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A 3 ps Synchronised Multi-frame Photographic Diagnostic for Target Experiments with the Iodine Laser*)

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Abstract

A laser system is described with which we obtain a sequence of 6 pictures (interferograms or shadowgrams) of the plasma produced by the iodine laser on solid targets. The system consists of a synchronously pumped dye laser amplified in dye cells pumped by an excimer laser. It delivers a pulse with an energy of 400 µJ and a length of 3 ps at a wavelength of 580 nm that is highly synchronous with the iodine pulse.

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Introduction

High-speed photography is a valuable tool for studying the coronal physics in laser-produced plasmas. Two years ago in our laboratory an actively-passively mode-locked flashlamp pumped dye laser was synchronised with the ASTERIX III iodine laser and was used as a diagnostic for laser-accelerated foils /1,2/ and for shock wave propagation and for internal breakdown in plexiglass /3/. For a detailed description of this set-up see /4/. In spite of the results achieved with this system its possibilities were rather limited: the energy (a few microjoules) and the beam quality (multi-mode) were insufficient for making more than one picture per target shot and for doing interferometry. In addition, the low repetition rate (1 pulse every 10 seconds) and critical maintenance imposed a restriction to applying it in more advanced diagnostic set-ups.

A new diagnostic system should ideally meet the following requirements:

- good synchronisability with the main (iodine) laser;
- operation independent of the iodine laser; operation in fast pulse mode or cw would greatly facilitate its alignment and testing;
- pulse duration independent of the duration of the main laser pulse, and short enough for resolving the fastest phenomena in the corona (~10^8 cm/s; with a spatial resolution of 1 µm this requires a pulse duration of a few ps);
- beam energy ≧ 100 µJ, sufficient for a sequence of several frames with relative time delay;
- beam quality suitable for interferometry;
- tunability in wavelength might be of interest in order to amplify the pulse in excimer lasers after frequency doubling.

To date the only lasers commercially available which are capable of delivering pulses of 1-5 ps duration are mode-locked Nd-glass and dye lasers. The Nd-glass laser has the disadvantage of low repetition rate; the so-called synchronously pumped dye laser on the other hand is quasi cw: this laser is pumped by an actively mode-locked argon laser of the same resonator length and delivers a pulse every 13 ns, but with low energy (2 nJ), and so amplification is necessary. Amplification of ps pulses in a series of dye cells has become a well-known technique. Marinero and Schäfer /5/ have reported on amplification of 2 ps pulses with N_2-lasers pumped dye amplifiers

to 100 µJ; Migus et al. /6/ have realized 0.5 ps /1.5 mJ pulses with a larger Nd YAG pumped system; recently Corkum /7/ reported on amplification of frequency-doubled 2.5 ps pulses at 308 nm in a XeCl-laser to an energy of 40 mJ. For our problem the right way therefore seems to be to generate the short (synchronised) pulse in a synchronously pumped dye laser, followed by amplification in dye cells to an energy of a few hundred microjoules.

GENERATION OF THE SYNCHRONISED PULSE

The picosecond pulse is generated in a Coherent 599-04 dye laser which is synchronously pumped with a CR 12 argon laser (Fig. 1). This laser is mode-locked acousto-optically with a quartz prism driven by a 467 SEM mode lock driver. The prism is temperature-controlled with stability better than 0.1°C. The RF driver is tunable from 37.2 to 38.5 MHz with a precision of 1 Hz. Part of the RF output is amplified to a 5 W/1 ms pulse to drive the crystal in the iodine oscillator. Both crystals (a prism in the argon laser and a rhomb in the iodine oscillator) were cut from the same mother block to ensure that the resonances are identical within 7 KHz. In addition, the rhomb in the iodine oscillator can be tuned over its temperature (3 KHz/°C in quartz).

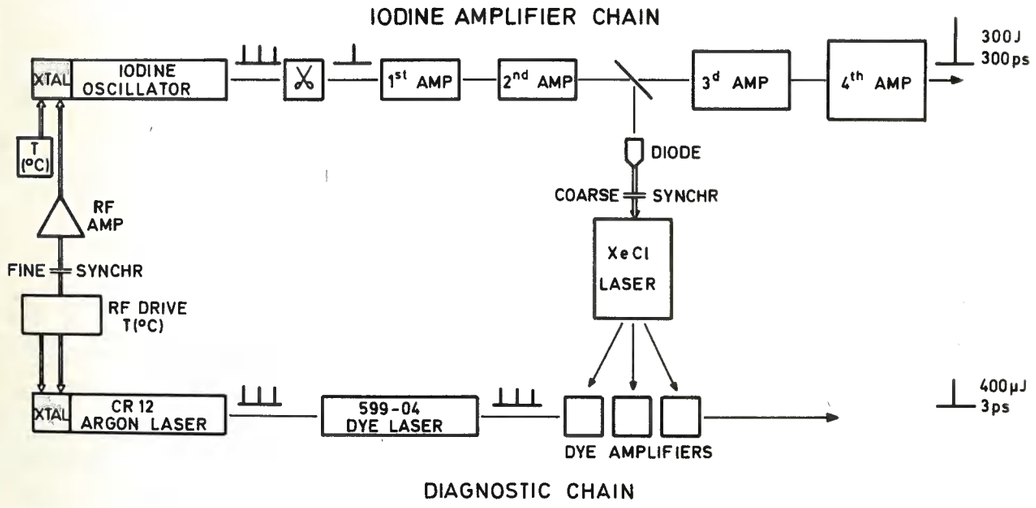

Fig. 1 Experimental set-up of the oscillator-amplifier chain to generate the synchronised diagnostic pulse.

To check the synchronism of the two mode-lockers, we monitored the pulse from the argon laser (width 150 ps) and the iodine pulse selected by the pulse selection system (width 600 ps) with a XA 1003 fast vacuum diode on a Tektronix 7104 oscilloscope. The jitter between the peak-to-peak distance of the pulses over two hours is less than 100 ps (i.e. the measurement accuracy).

For the amplification of the pulse in dye cells a Lambda Physik EMG 100 excimer laser was chosen for pumping the cells. This laser is thyratron-triggered and has a low jitter of 2 ns; we use the laser at 308 nm with XeCl. With argon as buffer gas it delivers 180 mJ in 30 ns, 120 mJ of it during the first 10 ns. To make sure that the right pulse from the dye laser is amplified, the excimer laser is triggered by part of the selected iodine pulse after the second iodine amplifier. For this purpose we had to shorten the time delay in the excimer laser between the trigger input pulse and laser action. In the commercial Lambda Physik lasers the delay is 700 ns. By modifying the trigger electronics in a way similar to /8/ we could bring the delay back to 250 ns with 2 ns jitter. For comparison we mention that the beam path of the iodine laser from the second amplifier to the target is 330 ns: we therefore have 80 ns at our disposal for amplification of the diagnostic pulse and guiding it to the target chamber. Fine synchronisation between the diagnostic and iodine laser is achieved by changing the length of the iodine mode locker; coarse synchronisation can be achieved by changing the cable between the trigger diode and the trigger electronics of the excimer laser.

AMPLIFICATION

We shall only briefly summarize our amplification chain and refer to the literature for an extensive discussion of amplification in dye cells /e.g. 5,6,7/.

We use three dye cells to amplify the output of the 599-04 dye laser (λ=580 nm, pulse duration 3 ps, energy 2 nJ) to an energy of 400 µJ. The first two cells (4 cm length, 2 mm depth) contain Rhodamine 6 G with concentrations of 6.6×10^{-4} mol/ℓ and 5×10^{-4} mol/ℓ dissolved in spectroscopic

grade ethanol. The cells are each pumped transversally with 6% of the XeCl-laser energy. After the second cell the ASE background is suppressed by a saturable absorber (Schott filter RG 630). The saturable absorber also blocks off the unamplified cw beam, which is important for our cameras with relatively long (0.1 s) opened shutters. The third dye cell is also transversally pumped with 80 mJ of the XeCl-laser. It is 4 cm in length, its active cross-section is 4×4 mm^2; the dye is Rhodamine 6 G in 1.5×10^{-4} mol/ℓ. For optimum energy extraction we found it profitable to use this last amplifier in double-pass configuration. We measured the duration of the amplified pulse with a streak camera (Imacon 675) to be less than or equal to 5 ps (i.e. the time resolution of the camera). The duration of the input pulse in the amplifier chain is 3 ps; this is measured with an autocorrelator. We therefore assume that the amplifier pulse will essentially have the same pulse length of 3 ps.

APPLICATION: MULTI-FRAME HIGH-SPEED PHOTOGRAPHY

One application of this diagnostic is the study of the plasma expansion during and after the heating pulse. We have constructed a simple diagnostic system, with which we can make 6 pictures of the irradiated target with one shot of the main laser: see Fig. 2. The amplified dye pulse is divided into 6 beams in a multi-reflex cell consisting of 2 mounts with small adjustable Al-coated mirrors. The 5 mirrors on the left mount are totally reflecting, while the 6 mirrors on the right mount have decreasing reflectances so that all transmitted beams have equal energy. The distance between the mounts is at minimum 10 cm and can easily be enlarged on the optical bench, allowing a minimum time delay of 0.6 ns between two diagnostic pulses. After the reflex cell we have a bundle of 6 parallel beams. To illuminate the target, these are deflected by a multivision prism filter as used in amateur photography. The target is imaged by an f/2 10 cm achromatic Zeiss lens with a magnification of 30. Of course, we have to separate the diagnostic beams again and use for that a second multi-prism filter. The image plane is occupied with 6 Polaroid cameras with 6.4 cm ø shutters. In case we want to do interferometry we simply place a Wollaston prism and an analyzer between the imaging lens and the second prism to obtain a Nomarski type interferometer /9/. An example of the beam quality at one of the Polaroid cameras is given in Fig. 3.

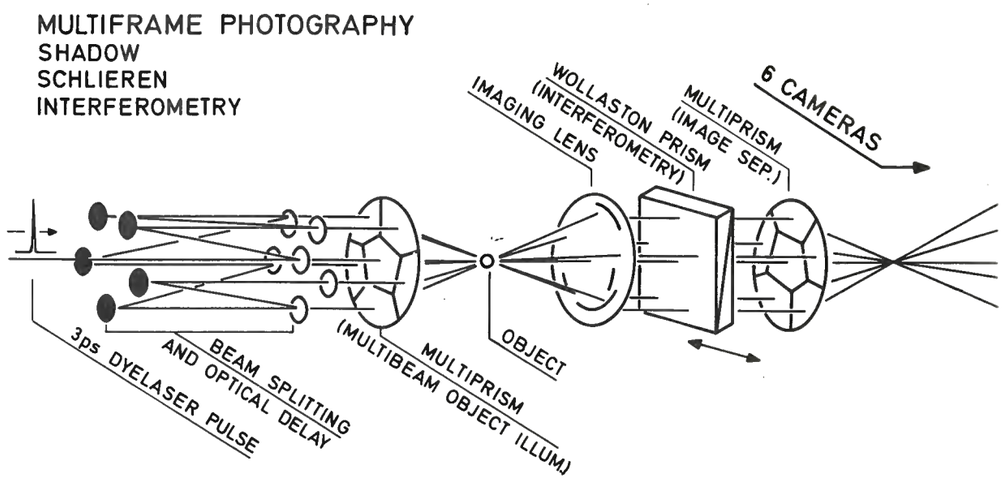

Fig. 2 Optical system to obtain 6 time delayed pictures of the expanding plasma.

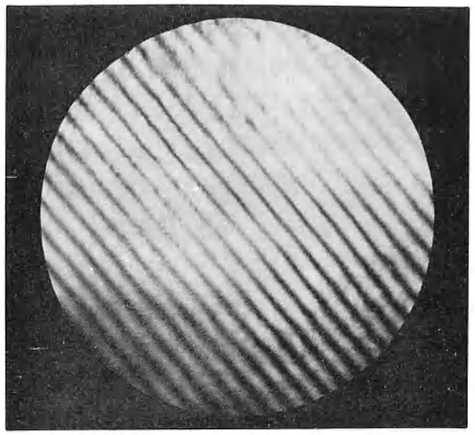

Fig. 3 Interferogram at one of the 6 Polaroid cameras with 6.4 cm ø aperture.

As an example of the possibilities of the diagnostic we show some pictures of a recent experiment in which we investigated the energy transport on free-falling spheres /10/. For technical details concerning the apparatus for obtaining the free-falling spheres see /11/. In Fig. 4 we see a multi-frame shadowgram of an unsupported 1 mm ø steel sphere. So far we obtain 5 pictures, for there are losses of energy in the multi-reflex cell caused

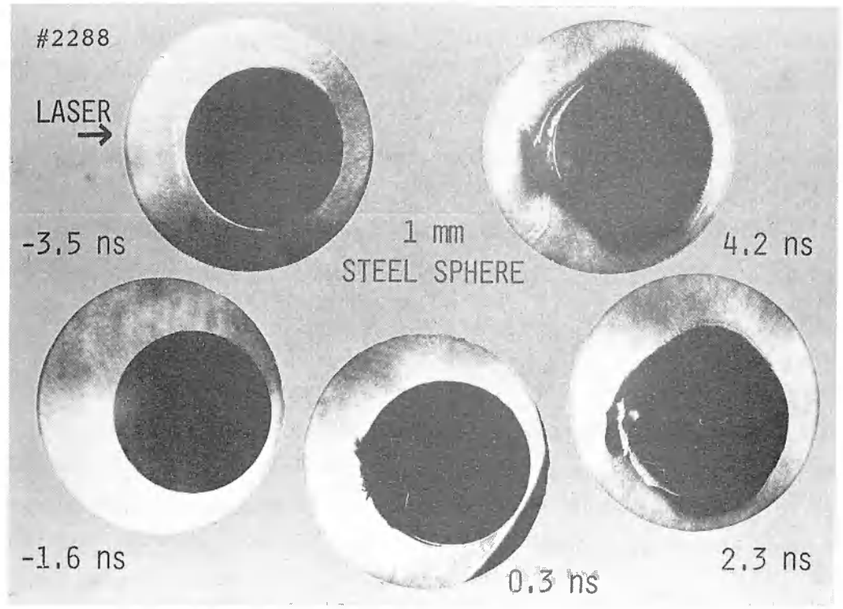

Fig. 4 Multi-frame shadowgram of a free-falling 1 mm ø steel sphere. The iodine laser comes from the left. The time delays are defined between the peak of main and diagnostic pulse.

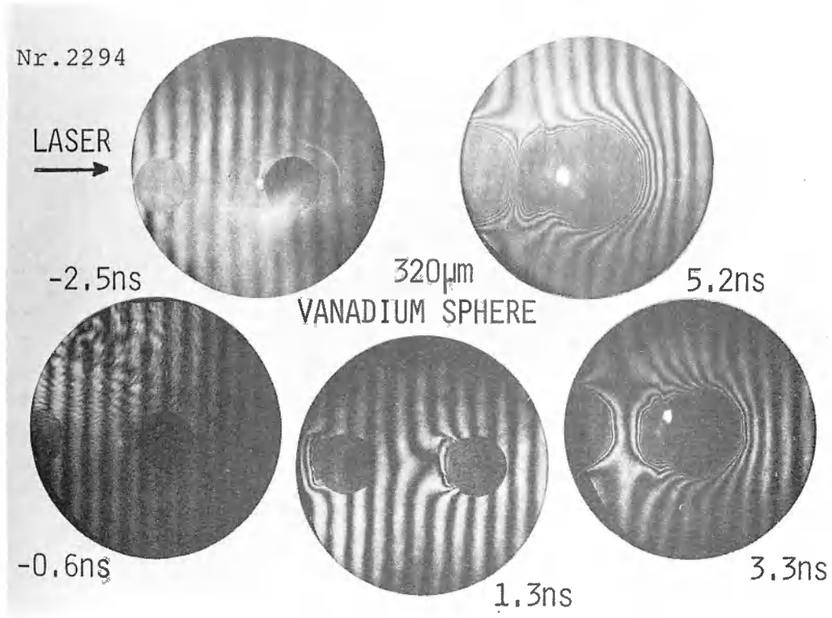

Fig. 5 Multi-frame interferogram of a free-falling 500 µm ø steel sphere. The iodine laser comes from the left.

by the Al-coatings (approximately 75%). In Fig. 5 interferograms of a 500 µm ø steel sphere are shown, from which more quantitative data can be obtained. The double picture of the sphere is due to the wave front splitting in the Wollaston prism. The minor inhomogeneity in the field illumination will be reduced by replacing the Al-coated mirrors in the multi-reflex cell by dielectric; this will increase the available energy of the diagnostic pulses at the target by a factor three. Then also a full sequence of 6 frames will be obtained.

In conclusion, we have constructed a 3 ps synchronised multi-frame photographic system for studies of laser-produced plasmas. The system has been successfully tested in experiments with the iodine laser. It should be possible to synchronise it as well with other acousto-optically mode-locked high-power (Nd or CO_2) lasers.

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H. Haas was involved to great extend in realization of the electronics.

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