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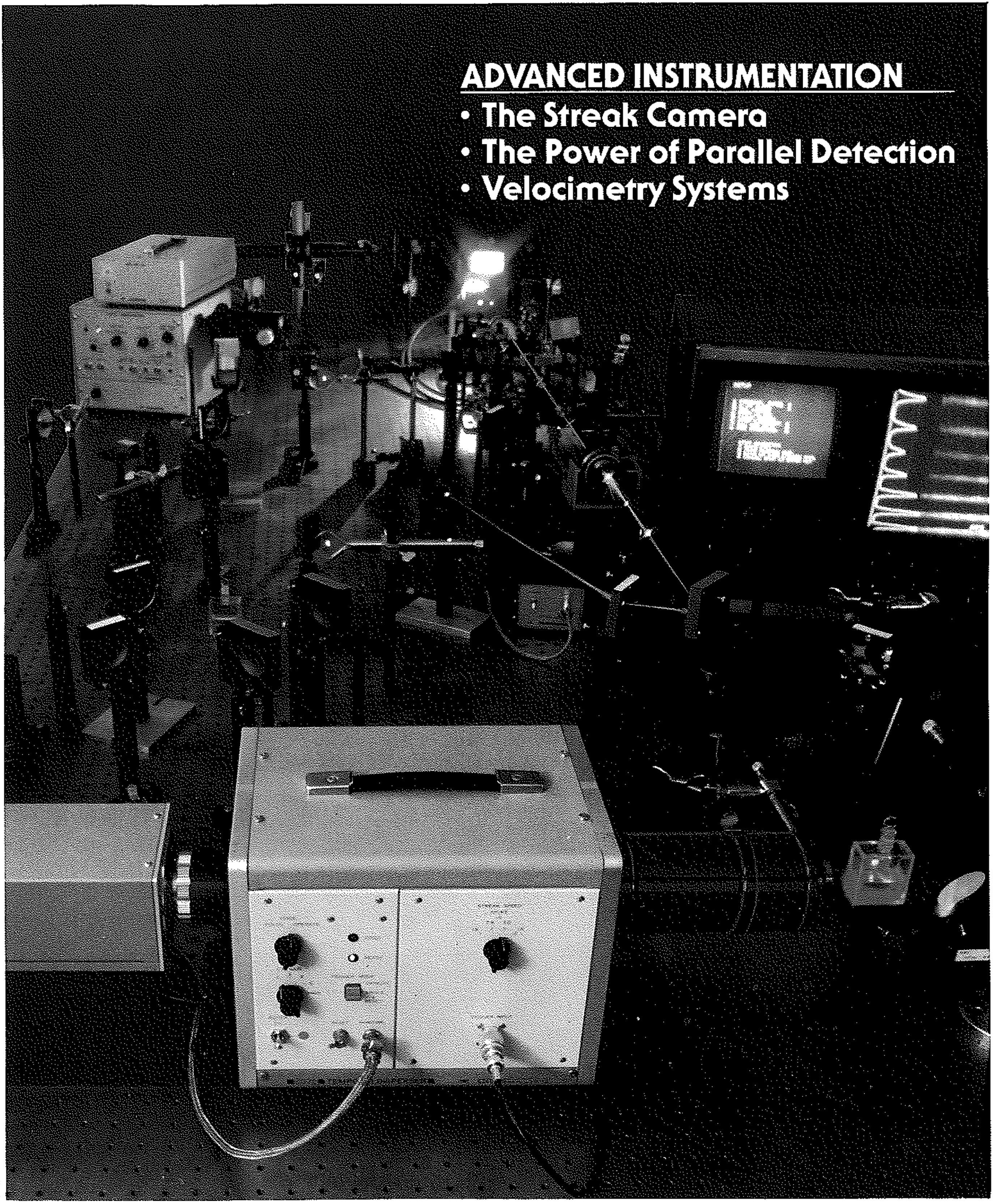

ADVANCED INSTRUMENTATION

- The Streak Camera
- The Power of Parallel Detection
- Velocimetry Systems

THE STREAK CAMERA

Already a unique diagnostic tool in the picosecond regime, the streak camera will ultimately be refined to yield data on the femtosecond scale.

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Over the years, scientists have used light to determine physical and chemical properties of materials,[1,2] a practice that goes back in time to Galileo. Since then, efforts have evolved along two different approaches. In one approach, the scientist studies the characteristic frequency spectrum of a material in order to derive information about its structure and internal processes. In the other approach, the scientist subjects the material to some outside shock and then measures the characteristic relaxation time — the interval that passes before the material returns to its original state.[1] It took over 400 years to develop versatile techniques to probe the molecular world directly. The forerunners of today's fast optoelectronics used visual responses, springs, rotating mirrors and other mechanical devices combined with slow electronics.[1,2]

A very few modern-day inventions have had a significant impact on our ability to measure and record fundamental processes on a molecular time scale. Among these are the photomultiplier, spectrometers, and oscilloscopes. Using the frequency and time domains, these devices have enabled researchers to derive a great deal of basic information from luminous events. However the slow electronic response times of the photomultipliers and oscilloscopes — about 1/2 nsec — limit their usefulness in measuring single-shot events. In addition, photomultipliers only yield single-point information with limited time resolution. A giant leap in improved time measurements resulted in the late 1960s with the development of lasers, which could emit picosecond pulses.[3,4] Now, even femtosecond pulses can be generated.[5] Novel instruments and experimental techniques were soon developed with a measurement capability orders of magnitude faster than ever attained before.[1-4] Indeed, ultrafast optoelectronics has become as important and revolutionary in giving fundamental information about materials as conventional spectroscopy has been over the past century. And the "super" ultrafast measuring tool to extract temporal as well as spectral data is the *streak camera.*[6-8]

Streak camera

The streak camera is a device that converts time information from a luminous event into spatial information. Figure 1 shows a streak camera system, consisting of a streak tube, imaging optics, fast sweeping electrodes and video display/computer equipment. The streak tube is the heart of the ultrafast camera. Loosely speaking, it combines the operating principles of the photomultiplier tube and the oscilloscope — that is, the photoelectric effect, electron beam-steering, and phosphorescence. During operation of the streak camera,[8] photons striking the photocathode of the streak tube produce an emission of electrons proportional to the incident light intensity. The electrons are then accelerated into the streak tube via an accelerating mesh and are electrostatically swept at a known rate over a known distance, thus converting temporal information into spatial information. These electrons then strike a microchannel plate located inside the tube that is capable of producing electron multiplication through secondary emission. The secondary electrons released at different times (in relation to the incident electrons) impinge upon a phosphor screen, forming the streak image. The streaked luminous output formed on the phosphor screen is captured on film or by an electronic video

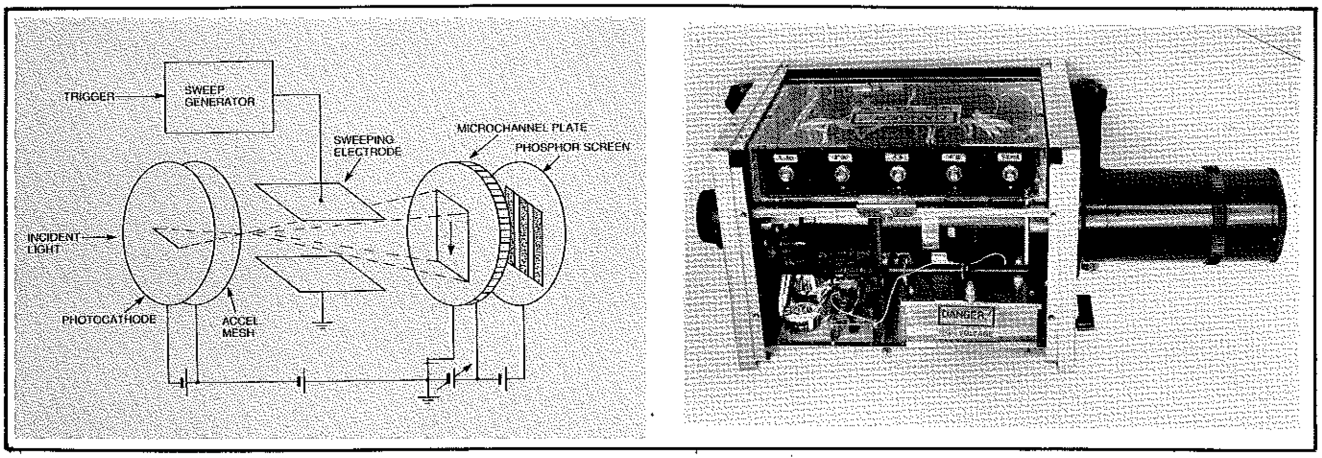

Figure 1. **(a)** *Schematic diagram of a streak camera;* **(b)** *Interior view of a streak camera.*

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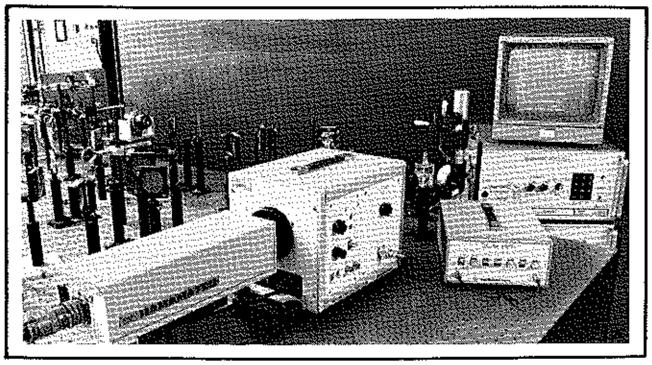

Figure 2. *Hamamatsu streak camera system.*

readout system, which interprets temporal information as a function of position. By viewing the entire luminous event, a streak camera "fingerprints" the time-resolved spectroscopic characteristics of a molecular system.[1,2] Just as each material has its own spectral signature so does it have a temporal signature. Although most compounds have been extensively mapped according to their characteristic spectral fingerprints, much work must be done to categorize the temporal fingerprints of materials.[1,2]

Set-up and basic operation

Using a streak camera is as simple as using an oscilloscope. However, just like oscilloscopes, all streak cameras[8] exhibit trigger jitter and trigger delay. Trigger jitter is the difference in the time between the arrival of the trigger signal and the beginning of the actual deflection sweep. Typically, jitter ranges from a few ps to tens of ns, depending on the streak camera model and manufacturer. Trigger delay is the amount of elapsed time between the production of a trigger signal (outside the streak camera) and the beginning of the deflection sweep. Typically, trigger delay ranges from 10 ns to greater than 100 ns, depending on the sweep setting.

To synchronize the arrival of the light signal with the beginning of the deflection sweep, it is necessary to compensate for the trigger delay. The easiest way to accomplish this is to optically delay the laser pulse over a long path length: the path (in time) must be equal to or greater than the longest trigger delay time of the system. It takes light 3.3 ns to travel a distance of about one meter; thus, if the trigger delay is 20 ns, the excitation pulse must be delayed along a six-meter path. This can be accomplished by bouncing the beam back and forth between mirrors. Early in the delay path, a portion of the laser pulse must be split off to a photodetector to produce an electrical trigger pulse necessary to trigger the deflection circuitry of the streak camera. Here, it is important to note that coaxial cables will delay the propagation of electrical signals by approximately 1.5 ns per foot. Therefore, trigger cables must be as short as possible to minimize the overall system delay.

After the streak camera is set up with an optical delay path long enough to accommodate the longest trigger delay time for a particular streak camera and sweep speed, a means to change the delay time in small increments is needed. A delay unit is placed between the trigger diode and the streak camera trigger input to compensate for day-to-day drift of the trigger delay time and the delay that occurs when changing from one streak speed to another. Most streak cameras require a trigger voltage signal of 2 to 10 volts into 50 ohms.

The jitter time largely depends upon the characteristics of the trigger pulse. In order to minimize jitter, the photodetector producing the trigger signal must always be operated below saturation. Therefore, it is wise to take care in choosing the type of photodiode used. It must produce a trigger pulse of voltage adequate to satisfy the trigger circuitry and should exhibit a risetime well within the requirements of the streak camera. In general, the less the rise time, the better. Typically, a risetime on the order of 0.5 ns is required for minimal jitter performance.[7,8]

After these conditions have been satisfied, an experimental setup at the sample site can be attempted.[8] Generally, the sample site is positioned close to the streak camera. The optical axis of the collection optics must be well aligned with that of the streak camera and the excitation area at the sample. The quantum efficiency of the sample, the collection solid angle, and the imaging of the emission region onto the slit of the streak camera will determine the best signal-to-noise ratio. Excitation and collection geometries can also influence the temporal resolution of the system. Typically, the kinetics from samples with low quantum yield $\sim 10^{-4}$ can be easily measured.[9] Samples under study should produce signals within the spectral response of the streak camera photocathode and associated optics. Focusing the streak camera optics for monochromatic aberrations will optimize the time resolution and maximize intensity. Time scales of the sample response should be commensurate with the full-scale deflection of the streak speed scale being used. Furthermore, calibration[10] of the streak camera's time and intensity axis is important for determining the real relaxation data. This is accomplished using a pair of mirrors of high reflectivity (~90%) separated by known distance. These data are

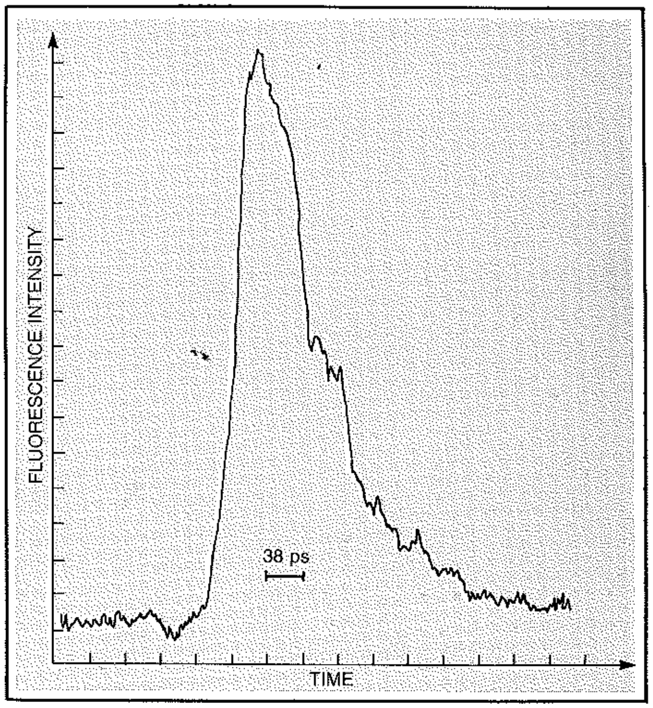

Figure 3. *A typical fluorescence kinetic curve measured by a streak camera system of the dye erythrosin in water, exhibiting risetime of less than 15 ps and a decay time of about 80 ps. No other instrumentation to date can time-resolve the full temporal profile with a single shot on a picosecond time scale. Alternative devices require multiple shot sampling of the event — and produce less temporal resolution.*

used to correct the time and intensity axis of the raw streaked data.[10]

Types of streak cameras

There are many versions of streak cameras for different time regimes 300 ps — 100 ns, 100 ns — 1 ms...etc.[8] These can be divided into two general classes — low and high repetition rates. The standard streak camera,[2,8]used mostly for single-shot events, is limited to a low repetition rate of about 1 kHz. This is caused by the limitation of available ramp voltage sweep generators. Synchroscan streak cameras,[2] however, use a sine wave generator, which is capable of detecting high-speed repetitive signals from 50 to 200 MHz.

Applications

The streak camera is indispensable in many areas of time-resolved studies in scientific research and engineering applications.[11-13] Researchers in biology, chemistry, and physics use the streak camera to measure the fluorescence and absorption kinetics of ultrafast light phenomena. Two of the practical applications[9,11-13] of streak camera systems are fluorescence relaxation time measurements (see Fig. 3) and measurements of transient absorption of materials. It is invaluable in the diagnostics of mode-locked and Q-switched laser pulses, pulse propagation studies and laser-plasma interactions, and can be used in the study of implosions in laser fusion experiments. The streak camera may facilitate laser pulse millimeter ranging of complicated and normally inaccessible structures. And, it is useful in diagnostics of high-energy particle beam interactions with matter and in nuclear explosion monitoring.

In the next decade, a temporal and spectral system will become commonplace and will replace the common spectrophotometer in most laboratories.

To meet its diverse application requirements, the streak camera must exhibit the following characteristics:[8] high temporal resolution, wide dynamic range, low time jitter, high sensitivity in a wide spectral range,[14] variable sweep speeds within a single unit, reliability and durability, ease of operation, compactness, and accessibility for automatic image processing.

At present, commercially available streak cameras are capable of time resolution under 2 ps with a dynamic range greater than 50:1 and time jitter under 30 ps.[8] They exhibit full-scale ranges from picoseconds to tens of nanoseconds in a single unit. Depending on the cathode of the streak tube, sensitivities would be equivalent to S-25, S-20 and S-1 surface responses. Figure 2 shows a typical commercial streak camera system. Development of the microchannel plate (MCP) and the microprocessor has helped advance streak camera technology. A note of caution: when coupling a spectrograph with a streak camera[14] to gather spectral as well as temporal information, time broadening through the spectrograph can occur if the scientist is not careful.

Prospects

In the future, streak cameras will find their way inside the heart of new analytic instruments for routine time-resolved spectroscopic analysis of materials. This will occur rapidly once the temporal and spectral fingerprints of various compounds have been sufficiently catalogued. Devices having an exciting source, sample site, temporal analyzer, and readout system will become a common instrument for diagnostics. One of the requirements that will be necessary for a commercial time-resolved analytic system to enter the marketplace is the reduction of trigger jitter. Significant progress in reducing trigger jitter to less than 2ps has been recently achieved.[15] In the next decade, a temporal and spectral system[16] will become commonplace and will replace the common spectrophotometer in most laboratories. The development of femtosecond sources[5] and the need for faster time measuring instruments points to the development of femtosecond streak cameras in the future.

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