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Energy–informational hybrid photovoltaic converter of laser radiation

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Abstract. The possibility of efficient conversion of constant laser radiation using α–Si:H/c–Si structures in the transparency window of the Earth's atmosphere at wavelength 1.06 μm is shown for the first time. A hybrid photovoltaic converter based on α–Si:H/c–Si cells and AlGaAs/GaAs photodetectors has been developed and manufactured. The photoelectric converter provides simultaneous conversion of radiation from two types of laser sources in the photovoltaic mode: continuous at a wavelength of 1.06 μm with an efficiency of ~ 26% and pulsed at a wavelength of 0.78 μm of ≤ 900 ps FWHM.

Keywords: laser radiation, transparency window, hybrid photovoltaic converter, AlGaAs/GaAs photodetectors, α–Si:H/c–Si structures

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Энерго-информационный гибридный фотоэлектрический преобразователь лазерного излучения

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Аннотация. Впервые показана возможность эффективного преобразования постоянного лазерного излучения с использованием α–Si:H/c–Si структур в окне прозрачности земной атмосферы на длине волны 1.06 μm. Разработан и изготовлен гибридный фотоэлектрический преобразователь на основе α–Si:H/c–Si и AlGaAs/GaAs элементов. Фотоэлектрический преобразователь обеспечивает одновременное преобразование излучения от двух типов лазерных источников: непрерывного на длине волны 1.06 μm с эффективностью ~ 26% и импульсного, на длине волны 0.78 μm с ≤ 900 ps FWHM.

Ключевые слова: лазерное излучение, окно прозрачности, гибридный фотоэлектрический преобразователь, AlGaAs/GaAs фотодетектор, α–Si:H/c–Si структура

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Introduction

Currently, free space optical communication (FSO) is becoming more widely used. FSO is used to provide wireless high–speed communication channels transmitting a signal over a distance up to 15 km at a speed up to 1 Gbit/s [1].

To ensure the autonomy of FSO operation in hard–to–reach areas, the creation of energy independent receiving and transmitting stations is promising. This paper presents the results of a study of a hybrid photovoltaic converter (HPVC). The HPVC is a prototype of energy independent receiving device created on the basis of an α–Si:H/c–Si heterojunction technology (HJT) cells and an information photoconverter (PC) assembled of four p–i–n AlGaAs/GaAs photodetectors (PDs) of laser radiation respectively, at wavelengths of 1.06 μm and 0.78 μm [2–4].

Experiment

The structures of the HJT cells were manufactured by deposition of native amorphous silicon (α-Si:H) 5–10 nm thick on a textured single–crystal silicon n–type substrate of 125 μm thick, n–α–Si:H (on the front surface) and p–α–Si:H (on the back surface) layers 10–15 nm thick and indium tin oxide (ITO) layers 100 nm thick. In the experiments, the HJT cells with a size of 156×156 mm^2 were used. On the surface of the ITO layers, silver contact tires with a width of 40 μm and a pitch of 1.2 mm are formed by screen printing.

The structure of p–i–n AlGaAs/GaAs PDs included: n–$Al_{0.2}G_{0.8}As$ – back potential barrier, n–GaAs (N_n=5·10^{17} cm^{-3})/i–GaAs (N_n=1·10^{15} cm^{-3}) layers 0.5/1 μm thick and 0.7 μm p–GaAs emitter (N_p=2·10^{18} cm^{-3}), p–$Al_{0.12}Ga_{0.88}As$ wide gap window 2 μm thick (N_p=5·10^{19} cm^{-3}). PDs were formed using the post–growth technology with a photosensitive surface diameter of 500 μm with a grid frontal contact.

Fig. 1 presents the spectral characteristics of the external quantum efficiency of the grown α–Si:H/c–Si power cells and AlGaAs/GaAs PDs structures. The spectral sensitivity of the HJT cell at room temperature is in the range of 300 nm–1200 nm, and AlGaAs/GaAs p–i–n PD is 700 nm–900 nm respectively.

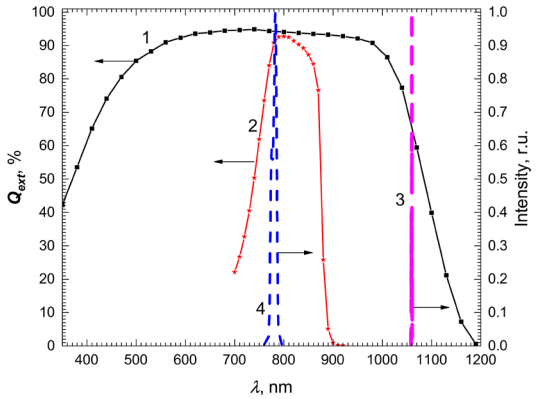

Fig.1. Spectral characteristics of the external quantum efficiency of α-Si:H/c-Si HJT cell (1) and AlGaAs/GaAs p-i-n PD (2), as well as emission intensity spectra of energy constant (3) and information pulsed (4) laser sources

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According to the method described in [3], samples of the HJT cells and AlGaAs/GaAs p–i–n PDs were selected and the HPVC was created based on them. The photo of the HPVC is shown in Fig. 2. The assembly of the information PC is made in the form of a quadrature of four series connected p–i–n AlGaAs/GaAs PDs. Silicone microlenses were mounted on the photoactive surface of each p–i–n AlGaAs/GaAs PD. Mounting and electrical connection of the p–i–n PDs is performed on an AlN heat sink base. The information PC with an optical concentrator (focon) is mounted directly in the center of the photosensitive surface of the energy HJT cell.

Measurements of the photovoltaic characteristics of the HPVC (Fig. 3) were carried out with simultaneous illumination by continuous laser radiation with a power density of ~ 51 mW/cm^2 at a wavelength of 1.06 μm and pulsed at a wavelength of 0.78 μm of ≤ 10 ps full width at half maximum (FWHM) and the 71 MHz frequency at an average power of ~ 120 mW. The illumination of the energy HJT cell was carried out from a multimode optical fiber with a homogenizer (200/400 μm) with a radiation intensity distribution close to the Gaussian distribution, simulating the scattering of laser radiation in the atmosphere. Fig. 3 shows the load current-voltage (I–V) characteristic of the HJT cell (curve 1) and photoresponse pulses of the information PC (curves 2–4). According to the measured load I–V characteristic, the efficiency of the HJT cell with the AlGaAs/GaAs p–i–n PC mounted on its frontal surface was ~ 26%.

To simulate the displacement of the signal source from the information receiver, the photoresponse pulses of the AlGaAs/GaAs p–i–n PC were measured under laboratory conditions when irradiated from an optical fiber with a divergence angle of 10° at different light spot areas.

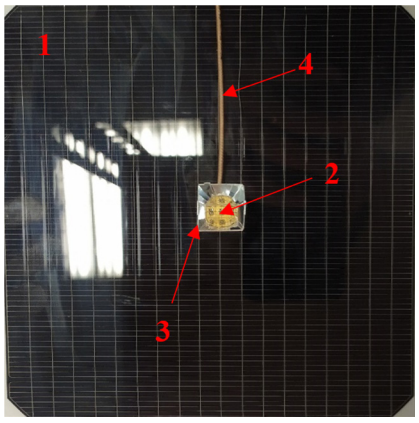

Fig. 2. A photograph of the developed and created energy–informational HPVC, where 1 is the energy HJT cell, 2 is informational AlGaAs/GaAs p–i–n photoconverter with silicone microlenses, 3 is focon, 4 is microwave cable

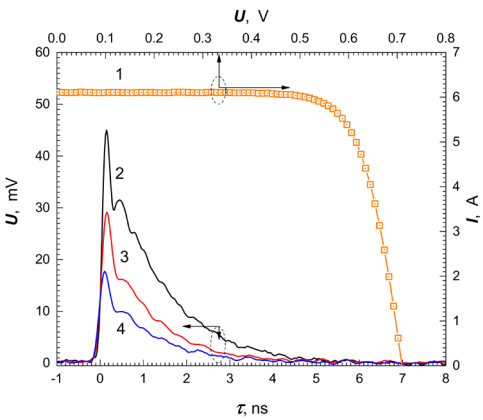

Fig. 3. Characteristics of the HPVC. Load I–V characteristics of the α-Si:H/c–Si HJT cell (continuous, 1.06 μm, ~ 51 mW/cm^2) with an informational AlGaAs/GaAs p–i–n PC mounted on it (1), photoresponse pulses of AlGaAs/GaAs p–i–n PC with a focon at the laser spot area of 0.2 (2), 0.8 (3), 2 (4) cm^2, (pulse: 0.78 μm, ≤ 10 ps FWHM, P_c = 120 mW)

The measured time parameters are shown in Table 1. According to the results obtained by increasing the area of the laser irradiation spot from 0.2 cm² to 2 cm², the maximum amplitude of the signal voltage at a 50 Ohm load drops by 60% (Fig. 3, curves 2–4). The photoresponse rise time (τ_{rise}) of the AlGaAs/GaAs p–i–n PC increased by 22%, the fall time (τ_{fall}) decreased by 7% and FWHM decreased by 22%. With an illumination spot area of 0.2 cm², the maximum value of the information photoelectric cell amplitude was 45 mV with the following parameters: τ_{rise} ~ 140 ps; τ_{fall} ~ 3.0 ns; ~ 900 ps FWHM (Fig. 3, curve 2). With an illumination spot area of 2 cm², FWHM was 700 ps, which corresponds to a bandwidth of ≤ 1.25 GHz (Fig. 3, curve 4).

Table 1

The measured time parameters

$S_{laser\ spot}$, cm²	U_{max}, mV	τ_{rise}, ns	τ_{fall}, ns	FWHM, ns
0.2	45	0.14	2.8	0.9
0.8	29	0.19	2.3	0.7
2	18	0.18	2.6	0.7

The inhomogeneity of the laser radiation profile is one of the factors limiting the effectiveness of the HJT cell needed to build an energetically independent laser channel in FSO. Therefore, an important task is to assess the effect of a not uniform illumination of the HJT cell photoactive surface on its photovoltaic characteristics. The load I–V characteristics of the HJT cell have been measured depending on the shading degree of the photosensitive surface of the element at a uniform power density of 100 mW/cm² of collimated optical radiation (AM1.5). Fig. 4 shows the dependences of FF and efficiency calculated from the load I–V characteristics on the shading degree of the photosensitive surface of HJT cells.

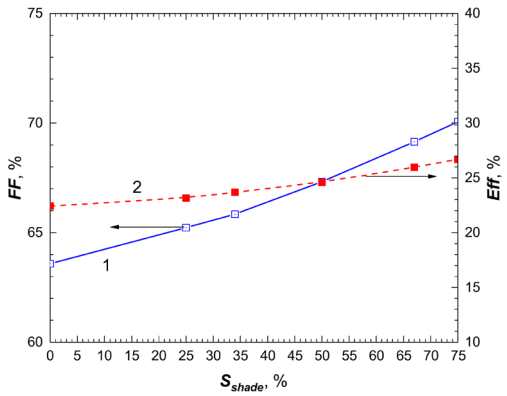

Fig. 4. Fillfactor (1) and efficiency (2) at different degrees of sample shading during pulsed excitation, at the power density 100 mW/cm² of the collimated optical flux AM1.5.

According to the obtained result, the HJT cells had demonstrated an increase of FF and efficiency with an increase in the shaded area. With an increase in the shaded area of the photoactive surface from 0% to 75%, the efficiency of the HJT cells increased from 22% to 26%. This change in FF and efficiency as well as a 4% decrease in the efficiency value at AM1.5 compared to laser radiation, is associated to the influence of the HJT cells surface spread resistance and thermal losses in short-wave radiation.

Conclusions

The hybrid photovoltaic converter was developed and manufactured based on the energy α–Si:H/c–Si HJT cell and information AlGaAs/GaAs p–i–n PC. In photovoltaic mode the hybrid photovoltaic converter provides simultaneous conversion of continuous laser radiation with a power density of ~ 51 mW/cm² at a wavelength of 1.06 μm with an efficiency of ~ 26%, and pulsed laser radiation at a wavelength of 0.78 μm of ≤ 900 ps FWHM.

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