1947

Pre-thermalizational Impact of Hot Carriers on Photovoltage Formation in a Single Junction Solar Cell

Jonas Gradauskas*[1, 2], Steponas Ašmontas[1], Oleksandr Masalskyi[2], Algirdas Sužiedelis[1], Aldis Šilenas[1], Aurimas Cerškus[1, 2], Aleksej Rodin[1], Ihor Zharchenko[1]

[1]Center for Physical Sciences and Technology, Lithuania, [2]VGTU, Lithuania

Visual

Topic 2: Evolving and Emerging Technologies: Tandems; Thin Film absorbers; III-V; New Materials and Concepts; Advanced Modelling/2.5 New Materials, Devices and Conversion Concepts

SUMMARY OF THE ABSTRACT

General look at the evolution of realized energy conversion efficiencies reported by the National Renewable Energy Laboratory since 1976 gives an impression that the efficiency of the classical single crystal silicon solar cell gets saturated. Marked latest incremental improvement in efficiency can be noted only with application of novel cell design like PERC and PERL structures in nineties, or later with introduction of silicon heterojunctions. The record level of 26.1% is still far below the theoretical Shockley-Queisser limit of about 32%. The theory assumes the low energy photons (below the bandgap E_g) to be not absorbed at all, while the residual energy of the high energy photons is accounted only via the process of lattice heating after the hot carrier thermalization.

In this presentation, we proceed our investigation of the hot carrier impact on photovoltage formation across a p-n junction cell [1-3]. As for silicon, calculations reveal that 19.1% of the total AM 1.5 G solar radiation can be supplied to heat carriers by the low energy photons ($h\nu < E_g$), and 33.6% of it – by the high energy photons ($h\nu > E_g$). Corresponding values of 33.0% and 21.7% are obtained in case of GaAs. Such percentage encourages for the experimental search of the hot carrier photovoltage (HCPV).

We show that before the thermalization, i.e. before they give their extra energy to the lattice, the hot carriers form photovoltage of polarity opposite to the generation-caused one. It should be noted that all the photons, both low and high energy, show their participation in the formation of HCPV (Fig. 1, processes 2 and 3, respectively).

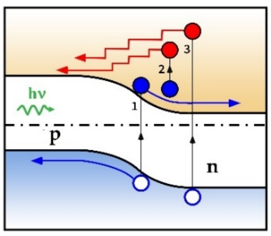

Fig. 1. Schematic formation of generation-induced photovoltage (blue arrows) and **hot carrier photovoltage** (red arrows) across a p–n junction; stepped red arrows indicate diffusion of hot carriers over the barrier and their simultaneous gradual energy loss (thermalization).

When Si and GaAs p-n junctions were exposed to nanosecond-long 1.06 μm and 1.34 μm pulsed laser light, the photoresponsecomponent of opposite polarity was observed in addition to the classical generation-induced photovoltage (Fig. 1, process 1) under certain experimental conditions. All its features: polarity, response speed, linear dependence on light intensity, its rise with forward bias voltage (lower potential barrier), spectral dependence, - stand for the proof that this component is the HCPV.

1. S. Ašmontas, J. Gradauskas, A. Sužiedėlis, A. Šilėnas, E. Širmulis, V. Švedas, V. Vaičikauskas, V. Vaičiūnas, O. Žalys, and V. Kostylyov. Photovoltage formation across Si p-n junction exposed to laser radiation.*Mater. Sci.-Poland* **36(2)**, 337-340 (2018).
2. 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).
3. J. Gradauskas, S. Ašmontas, A. Sužiedėlis, A. Šilėnas, V. Vaičikauskas, A. Čerškus, E. Širmulis, O. Žalys and O. Masalskyi. Influence of hot carrier and thermal components on photovoltage formation across across the p–n junction.*Appl. Sci.* **10**, 7483/1-8 (2020).

EXPLANATORY PAGE

AIM AND APPROACH

The aim of this presentation is to convince the Photovoltaic Community that hot carriers, prior to their thermalization, do participate in the total photovoltage formation and make direct harm to the efficiency of a p-n junction solar cell. In our research, we propose a novel approach to the understanding of the photovoltage which is a composition of three components resulting from three phenomena: carrier generation, carrier heating and lattice heating. Moreover, we remove the spectral limitation of the Shockley-Queisser theory from the infrared range.

SCIENTIFIC INNOVATION AND RELEVANCE

Both theoretical considerations and experimental proof of the presence of the hot carrier photovoltage are presented. This HCPV has polarity opposite to the generation-induced component and thus negatively influences the net functioning of a p-n junction solar cell.

RESULTS AND CONCLUSIONS

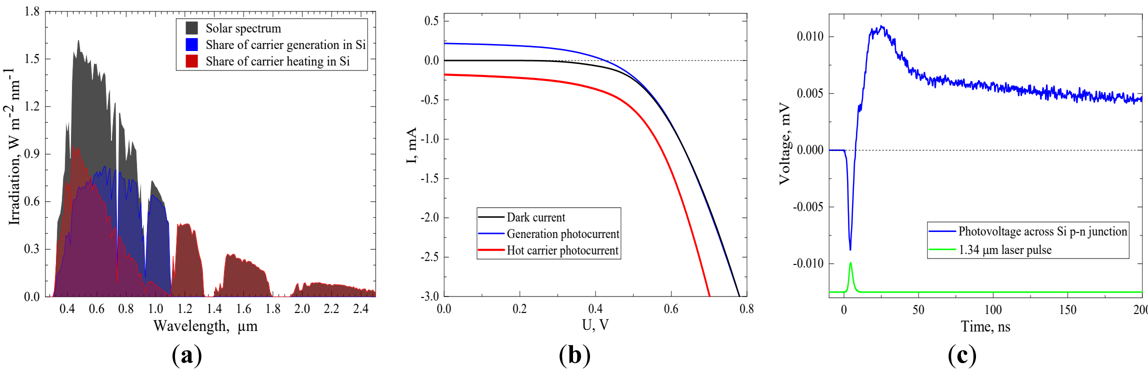

Fig. 2. a) Solar spectrum (grey), its share of carrier generation (blue) and its part of potential carrier heating in silicon (red). **b)** I-V characteristic of Si solar cell exposed to 1.34 µm laser light (hν = 0.93 eV < E_g = 1.12 eV): black – in dark, blue – generation, red – hot carrier photocurrent. **c)** Photovoltage (blue) across Si p-n junction: negative component stands for HCPV, and positive one corresponds to the generation; 1.34 mm laser pulse (green) is added as a guide to the eye.

As Fig. 2a shows, 52.7% of solar radiation can be potentially utilized for free carrier heating in Si (54.7% in GaAs). When the light photon energy is close to the band gap, two components of opposite polarity can be directly detected in the p-n junction photoresponse. The fast one repeats the light pulse and is undoubtedly attributed to the HCPV, while the opposite long-lasting one stands for carrier generation (Fig. 2c). Forward bias works in favor of the hot carrier photocurrent and suppresses the generation current (Fig. 2b); it is one of the proofs of the hot carrier effect.

Three points are to be concluded. First, hot carrier photovoltage is present at the formation of the photoresponse across a p-n junction. Second, maximum minimization of the HCPV may raise the efficiency of a single-junction solar cell. Third, if the Shockley–Queisser theory were revised by taking into account the direct negative impact of the hot carriers, the achieved practical solar cell efficiency will be closer to the lowered theoretical limit.