los Alamos. This work was performed under the auspices of the U. S. Department of Energy.

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