Features of testing micro-sized photovoltaic converters of laser radiation

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Received April 30, 2025
Revised June 25, 2025
Accepted July 15, 2025

A measuring stand using optical fiber for transmitting laser radiation has been developed for testing micro-sized (30–300 μm) photovoltaic converters. The setup allows to study the main characteristics of micro-sized photovoltaic converters: IV, response speed, and the spectrum of electroluminescence. Features of measuring photovoltaic parameters for various converter types are shown.

Keywords: laser radiation, micro-sized photovoltaic converter, measuring stand.

DOI: 10.61011/SC.2025.04.61716.7952

1. Introduction

Development of technology providing long-distance laser energy transfer (wireless or fiber optic) followed by conversion into electrical energy using photovoltaic converters (PVC) is one of the promising power industry areas [1]. PVC converting laser radiation with a power density from 100 W/cm^2 and higher are required for effective development of this technology. Conversion of laser radiation (LR) with high power density ($\sim$ kW/cm^2) would provide an increase in the distance, over which optical energy may be transferred, and in the field of application of this technology [2]. Recently, increasingly greater focus has been made on the creation and study of such high-power converters [3–7]. Creation of high-efficient photoconverters with photoreceiving surface dimensions from 30 μm to 300 μm (Figure 1) is one of the ways to increase the power density of radiation to be converted. In frontal PVC — this is the diameter of a circle, in „edge" PVC — this is the waveguide layer and photoactive region thickness ($p-n$-junction). To study the properties of such micro-sized PVC, precision stands shall be developed to measure the parameters of photoconverters exposed to high-density laser light free of temperature effects.

In [4], properties of GaAs PVC with a photoreceiving surface diameter of 30 μm, 50 μm and 150 μm were investigated, however, operating conditions (exposure to pulsed or continuous LR) of the measurement stand for power densities of 550–1900 W/cm^2 were not specified. This work continued the investigations of properties of high-density laser PVC with the measurement stand operating in a quasi-steady-state mode (exposed to 300 ns pulses [6] and further improvements were made. The system is used to study the properties not only of frontal photoconverters where the photoreceiving surface is parallel to the $p-n$-junction (Figure 1, *a*) [3,4], but also of an „edge" photoconverter where the photoreceiving surface is perpendicular to the $p-n$-junction (Figure 1, *b*) [5]. The measurement stand is used to record IV-curve (IV-C) at laser power densities from 100 W/cm^2 to 15000 W/cm^2, measure the response time of devices at test pulses with FWHM of $\sim$ 2 ns, record and review electroluminescence spectrum and additionally evaluate the waveguide layer thickness of the „edge" PVC.

The measurement stand is designed for operation in several modes:

1) IV-curve measurement with 300 ns pulse irradiation (Figure 2, *a*);

2) measurement of response speed parameters with 2 ns test pulse irradiation (Figure 2, *b*);

3) electroluminescence recording (Figure 2, *c*).

Scheme of the setup for various modes is shown in Figure 2, *a–c*. Optical fiber (for example, 50/125 μm), laser PVC (LPVC), microscope and three-axis micrometer movement system are the permanent components of the system because micro-sized photovoltaic converters require high-accuracy alignment between the optical fiber output end and input window or photoreceiving surface of PVC.

IV-curve measurement mode with 300 ns pulse irradiation. IV-curve measurement of the photovoltaic converter in quasi-continuous laser mode is used to examine PVC at high laser exposure power densities (up to 15000 W/cm^2) without heating effect. A 850 nm laser diode was used as a source of light for testing GaAs PVC and a 1550 nm laser diode was used for testing GaSb PVC. A laser diode driver provided generation of 300 ns rectangular shape pulses with a repetition rate of 1 kHz. Laser diode is connected to the 50/125 μm step-index optical fiber with a numerical aperture of 0.22. This mode prevents PVC heating because the mean laser power is low due to a large pulse ratio, and single pulse energy is insufficient for considerable heating of the $p-n$-junction region. Pulse duration is defined by minority carrier lifetime in the semiconductor material and by transient processes in the PVC electrical measurement circuit. To prevent PVC heating with forward current flow, voltage is also applied in pulsed mode using a switch consisting of two series-opposite connected field-effect transistors. Radiation and voltage pulse synchronization was provided by a pulse generator. Current and voltage are recorded using a digital

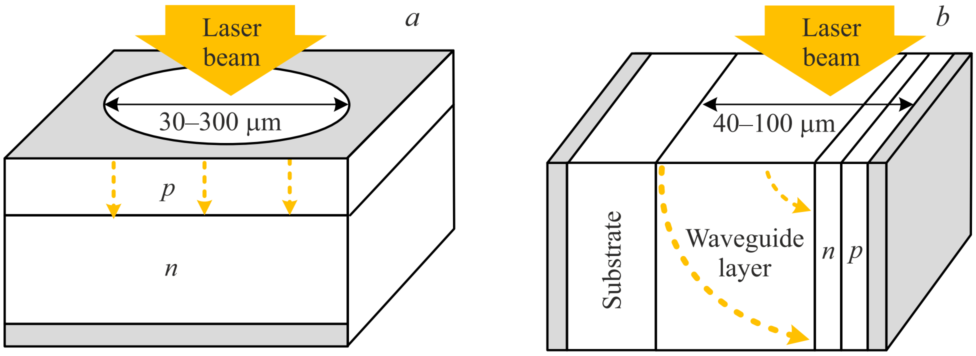

Figure 1. Two types of micro-sized photoconverters with typical dimensions of photoreceiving surface: *a* — frontal photoconverter; *b* — „edge" photoconverter with a waveguide layer.

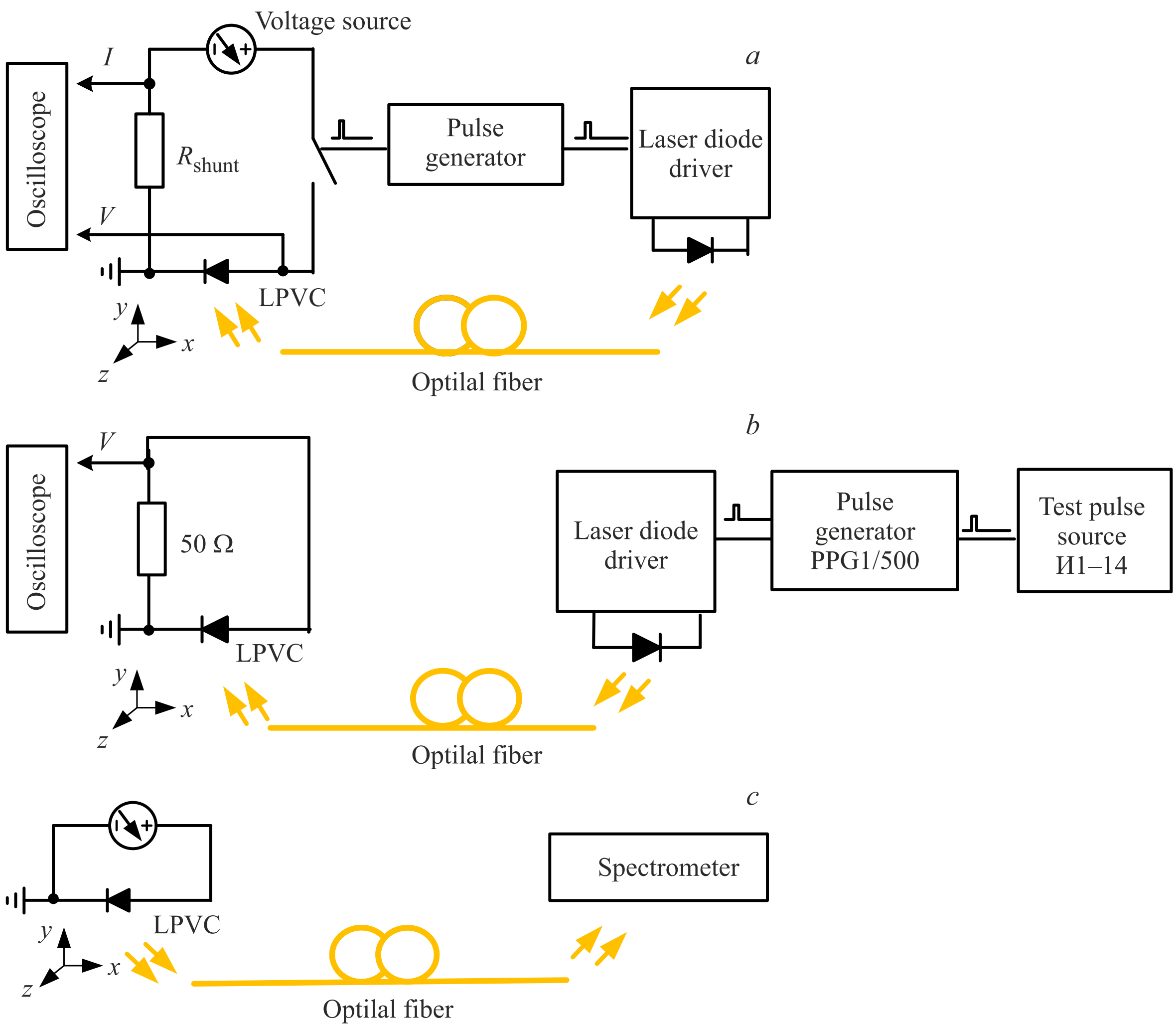

Figure 2. Scheme of the setup for measuring micro-sized photoconverter properties in various modes: *a* — IV-curves measurements; *b* — response speed measurements; *c* — electroluminescence recording.

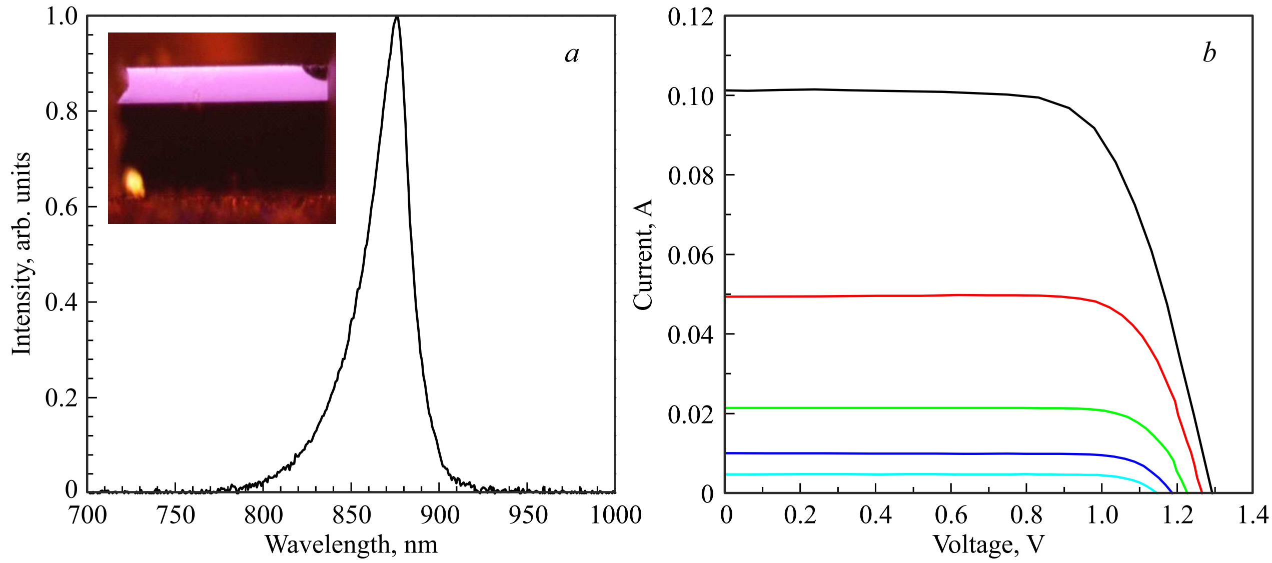

Figure 3. Micro-sized PVC characteristics: *a* — „edge" GaAs PVC electroluminescence spectrum and photo; *b* — IV-curves of „edge" GaAs PVC measured at various laser power densities.

oscilloscope with a bandwidth up to 1 GHz. Current was measured at a shunt resistance of 1 Ohm.

Response speed measurement mode. This mode is used to measure FWHM, rise and fall times, and photoresponse pulse amplitude for nanosecond laser pulse detection. A laser diode connected to the PPG-1/500 pulse generator serves as a pulse source to generate optical pulses with FWHM of 2.3 ns. The generator is actuated by the I1-14 test pulse source providing 100 ns 1 kHz sync pulses. MDO3102 oscilloscope was used to record the voltage waveform at various laser powers.

Electroluminescence recording mode. When forward current is passed through the photodetector, the latter functions in the LED mode. Thus, the electroluminescence spectrum peak may be used to determine the semiconductor material band gap (Figure 3, *a*). Dimensions of the photoreceiving surface of the „edge" photoconverter may be also measured using the image of the light-emitting PVC area. The spectrum peak is used to control and, if required in the next epitaxial process, to adjust alignment of the laser source wavelength and the band gap of the PVC active region material. The electroluminescence spectra were recorded using the same optical fiber as for the IV-curve measurement. For image recording, the „edge" photoconverter was placed on a microscope holder with a digital camera. In both cases, forward bias voltage was applied to the sample. The current was set to ~ 1 mA to avoid crystal heating without using a heat sink.

Focus shall be made on some aspects of calculating specific parameters of micro-sized PVC. Thus, the incident laser light power density is calculated using the photoreceiving surface area (Figure 1) [8]. Whereby, the PVC current density is calculated using the $p-n$-junction area. For frontal photoconverters (Figure 1, *a*), the $p-n$-junction area under the contact may be comparable with the photoactive area of the $p-n$-junction. For example, in [3], characteristics of the GaSb frontal laser PVC with a photoreceiving surface diameter of 30 μm were measured, while the $p-n$-junction was formed in the $\varnothing\,50\,\mu$m windows. For the micro-sized „edge" PVC (Figure 1, *b*), the $p-n$-junction area may be an order of magnitude larger the photoreceiving side surface area due to the longitudinal dimensions of PVC. This provides effective conversion of high-density light.

Figure 3, *b* shows IV-curves of the GaAs „edge" PVC measured at various laser power densities from 600 to 13000 W/cm^2. Spectral response SR may be evaluated using equation $SR(\text{A/W}) = I_{sc}(\text{A})/P_{in}(\text{W})$ [9] by the photoconverter photocurrent (I_{sc}) with fixed input radiation power (P_{in}). Measured values of fill factor FF, open circuit voltage U_{oc} short-circuit current I_{sc} are used to calculate the device efficiency (η) for various input laser powers P_{in}, accordingly, with different incident laser power density. For GaAs „edge" PVC with the AlGaAs (50 μm) waveguide layer, $\eta = 50-53\,\%$ was obtained with a laser power density of 1000–8000 W/cm^2 [5]. In the response speed test mode, FWHM of 3.2 ns and a photoresponse pulse front rise time of 0.88 ns were recorded for the PVC valve mode, and 2.6 ns and 0.77 ns, respectively, were recorded for a reverse bias of 10 V. For GaSb front photoconverters with 30 μm and 80 μm photoreceiving surface diameter, $\eta = 35-38\,\%$ up to 1600 W/cm^2 was obtained [3].

The stand is used to simulate operating conditions of photovoltaic converters in a wide exposure level range (from 100 to 15000 W/cm^2) without temperature effects and to measure the micro-sized PVC parameters in three various modes to provide conditions for future optimization of the high-efficient PVC technology intended for ultrahigh density laser radiation conversion.

Conflict of interest

The authors declare no conflict of interest.

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Translated by E.Ilinskaya