

Single-crystal silicon solar cell efficiency increase in magnetic field

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Received July 17, 2010

It is established in experiment that efficiency of unijunction (UJ) single-crystal silicon solar cells (Si-SC) with horizontal n^+-p-p^+ diode structure may increase by a factor of approximately 1.1 after their holding at room temperature during 7 days in perpendicularly oriented stationary magnetic field with 0.2 T induction. The subsequent stabilizing of the obtained positive effect is shown to be realizable by attachment of a thin magnetic vinyl layer (creating in the UJ Si-SC base crystal a magnetic field with induction not exceeding 0.05 T) to the UJ Si-SC at the back electrode side.

Экспериментально установлено, что КПД однопереходных (ОП) монокристаллических кремниевых фотоэлектрических преобразователей (Si-ФЭП) с горизонтальной диодной n^+-p-p^+ структурой может возрастать примерно в 1,1 раза после их выдерживания при комнатной температуре в течение 7 суток в перпендикулярно ориентированном стационарном магнитном поле с индукцией 0,2 Тл. Показана возможность последующей стабилизации достигнутого положительного эффекта за счет пристыковки к ОП Si-ФЭП со стороны тыльного электрода тонкого слоя магнитного винила, создающего в базовом кристалле магнитное поле с индукцией не более 0,05 Тл.

1. Introduction

Silicon consists at present a considerable part of total amount of base semiconductor materials for the solar cells (SC) [1, 2]. Therefore, actual is a search for ways to increased efficiency η of single-crystal silicon solar cells (Si-SC). In this connection, we were attracted by a recently published work on a magnetomechanical effect in Si single-crystal [3], the results of which indicate indirectly that a prolonged influence of a stationary magnetic field (SMF) with induction $B \approx 0.2$ T on a Si single crystal can result in reconstruction of the initial ensemble of point defects and their complexes therein. It is known [4] that the efficiency of single-crystal Si-SC rises with the increase of minority charge carriers (MCC) lifetime τ in the silicon base crystals (Si-BC), while $\tau \sim N_r^{-1}$ (where N_r is the bulk concentration of point defects in Si-BC, which effect as recombination centers). Therefore, we have supposed that since a holding of a single-crystal Si-SC in SMF with $B = 0.2$ T will be able to provide a reduction of N_r and thus increase of τ, then such a conditioning will provide an increased η of the objects under study. Thus, the first work tasks consisted in experimental verification of the above formulated idea. At the same time, it is known [3] that after the magnetic field influence is stopped, the result of its influence on a single-crystal silicon becomes relaxed in a time commensurable with duration of preceding exposure of the sample to SMF. In connection with the above and with practical importance of stabilizing the supposed effect of single-crystal Si-SC efficiency increase, the second task of this work was to

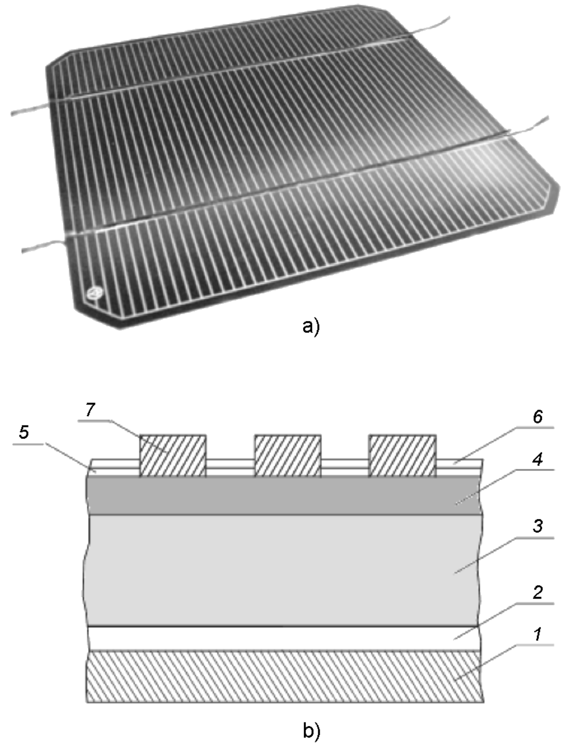

Fig. 1. General view of industrial solar cell from which the studied fragments were cut out (a) and schematic image of its vertical cross-section (b): *1*, back solid electrode; *2*, Si layer of p^+-type conductivity; *3*, Si layer of p-type conductivity; *4*, Si layer of n^+-type conductivity; *5* — passivating SiO_2 layer; *6*, antireflection Si_3N_4 coating; *7*, front metallization.

find out a possibility to save the attained result during long time.

2. Experimental

We investigated unijunction (UJ) single-crystal Si-SC being the fragments of industrial similar type devices of 125×125 mm^2 co-planar size. The latter had horizontal n^+-p-p^+ diode structure and were made from KDB-2 grade silicon grown by Czochralski method. The fragments under study have 20×20 mm^2 co-planar surfaces and Si-BC thereof was 200 μm thick. The general view of industrial device from which the abovementioned fragments were cut out and schematic image of the device are presented in Fig. 1. To condition the investigated UJ Si-SC in SMF, two 15 mm thick permanent magnets of 60 mm in diameter were used spaced at the distance of 20 mm, between which there was a practically homogeneous magnetic field with $B = 0.2$ T, measured by using a EM4305 teslameter. To stabilize the

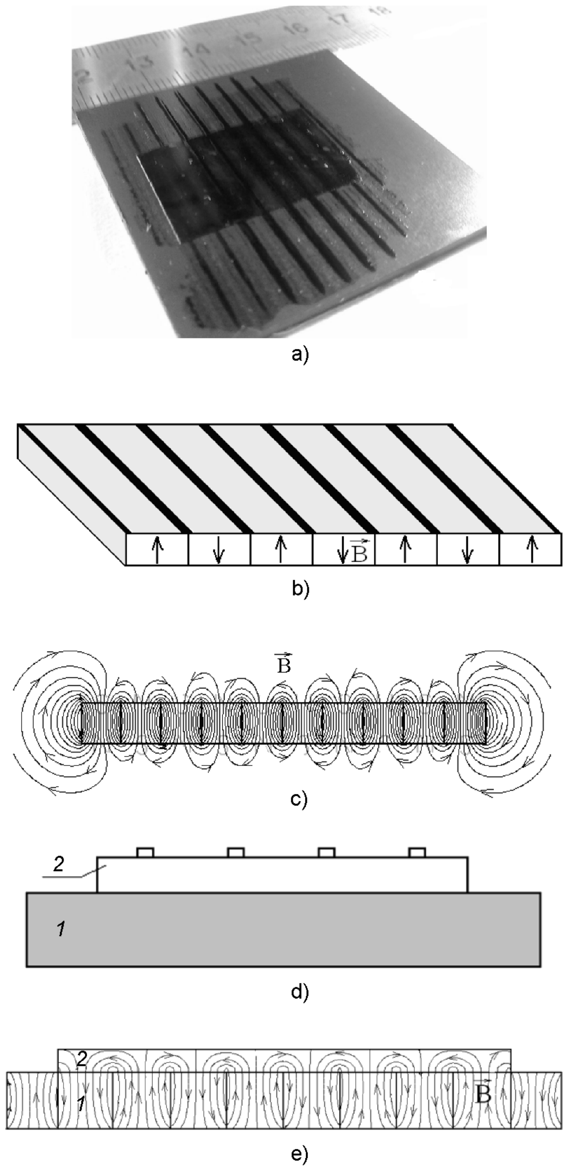

Fig. 2. Distribution of magnetic field generated by magnetic vinyl: a, visualization by magneto-powder method (image details are discussed in text); b, schematic image of magnetic field induction directions in sections of vinyl which corresponds to light stripes on fragment *a*; c, result of simulation by the Vizimag 3.193; d, placing manner of the magnetic vinyl (*1*) relative to UJ Si-SC (*2*); e, result of simulation of magnetic field distribution in two-layer system magnetic vinyl (1)/UJ Si-SC (*2*) by the Vizimag 3.193.

considered effect, the plastomagnet — about 1.5 mm thick flexible magnetic vinyl [5] was chosen. The peculiarities of magnetic field distribution created by this material immediately at its working surface were investigated by means of direct measure-

Table. Efficiency η and effective electron lifetime η_n^{ef} in Si-BC of *p*-type conductivity prior to and after the UJ Si-SC conditioning in SMF at $B = 0.2$ T

Parameters	Ordinary state ($B = 0$)	After processing in SMF					
		Initial state ($B = 0$)	After storage				
			$B = 0$	In contact with magnetic vinyl ($B = 0.05$ T)			
			7 days	7 days	14 days	21 days	30 days
η, %	10.3–11.1	11.8–12.5	9.2–10.5	11.8–12.4	11.6–12.2	11.5–12.2	11.5–12.2
τ_n^{ef}, μs	34–40	50–56	25–33	50–54	48–52	48–52	48–52

ments using the above-mentioned teslameter and method of powder patterns [6]. The image of magnetic vinyl used in this work with magnetic suspension applied on its working surface is shown in Fig. 2a. Magnetic vinyl creates in external near-surface space striate areas (wide light stripes in Fig. 2a, separated by narrow dark boundaries formed by the magnetic powder accumulations) with differently directed vertical component of magnetic field induction in the centers of intervals between the narrow dark boundaries. This fact is schematically presented in Fig. 2b. It is confirmed by (i) the results of vinyl magnetic field distribution simulation using Vizimag 3.193 software [7], shown in Fig. 2c, and (ii) corresponding measurements according to which the vertical constituent of magnetic field induction within 1 mm above the vinyl working surface reaches on the average 0.05 T. After UJ Si-SC holding in SMF of permanent magnets, the investigated objects were placed on the working surface of such vinyl with back electrode turned to the surface (Fig. 2d). The result of simulation of magnetic field distribution in the double-layer system magnetic vinyl (1)/UJ Si-SC (2) obtained using the Vizimag 3.193 software is shown in Fig. 2e.

The UJ Si-SC efficiency was determined according to standard technique at 25°C and AM1.5 illumination regime [8]. The effective electron lifetime τ_n^{ef} in *p*-type conductivity Si-BC was measured by the method of open circuit voltage decay after cutoff of the square light pulse illuminating the photoreceiving UJ Si-SC surface [4, 9]. The continuous illumination necessary at the measuring of UJ Si-SC light current-voltage characteristics, and pulse one required to measure τ_n^{ef} were realized using an universal light-emitting diode illuminator [10] developed and manufactured before.

3. Results and discussions

The values of η and τ_n^{ef} were measured for UJ Si-SC in the ordinary state, after conditioning in SMF of permanent magnets during 7 days and after their storage both with and without magnetic vinyl applied on the back surface. The results obtained are presented in the Table. The efficiency of the studied objects decreases in time after conditioning in SMF of permanent magnets, however, the magnetic vinyl applied to the back surface of UJ Si-SC changes the situation to a considerable degree. After storage of the studied objects in contact with magnetic vinyl during three weeks, the efficiency decreases insignificantly (from 11.8–12.5 % to 11.5–12.2 %), in contrast to the samples without attached magnetic vinyl, where the efficiency decreased down to 9.2–10.5 % during the first 7 days only. The subsequent storage of UJ Si-SC in contact with magnetic vinyl during additional 9 days did not accompanied by any change of efficiency attained after similar three-week storage. Thus, it is possible to conclude that application of magnetic vinyl allows to support the η value of increased initially in the stationary magnetic field within limits of 11.5–12.2 %, that exceeds considerably the initial values of this parameter amounting 10.3–11.1 %.

The revealed increase of UJ Si-SC efficiency from 10.3–11.1 % up to 11.8–12.5 % after conditioning of the devices in SMF with the subsequent stabilizing by magnetic vinyl at the level of 11.5–12.2 % correlates well with MCC lifetime change in *p*-type conductivity Si-BC of UJ Si-SC from 34–40 μs to 50–54 μs with the subsequent stabilizing by magnetic vinyl at the level of 48–52 μs. This can be due, for example, to the processes in the Si-BC crystal structure mentioned below. The V_{Si}–O_i, O_i–Si-O_i, V_{Si}–Si–V_{Si} complexes present in Si single crystal are effective recombination centers, that results in a reduction of MCC lifetime. Under the action of pressure and temperature, the ensemble of such complexes is able to reconstruct itself in that containing SiO_2 and Si-O_xV_y inclusions being not recombination centers. It is not impossible that similar transformations take place and in p-type conductivity Si-BC of UJ Si-SC under the influence of SMF at $B = 0.2$ T, because in [3] the activation of oxygen in silicon by magnetic field is stressed noticeably.

4. Conclusions

It is established in experiment that efficiency of unijunction single-crystal silicon solar cells with horizontal n^+-p-p^+ diode structure may increase approximately by a factor of 1.1 after the Si-SC conditioning at room temperature during 7 days in the perpendicularly oriented stationary magnetic field with induction 0.2 T. The subsequent stabilization possibility of the attained positive effect is shown resulting from attachment of a thin magnetic vinyl layer generating in the base crystal a magnetic field with induction no more than 0.05 T to the solar cells of the studied type from the side of back electrode.

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Підвищення ККД монокристалічних кремнієвих фотоперетворювачів у магнітному полі

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Експериментально встановлено, що ККД одноперехідних (ОП) монокристалічних кремнієвих фотоелектричних перетворювачів (Si-ФЕП) з горизонтальною діодною n^+-p-p^+ структурою може зростати приблизно у 1,1 рази після їх витримування при кімнатній температурі протягом 7 діб у перпендикулярно орієнтованому стаціонарному магнітному полі з індукцією 0,2 Тл. Показано можливість наступної стабілізації досягнутого позитивного ефекту за рахунок пристикування до ОП Si-ФЕП з боку тилового електроду тонкого шару магнітного вінілу, який створює у базовому кристалі магнітне поле з індукцією не більше 0,05 Тл.