HOT CARRIER EVIDENCE IN A SOLAR CELL

Jonas Gradauskas[1,2], Steponas Ašmontas[1], Algirdas Sužiedėlis[1], Aldis Šilėnas[1], Aurimas Čerškus[1,2], Viktoras Vaičikauskas[1], Ovidijus Žalys[1], Oleksandr Masalskyi[2]

[1]*Center for Physical Sciences and Technology, Vilnius, Lithuania*
[2]*Vilnius Gediminas Technical University, Vilnius, Lithuania*

According to the Shockley-Queissertheory, only photons with energy $h\nu$ close to a semiconductor forbidden energy gap E_g are used effectively for electrical power generation. Lower energy photons are assumed as not absorbed at all, while the residual extra energy of higher energy photons is reckoned in only through the process of carrier thermalization.

On the other hand, free carriers can be heated by the infrared radiation as well as by the photons supplying the mentioned extra residual energy. The intraband light absorption has been demonstrated to rise a hot carrier photoemf across a semiconductor l-h [1, 2] and p-n [3, 4] potential barrier illuminated with a CO_2 laser ($h\nu$ = 117 meV) radiation. The polarity of this emf is opposite to that of the classical carrier generation-induced one.

In this presentation, we show experimental evidence of direct hot carrier influence on net photovoltage formation across a semiconductor p-n junction. As an object of investigation, GaAs (E_g = 1.42 eV) p-njunction was illuminated with 25 ns-long laser pulses of 1.06 μm wavelength ($h\nu$ = 1.17 eV). Short enough pulse and proper value ofphoton energy opened possibility to observe simultaneous rise of three photoresponse components, as an extension of our previously declared two ones [5]. The first component, U_G, is caused by an electron-hole pair generation due to two-photon absorptionand is relatively slow. 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 emf caused by the carrier thermalization. See Fig. 1. Numerical modelling let us distinguish each component. As the research reveals, each component has its characteristic dependency on time with typical time-constants, laser intensity, applied bias voltage, sample temperature.Fig. 2 shows that U_{hc} decreases with reverse bias but still holds the linear law of dependence. Such behavior confirms its hot carrier-based origin. U_G behaves in different manner. Fig. 3 schematically explains these courses. At zero bias voltage, the junction potential barrier

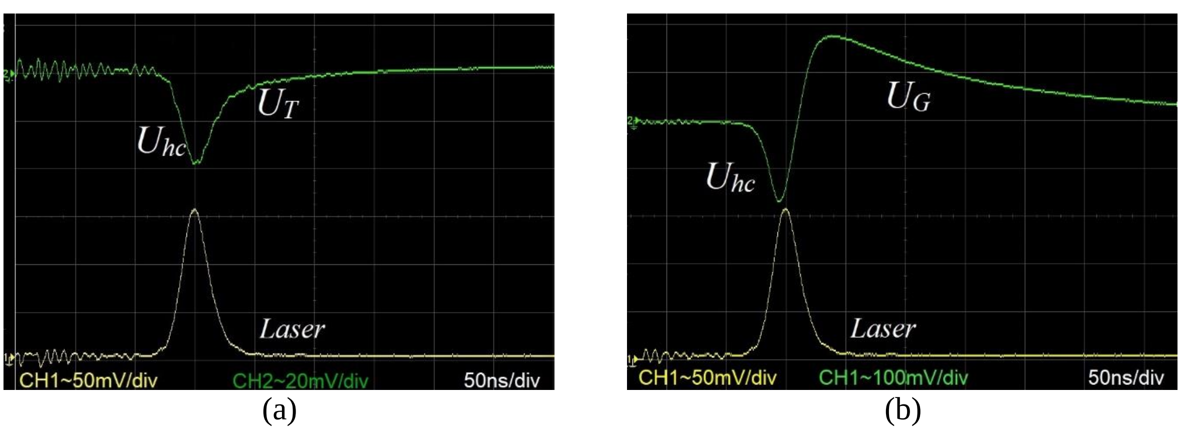

Fig. 1. Oscilloscope traces of photoresponse across GaAs p-n junction at low (a) and high (b) excitation level with indications of respective components. No bias voltage is applied.

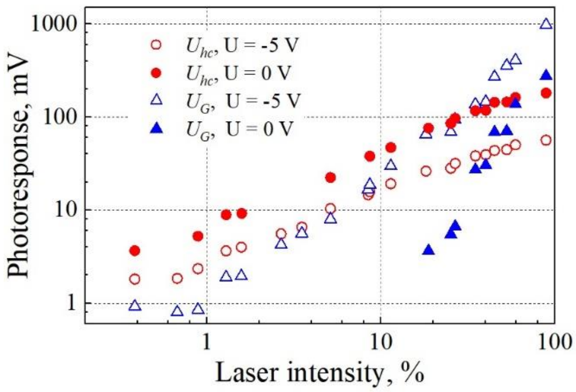

Fig. 2. Dependence of hot carrier component U_{hc} (red dots) and generation-caused component U_G(blue dots) induced across GaAs p-n junction on 1.06 μm laser intensity at zero bias (solid dots) and -5 V of reverse bias voltage (open dots).

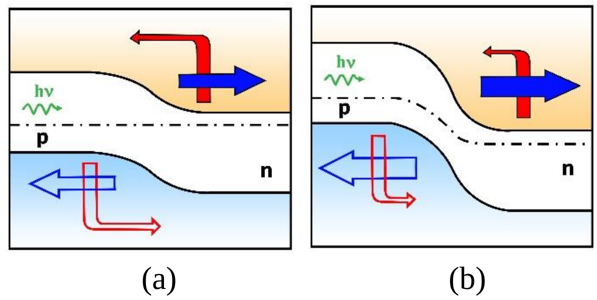

Fig. 3. Schematic description of hot carrier (red arrows) and generation-induced (blue arrows) photocurrents as zero (a) and reverse (b) bias voltage is applied. Hollow arrows stand for flows of holes.

islow enough to be overcome by the hot carriers. At reverse voltage, the increased barrier opposes to the flow of hot carriers. At forward bias (not shown in the figures), lower barrier is favorable for the hot carrier current.

As for conclusion, we show the photoresponse across a p-n junction is composed of three components. Their dependence on applied bias voltage and temperature gives evidence of the presence of hot carriers' emf and their injurious direct influence on the efficiency of a solar cell, i.e., not only through the thermalization. Thus, our findings open two ways for consideration. One, to boost the efficiency, carrier heating in a solar cell must be minimized by means of stronger infrared reflection, properly chosen operation temperature and barrier height (and width), non-heating effect of the absorbed high energy photons, etc. Another, involvement of the hot carrier emf *direct* input may possibly make lower the theoretical still "unattainable" Shockley-Queisser limit.

1. S. Ašmontas, E. Maldutis, E. Širmulis. CO_2 laser radiation detection by carrier heating in inhomogeneous semiconductors.*Int. J. Optoelectron.***3(3)** 263-266 (1988).
2. S. Ašmontas, J. Gradauskas, D. Seliuta, E. Širmulis. Photoresponsein nonuniform semiconductor junctions under infrared laser excitation.*Proc. SPIE* **3890**, 125-131 (1998).
3. A.V. Andrianov, P.M. Valov, V.L. Sukhanov, V.U. Tuchkevich, N.M. Smidt. Photoeffect on silicon p-n junction under intraband carriers heating by light. *Phys. Techn. Poluprovodn.***14**, 859–864 (1980).
4. S. Ašmontas, J. Gradauskas, D. Seliuta, E. Širmulis. Photoelectric properties of nonuniform semiconductor under infrared laser radiation. *Proc. SPIE***4423**, 18–27 (2001).
5. S. Ašmontas, J. Gradauskas, A. Sužiedėlis, A. Šilėnas, E. Širmulis, V. Švedas, V. Vaičikauskas, O. Žalys. Hot carrier impact on photovoltage formation in solar cells.*Appl. Phys. Lett.***113**, 071103/1-3 (2018).