Fotoelektrovara Si *p-n* sandūroje apšviestoje lazerio spinduliuote

Photovoltage across Si p-n junction exposed to laser radiation

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Electric energy generated by solar cells (SC) is most promising and environmentally friendly energy source. At the present time about 80% of worldwide SC are made from silicon. The efficiency of a single junction silicon solar cell produced in a scientific laboratory reaches 25,6% and is close to the theoretical limit of 33,3% [1]. Solar cell efficiency is limited by the efficient use only of photons having energy close to the forbidden energy gap. Photons with higher energies create electron-hole pairs, and the excess energy is transmitted to carriers, they become hot carriers. In an ideal single junction solar cell about 55% of incident solar radiation is lost due to the thermalization of hot carriers with lattice [2]. Ross and Nozik proposed the idea of hot carrier solar energy convertors in which photoexcited carriers could be extracted over a narrow range of energies at a rate faster than they lose the energy to the lattice [3]. Theoretical efficiency of such devices can be sufficiently high, up to 66%. Nevertheless, hot carriers must be taken into account during the study of photovoltage formation across a p-n junction under the sunlight illumination.

In this communication we present the results of experimental investigation of hot carriers' influence on the photoresponse formation across Si p-n junction illuminated by laser radiation of different wavelength.

The investigated p-n junction was produced by chemical vapor deposition of epitaxial p-type Si layer on n-type Si substrate. Electron density was 7×10^{15} cm^{-3}, and hole density was 5×10^{16} cm^{-3}.

Temporal analysis of the photovoltage U across the p-n junction induced by 25 ns-long 1489 nm pulsed laser radiation showed that it consists of two components:

$$U = U_f + U_{ph}. \quad (1)$$

Here U_f is the fast component with polarity corresponding to that of thermoelectromotive force of hot carriers [4], and U_{ph} is the slow component of opposite polarity; U_{ph} is caused by electron-hole pair generation. Investigations revealed that U_{ph} increases with the intensity of laser radiation following the square law. This fact indicates that electron-hole pair generation is determined by the two-photon absorption since the single laser photon energy is lower than the forbidden energy gap of silicon.

The dependencies U_f and U_{ph} on laser radiation wavelength are depicted in Fig. 1. It is seen that U_{ph} decreases with the wavelength increase, and at $\lambda > 2500$ nm the slow component of the photovoltage vanishes. Such behavior is associated with the diminution of two-photon absorption coefficient with wavelength [5]. At $\lambda > 2500$ nm the energy of two photons is lower than the forbidden energy gap of Si, and no generation of electron-hole pairs is observed.

The hot carrier thermoelectromotive force U_f also drops down when λ increases from 1489 nm to 1900 nm. However, at longer laser wavelengths, $\lambda > 1900$ nm, in contrast to U_{ph}, U_f does not tend to zero but even slightly increases. In this spectral range the hot carrier thermoelectromotive force is determined by the free electron and free hole absorption of the radiation.

As a result, the carrier heating reduces the efficiency of a solar cell as far as the polarity of the thermoelectromotive force of hot carriers is opposite to that of the classical photovoltage.

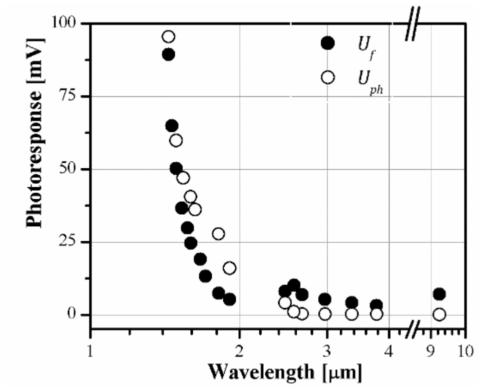

Fig.1. Spectral dependence of the hot carrier thermoelectromotive force U_f and the electron-hole pair generation-caused U_{ph} under laser illumination

Keywords: silicon, laser radiation, p-n junction, solar cell, hot carriers

References

[1] A. Polman, M. Knight, E.C. Garnett, B. Ehler, W.C. Sinke, Science **352**, aad4424 (2016).
[2] L.C. Hirst, N.J. Ekins-Daukes, Prog. Photovolt: Res. Appl. **19**, 286 (2011).
[3] R.T. Ross, A.J. Nozik, J. Appl. Phys. **53**, 3813 (1982).
[4] J. Gradauskas, E. Širmulis, S. Ašmontas, A. Sužiedėlis, Z. Dashevsky, V. Kasiyan, Acta Phys. Pol. A **119**, 273 (2011).
[5] A.D. Bristow, N. Rotenberg, H.M van Driel, Appl. Phys. Lett. **90**, 191104 (2007).