Laser Induced Hot Carrier Photovoltage Across p-n Junction

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Hot carriers are free carriers with energy higher than the average one. The Shockley-Queisser theory [1] does not take into account the direct impact of the hot carriers into the efficiency of a p-n junction solar cell.

In our communication we show that the laser light-heated carriers can cause the hot carrier photovoltage which opposes the classical photovoltage across a p-n junction. GaAs p-n-junction was illuminated with 20 ns-long laser pulses of 1.06 µm wavelength and pulse power 10 MW/cm^2. Short enough pulse and appropriate wavelength opened a way to reveal that the induced photovoltage consists of three components. The first one is the classical electron-hole pair generation-caused U_G, it is relatively slow. The second component is the hot carrier photovoltage U_{HC}. The third, thermal, component U_T is caused by the thermalisation of hot carriers and subsequent heating of the lattice. We propose a model of a p–n junction as a first-order LTI system allowing to reveal the individual input of each component into the total photovoltage signal. As Fig. 1 shows, the calculated results agree well with the experimental data [2].

The hot carrier photocurrent I_{HC} flows in direction opposite to I_G and increases as the p-n junction barrier is lowered by the bias voltage (Fig. 2). Under certain conditions, the magnitude of I_{HC} can be even bigger than the generation-caused photocurrent.

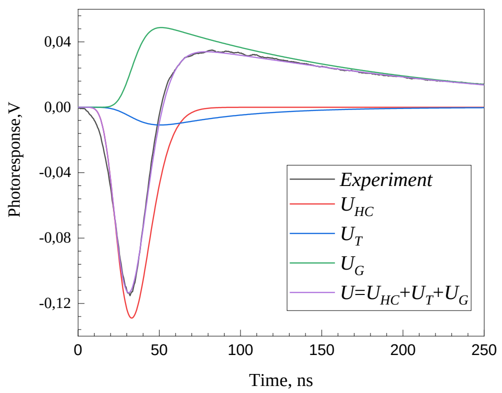

Fig.1. Experimental photoresponse across GaAs p-n junction (black line) and modelled its components.

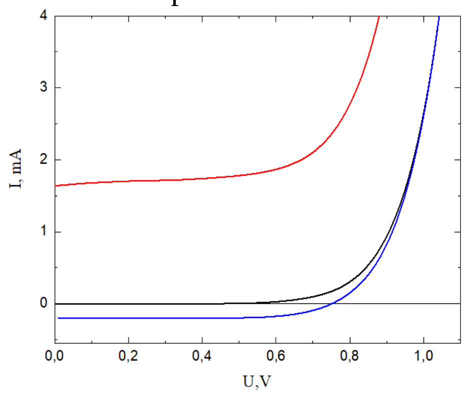

Fig.2. I-V curves of GaAs p-n junction in the dark (black line) and under pulsed laser illumination: blue line is I_G, and red line represents I_{HC}.

As for application, the direct influence of the hot carrier photovoltage can be the reason of still experimentally unattainable Shockley–Queisser limit, and it should be revised by taking into account this photovoltage of opposite polarity. Also, maximum reduction of the contribution of the hot carrier photovoltage will boost the efficiency of a p-n junction solar cell. The work was in part supported by the Research Council of Lithuania (grant No. 01.2.2-LMT-K-718-01-0050).

[1] Shockley W., Queisser H., J. Appl. Phys. 32, 510–519, (1961).
[2] Gradauskas J., et al., Appl. Sci., 10, 7483, (2020).