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Enhancement of Solar Cell Performance Based On Porous Silicon

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ABSTRACT

Recently, nanometer size semiconductors have been a topic of great interest. Chemical etching of silicon produce P-Si layers have a strong link between the details of processing and the optical and electronic properties of the resulting structure. This paper focuses on investigation the affecting of etching time on the, etching rate, electrical properties of Psi layer and photovoltaic properties of PSi/Si solar cell. Good photovoltaic (PV) properties (the fill factor (FF) 0.77, $\Delta\eta$ 28%) was obtain with 80 seconds etching time.

1. Introduction

Silicon is the cheapest semiconductor material and its technology is the most advanced material, well-developed and least expensive compared to the technology of complex other semiconductor and it is one of the most widespread surrounding materials and one of the most common [1]. Silicon based nanocrystallines/nanoporous are some new photoelectronic and informational materials developed rapidly in recent years. For a long time, silicon has been considered unsuitable for optoelectronic applications because bulk silicon emits hardly any useful light due to its indirect band gap nature [2]. This opinion was deeply changed after the discovery of bright emission from porous silicon (PSi) and nanocrystals [3]. PSi was first discovered in 1956 by Uhlir [4] during silicon electropolishing experiments. Since then not much attention was paid to this PSi layer but from the 1990s it has been under extensive investigation after the discovery of the light emitting properties of nano Psi in the visible region by L. Canham [5], who showed room-temperature photoluminescence of an anodized p-type silicon wafer [7]. These results are well understood on the basis of the quantum-confinement model,

$$E = E_o + \frac{3.73}{d^{1.39}} \qquad (1)$$

where the emission energy is shifted towards blue light with respect to the band gap of bulk silicon E0 = 1:17 eV and correlates with the nanocrystallite size d [7]. PSi has great scientific and technological interest because of its ample range of applications. Such material is very promising for application to silicon solar cells, due to its combination of light trapping, antireflection properties and light conversion ability [8].

PSi has emerged as an attractive material in the field of electronics and optoelectronics due to its broad band gap, wide optical transmission range (700–1000 nm), wide absorption spectrum, surface roughening, and lower effective refractive index, which can reduce the reflection losses of sunlight radiation, are the primary factors that enhance PSi compared with c-Si [9,10].

The amount of light reflection from the surface is the main obstacle in efficient solar cell performance because reflection is related to the refractive index of the material. For instance, the silicon refractive index is 3.5 which prevents an electron-hole pair from being generated and could reduce the efficiency of photovoltaic converters. Antireflection coatings (ARC) are able to reduce surface reflection, increase conversion efficiency, extend the life of converters and improve the electro physical and characterization of photovoltaic converters. It is attractive in solar cell applications because of its efficient ARC and other properties such as band gap broadening, wide absorption spectrum, and optical transmission range (700–1000 nm) [11]. In continuous to or work [12-17], herein we try to improving the fatigue life of brass alloy. Comparing with the fatigue life of the sample untreated by LSP, fatigue life is increased by 64% for brass at lower stress level. The fatigue crack initiation and growth of the sample treated by LSP could be restrained more effectively.

2. Experimental Methods

The preparation of the samples involved two steps: first, the preparation of the silicon solar cell starting with highly doped p-type (100) oriented silicon substrate with a resistivity of 0.05–0.1 Ω.cm, p-n junction made by deposed antimony (Sb) thin films on mirror like side of the wafer using thermal evaporation system (Balzer BAE 370) then the sample annealed in vacuum oven (memmert) for (400 °C, 10^{-3} bar), second, preparing PSi layer by cutting the wafer into small pieces, These pieces were rinsed with ethanol to remove dirt followed by etching in dilute (10%) hydro fluoric acid (HF) for a period of about (10 min) to remove the native oxide layer. The samples rinsed with ethanol and left in environment for a few minutes to dry and after that stored in a plastic container filled with ethanol to prevent the formation of oxide layer on the prepared sample. The chemical etching process has been carried out at room temperature.

The chemically etched area for all samples has been of (1.5 cm^2). The PSi was etched in (40% HNO_3, / 40% HF) mixture (1/1) for 20, 40, 60 and 80 s etching time, the samples are ultrasonic treatment during etching with 30 KHz frequency this treatment improve the porous silicon structure [12, 13].

Ohmic contacts of Al thick films were evaporated on both sides of the wafer using thermal evaporation system (Balzer BAE 370) in order to study the solar cell characters. The low resistivity of these wafers enables a good contact between the wafer and its back-side metallic connection (aluminum disk).

Thickness and porosity of the samples were calculated by the gravimetric method. The samples are weighted before etching (m_1), just after etching (m_2), and after dissolution of the PSi layer in a molar KOH aqueous solution (m_3). The porosity and thickness are given by the following equations, respectively,

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$$p\% = \frac{m_1 - m_2}{m_1 - m_3} \times 100 \quad (2)$$

$$d = \frac{m_1 - m_3}{\rho \times S} \quad (3)$$

where ρ is the Si density and S the anodised surface [14].

For current–voltage measurement, a Keithly-616 digital electrometer, Tektronics CDM 250 multimeter and a dual Farnel LT30/2(0 to 5) V power supply were used. The ideal factor (n) and resistivity of the silicon nano structured layer (ρ_{PSi}) are given by the following equations:

$$\rho_{ps} = \frac{dV}{dJ.d} \quad (4)$$

$$n = \frac{q}{KT} \frac{dv}{\ln \frac{dI}{I_S}} \quad (5)$$

where ρ_{PS} is the resistivity of PSi layer in Ω.cm, dV/dJ is the slope of the linear part of J-V characteristic and d is thickness of PSi layer [15].

The illumination was applied under simulated air mass (AM1) condition ($100mW/cm^2$) by halogen lamp type (Philips) with 120W power. This lamp was connected to a variac and calibrated by a Si power meter. V_{OC} and I_{SC} were measured in order to calculate the efficiency (η%) and the fill factor (F.F.) of the nanostructured solar cell using the equations (6, 7) [16].

$$\eta = \frac{P_m}{P_{in}} = \frac{FFJ_{SC}V_{OC}}{P_{in}} \quad (6)$$

$$FF = \frac{P_m}{J_{SC}V_{OC}} = \frac{J_m V_m}{J_{SC}V_{OC}} \quad (7)$$

3. Results and Discussion

The porosity is defined as the fraction of void within the PSi layer which is strongly dependent on the etching conditions [16]. Thickness and porosity measured by using (2) and (3) porosity percentage and thickness of the layer were calculated. The variation of porosity and thickness is shown in Fig. 1 and the numerical values are presented in Table 1.

Table 1 Listed etching time, porosity and thickness

Etching time (seconds)	Porosity (%)	Thickness (μm)
20	34	15
40	42	20
60	60	38
80	70	50

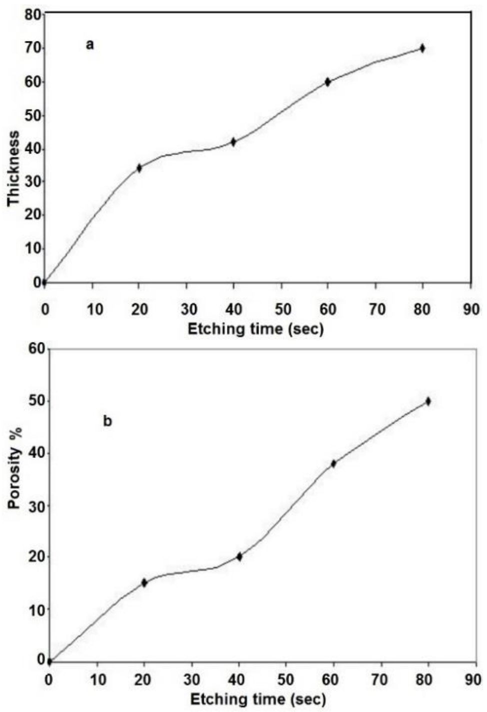

Fig. 1 a) Thickness as a function of etching time and b) porosity as a function of etching time

Fig. 2 shows the I-V dark characteristics in forward direction of PSi/Si solar cell. The forward current is very small at voltage less than 3 V. This current is known as "recombination current" which occurs at low voltages only. It is generated when each electron excited from valence band to conduction band will recombine with a hole in the valence band to get the balance back [23].

In the same figure we can see that the forward dark current decreased. This decrease in dark current can be ascribed to increasing of layer resistance which in turns decreases the thermally generated carriers (v < 3 KT/q) [24].

In Table 2 we can see that the value of ideality factor was found to be 7 for sample prepared at 20 s and about 8.1 for 80 s etching time. The increase of ideality factor with porosity can be attributed to the increase in density of state. This high value can be explained by the formation of high density of states at the sample interface between c-Si and porous Si which acts as recombination centers in the PSi layer (the surface state density of a PSi layer has to be multiplied by a factor of 200–800 according to the ratio of surface area to volume) [25].

The resistivity of the solar cell which is prepared with different etching time are also shown in Table 2, it is clear that the resistivity of porous layer increased by increasing etching time, this increase in surface resistivity is due to increasing in the porosity, and also because the pore trap carriers at its walls and also to increase the density of state PSi/Si interface [26].

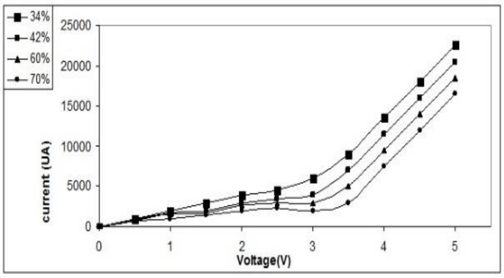

Fig. 2 I-V character of PSi/Si solar cell in different etching time

Table 2 listed results obtained from I-V dark measurement

Etching time (seconds)	Ideality factor (n)	Resistivity (Ω.cm)
20	7	$1.12x10^5$
40	7.3	$1.45x10^5$
60	7.8	$2.03x10^5$
80	8.1	$5.5\ x10^5$

From Table 3 we can see that the FF value increased from 0.73 to 0.77 as the etching time increased from 20 to 80 s and Δη increased from (19% to 28%) with increasing in etching time from 20 to 80 s. This improvement of the PV parameters may be due to the existence of two simultaneous phenomena: surface passivation by Si-H bonds and formation of an anti-reflecting coating.

It is well known [27] that the hydrogen provided by HF improves the short-circuit current and the FF. This phenomenon is amplified by the formation of a PSi layer which, owing to its large internal surface contains an important quantity of hydrogen in surface as well as in volume. The formation of the PSi layer decreases the N'-layer thickness and hence reduce the undesired dead layer.

Table 3 Effect of etching time on the solar cell parameters

Etching time (seconds)	F.F	Δη (%)
20	0.73	19
40	0.745	22
60	0.75	23
80	0.77	28

4. Conclusion

The samples were prepared by chemical etching method with four different etching times. We have studied the dependence of PSi thickness and porosity on etching time. The results show that the porosity thickness increases with etching time increasing, whereas the overall thickness of the PSi layer grows linearly in time. By increasing the porosity, Furthermore, the I-V characters of the prepared samples also study, we found that the ideality factor and the resistance values were increased with etching time increasing. By measuring the FF and the efficiency of the prepared solar cell it was found that the FF value increases 0.73 to 0.77 with etching time increasing from 20 to 80 seconds. Efficiency of the solar cell was and found it increased with etching time increasing reaching 28% that show preparing PSi layer on the top of solar cell is good way to increase the efficiency of this solar cell.

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