

Karštųjų krūvininkų fotosrovė - papildomi saulės elementų nuostoliai

Hot carrier photocurrent as an additional loss in solar cells

Oleksandr Masalskyi^{1,2}, Vladyslav Kyshchun¹, Jonas Gradauskas^{1,2}, Steponas Ašmontas², Algirdas Sužiedėlis², Aurimas Čerškus^{1,2}, Aleksej Rodin², Ihor Zharchenko^{1,2}, Edmundas Širmulis², Kazimieras Petrauskas²

¹Vilnius Gediminas Technical University, Saulėtekio al. 11, LT-10223 Vilnius

²Center for Physical Sciences and Technology, Saulėtekio al. 3, LT-10257 Vilnius
oleksandr.masalskyi@vilniustech.lt

Reducing the difference between the theoretically predicted maximum efficiency of solar cells and the lower efficiencies achieved remains one of the fundamental challenges in photovoltaic research. Addressing this gap requires not only advancements in material science and fabrication technologies but also the introduction of novel physical concepts and mechanisms.

Hot carriers (HCs) are one of the modern candidates for solving this problem. Light can heat the carriers in two cases. First, if the photon energy $h\nu$ is lower than the bandgap E_g , heating results from the intraband absorption. Such free carrier absorption is not spectrally selective and follows the classical Drude–Zener law. Another possibility for creating hot carriers is the interband absorption of photons with energy $h\nu > E_g$; the excess energy is given to the generated electron or hole [1]. Regardless of the type of excitation, HCs transfer their energy to the lattice, a process characterized by the energy relaxation time which is typically on a picosecond scale.

In this work, we review formation of hot carrier photocurrent across inorganic Si [2] (Fig. 1) and GaAs, and organic-inorganic hybrid perovskite solar cells (Fig. 2) [3].

Short nanosecond-long laser pulses of various photon energies used for the excitation enabled to reveal existence of photocurrent having polarity opposite to the classical generation-caused photocurrent. This “opposing” photocurrent was detected under the excitation of both high and low energy photons. It was fast, it followed laser pulse shape. Deep analysis of its features like polarity, response speed, independence of excitation wavelength, rise with forward bias voltage, - allowed definitely attributing this photocurrent to the HC effect.

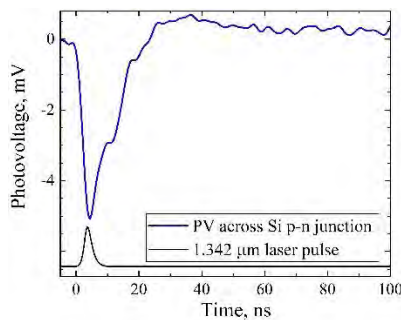


Fig.1. Photoresponse across Si solar cell at zero bias under excitation of 1.342 μm laser pulse ($h\nu < E_g$).

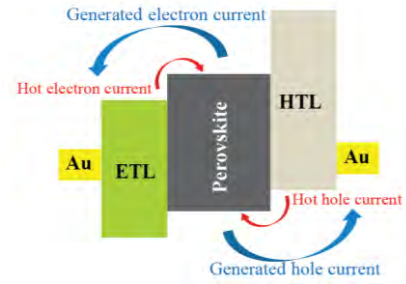


Fig.2. Schematic formation of generation-induced photocurrent (blue arrows) and hot carrier photocurrent (red arrows) across a perovskite solar cell.

We also show, that, in case of $h\nu < E_g$, the carriers can be heated not only by the intraband absorption, but also, depending on the excitation intensity, by the excess energy left after the two-photon absorption-caused carrier generation, just like it takes place in the case of $h\nu > E_g$.

Four points to conclude:

First, hot carrier photocurrent is present regardless of solar cell material and excitation wavelength.

Second, Hot carrier photocurrent flows in the direction opposite to the generation-caused current.

Third, the maximum power point of a solar cell operation is within the region of the forward bias, which is advantageous for the flow of the HC photocurrent.

Fourth, the hot carrier photocurrent should be admitted as a new intrinsic fundamental loss, pre-thermalization loss, which opposes the approach of the realized solar cell efficiency to the theoretically predicted one.

Keywords: hot carriers, solar cell, Si, GaAs, organic-inorganic hybrid perovskite, intrinsic loss, photocurrent.

References

- [1] I. Zharchenko, J. Gradauskas, O. Masalskyi, and A. Rodin, Opto-Electron. Rev. **32**, e150181 (2024).
- [2] J. Gradauskas, O. Masalskyi, S. Asmontas, A. Sužiedelis, A. Rodin, and I. Zharchenko, Ukr. J. Phys. Opt. **25** (1), 01106 (2024).
- [3] M. Mujahid, A. Čerškus, J. Gradauskas, A. Grigučevičienė, R. Giraitis, K. Leinartas, A. Lučun, K. Petrauskas, A. Selskis, A. Sužiedėlis, A. Šilėnas, E. Širmulis, and S. Ašmontas, Mater. **18**, 85 (2025).