STROBOSCOPIC OPERATION OF A SYNCHROSCAN STREAK CAMERA

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A synchronously driven streak camera with stroboscopic deflection drive and detection provides picosecond time resolution with direct photomultiplier read-out over an extended free temporal range. This technique and its limitations are described. The temporal resolution has been demonstrated to approach that obtained from the camera when operated in the conventional synchroscan mode employing an actively mode locked dye laser source. The increased temporal window has permitted the measurement of fluorescence lifetimes of several nanoseconds for various dye species.

1. Introduction

The synchroscan mode of operation of electron-optical streak cameras [1,2] is generally achieved by the application of a continuous, repetitive series of streaking ramps to the deflection plates of the image tube. Synchronism ensures that this deflection voltage is applied as each sequential time-evolving electron image passes between the deflection plates. The net effect is that successive identical sweep records are precisely superimposed on the image tube phosphor at high repetition rates while picosecond time resolution as short as 1 ps is maintained [3]. The most convenient method of producing the repetitive deflection is through the application of a high frequency (~80 MHz) sinusoidal voltage to the deflection plates. This voltage is generally obtained by the amplification of a low voltage sinusoid derived from a tunnel-diode oscillator, which is driven by the electrical signal from a fast photodiode detector of the laser pulse train or the luminous event under investigation [1,2]. The advantages of operating in the synchronous mode include (a) a high dynamic range is obtained because very low photocurrents are drawn and intensity dependent losses are minimized [4,5] (b) a high signal-to-noise ratio arising from the summation of very many time-dispersed records (>10⁸), (c) in many instances no further intensification of the swept image is needed, and (d) the output is conveniently read out, stored, analysed and displayed by conventional optical multichannel analyser systems.

However, if one considers a typical operating frequency ~140 MHz, the period of the sinusoidal deflection is ~7 ns and the linear (to within 5%) portion of the waveform suitable for deflection purposes lasts for approximately one sixth of the period (1.2 ns). This results in a practical limitation of the system for some applications such as fluorescence lifetime measurements for which significantly longer window times would be an advantage. We have recently reported a new read-out system [6] in which the deflection plates of the streak tube are simultaneously used to provide read-out of the time profile by relatively slowly scanning the repetitively time-dispersed image across a slit in front of a photomultiplier. In this arrangement the deflection system of the streak tube...
and photomultiplier takes the role of photographic or optical multichannel analyser (OMA) recording. However, the “free temporal range” or temporal window of the instrument is still largely limited to the linear part of the voltage sinusoid waveform.

We now describe the experimental demonstration of an extension of direct photomultiplier readout based upon stroboscopic scanning which considerably extends the temporal window.

2. Principle of stroboscopic operation

The sinusoidal deflection is symmetrical about the axis of the image tube, and in normal synchroscan operation, the arrival time of the event under examination is varied so that it is recorded during the linear period of deflection. The image of the resulting streak on the phosphor is then read out by an optical multichannel analyser. If only a narrow slit region of the central linear portion of the streaked image is detected by a photomultiplier then by continuously varying the relative phases of the deflection voltage and the repetitive light emitting signal, luminous events lasting up to half of the period of the sinusoid can be recorded while retaining a linear time scale. Two streak images will be observed for each period of the sine wave. Effectively the image is scanned across the detector [6] as distinct from normal synchroscan operation where the detector scans the static time dispersed image.

This technique can be achieved by operating the synchroscan streak camera in a continuous stroboscopic mode. In this case the frequencies of the repetitive luminous event being examined and the applied deflection ramp are arranged to be slightly different, such that a constantly varying phase difference occurs between the two, giving rise to a stroboscopic effect of the image on the output phosphor of the streak camera. By placing a slit on the axis of the output of the camera perpendicular to the direction of the sweep and detecting the intensity of the signal passing through the slit at the difference frequency, two time dispersed images per period of the sweep deflection are recorded. The time scale of the recorded traces are linear over the full half period. For a 140 MHz drive frequency a free temporal range of 3.6 ns is obtained, corresponding to a half-period of the driving voltage signal.

Previously a transient stroboscopic technique has been employed [7] to spread a number of pulses over the streak tube phosphor screen, for single shot photographic recording. With this technique it was possible to photograph all the picosecond pulses in the short burst from a pulsed mode locked Nd : YAG laser.

3. Experimental

The experimental arrangement used to demonstrate stroboscopic operation with a standard Photochron II streak tube [8] is shown in fig. 1. An oscillator operating at a preset frequency of 69.44250 MHz was amplified to 1 W and applied to the acousto-optic (AO) modulator of an argon ion laser. The resulting 60 ps pulses (at a repetition rate of 138.8850 MHz and average power of ~650 mW) synchronously pumped a rhodamine 6G dye laser to produce a train of pulses of duration ≤1 ps and average power ~30 mW. About 4% of this output was directed by a beam splitter BS1, on to a photodiode, the signal from which triggered a tunnel-diode oscillator to supply a sinusoidal deflection voltage synchronised to the drive laser pulses (also at 138.8850 MHz). This r.f. signal was amplified up to ~1 W in a preamplifier network. In normal synchroscan operation this signal is further amplified and applied to the deflection plates of the image tube. The phase of the deflection signal is then adjusted so that the record of the luminous-event under study falls within the linear part of the trace.

In stroboscopic operation the deflection voltage signal was separately derived from a variable frequency oscillator (±KHz) operating in the region of 69.44250 MHz. This variable frequency signal was maintained at a constant frequency difference from the fixed-frequency oscillator to produce a constant low strobe frequency. The main part of the mode-locked laser pulse train was directed into a Michelson interferometer mirror arrangement (M1, M2) to divide each pulse into two components separated by a fixed delay for calibration purposes. When measuring a fluorescence decay only one of these components was used and the fluorescence emitted from the sample was collected using lens L1 and focussed onto the 80 μm input slit of the streak camera. This slit source was then focussed (lens system not shown in fig. 1) with
An upper limit is set to the strobe frequency by the decay time of the PI1 phosphor of the streak tube. To measure this the difference frequency was set to ~500 Hz and the image of a single picosecond dye laser pulse was strobed across the phosphor screen. Fig. 2 shows the typical decay profile produced by the retention time of the phosphor. The measured 1/e

Fig. 2. Streak tube phosphor decay, 200 μs per major division.

unit magnification on to the photocathode of the image tube. For precalibration measurements the sample cell was replaced by a 100% mirror and the input beam suitably attenuated. With this method the normally static time-dispersed synchromscan image was continually swept across the phosphor of the image tube at a rate corresponding to twice the difference in frequency between the fixed oscillator and the variable frequency oscillator.

To minimize noise in the photomultiplier detection a mask was placed on the output phosphor of the streak camera to select only the central 10 mm of the swept image. Lens $L_2$ (f 1.5, 1 : 1 magnification) focussed the strobed image from the phosphor screen on to a 120 μm slit placed at the focal point of $L_2$. This slit was on the axis of the photomultiplier. The output signal was fed into the amplifier of a storage oscilloscope. Part of the signal from the frequency-doubled variable frequency oscillator (~1 W) was mixed with the amplified fixed frequency signal from the tunnel diode oscillator in a double balanced diode ring frequency mixer. After suitable filtering to remove the sum frequency component, the difference frequency was used to externally trigger the time base of the oscilloscope.
decay time of 500 μs clearly indicated that the strobe rates of much less than 500 Hz were necessary to obtain distortion free images. If we assume that the background due to the phosphor decay effectively decreases to zero in 10 decay periods (~5 ms) then strobe rates of <200 Hz are necessary. In the rest of the work described here, strobe rates of 10–50 Hz were used to eliminate any phosphor decay contribution. This requirement places severe constraints on the frequency stability of both oscillators over the recording period. Such a problem could be removed by replacing the phosphor by an internal slit electrode followed by an electron multiplier or by employing a slit diode array. Similarly using a phosphor with a more rapid decay time would greatly reduce the demands made on oscillator stability.

Fig. 3(a) demonstrates the temporal resolution of the system operating at a 20 Hz strobe rate. The recorded calibration dye laser pulses were 200 ps apart and gave rise to a measured pulse halfwidth of 15 ps. In normal synchronoscope-mode using identical electronics and an OMA read-out system the temporal resolution is typically 8 ps when used in conjunction with the synchronously pumped dye laser [9]. This degradation in temporal resolution in stroboscanscope mode was due to some minor inaccuracies in the positioning and width of the output slit of the camera plus the effects of residual phosphor retention. Fig. 3(b) was taken under similar conditions to that of 3(a) but operating at a rate of 30 Hz and is displayed on an expanded time scale. It is evident in the falling edges of the recorded intensity profiles that even at this relatively slow strobe rate some distortion due to the phosphor decay is still present.

4. Application to fluorescence decay measurements

The sensitivity of the system is decreased operating in strobe, as compared to synchroscope mode if the storage time of the phosphor exceeds the read-out time per unit of temporal resolution. As described above this limits the rate of overall trace recording. However, because the linear temporal window or free temporal range is increased, the technique can be readily applied to the measurement of species with relatively long lived fluorescence decays. Ethanol samples of dyes made up to concentrations of 5 × 10⁻⁵ M were placed in a 1 cm sample cell. Excitation was carried out using the unfocussed output of the dye laser tuned to ~600 nm. The generated fluorescence was collected at right angles to the direction of excitation and focussed onto the input slit of the streak camera. Typically strobe rates of 5–20 Hz were employed. Figs. 4(a) and 4(b) show recorded fluorescence decays of ethanolic solutions of the dyes DODCI (3,3'-diethyloxadiacarbocyanine iodide) and stain grade nile blue (5-amino-9-diethylaminobenzophenoxazonium perchlorate). The measured fluorescence lifetimes were 1.3 ns for DODCI, in agreement with previous results [10,11], 3.1 ns for nile blue and 1.52 ns for oxazine 1.
5. Conclusion

We have demonstrated the operation of a synchroscan streak camera in stroboscopic mode, which increases the linear temporal window of the system while maintaining picosecond time resolution. The retention time of the image tube phosphor limits the strobe rates to $\approx 20$ Hz. This limitation puts rather severe constraints on the frequency stability of the drive sources. Also there is a reduction in the overall sensitivity of the streak tube compared to that in normal synchroscan mode where effectively the recorded trace is read-out in multiplex form. However, the advantages of photomultiplier detection, with an improved signal-to-noise ratio over electronic amplifier systems, helps to compensate for this. The simplicity and usefulness of the technique has been clearly demonstrated in the measurement of relatively long fluorescence life-times of several dye species.

References