Section 3
DEVELOPMENT IN SUBPICOSECOND RESEARCH

3.A A Simple Jitter-Free Picosecond Streak Camera

The picosecond streak camera [43,44] is becoming a basic tool in the study of optical transients in the picosecond time scale. Other methods for accessing picosecond time resolution are gated frequency mixing[45], optical Kerr shuttering[46], two-photon fluorescence[47], and transient absorption spectroscopy[48]. In many cases, use of a streak camera can lead to higher optical sensitivity, time resolution, signal-to-noise ratio, and greater ease in data taking. With the development of streak tubes with resolution times of several picoseconds, the requirements for fast high voltage switching has quickly increased. We have demonstrated[49,50] for the first time that high voltage photoconductive switching can exceed all these requirements and hence provide an excellent streak camera driver. This section reports on a recent further development in this area which greatly simplifies the use of fast high voltage photoconductive switching applied to the streak camera and results in a subpicosecond single-shot jitter and unprecedented stability.

In order to achieve a time resolution of $\sim$ 1 psec, a photoelectron beam is swept at speeds approaching that of light across a phosphor screen in the streak tube (image-convertor tube). This requires an electrical ramp pulse of several kilovolts (1-5 kV) synchronized with high accuracy to the event to be observed. Conventional electronics can at best offer a jitter of $\pm$50 psec for short times with some long-term delay-drift. This comparatively small jitter is obtained with avalanche transistor stacks which produce limited voltage ramps, leading to reduced sweep rates. The highest sweep rates previously obtained were achieved with optically-triggered spark gaps switching up to 16 kV, but with a jitter of several hundred picoseconds. At a large streak rate, this jitter is not tolerable.

A streak camera was operated with a light-activated silicon switch for the first time with a jitter of $\pm$ 1.7 psec [49,50] using a microsecond-length pulsed bias to avoid thermal instability[50,51]. It was pointed out that a major source of this jitter was the small fluctuations in switched voltage due to the statistical error in timing of the q-switched envelope from the oscillator with respect to the bias pulse which was only flat to within a few percent. In order to resolve this difficulty, a switch was biased at 2 kV DC and held at liquid nitrogen temperature in an evacuated vessel to avoid thermal instability[52,53,54]. Although this eliminates the need for a pulsed bias, several problems enter with the use of cryogenics. Intrinsic silicon has a dielectric breakdown field strength of $\sim 3 \times 10^5$ V/cm at room temperature and $\sim 10^2$ V/cm at liquid nitrogen temperature. This is attributed to a loss of electron-phonon scattering which increases the carrier mean-free-path in the absence of impurities. In order to circumvent this problem, deep impurity levels were added via doping with Au at $\sim 10^{15}$ cm^{-3}, thus providing sufficient impurity scattering to maintain a small mean-free-path and hence a large dielectric breakdown field strength. The addition of the Au limits the resistivity, and our experience was that a maximum of 3 kV DC could be held off by Au:Si at 77°K. To achieve large sweep rates, which enable the streak camera to operate at ~1 psec resolution, larger voltages are needed. Also, the optical absorption coefficient of Si decreases as Si is cooled since at 1.06 μm the absorption is at the indirect edge (1.12 eV), and so the device becomes less sensitive (~6X) and can give voltage fluctuations which can lead to jitter in the streak camera. A further disadvantage of Au:Si is that the recombination time is only ~ 50 nsec maximum. Contact heating becomes a problem at pulse lengths > 5 nsec, so a 3 nsec pulse was used. A room-temperature DC-biased switch would be preferable to this for a streak camera driver because of ease of operation, simplicity, portability and compactness.

To this end, GaAs:Cr was chosen because of its high resistivity ($\sim 10^8 \Omega$—cm) and hence large DC holdoff without thermal instability, and its high dielectric strength. A 3 mm gap is biased at 0-5 kV DC (Figure 41). When excited by a laser pulse (50-100 μJ @ 1.06 μm) the sample becomes conducting with a risetime limited by the laser pulsewidth[51], and returns to a non-conducting state after about 1.3 nsec (1/3). During this time, the deflection plates of an image convertor tube are charged through a current-limiting resistor R_C, and remain charged until bias resistor R_B returns the voltage to its initial value. With $R_B = 10^8\ \Omega$ and $C_{plates} \cong 10^{-11}$F, this takes about 10^{-3} seconds. Thus, the

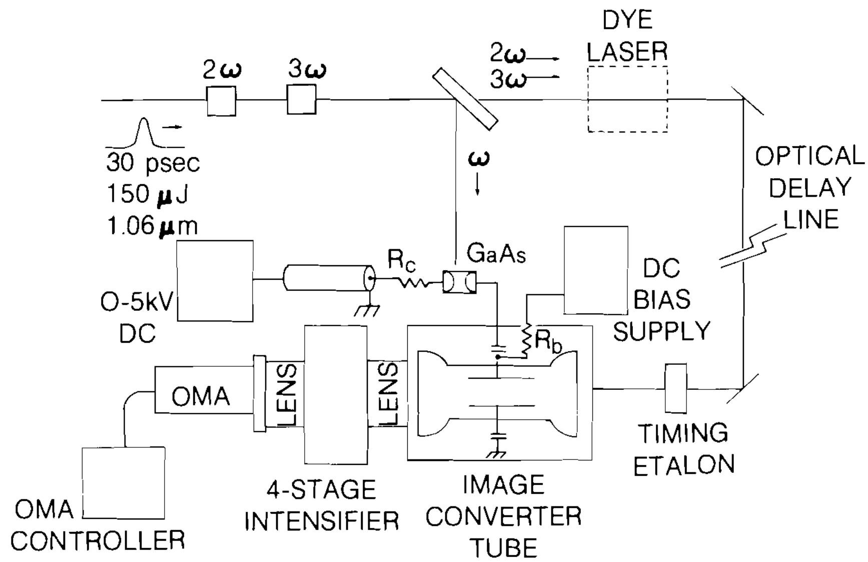

Figure 41

A single pulse is extracted with contrast ~10^6 from a mode-locked Nd^{+3}:YAG oscillator and frequency doubled and tripled for fluorescence kinetics studies. The remaining infrared energy (50-100μJ) is directed onto a 3 mm gap of GaAs doped with Cr which is DC-biased at 0-5 kV. Under the action of the laser pulse, the GaAs becomes conducting for 1.3 nsec and charges the deflection plates of the streak tube through a current-limiting, resistor R_C. The photoelectron beam is thus swept across the screen for 1.3 nsec and remains offscreen for ~ 1 msec while the plate offset bias resistor R_B discharges the plates. A short-cavity dye laser can be added to provide 10-15 psec pulses of selected wavelengths, and an OMA is used to collect and store the data.

photoelectron beam is swept linearly over 1.3 nsec from off-screen on one side to off-screen on the other side, and the beam remains off the screen for a very large time compared to the fluorescence decay times of many systems. In many experiments, one is interested in studying emission risetimes on the scale of single picoseconds from samples which emit for times long compared to this (nsec to msec). In these experiments, the beam must remain deflected for up to msec. Long fluorescence decay times lead to problems in repetitively-scanned systems. Ramps of longer than 1.3 nsec can be obtained with a double-stage charging configuration.

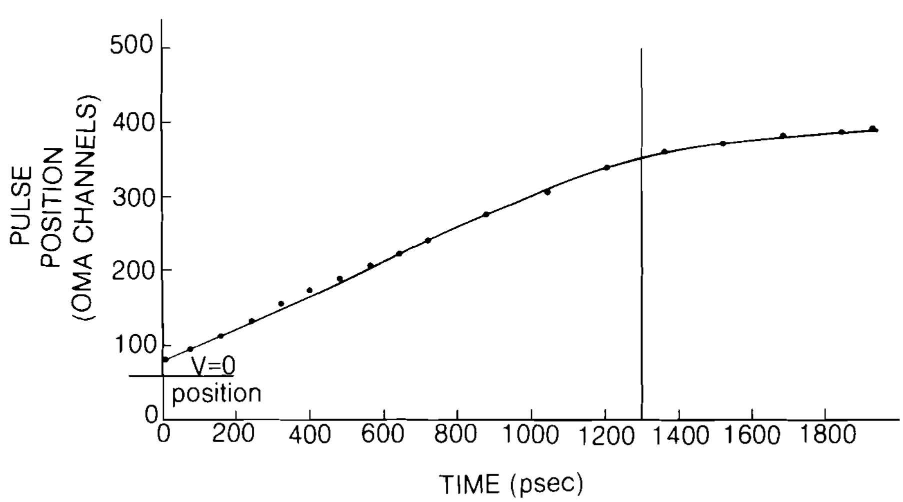

Figure 42

Pulse peak position is plotted as a function of optical time delay in the signal line, showing a 2% linear ramp over 1.3 nsec. Longer ramp times can be obtained by using a two-stage charging. This data was taken with R_C=300Ω and V_{dc}=200 V.

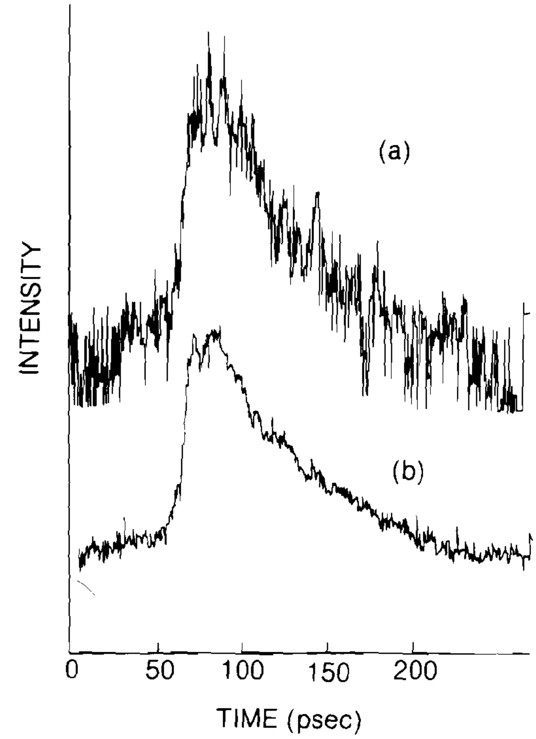

Figure 43
Fluorescence of Chlorophyll-A protein in leaf (a) 1 shot and (b) 20 shots accumulated. (Fluorescence attenuated to simulate small signal.) Signal-to-noise ratio is improved as the square root of the number of shots averaged.

Since the switching is purely photoconductive, good timing is expected compared to avalanche switching, and in this way, single-shot jitter is reduced to ± 0.8 psec at speeds of up to half the speed of light. The sweep speed is easily adjustable from 1 nsec full scale to 100 psec full scale by varying the DC bias voltage on the GaAs. Figure 42 shows the streak deflection function obtained

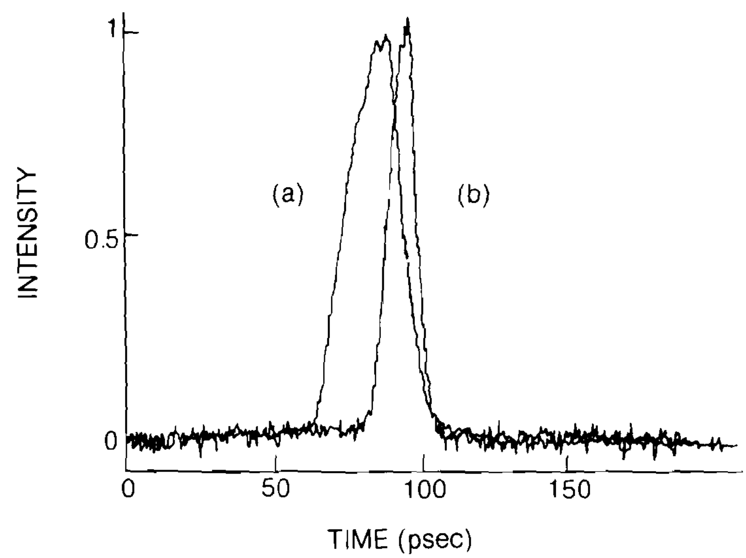

Figure 44
(a) Output at 580 nm from Rhodamine 6G in 500 μm wedged cavity with full (~20μJ) excitation energy in 30 psec and (b) output with input attenuated by ~30X. Note reduction in pulsewidth and time offset due to threshold of dye laser oscillation.

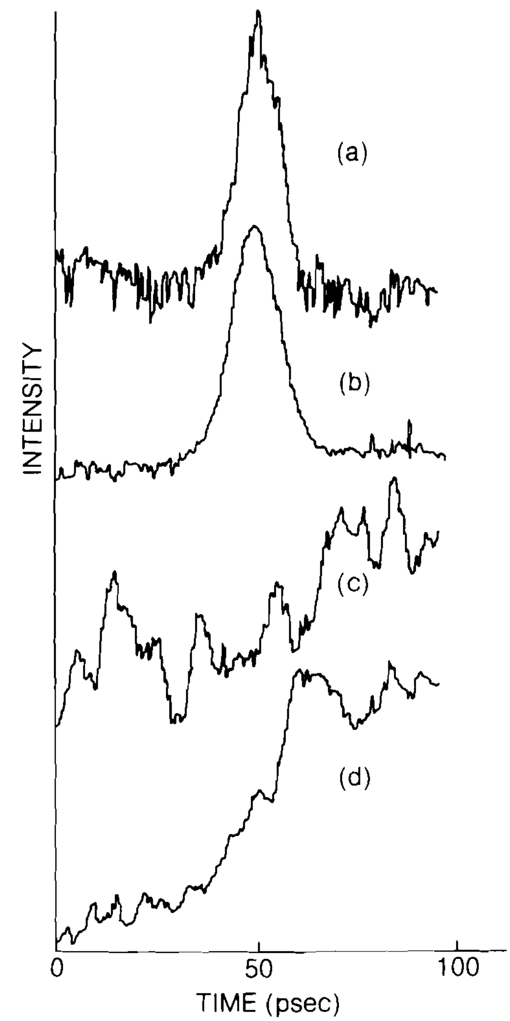

Figure 45
(a) Single shot of 14 psec dye laser pulse
(b) 20 shots of (a) accumulated
(c) single shot of Rose Bengal fluorescence, and
(d) 40 shots of (c) accumulated.

with $R_C = 300\ \Omega$ and 2000 volts bias. Signal averaging can be performed with this low jitter to increase further the available timing precision and signal-to-noise ratio. Figure 43 shows the effect of averaging an attenuated fluorescence signal to simulate low quantum yield.

To increase the versatility of the system, a wedged short-cavity dye laser was added (Figure 41) which when pumped with a single green pulse (530 nm) produces a 10-25 psec pulse of wavelength determined by the choice of the dye. The pulsewidth obtained is determined by the pump intensity. With an incident energy of ~ 20 μJ, the dye laser is pumped far above threshold and gives stable pulses of ~ 25 psec (Figure 44a). At 30 times less pump intensity, pulses of 10-15 psec are obtained (Figure 44b). A time offset of 12 psec is observed which is due to the thresholding effect of the dye laser. The effect of short-pulse signal averaging is demonstrated in Figure 45. A single dye pulse (R6G) at 580 nm is shown with one and twenty shots accumulated. This pulse is then used to excite Rose Bengal dye in water (~10^{-4}M) and the