REDUCTION OF JITTER IN STREAK-CAMERA SYNCHRONIZATION WITH PICOSECOND LASER PULSES

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A laser activated silicon switch generates the sweeping voltage for a picosecond streak camera. With a Photochron streak tube shot-to-shot jitter has been reduced to ±15 ps for writing speeds in excess of 2 × 10⁸ ms⁻¹.

Direct measurement of picosecond luminous phenomena requires the use of electron-optical streak-cameras, which can operate with time resolution of ≲1 ps [1]. However, shot-to-shot jitter in the synchronization of the voltage ramp, applied to the deflection plates, with the arrival of the light signal to be studied creates experimental problems. When subpicosecond time-resolution is required, the time interval displayed on the screen is only ~250 ps because of the very fast writing speeds [2]. Although jitter as low as 30 ps has been reported for some streak camera systems [1,3,4], further improvement and greater reliability is needed for the full exploitation of the new generation of femtosecond streak cameras now under development [5] for both single-shot [2] and synchron-scan [6,7] modes of operation.

Ultrafast semiconductor devices, first developed by Auston [8], have been shown to generate voltage pulses of amplitude up to 1.5 kV with picosecond risetimes [9]. Lee [10] employed GaAs devices to produce pulses up to 600 V amplitude and more recently voltages of ~10 kV have been used for Pockels' cell switching [11,12]. We report the use of a silicon switch to generate a stable low-jitter deflection voltage ramp for a picosecond streak camera. While the initial results show an overall jitter of ±15 ps over thousands of shots, for briefer periods of camera operation jitter as low as ±6 ps has been obtained. Since this best jitter performance closely approaches the time-resolution limit (3 ps) of the streak-tube employed, silicon and III–V semiconductor switches show great promise for driving femtosecond streak-cameras with precision and reliability.

The camera incorporated a Photochron I image tube [2] with a S11 photocathode and the output phosphor image was lens-coupled to a magnetically focussed image intensifier [13]. The camera has a temporal resolution of 3 ps for incident light at 530 nm at a streak speed of 2 × 10⁸ ms⁻¹. The streak-tube deflection sensitivity is ~300 V/cm and a voltage ramp of 1.5 kV provides a 5 cm streak length. Linearity is achieved by increasing the streak voltage amplitude and voltages up to 6 kV were employed. The stray inductance and also the capacitance of the deflection plates (~6 pF) limited the writing speed to a maximum value of 2.3 × 10⁸ ms⁻¹.

The construction of the switch was similar to that described by Lee [10] for GaAs. A slab of p-doped silicon of 17 × 10⁻⁶ Ωm resistivity and dimensions 6 mm by 4 mm by 0.5 mm thick, was mounted on a double sided printed circuit board, the bottom surface of which was used as a ground plane. Two 3 mm metallic strip electrodes were evaporated on to the silicon surface, leaving a well defined gap of 1.0 mm separation. The input and output cables were electrically connected to the electrodes of the switch via a 50 Ω copper strip line. The ‘dark impedance’ of the switch was ~1 MΩ so, before the arrival of the switching light pulse, any voltage signal arriving at the input electrode was totally reflected. When a laser pulse of 1.06 μm wavelength is incident on the silicon slab, electron-hole pairs are formed throughout the bulk of
the semiconductor thereby increasing its conductivity by many orders of magnitude. An applied voltage is then efficiently transmitted.

A schematic diagram of the experimental arrangement is shown in fig. 1. The mode-locked Nd : phosphate glass laser [14] produced trains of pulses separated by 8 ns with durations of between 6 and 10 ps. Typically the energy in each laser pulse was \( \sim 1 \text{ mJ} \) but only \( \sim 20 \mu \text{J} \) was used to switch the silicon device. Since the streak tube was not sensitive to 1.06 \( \mu \text{m} \) radiation, the operation of the streak camera was evaluated with the second harmonic laser radiation generated in an ADP crystal. A single pulse containing both fundamental \( (\omega) \) and second harmonic \( (2\omega) \) components was selected from the train of pulses by a Pockels’ cell switch (PC). The laser output was monitored by a photodiode and a storage oscilloscope. The initial trigger pulse was generated by a second photodiode with an avalanche transistor chain, which in turn triggered a Krytron switch (KS) in a Blumlein pulse-forming network. A 8 ns, 9 kV square voltage pulse was applied to the Pockels’ cell, and a fraction of this square voltage pulse was also used to bias the silicon switch. Synchronization of the arrival of the laser pulse and the application of the 8 ns duration voltage pulse to the switch was thus conveniently achieved.

The fundamental frequency laser pulse was reflected off the beam-splitter BS1 (\( \sim 100\% \) at 1.06 \( \mu \text{m} \)), and was directed on to the silicon slab with sufficient delay to ensure that the laser pulse arrived after the bias voltage had been applied. The second harmonic pulse was transmitted by the beam-splitter and passed through an optical delay line (cal BS) to provide two pulses of known separation, which were directed on to the streak-camera slit.

Fig. 2 shows a series of 6 consecutive streaks recorded on Polaroid film (Type 410). In each streak the pair of pulses is separated by 50 ps. The jitter (RMS standard deviation from average position on the screen) is \( \pm 11 \text{ ps} \). For a period of \( \sim 1 \) month during which \( \sim 5 \times 10^3 \) shots were fired the overall system jitter was consistently below \( \pm 15 \text{ ps} \). For several consecutive shots (e.g. the bottom four streaks of fig. 2) the jitter was as low as \( \pm 6 \text{ ps} \). The variations in jitter could arise from fluctuations in the bias voltage pulse or in the laser pulse intensity.

The linearity of the streak was checked by adding a second calibrated beam-splitter to the optical delay line. Fig. 3 shows a series of 5 consecutive shots. The results indicate the linearity to be better than \( \pm 2\% \) over the complete 250 ps duration of the streak record.

When the writing speed of the streak camera was
Fig. 3. Five consecutive streaks of pulse trains used for calibration of streak-camera. Sweep linearity was checked by microdensitometry of streak records photographed on Ilford HP5 film. Both pairs of pulses in each streak have separations of 50 ps.

varied by changing the amplitude of the voltage pulse applied to the semiconductor device, the records obtained showed that the jitter remained consistently better than ±15 ps.

**Conclusion.** The use of a semiconductor switch considerably reduces the synchronization jitter in streak cameras. In this way it should be possible to superimpose streak records to improve the signal-to-noise ratio while retaining the separate single-shot camera temporal resolution performance. Semiconductor switches are also being evaluated in our laboratory for use in repetitively-operating synchroscan streak cameras in conjunction with mode-locked continuous wave lasers [6,7].

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**References**