Optical fiducials for x-ray streak cameras at LLE

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The incorporation of an optical timing fiducial onto a time-resolved x-ray streak record permits one to precisely relate the x-ray emission to the incident laser pulse. At the Laboratory for Laser Energetics, our approach to recording fiducials is twofold. In addition to recording the x-ray emission on a bifurcated photocathode, we also streak the incident laser light at 351 nm, which is scattered from the target and an independent signal at $4\omega_0$ (264 nm), which is derived by frequency quadrupling a tiny fraction of the OMEGA laser driver output. The signal at $4\omega_0$ is transported through the vacuum wall to the streak camera photocathode via fiber optics. A 200-Å aluminum layer on mica is utilized for the UV sensitive photocathode. We will present examples and further details of this system.

INTRODUCTION

X-ray streak cameras are the primary instruments for studying the transient nature of laser-produced plasmas. However, in order to interpret the streak record correctly and to make meaningful comparisons with numerical code simulations of the experiments, it is necessary to precisely and unambiguously relate the time of the x-ray emission to the incident laser pulse.

A variety of techniques have been used to establish a timing fiducial for the x-ray emission. An x-ray fiducial can be obtained by coating the target with a thin layer of high-Z material whose characteristic x-ray emission is discriminated spectroscopically.[1-3] The drawbacks for this technique are that the presence of the high-Z layer can alter the laser plasma interaction significantly and that the timing of the onset of the x-ray emission relative to the laser pulse is not well defined. An alternative is to use a secondary laser pulse of short duration to generate a plasma off a subsidiary target which consists of a different Z material.[4] The synchronization of the two laser pulses can be measured using an optical streak camera, and again the x-ray signals are discriminated spectroscopically.

A simple, yet noninvasive method for obtaining a timing reference for the streak record is to use an optical fiducial.[5] This of course requires the incorporation of a bifurcated photocathode into the x-ray streak camera, one section optimized for x-ray sensitivity, the other for the optical or UV spectral region. Two methods are used for generating the optical reference signals for the time-resolving x-ray diagnostics on the 24 UV-beam OMEGA laser facility at the Laboratory for Laser Energetics. First, the fraction of the incident laser light (at 351 nm) that is scattered or refracted by the plasma is used to provide a direct timing fiducial. The second method involves the frequency conversion of a small fraction of the laser driver energy to the UV ($4\omega_0$ at 264 nm). This signal is then transported via an optical fiber through the vacuum wall to the streak camera photocathode. The absolute synchronization of this signal is obtained by timing it against the scattered light signal. The latter method of providing fiducials is useful for x-ray streak camera diagnostics which are not amenable to viewing the scattered 351-nm laser light directly.

The precision in timing the optical fiducials using the above methods depends on how well the scattered light signal represents the actual incident laser pulse. The most precise synchronization is achieved by using a mirror, in place of the plasma, to reflect the incident laser light to the streak camera. An additional benefit from recording the light scattered from the plasma is the insight it provides on features related to time-resolved absorption.

I. EXPERIMENTAL SETUP

Optical fiducials are now routinely recorded on all of the time-resolved x-ray spectra obtained with the streak camera/photographic camera elliptical analyzer x-ray spectrometer (SPEAXS) instrument.[6,7] In Fig. 1 we present a schematic of this system. With the "point" laser-produced plasma source at one focal point of the ellipse, both the x-ray signal which is Bragg reflected and the incident laser light (at 351 nm) which is scattered from the plasma and reflected by the x-ray analyzer crystal, pass through the second

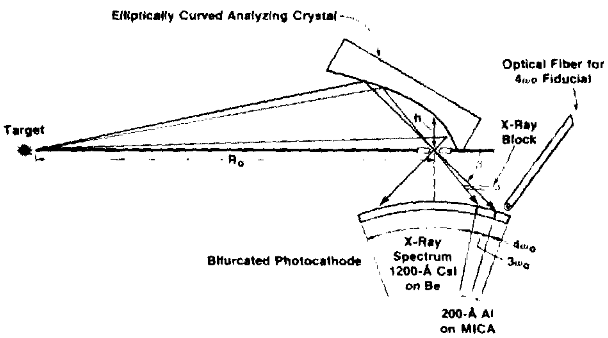

FIG. 1. Schematic of the geometry of the elliptical analyzer x-ray spectrograph with the optical fiducials signals incident on a bifurcated streak camera photocathode. The ellipse is characterized by $R_0 = 120$ cm and $L = 5.08$ cm.

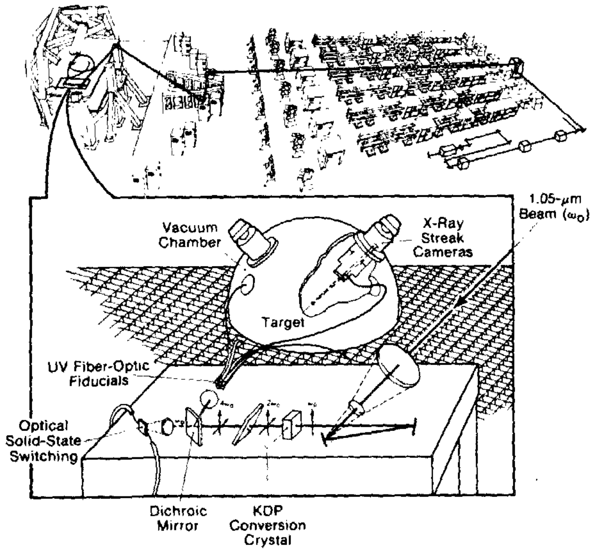

FIG. 2. Schematic for producing a $4\omega_0$ (264 nm) optical fiducial on the OMEGA laser facility.

focal point with no time dispersion across the spectrum. The bifurcated photocathode is located 4.4 cm from this second focal point and the time dispersion introduced by optical path differences in this section and by streak curvature in the streak tube itself amounts to less than 50 ps. This is corrected for in the data reduction. The streak camera photocathode dimensions are 1×45 mm^2; a section 8 mm long is used for the optical fiducials. The scattered UV light signal from the target to this section is enhanced by evaporating a 100-Å Al layer onto the x-ray analyzer crystal, thereby increasing its UV reflectivity.

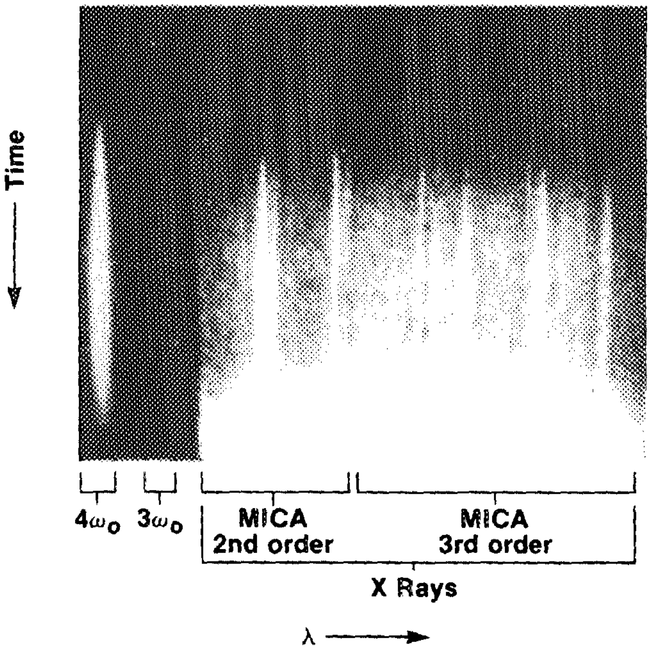

FIG. 3. Streak record showing the optical fiducial and x-ray spectrum from a glass microballoon target shot. The prominent x-ray spectral features are the silicon resonance lines: He_α and H_α in second order, and He_β, H_β, H_γ in third order off a mica analyzer crystal.

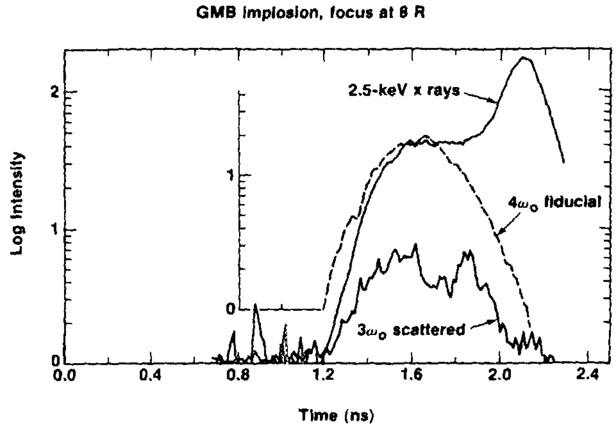

FIG. 4. Overlay of the x-ray and optical fiducial signals as reduced from Fig. 3.

The second optical fiducial on the streak records is the $4\omega_0$ signal at 264 nm. This is derived from the OMEGA driver line and fed into an array of quartz fibers for distribution to various streak cameras, as shown in Fig. 2. The optical fibers have a 400-μm-diam core and are typically 6.5 m long with a transmission at 264 nm of 75%/m. The multimode dispersion in these fibers is not a problem for the 400–600-ps pulses which we use.

The x-ray sensitive transmission-mode photocathode material that is commonly used is 1200-Å CsI on a 12.7-μm Be substrate. For x rays with energies < 1 keV, a 250-Å Au photocathode on a 2000-Å Parylene substrate is used. The secondary electron yields for both of these x-ray photocathodes are well known.[8] The transmission-mode photocathode for the optical fiducials consists of 200-Å Al on a mica substrate. Aluminum has been found to be the most sensitive photoemissive material for 351-nm irradiation.[9,10] Very thin layers of mica with a measured transmission exceeding 33% at 264 nm provide a simple, yet rugged substrate for the UV photocathode. These photocathode materials are stable and can withstand the occasional exposure to atmosphere.

II. EXPERIMENTAL RESULTS

The streak record from a 583-μm-diam glass microballoon target shot as obtained by the SPEAXS instrument is presented in Fig. 3. An overlay of the corresponding time line outs of the x-ray signal (2.3–2.45 keV) and the optical fiducial signals is shown in Fig. 4. In general, the scattered $3\omega_0$ signal will be shorter in duration than the incident laser pulse, but it does give an indication of the time-resolved absorption. Specifically, the second peak in the scattered $3\omega_0$ signal at 1.85 ns is attributed to an increase in refraction as the critical surface moves inward during the implosion. The peak in the x-ray signal at 2.1 ns is the contribution from the x-ray continuum which is emitted during and after the implosion. Here we define the implosion as the time corresponding to the minimum shell radius. The $4\omega_0$ signal (dashed line in Fig. 4) is more representative of the actual incident laser pulse shape. The line out on the figure is positioned according to our best estimate (± 20 ps) of the timing of the laser pulse with the x-ray and $3\omega_0$ signals, which are synchronized.

Through these optical fiducials we can now synchronize the streak records from various x-ray streak cameras to each other and to the incident laser pulse.

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