SPECTRAL PECULIARITIES OF HOT CARRIER PHENOMENON IN A SOLAR CELL

Ihor Zharchenko[1], Oleksandr Masalskyi[1,2] Jonas Gradauskas[1,2], Steponas Ašmontas[1], Algirdas Sužiedėlis[1], Aldis Šilėnas[1], Aurimas Čer. kus[1,3], Aleksej Rodin[4]

[1] Laboratory of Electronic Processes, Center for Physical Sciences and Technology, Lithuania
[2] Department of Physics, Vilnius Gediminas Technical University, Lithuania
[3] Department of Mechatronics, Robotics and Digital Manufacturing, Vilnius Gediminas Technical University, Lithuania
[4] Laboratory of Solid State Lasers, Center for Physical Sciences and Technology, Lithuania
ihor.zharchenko@ftmc.lt

!

According to the Shockley–Queisser theory, photons with energy lower than the forbidden bandgap of a material do not contribute to net photoresponse of a solar cell. Photons with energy higher than the bandgap participate in photoresponse formation [1].

The present work was initiated by the fact that photons with energy smaller than the bandgap can induce photovoltage across a p-n junction, the hot carrier photovoltage, and its polarity is opposite to the classical one [2]. Moreover, calculations show that the 10% share of the total absorbed incident solar light in GaAs belongs to the below bandgap photons, and it strongly depends on carrier concentration and thickness of the layer [3].

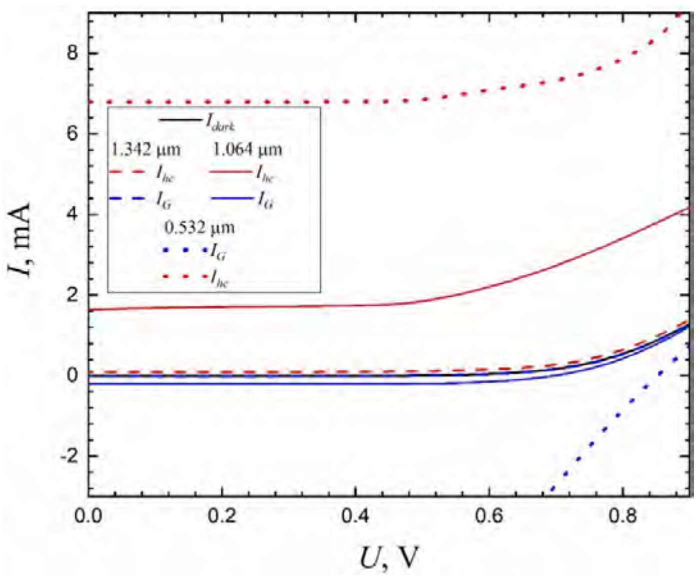

Fig.1. I-V characteristics of GaAs p-n junction under laser illumination of 0.4 MW/cm^2 intensity and wavelengths: 0.532 µm (dotted lines), 1.064 µm (solid lines) and 1.342 µm (dashed lines).

The LPE-grown GaAs p-n diodes (forbidden energy gap is 1.42 eV) were illuminated with pulsed laser irradiation of the same 0.4 MW/cm^2 intensity having different wavelengths of 0.532, 1.064 and 1.342 µm. The obtained results reveal several noteworthy points. First, the 1.342 µm-long photons (0.92 eV) mainly contribute to the hot carrier current and do not have enough energy to induce notable classical generation-caused photoresponse. Second, under the action of the 1.064 µm-long (1.16 eV) photons, the hot carrier photoresponse dominates over the classical photocurrent caused by the two-photon absorption since the extra energy left after the excitation of ordinary electron-hole pair, i.e., 0.9 eV, adds to the intraband absorption-caused carrier heating process. Third, even illumination of the diode with laser light of 0.532 µm wavelength (photon energy 2.32 eV is higher than the bandgap) shows, in contrast to the classical theory, that the hot carrier photoresponse is still present and quite marked; most probably it is raised by the excess energy (0.9 eV) left after the classical interband absorption which is much stronger than the two-photon absorption.

It was shown that negative hot carrier effect manifested itself in the p-n junction in both cases, below and above bandgap photons. Thus, the theoretical maximum efficiency of a single junction solar cells (Shockley–Queisser limit) needs revision by taking into account the contribution of the hot carrier phenomenon within the entire solar spectral range.

[1] W. Shockley, H. J. Queisser, Detailed Balance Limit of Efficiency of p-n Junction Solar Cells, J. of Appl. Phys. 32, 510-519 (1961).
[2] S. P. Ašmontas, J. Gradauskas, D. Šeliuta, Photoelectrical properties of nonuniform semiconductor under infrared laser radiation, Nonresonant Laser-Matter Interaction conference, Proc. SPIE 4423, 18-27 (2000).
[3] O. Masalskyi, J. Gradauskas, Pre-themalizational effect of hot carriers on photovoltage formation in a solar cell, Ukr. J. Phys. Opt. 23, 117-125 (2022).