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Signal averaging x-ray streak camera with picosecond jitter

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Signal averaging x-ray streak camera with picosecond jitter

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We have developed an averaging picosecond x-ray streak camera using a dc-biased photoconductive switch as a generator of a high-voltage ramp. The streak camera is operated at a sweep speed of up to 8 ps/mm, shot-to-shot jitter is less than ±1 ps. The streak camera has been used to measure the time history of broadband x-ray emission from an ultrashort pulse laser-produced plasma. Accumulation of the streaked x-ray signals significantly improved the signal-to-noise ratio of the data obtained. © *1996 American Institute of Physics.* [S0034-6748(96)02803-0]

I. INTRODUCTION

Ultrashort-pulse, high-intensity lasers interacting with solid targets make the generation of ultrashort x-ray bursts possible.[1,2] These ultrashort x-ray sources have applications in diffraction, holography, spectroscopy, and radiography of transient physical, chemical, or biological phenomena.[3] The streak camera is a unique tool for studying the time history of x-rays produced by these sources due to its high writing speed, its simplicity of operation, and data deconvolution. In order to improve both the signal-to-noise ratio of the data obtained and the dynamic range of the streak camera, it is extremely beneficial to sum the temporal x-ray signals, especially for the high repetition rate x-ray sources.

Commercially available x-ray streak cameras have a temporal resolution of the order of a few picoseconds, but have an internal jitter more than a few tens of picoseconds. This jitter is due to the statistical nature of the avalanche process in the high voltage ramp generators, such as krytrons or avalanche transistor stacks, making it difficult to average data. On the other hand, it has been shown[4] that with the use of a high voltage photoconductive switch, which provides the sweep voltage for an *optical* streak camera—a jitter of ±2 ps is achievable. In this paper we report on the use of a dc-biased semi-insulating (SI) GaAs photoconductive switch as a generator of a high-voltage ramp with a sweep speed of up to 8 ps/mm; shot to shot jitter is less than ±1 ps for the *x-ray* streak camera.

II. EXPERIMENTAL SETUP

Since the photoconductive switch output depends on the laser pulse parameters, a stable laser pulse with high intensity contrast is required. The laser used in the experiments is a Ti:sapphire CPA laser: energy 75 mJ, pulse duration 45 fs, energy stability ±5%, intensity contrast $>10^5$.[5]

The principal scheme of the experiment is shown in Fig. 1. A single pulse from the output of the CPA laser is split; one pulse passes through the saturable absorber and illuminates the SI GaAs switch, which is mounted close to the deflection plates of the streak camera. The switch becomes conductive with a rise time limited by the laser pulse width. This begins charging the deflection plate, while the other pulse is focused on the solid target generating keV x-rays. The streaked images of broadband x-ray emission passing through beryllium filters of different thicknesses were amplified by the MCP and read out with a CCD. The sweeping of the electron beam in the streak camera is thus synchronized to the x-ray signal allowing the accumulation of temporal x-ray signals. The sweep speed is easily adjustable by varying the dc bias voltage on the switch, and is linear to 5% over 300 ps.

For the high voltage ramp generation we have used a SI GaAs switch with a resistivity of 10^7 Ω cm. The dimensions were 10 mm long, 4 mm wide, and 0.5 mm thick. To reduce the contact resistance, two gold electrodes were deposited on the switch with a gap between the electrodes 4 mm wide. In spite of the high resistivity of SI GaAs, it cannot hold an electrical dc field greater than 6 kV/cm due to thermal runaway. The voltage switchout follows the equation:

$$V_{\text{out}}=\frac{Z_{\text{out}}}{Z_{\text{in}}+Z_{\text{out}}+r_{\text{cnt}}+r(E)}V_{\text{in}}, \tag{1}$$

where V_{in} is the bias voltage, Z_{out} is the characteristic impedance of the output cable, Z_{in} that of the bias cable, r_{cnt} is the resistance of the contacts, and *r(E)* is the gap resistance. The gap resistance is governed by the expression[6]

$$r(E)=\frac{h\nu l V_{\text{in}}}{2V_s e E_{\text{abs}}}, \tag{2}$$

where E_{abs} is the absorbed laser energy, ν is the optical frequency, l is the gap width, V_s is the carrier saturation velocity ($\sim 10^7$ cm/s), e is the charge of the electron, and h is Planck's constant.

Figure 2 shows the dependence of the switching efficiency in the 50 to 50 Ω geometry as a function of the laser flux. As the laser flux increases the resistance of the gap becomes smaller. At a laser flux greater than 30 μJ/mm^2 the switch goes into the saturated regime. In this regime the gap resistance is much smaller than the line impedance, i.e., $r(E) \ll Z_{\text{in}} + Z_{\text{out}}$, and according to Eq. (1) the switching

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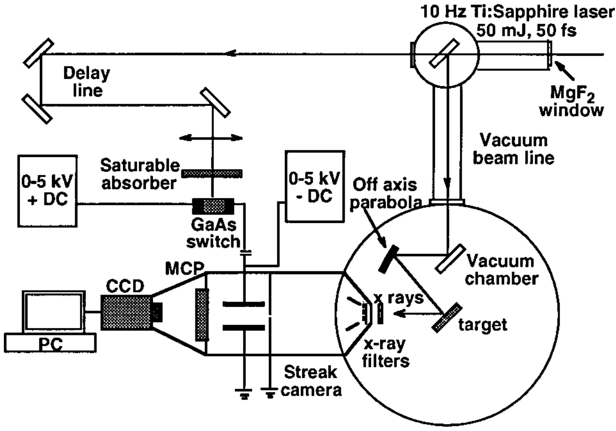

FIG. 1. Experimental setup for the investigation of x-ray emission with signal averaging x-ray streak camera.

output will be less sensitive to the fluctuation of the laser energy, and thus less sweep speed fluctuation is expected. We measured experimentally the output voltage amplitude fluctuation to be about ±0.1% at a laser flux greater than 100 μJ/mm^2. When the bias voltage is of 2.4 kV this amplitude fluctuation should lead to a streak camera jitter of less than 1 ps.

As the laser flux increases, the peak of the output signal becomes more stable, but the front shoulder of the electrical pulse, which results from the amplified spontaneous emission (ASE) of the laser, grows linearly. Figure 3 (a) shows the typical signal at the output of the switch. The maximum amplitude of the front shoulder reaches up to 30% of the main electrical pulse amplitude and has a fluctuation of about ±30%. This electrical prepulse will lead to a zero-time offset fluctuation of the streaked images and to a slope variation of the ramp. At high laser flux we also observed a prepulse which is 10 ns in front of the main pulse because of the finite extinction ratio of the Pockels cell used as a pulse cleaner. To prevent the effect of fast surface recombination, which is shown as the front sharp peak in Fig. 3(a) and fluctuates more than the flattop does, we illuminated the switch from the opposite side of the gold contacts. In this case bulk recombination will dominate the switching operation. While keeping the switch in a saturated regime, we reduce the influence of prepulses by placing the cell with a saturable absorber in front of the switch [see Fig. 3(b)]. The saturable absorber is prepared by mixing HDITCP dye with the solvent Ethanol-Glycol at 1.98×10^{-5} mol/L. It has a transmission of 1% at 790 nm at low laser intensities and transmission of 70% for the main pulse at a laser flux greater than 50 GW/cm^2.

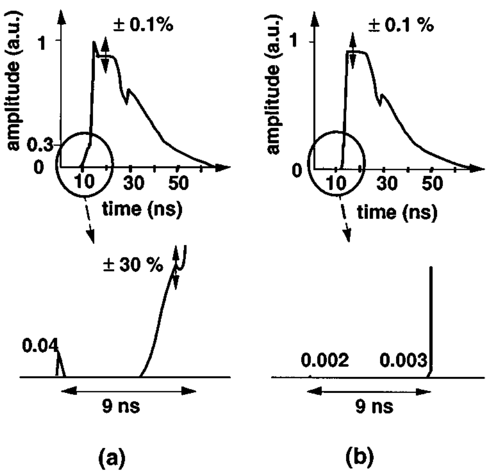

FIG. 3. Typical electrical signals at the switch output (a) front-side illumination, and (b) back-side illumination and saturable absorber in front of the switch.

III. EXPERIMENTAL RESULTS

To determine the jitter of the streak camera we used the direct laser illumination of the photocathode which consisted of 500 Å of gold on 1 μm of plastic foil. A bias of 1.9 kV dc was applied to the switch with a 4 mm gap. The laser flux on the switch was about 100 μJ/mm^2. The rise time of the voltage ramp is limited by the RC charging time of the deflection plates, with a capacitance of 9 pF which is equal to 450 ps. The sweep speed of the streak camera was calibrated by placing the glass plate in half of the laser beam in front of the photocathode and was measured to be equal to 16 ps/mm. Figure 4 shows the experimental data line outs of the images for the single shot and accumulated 10 and 50 shots, which were taken at the 10 Hz laser repetition rate. To show the

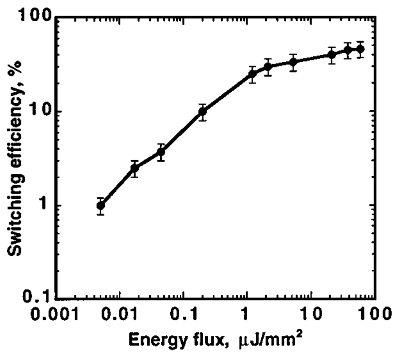

FIG. 2. Switching efficiency of semi-insulating GaAs switch as a function of the laser flux on the switch.

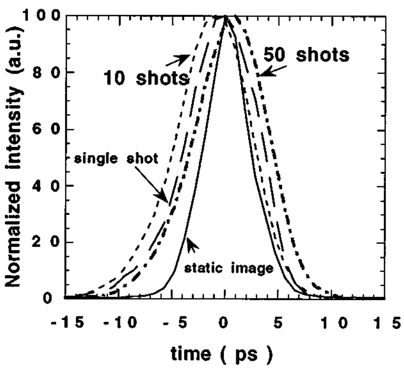

FIG. 4. Experimental data line outs showing ±1 ps jitter with direct laser illumination of the gold photocathode of the streak camera.

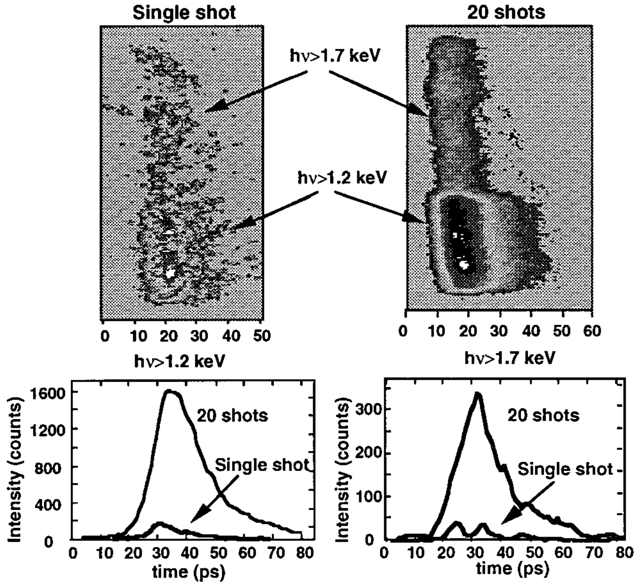

FIG. 5. Streaked images of the broadband x-ray emission from Ni target passing through 25 μm (cutoff energy $h\nu > 1.2$ keV) and 50 mm (cutoff energy $h\nu > 1.7$ keV) Be filters and corresponding line outs for the single shot and 20 accumulated shots. Signal-to-noise ratio is significantly improved after averaging 20 shots.

spatial resolution of the streak camera the static image line outs have been drawn on the same plot. The comparison of the row of the single shot data and accumulated data shows less than ±1 ps jitter of the streak camera and was limited by CCD camera resolution. Full width at half-maximum (FWHM) of the accumulated data is about 1 ps broader than single shot ones due to the averaging effect. To further increase the sweep speed we have used two SI GaAs switches each with a 4 mm gap that drive two deflections plates with bias of opposite polarities. At 2.0 kV dc we have reached a sweep speed of 8 ps/mm.

The x-ray streak camera has been used to measure the time history of the broadband x-ray emission from a solid Ni target at a laser intensity of 10^{17} W/cm^2. A photocathode consisting of 1500 Å of KBr and 250 Å of aluminum on 1000 Å of Lexan was used to increase the sensitivity to x-rays and to narrow the secondary electron distribution. The streaked images of x-ray emission passing through Be-filters 25 μm and 50 μm thick and corresponding line outs for 1 shot and 20 accumulated shots are shown in Fig. 5. It is clear from the figure that the accumulation of x-ray images significantly increased the signal-to-noise ratio of the data. We mention here that the measured FWHM of the x-ray pulse with cutoff energy $h\nu > 1.2$ keV is about 20 ps and with cutoff energy $h\nu > 1.7$ keV is about 15 ps and were not limited by the streak camera resolution. The relatively long pulse duration of x-rays can be explained by insufficient laser contrast for the deposition of short laser pulse energy at densities close to solid.[7–9]

In summary we have demonstrated an averaging x-ray streak camera with picosecond jitter. Use of the signal averaging greatly enhances the quality and reliability of the data obtained, and permits many experiments with relatively low x-ray yield which are not possible with standard jitter and drift parameters.

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