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Power-communicating photo-receiving device

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Abstract. The work is devoted to the creation of a power-communicating photo-receiving device for an autonomous laser communication unit, designed to receive energy from powerful laser radiation and convert it into electricity, as well as for simultaneous registration of information high-frequency optical signals. The presented results demonstrate the possibility of photo-receiving device practical use in laser communication system, including power supplying of the active equipment.

Keywords: wireless power transmission, laser beam, photo-receiving device, photovoltaic cell, high-speed photodiode

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Энергоинформационное фотоприемное устройство

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Аннотация. Работа посвящена созданию энергоинформационного фотоприемного устройства для автономного узла лазерной связи, предназначенного для приема энергии мощного лазерного излучения и преобразования ее в электроэнергию, а также для одновременной регистрации информационных высокочастотных оптических сигналов.

Ключевые слова: беспроводная передача энергии, лазерный луч, фотоприемное устройство, фотоэлектрический преобразователь, быстродействующий фотодиод

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Introduction

The data transmission by modulated laser radiation propagating in the optical fiber line has become widespread. Technologies for simultaneous transmission of optical power and data by the laser radiation in an optical fiber have been earlier investigated [1]. Optical power of several watts through the fiber for a distance up to 200 m can be transmitted to the electricity with the 20% efficiency: electricity conversion cycle, due to limitations of the transmitted power caused by overheating of the fiber at high power up to self-destruction [2].

Optical systems for data transmitting through open atmospheric or space channels have also been developed and implemented. For example, in Russia, the transceiver apparatus of atmospheric optical communication lines is mass-produced by two companies, Mostkom CJSC (Ryazan) (Artrolink), and Catharsis NPK LLC (St. Petersburg) (Lantastica TZR).

Contactless and wireless transmission of laser radiation power pass through the open channel, followed by its photoelectric conversion at the terminal device [3]. This power transmission method has obvious advantages: the power can be increased (up to hundreds of kW) compared to the power transmission through an optical fiber; the power density and data transfer rate can be improved, narrower beam focus and smaller diameters of the transmitter and receiver can be achieved compared to the method of power transmission using microwave radiation [4]. The main applications of laser power transmission technology through an open channel are the following:

- remote power for the industrial and specialized mobile terrestrial equipment;
- remote power organization for the repeaters of 5G data transmission networks;
- cargo delivery to Earth orbit;
- generated power transmission from space stations to ground-based consumers or to the lunar surface, including for powering lunar rovers and stationary research vehicles;
- wireless charging of household devices;
- in medical technology – wireless power transmission of the laser IR radiation through the skin directly into the patient's body for recharging biosensor batteries and smart implants.

In the next decennary, wireless power transmission could become an important part of power grids.

The development of laser power transmission systems has recently been intensified [5] due to the appearance of efficient photovoltaic cell and powerful efficient compact lasers with low beam divergence.

For example, the Russian Rocket and Space Corporation Energia has developed a Pelican laser power transmission system [6]. This system can be used to power, for example, microrovers, research stations with drilling rigs, light beacons to provide landings of automatic and manned spacecraft on the shaded side of the moon. The maximum distance from the source to the receiver is about 300 km. The system is capable to transmit 750 W of electric power at 3000 W of optical power.

The Japanese Aerospace Exploration Agency develops a laser system for power transmission from space to Earth and at interorbital optical communication over long distances. Laser wireless power transmission system investigation by a continuous fiber optic laser (emission wavelength 1070 nm and 500 W power) has been reported [7]. The ability of the beam alignment with an accuracy of 1 μrad has been demonstrated.

A laser system recently developed by PowerLight powered one of Ericsson's 5G cellular base stations, which was not connected to any other power source [8]. The system supplied more than 480 W of electrical power at 300 m. At an early date, the system will be improved to transmit 1 kW over a distance of more than 1 km. The wireless power of 5G stations can improve systems portability, stations can be quickly temporarily deployed in places with increased traffic, for example, at festivals, exhibitions, conferences, or during natural disasters when other communication infrastructure were disrupted.

Laser system for transmitting through an atmospheric channel and converting laser radiation achieved 11.6% efficiency (electricity-electricity) at transmission range 100 m, and generated electrical power 9.7 W [9]. Multi-cell semiconductor photovoltaic (PV) converters with an optimized *p*++-GaAs/*p*-InGaP/*p*-GaAs/*n*-GaAs/*n*-AlGaAs/*n*-GaAs/*n*-Ge structure and with 40.4% efficiency at standard test conditions (STC) (60 kW/m2laser intensity, 24 W laser optical power, wavelength 793 nm) was used in the system.

The problem of the space antenna reflecting surface transforming can be solved by curtain deforming with the help of actuators. Power and data are supplied to the actuators by laser beam through the open channel from a semiconductor laser to a photoconverter located directly on the actuator [10]. So antenna weight can be reduced, function reliability can be increased, transformation of antenna shape in order to change radiation diagram can be controlled. A test sample integrating laser source and a photodetector module including four combined PV cells for modeling the power transmission through an open channel were developed in the Ioffe Institute. The photoconversion efficiency 26.3% (1 W) was achieved.

Photo-receiving device construction

Compact full-size photo-receiving device for simultaneously receiving power and data transmission through an open laser atmosphere channel was developed and manufactured in the presented work. The main criteria for the device design were construction simplicity and low cost.

The created photo-receiving device (Fig. 1) includes five photovoltaic converters (PVC) based on a silicon HJT structure (157×157 mm^2 each), and one low response time photodiode based on a lattice-matched InGaAs PIN semiconductor structure (wavelength 1.55 µm), located in the focus of a concentrator. The concentration system includes a conical reflecting secondary optics (hollow aluminum focon and eight mirrors) and Fresnel lens. Four PVCs are placed around the central PVC cell. The central PVC is transparent to information optical signal 1.55 µm wavelength. Low response time InGaAs photodiode with concentrator is located behind the central photoelectric converter. Centrosymmetric beam (for example Gaussian distributed) in Si photosensitivity spectral range falls to the photo-receiving panel: central and peripheral PVCs. Four peripheral PVCs have eight mirrors to reflect peripheral laser radiation to them and the intensity of peripheral radiation increases. Photocurrent values of central and peripheral PVCs align and all Si cells can be series connected without electrical losses to increase the photo-receiving panel efficiency. The spectral range for ‘power’ laser radiation conversion for Si photo-receiving device is 0.6—1 µm. Due to the human eye invisibility requirement and the presence of atmospheric transparency windows, it should be in the ranges of 0.85—0.9 µm or 0.95—1 µm. The wavelength of the information high frequency modulated radiation should be in the range of 1.3—1.6 µm due to the Si cell transmission spectra.

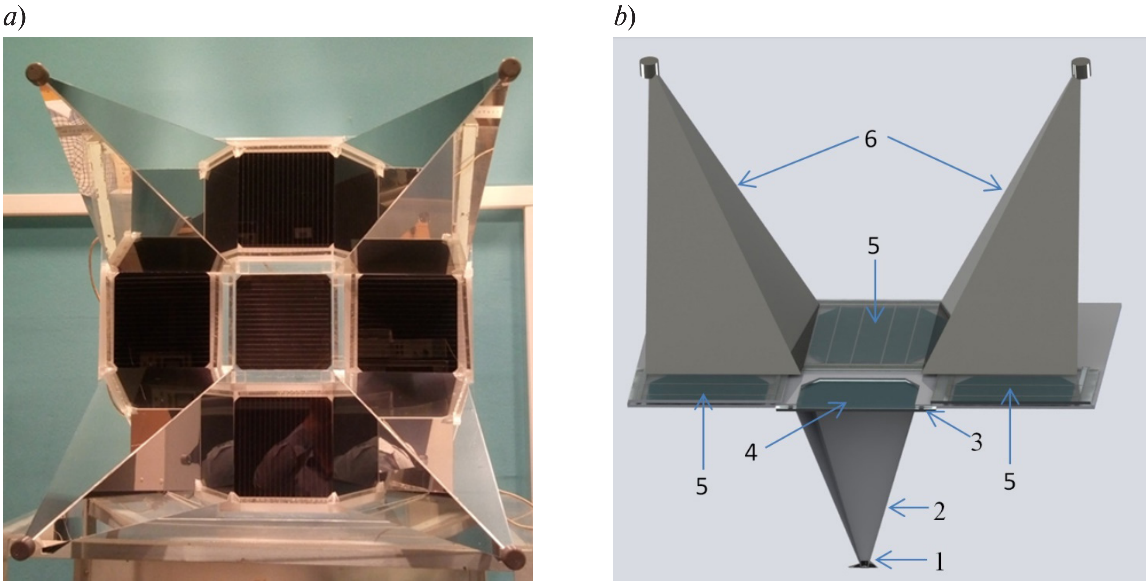

Fig. 1. Power-communicating photo-receiving device (*a*), sectional view (*b*).
InGaAs PIN photodiode *1*, hollow focon *2*, Fresnel Lens *3*, two-sided photosensitivity Si cell *4*, transparent to information optical signal, Si photovoltaic converters *5*, reflectors *6*

Experimental results

A comparative analysis of the Si cell transmission spectra and the low response time photodiode photosensitivity is shown in Fig. 2. Overlap of InGaAs PIN photodiode photosensitivity and the transmission spectra of Si PVCs is observed. It is necessary to protect the low response time photodiode from solar radiation, for example, by an interference filter. The complex shape of the PVCs transmission spectrum has two minima at about 0.12 μm and 0.14 μm, related to the multilayer construction of the central PVC cell. It includes the multilayer silicon HJT structure, the glass on the one side of silicon structure and a transparent laminating film on the other side.

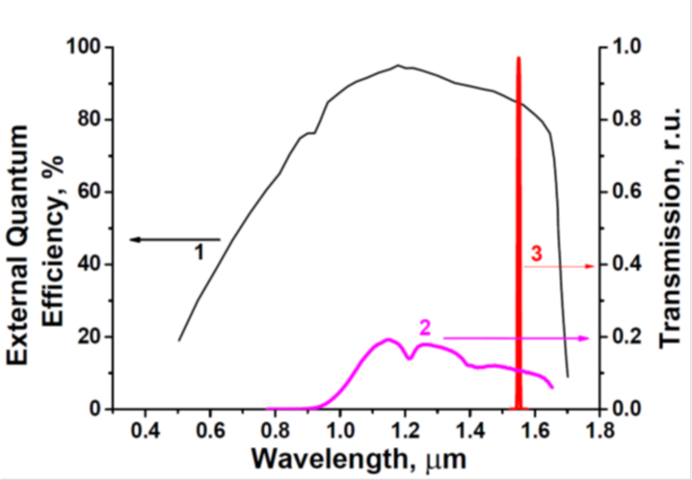

Fig. 2. External quantum efficiency of a low response time photodiode (*1*), the transmission spectra of a silicon solar cell (*2*), the transmission of an interference filter (*3*)

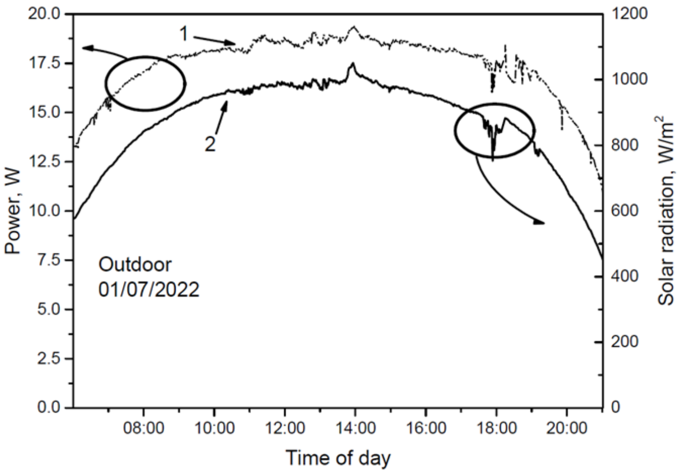

Fig. 3. Photoreceiving device power generation (*1*) of and daily solar radiation (*2*)

At the daytime, the photo-receiving device can generate additional electricity by converting solar radiation (Fig. 3).

Photo-receiving device was installed on the solar tracking system during the solar day. The generated power and the global solar irradiation were measured by photovoltaic monitoring complex [11] (generated power during the day is 270 W·h, all day solar irradiance is 12088 W·h/m^2).

Conclusion

The technical and organizational aspects for the photo-receiving device have been designed. Method of simultaneously registration of information high-frequency optical signal and powerful laser energy conversion is presented.

The main technical parameters of the developed photo-receiving device are as follows:

- electrical power is 80 W;
- data receiver cut-off frequency is 600 MHz;
- dimensions (LxWxH) are 570×614×600 mm.

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