Internally intensified Photochron II streak tube

Optics Section, Blackett Laboratory, Imperial College
Prince Consort Road, London SW7 2BZ, England

Abstract

The salient design features of a version of the Photochron II streak tube having an internal microchannel plate intensification stage are described. Experimental results are presented to demonstrate that a streak camera incorporating this image tube has a temporal resolution ≈1 ps in the synchroscan mode of operation and ≈4 ps in single-shot operation.

Introduction

The Photochron II streak tube that was first described at the 11th International High Speed Photography Congress was developed primarily for use in a single-shot streak camera. It was subsequently demonstrated to have a limiting time resolution ≈0.9 ps when the cathode was illuminated close to the long wavelength threshold in order to minimise the photoelectron transit-time dispersion. Although a time resolution of 2.5 ps has been achieved for this type of tube in a repetitive (or Synchroscan) streak operation in conjunction with a CW mode-locked dye laser, we recognised that some redesign was necessary to ensure that the instrumental function could be an optimum in this mode.

This development of a synchronously-operating streak camera with picosecond or subpicosecond resolution is of particular importance at present, because CW mode-locked lasers produce the shortest, frequency-tunable light pulses currently available. When such lasers are used in conjunction with a Synchroscan camera, a large variety of time-domain spectroscopic studies in chemistry, physics, etc., can be conveniently carried out over an extended spectral range with extremely high detection efficiency.

To enhance the operation of the Photochron II for RF deflection voltages, the design of the mechanical and electrical connections to the deflectors was modified so that the power efficiency and sensitivity of deflection could be substantially improved. An internal microchannel plate intensification stage was also incorporated into this updated streak tube which has been designated as the "Photochron IIA" and its design and performance characteristics are the subject of this paper.

The Photochron IIA streak tube

The Photochron IIA streak tube is shown photographically and schematically in figures 1 and 2 respectively. The geometry of the electrodes which constitute the electron-lens are the same as in the Photochron II, but the applied voltages have been altered so that 11 keV photoelectrons pass through the anode aperture and are focussed at the input face of a microchannel plate (MCP). This 40 mm diameter MCP is comprised of 12.5 μm diameter channels angled at 15° to the tube axis and having a length-to-diameter ratio of 80:1.
Intensified image is proximity focussed (MCP-to-screen separation is 0.8 mm) onto a P20 phosphor screen. For the typical set of "focus" voltages given in table 1, the static spatial resolution at the screen was 25 lp/mm and the electron-optical magnification was x2.

Table 1. Electrode "focus" potentials.

<table>
<thead>
<tr>
<th>Electrode</th>
<th>Photocathode</th>
<th>Mesh</th>
<th>Cone</th>
<th>Anode/ MCP Input</th>
<th>MCP Output</th>
<th>Screen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential (kV)</td>
<td>-15</td>
<td>-14</td>
<td>-14.3</td>
<td>-4</td>
<td>-3</td>
<td>0</td>
</tr>
</tbody>
</table>

With regard to the construction of the tube, the body wall between the anode and MCP input was fabricated in stainless steel. The deflectors were mechanically supported by insulating pillars which were anchored to the stainless steel body and copper electrical connections were made via suitable metal-to-ceramic feedthroughs which subtended an angle of approximately 45°. The deflection sensitivity was measured to be 200 V cm⁻¹ (cf. 300 V cm⁻¹ for Photochron II) and so for equivalent deflections, the RF power requirement of the Photochron IIA is substantially lower than that of the Photochron II. This has the practical advantage that the RF powers can be conveniently produced and that electromagnetic interference and induced drift arising from heating effects are significantly reduced. With regard to single-shot streak operation, the advantage of better deflection sensitivity was supplemented by the feature that the krytron or Austin-switch circuit network that is used for generating the fast deflection ramp voltages could be connected to the tube with a much lower inductance than that previously encountered with the construction of the Photochron II. As a result, the rate of change of voltage and linearity of the streaking ramp were improved. In addition, the absence of electron-optical distortions associated with a fibre-optically coupled "inverting" image intensifier also ensures that streak linearity is retained over the full diameter of the screen.

Synchroscan streak operation

In the evaluation of the performance of a Photochron IIA camera in synchroscan streak operation, we used the experimental configuration shown schematically in figure 3. The source of test light pulses was a passively mode-locked CW Rhodamine 6G ring dye laser. The durations of the hypershort pulses were measured with a second harmonic generation autocorrelator to be <0.2 ps (see figure 4) when the laser wavelength was tuned to 615 nm and when the cavity roundtrip frequency was 82 MHz. To produce the synchronous sinusoidal deflection voltage for the streak camera, an intensity component of the train of laser pulses was directed onto a photodiode which provided the trigger signal to a tunnel-diode oscillator. (To ensure the optimum high-frequency response, this photodiode/tunnel-diode oscillator electronic circuit had been configured into a compact microtransmission line network). The output of the tunnel-diode oscillator at 82 MHz was frequency doubled and then amplified by a transistor amplifier to a power of 12 W. At this power level, the observed streak speed was 6 x 10⁹ cm s⁻¹. In contrast, it has been observed that an RF power input of 20 W is required to produce a streak velocity of 4.5 x 10⁹ cm s⁻¹ in the
Photochron II. To increase this velocity to \(6 \times 10^9\) cms\(^{-1}\), would require a power in excess of 36 W and this clearly illustrates that the power efficiency of the Photochron IIA is at least three times higher than that of the Photochron II.

For the Synchroscan streak measurements, a voltage differential of 1000 V was maintained across the microchannel plate and this gave a net overall gain \(\approx 50\), compared to the unintensified counterpart. The streak images were directly recorded and displayed using an optical multichannel analyser (B & W Spektronik - OSA 500: WP1/2) which was lens coupled to the screen of the streak tube with an optical magnification of \(x 2\). An example of the recorded intensity profiles of a pair of streak images is reproduced in figure 5 where the calibration delay was set to 33 ps. The overall recorded duration (FWHM) of 1.2 ps represents the convolution of the camera instrumental function with the width of the incident laser pulses and any jitter present between the camera drive signal and the laser pulse train.

By considering that the instrumental function is due mainly to the photoelectron transit-time dispersion and the technical time resolution then the following estimate can be made. For the 520 photocathode illuminated at a wavelength of 615 nm, the temporal dispersion of the photoelectrons is \(0.9\) ps. Interestingly, it was observed that the spatial extent of the recorded streak images was equal to the width of the recorded static slit image which indicated that the equivalent dynamic spatial resolution was 20 lp/mm. When this is combined with the measured streak velocity of \(6 \times 10^9\) cms\(^{-1}\) the technical time resolution limit is deduced to be 0.8 ps. Assuming gaussian pulse shapes, then the instrumental time resolution is estimated to be 1.2 ps.

The implication that follows from these streak results is that the duration of the laser pulses and the jitter are both subpicosecond. Independent measurements indicate that for the type of mode-locked CW ring dye laser used in this evaluation, the pulses have femtosecond durations\(^3,4\) and it can therefore be concluded that the camera temporal resolution is 1.2 ps and also that the triggering jitter is subpicosecond.

**Single-shot streak operation**

For evaluation of the camera performance in single-shot streak operation, the voltage differential across the MCP was increased to 1400 V by altering the anode/MCP input voltage to \(-4.4\) kV and adjusting the cone voltage for optimum focus. Under this condition, the internal gain of the MCP is \(5 \times 10^4\) \(^{13}\) and when due account is taken of its transmission ratio and detection efficiency for 11 keV electrons, the operation of the Photochron IIA should be equivalent to our standard Photochron II camera which has a fibre-optically coupled microchannel plate image intensifier with a measured gain of \(3 \times 10^6\). It is also worth pointing out that in our earlier work\(^1,19\) with the Photochron II streak camera, it was necessary to "gate on" the MCP intensifier for \(200\) ps, whereas in our present internally intensified version, there is no requirement for gating.

The test light pulses that we used were produced by amplifying single pulses from the
CW mode-locked ring dye laser at a 10 Hz repetition rate using a multi-stage dye amplifier. When measured by the two-photon fluorescence technique, their duration was inferred to be 0.2 ps, as indicated in figure 6.

Figure 6. TPF trace of amplified laser pulses.

For convenience, the 164 MHz sinusoidal deflection voltage that had been used for synchronscan operation was retained but streak images were now recorded during one linear sweep only. The intensity profiles corresponding to a typical result are shown in figure 7 where the duration (FWHM) of the recorded streaks is 4.1 ps. The streak velocity in this instance was $3 \times 10^9$ cm/s which, when taken with the equivalent dynamic spatial resolution of 10 lp/mm gives a technical time resolution limit of 3.3 ps. Combining this with the photoelectron transit time dispersion of 0.9 ps, gives an estimated camera instrumental function of 3.5 ps. Because the incident test light pulses were hypershort (<0.2 ps), it would therefore be expected that the recorded streak duration should be ~3.5 ps. The disparity between the predicted and measured values for the temporal resolution in this single-shot streak operation is most probably due to the onset of intensity-dependent temporal broadening arising from either space charge effects, or gain saturation in the MCP or a combination of both influences. Further investigations are currently underway using a GaAs opto-electronic Auston switch for the generation of faster voltage ramps so that the limiting time resolution and general dynamic performance characteristics (e.g. dynamic range) in single-shot streak operation can be fully established.

Conclusion

The Photochron II A has been shown to be a convenient and high performance image tube that is eminently suitable for use in synchronscan and to a lesser extent, in single-shot picosecond streak camera systems. It is expected that the results of ongoing experimental evaluations will indicate that better performance can be achieved in single-shot operation to that demonstrated in the preliminary study described here.

Acknowledgements

The collaboration of Dr. R. Field (Electron-Optics Division, Mullard Ltd.) and Mr. F. Barlow, (Instrument Technology Ltd.) are gratefully acknowledged in respect of the prefabrication of the MCP intensification section and the construction and processing of the overall streak tube respectively. The financial support for this work was provided by the Science and Engineering Research Council.

References


