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TITLE: ULTRAHIGH-BRIGHTNESS XeCl LASER SYSTEM

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# Ultrahigh-brightness XeCl laser system

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## ABSTRACT

A laser system that produces terawatt-level pulses of 308-nm light with near-diffraction-limited beam quality is under development. Pulses of 175-fs duration are generated at 616 nm in a synchronously-pumped mode-locked dye oscillator. These pulses are amplified in a three-stage dye amplifier longitudinally pumped by the frequency-doubled output of a regenerative Nd:YAG amplifier. Output of the dye amplifier is frequency-doubled in a BBO crystal and amplified in a chain of XeCl excimer stages. The optical design maintains high beam quality throughout.

## 1. INTRODUCTION

The interaction of matter with intense electromagnetic fields is an area of rapidly growing research interest. Ultrashort laser pulses focused to near the diffraction limit provide an attractive means of producing irradiances > $10^{16}$ W cm$^{-2}$ for such studies. Ultrahigh brightness systems have been demonstrated using $CO_2$,[1] Nd:YAG, Nd:Glass,[2] $Cr:BeAl_2O_4$,[3] various dyes,[4,5] or excimers[6-13] as the final amplifying media. Focal spot intensities of $10^{16}$-$10^{18}$ W cm$^{-2}$ have been reported in several laboratories.[4,8,11,12] Increasing the focal intensity towards $10^{20}$ W cm$^{-2}$ generally requires more energy, shorter pulses, and better beam quality than are characteristic of existing systems. This paper reports a XeCl-based laser system that demonstrates significant improvements over existing ultrahigh brightness laser systems.

The system employs a conventional architecture. Pulses of nominally 175 fs are generated at 616 nm in a synchronously mode locked linear cavity dye oscillator. This pulsewidth is close to the bandwidth limit of XeCl[10] so further pulse shortening is unnecessary if temporal broadening is minimal through the optical train. Individual oscillator pulses are amplified in a three-stage dye amplifier. Pump power for all dye gain stages is supplied by doubled Nd:YAG. The 616-nm output is then frequency-doubled in a BBO crystal.

The first XeCl amplifier is a small aperture, commercial device. The second is an x–ray preionized 10 x 10-cm-aperture discharge-pumped system operating at 1 Hz. Output from this stage will be focused using reflecting optics.

## 2. 616-NM OSCILLATOR-AMPLIFIER

The ultrashort pulse visible oscillator-amplifier system is depicted in Figure 1. The system produces 200 μJ pulses at 616 nm with nominally 190-fs duration. It is described in more detail in Reference 14.

The linear cavity dye oscillator employs separate gain and absorber jets and a pair of dispersion compensating prisms. Rhodamine 590 and DODCI, respectively, are the gain and saturable absorber dyes. Both are dissolved in ethylene glycol. Pump power is 900 mW of 532 nm light supplied by the frequency-doubled output of an actively mode-locked cw Nd:YAG oscillator, a Coherent Antares 76-s. Repetition rate is 82 MHz. The oscillator lases at 628 nm without the birefringent filter, BF, and produces pulses as short as 70 fs. A single-plate birefringent filter tunes the oscillator to 616 nm. Output pulsewidth (determined by autocorrelation and assumption of $sech^2$ pulse shape) is 175 ± 10 fs. Spectral width is 3.9 nm, indicating a pulse less than 20% broader than the transform limit. Continuous power output is 100 mW. This corresponds to 1.2 nJ per pulse and a peak power of 7 kW.

Pump power for a dye amplifier is derived from the cw Nd:YAG pump oscillator through a Nd:YAG regenerative amplifier. Approximately 20 % of the 8 W output of the mode-locked pump oscillator is split from the beam going to the dye oscillator to provide injection pulses for the regenerative amplifier. The amplifier itself employs a single intracavity Pockels cell, PC, to perform cavity Q switching, input pulse selection, and cavity dumping functions.[15] In the quiescent state, cavity oscillation is prevented by the crossed polarizers, P1 and P2. Pulses injected into the cavity off P1 are also rejected by P1. The Faraday isolator prevents these rejected pulses from coupling back into the oscillator cavity. Biasing the Pockels cell to its half wave voltage while an injected pulse is between PC and end mirror M1 traps that pulse in the cavity until bias is removed (while the pulse is between PC and mirror M2). While this pulse is trapped, additional injected pulses are rejected by P2 without amplification. M1, M2, and aperture A form a self-filtering unstable resonator cavity.[16] M1 and M2 have focal lengths of 25 and 200 cm, respectively, and A (0.7 mm diameter) is located at their common focus. P1 and P2 are thin film dielectric polarizers. The maximum energy extractable from this amplifier is limited by the optical damage threshold of the Pockels cell. Four round trips produce 80 ± 5 mJ in this application. This output is then frequency doubled in a 15 mm-long KD*P crystal to produce 40 mJ of 532 nm light to pump the dye amplifier.

The dye amplifier consists of two flowing gain cells longitudinally pumped for maximum gain uniformity and hence minimum spatial distortion in the amplified pulse. Rhodamine 640 dissolved in methanol is the gain medium. The first cell is pumped from both ends by small fractions of the 532 nm pump pulse (1% to the input end and 4% the output end). The remaining 95% of the 532-nm energy pumps the second dye cell which amplifies the pulse to the 200-μJ level. Total amplified spontaneous emission (ASE) accompanying the output pulse is < 500 nJ. Autocorrelation of the output pulse indicates a pulsewidth of 190 ± 15 fs. This slight temporal broadening is believed due to self-phase modulation in the dye. Pinhole transmission measurements indicate the beam diameter at focus is 1.4 times diffraction-limited.

## 3. UV CONVERSION AND PREAMPLFIER

Output from the dye amplifier is frequency doubled to 308 nm in a 0.5 mm long BBO crystal with a conversion efficiency of 20 %. The UV pulse is expanded spatially and amplified to 3 mJ in a single pass through a Lambda-Physik 201 MSC amplifier. This amplifier is followed by a vacuum spatial filter with its aperture set 1.9 times the first airy disc diameter. Approximately 2 mJ passes through the filter, indicating little degradation of beam quality in the doubling crystal, preamplifier, and associated optics. The beam is then expanded in a 6.7x reflecting telescope to match the input aperture of the final amplifier.

## 4. FINAL AMPLIFIER

The final amplifier is illustrated schematically in Figure 2. It is an x ray preionized, discharged pumped device with two identical, independently pumped gain regions. Each discharge volume measures 10 x 10 x 250 cm and is preionized by 130 keV x rays from a common preionizer unit. Electrical pump power for each section is supplied by a thyratron-switched capacitor- discharge system with a two-stage magnetic pulse compressor to reduce the pumping time to about 60 nsec FWHM. The amplifier is designed to fire at a sustained repetition rate of 1 Hz. Hence it includes a transverse gas flow and gas cooling system. Wavefront distortion across 80% of the aperture is measured at less than λ/20 at 632.8 nm in flowing unpumped gas. Gas clearing time after a shot is 800 ms, permitting fresh,cold gas to be used for each shot.

The amplifier was originally operated with a He diluent at a total pressure of 1100 Torr. Better gain uniformity has been achieved using a $N_2$ diluent and a total pressure of 1700 Torr. Pump rate is presently about 100 kW $cm^{-3}$. Small-signal gain in each pass of the amplifier measures 4.6 on the centerline and falls by about 25% at the top and bottom of the discharge. Gain is constant to within ± 10% across the aperture between cathode and anode. Optimization of gas mix and pressure, preionization, and pulse power circuitry is underway to increase the gain to between 5.0 and 6.0 across the entire aperture.

Initial amplification experiments with an ultrashort pulse from the low level stages produced total output energies of order 80 mJ. This is expected to increase as pump rate and gain are increased across the aperture.

## 5. BEAM TRANSPORT

With the final amplifier operating at its design point, the peak optical intensity at the output window will be about $5 \times 10^{10}$ W $cm^{-2}$. Brightness preservation between the gain medium and a target requires minimizing two-photon absorption, non-linear refraction, and color center absorption in the windows and reducing both linear and nonlinear refractive effects in air. Brightness losses in air can be eliminated by transporting the beam in vacuum. Two-photon absorption in windows can be minimized by choosing window materials, such as the alkali earth halides, that have band-gap energies greater than twice the 4 eV photon energy.[17] Most of these alkali earth halides also show little tendency to form color centers at 308 nm. ($MgF_2$ and LiF form color centers readily at 248 nm.) Nonlinear refraction (self focusing) cannot be eliminated at these intensities. It can be minimized by choosing window materials with low nonlinear refractive index ($n_2$), minimizing the total thickness of the window(s) between final amplifier and target, and eliminating "hot spots" in the beam

## 6. SUMMARY

An ultrahigh-brightness laser system based of XeCl is nearing completion. Pulses of < 200 fs duration have been generated and amplified at 616 nm, frequency-doubled, and amplified by two XeCl amplifiers. The 100 cm$^2$ aperture final amplifier is being optimized. No significant temporal broadening has yet been observed in the system. Beam quality is maintained near diffraction limit. This system, operating at 1 Hz, promises to provide focal spot intensities significantly greater than $10^{18}$ W cm$^{-2}$ for laser-matter interaction studies.

## 7. ACKNOWLEDGEMENTS

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## (FIGURE CAPTIONS)

Figure 1. Optical schematic diagram of 616-nm oscillator-amplifier system. BF, birefringent filter; M1 and M2, mirrors, P1 and P2, thin film dielectric polarizers, PC, Pockels cell, A, aperture

Figure 2 Schematic diagram of the final amplifier Each discharge region is 25 cm in length

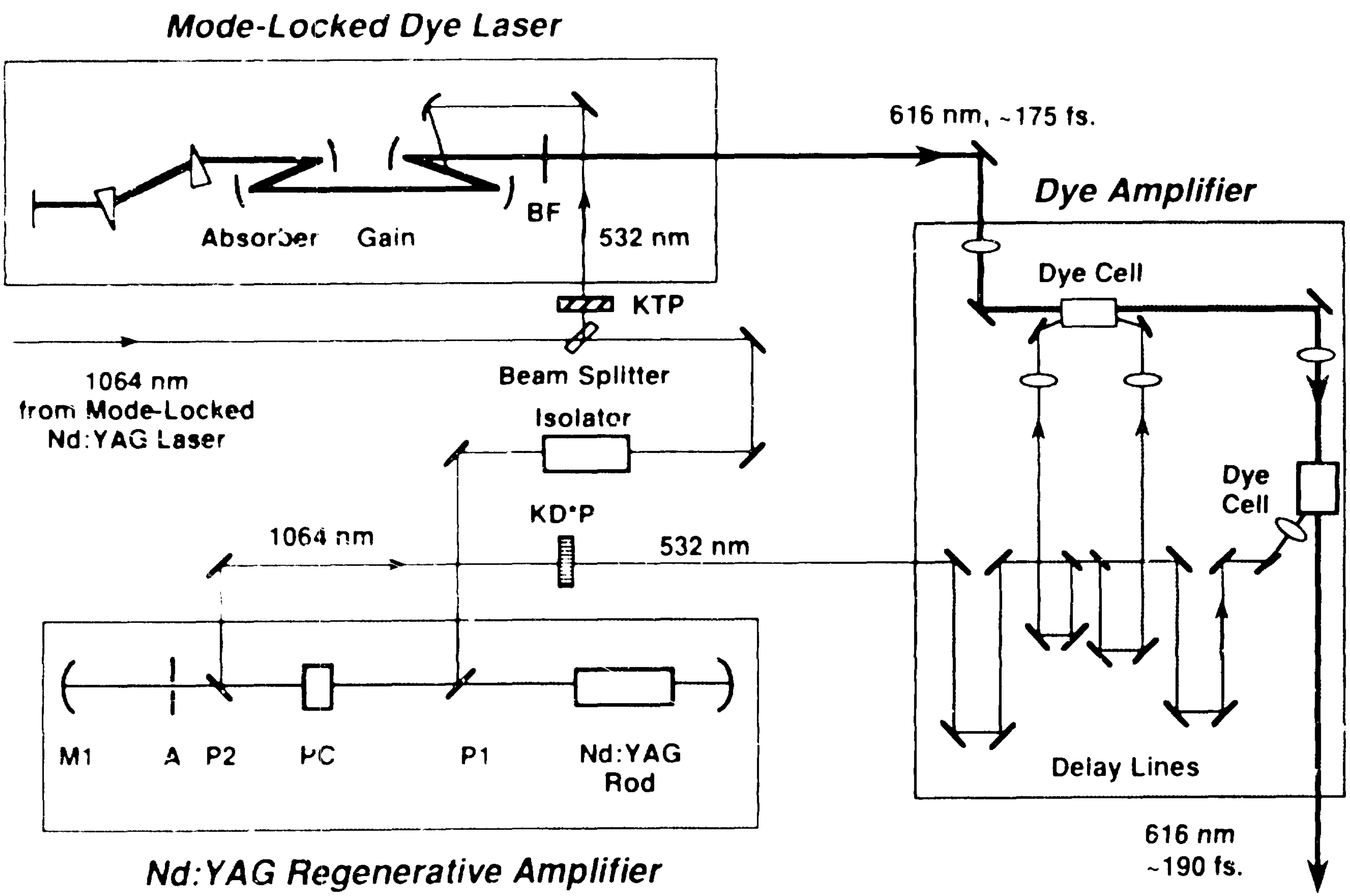


Figure 1

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# LARGE APERTURE AMPLIFIER

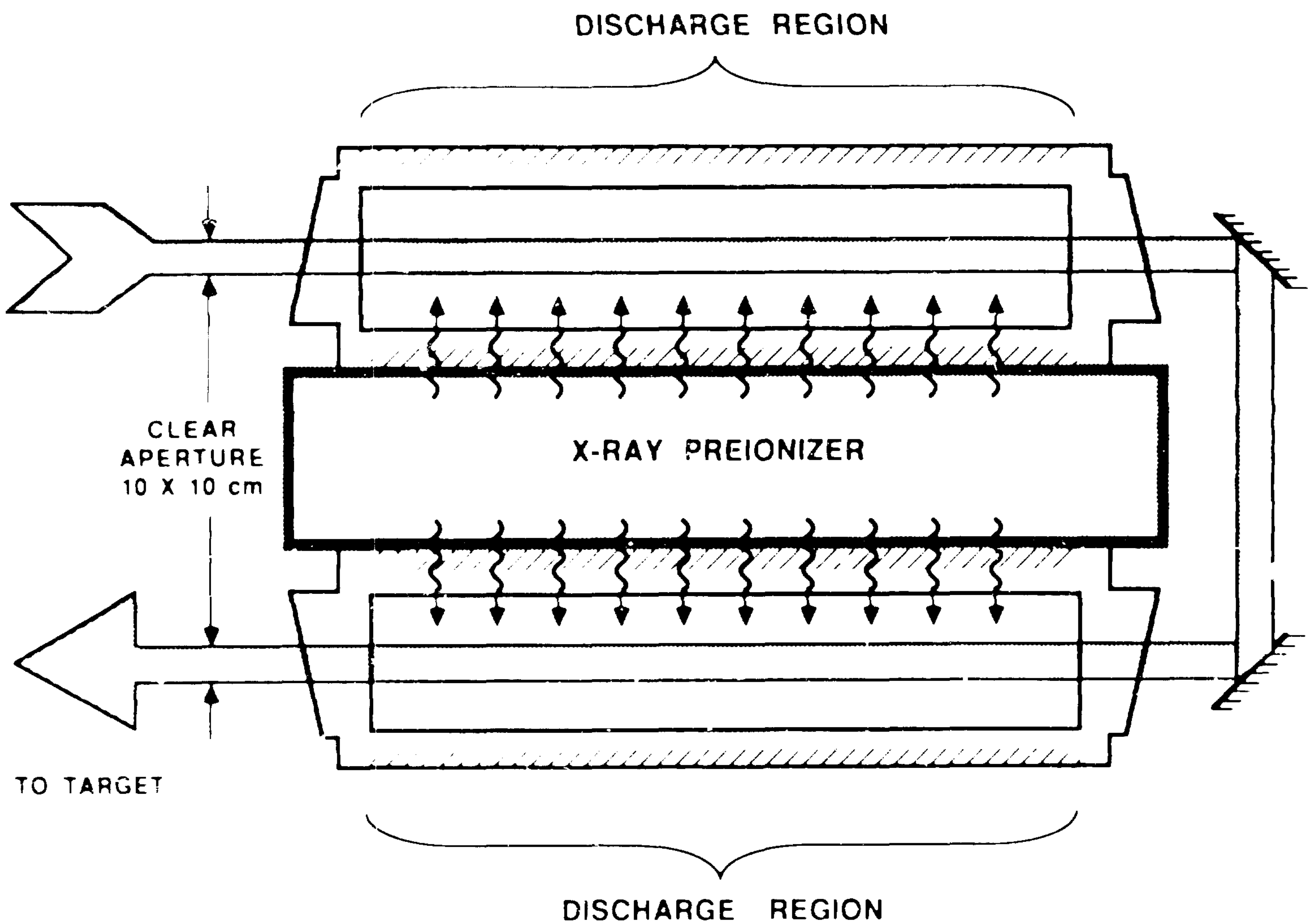


Figure 2

CLS-VG-3579 A