EFFECT OF DEEP TRAPS ON HOLE PHOTOCURRENT SOLAR CELLS BASED ON HYDROGENATED AMORPHOUS SILICON

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The use of amorphous hydrogenated silicon $a-Si:H$ to create barrier devices for microelectronics seems to be of many savers, especially in the manufacture of photovoltaic cells.

Recently, interest in the creation of solar cells on the base of μc-$Si:H$ based devices has increased. The reason for this is the creation of solar cells with a vertical structure based on μk-$Si: H$, n-$Si: H$ and a-$Si: H$ [1], as well as the use of a-$Si: H$ as the basis of the matrix for creating flat screens [2].

The predominant characteristics $a-Si:H$ over other semiconductors used for these purposes are low deposition temperature $\sim 300-400^0C$, the possibility of obtaining homogeneous films with a large area, the creation of a $p-n$ transition with high spectral sensitivity to visible light, etc. [3]

The main parameters of photovoltaic devices are associated with recombination processes, and the study of this dependence is important. The efficiency of solar cells $a-Si:H$ on standard conditions (AM spectrum 1.5, 0.1 W / cm^2) reached 16,6 %. It's further increase is hampered by the main low value of the hole component of the photocurrent relative to the electron.

To increase the hole photocurrent, it is necessary for solar cells based on $a-Si:H$ in $p-i-n$ structures to dope a bit the i-layer with boron. But this leads to a decrease in resistance and, in its turn, a decrease in the idling voltage.

In many studies, the photoconductivity of lightly doped and pseudo-doped samples was investigated. In these studies, it was shown that without changing the width of the mobility gap and the state of the Fermi level, one can obtain samples with good photoconductivity.

But in these works the names are not shown, which charge states in the mobility gap affect hole photoconductivity.

This is mainly due to the fact that, under normal conditions, that is, solar cells and stationary photoconductivity, it is impossible to obtain a monopolar hole photocurrent.

However, dividing an electron-hole pair of photogenerated electron-hole pair in some devices, and moving only a hole along the volume of a semiconductor, one can study its interaction with charge states. One of these devices is the target of a vidicon. Therefore, in this work, we used the data obtained in to study the hole parameters.

In [4], it was shown that to use a $a-Si:H$ as a target of vidicon, linearity of lux-ampere characteristics (LACH) is necessary. Within the power of illumination, this is ensured due to the monomolecular nature of the recombination, which leads to a low inertia of the device. Low inertia ensures the reliability of the parameters obtained due to the smallness of the residual photocurrent. From the data of, it follows that the transfer of charge carriers in $a-Si:H$ improves and becomes less inertial with the addition of a small amount of impurities, but the physical nature of such a change has not been studied.

In this article, the energy position of the levels that affect the LAF and the inertia of photovoltaic devices operating in pulsed mode, using the Vidicon target as an example were estimated.

As is known, if the thickness of the *i*-layer is much larger than the thickness of the *p* and *n* layer in $p-i-n$ structures, the long-wavelength light of the main is absorbed by the surface or layer. This means that when exposed to an external voltage, injection of holes or electrons is created (at a reverse voltage injection of holes occurs). Therefore, the photocurrent can be considered currents limited by space charges.

In our previous works, we obtained analytical expressions describing a hole photo volt-ampere characteristic of a structure based on.

A photo volt-ampere characteristic consists of several separate sections, and analysing each section one can obtain a lot of information about the nature of the photocurrent.

Methods for growing $a-Si:H$ and manufacturing targets based on them are described in [4]. The target structure is a successively deposited structure layer on a glass substrate. n^+ - $a-Si:H$ - (0.1 μm), $i-a-Si:H$ (1.5–2 μm), Sb_2S_3 (0.1 μm). The structures were illuminated from the side of the substrate, and the electron beam was read from the side Sb_2S_3. Positive mixing was applied to structure.

The parameters of the i-layer ($i-a-Si:H$) obtained under the same conditions are as follows: the optical band gap $E_g = (1{,}90 \pm 0{,}05)$ eV, the activation energy of the dark conductivity (σ_T) $\Delta E = (0{,}9-1{,}0)$ eV, the photoconductivity $\sigma_F = 10^{-6}$ $Om^{-1}sm^{-1}$ (at $F = 10^{15}$ $sm^{-2}s^{-1}$, $\lambda = 625$ nm, T=300 K), the ratio $\sigma_F/\sigma_T = 10^{15}$. In the case of shortwave illumination (λ = 420 nm) of the Vidicon target from the structure side, light is absorbed in the near-surface region, i-layer, $\alpha = 10^5$ sm^{-1}, and therefore only holes pass through the entire layer thickness. From this it follows that, by the value of the photocurrent of the target of a vidicon, one can observe the transfer of holes and their interaction with levels in the forbidden band.

In accordance with the Rose model, if minority charge carriers interact with traps (sticking or recombination centers) of one type of sufficiently high concentration during transfer, then LACH has a linear character. To the graph shown in Fig. 1, it can be seen that in the case of vidicon targets based on $a-Si:H$, when interacting with holes through the i-layer, they interact with only one type of level.

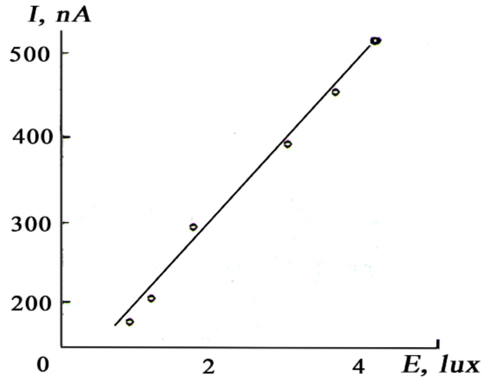

Fig. 1. Luxampere characteristic of vidicon targets based on *a - Si:H*.

In the mode of operation of a vidicon (quasi-stationary), these levels should be the levels of sticking, which leads to an increase in the inertia of the device. In the field of monopolar photoconductivity, the phenomenon of charge carrier sticking is divided into two extreme cases:

- α-equilibrium of free holes with sticking centers is established faster than their lifetime;
- for β-equilibrium of charge carriers between sticking levels and the V-zone, significantly longer time is required than the carrier lifetime.

In both cases, “tails” may appear in the photocurrent dependencies. Based on these data, the character of sticking can be determined from the relaxation curves of the photocurrent of the target of a vidicon. In it was shown that the β-sticking process is observed in the operation mode of a vidicon and this mainly affects the inertia of the vidicon target. To reduce this effect, it is necessary that the time to establish an equilibrium with the V-zone does not exceed the scan period of 1/40 s. If the residual photoconductivity is 5-8% of the total value of the current pulse, then

$$\Delta n \tau_p \gamma_{tp} N_t \approx 10^{-1} \cdot \Delta n \quad \text{or} \quad \tau_p \gamma_{tp} N_t \approx 10^{-1} \cdot \Delta n, \qquad (1)$$

here $$\tau_p = (1/\gamma_{np}N_v)\exp(|E_{tp} - E_v|/kT) \geq 1/40 \qquad (2)$$

From formula (2), it is possible to determine the energy band of traps affecting the inertia of the target, but for this you need to have additional information about the lifetime of minority charge carriers and the concentration of traps. The lifetime of holes in $a-Si:H$ $\tau = 10^{-8}$ s, and the average concentration of traps for the base samples was determined from studies of the temperature dependence of the photovoltage and is equal to $N_t = 10^{16}$ sm^{-3}. Then from (1) it is possible to calculate the current carrier capture coefficient of $\gamma \approx 10^{-9}$ sm^3 s^{-1}. If we take into account that $N_v = 10^{21}$ sm^{-3}, then from (2) we get

$$\exp(|E_{tp} - E_v|/kT) \geq 0{,}25 \times 10^{11}; \qquad |E_{tp} - E_v| \geq 0{,}6 \text{ eV}.$$

Thus, it can be assumed that the inertia of the vidicon target is affected by traps located 0.6 eV above the valence band. At the same time, in order for the target to have the inertia required for the device, the concentration of traps should not exceed 10^{16} sm^{-2}.

In fig. 2 shows the current-voltage characteristics (I-dark, II- when illuminated) of a vidicon target made of undoped and boron-doped $a-Si:H$. It can be seen that the growth and saturation of the photocurrent in targets made of boron doped $a-Si:H$ (curve 1) occur at lower voltages than in undoped samples (curve 2). The photoconductivity decay time (relaxation time) in these targets differs by three times in favor of the doped target. Apparently, to obtain targets that satisfy the above requirements, it is necessary to use lightly doped boron $a-Si:H$.

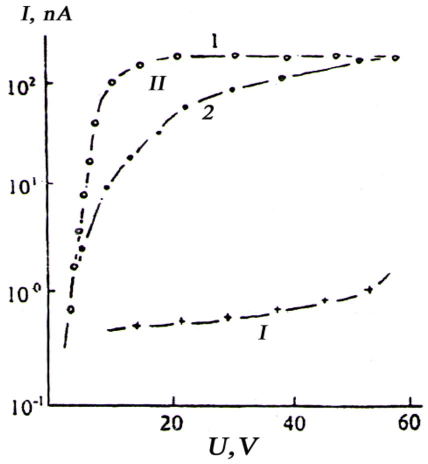

Fig. 2. Photo (II) and dark (I) current-voltage characteristics of vidicon targets based on *a - Si:H*: 1-boron-doped sample, 2-undoped sample.

As is well known (see, for example, [5]), in $a-Si:H$ neutral dangling D^0 bonds, the levels are located (0.55–0.65) eV above the valence band ceiling and limit the transfer of holes. When doping with boron, the neutral dangling bonds $D^0 \rightarrow D^+$ (D^+ -positively charged dangling bond) are recharged and their concentration N_t decreases. Accordingly, the influence of deep traps D^0 on the inertia of the devices decreases.

Thus, by introducing a small amount of boron impurities into $a-Si:H$, one can control the concentration of deep centers and make photo cells and photo sensors based on desired photoelectric properties and characteristics.

In addition, by changing the scan period, one can obtain information on hole traps located in different energy positions in the mobility gap $a-Si:H$.

References

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