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Modelling of photoresponse components induced by laser pulse across a p-n junction

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Summary: The photoresponse signal induced by 1.06 μm laser pulse across a Gals p-n junction is shown to be composed of three pronounced components resulting from hot carrier, heating lattice, and two-photon absorption phenomena. The first one is fast and has polarity of thermoelectromotive force of hot carriers. The second one has the same polarity, is slower, and is caused by the junction heating. The third one, respectively, is the classical electron-hole pair generation-induced photovoltage with polarity opposite to that of the first two. Good agreement between experimental and calculated results is achieved. The proposed model enables revealing contribution of each component to the net magnitude of the photoresponse, and can open the way in reducing negative impact of hot carriers into photovoltage of a solar cell.

Keywords: Photovoltage, hot carriers, p-n junction, laser radiation, solar cell, GaAs.

1. Introduction

Renewable energy such as the one generated by solar cells is the most promising and environmentally friendly energy. Reduce of the production price of a solar cell and increase of its conversion efficiency will make photovoltaic energy more profit-making. Conversion efficiency of a single p-n junction semiconductor solar cell is fundamentally constrained by the Shockley-Queisser limit since only light photons having energy close to the forbidden energy gap are effectively used [1].

When photon energy is larger than semiconductor forbidden energy gap E_g, the illumination leads to electron-hole pair generation, and an ordinary photovoltage arises across a p–n junction due to separation of electrons and holes in the internal electric field of the junction. Extra photon energy left after the pair generation is used of no avail for the lattice heating. The Shockley-Queisser theory assumes that lower energy photons are not absorbed at all. However, it was shown that when the photon energy is lower than the forbidden energy gap, the intraband free carrier absorption leads to carrier heating. As a result, hot carrier photovoltage is induced across a potential barrier [2].

In this communication, we reveal simultaneous coexistence of the three photoresponse components induced by pulsed laser radiation across a GaAs p-n junction.

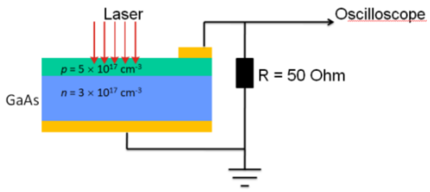

Fig. 1. Schematic of the sample and measurement circuit.

2. Experimental

The investigated GaAs p-n junctions (Fig.1) were fabricated by liquid phase epitaxy-grown 5 μm-thick p-type layer (hole density 5×10^{17} cm^{-3}) on n-type substrate with electron density 3×10^{17} cm^{-3}.

For excitation, Nd:YAG laser with wavelength 1.06 μm, pulse duration 25 ns, repetition rate 50 Hz, and maximum pulse power 1.6×10^4 W was used. Measurement scheme is presented in Fig. 1. Temporal behavior of the photoresponse and laser pulse shape were recorded by digital storage oscilloscope Agilent Technologies DSO6102A. All the measurements were carried out at room temperature.

3. Results and discussion

Fig. 2 presents temporal profile of the photoresponse across the GaAs p–n junction induced

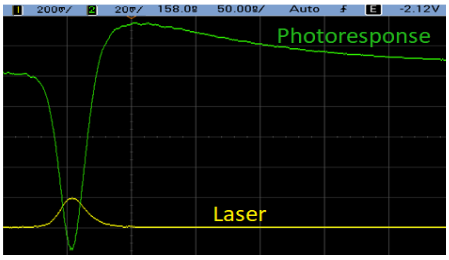

Fig. 2. Oscilloscope traces of photoresponse (green) across GaAs p-n junction and laser pulse (yellow).

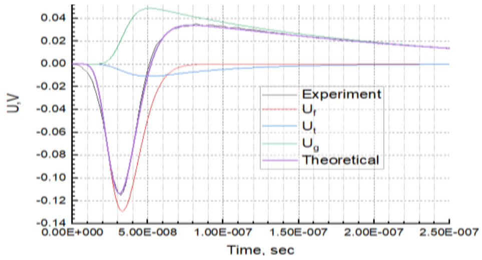

Fig. 3. Experimantal photoresponse across GaAs p-n junction (black) and calculated its components.

by the laser pulse at moderate excitation level (20% of maximum value). Obviously, the response consists of at least two components of opposite polarity.

The laser photon energy is less than GaAs forbidden energy gap, 1.17 eV and 1.42 eV, respectively. Therefore, our model assumes that the photoresponse across the GaAs p–n junction can be expressed as

$$U(t) = U_f(t) + U_t(t) + U_G(t), \qquad (1)$$

where $U_f(t)$ is the hot carrier emf, $U_t(t)$ is the lattice heating component resulting from thermalization of hot carriers, and $U_G(t)$ is electron-hole pair generation based component arising due to two photon absorption [3]. The polarities of the first two components and the third one are opposite.

Temporal analysis of the photoresponse was carried out to separate the input of each component. Time-dependence of the laser pulse intensity can be properly approximated as

$$I(t) = I_m \left(\frac{t}{\tau_p} \right)^{10} \exp\left[10 \left(1 - \frac{t}{\tau_p} \right) \right], \qquad (2)$$

where I_m is the peak intensity and τ_p is the laser rise-time. The hot carrier component $U_f(t)$ can be expressed as

$$U_f(t) = I(t) \cdot K_f, \qquad (3)$$

where K_f is the amplification coefficient of hot carrier emf. The lattice heating component $U_t(t)$ attributed to the thermoelectric emf can be found by solving the differential equation

$$\frac{dU_t(t)}{dt} = \frac{\overline{U}_t(t) - U_t(t)}{\tau_t}, \qquad (4)$$

where τ_t is the thermalization time constant, and the forcing function is

$$\overline{U}_t(t) = I(t) \cdot K_t, \qquad (5)$$

where K_t is the amplification coefficient of the thermoelectric emf. The two-photon excitation caused component of the photoresponse, $U_t(t)$, is found from

$$\frac{dU_G(t)}{dt} = \frac{\overline{U}_G(t) - U_t(t)}{\tau_G}, \qquad (6)$$

where τ_G is the characterist of decay time of $U_G(t)$ and

$$\overline{U}_G(t) = I^2(t) \cdot K_G, \qquad (7)$$

where K_G as the amplification coefficient.

The values of all time constants were taken from the experiment. Fig.3 shows influence of all three components on photoresponse and good matching between experimental and theoretical photoresponses.

The first component, U_f, has polarity of thermoelectromotive force of hot carriers. The second one, U_t, also has the same polarity. The third component, U_G, is a classical carrier pair generation caused photovoltage with polarity opposite to the two others.

4.Conclusions

The proposed model of detection separate photoresponse components agrees well with the experimental results. Thus, it enables purifying individual input of each component and opens possibility to change their contribution into the net.

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