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ABSTRACT

We have used the SHIVA laser system to accelerate carbon disks to speeds in excess of 100 km/sec. The 3KJ/3 ns pulse, on a 1 mm diameter spot of a single disk produced a conventional shock of about 5 MB. The laser energy can, however, be stored in kinetic motion of this accelerated disk and delivered (reconverted to thermal energy) upon impact with another carbon disk. This collision occurs in a time much shorter than the 3 ns pulse, thus acting as a power amplifier. The shock pressures measured upon impact are estimated to be in the 20 MB range, thus demonstrating the amplification power of this colliding disk technique in creating ultra-high pressures. Theory and computer simulations of this process will be discussed, and compared with the experiment.

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A standard way of creating moderately high pressure shock waves in the laboratory is to drive a flyer plate into a sample. Peak velocities in the low 10 km/sec range have been achieved, leading to peak pressures in the 1 MB range. In recent years laser irradiated disks have been ablatively accelerated to speeds in the 100 km/sec range,[1,2] pointing to the possibility of using them as flyer plates to generate shocks of many tens of megabars as they impact a second, sample-disk.

Previously, lasers have been used to directly illuminate a sample, driving a strong shock into it. A problem with that approach is the appreciable decay of the shock as it propagates to the preheat-free back of the sample. The decay is due to rarefactions from the irradiated surface catching up with the shock.[3,4] Thus achieving high pressures in a preheat free environment using lasers on a single disk has been a difficult task. A way of avoiding the rarefaction problem and simultaneously creating very high pressures is to use the flyer plate technique. We accelerate a disk via laser driven ablation, store the absorbed laser energy as kinetic-in-flight energy over the long laser acceleration time, and redeliver it as thermal energy upon impact with a second, sample disk. This impact occurs on a much shorter time scale, thus acting as a power amplifier. Computer studies[5] have shown that this technique maintains a steady non-decaying shock as the shock traverses the impact ("sample") disk.

In this paper we report on experiments performed on the SHIVA laser system at LLNL by a joint LLNL-NRL team. While it wasn't the main goal, these experiments did serve as a proof of principle demonstration that steady, high pressure shocks can be created upon impact of a laser accelerated flyer plate with a sample. We also compare the data with simple theories and complex computer simulations, and find good agreement among all three.

For this experiment[6,7] ten beams of the SHIVA laser (3-3.5 ns, 3-4kJ, 1.06 micron) were focused to a 1 mm diameter spot and overlapped onto carbon foil targets. These foils were typically 10 microns thick and 2.5 mm in width. Arrays of diagnostics monitored the absorption fraction, suprathermal x-ray production, optical emission from the rear surface of the target, and many other quantities. The dynamics of the target foil was determined with streaked x-ray shadowgraphy. The principal aim of the experiment was to determine the uniformity of the accelerated foil's velocity profile. This is done utilizing the double foil technique,[8] in which the degree of simultaneity of the shock breakout across the back face of the second (impact) foil is a measure of the velocity uniformity of the impacting first foil across its face. We therefore keep the back face of the second foil as flat and uniform as possible. Had this been principally a shock wave experiment we would have put a step on the back of the second foil in order to measure shock velocities.

Figure 1a shows a streaked x-ray shadowgraph[9] of a single foil accelerated to about 100 km/sec. The backlighting x-rays, produced by a Pd target illuminated by eight other beams of SHIVA, are in the 2.8-3.2 keV range. Thus through the 1 mm accelerated portion of the foil, a shadow will be cast by densities in excess of 0.3 gm/cc. The image of the target was focussed onto an x-ray streak camera with the slit parallel to the direction of motion. Spatial and temporal resolution were 6-7 micron and 20 ps, respectively.

Relatively thick targets were chosen for these studies so that the fraction of mass ablated was small, making target accelerations nearly proportional to the ablation pressures. A simple estimate of the driving pressure can be obtained from the measured velocity, v. With an unablated areal density, m, of 1.8 mgm/cc, and a pulse length of 3.5 ns, setting $v=Pt/m$ we get P=5-6 MB. Complex LASNEX code simulations also predict 5.5 MB pressures, and the code's post-processed simulation of the x-ray shadowgraph matches the data extremely well, as shown in Figure 1b.

In this single foil, a conventional 5 MB shock is launched. We would expect such a shock to traverse the 10 micron thick sample in 0.3 ns and to raise the foil to about 7 ev. Thus a 7 ev signal should appear at the back about 1.5 ns before the peak of the 3.4 ns wide pulse. This behavior was seen repeatedly, and again, the hydro code simulations match the data quite closely. Figure 2 shows the sharp shock as it breaks out of the single foil. The shock is followed by hot electron "post-heat". We believe this to be due to plasma instabilities turning on later in the pulse when the density scale lengths in the underdense plasma have built up.

A second impact foil was placed parallel to and 200 microns behind the first laser illuminated and accelerated foil. Nonuniformities in the impact time of the accelerated foil are monitored by observations of the light emitted from the rear surface of the impact foil. Figure 3b shows a streak record of such an emission, produced upon impact with a laser accelerated first carbon foil moving at about 100 km/sec. The skewness of the image has been traced to the overall skewness of the incident illumination intensity within the focal spot. Otherwise, on a scale smaller than the overall skewed spot, the foil was seen to be accelerated rather uniformly. This is an important test to have passed, since in future experiments with stepped samples, uniformity of the incident shock is an obvious requirement. X-ray shadowgraphy shows the collision process quite clearly (Figure 3a). The collision occurs near the end of the laser pulse, thus an efficient storage of the laser energy (in first foil kinetic energy) is taking place. The sub-ns reconversion of that energy during the collision is thus a process of power amplification. The optical emission from the impact shock breakout varied from shot to shot, but was never less than 20 eV, and was as high as 60 eV! Compared with the 7 eV conventional shock of a single foil, this already shows the success of the laser-flyer-plate method in producing ultra high pressure shocks. (See Fig. 4.)

Estimates of the shock pressures produce upon impact can be obtained both from simple models and code simulations. The strong shock relations can be applied in a straightforward way to the impact of plate 1 with density rho1 and velocity v onto plate 2, stationary and with density rho2. Denoting the density ratio rho1/rho2 as R, we find, for a gamma = 5/3 for example, that $P=(4/3)\mathrm{rho1}\cdot v^2/(R+2\sqrt{R}+1)$. In our case both densities are about .5 gm/cc. They have been decompressed due to electron preheat, but the fact that they cast x-ray shadows shows that their densities are at least 0.3. With v≈100 km/sec, we obtain pressures in the 20 MB range. This is quite consistent with the 20-40 eV optical emission from the impact-shock breakout. Thus we have amplified our single foil 5 MB shock into an impact shock of 20 MB.

Simulations of the impact process have been carried out using LASNEX. As mentioned earlier, the first foil acceleration history is modelled quite accurately. The code predicts an impact pressure of about 20 MB, in agreement with the simple estimates. The 20 eV shock signal seen in the experiment is also predicted by LASNEX. The breakout time of the shock is quite sensitive to the amount of preheat at the back of the second impact foil. If the sample is preheated, the back of it blows off. The shock must now travel further before it catches up to that rear surface and can breakout. The code predicts a full 2 ns delay in shock breakout time between zero preheat and (the observed) 5 eV preheat case. In addition, with the observed 5 eV preheat, the shock breakout time predicted by LASNEX is precisely the observed breakout time. Thus all observables are matched by the code, and are indeed tied together in a self consistent way. In summary, we have demonstrated that ablative acceleration by laser illumination can accelerate flyer plates with velocity uniformity suitable for subsequent impact onto a second sample foil. We have shown how an otherwise conventional 5 MB laser driven shock can be improved upon, by letting the flyer plate impact a second disk, creating a 20 MB impact shock. Since the hard part has been achieved, namely getting the flyer plate up to 100 km/sec, it is now simply a matter of proper choice of flyer and impact foil materials in order to achieve pressures significantly higher than 20 MB, and with less electron preheat. This work was supported by the U. S. Department of Energy.

REFERENCES:

[1] Grun, J., et. al., Phys. Fluids 26 (1983) 588.

[2] Price, R. H., et. al., in W. J. Nellis, L. Seaman, and R. A. Graham (eds.), Shuch Waves in Condensed Matter, 1981 (AIP, N.Y. 1982) 155.

[3] Harrach, R. J., et. al., ibid. 164.

[4] Trainor, R. J., and Lee, Y. T., Phys. Fluids 25 (1982) 1898.

[5] Harrach, R. J., and Szoke, A., Univ. of Cal. Report No. UCRL-86798-Rev. 1, January 1982.

[6] Obenschain, S. P., et. al., Phys. Rev. Lett. 50 (1983) 44.

[7] Campbell, E. M., et. al., to be published in Appl. Phys. Lett.

[8] Whitlock, R. R., et. al., Appl. Phys. Lett. 41 (1982) 429.

[9] Price, R. H., et. al., SPIE Vol. 348, High Speed Photography (1982) 714.

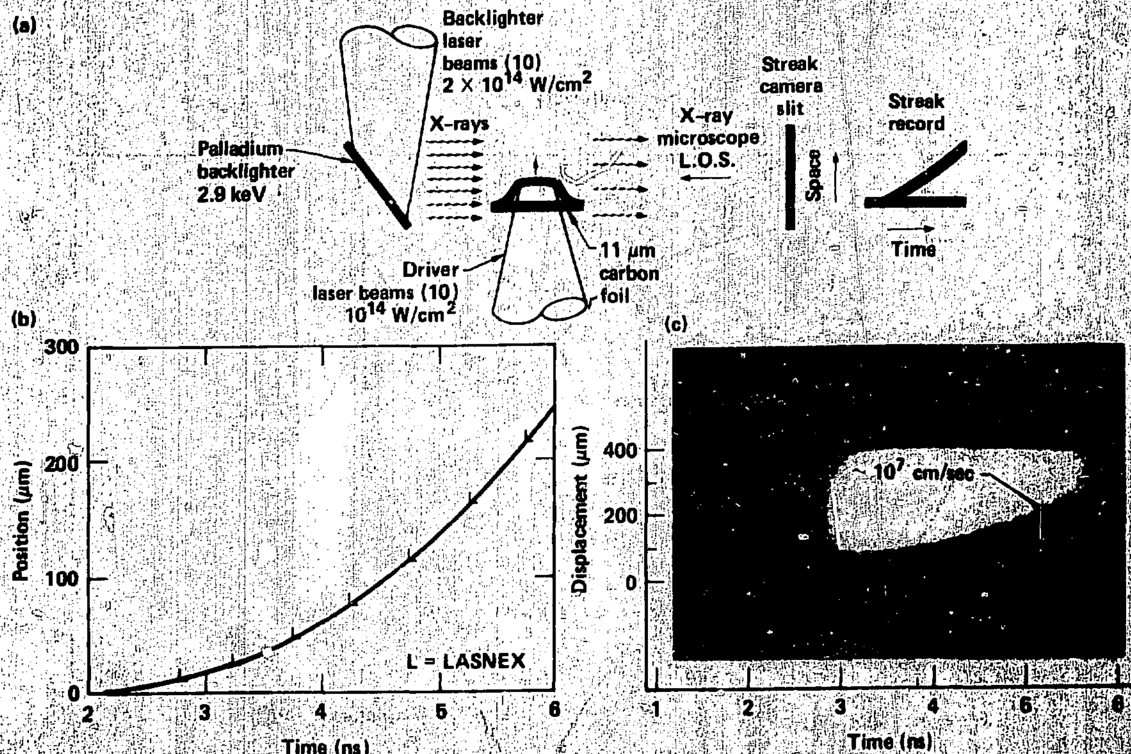

FIG. 1. (a) Experimental set-up. (b) Solid line: Trace of x-ray shadow ... L: Prediction from LASNEX simulation post-processed to produce a theoret...

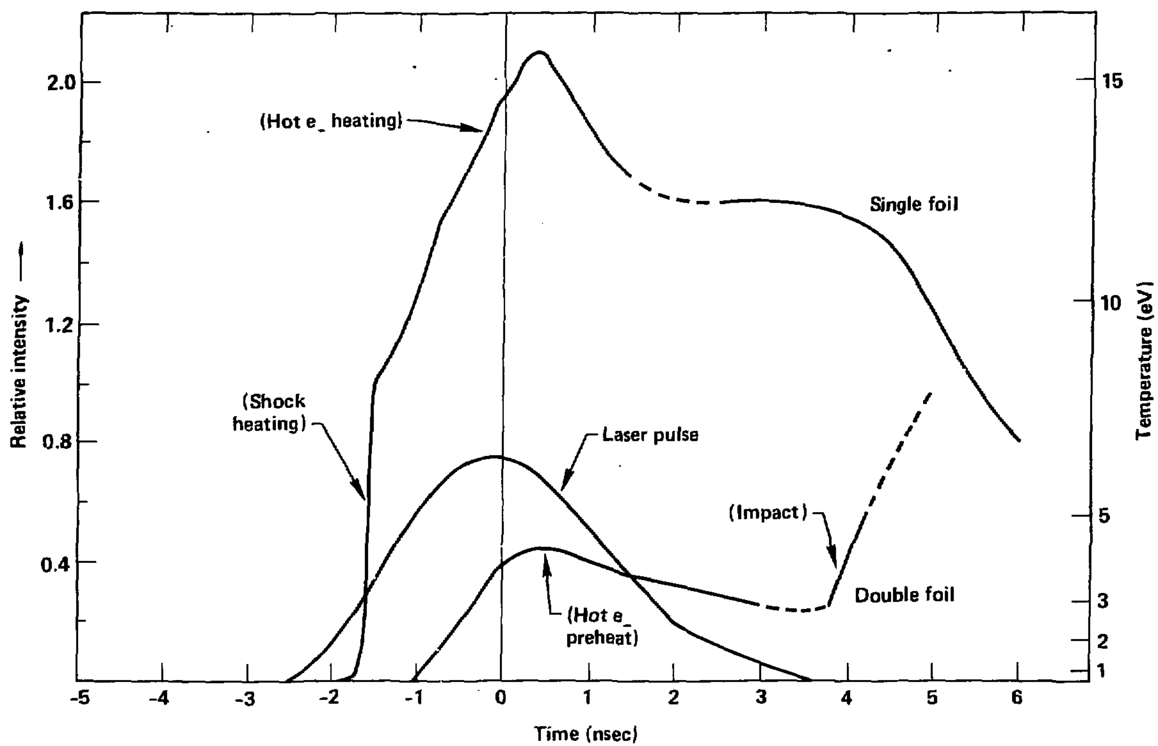

FIG. 2. Time history of emission from the rear of a single and double foil.

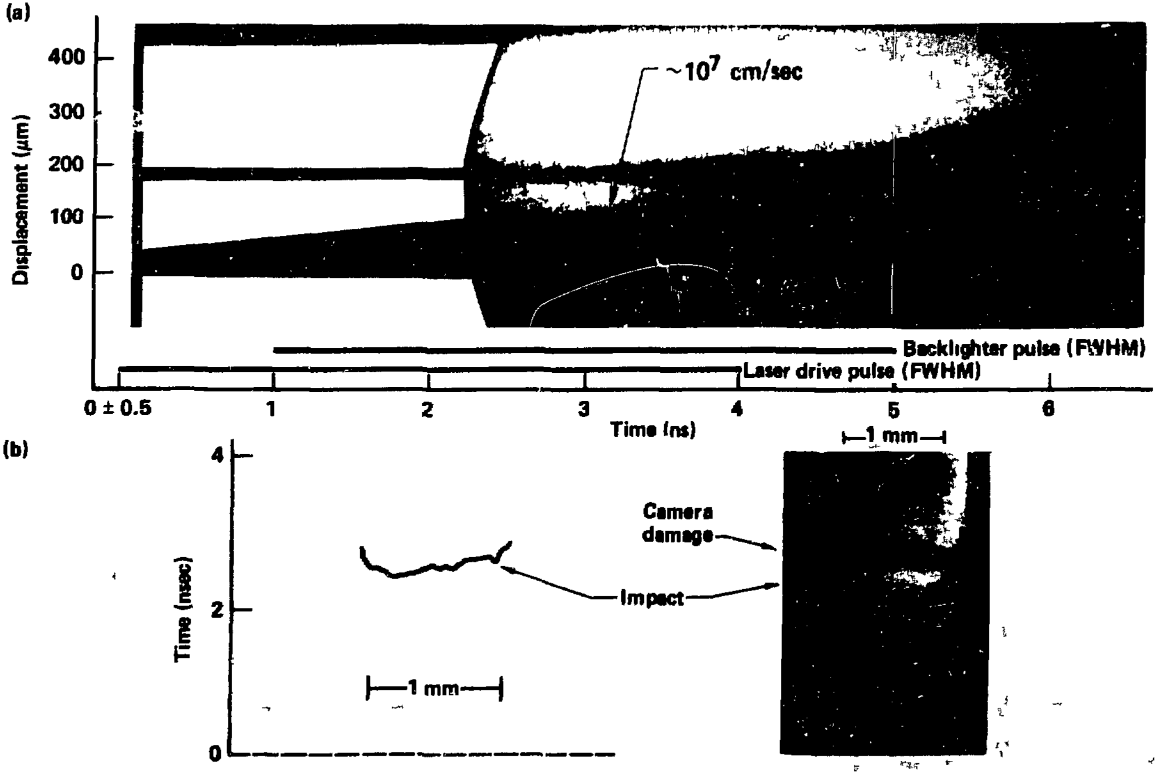

FIG. 3. (a) X-ray shadowgraph of the collision of an accelerated foil with an impact foil above it. (b) Optical streak record of emission from rear of impact foil, showing near uniformity in breakout time.

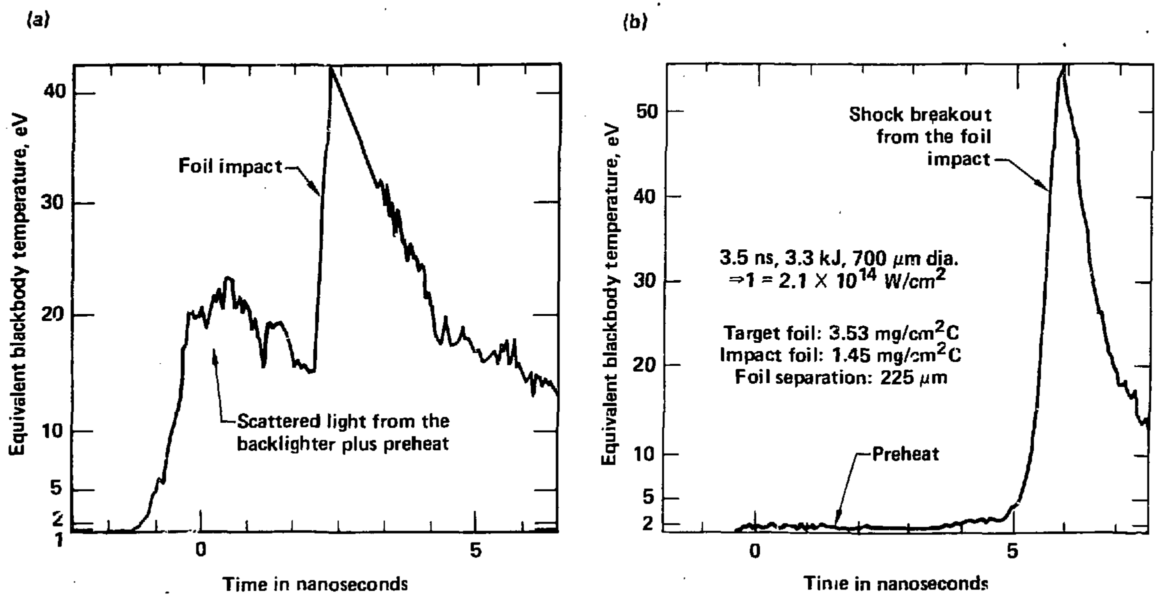

FIG. 4. (a) Time history of emission from rear of impact foil. Conditions as described in text. (b) Same as (a), but higher irradiance, thicker first foil, and larger foil separation.