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Formation and Characteristics Study of Nanostractured Solar Cell

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Abstract

Electrochemical and photoelectrochemical etching technique have been employed to produce nanostructured solar cell. Various preparation conditions were examined. The I-V characteristics measurements were adopted to study effects of these parameters on the solar cell efficiency. We found that when shorter laser wavelength used to illuminate the porous layer during the etching process, the conversion efficiency of the solar cell increases . While doping the porous layer with phosphorous increases the nanostructured solar cell efficiency by 30 %.

Keywords: porous silicon, solar cell, photoelectrochemical etching.

تصنيع ودراسة خصائص خلية شمسية ذات تراكيب نانوية

الخلاصة

تم الاعتماد على تقنية التنميش الكهروكيميائي والكهروكيميائي الضوئي لانتاج خلية شمسية ذات تراكيب نانوية بظروف تصنيع مختلفة. تم دراسة الخصائص الكهربائية تيار-جهد للخلية الشمسية, ودراسة تاثير عملية الاشابة على الخلية الشمسية النانوية. تم ملاحظة عند استخدام اطوال موجية قصيرة اثناء عملية التنميش يؤدي الى زيادة في قيمة الكفاءة للخلية الشمسية. كما ان اشابة الطبقة المسامية بمادة الفسفور يؤدي الى زيادة في كفاءة الخلية الشمسية الى 30%.

Introduction

Despite very extensive investigation studies on solar cell, the classical silicon photovoltaic cells built on the basis of mono- and multicrystalline silicon are the most popular semiconductor instruments of that type. For many years, investigations have been carried out to improve the efficiency of solar cells [1-4].

One of the possibilities to improve the solar cell conversion efficiency is the nanostructured solar cell which is based on porous silicon PS material [5-8]

Porous silicon can be considered as a silicon crystal having a network of voids in it. The nanosized voids in the bulk Si result in a sponge-like structure of porous and channels surrounded with a skeleton of Si nanostructure. The physical properties of porous silicon are fundamentally determined by the shape and diameter of pores, the thickness and the relative content of Si, voids. These parameters depend on preparation conditions, so that it is possible to design materials with physical properties of those between Si and air (or the medium which fills the porous). In addition, when the feature size of the Si wires is less than a few nanometers, various quantum-size effects occur which make PS even

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more fascinating. Because of its versatility and tunable designable characteristics, PS has become a popular material among scientists and technologists, and has been applied in various fields [5].

Visible photoluminescence and electroluminescence of porous silicon becomes one of the most interesting materials in very large application fields. Much attention is presently devoted to the optoelectronic properties of PS in view of their application to light emitting and light sensing devices. The features of porous silicon are summarized as follow band gap broadening, absorption spectrum in the range (0.8-1.3) eV, very good optical transmission by wavelength (700-1000) nm and photoconductivity imply utilization of PS in silicon solar cell[6-7].

Some tentative efforts were conducted in order to take advantage from this material in photovoltaic processes. In some works [7-8], the photovoltaic effect of structure with PS layer has been reported. According to the quantum confinement model a heterojunction can be formed between Si substrate and PS layer because the latter has a bigger bandgap (1-2.2)eV compared to c-Si. It is therefore, expected that a heterostructure with PS layer can absorb a wide range of the radiation spectrum. The proposed idea for many groups is the top n+ region of a shallow n+/p junction to be modified by formation of a thin PS layer [8].

On the other hand, there is an opinion that the main performance improving factor is the rough surface of PS. The effective refractive index lower than refractive index of c-Si, can decrease the reflection losses of the sunlight radiation.

Thus, many attempts have been carried out to introduce PS in photovoltaic devices. Primitive solar cells using PS have been demonstrated. However, few higher efficiency cells based on PS were reported. In forming PS, highly textured surface are obtained, enhancing light trapping and its potential use as an antireflection coating [9-10].

This work presents a comparative study of the formation of PS in different substrates (n, n^+). The PS layer was formed on the top layer (n-region) of p-n junction and the photovoltaic properties of PS/n^+/p solar cell are investigated, and compared to the conventional solar cell. The PS layer was synthesized by electrochemical etching and photoelectrochemical etching. Moreover, the effect of different wavelength on electrical parameters of the nanostructured solar cell has also been reported.

Experiment

Conventional solar cell wafers of thickness 300µm have been used in this work. The top surface layer of the wafer is doped with phosphorus to produce n-type conductivity layer with depth 0.5µm and sheet resistance (45Ω/sq.). Whereas the basic substrate is p-type and sheet resistance (26Ω/sq). The wafers were cleaned in an ultrasonic bath in acetone following by rinsing with deionized (DI) water. A good ohmic contact on the backside of the wafer was obtained when Al film was evaporated.

In this work, porous layer have been synthesized on the top surface (n-type) of the p-n junction by two methods of etching; the first, electrochemical etching at constant current density of $30mA/cm^2$ for 10min. The etching solution was a mixture of 30% hydrofluoric acid and ethanol in volume ratio of (1:1). On the other side, effect of light on the electrochemical etching EC (photoelectrochemical) PEC on the solar cell characteristics was investigated illumination with different wavelengths (532, 632, 810) nm. After etching processes the wafer rinsed with DI water and blows dry.

Q-switched Nd:YAG Laser wavelength of 1046nm, pulse duration of 10nsec and repetition frequency of 1Hz was used, to produce the required doping of the surface layer (PS layer) at the top of the porous layer in the vacuum.

For current –voltage measurement, a Keithly-616 digital electrometer , Tektronics CDM 250 multimeter and a dual Farnel LT30/2 (-3 to 3)V power supply were used. The forward current was recorded when a positive voltage was applied to Al metal contact with the nanostructure layer with respect to Al electrode on the crystalline silicon substrate and calculated the ideal factor n of this structure by using the relation:

$$n = \frac{q}{KT}\frac{dV}{d\ln\frac{I}{I_o}} \qquad ....(1)$$

where $\frac{dV}{d\ln I}$ is the slope of the linear region of (I-V) plots, q is electron charge, K Boltezman's constant and T temperature.

The scanning electron microscopy SEM was used to examine the surface structure. The illumination was applied under simulated air mass (AM1) condition ($100mW/cm^2$) by a halogen lamp type (Philips) with 120W power. This lamp was connected to a variac and calibrated by a Si power meter. We measured V_{OC} and I_{SC} to calculate the fill factor (FF) and the efficiency (η%) of the nanostructured solar cell using the relations [13]:

$$FF = \frac{I_m V_m}{I_{SC} V_{OC}} \qquad ....(2)$$

$$h = \frac{FF \; I_{SC} V_{OC}}{P_{in}} \% \qquad ....(3)$$

Where V_m maximum voltage and I_m maximum current, this represents the maximum power output (maximum power rectangle) of the solar cell.

Results and Discussion

The (J-V) characteristics of the nanostructured silicon solar cell at room temperature prepared by both EC & PEC were investigated. Both EC and PEC were performed at current density of $20mA/cm^2$, etching time of 30s and HF acid concentration of 30%.

I-V characteristics corresponding to the two different PS/p-n structure were measured in -3 to 3 V range. The experimental results indicated that all structures analyzed in the present work show a symmetrical rectifying behavior for forward and reverse biasing as shown in Fig. (1).

The effect of using green laser light (532nm) on the porous surface layer formed during electrochemical etching process was examined. The light irradiation leads to increase the number of the photogenerated holes at surface due to absorption and hence increase the etching efficiency and subsequently the surface area.

The green laser light (532nm) has a high photon energy (2.3eV) and low penetration depth (0.4µm) therefore, this laser is appropriate to reduce the silicon nanocrystalline. The electrochemical etching produces various sizes of nano- and micro-particle which decrease gradually at longer irradiation time. In photoelectrochmical etching the porous layer produced which leads to synthesize porous structure of two layers. The thickness of the upper layer is smaller due to the small penetration depth [11-12].

The diode ideality factor n which is calculated by using eq.(1). It is found the shown the n depended to the structure of solar cell. The ideal factor was be increased from 1.5 to 1.9 in nanostructure layer which prepared by EC and PEC respectively.

Figure (2) shows comparison between the electrical characteristics of a nanostructured solar cell and n-type Si wafer prepared at similar conditions since illumination side for the irradiation face in the solar cell is the n-type Si. The etching current density was $10mA/cm^2$, while the substrate resistivity ρ=4×10-3 Ω.cm. The resistivity of the solar cell was drastically increased despite that the irradiation time in PEC method is shorter than that for the solar cell to avoid the penetration of porous layer through the p-n junction. The irradiation time for the solar cell device was 30min while for n-type sample was 90min. This is attributed to the effect of the p-type layer in the solar cell which facilitates providing n-type side with the required holes to start the chemical reaction.

The SEM image in figure (3) represents the top surface of silicon (p-n) junction etched with $75mA/cm^2$ and duration of 30 min as well as illuminated with light of λ=532nm. The surface morphology of the produced nanostructured solar cell reveals existence of macroporous layer with a column size of about few microns as shown in figure (3).

Moreover, the electrical characteristics of the two nanostructured solar cells prepared at different doping concentrations (0.1 and $4x10^{-3}$Ω.cm) have also been studied. Both cells were prepared at $10mA/cm^2$ current density, 1min etching time and 30% HF concentration using the green laser light (532nm). The low resistivity helps to increase the hole accumulation at the surface. As well as, high doping ($1019cm^{-3}$) allow the charge carrier to pass through the depletion layer. We found the electrochemical etching process is faster, and the efficiency was higher, for case of n^+ layer due to the increase of the charge carriers concentration, which are electrons in this case (electron current), and the increasing drift of the opposite carriers (hole current). Accordingly, supplying the surface with additional holes will be more efficient. The photonic irradiation has the same effect in the case of two wafers with different conductivities (n and n^+) but the final yield is increasing the surface resistivity due to the drastic increase in the surface area and hence decrease the efficiency of nanostructure solar cell. The efficiency η% and FF calculated by using eq. (2) and (3) shows the efficiency of the solar cell at n+ and n were 0.4% and 1% respectively. This introduces effect on the value of fill factor which becomes 0.3 and 0.41 for n^+ and n respectively.

The wavelength of used laser for the irradiation of the solar cell during PEC process has a reasonable effect on the efficiency of the nanostructured solar cell due to its role in determining the thickness of the porous layer when its compared to that of n^+ layer.

Figure (5) illustrates effects of illumination with different laser wavelengths on the nanostructured solar cell compared with solar cell produced without light illumination (EC) at the same conditions ($20mA/cm^2$, 10sec, 30%). As well, using green laser light (532nm) increases the solar cell efficiency, Table (1). This wavelength has too small penetration depth (0.4µm) inside cell surface [11].

Increasing the illumination wavelength leads to increase the penetration depth to reach higher value (10 µm) at λ=810nm. This mean increasing of PS layer thickness to value more than the active layer thickness (n-type) leads to decrease the nanostructured solar cell efficiency. Therefore, the longer laser wavelength (λ=810nm) has a negative role in the nanostructured solar cell production. Nevertheless, this wavelength could be very useful when the nanostructured surface is prepared in p-type sample then doped to produce the solar cell. Since the porous layer thickness is limited by the active layer thickness of solar cell (n-type) thickness. Therefore, short wavelength is preferable for the illumination during the etching process.

We found that nanostructured solar cell efficiency is lower than that of ordinary cell when longer wavelength was used and that is due to two reasons; the first is related to the removal of the antireflection coating layer during etching process and the second is related to the junction penetration by the porous layer which leads to decrease the efficiency. Therefore, the doping process of the porous layer nanostructurerd solar cell is very crucial parameters. A Nd:YAG laser was used to diffuse the dopant phosphorus in the porous structure. It is found that when the laser energy used for the doping process increased, the solar cell efficiency increases. This is attributed to the diffusion of phosphorous atoms within the porous region. As the laser energy increases, the values of I_{SC} increases and reach the optimum at 500mJ. Then, the efficiency starts to decrease due to the removal of phosphorous because of the vaporization effect on the cell surface. Therefore, laser energy of 500mJ was carefully selected to study the effect of number of laser pulses on solar cell efficiency. Figure (6) shows the effect of laser energy on the value of I_{SC} at certain value of V_{OC} (250mV).

Several laser pulses were also used for doping process with 500mJ energy. It is shown that the efficiency of solar cell was increased with increasing number of laser pulses and the maximum value of I_{SC} was obtained at 15 pulses. Then this value tends to decrease, as shown in Fig. (7).

Conclusions

The photoelectrochemical etching produces a porous structure of higher resistivity when ordinary solar cell was used as a starting material compared with that for n-type silicon and shorter laser wavelengths is preferable to produce nanostructure solar cell of enhanced the efficiency to about 30%. The doping process has increased the efficiency of the nanostructured solar cell to about 5%. Thereefor, doping of the porous layer of the nanostructured solar cell should be considered to improve the overall efficiency.

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Table (1) Influence of wavelength on photovoltaic parameters of solar cell.

20mA/cm², 10sec, 30%HF con.				
Wavelength(nm)	η%	FF	I_{SC} (mA/cm²)	V_{OC}(mv)
EC (no irradiation)	**0.25**	**0.23**	**2.4**	**460**
532	**0.29**	**0.32**	**2.5**	**450**
632	**0.19**	**0.34**	**1.7**	**390**
810	**0.12**	**0.23**	**1.45**	**380**

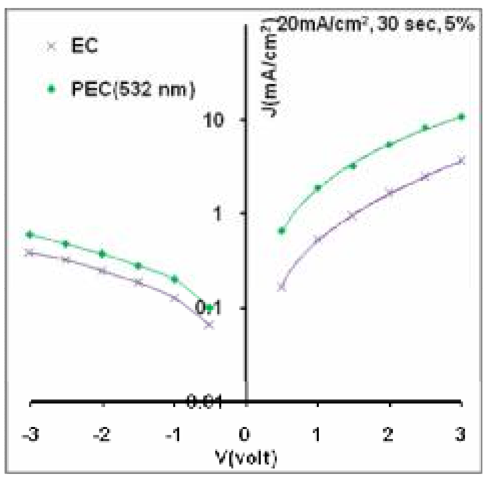

Figure (1) Dark, forward bias and reverse bias I-V characteristics of nanostructured solar cell.

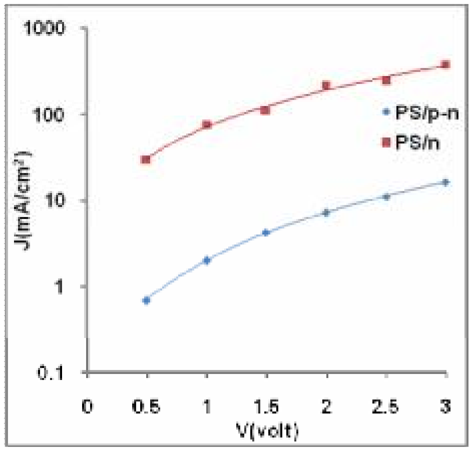

Figure (2) I-V characteristics at different substrate.

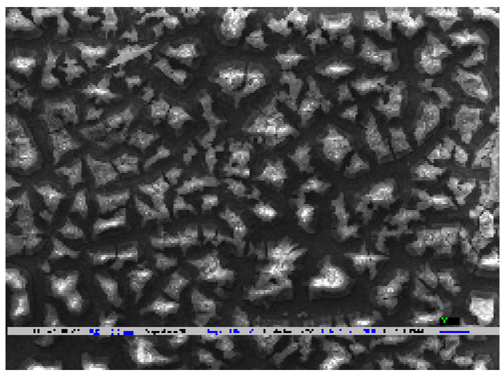

Figure (3) SEM micrographof the surface of porous silicon layer prepared by photoelectrochemical etching.

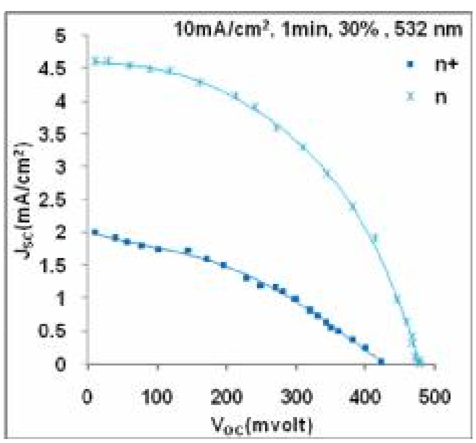

Figure (4) Effect of substrate resistivity on characteristics of nanostructure solar cell.

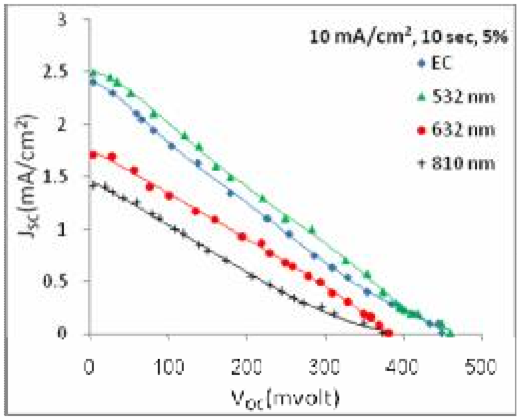

Figure (5) Effect of wavelength on I_{SC}-V_{OC} characteristics of solar cell.

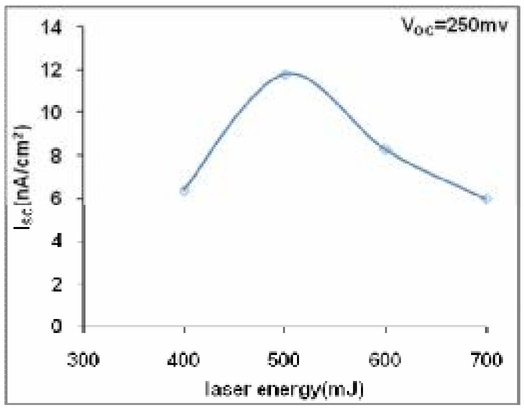

Figure (6) Effect laser energy on short circuit current of solar cell.

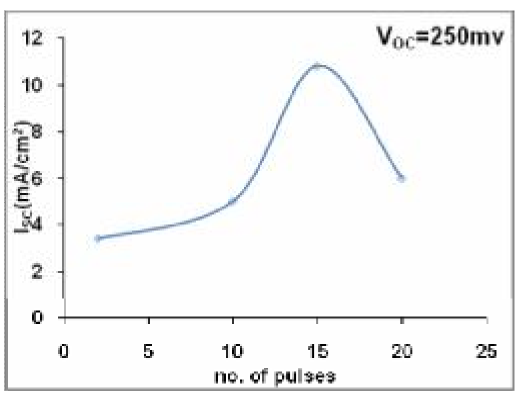

Figure (7) Effect no. of laser pulses on I_{SC} at V_{OC} =250mv.