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A pulsed photoactivatable switch based on a semiconductor laser and an AlGaAs/GaAs high-voltage photodiode

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An approach is proposed for generating short electrical pulses in a circuit with a payload, which can be semiconductor laser diodes. Within the framework of the proposed approach, a switch based on a high-voltage AlGaAs/GaAs photodiode was used to generate electrical pulses, and a high-power semiconductor laser operating in gain switching mode was used for its photoactivation with sub-ns transient times. Studies of the dynamics of photoactivated switches have shown their capability to produce voltage pulses, under an equivalent load of 50 ohms, with a peak amplitude of 19 V, a pulse width of 300 ps and a leading edge of 80 ps, which was observed when photoactivated by an optical pulse of a semiconductor laser with a peak power of 9.5 W, a leading edge of 35 ps and a pulse width of 100 ps.

Keywords: pulsed current switch, photoactivation, semiconductor laser.

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1. Introduction

The generation of high-power optical pulse sequences with repetition frequencies in the GHz range by semiconductor laser diodes is relevant for a number of practical problems. These include the challenges in the field of information technology associated with the transmission of information in free space [1–3], or radiophotonics for the transmission of microwave energy using high-power optical pulses [4]. The use of semiconductor lasers is due to their availability, small size and a wide choice of spectral characteristics. However, there is a challenge facing the development of sources of high-power laser pulses of subnanosecond duration and the shorter the pulse duration, the higher frequencies can be implemented, which will enable increasing the channel information capacity. Available solutions based on information lasers cannot be used as they do not allow obtaining the required level of optical power. In addition, the presence of a constant component of optical power does not allow using such sources in the developed radiophotonic paths [4]. The simplest way to generate powerful optical pulses of subnanosecond duration by semiconductor lasers is based on implementing the gain modulation mode. In [5] it was shown that the shape of the pumping current pulse (amplitude, duration) has a significant effect on the laser pulse performance. In this case, in the gain modulation mode, reduction of the optical pulse duration and increase of the peak power are possible not only due to the choice of design of the laser heterostructure and laser crystal, but also to the shape of the pumping current pulse. In general, to increase the peak power and reduce the laser pulse duration, it is necessary to both reduce the cavity length, increase the optical limitation factor and the active region volume, and reduce the pumping current pulse duration to subnanosecond values. This will make it possible to implement conditions for generating powerful optical pulses with a duration of several tens of picoseconds. In case of high-power semiconductor lasers, when the peak power exceeds the level of one unit watt, the amplitude of the pumping current can also exceed the level of one unit ampere at the duration in the subnanosecond range. Designing current generators that provide such characteristics is challenging, especially if the repetition frequencies are in the GHz range. Thus, new approaches for generating high-frequency sequences of high-power laser pulses should be developed. An approach, which can be considered as a basis for solving the problem of pumping successive assemblies of high-power semiconductor lasers with short current pulses to implement various generation modes, has been investigated in the scope of this study. The basic principles of this approach are given in Figure 1. In the general case, the circuit can be built based on a series-connected fast current switch, capacitive storage and a number of laser diodes (Figure 1). Usually the role of a fast current key is played by field-effect transistors, but their inclusion requires using the same fast drivers, which limits the possibility of obtaining high-current subnanosecond pulses with high repetition frequencies. To generate a sequence of current pulses with the required characteristics, we propose using a circuit in which a high-voltage photoactivatable key (PAC) based on a photodiode performs the function of a fast-acting high-current key. In this case the mechanism of generating current pulses will consist in transferring the PAC into a conducting state due to an external laser pulse, then the amplitude and duration of the generated current pulses will be determined by the voltage that can block the PAC in the closed state, the external capacitive storage (capacitor in Figure 1), as well as the equivalent load in the form of a set of series-connected laser diodes and the speed of the PAC. It is also important to note that using the high-voltage PAC will increase the number of lasers in series and thus provide flexibility in implementing conditions for frequency or peak power enhancement through the use of appropriate fiber adders. Photoactivation of PAC requires using a compact and efficient source of short laser pulses of subnanosecond duration. As noted above, the solution to this problem can be based on semiconductor lasers operating in gain switching mode. In this case, due to the effect of duration compression in the gain modulation mode, relatively simple current generators providing pumping current pulses with duration in the nanosecond range can be used to generate optical pulses with duration of hundreds of picoseconds, which is sufficient for photoactivation. Examples of optimal designs of such laser structures and experimental implementation were discussed in [5–7] and their distinctive features are related to the use of a bulk active region with a low PAC torus of optical limitation and a sufficiently extended resonator of length of units of millimeters. For a laser diode operating in the gain modulation mode, current pumping conditions must be implemented under which generation occurs only for the first relaxation peak. Thus generated laser pulses of subnanosecond duration provide photoactivation of fast-acting high-voltage PAC and allow implementing conditions for pumping a number of series lasers already by current pulses of subnanosecond duration, which, as noted above, will solve the problem of increasing the peak power of laser pulses and reducing their duration. The proposed circuit design provides high relative stability of optical pulses generated by a set of lasers, since pumping is carried out from a single PAC-based current switch. The use of a fiber adder will make it possible to convert the generated sequence of laser pulses either to solve the problem of multiple increase of peak power, if the laser pulses are added together through delay-compensating fiber adder channels, or to generate a high-frequency pulse sequence, if the fiber adder channels introduce a corresponding delay relative to each other, as shown in Figure 1. For the case of radiophotonic applications, a sequence of laser pulses from a fiber adder, which generates the necessary delays, can be fed to a photodetector included, for example, with a load in the form of an antenna array (Figure 1).

From the above description, it can be seen that the key challenge is related to the need to develop a pair of fast high voltage PAC−subnanosecond laser photoactivation diode (PAC-LPAD). The purpose of the proposed paper is to present the experimental results of the PAC-LPAD pairs.

2. Experimental samples and results

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A basic diode structure design including doped p-AlGaAs, and n-AlGaAs emitters with an undoped GaAs layer located between them with a thickness of $4\,\mu$m was proposed for the PAC. The schematic band diagram is shown in Figure 1, *b*. The structure was grown by MOS-hydride epitaxy. From the proposed heterostructure design, PAC samples with a circular receiving window with a diameter of $210\,\mu$m were manufactured, and the anode electrode had overall dimensions of $360-510\,\mu$m. he use of the PAC design, in which the bulk charge region is located in the GaAs layer, imposes the requirements on the spectral range of laser radiation sources. In this case, the LPAD spectrum must overlap with the absorption spectrum of the GaAs region. In the scope of this study, we used an emitter based on the developed design of heterostructure [6], with an emitting aperture width of $100\,\mu$m, providing an operating peak optical power of 9.5 W at a first oscillation duration of ~ 100 ps with a laser generation wavelength of 860 nm. The shape and peak power of the laser pulses used for photoactivation were obtained using a technique developed by us for measuring the integral generation dynamics of high-power multimode semiconductor lasers, as described in [8]. To do this, an optical system was used to build a magnified image of the output end of the laser emitter, along which the scanning and sequential measurement by a fast-acting photodetector took place. This makes it possible to obtain correct shapes of short laser pulses measured by fast-acting photodetectors, the size of the active site for which is considerably smaller than the emitting aperture of the semiconductor laser. In the developed bench we used a fast photodetector NewFocus 1444-50 (20 GHz), pulses from the photodetector were recorded with an Agilent 86117A stroboscopic oscilloscope (50 GHz). To calculate the peak optical power, the average optical power of the pulse sequence was pre-measured using an OPHIR 3A-P-FS-12 sensor.

The PAC sample under study was coherently mounted on an RF strip line, and the bias voltage was applied and the photoresponse signal was removed through a Tektronix PSPL5580 BiasTee auxiliary circuit with a frequency bandwidth of 18 GHz. The photoresponse signal was recorded on a 50 ohm load using an Agilent 54855A oscilloscope (6 GHz) and RF attenuators selected according to the recorded signal amplitude. For photoactivation of the high-voltage PAC, radiation from the LpAD was applied using an optical fiber with a core diameter of $50\,\mu$m. Then the radiation was focused on the receiving site of the PAC using a pair of aspherical lenses. The required size of the illumination spot was provided by adjusting the detector relative to the focal plane using high-precision mechanical linear translators.

In the first stage, PAC output performance was measured at low peak LPAD power. Figure 2 shows experimental results demonstrating the dynamics of the load voltage pulse at various PAC bias voltages and illumination by an optical pulse from an LPAD with a single first oscillation shape, a leading edge of 35 ps (at the 20−80 %), level), a duration

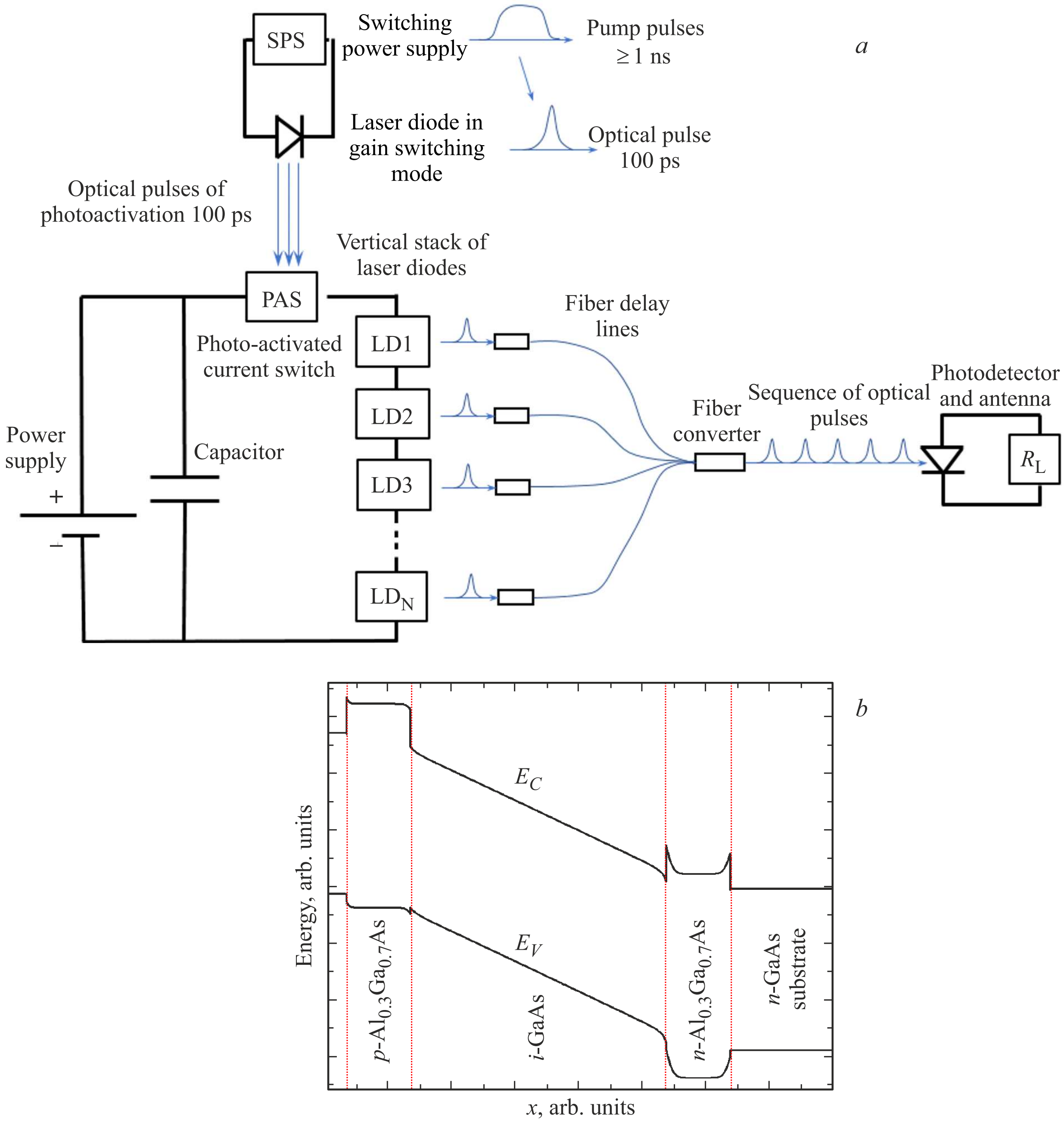

Figure 1. *a* — Layout diagram of generating a high-frequency pulse sequence on an antenna load. PAS — phototactivatable current key, LD — laser diode, SPS — switching power supply, RL — antenna load. *b* — a schematic representation of the area diagram without an offset.

of 80 ps (at the half-amplitude level), and a peak power of 280 mW.

It can be seen that the leading edge duration of the payload voltage pulse decreases from 400 to 100 ps as the PAC bias voltage increases from 0 to ~ 20 V. The leading edge duration correlates with the dependence of the total voltage pulse duration at the payload, which also decreases from 1.5 to 350 ps over the specified range of reverse PAC voltages. For fixed peak LPAD power, further increasing the PAC bias voltage to 50 V does not provide a significant increase in turn-on speed and payload voltage. Figure 3 shows the dependencies obtained for two values of peak power P1 and P2. It can be seen that the increase in the peak power of LPAD in general retains the observed qualitative dependence (Figure 3), but for voltages > 20 V there is still a growth of the voltage amplitude on the payload, albeit much weaker, which may indicate the activation of shock ionization channels at a higher peak current.

As shown above, the achievable value of the peak voltage on the payload is directly related to the peak power of

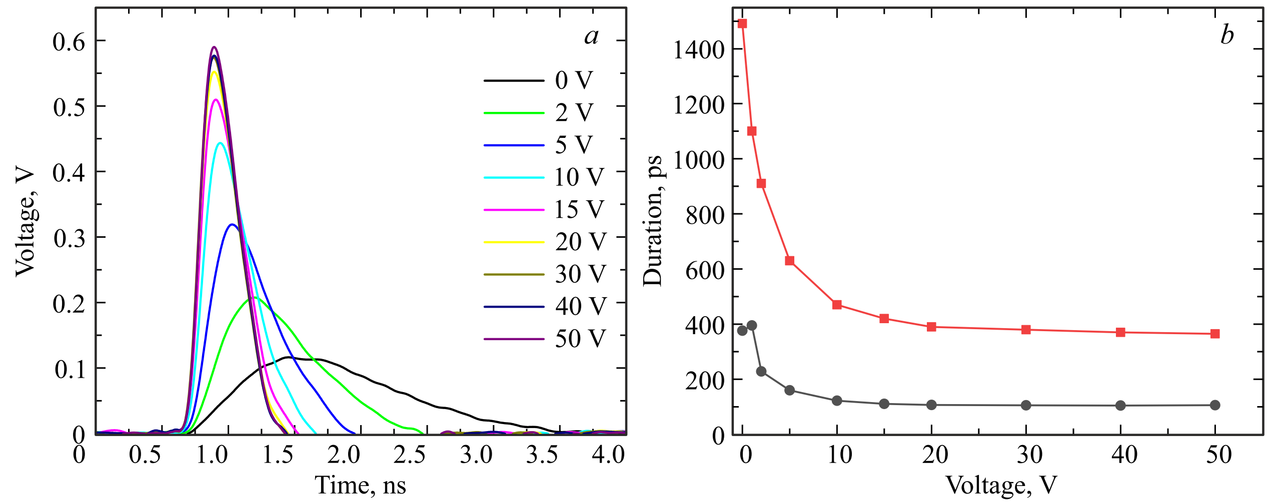

Figure 2. *a* — voltage pulses at 50 ohms load for different PAC reverse bias voltages; *b* — dependence of leading edge duration for 20–80 levels % (circles) and half-height voltage pulse duration (squares) at 50 ohms load on PAC reverse bias voltage. Photoactivation of the PAC was performed by a laser pulse with a duration of 100 ps with a leading edge of 55 ps and a peak power of 280 mW.

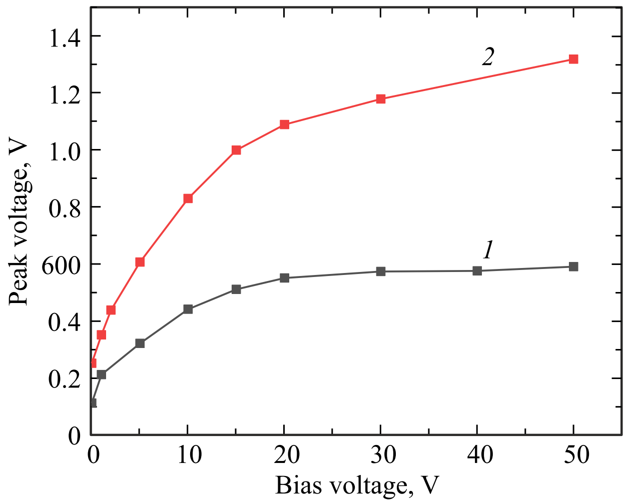

Figure 3. Dependences of the amplitude of the voltage pulse on the 50 ohm load on the PAC bias voltage during photoactivation by a laser pulse in the form of a single first oscillation with a leading edge of 35 ps and a peak power of 280 (*1*) and 600 mW (*2*).

the LDFA pulse. That is why, at the final stage, the shape and amplitude of the voltage pulse generated in the PAC circuit were investigated as a function of the peak power of the exposure pulse. For the experiments, a laser pulse generated by LPAD was used, which had both a single first oscillation with a leading edge of 35 ps and a duration of 80 ps, and a slow part whose intensity was ~ 10 times lower (Figure 4, *a*). During the experiment, the peak power emitted by the LPAD remained unchanged at 9.5 W. Reduction of the power supplied to the PAC receiving site was provided by a set of optical filters, which made it possible to obtain laser pulses for photoactivation of the same shape, with the minimum peak power in the experiment reaching 250 mW. For the studies, the reverse bias voltage of the PAC was kept constant at 50 V. Figure 4 shows that the dependence of the photoresponse amplitude on the photoactivation pulse power is linear up to voltages of 9 V. However, with further increase of the photoactivation power, some saturation is observed, and the maximum amplitude of the photoresponse reaches 19 V at the peak photoactivation power of 9.5 W. For the whole range of photoactivation powers under study, the dynamic characteristics of voltage pulses generated in the PAC circuit were quite similar (Figure 4). The achievable duration of the voltage pulse edge was from 80 to 90 ps, and the pulse duration at half-height was from 300 to 340 ps. Thus, the developed PAC-based keys can generate current pulses with amplitude up to 380 mA and duration up to 300 ps in a circuit with a 50 Ohm load. In future, the load in the circuit can be reduced to increase the current amplitude.

3. Conclusion

To conclude, we can say that the use of a pair of fast-acting high-voltage PAC–subnanosecond laser photoactivation diode allows solving the problem of generating subnanosecond electric pulses. In this case, changes in the parameters of the generated pulses can be implemented both by optimizing the load and the design of PAC assemblies which can be used as a set of series-connected elements. However, further optimization should be carried out through experiments with a payload in the form of assemblies of series-connected semiconductor lasers to evaluate the requirements for the shape and amplitude of the generated electric pumping pulses.

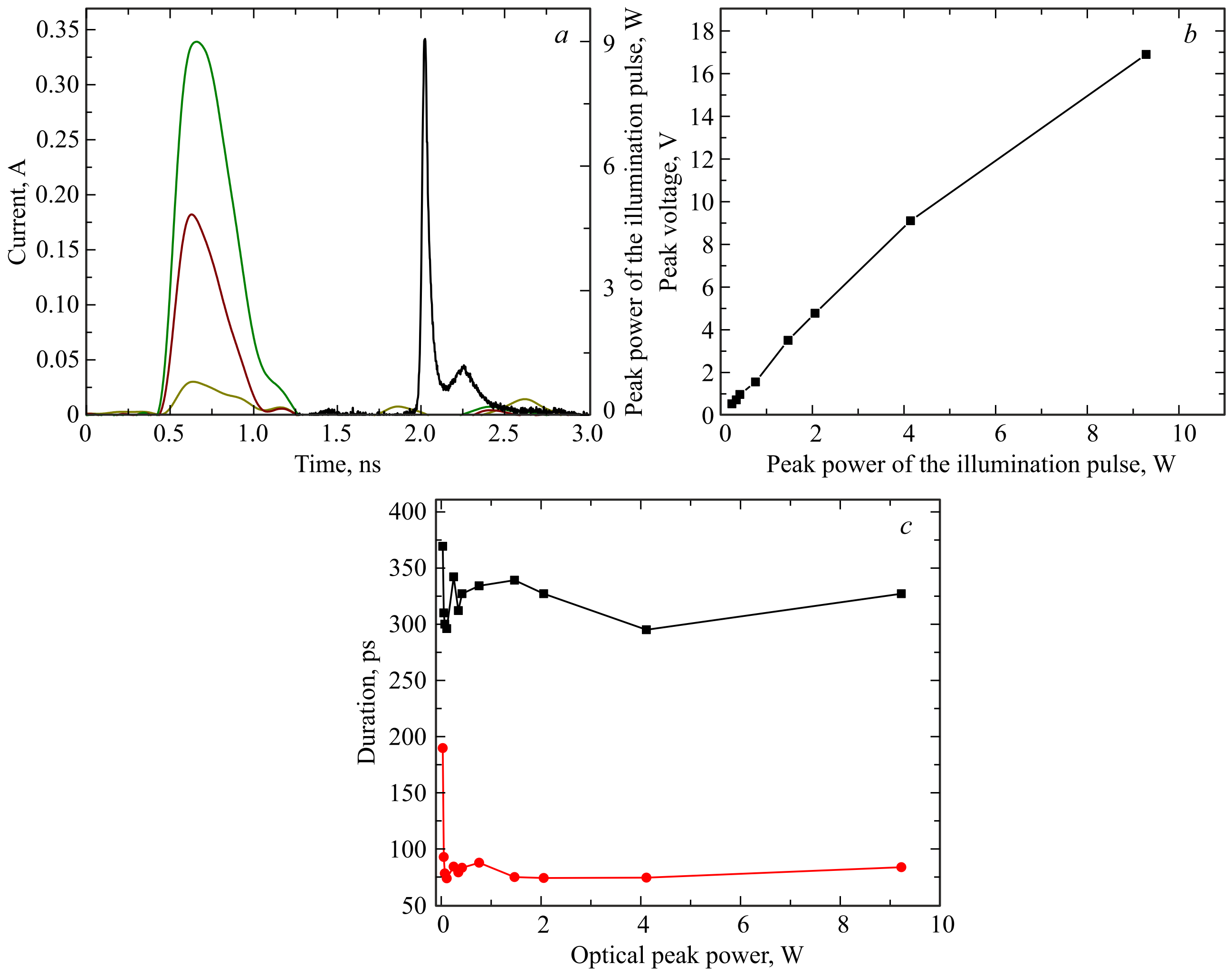

Figure 4. *a* — current pulses for different values of peak power of laser photoactivation pulses, at a PAC reverse bias voltage of 50 V and the shape of the laser photoactivation pulse with maximum peak power; *b* — the dependence of the peak voltage at the 50 Ohm payload on the peak power of the laser photoactivation pulse; *c* — dependence of the leading edge duration for 20−80 % levels (circles) and half-height voltage pulse duration (squares) on a 50 Ohm load on the peak power of the laser pulse for a PAC 50 V reverse bias voltage.

Conflict of interest

The authors declare that they have no conflict of interest.

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