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DOPPLER VELOCIMETER FOR LASER ACCELERATED TARGETS.(U)

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A doppler velocimeter utilizing a spectrograph and a short pulse laser probe is described which provides good spatial (20 [redacted]) and subnanosecond temporal resolution. This system has been used to measure the velocity profiles of targets ablatively accelerated to very high velocities by a high power laser beam. A unique aspect of this velocimeter is that the doppler wavelength shifts are measured directly rather than employing interferometric techniques.

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DOPPLER VELOCIMETER FOR LASER ACCELERATED TARGETS

In this paper we describe a laser doppler-shift velocimeter which provides spatially resolved velocity profiles of an accelerating surface. Measurement of the doppler shifts of laser light reflected from free surfaces has been used to measure velocities in many experiments, particularly those dealing with shock waves.[1,2,3] To the authors' knowledge, all of the systems used to conduct these doppler measurements have been interferometric, where doppler-produced phase shifts are measured. None of these systems provides spatially resolved velocity profiles for an arbitrary target surface. For the case of the very rapid acceleration to high velocities that can be encountered in ablative acceleration[4] or shocks[5] produced by high power lasers, the use of interferometric velocimeters requires the availability of very fast >>1 GHz detectors capable of measuring the rapid fringe shifts produced. For the velocimeter discussed herein, the wavelength shifts of the reflected probe laser light are measured rather than the phase shifts. In this relatively simple system, a one-dimensional velocity profile of the accelerated surface is easily obtained. In addition, there are no restrictions on the surface quality of the accelerated object being probed other than its ability to reflect the probe light. This type of velocimeter was found to be well matched to the relatively high velocity regimes ($>10^5$ cm/sec) encountered in the ablative acceleration of thin targets by a high power laser.

The experimental apparatus is shown in Fig. 1. The front surface of

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a thin target foil is irradiated by a high power 1.06 μm 3-nsec-duration laser beam which causes the target to be accelerated in reaction to material ablated from its surface.[4] The rear surface of the accelerated target is illuminated by a subnanosecond-duration 5320 Å optical probing beam. The image of the target is focused onto the entrance slit of a stigmatic spectrograph and wavelength shifts are recorded on photographic film. The wavelength of light reflected at normal incidence from the moving target is doppler-shifted by the amount

$$\Delta\lambda = 2\lambda v/c, \quad (v \ll c), \tag{1}$$

where λ is the probing light wavelength, v is the normal component of the target velocity, and c is the speed of light. The spectrograph provides measurements of the doppler shifts of probe light reflected from the target surface as a function of position across the target diameter. By using a very narrow entrance slit width to the spectrograph, one obtains the velocity profile of a narrow region across the accelerated target (see Fig. 1 inset). Using inexpensive doublet and triplet focusing lenses, 20 μm spatial resolution is easily attained in this system. We shall briefly discuss the limits of and considerations for using this technique both in a general context and in the more specific context of monitoring ablatively accelerated targets.

The sensitivity of the doppler velocimeter discussed above is limited by the wavelength resolution of the spectrograph and the bandwidth of the probing light. For the experiments discussed herein, a 3/4-meter f/7-spectrograph was employed with a 1200-line/mm grating (102mm x 102mm) in first order. This instrument has a resolution of approximately 0.1 Å for resolving adjacent spectral lines near the probing wavelength. However the resolution for measuring doppler shifts can be pushed to approximately

.03 Å with this instrument by using the techniques described later which involve use of a displaced laser reference line. This resolution yields a minimum detectable velocity of about 10^5 cm/sec. Factors of two or three improvement in this resolution could be attained by using (commercially available) higher resolution spectrographs.

Aside from the wavelength measuring apparatus, there are other considerations which cause a trade off between velocity and time resolution. The time resolution is obtained here by using a short duration probing pulse. Optimally, the probe beam pulse is time-bandwidth limited with a bandwidth $\Delta\lambda_\tau$ given by:

$$\Delta\lambda_\tau \approx \frac{\lambda^2}{\tau c}, \quad (2)$$

where τ is the probe pulse length. The best wavelength and thus velocity resolution calls for the maximum acceptable pulse duration.

For the case of an accelerating target, the doppler shift is a function of time and yields a time-integrated linewidth which may be given approximately by:

$$\Delta\lambda_a \approx 2a\tau\lambda/c, \quad (3)$$

where "a" is the acceleration. Freezing the velocity profile of the accelerating target thus calls for a short duration probe pulse. The optimum compromise between the two considerations discussed above calls for $\Delta\lambda_a \approx \Delta\lambda_\tau$, which upon solving for the pulse length using Eqs. (2) and (3) yields

$$\tau \approx \left(\frac{\lambda}{2a}\right)^{\frac{1}{2}}. \quad (4)$$

For the best time and velocity resolution during the acceleration one should match the probing duration to the accelerations likely to be encountered. For the case of our ablatively accelerated targets, accelerations of order 10^{14} - 10^{16} cm/sec^2 are encountered, which for the 5320 Å probe employed, call optimally for pulse durations of (500 - 50 psec). The longer pulse durations would be optimum for the case of lower acceleration rates.

Figure 2(a) shows a typical velocimeter result. The front of a 7 μm thick aluminum foil target was irradiated by a 3-nsec-duration laser beam focused to intensities of approximately 5 x 10^{12} W/cm^2 within a 200 μm focal spot diameter. In this case, the probe beam was reflected off the rear surface of the target at a time near the peak of the main laser pulse. The probe beam is produced by doubling the fundamental of a single transverse and longitudinal mode YAG oscillator and slicing it to 400 psec duration using a Pockels cell. This nearly time-bandwidth limited probe pulse is reasonably well matched to the acceleration encountered here (~5 x 10^{14} cm/sec^2), but is somewhat longer than the optimum 200 psec probe length that Eq. (4) would specify. The laser spectral line reflected from the foil target is bent (doppler-shifted) towards shorter wavelengths in the region where the target is being accelerated in reaction to laser induced ablation of the target front surface. The probe light reflected from regions well removed from that irradiated by the main laser do not accelerate and provide a reference for zero doppler shift. A reference line is positioned nearby by rotating the spectrograph grating a small amount and reflecting a preshot probe pulse from the unaccelerated target. Quantitative data is obtained by densitometering the film to accurately determine the displacement of the shifted probe line as a function of distance across the target image. See Fig. 2(b).

We find that the velocimeter works well with a variety of opaque target materials. For the case of materials with a shiny, highly polished (*rather than diffusive*) surface it was found advantageous to use a relatively low f-number collector lens (L1 in Fig. 2) to image the target. With the low f-number, relatively large ripples and tilts of the target before and during the acceleration can be tolerated. This advantage of course has to be balanced against the limited depth of field with a small f-number lens and the spread in doppler shifts of light scattered and collected by the lens at different angles to the target normal.

As described, the velocimeter provides a single frame picture of the velocity profile of the accelerating target. Frames at different times are obtained by varying the time of incidence of the probing beam with respect to the main laser beam. Multiframe data can be obtained by using probing beams of different wavelengths and delaying the time of incidence of the various wavelength probes on target with respect to one another. A simple way to do this, which we are exploring, is Raman shifting a part of the original optical probe to a different wavelength.

For any doppler shift technique to work, the surface being probed must be reasonably reflective. In probing ablatively accelerated targets, we find that at later times in the interaction, the rear target surface becomes highly absorptive to the probe light. Figure 3(a) shows photographs of the rear surface of a 7 μm Al target illuminated by the probe beam at several times before and after the main laser pulse. The decreased reflectivity at late times is clearly evident. This is most likely caused by the rear surface becoming hot enough to form a highly collisional plasma in which the probe light is absorbed. Figure 3(b) comparing densitometry across one of the probe reflection photographs to that of a photograph of time-integrated light emitted from the rear target surface supports this thesis. As can be seen, the widths of the emission and absorption regions are nearly identical. A collisional, absorptive plasma would also emit light. We find that the reflectivity of the rear surface decreases earlier with thinner targets and higher laser irradiances. By judicious choice of target thickness we have measured target accelerations through the time of the peak of the 1.06 μm laser pulse at moderate intensities ($\sim 10^{13}$ W/cm^2).

In conclusion, we have described a relatively simple doppler velocimeter which has proven useful in spatially and temporally resolving the velocity profiles of laser accelerated targets. Subnanosecond resolution of the velocity profiles of targets accelerated at rates exceeding 5×10^{14} cm/sec^2 to velocities exceeding 10^6 cm/sec has been routinely achieved using this velocimeter. Detailed results and interpretations of these measurements will be presented elsewhere.[6] The techniques described herein should also be useful in other circumstances where relatively high velocities are encountered.

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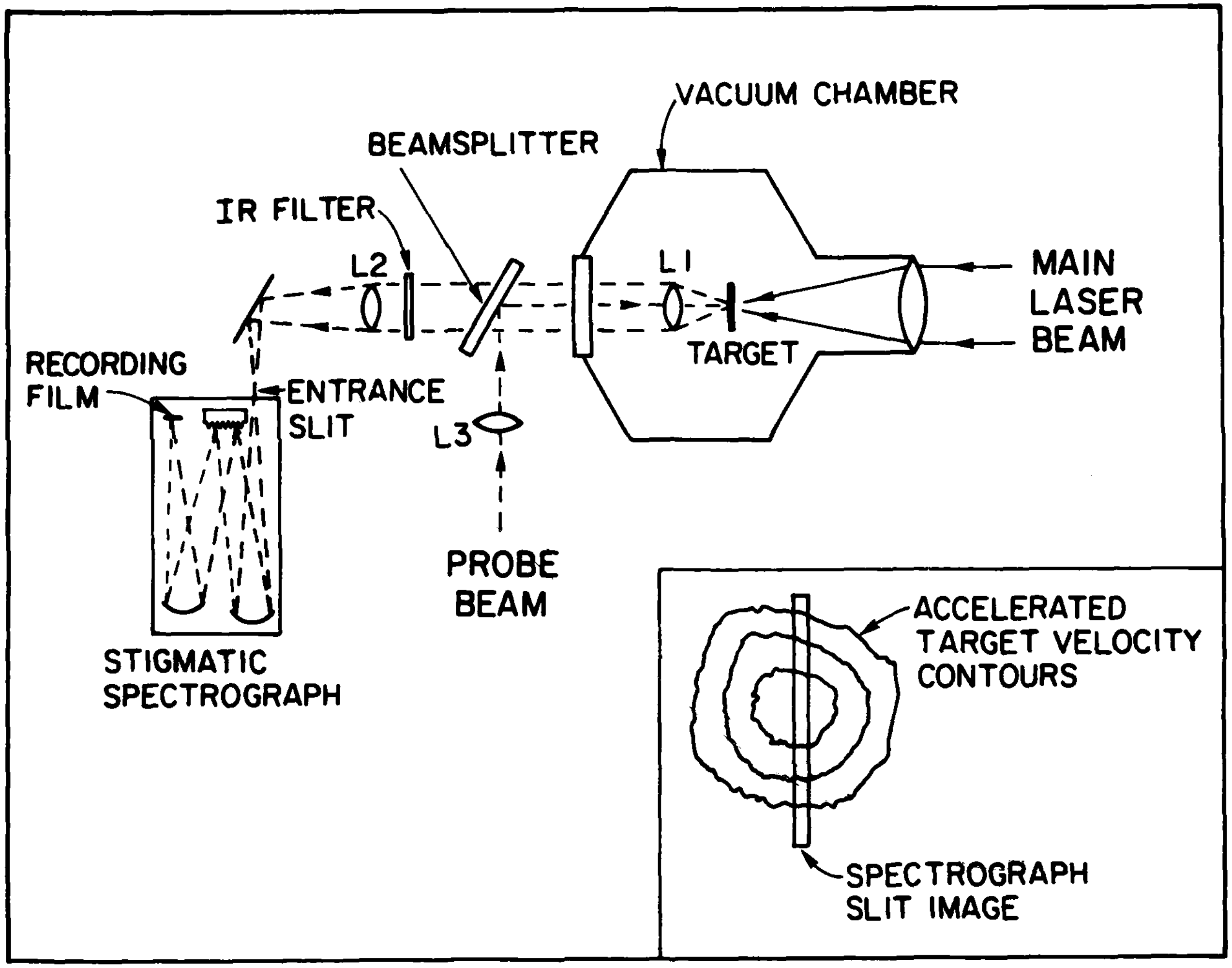

Fig. 1 — Experimental arrangement of doppler velocimeter used to measure velocity profiles of an ablatively accelerated foil target. The lens pair L1 and L2 focuses the target image onto the spectrograph. The lens pair L1 and L3 telescopes the optical probe beam down for increased intensity.

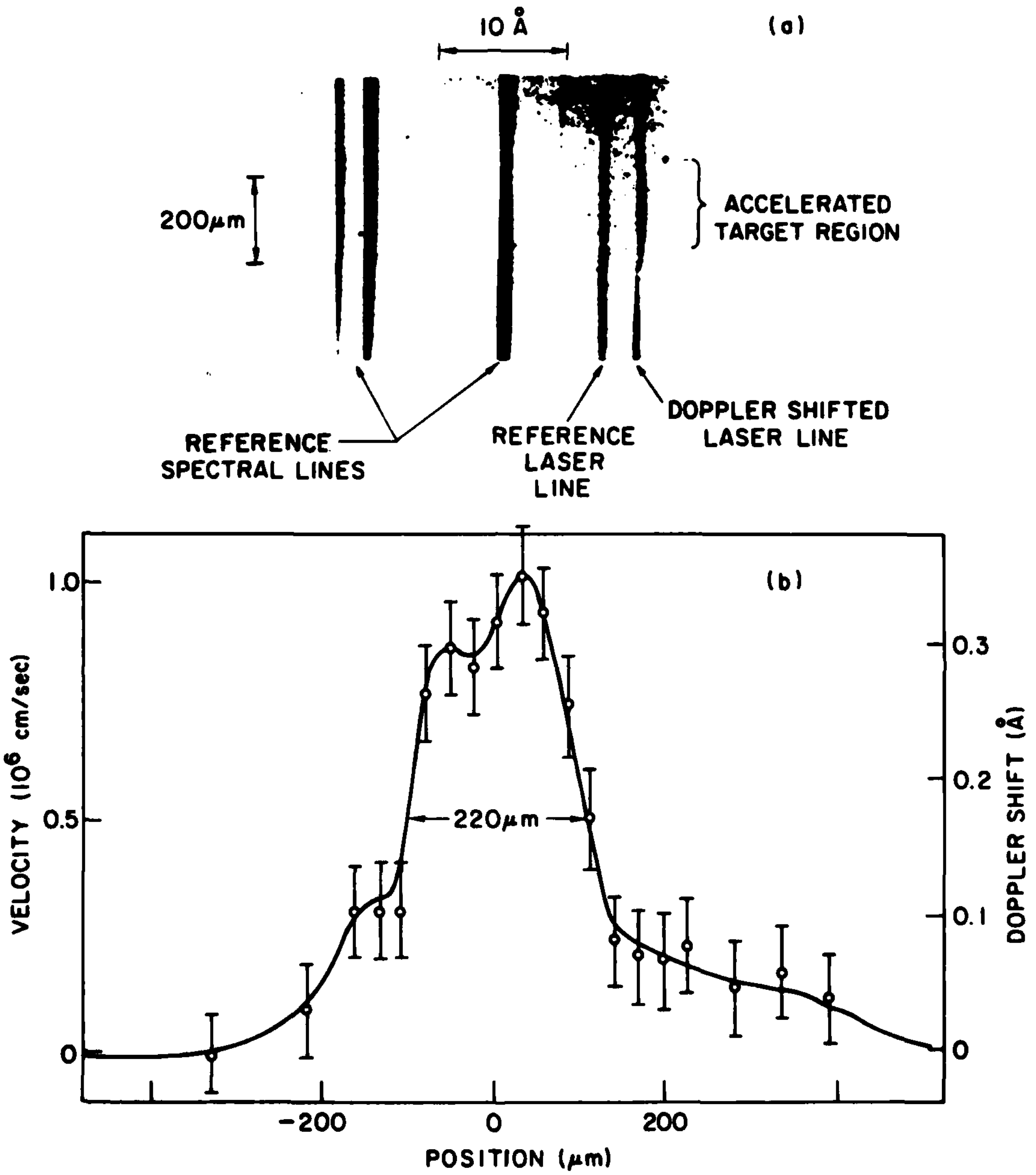

Fig. 2 — Fig. 2(a) shows raw data produced at the film plane of the doppler velocimeter. The accelerated target region corresponds to a bump on the laser line. The velocity profile obtained by densitometering the film shown in Fig. 2(a) to determine precisely the wavelength shift is given in Fig. 2(b).

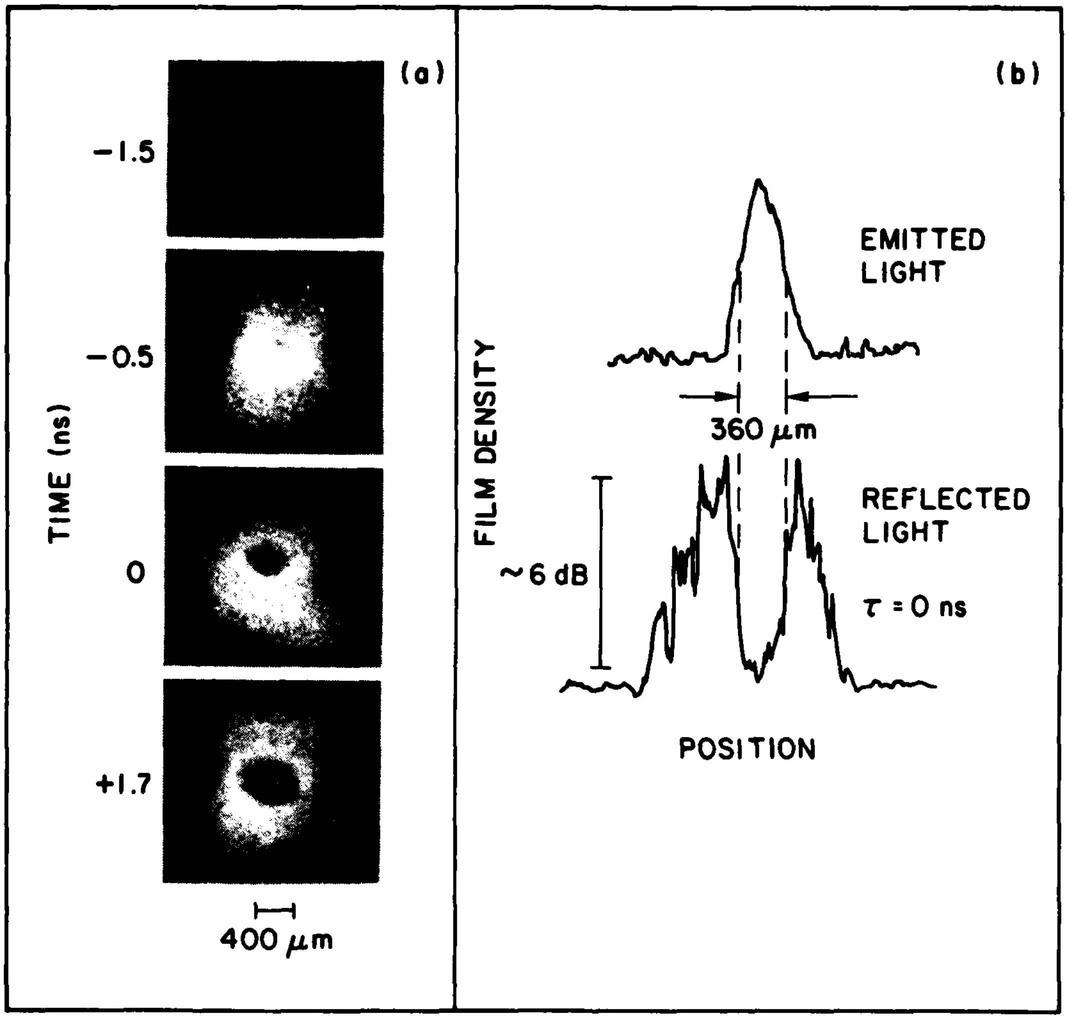

Fig. 3 — Photographs of the rear surface of a 7μm thick Al foil target illuminated by the optical probe at several times with respect to the peak of the main laser pulse are given in Fig. 3(a). A comparison of densitometry traces of photographs of the rear target surface taken in the probe light, and emitted light from the rear target surface is given in Fig. 3(b). A narrowband interference filter eliminated most of the emitted light for the probe illuminated case.

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