Influence of Polymer Coatings on the Carrier Life Time in Solar Silicon Crystals

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Influence of polymer coatings on the photovoltage drop kinetics in solar Si crystals exposed to magnetic field action and X-ray irradiation is studied. The features found in the behavior of the electrophysical parameters suggest slowing down the photovoltage drop in the presence of polymer coatings at the surface of solar Si crystals. These features may be due to the influence of polymer coatings to reduce the concentration of recombination centers in crystals solar-Si.

Keywords: Solar Si, Carrier life time, Magnetic field, X-ray irradiation.

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1. INTRODUCTION

Dependence of the solar cell (SC) parameters on the life time of minority carriers in various type SCs, including the SCs made from conventional solar Si crystals, has been studied by many researchers. Quite complete information on the results of above-mentioned investigations can be found in [1, 2]. The ability of SC to generate photocurrent under illumination by the light of a given wavelength can be evaluated quantitatively by the collection efficiency. This parameter is known to be a ratio of the number of carriers that contribute to photocurrent to the total number of carriers generated on absorption of the incident light. The short circuit current generated in the SC rises approximately linearly with lg(Ln), where Ln is the carrier diffusion length.

The SC efficiency is significantly dependent on the diffusion length and, correspondingly, on the life time of carriers. A relative change in the efficiency caused by carrier life time variation is well approximated by relation $\Delta\eta / \eta \sim 0.1 \cdot \ln(\Delta\tau / \tau)$. For finished silicon SCs the life time of the minority carriers of the initial material should considerably exceed 10 μs and, if possible, should reach a value of 100 μs.

As is known, the concentration of recombination centers that determine the carrier life time can change under action of a variety of factors. Redistribution of recombination centers affecting the carrier life time can result not only from certain kind of treatment (chemicals, irradiation, magnetic field), but also from such processes as gettering and adsorption of impurities by the surface as well as coating the surface. All these can make the carrier life time of the initial material to grow or fall: both effects are observed.

It has been found [3] that pretreatment of silicon photoelectric converters of solar energy in a stationary magnetic field with induction of $B = 0.2$ T during 7 days has a significant impact on the initial parameters of such devices, resulting in raising their efficiency. A drawback of the results reached in [3] is a degradation of the efficiency increase effect on prolongation of the magnetic treatment.

In our previous work [4] we determined the peculiarities of the effect of magnetic treatment (MT) in stationary magnetic field on the photovoltage drop in solar Si crystals. These features are as follows. MT consisted in exposing the samples to a weak stationary magnetic field ($B = 0.17T$) for $t_{MT} = 7$ days. After MT termination, one could observe a decrease in the time constant for long-term photovoltage drop component (τ_2) compared to parameter τ_2 for the reference samples that were not subjected to MT. The effect detected just after MT termination remained constant for a long time of observation (230 days). In studying the behavior of the short-term photovoltage drop component (τ_1) under MT we observed a peculiar 'aftereffect'. This aftereffect lied in the fact that parameter τ_1 just after MT termination dropped 3 times and continued to fall later. For example, in 30 days after MT it decreased about 10 times. The found degradation effects attributed to carrier life time change under action of magnetic field served as an impetus for searching and trying those factors which improve and stabilize the electrophysical characteristics.

Some gaps and, sometimes, contradictions in studies concerning the influence of external factors on the carrier life time in solar silicon proves the relevance of the subject under discussion. Increasing the efficiency of the SCs of standard design requires further accumulation of new experimental data on the methods and possibilities of the sunlight capture and retention system optimization.

The aim of this work was to investigate the optimal combination of a passivation polymer coating and magnetic treatment which together eliminate degradation of the electrophysical parameters determining the photovoltage in solar Si crystals.

Besides investigating the magnetic field effect on the 'solar Si – polymer coating' structure, our aim was also to study the influence of X-ray illumination on the photovoltage drop kinetics.

2. EXPERIMENTAL

To achieve the goals, we worked through the methodical aspects allowing to improve the electrophysical characteristics determining the SC efficiency.

As a passivation coating an epoxy-urethane composition was used. The use of such a material as an optical coating requires determination of its optical transparency. We found that transmittance of epoxy-urethane coatings without filler was 59 % and those with filler reached 77 %.

In this work we used the unfilled epoxy-urethane coatings. The filled ones we plan to study in the future.

Magnetic treatment of the ‘solar Si + passivation polymer coating’ was carried out by means of long-lasting (200 days) exposition of the samples to a stationary magnetic field with an induction of $B = 0.17T$.

We also used a low-energy and low-dose X-radiation (the energy of the $Cu_{K\alpha}$ line was $W = 8$ keV, the absorbed dose was $D = 0.3 \cdot 10^2$ Gy). The response to magnetic treatment and X-irradiation were changes in time constants for short-term and long-term photovoltage drop components. Photovoltage drop kinetics was investigated by means of the capacitance method. Investigation of relaxation photovoltage was carried out on an automated setup, which provides a read the signal over the sample surface. The photovoltage was generated by a red laser diode with a wavelength of 650 nm and a power of 7 mW.

3. EXPERIMENTAL RESULTS AND DISCUSSION

In this work we have found that applying polymer (epoxy-urethane) coatings on the solar Si surface results in a few positive from a practical point of view results. Let us consider them in brief. As is seen from Fig. 1, a 20-μm-thick polymer coating applied on the solar Si surface makes it possible to increase the time constants of both the short-term and long-term components of the photovoltage drop. MT of polymer-film-coated solar Si samples causes an additional rise in the time constants of the both components of the photovoltage drop.

It should be noted that the effect of carrier life time increase and, consequently, diffusion length increase detected just after MT termination gradually relax. The time constants of short-term and long-term drop components after the end of the relaxation observation period (230 days) reached the values of τ_1 and τ_2 typical for polymer-film-coated solar Si crystals. So, under conditions of MT the polymer coating slows down the process of τ_1 and τ_2 parameter degradation. Unattainability of complete relaxation of short-term and long-term components to the initial values characteristic of polymer-free solar Si samples points to the occurrence of residual effect.

The obtained results concerning an increase in the carrier life time on applying a polymer coating on the solar Si surface can be accounted for in the following way. It is known [5] that the basic physical mechanism explaining magnetosensitive effects and phenomena in non-magnetic materials is the mechanism of singlet-triplet conversion occuring in the point defect complexes. Magnetic-treatment-stimulated singlet-triplet transitions change the spin configuration in point defect complexes and lead to breakage of chemical bonds in structural nanoclusters. In silicon, that kind of spin-dependent processes causes breakage of Si-Si bonds

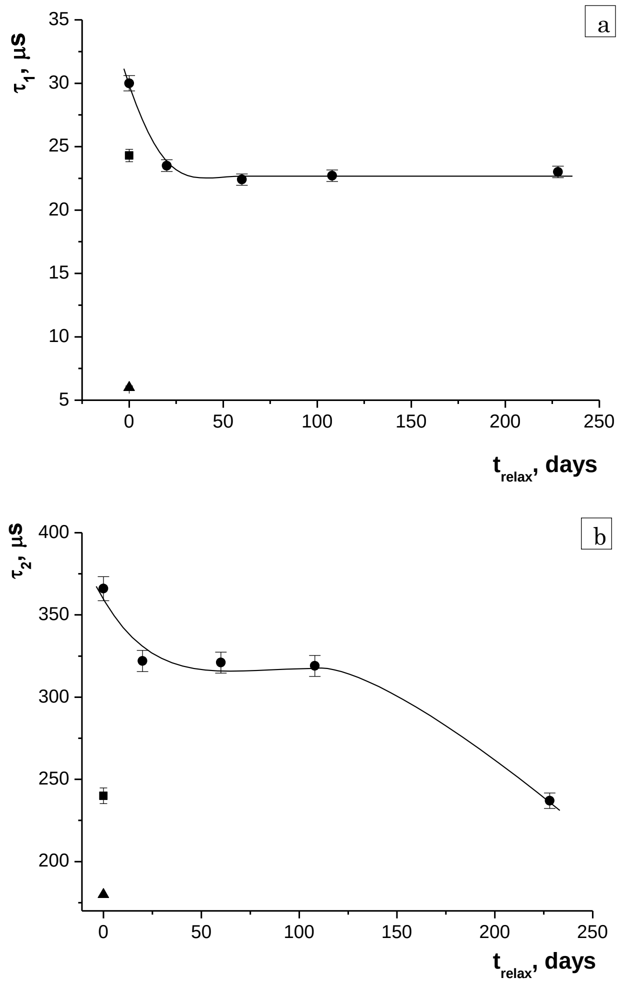

Fig. 1 – Time constants of short-term (a) and long-term (b) components of the photovoltage drop in solar Si samples vs time elapsed after MT termination. Solar Si samples: ▲ – without polymer film; ■ – with polymer film; ● – with polymer film after magnetic treatment ($B = 0.17$ T, tMT = 200 days). Polymer film thickness $h = 20$ μm

as well as predominating in silicon Si-O bonds of oxyde precipitates. Another aspect of magnetic influence on silicon consists in structural rearrangement caused by strengthening the interdefect interaction. The process of interdefect solid-state reactions in silicon crystals ends with formation of oxygen-vacancy (O-V) complexes which are known in the literature [6] as type A defects. It is not inconceivable that the presence of polymer coatings passivating the solar Si surface eliminates the MT-induced process of chemical bond breakage and thus eliminates the process of formation of deep recombination centers affecting the carrier life time. A decrease in the concentration of recombination centers forming deep recombination levels in the solar Si band gap leads to an increase in the non-equilibrium carrier life time and, as a result, give grounds for raising the efficiency of solar-Si-based solar cells.

So, in conventional solar Si crystals used in solar energy applications the following peculiarities in the behavior of the electrophysical parameters are observed on depositing polymer coatings and under magnetic treatment.

1. The presence of passivation polymer film on the surface of solar Si samples and carrying out a long-lasting (200 days) magnetic treatment results in an increase in time constants of both short-term and long-term components of photovoltage drop. Growth of carrier diffusion length and, consequently, of carrier life time can raise the photocurrent and, as a result, the efficiency of SCs.

2. After MT termination one can observe a gradual relaxation of MT-induced increased time constants for short-term and long-term components of phovoltage drop in solar Si crystals, both components not relaxing to the values characteristic of the reference (initial) solar Si samples. Observed relaxation of the τ_1 and τ_2 parameters to the values characteristic of the polymer-coated samples points to the fact that polymer coating slows down the degradation process for the τ_1 and τ_2 parameters.

Studying the irradiation effect caused by the action of low-energy ($W = 8$ keV) and low-dose ($D = 0.3 \cdot 10^2$ Gy) X-radiation on the electrophysical characteristics of the 'solar Si + polymer coating' structure, we found the following features.

1. Unlike magnetic treatment, X-irradiation changes the photovoltage drop kinetics not just after termination of the X-rays action but after a certain lapse of time (Fig. 2). The maximum effect caused by the X-irradiation is reached in 100 days. The latter points to the existence of the 'aftereffect'. This aftereffect suggests a long-term nature of the X-irradiation-induced structural rearrangement.

2. X-irradiation results in an increase in time constants of both components of the photovoltage drop. The time constant for the short-term component increases 2 times, while that for the long-term one does so 1.5 times.

3. After reaching the maximum increase the τ_1 and τ_2 parameters afterwards slowly relax, approaching the values characteristic of the 'solar Si + polymer coating' structure before the X-irradiation. The latter points to the existence of the 'residual effect' after relaxation and suggests slowing down in degradation of the studied parameters.

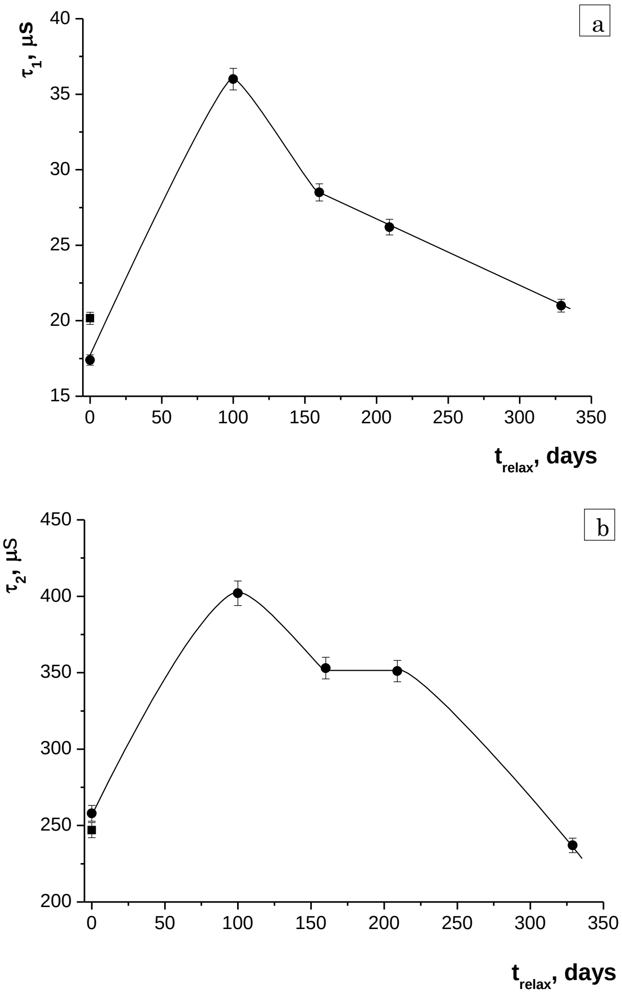

Fig. 2 – Time constants of short-term (a) and long-term (b) components of the photovoltage drop in solar Si samples vs time elapsed after X-irradiation termination. Solar Si samples: ■ – with polymer film; ● – with polymer film after X-irradiation ($D = 0.3 \cdot 10^2$ Gy). Polymer film thickness $h = 20$ μm

Вплив полімерних покриттів на час життя носіїв в кристалах кремнію, що використовуються в сонячній енергетиці

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Вивчено вплив полімерних покриттів на кінетику спаду фото-ЕРС в кристалах solar-Si в умовах магнітного та рентгенівського впливів. Встановлені особливості в поведінці електрофізичних параметрів вказують на уповільнення спаду фото-ЕРС при наявності на поверхні solar-Si полімерних покриттів. Ці особливості можуть бути обумовлені впливом полімерних покриттів на зниження концентрації рекомбінаційних центрів в кристалах solar-Si.

Ключові слова: Solar-Si, Час життя носіїв, Магнітне поле, Рентгенівське випромінювання.

Влияние полимерных покрытий на время жизни носителей в кристаллах кремния, используемых в солнечной энергетике

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Изучено влияние полимерных покрытий на кинетику спада фото-ЭДС в кристаллах solar-Si в условиях магнитного и рентгеновского воздействий. Установленные особенности в поведении электрофизических параметров указывают на замедление спада фото-ЭДС при наличии на поверхности solar-Si полимерных покрытий. Эти особенности могут быть обусловлены влиянием полимерных покрытий на снижение концентрации рекомбинационных центров в кристаллах solar-Si.

Ключевые слова: Solar-Si, Время жизни носителей, Магнитное поле, Рентгеновское излучение.

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