MAX-PLANCK-INSTITUT FÜR PLASMAPHYSIK

GARCHING BEI MÜNCHEN

INVESTIGATION OF LASER-TARGET INTERACTIONS WITH PICOSECOND MICROPHOTOGRAPHY

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Abstract

The investigation of the interaction between the laser light and the pellet in laser-fusion experiments, whose typical time scale is ~ 100 ps, requires high-speed diagnostics. In this work a 5 ps single pulse from a mode-locked dye laser pulse train was utilized for time-resolved microphotography. The spatial resolution obtained was better than 5 μm. This technique was applied to investigate plasmas produced by a 20 J/5 ns Nd-glass laser pulse with solid targets of deuterium and other materials. Expansion of plasmas, blow-off of target materials with velocities up to 10^7 cm/s, and propagation of shock waves in targets could be studied.

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The understanding of heating, expansion or instability of laser-produced plasmas, especially in a case of pellet compression, requires an observation of plasma shape, and more precisely of its density distribution during the heating. As such a laser-heated plasma has normally a characteristic size of 100 μm and a lifetime of 10^{-9} s or less, a spatial resolution of better than 10 μm and a temporal resolution of about 10 ps are required. These conditions can be met by microphotography using a single pulse picosecond background illumination. With this technique the "corona" of a laser irradiated target up to plasma densities of 10^{20} - 10^{21} electrons/cm^3 and, at least in the case of plane transparent targets, the laser driven shock wave can be investigated.

The experimental set-up is shown in Fig. 1. The laser for heating is a Nd-glass laser and its pulse duration at half maximum is 5 ns. It is irradiated on the target surface through an aspherical lens of f = 7.5 cm. For background illumination we used a Rhodamin 6G dye laser (Electro-Photonics SUA-10). The duration of a single pulse is about 5 ps. At the best condition, the energy of one mode-locked single pulse is about 50 μJ. The wavelength was set to be 605 nm. One of these pulses is selected out by a pulse selecting system. The transmission rate, when it is opened, is about 10 %, and the intensity ratio, which is the ratio of transmissions when it is opened and closed is higher than 3000. It is just enough to suppress the background illumination coming from the integration of whole pulse train. The aperture of the objective lens is reduced to be about F/6 - 9, so as to suppress the self-luminosity of the plasma on the film. The spatial resolution is therefore limited with this size of the aperture, but still the highest resolution of better than 5 μm is experimentally attained. A narrow band interference filter ($\Delta\lambda$ = 20 Å) is also used to suppress the self-luminosity. As the energy of a single dye laser pulse is low (less than 1 μJ) we had to use Polaroid film of ASA 3000 or sometimes 10 000.

Firstly, the propagation of shock wave and a crater formation in transparent materials has been investigated by using this system. The data are shown in Fig. 2 and Fig. 3. In Fig. 2, a plexiglass target is used and the glass laser pulse is focused on the surface. The focal spot size is about 30 μm. At 8 ns from the beginning of the heating pulse, the plasma is already flowing out, but the shock wave or crater cannot yet be observed. At 14 ns, the shock wave appears, and behind of it the crater formation is seen. The increase of crater size ends at about 50 ns, but the shock wave propagates further. The velocity of it at the beginning is of the order of 10^6 cm/s, but it asymptotically decreases into the sound velocity of the material ($3 \cdot 10^5$ cm/s in this case).

A similar experiment was also made by using a solid deuterium target. It is shown in Fig. 3. As the deuterium ice is more compressible than the plexiglass, the crater size is much larger, and its propagating velocity is also higher. A detailed evaluation of shock wave propagation in this experiment has been recently performed /1/.

The plasma formation at much earlier stage has been observed through a Schlieren method. A cylindrical plexiglass target was used in this case. Some results are shown in Fig. 4. In a Schlieren set-up (dark field) only light rays which are deflected due to a density gradient contribute to the formation of a image of the plasma. Therefore the white area in front of the target indicates the presence of an inhomogeneous plasma. On its left boundary (near the target surface) the density gradient is so steep that the light rays are deflected out of the aperture of the objective, on its right boundary (towards the vacuum) the density gradient becomes so smooth that the light rays are no longer deflected. At the beginning of heating the region of plasma production is confined to the focal spot area, but it later extends rapidly along the target surface with a velocity of 10^7 cm/s. In the direction normal to the target surface, the development of the density profile can be studied from a series of exposures with different positions of the Schlieren blade.

Data from such a series are plotted in Fig. 5. Each mark corresponds to a different Schlieren position. Using a simple model of plasma expansion, the deflection of a light ray can be correlated with the density in the plasma. The curves in Fig. 5 show therefore how the position of various equi-density surfaces shifts with time. During the rise-time of the laser pulse the density profile changes rapidly, but later becomes approximately stationary especially near the surface of the target.

Limitations with the present set-up are the low pulse energy from the pulse laser, which prevented us (due to plasma self-luminosity) from using the full aperture and hence resolution (1 - 2 μm) of the specially corrected F/2 objective. Also the speckle patterns present due to the multimode structure of the dye laser beam are a limitation with respect to Schlieren and interferometric techniques. These limitations could be overcome with a more powerful, spatially coherent laser beam. Nevertheless the present study has already resulted in useful information on the plasma with high spatial and temporal resolution.

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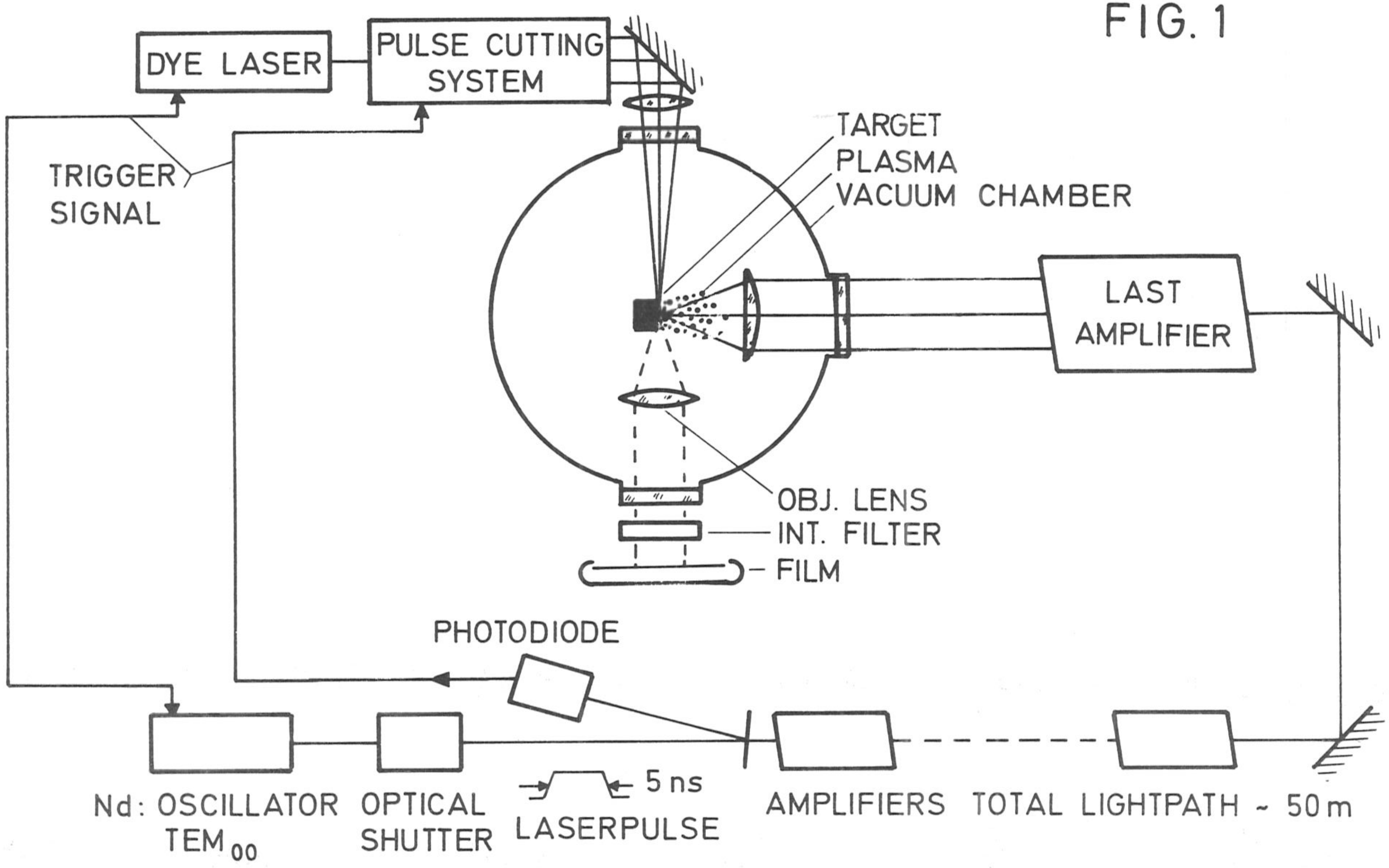
Reference: /1/ C.G.M. van Kessel and R. Sigel, Phys. Rev. Lett. 33, 1020 (1974)

FIG. 1


DYE LASER
PULSE CUTTING SYSTEM
TRIGGER SIGNAL
TARGET
PLASMA
VACUUM CHAMBER
LAST AMPLIFIER
OBJ. LENS
INT. FILTER
FILM
PHOTODIODE
Nd: OSCILLATOR TEM00
OPTICAL SHUTTER
5 ns
LASERPULSE
AMPLIFIERS
TOTAL LIGHTPATH ~ 50 m

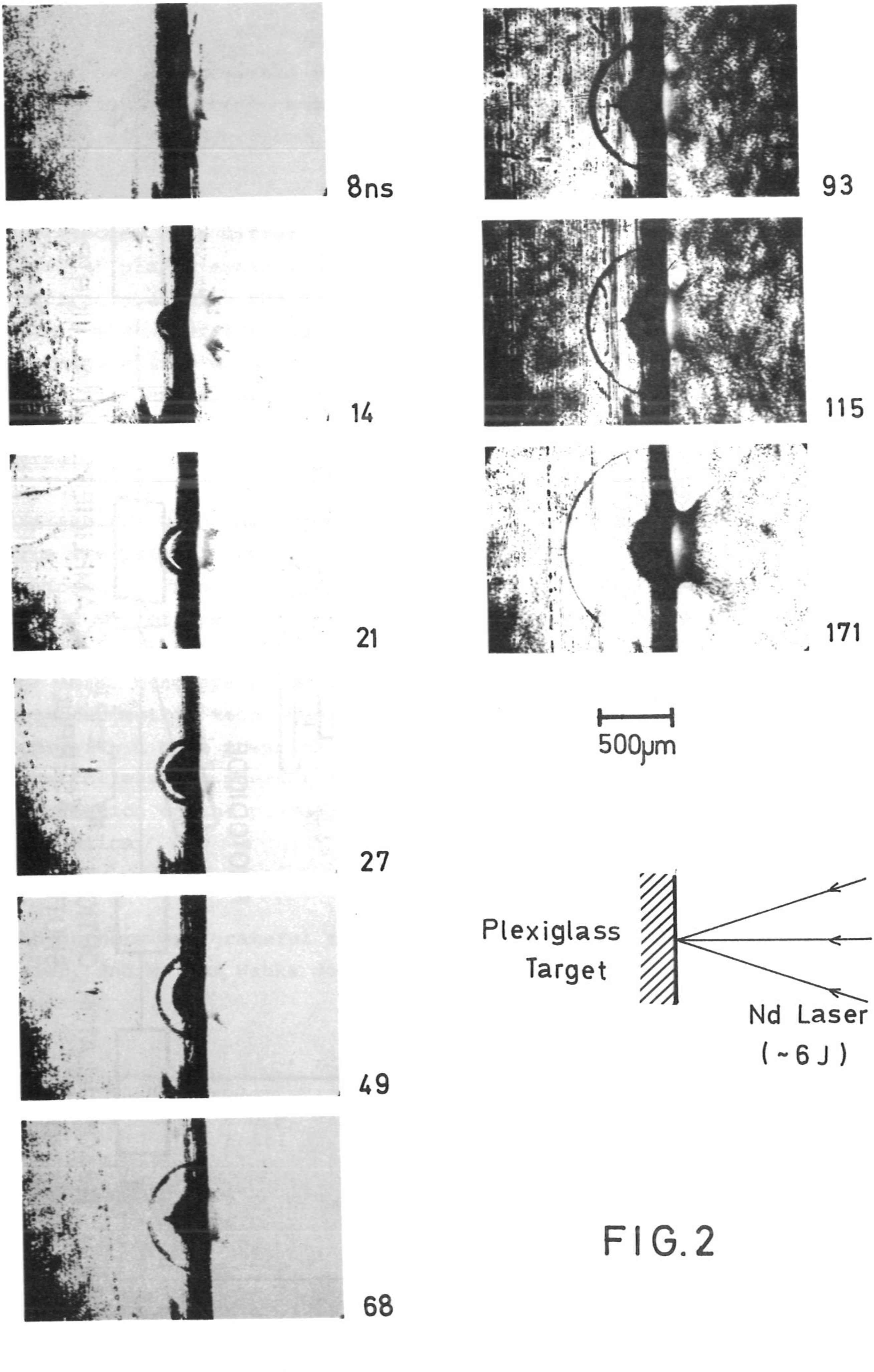

8ns
14
21
27
49
68
93
115
171
500μm
Plexiglass Target
Nd Laser
(~6 J)

FIG.2

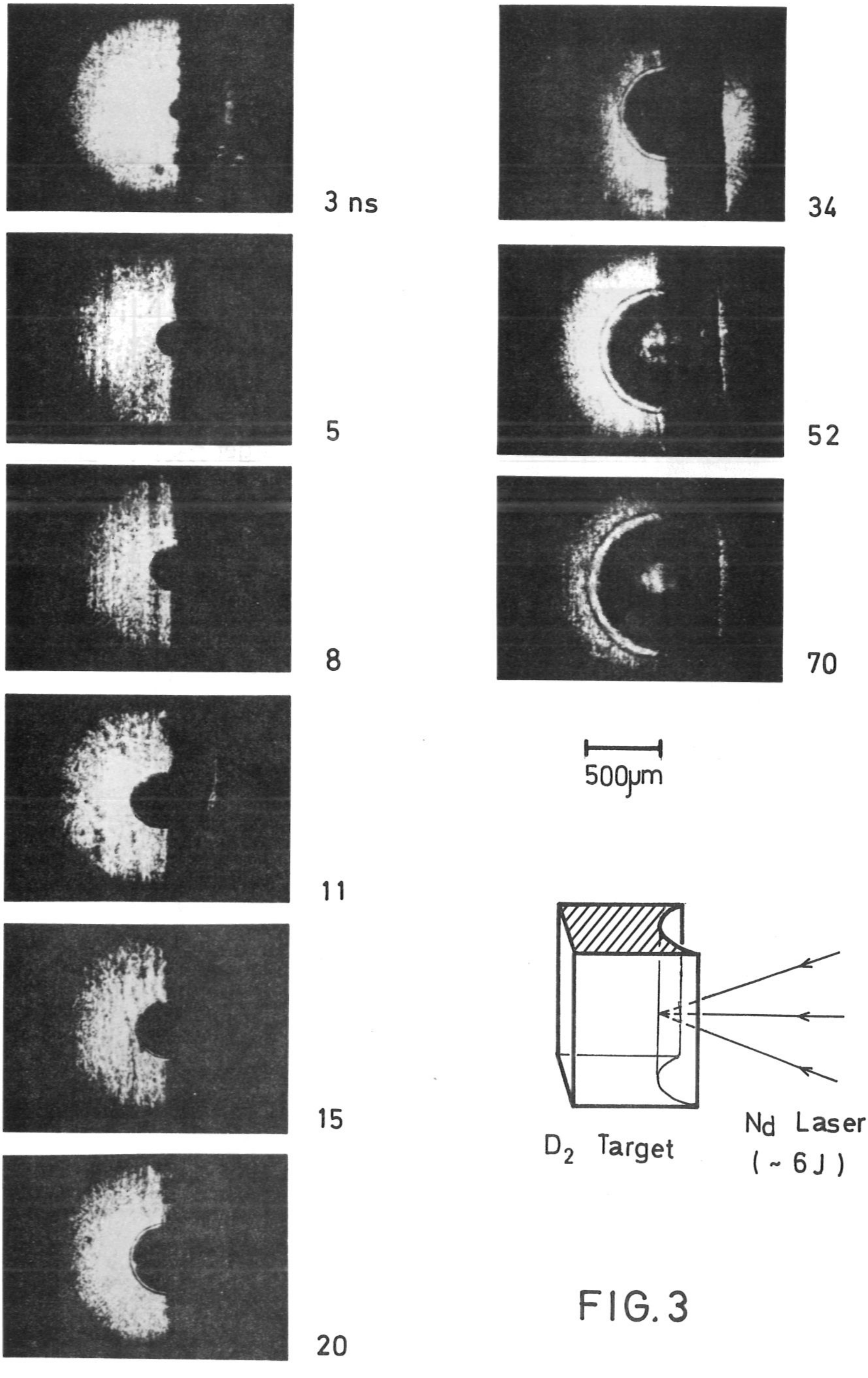
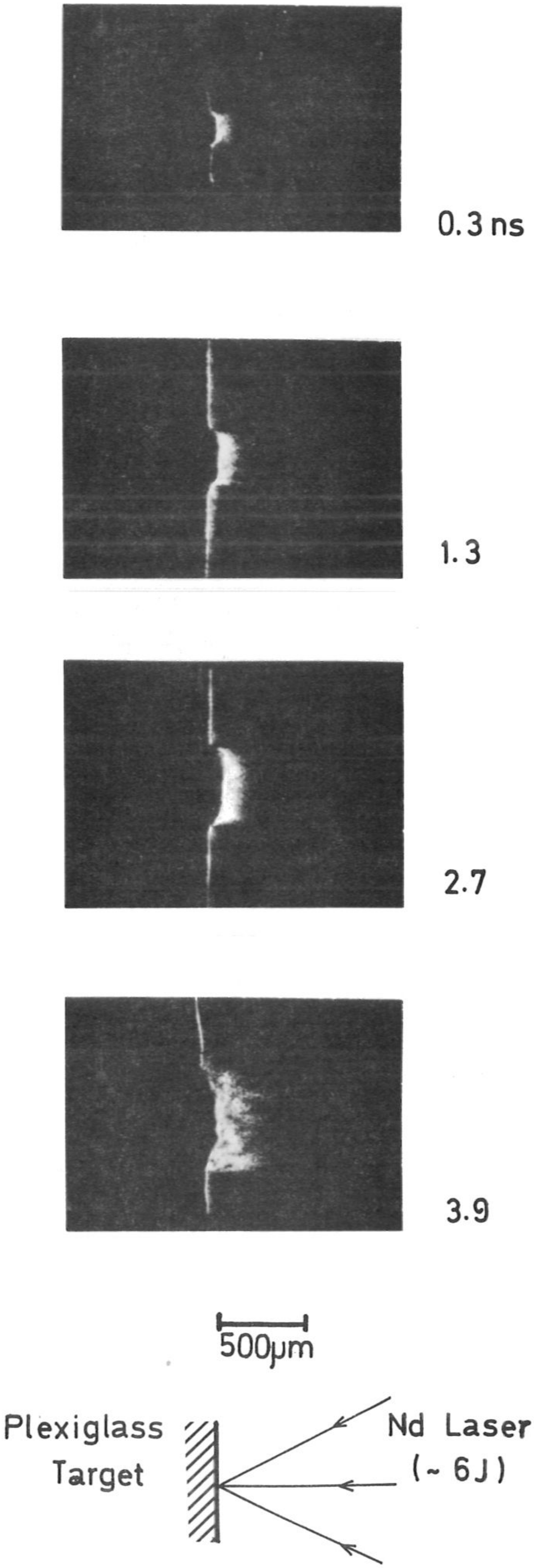


FIG. 3


0.3 ns
1.3
2.7
3.9
500μm
Plexiglass Target
Nd Laser (~ 6J)

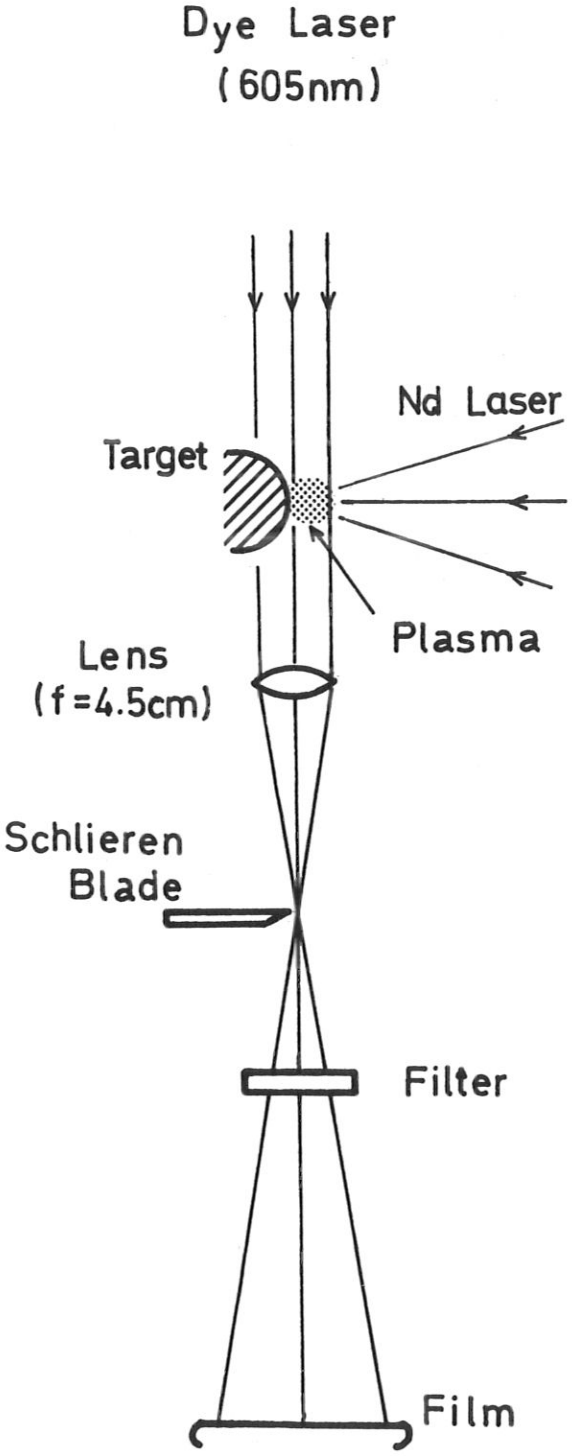

Dye Laser (605nm)
Nd Laser
Target
Plasma
Lens (f=4.5cm)
Schlieren Blade
Filter
Film

FIG. 4

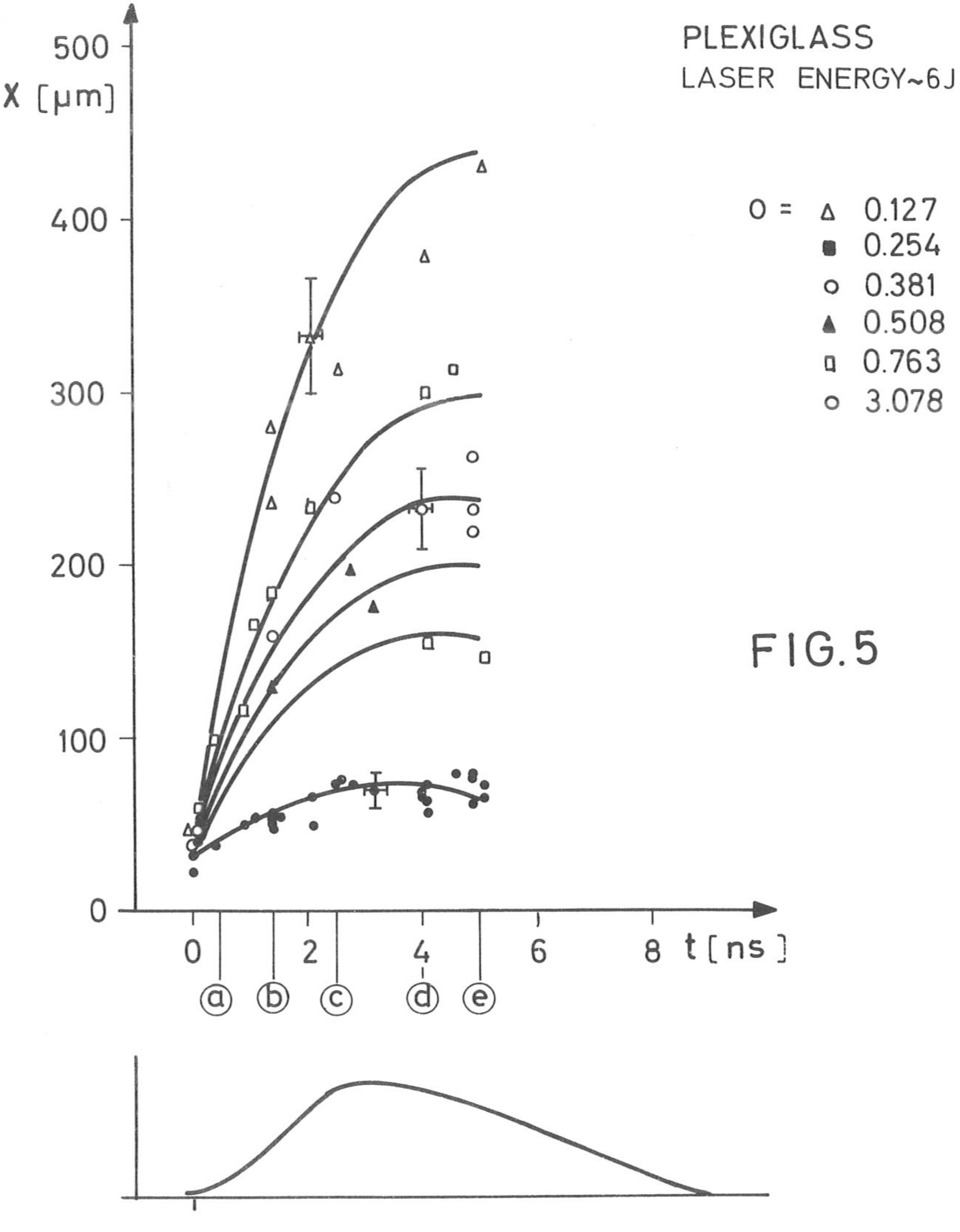

PLEXIGLASS
LASER ENERGY~6J
O = △ 0.127
● 0.254
○ 0.381
▲ 0.508
□ 0.763
○ 3.078
500
400
300
200
100
0
X [μm]
0
2
4
6
8
t [ns]
ⓐ
ⓑ
ⓒ
ⓓ
ⓔ

FIG.5