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Reflectivity effect of the PS on solar cell efficiency

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1. Introduction

The reduction of silicon through the layer thickness decreasing accompanied by low surface reflection is one of the immediate research challenges in photovoltaic applications [1]. First essential goal for photovoltaic power production is to reach grid parity; two ways exist to reach this goal; higher efficiency and lower production cost. Porous silicon (PS) has more possible applications in photovoltaic and hold potential to contribute to desired development [2]. The used of macro porous silicon is one of multi chooses to prepared thin layer of crystalline silicon with low reflectivity [3]. Porous silicon (PS) is silicon with pores inserted into its complex structure in macroscale sized like sponge structures which are used as high potential anti reflection material due to their enhanced absorption properties. It is fabricated when crystalline silicon wafers are etched photo-electrochemically in hydrofluoric acid HF based electrolyte sol this method can be controlled through several parameters such as current density, power density, etching time and HF concentration etc. [4]. It is a promising material due to the excellent optical, mechanical, thermal properties, chemical stability and the low cost [5] therefore, has a wide range of potential application like photovoltaic devises, chemical sensors, biological sensors etc. [6-10]. Laser assisted etching (LAE) an easy method and no thermal effect, where light or laser illuminated the silicon electrode during the anodization procedure. This illumination leads up to the creation of electron-hole pairs at the top layer due to light absorption, as a result reduction in sizes [11]. PS shows interesting characteristics like low refractive index, good light trapping thereby decreased reflection losses of solar cells; direct band gap, variable reflectivity, randomized morphological structure, and blue photoluminescence make this substance to be interest electric in photo detector applications [12, 13]. The main objective of this work is to study the effect of different illumination of PS formed on solar cell; which plays a significant role in controlling the porous morphology and considered as an important feature for nanostructured anti reflection solar cells.
2. Experimental

PS samples were synthesized via laser assisted etching of (n-type) silicon (100) orientation with a resistivity (10Ω.cm) at constant etching time (8min), power density (20mW/cm2) and current density (10) mA/cm2. The etching method of (n-type) silicon carried out in Teflon cell which does not react with HF showing very offensive nature. The experimental setup is illustrated in figure (1) [14].

![Experimental setup for laser assisted method.](image)

Silicon acts as the anode to remove the electrons from solution and Platinum acts as cathode to provide electrons to the solution. The samples were immersing in (25%) concentration mixture by (HF) acid to ethanol (C2H5OH) (1:1) rate. Ethanol adding to HF to reduce the surface tension of hydrogen bubbles. Thereby it allows the hydrogen gas formed through the reaction to escape and prevents sticking to the etching surface and improves the homogeneity of porous layer [15]. The setup included a (DC) power supply, AVO meter and illumination source (red and green laser diode with wavelength (645nm and 532nm) respectively. The resulting PS layer was studied via scanning electron microscope (SEM) (Tescan VEGA 3 SB), used to weighting measurement for porosity, the Sartorius (BL210S) digital steelyard with reliability of (10-4gm) instrument. reflectance spectra of prepared samples were recorded TF Prop Spectroscopic reflectometer (SR UV-VIS) series, and He-Cd laser was used as a source of illumination, spectra were collected in the wavelength range 400-700nm.

3. Results and discussion

The change of illumination wavelengths was studied based on the analysis of the SEM images. Used fixed each of the illumination intensity 20mW/cm2, etching time (8min) and current density (10mA/cm2) to prepared porous silicon structures. Figure (2) represents the surface morphological with different illumination wavelengths (green 532nm and red 645nm) laser; the following notes can be summarized based on the SEM images, which randomly distributed pores are observed on the silicon surface. Several pores had star fall, connected and circular shape. Figure (2) illustrates the SEM images (top view) of PS, from this images can be notice that the pore width increases with decreasing of illumination wavelength which attributed to increasing of holes’ number on Si surface with short wavelength lead to preferential dissolution between nearest-neighbour pores, thereby promoting the pore-pore overlap. Pores shape in figure (2a) which appearances in non-uniform distribution with thick walls were evidently on the PS surface in multilayer. While figure (2b) illustrates PS layer prepared
under illumination wavelength (645nm), star fall and connected pores were appear in semi uniform distributed shaped, this different of PS structures for each wavelengths; due to the different surface absorption of illumination wavelength and to non-uniform of power density distribution of illumination (attributed to that laser beam intensity will decreased from center to its edges (Gaussian beam)), which lead to non-uniform hole-photo generation consequently. The irregular distribution of pores could enhance the photo conversion as a result of the widened PL peaks.

Figure 2. SEM images of PS layer formed by used different illumination of lasers a) green laser (532nm) and b) red laser (645nm).

Pores shape in fig (2a) which appearances in non-uniform distribution with thick walls were evidently on the PS surface in multilayer. While figure (2b) illustrates PS layer prepared under illumination wavelength (645nm), star fall and connected pores were appear in semi uniform distributed shaped, this different of PS structures for each wavelengths; due to the
different surface absorption of illumination wavelength and to non-uniform of power density distribution of illumination (attributed to that laser beam intensity will decreased from centred to its edges (Gaussian beam)), which lead to non-uniform hole-photo generation consequently. The irregular distribution of pores could enhance the photo conversion as a result of the widened PL peaks. The peak position of photoluminescence spectrum for samples prepared for different lasers; intensity is regularly depending on the quantum size influence in nanostructures because porous silicon is included of Si nano-wires and high energies quantum dots. Highest value of photoluminescence as a result of porosity increased, while the blue shifting of peak position is due to the decreasing of nanocrystallite size for silicon, figure (3) displayed that: The PL intensity has been found to appear at (421 and 419 nm) respectively, indicating that there is a blue shift of the PL intensity and can be note it increased. This behaviour illustrates changed total volume of the nanocrystallites on the surface of PS [16]. The visible range of PL emission and a blue shift with the porosity of PS are strong evidence for a quantum confinement in PS.

![Figure 3. PL spectra of PS samples prepared in different illumination wavelengths (532 and 645) nm at fixed each power density (20 mW/cm²), current density (10mA/cm²) and etching time (8min).](image)

The reflectivity was studied for both illumination wavelengths (532nm) and (645nm) it relies on the surface topography which mean porosity of silicon, it decreased with increased porosity figure (4) illustrates that: The variation of optical properties (reflectivity and refractive index) are generally attributed to porous layer nature, lowest effective reflectance was obtained from PS layer prepared under red illumination wavelength (645nm), figure 4(a) illustrate the reflectivity that decreased from (1.4%) to (0.66%), whereas varied from (1.28%) to (0.64%) in (b), this varied depending on porosity and can be calculated easily via using Looyonga equation (1) [17]:

\[ n_{PS}^{2/3} = (1-p) n_{Si}^{2/3} + p n_{air}^{2/3} \]  

(1)

Where \( n_{PS} \) refractive index of porous silicon, \( p \) porosity of porous silicon, \( n_{Si} \) refractive index of bulk silicon (3.4) and \( n_{air} \) refractive index of air (1.0003), can be determined using reflection spectrum as viewed and using eq. (2) [18], we found the porosity value of green illumination wavelength reach to (88.9%) and for red illumination wavelength about (89.3%).

\[ R= \left(\frac{n_{PS} n_{air}}{n_{PS}+n_{air}}\right)^2 \]  

(2)
Where $R_\text{PS}$ is porous silicon reflectivity at (500nm) So, the refractive index value of bulk silicon can be noted that decreased from (3.4) to (1.217), (1.209) for green and red illumination wavelength respectively this decreasing relies on natural structure of PS layer and controlled by the pores respected to high porosity [13].

![Figure 4 a, b. The reflectivity of PS prepared at different illumination wavelengths a) Green laser (532nm). b) Red laser (645nm).](image)

The peak positions of the reflectance are compared with other reports work and have found good results with enhancement of refractive indices [19, 20]. The effective values of porosity on the reflectivity and refractive index due to fact of effective dielectric constant of porous material system caused decreasing in reflectivity as in antireflection coating for wavelength in range (400-800) nm that is suitable for solar cell applications. The reflectivity effect on solar cell efficiency ($\eta$) can be displayed when $V_{oc}$ equal to (595mV), FF about (0.75) and supposed the $J_{sc}$ equal to $J_{ph}$ which can be determined via eq. (3) [21]:

$$J_{ph} = \frac{P (1-R) \eta \cdot q}{h \nu}$$  \hspace{1cm} (3)

Where $J_{ph}$ Where: ($P_{in}$) is incident power in (Watt), ($R$) the reflectivity of PS layer, ($\eta$) quantum capability, ($\nu$) laser frequency, ($h$) plank fixed and ($q$) electric charge., to calculate the efficiency of solar cell by reflectivity effect at (500) nm region for each (532 and 645) nm illumination wavelengths used eq. (4):

$$\eta \% = \frac{J_{ph} \cdot V_{oc} \cdot FF}{P_{in}}$$  \hspace{1cm} (4)
The efficiency values of PS ARC prepared under (532nm) wavelength reach to (14.25%) larger than red illumination wavelength about (14.23%), this mean increasing the light conversion efficiency of solar cell by tripping of the incident radiation, thereby enhancement the photovoltaic properties.

4. Conclusion

When preparing porous silicon by laser assisted etching for different illumination wavelengths results can be concluded by: The surface topographical properties of porous silicon can be easily and effectively controlled by adjacent the laser wavelength, where the morphology of PS prepared at red laser (645nm) which more regularity than the green laser (532nm). The photoluminescence of porous silicon revealed three peaks with blue shift spectroscopy, that is relates with larger pore sizes and hence larger energy gaps. Enhancement optical properties (reflection) of porous silicon layers have been carried out; therefore, reflectivity of PS much lower than Si reaches to less than 1% we found that the reflectivity effect on solar cell efficiency about (14.25%).

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