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Detection of radiation from a Ti : sapphire laser with a high space – time resolution

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Abstract. **A high space – time resolution is achieved in detection of radiation from a Ti : sapphire laser by the methods of femtosecond photoelectronics. A time resolution of 2×10^{-13} s is obtained at wavelength of 800 nm in a linear scan regime for a streak speed of 5×10^{10} cm s^{-1}, an input power density of $(1 - 5) \times 10^3$ W cm^{-2}, and a linear dynamic detection range no more than 10.**

Keywords: *femtosecond laser, space – time image detection.*

1. Introduction

The advent of Ti : sapphire lasers at the late 1990s, which emit ultrashort 5-fs single pulses in the near IR region [1], posed the problem of a direct (linear in time and intensity) imaging with the femtosecond time resolution. The concepts of measurements used in autocorrelation methods, which require *a priori* knowledge of the pulse shape and are reduced to the solution of an inverse problem, cannot give unambiguous information on the time intensity profile of femtosecond pulses. The problem of femtosecond imaging of single fast processes in different spectral regions (from soft X-rays to the IR region) and in a broad intensity range (from picowatts to petawatts per square centimetre) also remains unsolved.

Researchers at the Photoelectronics Department of General Physics Institute, Russian Academy of Sciences have developed, based on long-standing studies [2, 3], devices and methods for optical imaging of ultrashort processes in the spectral range from 115 to 1550 nm with a record time resolution of 2×10^{-13} s and a high spatial resolution of 30 line pairs per mm.

2. Experimental setup

We used in experiments a Spectra-Physics femtosecond laser system. A master oscillator was a Kerr-lens mode-locked Ti : sapphire laser. The oscillator emitted 60-fs single pulses with a repetition rate of 82 MHz and an average power of 0.6 W (the single pulse energy incident onto the photocathode was 2 pJ). The duration of single pulses increased up to 120 fs after a regenerative amplifier and their maximum energy was 1.8 mJ.

The diameter of the working area of an image converter tube (ICT) was 5 mm. In front of the image converter, a mechanical slit was placed whose width could be varied with an accuracy of 5 μm. The slit was illuminated by a laser beam of diameter 5 mm. The slit was imaged to the ICT photocathode using an optical system containing two Gelios-44 objective lenses and a set of filters. According to our estimates, the duration of input pulses increased in the imaging system up to 130 fs if they arrived directly from the master oscillator and up to 160 fs if they arrived from the regenerative amplifier. The duration of laser pulses was measured with an autocorrelator. The spatial resolution of the detection system referred to the photocathode plane was 30 line pairs per mm. Silver-oxygen-cesium photocathodes used in the ICT provided the detection of laser pulses in the spectral range from 115 to 1550 nm.

To obtain the image of the entrance slit, it should be illuminated synchronously with a 5-ns voltage pulse applied between a grid and a photocathode. The electric field strength at the photocathode in the experiments was 13 kV mm^{-1}. Laser radiation from the regenerative amplifier was incident on a slit of width 30 μm. The image of a time-resolved process on the screen of a femtosecond ICT was detected with a C 4880-06 Hamamatsu CCD camera equipped with a microchannel plate image intensifier with a gain of 3×10^4. The detected half-width of the slit image on the ICT screen was 100 μm for the electrooptical magnification of $2.8^{\times}$.

3. Experimental results

The first series of experiments was devoted to calibration of the streak speed over the ICT screen. For this purpose, we introduced thickness-calibrated glass plates into half the laser beam. Paired laser pulses with the known time separation were detected on the screen. A calibrated delay with a step of 10 ps was introduced into the streak triggering circuit. The nonlinearity of the streak speed was estimated by moving the image of paired pulses over the screen.

Fig. 1 shows the detection of the paired laser pulses separated by 3.66 ps. The pulse intensity at the ICT input photocathode (5×10^4 W cm^{-2}) was more than an order of magnitude higher than the laser radiation intensity that is typical for the linear (in intensity) detection. This was necessary for a more accurate determination of the position of the paired pulses. We found that the jitter of the streak triggering did not exceed 20 ps for the time of detection on

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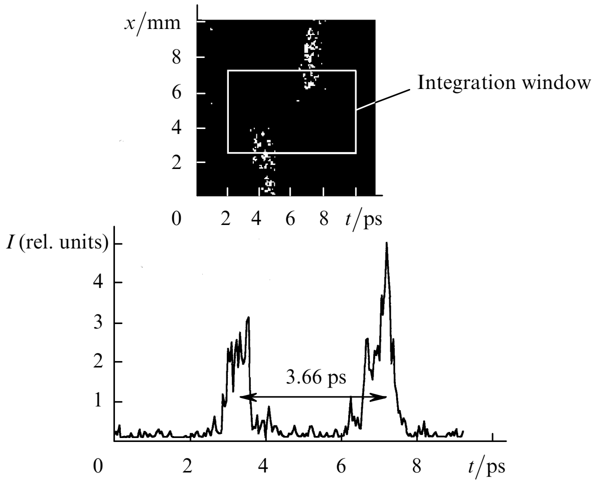

Figure 1. Calibration of the streak speed using time-delayed two parts of a single laser pulse: (a) image on the ICT screen and (b) the corresponding microdensitogram.

the 25-mm screen equal to 50 ps. Therefore, the streak speed for photoelectron images on the ICT screen was 5×10^{10} cm s^{-1} for the nonlinearity below 10 %.

In the second series of experiments, we measured the maximum time resolution of the ICT. The time resolution calculated taking into account the streak speed, the electric field strength at the photocathode, the radiation wavelength, etc. was no more than 200 fs. We measured the maximum achievable half-width of the detected pulse, which represented a convolution of the time instrumental function of the ICT and a 160-fs input laser pulse.

Fig. 2 shows a typical single laser pulse detected on the ICT screen. The curvature of the image was caused by different flight times of axial and periphery photoelectrons. It was taken into account in the computer processing and was used for the additional calibration of the streak speed. The FWHM pulse duration measured on the screen was 240 ± 40 fs depending on the position of the integration window. Taking into account the duration of the input laser pulse, the time resolution of the ICT proved to be no more than 200 fs.

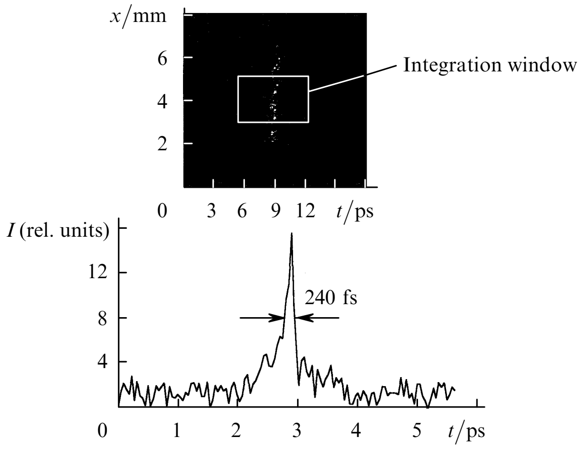

Figure 2. (a) Time scan of a 160-fs single laser pulse on the ICT screen and (b) the corresponding microdensitogram.

The experiments were performed using the incident laser pulse intensity on the photocathode equal to 1 – 5 kW cm^{-2}, while the photocathode sensitivity at 800 nm was ~ 0.4 mA W^{-1}. This means that from 400 to 2000 photoelectrons were involved in the imaging. The processing of the detected images gives the value of the same order of magnitude.

Analysis of the images of a laser pulse containing more than 300 points (counts) of different intensity shows that the accuracy of determining the time intensity profile of the laser pulse is rather high (better than 5 %, based on the number of detected counts). About 150 resolved elements are contained along the spatial axis (the height of the entrance slit is 5 mm, and the size of a pixel along the slit is 30 μm). In turn, each pixel of the time-resolved image on the screen contains on average approximately two counts, so that the error of measurements increases here up to 70 %.

In the third series of experiments, we measured the dynamic range of detection for the maximum time resolution. For this purpose, we varied the radiation density on the photocathode using a linear attenuator and measured the FWHM pulse duration, keeping this duration no more than 20 % greater than the FWHM measured for a minimum detectable incident laser power density. Our measurements showed that the dynamic range of the ICT does not exceed 10, in good agreement with the results of computer simulations.

4. Conclusions

The experimental results presented above have demonstrated the application of the equipment developed at General Physics Institute, Russian Academy of Sciences for detecting space-time pattern of fast processes (laser radiation and laser-induced processes) with a time resolution of about 200 fs. This resolution is only an order of magnitude differs from the values (several tens of femtoseconds) that have been predicted by E.K.Zavoiskii and his pupils fifty years ago [4].

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