JOURNAL OF OPTOELECTRONICS AND ADVANCED MATERIALS, Vol. 11, No. 11, November 2009, p. 1632 - 1636

The performance of silicon solar cell with different texturing processes

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A solar cell was fabricated by different texturing methods using pyramids, acidic solutions and porous silicon. Surface morphology and structural properties of porous silicon have been studied by using scanning electron microscopy and atomic forces microscopy images. Optical reflectance was obtained by using optical reflectometer. I-V characterization of fabricated solar cell was investigated. The results showed that the solar cell efficiencies were 2.76 % for pyramids, 3.34 % for acidic solutions and 11.23 % for porous silicon. Porous silicon texturing revealed an excellent reduction in the reflection of incident light compared with different texturing processes, with a good light-trapping of wide wavelength spectrum, which could produce high efficiency solar cells.

(Received September 24, 2009; accepted November 12, 2009)

Keywords: Texturing, porous silicon, Solar cells, High efficiency

1. Introduction

Surface texturing processes are suitable tools to enhance the conversion efficiency of silicon solar cells and to reduce the reflection of incident light. The main problems presented by solar cell fabrication are the elimination of cell surface reflection, dissipation of surface radiation heat, radiation loss, light-trapping of wide wavelength light and simplifing the technological processes for both cheap and high quality material [1].

Porous silicon (PS) is an attractive material for solar cell applications due to its broadening band gap, wide absorption spectrum, wide optical transmission range (700– 1000 nm), and a good antireflection (AR) coating for Si solar cells. It can be used for surface passivation and texturisation [2-7]. One of the promising techniques for PS is an electrochemical process [8-11]. According to the quantum confinement model, a heterojunction can be formed between Si substrate and porous layer due to its band gap (1.8–2.2 eV) compared to crystalline silicon (c-Si) [12]. The utility of PS as an anti-reflection coating in solar cells is well known, but it is impetrated to prepare PS with less defect density in order to improve the solar cell efficiency [13].

This work investigated the increase of silicon solar cell the efficiency by using various methods of texturing designing, patterning and surface etching processes, which are led to obtain the reined structures with very incident optical radiation loss.

2. Experimental procedure

Surface texturing was investigated by using pyramids, acidic solutions ($HNO_3+HF+CH_3COOH$, 15:3:2) and porous silicon texturing. P-type Si wafer, <111> orientation, 0.75 $\Omega.cm$ resistivity and 283μm thickness has been used. The pyramidal texturisation of silicon wafers after silicon dioxidion made square patterned windows which were exposed to UV source. Through the open window in oxide, silicon was symmetrically etched in 48% KOH concentration at a temperature about 80 C^o.

Texturing by chemical etching was used to synthesis the porous silicon, therefore, silicon sample was immersed in acidic solution (HNO_3: HF: CH_3COOH, 15:3:2) at room temperature for 25 minutes. After the etching process, the samples was rinsed in distil water and dried in nitrogen source.

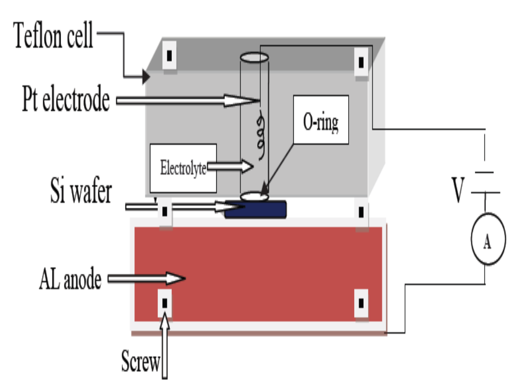


Fig. 1. The electrochemical etching set-up.

For etching porous silicon texturing, the wafer was placed in electrolyte solution (HF: ethanol, 1:3) with current density of 60 mA/cm2 and 30 minutes etching time. Before the etching process, Si substrate was cleaned by the RCA method to remove the oxide layer.

Si wafer was immersed in HF acid to remove the native oxide. The Teflon electrochemical cell was made with circular aperture on its bottom and sealed with silicon wafer. The cell's two-electrode system was connected to the silicon wafer as anode and platinum as cathode, as shown in Fig. 1. The synthesis was carried out at room temperature; all samples were rinsed in ethanol and dried in air after the etching process.

Surface morphology and structural properties of PS were characterized by using scanning electron microscopy (SEM) and atomic forces microscopy (AFM).

Fig. 2 shows the schematic diagram of solar cell based-on PS. Si wafer was doped with phosphorus to become n-type. Aluminum evaporation was used for the back contact and silver metallization for the front. These contacts were annealed under 400 C0 for 20 min.

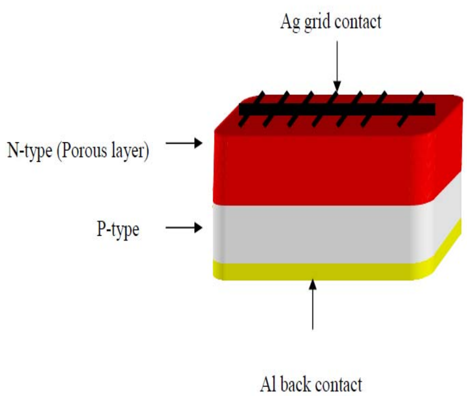


Fig. 2. Solar cells based on porous-silicon.

The fabricated device was examined by using current-voltage (I-V) characterization. Optical reflectance was characterized by using optical reflectometer (Filmetrics F20).

3. Results and discussion

SEM images revealed the surface morphology and microstructure of the surface texturing. Fig. 3 shows the topography of pyramid silicon texturing with pyramid size (100 μ*m*). The effects of acidic solution on surface textures being isotropic texturing are shown in Fig. 4. Fig. 5 shows the random porosity and pore size distribution in different locations. This means that the pore diameter and microstructure depend on anodization conditions such as HF: ethanol concentration, etching time, and current density [14]. Much more homogeneous and uniform distribution of pores could be showed on this sample in comparison to other samples, which were prepared with different electrolyte composition [15]. This distribution could be attributed to the ethanol which acts as an active surface agent: removes hydrogen bubbles during etching, reduces surface tension, and therefore the layers have higher porosity [16].

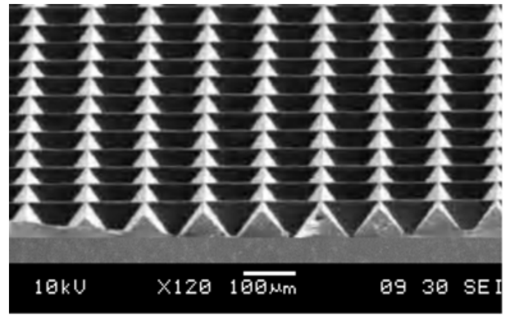


Fig. 3. SEM image of pyramids texturing prepared by KOH etching.

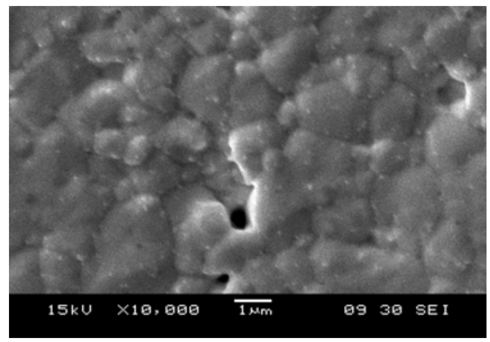


Fig. 4. SEM image of surface texturing prepared by (HNO3:HF:CH3COOH) etching.

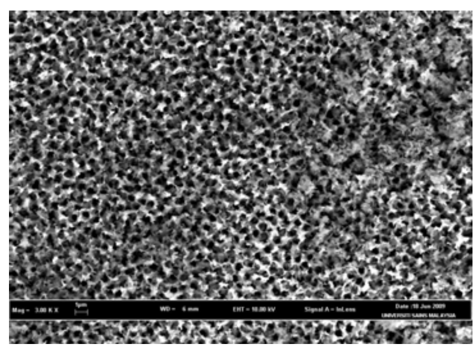
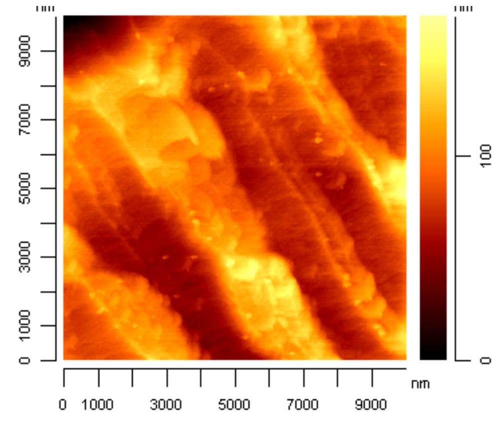
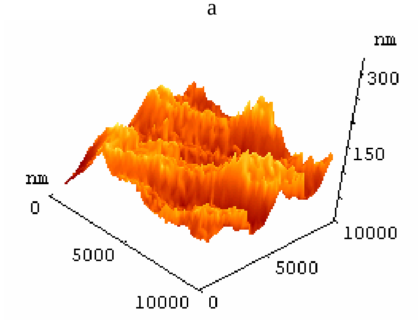


Fig. 5. SEM image of porous silicon.

Fig. 6 shows the statistical distribution of pyramid heights. This histogram distribution is a key parameter in the information about the number of pyramids, uniformity, and the texturing process which has created different size pyramid in non-textured regions. Fig. 7 reveals much smoother surface texturing treated with an acidic solutions compared to pyramids and PS surface texturing which are shown in figures (6) and(8). The high degree of roughness PS with the presence of nanocrystal layer implies the possibility to enhance the photoconversion process due to the high shift processes of luminescent as shown in Fig. 9, which means that the solar cell performance depends on the roughness, reflectance and photoluminescence of solar cell surfaces.



a



b

Fig. 6. AFM images of pyramids texturing.

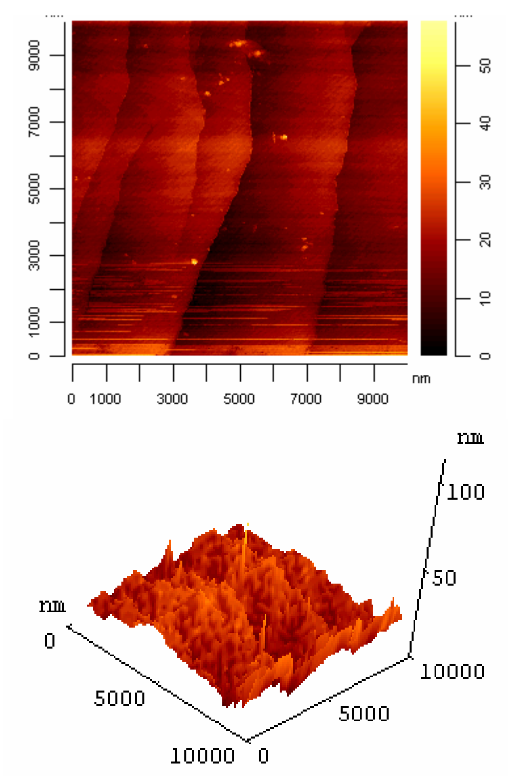


Fig. 7. AFM images of acidic texturing.

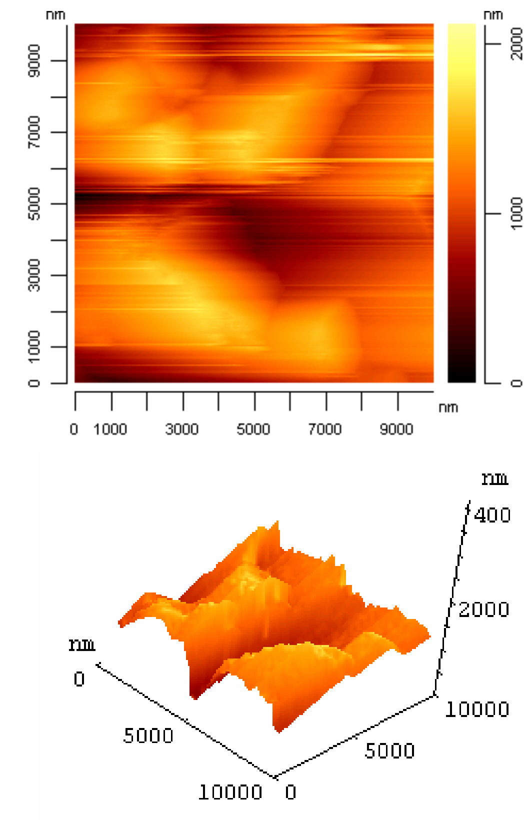


Fig. 8. AFM images of porous silicon.

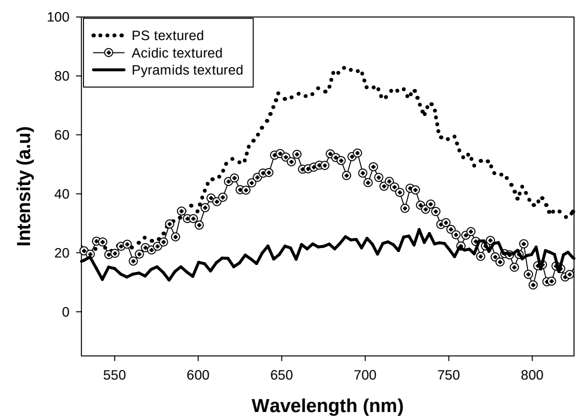


Fig. 9. Photoluminescence spectra of silicon textures by (a) PS (b) Acidic solutions (c) Pyramids

Fig. 10 shows the various surface texturing reflections. PS surface texturing clearly reduced the light reflection and increased the light-trapping upon wide wavelength range compared to surfaces texturing affected with acidic solutions and pyramids due to the reconstructed porous silicon which led to reduce the reflection.

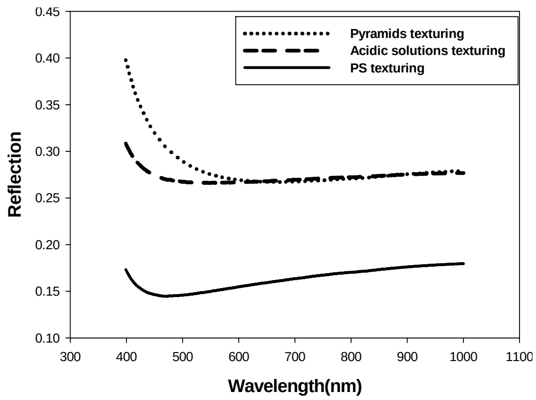


Fig. 10. The reflectance spectra for grown silicon and porous silicon.

The open-circuit voltage Voc, short-circuit current Isc, maximum voltage Vm and the maximum current Im are the prominent parameters, which determind I-V characteristics be used to investigate the solar cell efficiency. The efficiency of the cell at the maximum power point can be calculated as following.

$$\eta = \frac{P_m}{P_{in}} = \frac{I_m V_m}{P_{in}} \quad (1)$$

The fill factor (FF) is

$$FF = \frac{I_m V_m}{I_{sc} V_{oc}} \quad (2)$$

Where, *Pm* is an output power, *Pin* is an incident power.

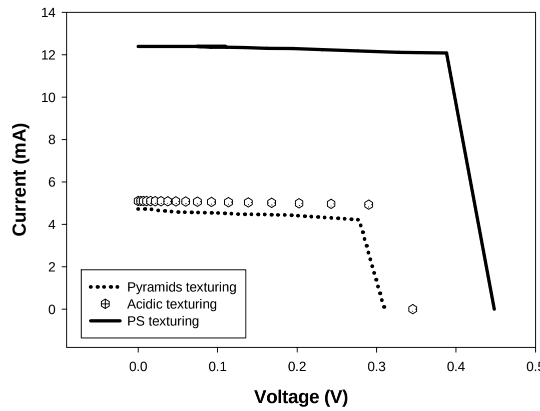


Fig. 11. Current-voltage (I–V) measurements with different methods of silicon textures.

Table 1. Calculations of fill factor (FF) and efficiency (η) *to porous texturing, acidic texturing and pyramids texturing.*

Samples	V_m(V)	I_m(mA)	V_{oc}(V)	I_{sc}(mA)	FF	Efficiency(η)
PS texturing	0.36	12.39	0.44	12.4	82.4	11.23 %
Acidic texturing	0.26	5.09	0.34	5.1	77.23	3.34 %
Pyramids texturing	0.231	4.78	0.309	4.78	74.95	2.76 %

Fig. 11 shows the increased efficiency of PS cell compared with the efficiency of bulk Si cells with acidic solutions and pyramids texturing. This is attributed to the increase in the open circuit voltage without significant loss in the short circuit current of solar cells as shown in Table 1. It can be concluded that the properties of porous surface texturing could be enhanced to increase the conversion efficiency of silicon solar cells.

4. Conclusion

The results improved the high performance of porous silicon texturing solar cell compared to bulk silicon texturing (acidic solution and pyramids) solar cells. In comparison, the output of solar cell efficiencies are 2.76 % for pyramids, 3.34 % for acidic solutions and 11.23 % for porous silicon .It can be explained that only under high qualitative texturing of silicon surface with porous layer the efficiency has increased in terms of minimum optical loss and decreased recombination loss on the surface.

Analysis of the results has given evidence that the increased photocurrent and efficiency are mainly caused by minimum of reflection loss. This advantage correlates to the decrease in the average optical reflection coefficient.

The achievement of photovoltaic conversion efficiency at 11.23% or higher could lead to the reduced cost of large-scale solar to generate electricity, using the electrochemical etching which is a promising and interesting technique for solar cell manufacturing.

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