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# Degradation study of subnanosecond photovoltaic module parameters during thermocycling

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The degradation of microwave module parameters of series-connected $p{-}i{-}n$ AlGaAs/GaAs photovoltaic converters under thermocycling in the temperature range of 25–80°C and continuous laser radiation from multimode optical fibers with a total power of 2 W at a wavelength of 810 nm has been investigated. During thermocycling, stabilization of the photovoltaic parameters of the microwave module was observed with a decrease in the output electrical power from 955 mW to 926 mW and a decrease in efficiency by 3%.

**Keywords:** $p{-}i{-}n$ AlGaAs/GaAs photovoltaic converter, microwave module, multimode optical fiber, thermal cycling, electrical power, efficiency.

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The engineering of hardware components for radio-optical phased arrays [1–6] is one of the promising trends in science and technology. These hardware components include, e.g., high-power microwave photovoltaic modules (PVMs) based on $p{-}i{-}n$ AlGaAs/GaAs photodiodes with subnanosecond response times and high efficiencies ($\sim 55\%$) [5]. State-of-the-art photodetectors need to provide long error-free running periods in their standard operation regime and ensure continuous operation under normal climatic conditions [7]. In the present study, the results of examination of photovoltaic parameters of a microwave PVM built from series-connected heterostructural $p{-}i{-}n$ AlGaAs/GaAs photovoltaic converters (PVCs) under thermal cycling and optical excitation in the 25–85°C temperature range are reported.

The examined microwave PVM, which is a line of 16 series-connected $p{-}i{-}n$ AlGaAs/GaAs PVCs mounted on an AlN microstrip, is shown schematically in Fig. 1, *a*. Heterostructural AlGaAs/GaAs PVCs were grown by molecular beam epitaxy. The PVC structure included an $n$-$Al_{0.2}Ga_{0.8}As$ back potential barrier; an $n$-GaAs ($N_D = 1 \cdot 10^{18}\,cm^{-3}$)/$i$-GaAs ($N_D \sim 1 \cdot 10^{16}\,cm^{-3}$) base layer 0.3/1.5 $\mu$m in thickness with an undoped $i$ layer; a $p$-GaAs emitter 1.0 $\mu$m in thickness with doping level $N_A = 1 \cdot 10^{18}\,cm^{-3}$; a $p$-$Al_{0.13}Ga_{0.87}As$ wide-gap window 3 $\mu$m in thickness ($N_A = 1 \cdot 10^{19}\,cm^{-3}$); and a $p^+$-GaAs subcontact layer. PVC chips were formed on epitaxial wafers in a post-growth process with a contact grid on the frontal photosensitive surface 300 $\mu$m in diameter. The frontal ohmic contact was formed from Ag(Mn)/Ni/Au layers with an overall thickness of $h = 3600$ Å, while the back contact was based on Au(Ge)/Ni/Au layers with $h = 2000$ Å. The mesa structure was etched to a depth of $\sim 10\,\mu$m with passivation of the side surface by dielectric $Si_3N_4$.

A pulsed laser operating with radiation output from a 200 $\mu$m optic fiber at a wavelength of 780 nm with a half-

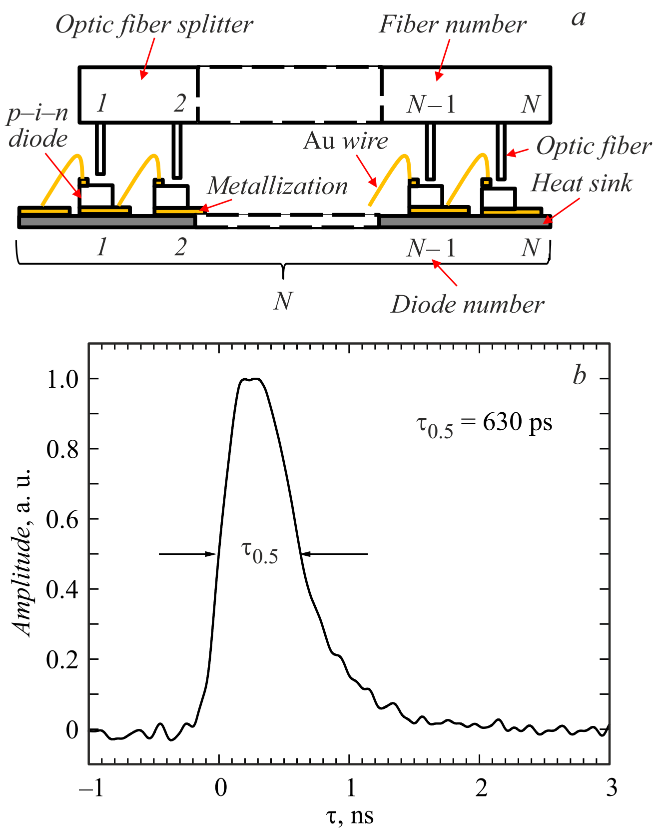


**Figure 1.** *a* — Diagram of the microwave PVM consisting of $N = 16$ series-connected $p{-}i{-}n$ AlGaAs/GaAs PVCs with a photosensitive surface diameter of 300 $\mu$m; *b* — photoresponse pulse of the $p{-}i{-}n$ AlGaAs/GaAs PVC with a mesa diameter of 300 $\mu$m at a matched load under excitation by a laser pulse with a width of 10 ps at a wavelength of 780 nm.

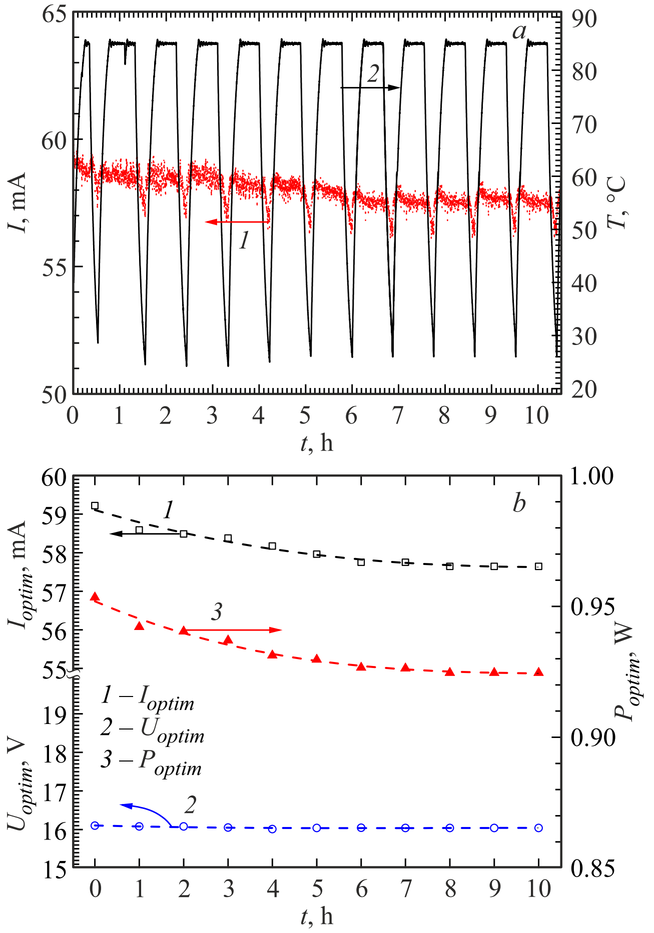


**Figure 2.** *a* — Variation of photocurrent of the microwave PVM (Fig. 1, *a*) at the optimum load (*1*) and temperature variation (*2*) under thermal cycling within the 25–85°C range and illumination by continuous laser radiation with a total power of 2 W and a wavelength of $\lambda = 810$ nm; *b* — dependences of current (*1*) and voltage (*2*) at the optimum load and electrical power (*3*) at the microwave PVM output on the duration of thermal cycling.

height duration of 10 ps and a repetition rate of 71 MHz was used to estimate the response time of $p-i-n$ AlGaAs/GaAs PVCs in the microwave PVM. The minimum half-height duration of output electrical pulses of the used PVCs was $\tau_{0.5} = 630$ ps (Fig. 1, *b*).

In the course of thermal cycling, the PVM was excited by a constant optical signal from multimode 200 $\mu$m optical fibers with a 1/16 splitter (see Fig. 1, *a*). A laser operating at 810 nm with a total power of 2 W was the source of this continuous optical signal. The source of continuous laser radiation with optic-fiber output provided the highest stability of radiation wavelength (0.3 nm/K) within the range of maximum values of the external quantum efficiency and the efficiency of ultrahigh-frequency $p-i-n$ AlGaAs/GaAs PVCs used in the microwave PVM. The temperature regime and duration of thermal cycling (Fig. 2, *a*) were chosen according to the range of permissible temperatures for efficient microwave PVM operation and the procedure outlined in [7]. The heating and cooling times were equal and totaled to $\sim 30$ min. The length of exposure of the microwave module at maximum temperature $T_{max} = 85$°C was $\sim 24$ min. Thermal cycling was performed in an automatic mode with the use of a temperature controller (based on a microprocessor board) under normal pressure and an ambient temperature of $\sim 25$°C. The temperature regime was adjusted by a Peltier element. A platinum thermosensitive resistance (Pt100) connected on a four-wire basis via a meter based on a MAX31865 microchip was used to determine the PVM temperature. Load current–voltage curves were recorded every 15 s (simultaneously with temperature measurements). The intensity of continuous laser radiation with a wavelength of 810 nm was checked at the start and the end of thermal cycling with an optical radiation power meter. The measured values agreed within the measurement accuracy of the optical radiation power meter (±0.5%).

Photovoltaic PVM parameters were calculated from the current–voltage curves measured under illumination in the course of thermal cycling. Figure 2, *a* presents the diagram of variation of the PVM photocurrent at the optimum load point (curve *1*) and the temperature variation (curve *2*). Figure 2, *b* shows the resulting current (curve *1*), voltage (curve *2*), and electrical power (curve *3*) dependences at the microwave PVM output under thermal cycling. It can be seen that the photocurrent and voltage at the optimum load point stabilize at 57.65 mA and 16.02 V, respectively, after 7-hour-long thermal cycling within the 25–85°C temperature range. In 10 h of tests, the output electrical PVM power decreased and stabilized at $\sim 924$ mW. Figure 3 presents the relative variation of the PVM efficiency in the process of thermal cycling. The magnitude of efficiency reduction was $\sim 3$%.

The data obtained in the examination of photovoltaic parameters of the microwave PVM under thermal cycling

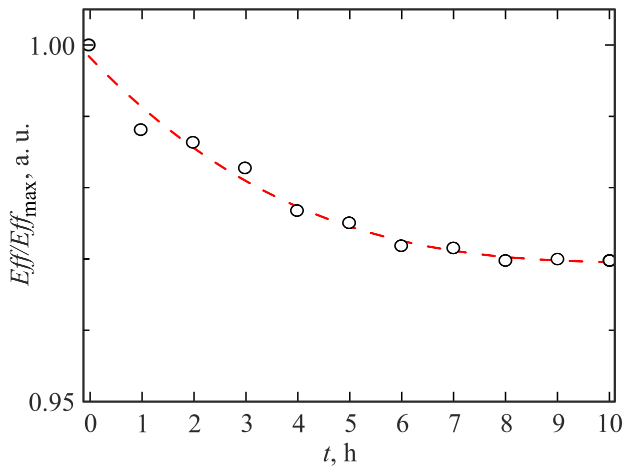


**Figure 3.** Variation of the efficiency of the photovoltaic module in the process of thermal cycling within the 25–85°C temperature range under excitation by continuous laser radiation with a power of 2 W and a wavelength of 810 nm.

within the 25–85°C temperature range and excitation by continuous laser radiation with a power of 2 W and a wavelength of 810 nm demonstrated that the output parameters of the module containing 16 series-connected ultrahigh-frequency $p-i-n$ AlGaAs/GaAs PVCs stabilized within 10 h of thermal cycling. The output electrical power of the module decreased from 953 to 924 mW, and the magnitude of efficiency reduction under optical excitation by continuous laser radiation was 3%. These values are indicative of a fine temperature stability of parameters of the microwave PVM in the photovoltaic operation mode.

### Conflict of interest

The authors declare that they have no conflict of interest.

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