TIME-RESOLVED MEASUREMENT OF THE LAUNCH OF LASER-DRIVEN FOIL PLATE

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Abstract. Foil plates (or mini-flyers) have been launched to high velocity by a tabletop laser system, and their velocity histories have been measured by a push-pull type VISAR coupling with an electronic streak camera for recording the quadrature outputs. Typical results are presented for Al (10 μm-thick), Pt (10 μm), Au (5 μm) and Cu (5 μm) foil plates at laser intensities ranging from 20 to 400 GW/cm$^2$. For the 10 μm-thick Al, velocities over 13 km/s within about 30 ns have been detected with a time resolution of ~300 ps and ~2% error for the peak velocity.

INTRODUCTION

Dynamic high pressures up to tera-pascal (TPa) have been generated with the direct irradiation of strong laser beam on condensed matter in the past decade. This progress offers a new opportunity to study material property under the extreme condition in laboratory. To improve the shock compressing condition of the target sample, an indirect irradiation idea, that we call laser gun, is now being proposed. Analogous to a propellant gun, a foil plate (or mini-flyer) is launched to high velocity driven by pulsed laser beam, and then impacts with a static target. This flyer-impact system may provide a well-controlled, stable shock wave compression for the sample, and also a significant preheating of the sample may be avoided, which is inevitable in the direct irradiation experiments. In order to well characterize the performance of laser gun, a time-resolved measurement on the launch of foil plate is required. A challenge of this measurement, however, comes from: (1) the foil acceleration process being extremely fast that the velocity rises up to a few km/s or even more within a time duration on the order of nanosecond, and (2) the small size of mini-flyer, which is normally hundreds of μm or 1~2 mm in diameter. Previously, the time-resolved velocity profiles have been measured for the foil plates tamped with a substrate at low laser irradiance (<5 GW/cm$^2$).$^{1,2}$ Probing the velocity at higher laser intensity is not satisfactory yet. In this report, we present a measurement on Al, Pt, Au and Cu foil plates irradiated at laser intensities up to 400 GW/cm$^2$. An optical system that couples with an electronic streak camera (ESC) for recording the quadrature outputs of push-pull type VISAR has been established, which provides high time resolution (300~500 ps) and high accuracy in the velocity history measurement.

EXPERIMENTAL TECHNIQUE

To drive the foil plate, a tabletop-type compact laser system (Q-switched Nd:YAG laser) was used.
The pulsed laser beam with wavelength of 1064 nm, pulse duration (FWHM) of 10 ns and a Gaussian spatial profile was focused onto a foil plate located inside a vacuum target chamber. The focused beam diameter of the driving laser was ~2 mm. Irradiation intensity was from 20 to 400 GW/cm² with the changes of laser energy from 8 to 100 J.

To measure the foil plate’s velocity history, a push-pull type VISAR was employed. Compared with other velocity interferometers, such as FP3 (Fabry-Perot interferometer) and ORVIS4 (optically recording velocity interferometer system), the push-pull type VISAR has great advantages that it provides almost a continuous and an excellent accuracy in velocity measurement because of the usage of four quadrature outputs with special phase difference.5,6 In the conventional use of push-pull type VISAR, a PMT system, that consists of four photomultiplier tubes (PMTs) and one or two oscilloscopes, is used to record the quadrature outputs.5,6 It provides a time resolution normally about 2–3 ns. To achieve higher time resolution, in this work the quadrature signals have been recorded by an optical system, that we call ESC system.7,8 The VISAR’s output signals have been transmitted through an optical fiber directly to an ESC. A fast rise-time ESC (C5680 streak camera, HAMAMATSU PHOTONICS K. K, Japan) is used, which provides a time resolution less than 50 ps by using a sweep unit M5677. Considering also the time dispersion in optical fibers and the VISAR’s intrinsic rise time, a time resolution of about 300–500 ps is obtained for the present recording system.

RESULTS AND DISCUSSION

Figure 1a shows a typical interferential fringe pattern recorded by the ESC system from a 10 μm-thick Al foil plate irradiated at 340 GW/cm² (shot No. 00616s5). The time resolution is about 300 ps given the Velocity Per Fringe (VPF) constant of 10.05 km/s/fringe. Time axis increases from the top to the bottom and the total record is 100 ns. The four outputs of push-pull type VISAR, 1A, 1B, 2A, and 2B, are recorded simultaneously, and fringe patterns are evident by a variation of light intensity with time. The vertical dark lines in outputs 1A, 2A

![Figure 1a](image_url)

**FIGURE 1.** VISAR record and analysis in shot 00616s5. (a) Fringe pattern recorded by the ESC system from 10μm-thick Al foil plate driven at 340 GW/cm²; (b) Digitized data of outputs 1A and 1B; (c) Subtractions of (1A-1B) and (2A-2B).
FIGURE 2. Velocity profiles of Al 10μm-thick, Pt 10μm-thick, Au 5μm-thick and Cu 5 μm-thick foil plates.

and 2B are due to the break of fibers or separation at the time of fabrication. The output records are analyzed with an image readout system that yields the data by digitizing the image with 1024 intervals. The time relationship between each interval has been calibrated by the manufacture and no interpolation has been made during our data reduction. Figure 1b is the digitized outputs of 1A and 1B, showing a 180° phase difference. Figure 1c indicates the subtractions of outputs (1A-1B) and (2A-2B), and they exhibit 90° phase relationship.

These results demonstrate the excellent push-pull phase relationship among these quadrature outputs.

The velocity history, v(t), has been computed from the VISAR fringe count, F(t), with the equation,

\[ v(t - \frac{1}{2} \tau) = \text{VPFxF}(t), \tag{1} \]

where \( \tau \) is the delay time of VISAR's etalon, and \( F(t) \) can be known from,

\[ F(t) = \theta(t)/2\pi, \tag{2} \]
and \[ \theta(t) = \tan^{-1} \left[ \frac{D_2(t)}{D_1(t)} \right]. \]  

(3)

D_1(t) and D_2(t) are the amplitudes of the two fringe data sets shown in Fig. 1c. D_1(t) is the subtraction of (1A-1B), and D_2(t) is (2A-2B). They possess the same amplitude and 90° phase difference. This calculation has been done with a computer program and the result is presented in Fig. 2a as indicated by 340 GW/cm². Given that about 1.1 fringes were recorded (Fig. 1c), the accuracy of peak velocity is about 2% in this shot.

Typical velocity profiles are presented in Fig. 2 for the foil plates Al (10 \( \mu \)m-thick), Pt (10 \( \mu \)m), Au (5 \( \mu \)m) and Cu (5 \( \mu \)m), respectively. Repeated experiments have been conducted at the fixed laser conditions to check the reproducibility. Good coincidence in a series of shots is evident. The difference of acceleration property among the four kinds of foil plate is significant. 10 \( \mu \)m-thick Al foil plate appears to be the most favorite one to generate high velocity under the same laser intensity. A terminal velocity increase from 1.5 to 13 km/s has been observed as the laser intensity increases from 28 to 380 GW/cm². 5 \( \mu \)m-thick Cu foil plate is the second candidate to generate high velocity, and then Au (5 \( \mu \)m) and Pt (10 \( \mu \)m), respectively (Fig. 2).

In terms of shock impedance, Pt flyer is the highest, then Au, Cu, and Al is the last. However, since Al flyer has significantly higher acceleration velocity than the rest of three, it can generate much stronger dynamic pressure under the same driving laser intensity. With the present tabletop laser system, a shock pressure of ~500 GPa can be generated in a Pt target sample by using an impact of 10 \( \mu \)m-thick Al foil plate at ~13 km/s. Higher shock pressures may be produced by reducing the laser beam diameter down to less than 2 mm or using thinner foil plate. However, the two-dimensional effect in pressure generation will be more significant.

**ACKNOWLEDGEMENTS**

The authors gratefully acknowledge L. M. Barker at Valyn International for the technical support. This research was supported by a grant from the COE project in Advanced Materials Laboratory, National Institute for Materials Science (NIMS), Japan.

**REFERENCES**


