A Compact Synchroscan Streak Camera Using a Microchannel Plate Incorporated Tube

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Abstract—**A compact synchroscan streak camera, which incorporates a microchannel plates providing a high light gain, has been constructed. The camera has been operated in synchronism with a synchronous-passive hybrid mode-locked CW dye laser, and the overall time resolution has been 10.8 and 25.9 ps for a recording of ~160 and ~10^8 cycles of dye laser pulses, respectively. In addition, by using the camera system with the dye laser a weak fluorescence profile (a quantum yield of ~10^{-3}) of an important biomolecule has been directly observed on a picosecond time scale.**

INTRODUCTION

ULTRA-SHORT pulse lasers have opened a wide interdisciplinary field of investigations on optical phenomena that occur on a picosecond time scale. The advance in the development of those light sources has also enabled us to develop new measurement techniques capable of picosecond time resolution, such as the streak camera, light gating, and pump and probe methods [1]. Among them, a picosecond streak camera (SSC) operating in synchronism with a mode-locked CW laser provides real-time measurement of the excitation decay of luminous materials, which have a low fluorescence quantum yield and do not prefer high-power excitation because nonlinear effects or photodegradation would be caused by high power [2]–[4]. In this paper, we report the operational characteristics of a newly developed compact SSC with a microchannel plate (MCP) providing a high light gain and its application to the measurement of a picosecond fluorescence decay of a biological molecule having a very low quantum yield (~10^{-3}).

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SYNCHROSCAN STREAK CAMERA AND EXPERIMENTS

The experimental arrangement for the compact SSC (C1587X) [5] operating in synchronism with a synchronous-passive hybrid mode-locked (HML) CW dye laser [6] is shown in Fig. 1. The new streak tube (N1643X) [5] incorporates the MCP as an image intensifier and has a high light gain such as 10^4. A multialkali photocathode is prepared on UV glass window. Hence, it has a sensitivity in the wide spectral range of 200 to 800 nm. The outside diameter and the length of the compact tube are 52 and 210 mm, respectively. The 7-mm effective diameter of a photocathode corresponds to the screen of 15 mm on a phosphor because the image magnification

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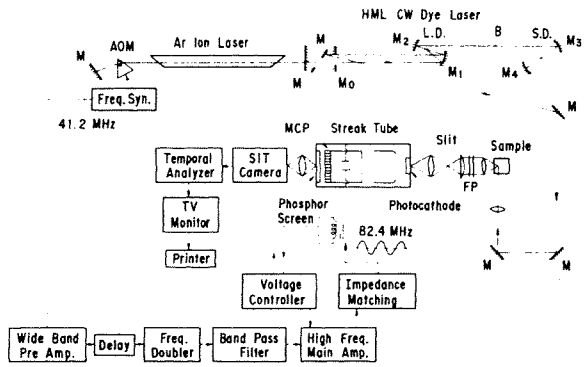

Fig. 1. Schematic diagram of a newly developed synchroscan streak camera and an experimental arrangement.

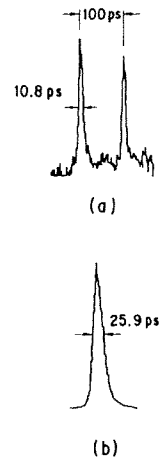

Fig. 2. Intensity profiles of dye laser pulses displayed on a TV monitor by using the synchroscan streak camera system. (a) and (b) correspond to integrations N_{integ} of the streaked pulses of ~160 and ~10^8, respectively.

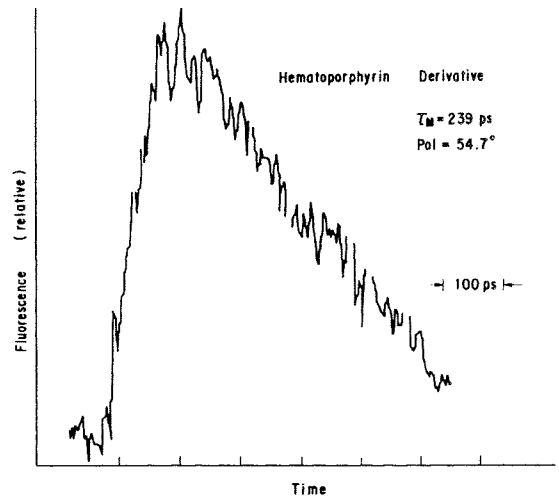

Fig. 3. Fluorescence profile of hematoporphyrin derivative in phosphate buffer saline solution, observed by using the synchroscan streak camera system. τ is fluorescence life time and Pol. is the polarizer set angle (degree).

factor of the tube is 2.2. A synchronous output (41.2 MHz) from a frequency synthesizer (Anritsu MG 545A:frequency stability of 1×10^8) driving a mode-locking modulator of a pumping Ar-ion laser is used as a triggering signal for driving the continuous sinusoidal ramp voltage to the streak-camera deflection plates, which is in synchronism with the repetitive incident light. The high-frequency electrical signal, after passing through a frequency doubler, is amplified to powers of up to ~6 W at 82.4 MHz, and the voltage (1.2 kV) is supplied to the deflection plates which are incorporated into a resonant LC circuit ($Q = 36$). The linear portion of the amplified sine wave (300 V) is used to sweep the whole screen (the phosphor) in order to eliminate the nonlinearity. The deflection sensitivity of the tube is ~50 mm/kV. A negative feedback circuit is also applied to eliminate the small variation of the sweeping speed caused by the drift in the components of various circuits. In addition, the streak camera provides a shuttering capability which is able to gate photoelectrons in the tube by gating at both the photocathode and MCP. The shutter time is selectable from 1 μs to 1 ms. The superimposed light-intensity profiles on the phosphor are imaged on and amplified by a silicon-intensified-target vidicon (SIT camera). The resultant amplified images are processed by a microprocessor-based image analyzer (Temporal Analyzer). The processed signal is available instantly on a TV monitor and can be transferred to a printer [7].

The HML CW dye (Rhodamine 6G) laser used here is the same one that we described in an earlier paper [6], which produced the pulse duration of 0.4 ps at its best. For the present operational conditions, the pulse duration of ~0.8 ps and the average power of ~50 mW are obtained. For the single-shot mode (not a synchroscan mode), it has been confirmed by using a single 4-ps FWHM, 530-nm second-harmonic pulse from an ML Nd:glass laser that the streak tube has a temporal resolution limit of 8 ps. For the synchroscan mode, the overall resolution of the system operated synchronously with the above mentioned HML CW dye laser has been examined by measuring the duration of pulses from its laser. The recorded pulse durations when the camera has been gated at the shutter time of 2 μs (corresponding to ~160 superimpositions) and not gated (corresponding to ~10^8 superimpositions) have been shown to be 10.8 and 25.9 ps, respectively, as shown in Fig. 2(a) and (b). The time calibration was done on the basis of the measurement of the separation (100 ps) of the two pulses generated in the usual optical delay arrangement. Under the present condition, the following three factors are thought to limit the instrumental time resolution: the first is frequency jitter of the sweeping deflection voltage of the SSC itself; the second, interpulse jitter of the pumping Ar-ion laser; and the third, interpulse jitter of the dye laser itself. However, at present, it is not possible to say which factor is the most severe since it is difficult to experimentally separate each factor.

In order to demonstrate that the constructed SSC is useful for observing a very fast and weak fluorescence decay, the fluorescence lifetime measurement of hematoporphyrin derivative (HpD) in a phosphate buffer saline solution (PBS) has been successfully attempted (no direct measurement so far had been reported [8]). By using the SSC system, as shown in Fig. 1 the decay was observed. The HpD molecules, which are biomolecules extremely important for the laser irradiation

treatment of cancer [9], emit a very weak fluorescence (a quantum yield of 2.1×10^{-3}) in the wavelength region from 600 to 700 nm. A continuous train of excitation pulses at 570 nm, to avoid photodegradation due to irradiation around 400 nm, is focussed by a lens into the sample cell containing the circulating HpD dye solution. The line of focus is directed just inside the output face of the cell to minimize any reabsorption of the fluorescence. The fluorescence band from the porphyrins is efficiently selected by using an interference filter which eliminates the excitation radiation at 570 nm. The fluorescence at 90° with respect to the input direction is focussed on the input slit (slit width ~20 μm) of the streak camera by a lens after passing through a polarizer set at 55° and the filter. When the gain of the MCP has been set at maximum, the decaying fluorescence profiles have been observed on the TV monitor, as shown in Fig. 3. From the decay, a fluorescence lifetime of HpD in PBS has been determined to be 239 ps. It is found from the comparison with a fluorescence lifetime obtained by calculations for a similar metal-free porphyrin [10] that the measured value appears to be reasonable.

Conclusion

A compact synchroscan streak camera has been developed, and it has been shown by measuring durations of pulses from the HML CW dye laser that its overall time resolution is 10.8 and 25.9 ps for ~160 and ~10^8 superimpositions, respectively. In addition, it has been demonstrated that the camera system is useful for observing a very fast and weak fluorescence profile of a biomolecule.

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