Quantum Electronics **44** (8) 798 – 800 (2014)

PACS numbers: 06.30.Ft; 06.60.Jn; 42.65.Re
DOI: 10.1070/QE2014v044n08ABEH015501

PS-1/S1 picosecond streak camera application for multichannel laser system diagnostics

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Abstract. **A PS-1/S1 picosecond image-tube streak camera (ITSC) with slit scan (streak camera), developed and manufactured at the General Physics Institute RAS, has been used to measure the spatiotemporal characteristics of ultrashort laser pulses generated by a petawatt-power laser installation 'FEMTO' at the Institute of Laser Physics Research in Sarov. It is found that such a camera is suitable for measuring the spatial and temporal parameters of single laser pulses with an accuracy of about one picosecond. It is shown that the intensity time profile of a train of picosecond pulses may be precisely defined for the pulses separated in time by a few picoseconds. The camera allows the contrast of radiation to be determined with a high (no less than 10^3) accuracy; spatial distribution of the laser pulses can be measured with an accuracy of tens of microns, and the temporal separation of single laser pulses can be identified with an accuracy of 1 – 1.5 ps.**

Keywords: *streak camera, spatial and temporal resolution, pico-femtosecond pulse.*

1. Introduction

For efficient application of laser radiation in high-energy experimental physics, including experiments on interaction of radiation with matter and high-temperature plasmas, it is important to have detailed information about the spatial and temporal behaviour of picosecond laser pulses at each point on the entire optical pathway within a multichannel laser system as well as about the separation of single laser pulses in space and time. There is therefore a need for a diagnostic instrument that would ensure the spatiotemporal measurements with a required accuracy and be easily integrated into computer-controlled multichannel laser systems.

Given our more than 50 years of experience in the design and application of streak cameras, we believe that these are high-speed image-tube streak cameras [1] that are capable of extracting precise estimates on the spatial and temporal characteristics of a multichannel laser system. These unique diagnostic tools provide precision measurements in the spectral range from the soft X-ray (0.1 nm) to near-infrared (1.6 μm) with a sub-picosecond time resolution and 10-micron (no less than 30 line pairs per mm) spatial resolution.

The works on electron-optical instrumentation in the pico-femto-attosecond range, focused on the use in laser and plasma physics [2], were initiated at the P.N. Lebedev Physics Institute of the Russian Academy of Sciences (FIAN) at the end of the 1960s and then have been continued at the A.M. Prokhorov General Physics Institute of the Russian Academy of Sciences (IOFRAN) since 1983. In our paper we present the results obtained with the use of the PS-1/S1 picosecond streak camera developed at IOFRAN for the spatial and temporal measurements of ultrashort laser pulses generated by the petawatt-power laser system 'FEMTO' at the Institute of Laser Physics Research in Sarov [3].

2. PS-1/S1 image streak camera

The basis of the PS-1/S1 camera is a very reliable and well reproducible picosecond time-analysing image converter tube – PIF-01 model (Fig. 1). The theoretically predicted ultimate temporal resolution at the photocathode centre of the PIF-01 tube amounts to 300 fs provided that the electric field of 3 kV mm^{-1} is ensured near the photocathode surface. The best experimental result only approaches half a picosecond. The silver – oxygen – caesium (S1) photocathode of the PIF-01 tube is formed by depositing the ingredients on a low-resistance substrate. We also manufacture the streak tubes

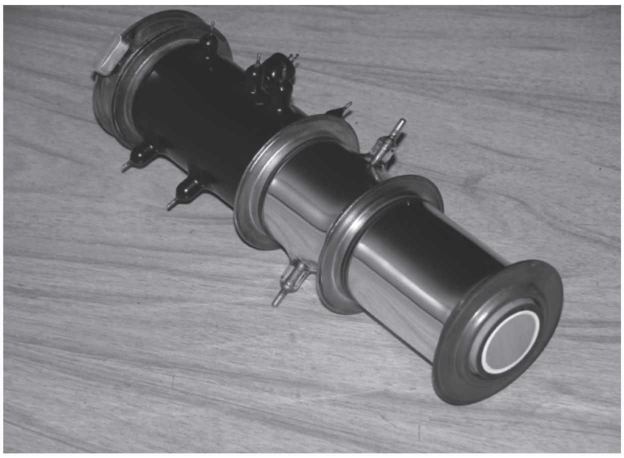

Figure 1. PIF-01 – a picosecond streak image converter tube designed and manufactured at the Department of Photoelectronics, IOFRAN.

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Received 29 March 2014
Kvantovaya Elektronika **44** (8) 798 – 800 (2014)
Translated by M.A. Monastyrskiy

with S20 and S25 photocathodes, thereby overlapping the spectral sensitivity range from 115 nm to 1550 nm.

The PS-1/S1 picosecond streak camera based on the PIF-01 tube (Fig. 2) was designed, manufactured and tested as early as in 1995 [4]. The experimentally measured maximum temporal resolution of the PS-1/S1 streak camera at the streak speed of $(1-2)\times 10^{10}$ cm s^{-1} is equal to 1 ± 0.2 ps at the laser radiation wavelength of 800 nm. The minimum triggering delay of the camera is 15 ns at the triggering jitter of ±3 ps. Such a minor instability allows the camera to operate in the regime of accumulation of very weak input signals of picosecond duration.

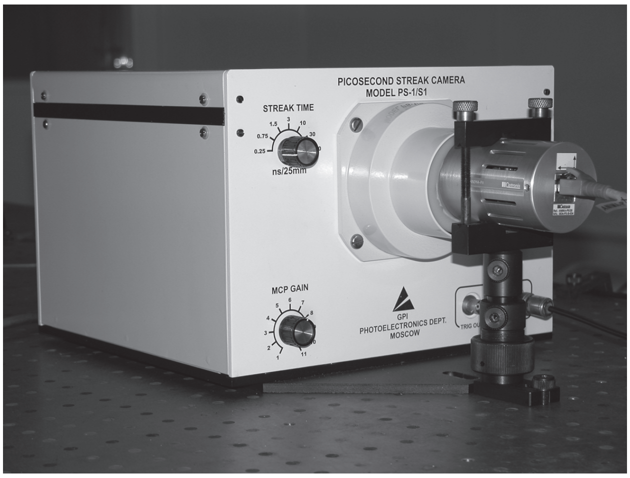

Figure 2. PS-1/S1 picosecond image-tube streak camera developed and manufactured at the Department of Photoelectronics, IOFRAN.

As a rule, to read out and process temporally analysed images from the output phosphor screen of the image-tube streak camera (ITSC), we have used a C8484-05G CCD system (Hamamatsu, Japan). The PIF-01 tube phosphor screen is imaged onto the CCD matrix by means of high-aperture lenses via an external image intensifier with a microchannel plate (MCP). In one of recent configurations of the PS-1/S1 camera, an ANIMA-PX/25 readout CCD system (Optronis, Germany) was applied, being joined to the tube output phosphor screen through a fibre-optic output window with the transformation coefficient of 25 mm/11.5 mm. The PS-1/S1 camera specifications are given below.

Streak tube type	PIF-01
S1 photocathode spectral range/nm	350 – 1300
Microchannel image intensifier model	EP-10
MCP maximum gain	3×10^4
Number of gain stages	11
Streak durations over the 25 mm phosphor screen/ns	0.21, 0.765, 1.5, 3, 10, 30, 100
Dynamic spatial resolution along the slit durations/line pairs per mm	10
Temporal resolution for the streak tube with S1 photocathode/ps	better than 1
Intensity dynamic range at maximum temporal resolution	at least 10
Streak nonlinearity (%)	no more than 10
Triggering delay/ns	no more than 15
Triggering jitter/ps	no more than ± 3

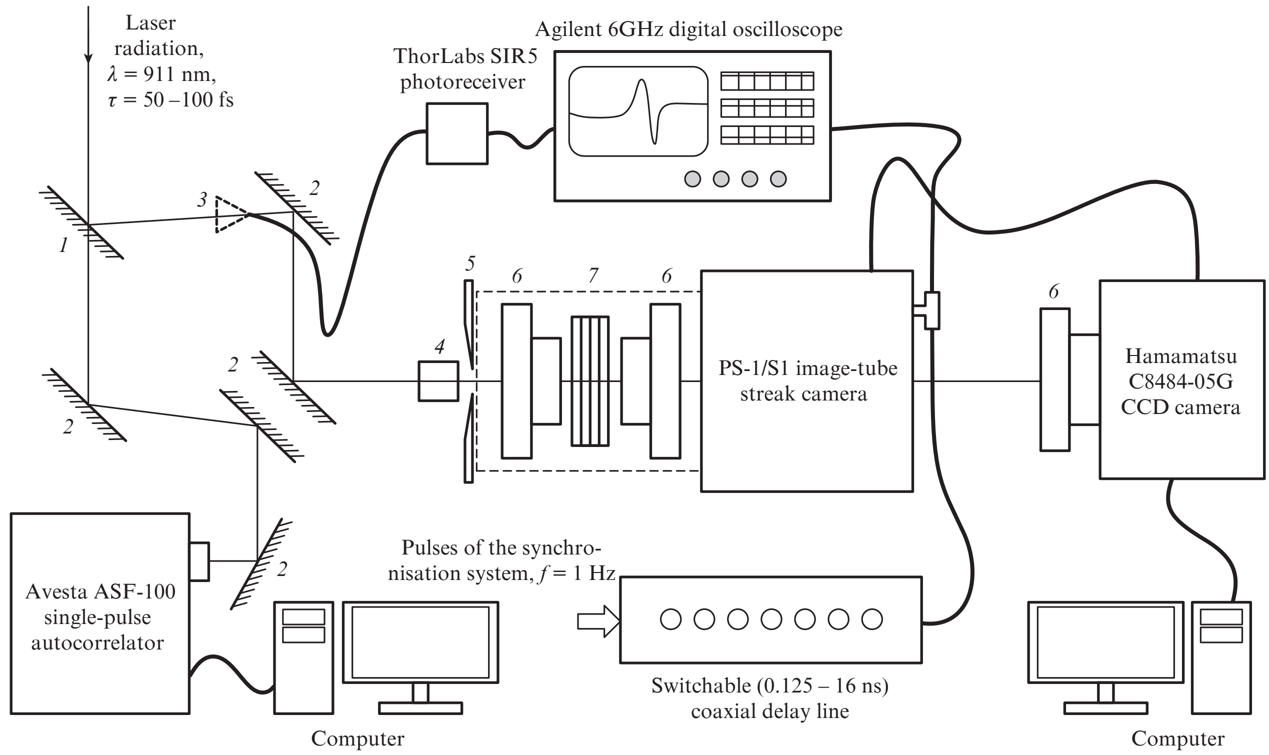

Figure 3. Experimental setup for testing PS-1/S1 streak camera: (*1*) semi-transparent mirror; (*2*) highly reflecting mirror; (*3*) multimode fibre; (*4*) separating plate; (*5*) micrometric slit; (*6*) Helios-44 lenses; (*7*) set of filters.

3. Experimental setup

The experimental setup for testing the PS-1/S1 picosecond ITSC is shown in Fig. 3. The single 50 – 100 fs laser pulses at a wavelength of 911 nm are generated with a repetition rate of 1 Hz within one of the 'FEMTO' channels [5]. The output energy of a single pulse is close to 10 mJ. The autocorrelation function of a single laser pulse, measured by the Avesta ASF-100 autocorrelator, is shown in Fig. 4.

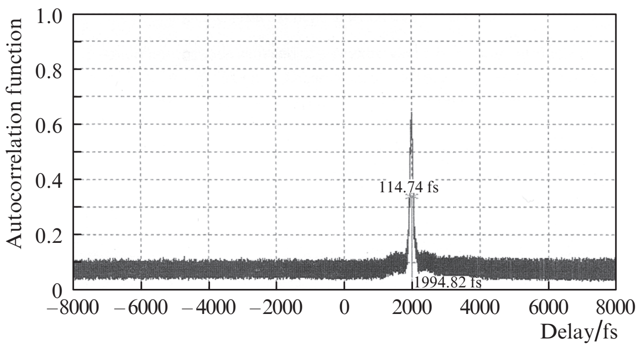

Figure 4. Autocorrelation function of single laser pulses generated by the 'FEMTO' installation.

A small portion of the output laser beam was directed onto the entrance slit of the ITSC through a calibrated plane-parallel glass plate which overlaps half of the entrance slit height. The ITSC was triggered by means of the synchronisation system comprising a high-precision switchable coaxial delay line (0.125 – 16 ns). To control the delay time, the Agilent oscilloscope (6 GHz) was used. The input optical system consisting of two 'Helios 44' lenses imaged the input slit onto the tube's photocathode with a 1:1 scale. Filters that do not cause the defocusing of the entrance slit could have been placed between the lenses.

The images taken from the output phosphor screen of the PIF-01 tube were projected into the C8484-05G CCD camera through the external image intensifier with a MCP (EP-10 model) and relay lenses. A specialised software provided a complete set of functions to process the registered chronograms: measuring the intensity profile in time, measuring the duration of laser pulses according to FWHM or any other level, temporal separation of single pulses, measuring the nonlinearity of the streak speed across the phosphor screen in the streak regime, subtracting the noise and improving the signal-to-noise ratio in the recorded images, and so on.

4. Experimental results

To determine the streak speed and its nonlinearities along the output phosphor screen of the camera, a 15-mm-thick glass plate (K-8) was used, which was placed at the camera's front end, thus overlapping half of the entrance slit height. The calibrated time delay between the upper and lower portions of the beam constituted 25 ps. Figure 5 shows a chronogram and corresponding microdensitogram at the 1-mm-thick glass plate. The maximum streak speed was shown to be 160 fs pixel^{-1}.

The experiments to measure the ultimate instrumental response function (IRF) of the PS-1/S1 ITSC have shown its value to lie in the range of 1 – 2 ps. A minimal IRF value at the FWHM level amounted to 1.1 ps (6.99 pixel). The autocorrelation function for this particular input laser pulse gives a value of 100 fs.

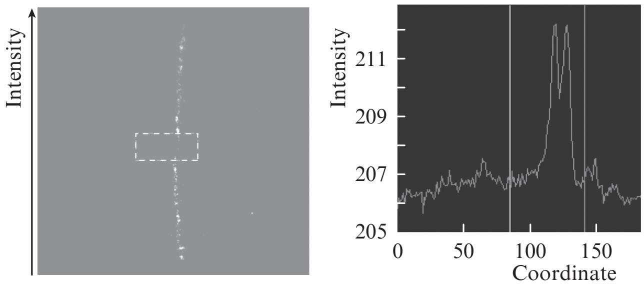

Figure 5. Chronogram of a single femtosecond laser pulse taken from the PS1/S1 phosphor screen and the corresponding microdensitogram; the distance between the 'upper' and 'lower' parts of the pulse is 1.66 ps.

5. Conclusions

Thus, we can make the following conclusions on the basis of experimental results obtained in the course of testing the PS-1/S1 picosecond image-tube streak camera on the laser installation 'FEMTO':

– The PS-1/S1 camera is quite suitable for the measurements of single laser pulses with a time resolution of about one picosecond, as well as for the measurements of a train of single laser pulses following with the same period.

– The PS-1/S1 camera can be used to control the spatial distribution of laser light irradiating a target.

– Due to a wide range of available streak speeds, the PS-1/S1 camera can be used to record the laser pulses of nano- and subnanosecond duration, which allows employing the camera in computer-controlled multichannel laser systems.

– Finally, we should mention about the use of the streak camera in the femtosecond time range (we have previously reported on the achievement of the 200 fs time resolution using the experimental streak tube of PV-FS type [6]).

Acknowledgements. The authors thank the staff members of the Institute of Laser Physics Research of the Russian Federal Nuclear Centre – VNIIEF and the Department of Photoelectronics of the A.M. Prokhorov General Physics Institute for their kind assistance in the organisation and successful implementation of testing of the PS-1/S1 camera on the laser installation 'FEMTO' in Sarov.

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