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High Speed Imaging of Raleigh-Taylor Instabilities in Laser Driven Plates

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High Speed Imaging Of Raleigh-Taylor Instabilities in Laser Driven Plates[1]

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ABSTRACT

We have previously reported our observations of the dynamic behavior of laser driven plates[2] [3]. Recent improvements and modifications of the imaging techniques have identified and provided measurements of Raleigh-Taylor (R-T) instabilities that occur in these events. The microscope system in the LLNL Micro Detonics Facility, was converted to an epi-illuminated polarization configuration. A double pulse nanosecond illuminator and a second independently focusable frame camera were also added to the system.

A laser driven plate, that is a dense solid driven by a laser heated, lower density plasma, is inherently R-T unstable. The characteristics and growth of the instability determine whether or not the plate remains intact. In earlier reports we correlated the surface patterning of thin plates with the fiber-optical transmission modes. In subsequent experiments we noted that the plasma burn through patterning in thin plates and the surface patterning of thicker plates did not correspond to the thin plate early time patterning. These observations led to the suspicion of R-T instability. A series of experiments correlating plate thickness and pattern spatial frequency has verified the instability.

The plates are aluminum, deposited on the ends of optical fibers. They are launched by a YAG Laser pulse traveling down the fiber. Plate velocities are several kilometers per second and characteristic dimensions of the instabilities are a few to tens of microns. Several techniques were used to examine the plates, the most successful being specularly reflecting polarization microscopy looking directly at the plate as it flies toward the camera. These images gave data on the spatial frequencies of the instabilities but could not give the amplitudes.

To measure the amplitude of the instability a semi-transparent witness plate was placed a known distance from the plate. As above, the plate was observed using the polarization microscope but using the streak camera as the detector. Both the launch of the plate and its impact into the witness plate are observed on the streak record. Knowing the plate velocity function from earlier velocimetry measurements and observing the variations in the arrival time across the plate, the amplitude of the instability can be calculated.

2. EXPERIMENTAL APPARATUS

Laser driven plates have been used for several years for high velocity shock wave and impact studies. In previous reports ablation and ionization rates were examined using both frame and streak microscopy.

In all previous cases a roughening or patterning of the plate surface was observed in coincidence with the onset of motion. In this study this patterning was examined as a function plate thickness and laser energy. Two experimental techniques new to the Micro Detonics Facility, µDF, were used for this study

The laser drive, shown in figure 1, is similar to that reported previously. The driving laser was a Q-switched Cr:Nd:GSGG laser (Allied Signal) that provided an output >100mj in a 13ns FWHM pulse. The laser was focused into the 400µm diameter fiber with a 150mm focal length lens. The beam quality was sufficiently good to reliably couple up to 45mj into the fiber without fiber damage. Throughout these experiments the laser was driven at constant flashlamp energy to maintain constant pulse characteristics. Energy into the fiber was adjusted with neutral density filters. A sample the beam is directed to an energy meter by an uncoated beam splitter just before the focusing lens. The energy meter is normalized to a calorimeter collecting all the light passing through an uncoated fiber.

All the fibers used in this experiment were 400µm diameter core high OH fused silica 2m long. The fibers were all cut to precisely the same length, jacketed and SMA terminated. Except for a few fibers, that were left uncoated for diagnostic purposes, the finished fiber assemblies were coated at Sandia Labs in Albuquerque. The flyer coatings were pure aluminum except for a small number with a thin Al_2O_3 insulating layer.

Two lasers are used for diagnostic illumination, an Argon (514nm) cw laser for the streak camera and a 1ns pulsed YAG driven dye laser (590nm) for the frames. The broadband dye laser is used to suppress laser speckle in the magnified images. The dye pulse is fed by an optical fiber which is split. One leg of the split is delayed by an appropriate run of fiber then the two legs are recombined, providing two pulses with an adjustable timing separation for the two camera frames.

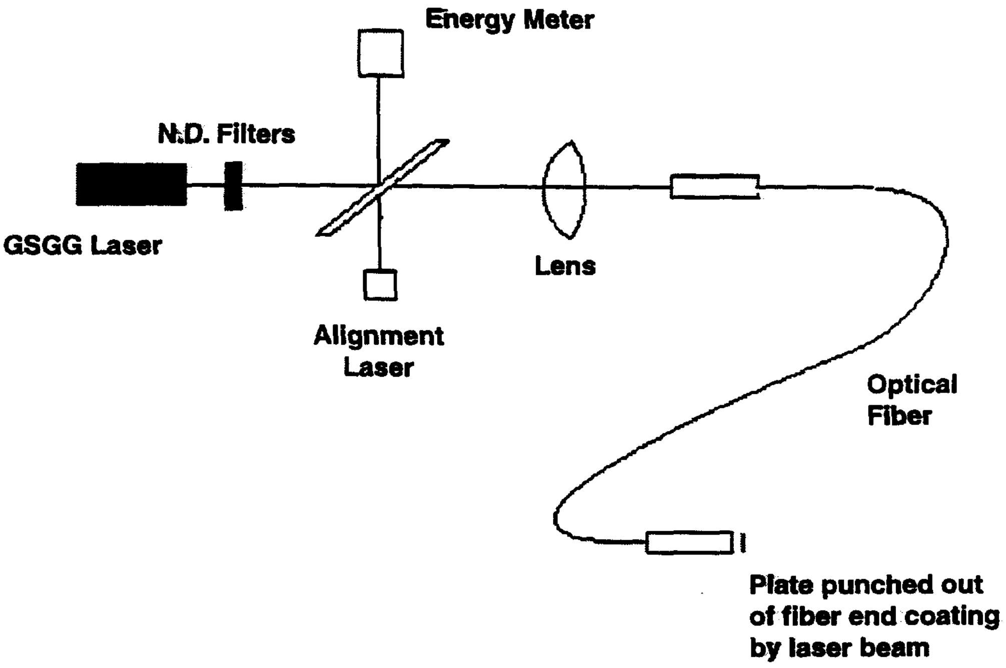

Figure 1. Experimental arrangement for laser driving of plates.

The microscope was modified to an epi-illuminated polarization configuration to enhance the visibility of the patterning (figure 2). In this arrangement polarized collimated laser illumination is input through a polarizing beam splitter. A quarter wave plate between the objective and the object causes the specularly reflected light to be rotated by 90^0, allowing it to pass through the splitter to the cameras. Light reflected from the objective lens does not pass through the λ/4 plate so does not get back to the cameras. However, light reflected from the second surface of the uncoated λ/4 plate will blind the cameras unless the plate is tilted to direct the light out of the cameras. The λ/2 plates are used to adjust the ratio pulsed dye and CW argon laser illumination and the ratio of light to the two cameras. In this configuration light from both lasers have the same polarization at the camera splitter thus the Argon and Dye beams can not be separated to the two cameras. The argon light on the frame camera is insignificant because of the 15ns gate of the camera, however, the 1ns dye pulse flares badly on the streak record.

The optics and cameras have been described elsewhere and were used with magnifications of 10X to the streak camera and 20X to the frames. The major change to the camera system has been the addition of a second frame camera. As before the frame camera is built around a 75mm planer diode, gatable to about 15ns. The second frame is independently triggerable with any desired interframe and exposure times. As before the recording medium is film (TMAX-400). A partially reflecting coated plate beam splitter is used after the final magnifying relay lens. A corrector plate is used in the transmitted beam to reduce the astigmatism and distortion caused by the splitter. Both frames are mounted on a common base and can be focused together. A 100mm slide was provided to allow differential focus of the two cameras, at 20X magnification this yields 250μm of focal shift at the target. The differential focus also slightly changes the magnification of one frame with respect to the other.

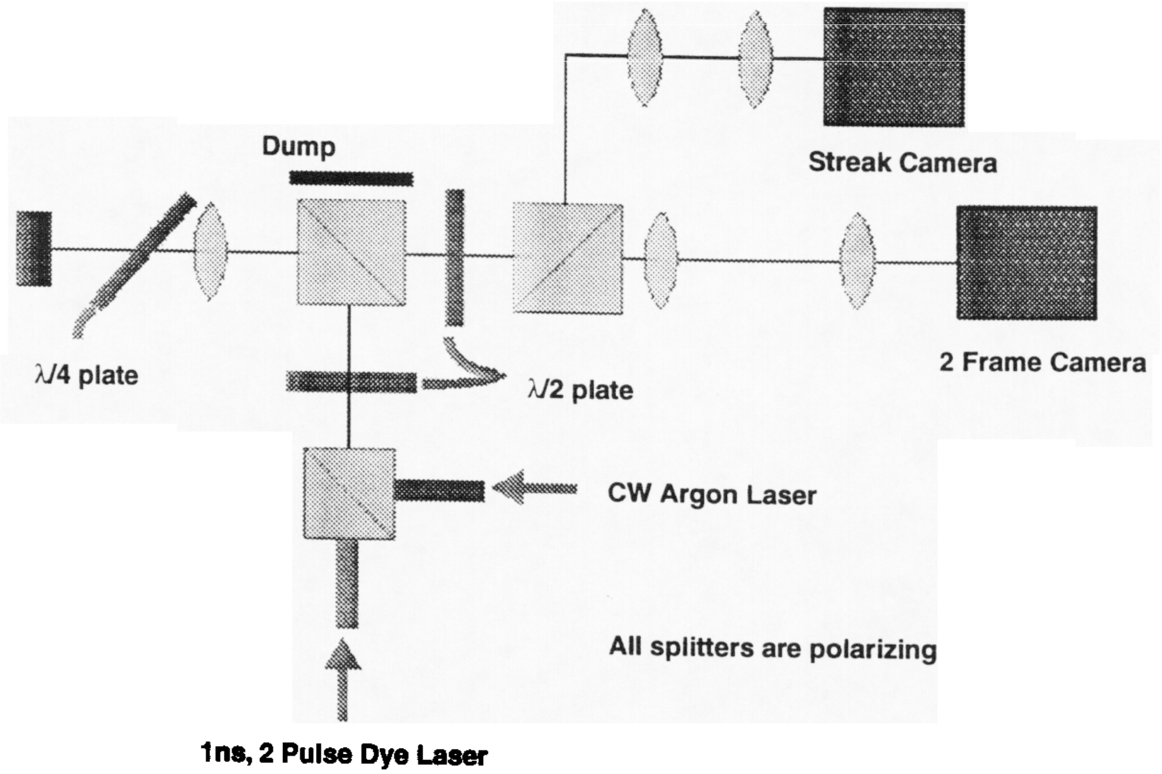

Figure 2. Epi-polarizing microscope for specular objects.

3. EXPERIMENTS

Experiments reported earlier examined the behavior of laser driven plates in the thickness range of 0.5-4μm[4]. The initial purpose of this study was to extend the study towards thicker plates. Coated fibers with 4, 8, & 18μm of aluminum were used for this study. The flyers were launched at energies of 7, 22 & 33mj. A few were launched with energies as high as 44mj. The total number of experiments was limited by the availability of coated fibers. The initial series of experiments were designed to examine each of the flyer thickness' at each energy. Two frame images 20ns apart and a streak record were taken for each shot. The two frames were differentially focused about 50μm apart to look at the flyer near jump off then again after most of the acceleration had taken place. After about a weeks preparation, a total of fourteen experiments were conducted over two days.

Spatial calibration was provided by photographing a precision etched nickel mesh. Film was batch processed by hand in deep tanks then printed at constant enlargement. Corrections were made for the magnification difference of the differentially focused frames and the image inversion from the beam splitter.

Temporal calibration is recorded on each streak record in two ways. A small sample of the 532nm dye laser drive pulse is split seven ways then directed through a series of fiber delay lines. The seven lines are recombined to a pair of fibers, which are recorded on the streak record and the monitoring oscilloscopes respectively. The arrival of the dye laser pulses at the experiment are recorded by a fast (50ps) vacuum photodiode and are also observed by the streak camera.

Cross timing of the flyer drive laser and the dye laser is provided by an S1 photocathode MCP multiplier tube sampling the laser output. The signal from the S1 tube and the dye laser photodiode are added on a single sweep of a Tektronics 7104 oscilloscope. The correct cable length for the S1 tube was established by using a common S1 photodiode detector to simultaneously record both the arrival of the dye laser pulse and the flyer drive pulse through an uncoated fiber. Consequently the oscilloscope record directly displays the temporal relationship between the pulse driving the flyer and the timing of the images.

All electronic delay generators had less than 50ps jitter and all laser Q-switch triggers were modified to minimize jitter. However, the jitter between the Q-switch turn on and the peak of the out put pulse could not be controlled. Consequently there was about a 10ns jitter between flyer drive laser and the dye laser illuminating the image of the flyer. Thus although we could not precisely, to within 10ns, when the images would be recorded with respect to the flyer driver, the timing was recorded and could be determined after the fact.

After the initial set of experiments we felt it was important to determine the amplitude of the observed structures. Our approach was to place a semitransparent target in the path of the flyer. The transparency of the target was adjusted to approximately equal reflections from both the target and the flyer seen through the target. In this way both the launch and impact could be observed on the same streak record. For these experiments a 75μm shim was used between the fiber ferrule and the target. The target was just a front surfaced neutral density filter, N.D. 0.3 & 0.5 were both used. The frame cameras were not used in these experiments to avoid the dye laser appearing on the streak record. Only a few experiments were performed with the remaining coated fibers.

4. EXPERIMENTAL RESULTS

The recorded images of the initial run were correlated with both flyer thickness and drive energy (figures 3&4). It was immediately obvious that there was a strong relationship between the flyer thickness and the spatial frequency of the surface disturbances. Clearly the surface disturbance was not simply the print through of the fiber optic transmission modes as had been previously hypothesized[5]. Raleigh Taylor instability in a solid plate has a thickness over pressure dependence of the critical wavelength, λ_c, of the disturbance[6];

$$\lambda_c = 2\pi(3GX/P)$$

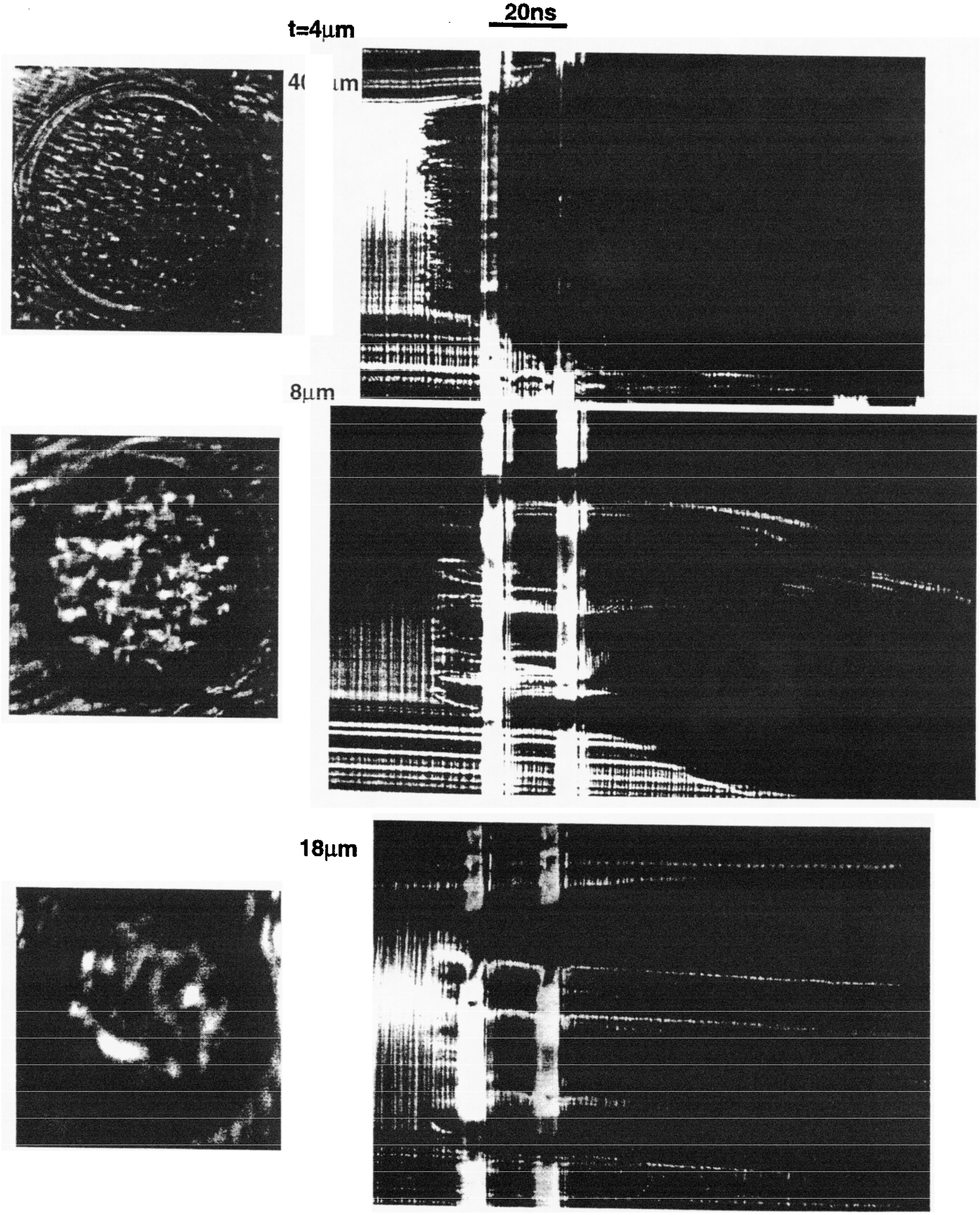

Figure 3. Frame and streak images varying thickness at constant energy.

where, G is the sheer modulus of the plate, X is the plate thickness and P is the drive pressure. The critical wavelength is the shortest wavelength disturbance that is unstable through the plate, with the maximum instability at $\lambda_m \sim 1.7\lambda_c$[7]. The wavelength of the fiber transmission modes are consistent with the observed disturbances of the thin flyers (figure 5). This indicates that the fiber modes probably are the driving perturbation but in the thicker plates only the longer wavelengths are amplified.

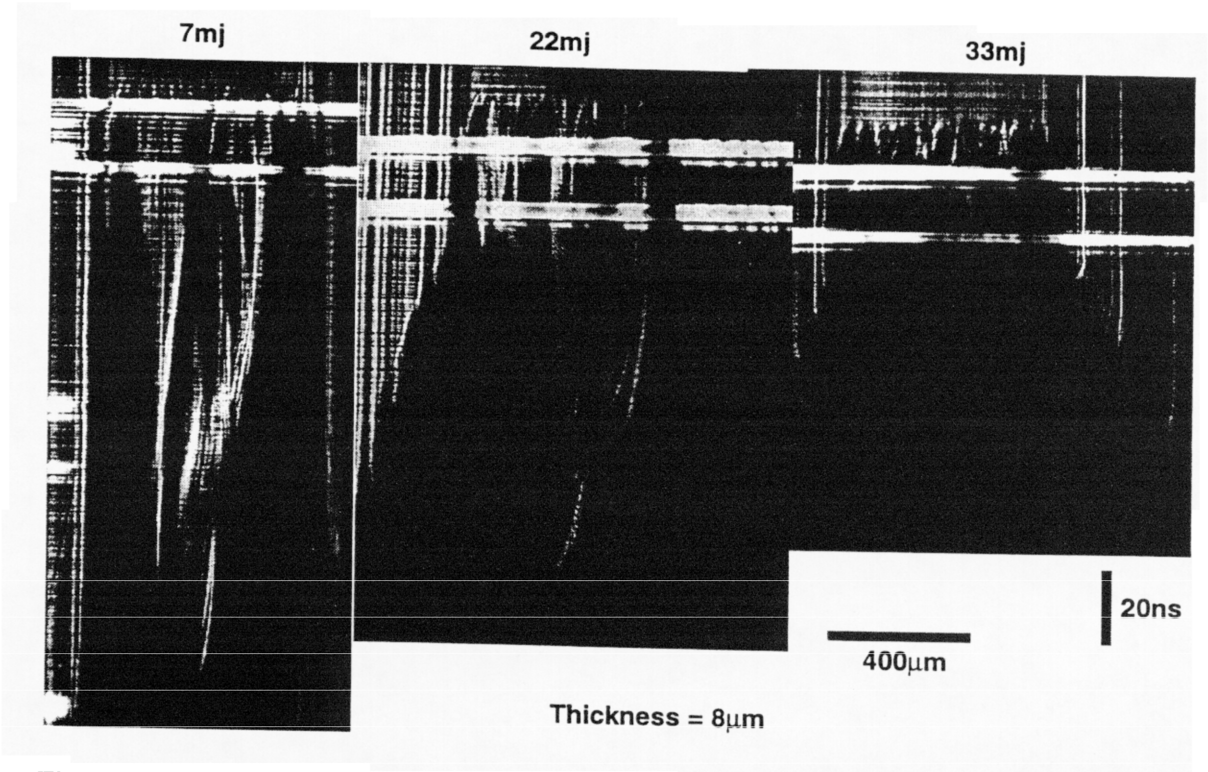

Figure 4. Streak records varying energy at constant thickness.

Conversely there appears to be no correlation between perturbation wavelength and drive laser energy. This indicates that above the ionization threshold, the pressure on the plate is a constant with laser energy, which implies the plasma is heated to a certain ionization state. Increasing laser energy increases the amount of material ionized and increases the length of time the pressure on the plate is maintained. Increasing the drive laser energy results in a higher velocity flyer and probably an increased amplitude of the perturbation but the wavelength of the perturbation is the same.

Although we had previously observed structures on laser accelerated flyers, we had not correlated their behavior with thickness or energy. Thus we had not previously realized that we were observing RT instabilities. Once these correlations were made and RT instability identified then the impact experiments were started to measure the amplitudes of the instabilities. Because of the limited number of available flyers only a few experiments were conducted at constant thickness (figure 6). Although impact flash in some cases obscured the perturbation and air breakdown at the fiber gave inconsistent results, the amplitudes of the disturbances observed were about twice the thickness of the flyer. This result is quite significant and merits revisiting once further samples are available.

The neutral density filter impact target was only partially successful because of the impact flash problem. In future experiments we will probably use a metal coated glass with a clear stripe to view the flyer jump off.

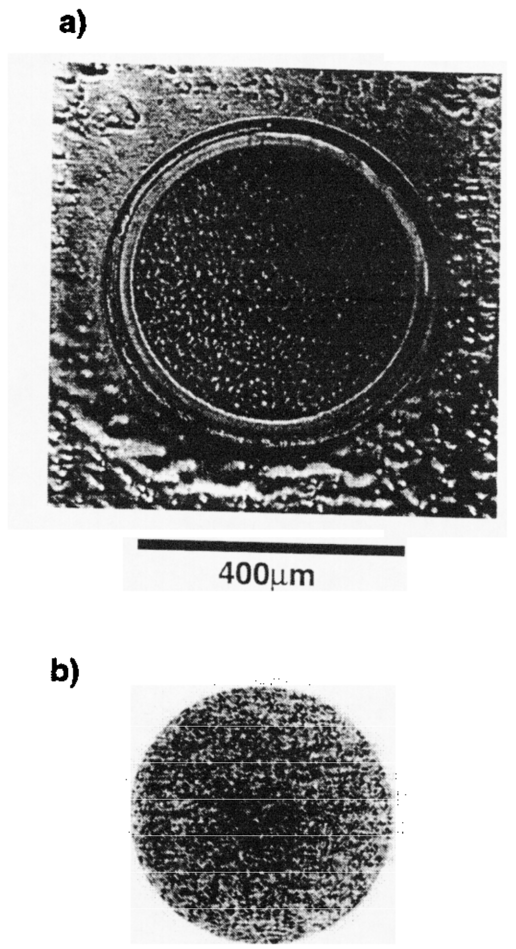

Figure 5. a) Pattern on 1µm flyer, compared to b) laser intensity at output surface of uncoated fiber.

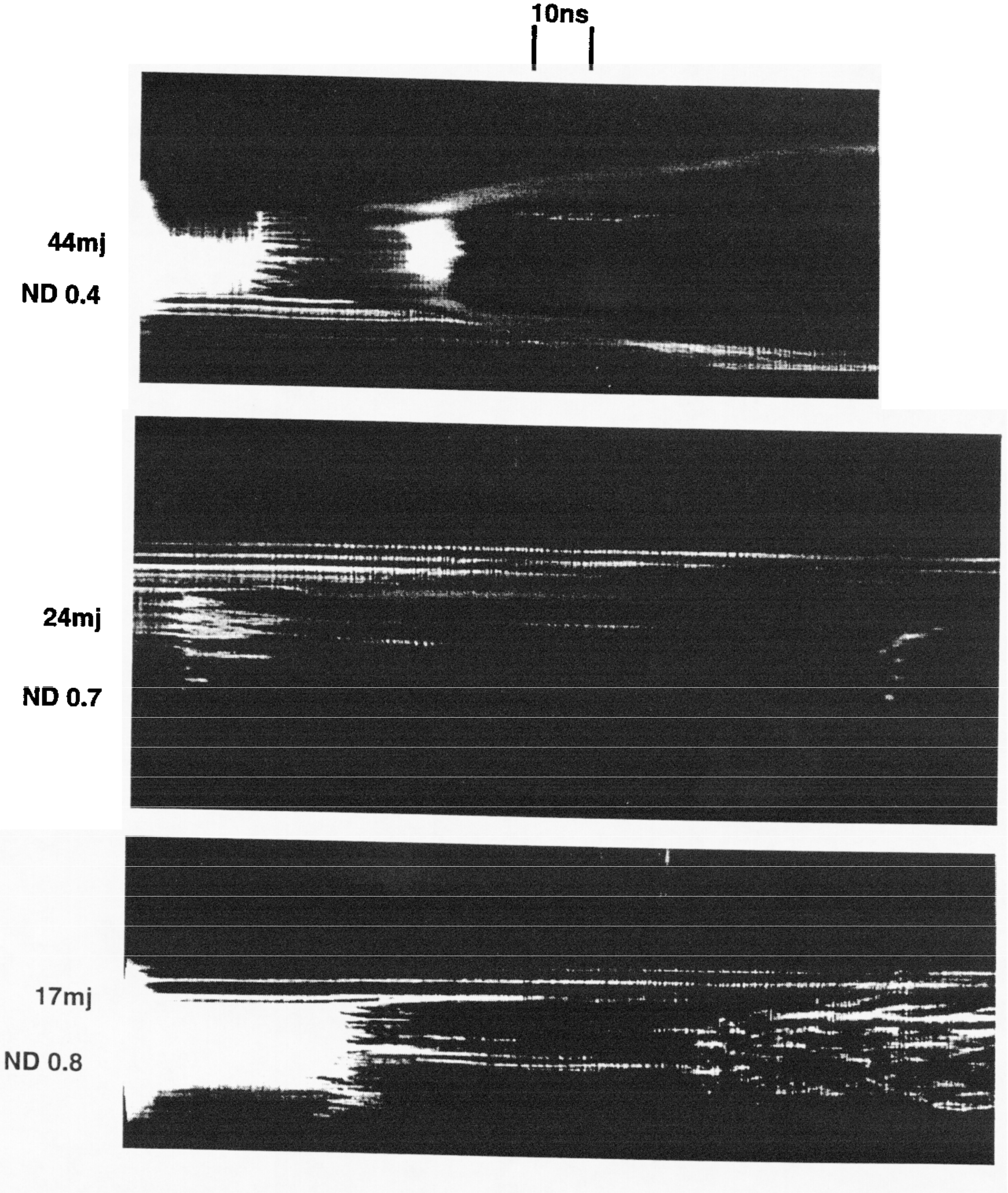

Figure 6. Streak images of flyers impacting neutral density targets. Time is moving from left to right. The first disturbance is the launching of the flyer, the second is the impact into the target.

5. BIOGRAPHY

Alan M. Frank is the developer and lead physicist of the Lawrence Livermore Laboratory's Micro Detonics Facility. He has been a physicist and optical systems engineer at LLNL for 22 years. He is the deputy United States Delegate to the Congress on High Speed Photography and Program Chairman of the 22nd Congress. He is a founder and retired Steering Committee Chairman of the Conference on Lasers & Electro Optics (CLEO). He is the 1985 recipient of the Harold Edgerton Award for high speed photography.

Key Words: High Speed Microscopy, Raleigh-Taylor Instabilities, Laser Driven Plates.

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[1] Work performed under the auspices of the United States Department of Energy at Lawrence Livermore National Laboratory under contract W-7405-ENG48 and at Sandia National Laboratory under contract DE-AC04-94-AL85000.

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