Performance of the Asterix III High Power Iodine Laser

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***Abstract*—For more than 500 shots the 1 TW iodine laser Asterix III has demonstrated high reliability for light-plasma-interaction experiments. Improved laser parameters and new measurements of light pulse properties are reported.**

I. INTRODUCTION

SINCE the high power iodine laser Asterix III initially achieved an output power of 1 TW two years ago, more than 500 target shots have been made. During this two-year period, it was demonstrated that a large iodine laser can meet the requirements of high-quality target experiments. The iodine laser itself was found to be a reliable tool for laser-irradiated plasma experiments.

Following an introductory survey of the iodine laser system, the present status of Asterix III and the details of those parameters that characterize the laser pulses are described.

II. SYSTEM CONFIGURATION

The schematic of the Asterix III laser system is shown in Fig. 1. The terawatt output pulse is generated by a single oscillator-amplifier chain. A pulse is selected from a mode-locked oscillator pulse train by an optical switch out and amplified by four amplifier stages of successively increasing diameters, lengths, and stored energies. Along the diverging beam path of 150 m, the beam diameter is intentionally increased from 0.2 to 16 cm.

Unlike a comparable Nd-glass laser system [1] and differing from our previously reported Asterix III configuration [2], the present Asterix III iodine laser system needs only *one* Faraday rotator placed between the third and fourth amplifiers to protect the laser system from retroreflected light from the target. This is due to the fact that the spectral bandwidth of the retroreflected laser light is much broader than the gain bandwidth of the iodine laser amplifiers.

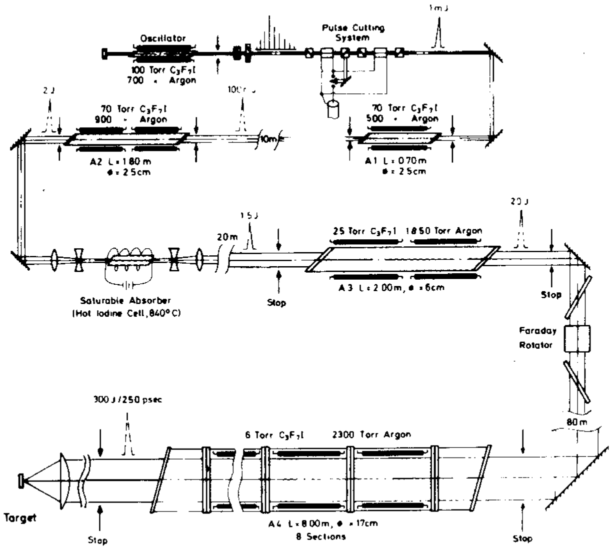

Fig. 1. Schematic of Asterix III iodine laser.

An important property of the high power iodine laser is that the laser pulse is amplified in a range where the amplifiers start to saturate. As a consequence, the small signal gain exceeds the actual energy gain by three orders of magnitude. This requires special measures to reduce the prepulse power so that sensitive targets are not damaged before the main pulse strikes the target. In order to reduce the leaking of the oscillator pulse train through the closed pulse selection system, an optical switch-out with two Pockels' cells/Glan prisms in series is used to achieve a contrast ratio better than 10^9.

The other source of potential target damage, amplifed fluorescence, is suppressed by a saturable absorber using thermally dissociated iodine molecules. This absorber exhibits a ratio of small signal to saturation transmission of about 10^{-3}.

Special emphasis should be put on the fact that for a 1 TW iodine laser there is no need for spatial filters to strip off intensity fluctuations in the beam cross section.

III. PERFORMANCE DESCRIPTION

A. Pulse Energy, Duration, and Power

With the Asterix III laser, an output power of 1 TW has been realized at an energy level of 300 J on target and a pulse duration of 280 ps. Fig. 2 depicts the energies of the last 246 shots correlated with shot numbers. Most of the shots exhibit energies near 100 J because of lower pumping energy to the flashlamps. The indicated high energy shots were taken at the full pumping energy of 370 kJ. The 300 J output energy corresponds to an overall efficiency of 0.08 percent. It should, however, be

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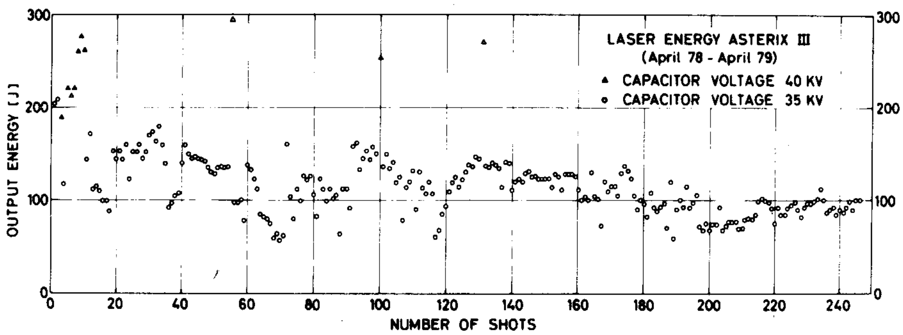

Fig. 2. Output energies of Asterix III for the last 246 shots.

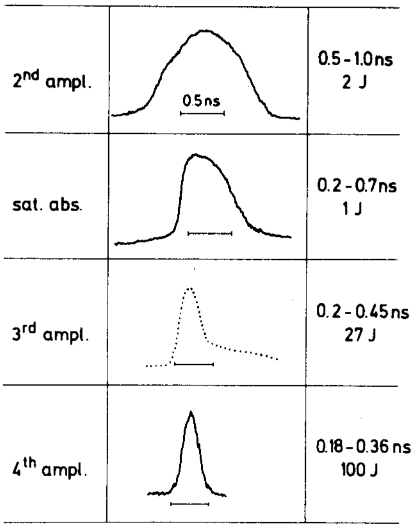

Fig. 3. Number of laser pulses versus pulse duration histogram. Pulse durations longer than 0.4 ns are due to oscillator malfunctions.

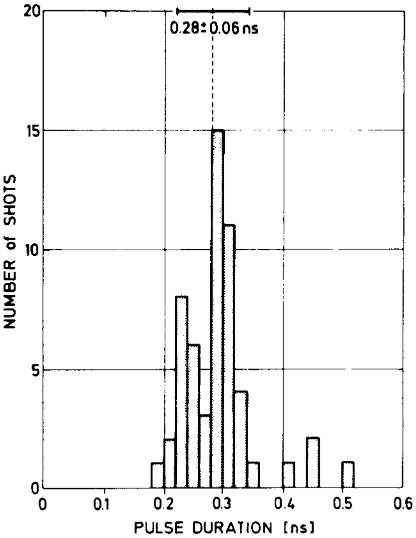

Fig. 4. Time evolution of the laser pulse along the chain. Right column tabulates the range of observed pulse durations.

emphasized that this efficiency was obtained without significant optimization of the laser chain.

The histogram in Fig. 3 shows that pulse durations range from 180 to 360 ps with a mean value of 280 ps. The few pulses shown with longer durations are correlated with oscillator malfunctions.

The temporal shape of the laser pulse evolves as it travels along the laser chain. As shown in Fig. 4, a substantial pulse steepening and shortening takes place in the saturable absorber and to a minor degree also in the saturated final two amplifiers. Altogether the pulse length decreases from 750 ps at the oscillator to 280 ps at the output.

Bandwidth measurements performed with a Fabry-Perot interferometer yielded a pulse bandwidth of about 2 GHz. Pulse duration and bandwidth measurements revealed that the iodine laser pulses are transform limited. This result is supported by streak camera measurements of a temporally smooth pulse without any substructure longer than the 20 ps time resolution of the EPL ICC 512 camera.

B. Prepulse Energy

The prepulse energy was measured with a sensitivity relative to the main pulse of 3×10^{-10}. Only the prepulses leaking through the pulse selection system have been observed. This contribution to the prepulse energy was only 2 μJ, whereas the contribution of amplified fluorescence lies below our detection threshold of 100 W. The threshold for energy detection with respect to the flashlamp pumping time of around 10 μs is less than 1 mJ.

C. Beam Quality

In order to get a measure of the beam quality, the focusability of the laser beam has been measured using both multiple spot and diaphragm methods. The results of both methods agreed within experimental error. In Fig. 5, the ratio of measured focal spot sizes to the ideal spot sizes is plotted versus the beam path length in the Asterix III system. At the exit of the fourth amplifier, the focal spot size was 2-3 times larger than the diffraction limit. It should be emphasized that the target focal spot is independent of the output power. Therefore, we ascribe the observed deterioration of beam quality along the beam path to intensity-independent influences. In contrast to comparable Nd-glass laser systems, at our power levels and conditions, we have found no nonlinear contributions from the laser medium and only small contributions from optical glass components. In addition, the nonlinear contribution of anomalous dispersion, which arises when the gain line saturates, has not been observed to be of significance. Finally, the beam quality along the beam path is reduced by windows, mirrors, and polarizers as well as gaseous optical inhomogeneities in the laser

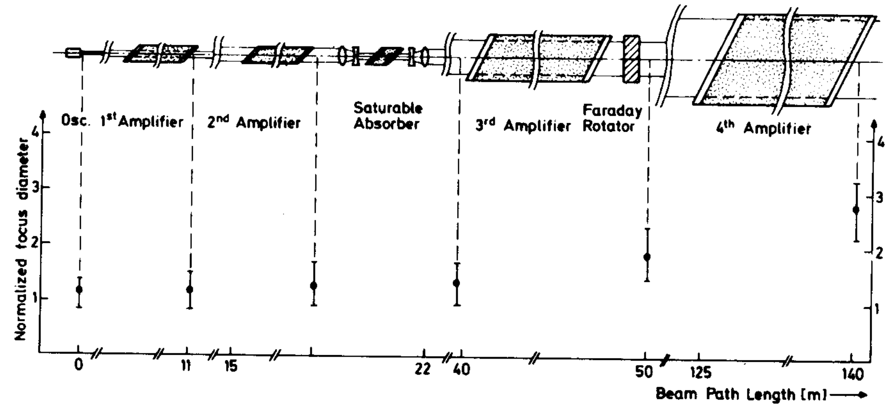

Fig. 5. Relative focused spot size of Asterix III laser at various locations along the laser chain.

Fig. 6. Lateral shearing interferogram after the 16 cm aperture amplifier. The illustrated deviations from a straight line are of stochastic nature and correspond to a wavefront distortion of about one wavelength.

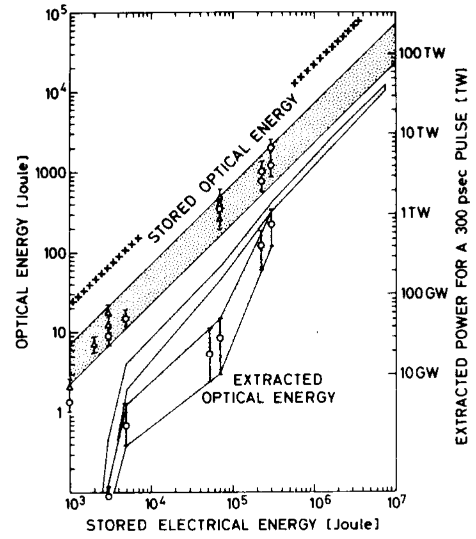

Fig. 7. Optical energies as a function of electrical bank energies. Circles and triangles represent experimental values derived from Asterix III and Plasterix, respectively. The grained band denotes the stored optical energy, the mottled band denotes the extracted optical energy, and the dotted band illustrates the projected extracted energy after the staging has been optimized. Note that the upper band can be shifted to the cross-hatched line if anticipated increases of amplifier pumping efficiencies are realized.

medium and in the air lying between amplifiers. To investigate these effects we took lateral shearing interferograms at different positions along the beam line of Asterix III.

Fig. 6 is an example of an interferogram taken in the horizontal shear direction at the 16 cm exit aperture of the fourth amplifier. Here the maximum wavefront distortion is approximately one wavelength. A comparison of interferograms from different shots with and without the fourth amplifier in operation allowed us to identify random air turbulence along the beam path as the main source of wavefront distortion in Asterix III.

In addition, the directional stability of the laser beam was measured in a series of shots. In the horizontal and vertical directions, a maximum deviation of 20 ± 5 μrad was found, presumably caused by temperature gradients in the active medium and mechanical instabilities in the mirror mounts.

VI. Scaling of Iodine Lasers to Higher Powers

In Fig. 7, the scalability of the iodine laser to higher powers is illustrated. The thick upper band covers experimental values for stored energies as a function of the pumping energy. When improvements in amplifier pumping efficiency are realized, we estimate that the stored energy at a given input energy can be doubled. This estimate is shown in the cross-hatched line in Fig. 7. The lowest band shows our current output energies at different amplifier stages of Asterix III and Plasterix, respectively. The middle band illustrates an optimized staging of the present iodine laser. Assuming final amplifier apertures of 90 cm, output energies as high as 10 kJ/chain can be anticipated, delivered independently of pulse duration (from 0.2 to a few ns) in a high-quality beam.

V. Summary

Asterix III has demonstrated that the iodine laser meets all the requirements for high-quality laser plasma experiments. Furthermore, this performance is achieved without nonlinear degradation of the beam quality. Concerning performance, complexity, scalability, and costs it compares well with the other large fusion lasers. In addition, it has the advantage of a good repetition rate (1 shot/10 min) and still pulsewidth flexibility. Its potential for further improvements has not yet been fully explored.

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