Initial Target Experiments with the Iodine Laser*

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Abstract

An iodine laser with output powers up to 40 GW and energies up to 30 J has been built specifically for laser-plasma experiments. Target laser problems such as prepulses, isolation of the laser against backreflected light and focusibility of the outputbeam are discussed. Maximum intensities up to 10^{15} W/cm^2 are obtained. First reflection data obtained with a plane plexiglasstarget are presented.

1. Introduction

During the last years the production of high-power radiation with the iodine laser has been demonstrated at several places in the world /1, 2/. At Garching recently 1 TW pulses of 500 J within 500 ps have been obtained /3/. However, until now no experience existed in using this type of laser for plasma production. In this report we present preliminary results of the first target experiments. The main goal of these experiments is to investigate target-laser problems, which occur if a laser is used for plasma production. Important problems are target damage by prepulses, focusibility of the beam and isolation of the laser against backreflection.

2. Setup

Figure 1 shows schematically the setup of the laser ("Plasterix"), which is similar to "Asterix II" /4/. An acoustooptically mode-locked oscillator is followed by a pulse cutting system for single pulse selection and 3 amplifiers A 1, A 2 and A 3. A contrast ratio better than 1 : 10^8 for the pulse selection consisting of 2 KD*P-Pockels cells and 3 Glan prisms has been measured. For isolation against backreflection from the target Faraday rotators are installed. To minimize selfoscillation the amplifiers and also the final amplifier and the target are seperated by large distances, the total light path being 70 m. A saturable absorber /5/ for prepulse suppression, isolation and pulse shortening /6/ will be installed in the future, but was not used for the results presented here.

Typical parameters of the laser are given in table 1. The maximum energy obtained was 30 J within 600 to 800 ps FWHM. The large signal gain of the total system is about 10^4, whereas

Table 1 Typical Laser Parameters

	Osz.	A 1	A 2	A 3
Length (cm)	100	150	150	170
Diam. (cm)	0.8	2.6	2.6	7
Capacitor Energy (kJ)	1	2	3	70
$P_{C_3F_7J}$ (Torr)	100	70	70	30
P_{Ar} (Torr)	700	200-400	600-700	1500-2000
Laser energy stored (J)	1.3	9	12	170
Energy extracted (J) (ns-pulse)		0.1	2	30

the small signal gain is much larger, 10^6 to 10^7.

An aspherical f/1 lens (f = 13 cm) focuses the laser beam (of 6,5 cm diameter in front of the focusing lens) onto plane solid targets, see Fig. 2. The diagnostics used allow for measurement of the incident and backscattered light by calorimeters and vacuum photodiodes, of prepulses by a prepulse detector (vacuum photodiode operating on a μs time scale) and of back-reflected light after amplification by the final amplifier. Plasma ions were monitored by time-of-flight ion collectors.

3. Focal spot diameter

The focal spot diameter obtained with the aspherical lens has been measured by the multiple spot method. For that purpose the laser beam is split into several directions by two nearly parallel mirrors and is focused onto Polaroid film to give a series of burn spots. The laser was fired at full power with attenuators in front of these mirrors. From the radial intensity distribution thus obtained the radius for half energy is calculated by integration. It is plotted in Fig. 3 for different axial positions. In the focus the radius for half energy is 20 μm, yielding an average intensity of 10^{15} W/cm^2 for 20 J laser pulses of 0.7 ns duration. Since the large aperture lens used is not perfect, we conclude that the actual beam divergence is less than 2 x 20 μm/13 cm = 300 μ rad, which is about 10 times the diffraction limited value.

4. Prepulses

In any laser system consisting of an oscillator followed by an amplifier chain operating in saturation for high efficiency, the ratio of small to large signal gain is high. In such systems (for example, the iodine laser) the prepulse problem has to be considered carefully.

The output from the pumped amplifier chain has been measured when the oscillator was blocked. For high gains, which are necessary for an output energy of 30 J, we then found energies of about 100 mJ. This energy appeared in several spikes of about 100 ns duration. This type of radiation is attributed to selfoscillation of the entire amplifier chain. Since the main pulse passes the amplifier chain not before the selfoscillation sets in, this gives rise to prepulses of the order of 10 mJ/100 ns per selfoscillation spike. We mention that these values should not be considered as fixed, since they may depend critically on details in the setup of the laser.

Compared with that contributions due to amplified spontaneous emission and due to the finite contrast ratio of the pulse cutter are expected to be much smaller. The fluorescence was estimated from

$$E_{fl} = \tau A E_{st} \frac{\Delta\Omega}{4\pi} \frac{g_{sm}}{\ln g_{sm}} f \; ;$$

where τ is the pumping time, $A_0 = 8s^{-1}$ the coefficient for spontaneous emission /7/, E_{st} the energy stored in the amplifier, $\Delta\Omega$ the solid angle with which the first amplifier views the focusing lens, g_{sm} the small signal gain and $f \lesssim 1$ a factor accounting for the narrowing of the spontaneous line profile during the amplification. For typical parameters of the total amplifier chain one finds $E_{fl} \approx 10$ to 100 µJ within the pumping time of about 10 µs. Modelockpulses passing the closed pulse selector give at the output an energy of 10 to 100 µJ/ns taking into account the measured contrastratio of the pulse selector and the small signal gain of the amplifier chain.

Thus at present in the Plasterix system the largest contribution to prepulses is caused by selfoscillations of the system. The measured values, producing intensities of the order of 10^9 W/cm^2 on the target, can probably be tolerated in experiments with transparent targets /8/. To allow, however, a wider class of experiments including those with nontransparent targets selfoscillations have to be reduced. In the future we will investigate optimum conditions including saturable absorbers to minimize this prepulse contribution.

5. Backreflection and Isolation

In the first interaction experiments the reflection R_L back through the lens from a plane plexiglass target ($C_5\ O_2\ H_8$) being perpendicular to the laser axis has been measured. Figure 4 shows the variation of R_L for various target positions for a roughly constant laser energy of about 8 J. We mention that finer structures as found for the dependence of R_L on the target position in very careful experiments with a Nd-laser /8/ may be present but are not resolved in these first iodine target shots. For the points of highest reflection the diameter of the crater produced on the plexiglasstarget is smallest, being 250 µm. In Fig. 4 also the velocity of the main part of the plasma (defined by the maximum of the ion current) as measured by a time-of-flight probe viewing under 45° to the laser axis is plotted. We remark that in the region of highest reflection fast ion groups appear as is expected on the basis of experience with Nd-glass laser experiments with the intensities applied here /9/.

Fig. 4 shows considerable high reflection losses up to about 40 %, when the target is in the position of maximum reflection. Since we have measured here only the reflection losses through the focusing lens, we can conclude that for this target position the absorption is less than about 60 %. However note that the focusing lens is larger in diameter than the incident beam and therefore the reflected light is collected in a solid angle 4 times larger than the solid angle of the incident light.

For the isolation of the laser the amplification of the reflected light coming back through the amplifier chain is of importance. Therefore the backreflected energy has been measured in front and behind the final amplifier. Simultaneously the divergence of the backreflected beam has been controlled with burn paper in front of the dielectric polarizers of the Faraday rotator system. Even for well collimated beams the backamplification by the final amplifier did not exceed values between 1.5 and 2. We assume this weak backamplification can be attributed to spectral broadening of the backscattered light /10/, which may be large compared with the gain bandwidth of the final amplifier which is only 0.4 Å /7/. Estimating the backamplification by

$$g_{back} = \int g_{pL}(\nu) \cdot g_{sm}(\nu)\, d\nu$$

where $g_{pL}(\nu)$ is the line profile of the backscattered light and assuming $g_{sm}(\nu) = \exp(\sigma(\nu)\Delta n L)$ (the small signal gain), one finds that the measured values of g_{back} are consistent with 5 to 10 Å broadened backscattered light. These results will be supplemented by spectral measurements in the future.

6. Summary

The iodine laser with its potential to produce sub-ns TW pulses is a powerful candidate for laser-fusion experiments. We have now, for the first time, demonstrated the suitability of the iodine laser for plasma production experiments. The output beam has been focused to 40 µm diameter for half energy yielding intensities up to 10^{15} W/cm^2. Isolation against backreflection turned out to be a minor problem due to spectral broadening of the backscattered light. The contribution from selfoscillation dominates prepulses, whose suppression must be improved in future experiments. Initial reflection data obtained with a plexiglass target gave values up to 40 % into the focusing optics indicating an absorption not higher than 60 %.

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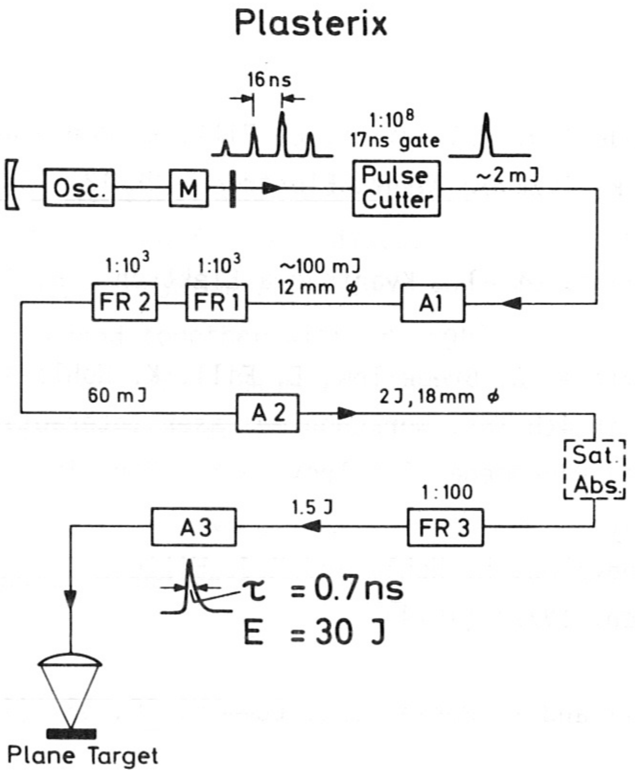

Fig. 1 Schematic setup of the iodine laser Plasterix

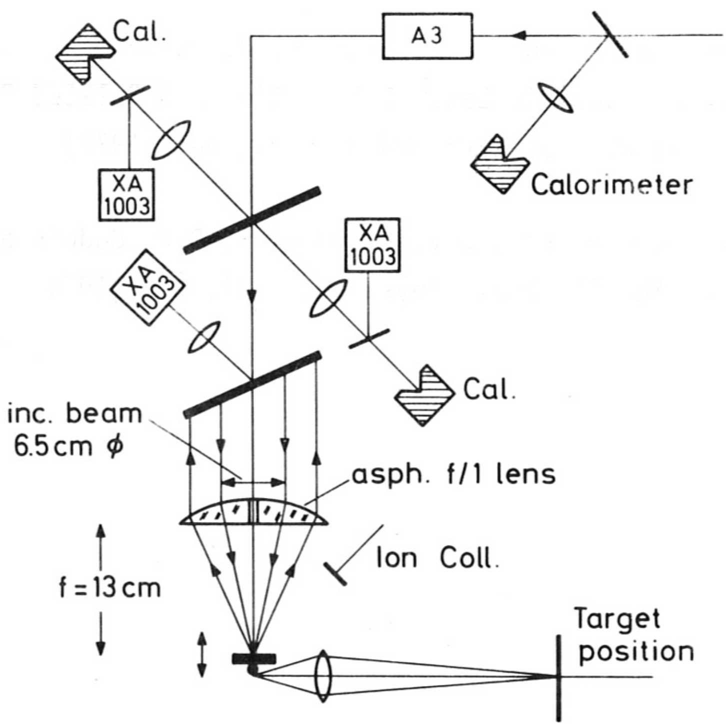

Fig. 2 Schematic setup of the diagnostics used

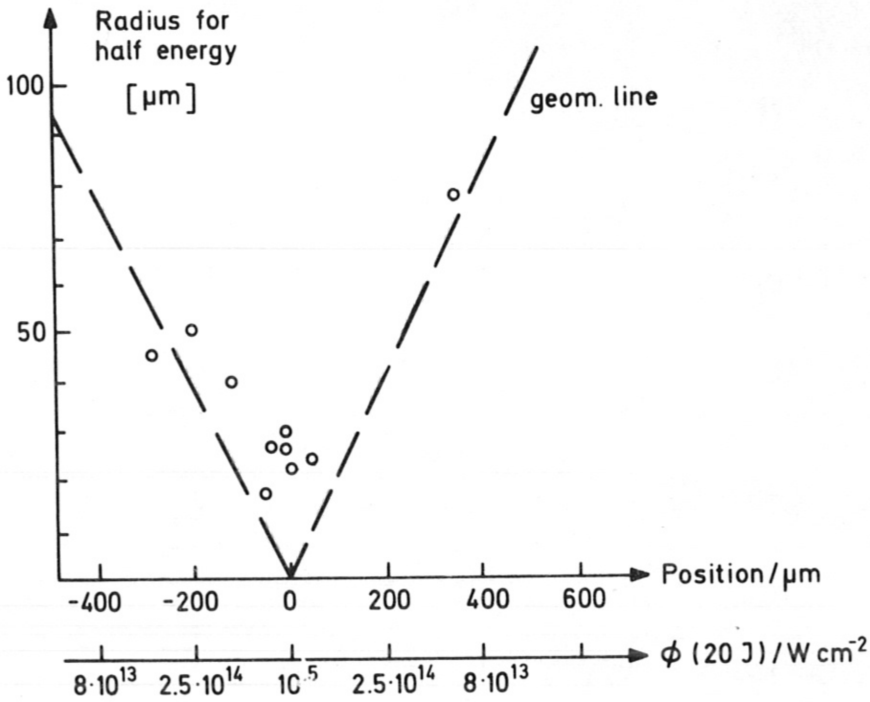

Fig. 3 Focal spot diameter (radius for half energy) in the focal region. Also shown is the geometrical contour for half energy (broken line)

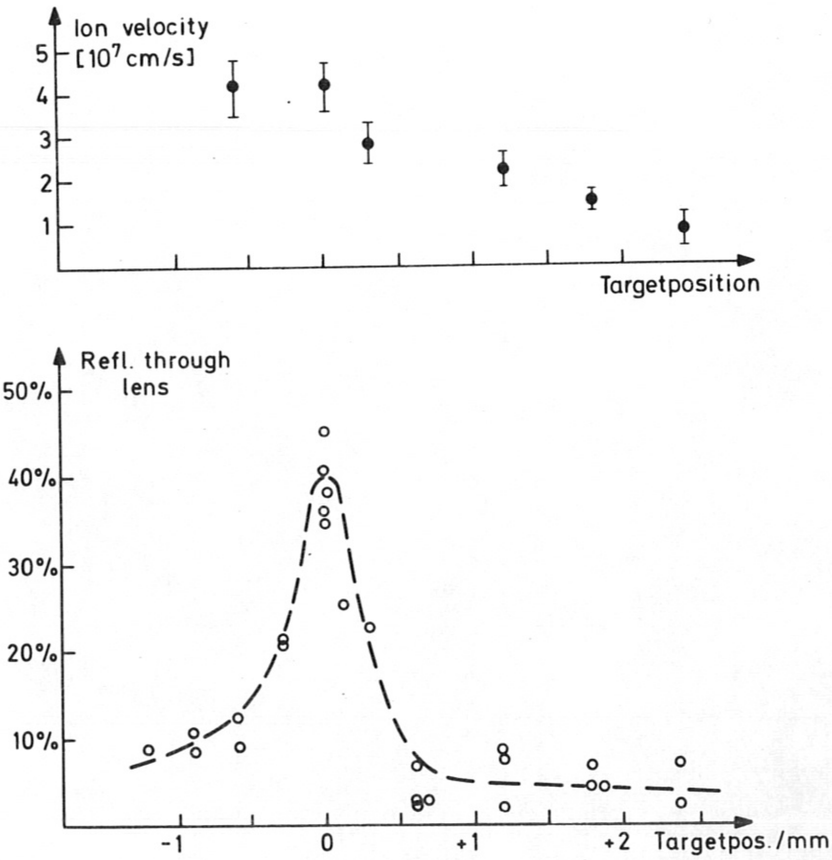

Fig. 4 Reflection through the lens and ion velocity for different target positions with a Plexiglass target