Tiesioginė karštųjų krūvininkų įtaka saulės elemento su p-n sandūra veikimui

Direct impact of hot carriers on the operation of a p-n junction solar cell

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The Shockley-Queisser theory puts limits on efficiency of a single-junction solar cell [1]. It assumes that only photons having energy close to a semiconductor forbidden energy gap are used effectively in the formation of an electrical output signal. Residual extra energy of the high energy photons not used for the electron-hole generation is scored up only through the process of carrier thermalization, i.e. through the lattice heating, and this way influencing solar cell efficiency. Low energy photons are assumed to be not absorbed at all.

Our investigation is initiated by our confidence that photons having energy larger than the band gap as well as photons having energy smaller than the forbidden energy gap need to be accounted through the hot carrier phenomena participating in the photoresponse formation before the lattice heating.

In this work, we proceed experimental results demonstrating direct impact of the hot carriers on the operation of a single-junction solar cell. As objects of investigation, GaAs and Si p-n-junction were illuminated with ns-long laser pulses of 1.06 μm and 1.34 μm wavelength at different intensities (see Fig.1).

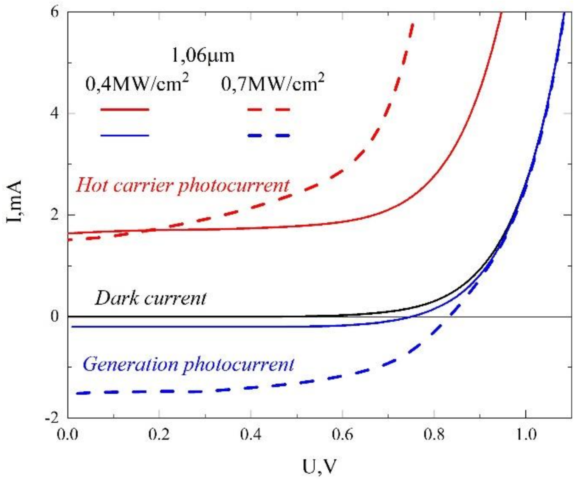

Figure 1. I-V characteristics of GaAs p-n junction in the dark (black line) and under pulsed 1.06 μm laser illumination: blue lines stand for photocurrent caused by carrier pair generation, and red ones represent the hot carrier photocurrent at different laser intensities (0.4 MW/cm^2, solid lines; and 0.7 MW/cm^2, dotted lines).

In addition, we state that the photoresponse signal consists of three components, and we propose a model of p-n junction as a first-order linear time-invariant (LTI) system

$$\tau \frac{dU}{dt} + U = \bar{U}(t), \quad (1)$$

where τ represents the exponential decay constant typical of each component, $U = U(t)$ is a photovoltage function of time, and the forcing function $\bar{U}(t)$ depends on the laser pulse and on the physical phenomenon giving rise to a particular photoresponse component. The model allows to reveal the individual input of three components on photoresponse signal. The first, U_G, is a relatively slow component caused by a classical electron-hole pair generation. The second one, U_{HC}, is fast, follows the laser pulse shape and has opposite polarity; this is an inherent feature of the hot carrier photovoltage. The third one, U_T, has the same polarity as U_{HC} but is much slower; it is attributed to the thermoelectric electromotive force caused by the junction heating [2].

As for conclusion, photovoltage across a p-n junction consists of three simultaneous components arising due to electron-hole pair generation, hot carrier effect and semiconductor lattice heating after the thermalization. We have developed a model that allows revealing the individual input of each component. The hot carrier photovoltage might be the reason for still experimentally unattainable Shockley–Queisser limit, and we intend to initiate the PV community to revise the theory by taking into account the direct negative impact of hot carriers. As for application, the minimized hot carrier effect will raise the efficiency of a single-junction solar cell.

Keywords: hot carriers, p-n junction, silicon, GaAs, solar cell, Shockley-Queisser theory.

References

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