Dynamic performances and applications of a new two picosecond streak camera system

E. Inuzuka, Y. Tsuchiya, M. Koishi, M. Miwa
Hamamatsu TV Co., Ltd., 1126-1 Ichino-cho, Hamamatsu, 435, Japan

Abstract

The dynamic measurements of a new 2 picosecond (ps) streak camera combined with a silicon intensifier target (SIT) TV camera and a microprocessor based multi-window Temporalanalyzer (MWTA) have been carried out with the help of several types of picosecond lasers. Limiting temporal resolution has been measured to be 1.67 picosecond at FWHM using 0.75 ps pulses from the passively mode-locked dye laser excited by an Ar^+-ion laser. Intensity dependent temporal resolution has also been measured with the 4±1 ps laser pulse from the mode-locked Nd:Glass laser to define the dynamic range in various streak ranges. Direct observation of the fine structure in the light pulses emitted from a laser diode has shown a good application of the 2 ps streak camera system.

Introduction

A C1370 compact 2 picosecond streak camera using a streak tube with a built-in micro-channel plate electron multiplier (MCP) was developed and reported in the previous congress.[1] A micro-processor based multi-window Temporalanalyzer (MWTA) was also reported to be developed.[2] They have been combined together with a silicon intensifier target (SIT) TV camera. Such a streak camera system has made the measurement of ultra-short light pulses very precise and rapid.

In this paper, the basic performances of the streak camera such as gating function, streak linearity and triggering jitter are described. Then, the dynamic performances of the streak camera system such as limiting temporal resolution and the relation of the intensity dependent temporal resolution to the dynamic range are evaluated. Further, as an example of the application of the streak camera system, direct observation of the fine structure of the laser diode will also be described.

Description of the new 2 ps streak camera

The external appearance and internal block-diagram of the new 2 ps streak camera are shown in Fig.1 and Fig.2 respectively. The streak camera has been improved to have a gating function. Since the extinction ratio should be high enough to eliminate the false signal overlap during the retrace sweep or background build-up during the stand-by period, both photocathode and microchannel plate are gated. Gating function is very effective in the measurements as only one part of the long pulse train or a pulse absorption of a long reference pulse must be observed. It has not only eliminated the need of the optical shutter but

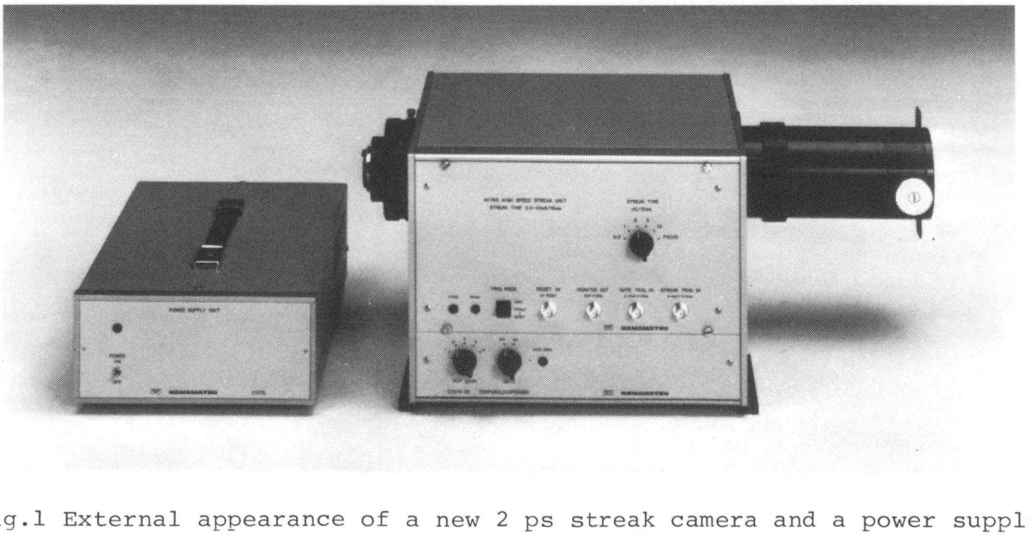

Fig.1 External appearance of a new 2 ps streak camera and a power supply

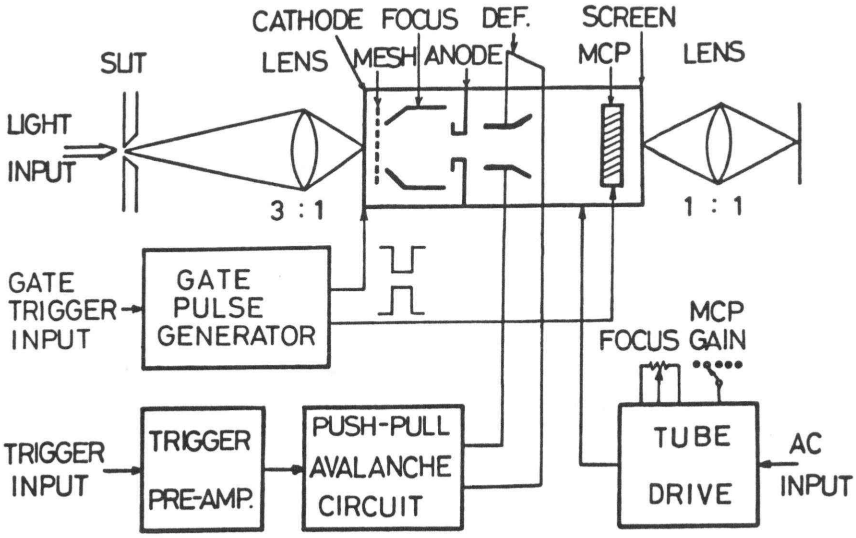

Fig.2
Block diagram of a new 2 ps streak camera

also made the adjustment of the trigger timing very easy.

The range of the streak time has been changed to 0.3, 1, 2, 5 and 10 ns/15mm which streak speed correspond to 50, 15, 7.5, 3 and 1.5 mm/ns respectively. The streak speed in the fastest range has been increased to 50 mm/ns in order to guarantee the temporal resolution of less than 2 ps with a margin. The linearity of the streak speed has also been improved by using the two separate streak module for the faster and slower streak ranges. The triggering jitter is small enough to observe streak image efficiently.

Basic performances of the 2 ps streak camera

Basic performances such as gating function, streak linearity and triggering jitter are evaluated as follows.

Gating function

Gating characteristics have been measured with the help of the diode laser pulse. The streak camera was operated in the focus mode. A slit image on the phosphor screen is picked-up by SIT camera and accumulated by the Temporalanalyzer. In Fig.3, the output intensity is plotted against the delay time between the diode laser pulse and the gate trigger signal. The data shows the extinction ratio of greater than 10^6:1 which is proved to be sufficient in the measurement of temporal resolution as shown later. The lump of the rising part is due to the LED mode luminescence of the laser diode. The pulse width of the laser mode output from the laser diode is approx. 100 ps. The rise and fall time of the gating characteristics are both around 150 ns by ignoring the lump. The gating pulse width is maximum 3 μs and is automatically short-cut after the streak sweep in order to eliminate signal overlap during the retrace period. Minimum gate width is 300 ns.

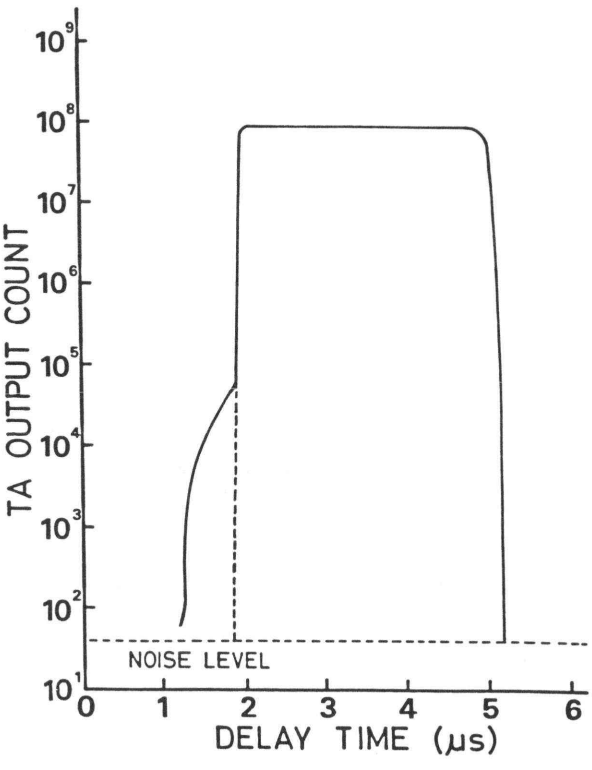

Fig.3 Gating characteristic

Streak linearity

The linearity of the streak sweep has been measured with the mode-locked Nd:Glass laser and the etalon. Fig.4 shows the typical linearity curve for the fastest streak range (50 mm/ns;0.3 ns/15mm). The non-linearity of the streak speed is measured to be less than ± 5 %. The curve of the graph is mainly due to the geometric distortion in the SIT camera.

Triggering jitter

The triggering jitter of the streak camera system has also been measured with the same set-up as the measurement of the gating function except the streak camera is operated in the streak mode. The average FWHM of the laser diode in the single streak is measured to be 50 ps. And when these pulses are integrated for 100 streaks, intensity profile becomes 57 ps due to the triggering jitter. Thus the jitter is calculated to be ± 13.7 ps (27.4 ps) FWHM, if the pulse shape and the distribution of the jitter are assumed to be Gaussian.

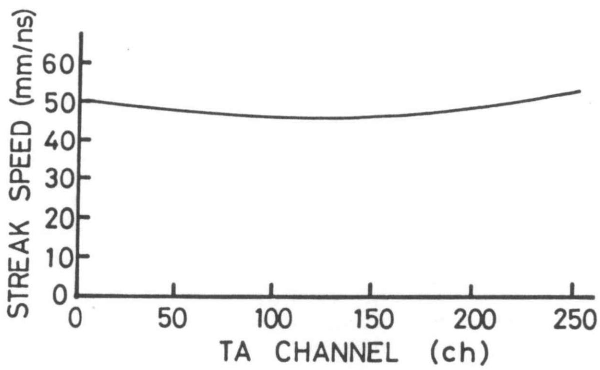

Fig.4 Linearity of the streak speed

Dynamic performances of the 2 ps streak camera

Limiting temporal resolution and the intensity dependent temporal resolution have been evaluated as follows.

Limiting temporal resolution

To determine the limiting Temporal resolution of the streak camera, sub-picosecond pulse from the passively mode-locked dye laser excited by Ar^{+}-ion laser was used. The set up for the measurement is shown in Fig.5. The output from the dye laser is 0.75 ps FWHM in duration and a repetition rate of 133 MHz. Such pulse train was passed through the delay generator to produce double pulse for calibration of time scale, and directed to the streak camera. In this measurement gating function was used to avoid background build-up. Repetition rate was too high for the streak trigger to be accepeted. Trigger signal was picked-up by PIN photodiode and fed to the trigger recognizer head (Tektronix S-53) so that the repetition rate would be reduced from 133 MHz to approx. 40 KHz. This signal was then amplified and fed to gate trigger input. Further, the same signal was fed to streak trigger input after delayed for approx. 400 ns which is enough for gating action to be settled. Although the repetition rate was still too high, the streak trigger input was limited to 1 KHz automatically in the continuous mode, or could be operated in single mode by manual reset.

Fig.6 shows the chart recorder output of the intensity profile analyzed by MWTA. The average pulse width of the double pulse is measured to be 1.83 ps FWHM. After deconvolving the laser pulse duration of 0.75 ps, the limiting temporal resolution of 1.67 ps is obtained.

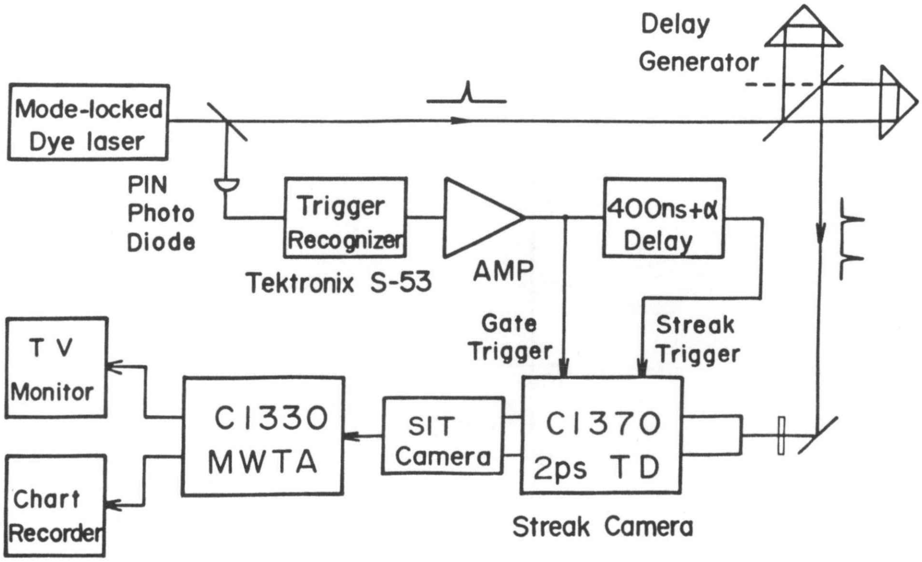

Fig.5
Set-up for the measurement of the limiting temporal resolution

Intensity dependent temporal resolution

The relation of the intensity dependent temporal broadening to the dynamic range of the streak camera have been investigated by several authors.[3~9] In these papers, the dynamic range was defined by the ratio of the intensity from which the streak image is broadened by 20 % to the background noise or film fog level. This definition would be meaningless, when the streak camera system has enough gain to output the signal sufficiently larger than noise level under the single photoelectron input. For the practical definition of the dynamic range, the lower limit should be replaced by the lowest intensity of which the pulse width can be measured.

The dynamic range of the new 2 ps streak camera system has been evaluated using 4±1 ps, 530 nm second harmonic pulse from a mode-locked Nd:Glass laser. In Fig.7, output pulse width is plotted against the input energy density at the streak speed of 50 mm/ns. Under the new definition such as the ratio of the intensity from which the streak image is broadened by 20 % to the lowest measurable intensity, the dynamic range of 170 at the measured FWHM of 3.5 ps is obtained. Fig.8 shows the dynamic range plotted against the measured FWHM in the various streak ranges. In these measurement, both the MCP gain and SIT camera gain have been adjusted to optimize the signal output. In case of single shot measurement as these gains are fixed, the dynamic range might be limited to the order of 100.

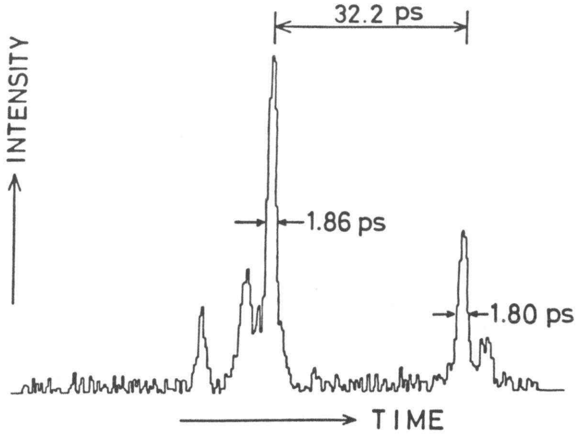

Fig.6 Intensity profile of the double pulse

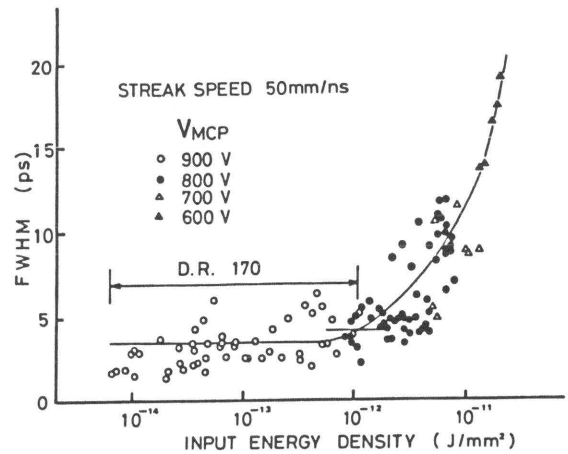

Fig.7 Intensity dependent temporal resolution

Minimum detectability

The minimum detectable intensity at the input slit of the streak camera is measured to be approx. 6×10^{-15} J/mm^2 from the above measurement. The width and the effective length of the slit were 30 μm and 2.3 mm, respectively. Thus, the photon number at the photocathode of the streak tube is calculated by the formula

$$Np = \frac{6 \times 10^{-15}}{h\nu} \times 0.03 \times 2.3 \times \eta \qquad (1)$$

$$= 7.7 \times 10^{2} \text{ (photons)},$$

where hν is the energy of the photon at the wavelength of 530 nm and η is the efficiency of the input optics (0.7). The 2 ps streak camera system showed such a low minimum detectability as 770 photons at the photocathode of the streak tube to be measured.

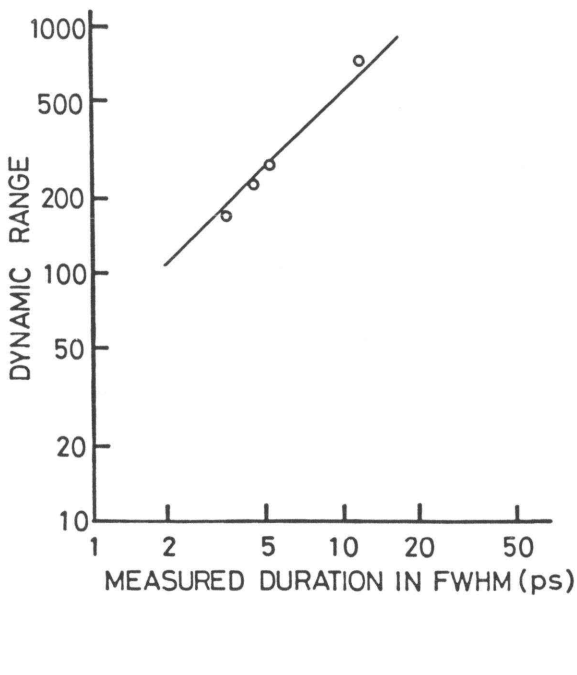

Fig.8 Dynamic range vs. measured FWHM →

Main performances of the 2 ps streak camera system

Main performances of the 2 ps streak camera system are shown as follows.

Streak sweep range	0.3, 1, 2, 5 and 10 ns/15mm (50, 15, 7.5, 3 and 1.5 mm/ns)
Sweep non-linearity	$\leq \pm 5$ %
Triggering jitter	$\leq \pm 20$ ps
Extinction ratio of gating	$\geq 10^6$:1
Limiting temporal resolution	$<$ 2 ps
Dynamic range	$\geq$ 50:1

An application of the 2 ps streak camera system

As an example of the application of the 2 ps streak camera system, a picosecond substructure in the light pulses emitted from a laser diode has been observed directly.[10] The laser diode used in the experiment is a GaAlAs single heterostructure diode with no antireflection coating in both facets. The cavity length of the diode is 340 μm (nominal). It was driven by a short pulse current generated by an avalanche mode transistor. The output laser pulses were directly observed by the streak camera system.

Fig.9 shows a typical example of the streak image and its intensity profile of a single burst, displayed on the TV monitor. It shows the pulse envelope having the duration of approx. 70 ps FWHM with many substructures. The average duration and time interval of the substructures are measured to be 2.3 ps and 6.8 ps, respectively. After deconvolving the temporal resolution of the system (1.6 ps), the average pulse duration of 1.6 ps is obtained. The spectral profile of the laser pulse was measured by a spectrometer (Jarrell Ash AA-1E) as shown in Fig.10. The spectrum consists of a few tens of Fabry-Perot modes of the laser cavity. The mode spacing and the spectral FWHM are measured to be 0.275 nm and 2 nm, respectively at the peak wavelength λ of 793 nm. The corresponding round trip time is $T = \lambda^2/\delta\lambda s \cdot C = 7.6$ ps, where $\delta\lambda s$ is the mode spacing. It is in good agreement with the average time interval and the calculated value of 8 ps from the cavity length of the diode ($2\ell n/c$).

The time-bandwidth product is calculated to be $\Delta\nu\Delta t = (\Delta\lambda c/\lambda^2)\ \Delta t = 1.5$ where $\Delta\lambda$ is the spectral FWHM of 2 nm and Δt is the average duration of 1.6 ps. This is about 4 times greater than the value calculated for a transform-limited Gaussian pulse. From the result some broadening both in the spectrum and in the duration are suggested. Further, such pulse oscillation is supposed to be a partial mode locking in the diode laser itself. These results show the importance and convenience of the 2 ps streak camera system as a diagnostic tool for a picosecond phenomena.

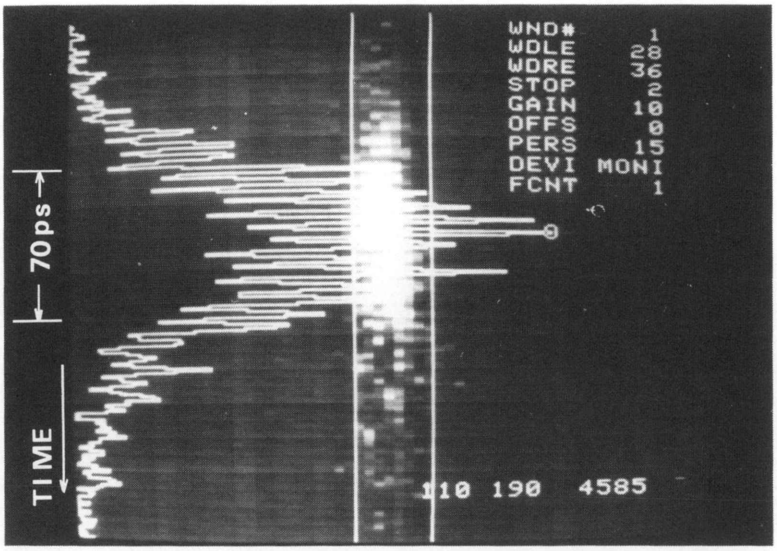

Fig.9 Streak image and the intensity profile of the single burst from laser diode

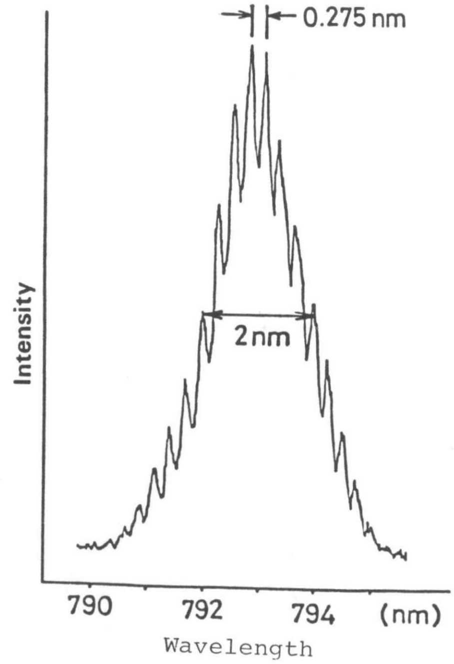

Fig.10 Emission spectrum of the laser diode

Conclusion

The basic and dynamic performances of the new 2 ps streak camera system have been evaluated. The introduction of the gating function have made the measurement of the limiting temporal resolution using repetitive pulses from the mode-locked dye laser, very easy and efficient. A high dynamic range of 170 at the measured duration of 3.5 ps FWHM is obtained under the new practical definition. From the direct observation of the fine structure of the laser diode pulses, the high quality and effectiveness of the 2 ps streak camera system have been confirmed.

Acknowledgements

The authors wish to thank Mr. T. Hiruma for his continued guidance and encouragement, Mr. K. Suzuki and Mr. Y. Takiguchi for their engineering support.

References

1. E. Inuzuka et al. "Development of a New 2 picosecond Streak Camera" presented at 14th International Congress on High Speed Photography and Photonics, Moscow, (1980)
2. Y. Tsuchiya et al. "Two-dimensional Direct Readout System for Streak Cameras" presented at 14th International Congress on High Speed Photography and Photonics, Moscow, (1980)
3. W. Friedman et al. "Dynamic Range and Spatial Resolution of Picosecond Streak Cameras" SPIE Vol. 97, (1976) pp. 544-548.
4. D. J. Bradley et al. "Intensity Dependent Time-resolution and Dynamic Range of Photochron Picosecond Streak-Cameras" Rev. Sci. Instrum. Vol. 49, (1978) pp. 215-219.
5. R. Kalibjian "Space-charge Temporal Broadening Effects in Streak-camera tubes" Proc. 13th ICHSPP, Tokyo, 1978, SPIE Vol. 189, pp. 452-455.
6. S. Thomas et al. "Dynamic Range Studies of the RCA Streak Tube in the LLL Streak Camera" ibid. pp. 471-475.
7. D. J. Bradley et al. "Intensity Dependent Time Resolution and Dynamic Range of Photochron Picosecond Streak Cameras II. Linear Photoelectric Recording" Rev. Sci. Instrum. Vol. 51, (1980) pp. 824-831.
8. D. R. Hull et al. "Dynamic Range Measurements on Streak Cameras with Picosecond Time Resolution" J. Phys. E : Sci. Instrum. Vol. 13, (1980) pp. 685-690.
9. H. Niu et al. "Theoretical Analysis of Space-charge Effects in Photochron Streak Cameras" Rev. Sci. Instrum. Vol. 52, (1981) pp. 1830-1836.
10. Y. Tsuhciya et al. "Direct Observation of Picosecond Light Pulses from a Pulse-current pumped Semiconductor Laser" J. Appl. Phys. to be published.