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THE INFLUENCE OF THE SPECTRUM AND THE LEVEL OF ILLUMINATION ON THE LIFETIME OF CHARGE CARRIERS IN CIGS SOLAR CELLS

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Abstract: The lifetime of non-equilibrium photo generated charge carriers in the thin-film copper indium gallium selenide CIGS-based solar cell was determined under illumination with monochromatic radiation of different wavelengths ($\lambda \approx 395$ nm, 460 nm, 630 nm, 900 nm). It was found that the lifetime of nonequilibrium charge carriers generated depends on the absorption coefficient and radiation intensity.

Keywords: CIGS, solar cell, lifetime, generated charge carriers, monochromatic radiation, open circuit voltage, recombination processes, defect states.

An investigation of the relaxation characteristics of solar cells, such as attenuation of the open circuit voltage ($V_{oc}$) when irradiated with intermittent light, makes it possible to establish the mechanism of photogeneration of non-equilibrium photo generated charge carriers and their recombination processes. The lifetime of non-equilibrium photo generated charge carriers, provided that there are no other external factors, is determined by the relation (1) [1]:

$$\frac{d\Delta n}{dt} = \frac{\Delta n}{\tau} \tag{1},$$

where $\Delta n$ is the concentration of photogenerated charge carriers, $\tau$ is the relaxation time or lifetime of the photo generated charge carriers.

The solution of equation (1) has the following form (2) [1]:

$$\Delta n = \Delta n(o) \times \exp\left(-\frac{t}{\tau}\right) \tag{2},$$

$\Delta n(o)$ is the stationary maximum value of the photo generated charge carriers. To determine $\tau$, photo generated charge carriers, the decay time from $\Delta n(o)$ - to the level of $\Delta n(0)/e$ or $\Delta n(0)/2.72$ is determined.

Fig. 1 and 2 shows the experimental results of the dependence of $\tau$ on the value of $V_{oc}$, for solar cells based on a thin-film CIGS layer [2,3], when illuminated with monochromatic radiation in the ultraviolet (UV) range with a maximum at a wavelength of $\lambda \approx 387$ nm ($hv \approx 3.2$ eV), blue range with a maximum at a wavelength of $\lambda \approx 460$ nm ($hv \approx 2.7$ eV), a red range with a maximum at a wavelength of $\lambda \approx 630$ nm ($hv \approx 2.0$ eV) and infrared radiation with a maximum at a wavelength of $\lambda \approx 900$ nm ($hv \approx 1.38$ eV). The experiments were carried out in the photovoltaic mode - the $V_{oc}$ mode, and the value of $\tau$ was determined from the relaxation curve. $\tau$ was estimated using relation (2). Since the photosensitive active base of solar cells based on the CIGS thin-film layer is p-type, $\tau$ means the lifetime of photo generated no equilibrium electrons. It follows from the
experimental results that $\tau$ of the photo generated no equilibrium electrons in the n-CdS / p-CIGS heterojunction, in the case of UV illumination, the value of $\tau$ decreases with increasing $V_{oc}$, when $V_{oc}$ changes from 100 mV to 300 mV, $\tau$ decreases from 345 to 330 $\mu$sec. In the case of illumination with blue light, the value of $\tau$ does not change when $V_{oc}$ changes from 100 mV to 200 mV and is larger than when illuminated with UV light. As the value of $V_{oc}$ increases, from 200 mV to 300 mV, $\tau$ decreases from 400 to 330 $\mu$sec. Red illumination gives an increase in $\tau$ with increasing $V_{oc}$. The values of $\tau$ gradually increase from 350 to 460 $\mu$sec, with an increase in $V_{oc}$ from 100 to 300 mV. When illuminated with IR radiation, $\tau$ does not change and has a value of $\approx 400$ $\mu$sec, when $V_{oc}$ changes from 100 to 200 mV, then $\tau$ increases to 460 $\mu$sec when $V_{oc}$ changes from 200 to 300 mV.

UV radiation (Fig. 1) is absorbed on the surface of the n-CdS layer and a few photo generated charge carriers reach the heterojunction, as in the case of the blue light, which is absorbed deeper in the n-CdS and p-CIGS layers [4]. Recombination centers are mainly located on the surface of the n-CdS layer [5], as a result of this fact, there are fewer $\tau$ no equilibrium carriers when illuminated with UV radiation than in the case of blue light illumination. A decrease in $\tau$ with increasing $V_{oc}$ is associated with a change in the quasi-Fermi level with increasing $V_{oc}$; then the defective states are recharged, as a result of which the recombination states become active and decrease $\tau$ of no equilibrium charge carriers.

Fig. 1. Dependences of $\tau$ on $V_{oc}$, for a solar cell based on a thin-film CIGS layer, with UV illumination $\lambda \approx 395$ nm ($hv \approx 3.05$ eV) by radiation and blue light $\lambda \approx 460$ nm ($hv \approx 2.7$ eV).

Red light (Fig. 2) is absorbed at the n-CdS / p-CIGS heterointerface and almost all photo generated charge carriers reach the heterojunction. IR radiation is absorbed deeper in the p-CIGS layer. Since the concentration of recombination centers of the heterointerface of n-CdS / p-CIGS is higher than that of p-CIGS, due to which $\tau$ no equilibrium carriers are larger when illuminated with IR radiation than in the case of red light. An increase in $\tau$ with increasing $V_{oc}$ is also associated with a change in the quasi Fermi level with increasing $V_{oc}$, when charge exchange occurs for defective states, as a result of which the recombination states become less active and increase the lifetime of no equilibrium carriers. An increase in $\tau$ with increasing $V_{oc}$ is also associated with a change in the
Fig. 2. Dependence of $\tau$ on $V_{oc}$ for a solar cell based on a thin-film CIGS layer, when illuminated with red light, $\lambda \approx 630$ nm ($h\nu \approx 2.0$ eV) and IR radiation $\lambda \approx 900$ nm ($h\nu \approx 1.38$ eV).

The quasi Fermi level with increasing $V_{oc}$, when charge exchange occurs for defective states, as a result of which the recombination states become less active and increase the lifetime of nonequilibrium carriers.

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