Al-Nahrain University, College of Engineering Journal (NUCEJ) Vol.18 No.2, 2015 pp.309 - 314

Fabrication and Investigation of Nanostructured Monolayer Porous Silicon (PSi) Based for Silicon Solar Cell Applications

Saad A. Mohammed Salih
Al-Nahrain University / College of Engineering / Baghdad /IRAQ
Saad91932000@yahoo.com

Mayameen S. kadhim
Al-Nahrain University / College of Engineering / Baghdad /IRAQ
Mayameen.laser@yahoo.com

Abstract

Fabrication of PSi is generated successfully depending upon photo-electrochemical etching process. The purpose is to differentiate the characterization of the PSi monolayer based on c-silicon solar cell compared to the bulk silicon alone. The surface of ordinary p-n solar cell has been reconstructed on the n-type region of (100) orientation in order to enhance the conversion efficiency. The process relied on varying the etching time with fixed current density. The other process conditions were kept constant, for instance, HF concentration, current density, temperature,etc. The role of different laser types and powers illuminated the n-region has been realized. In particular, the blue laser (473nm of two powers 50 and 100mW) appears to be the most operative wavelength to obtain the optimum efficiency and pore sizes as well as the etching rate. The samples were tested and characterized by the (I-V)

Measurement and analyzed by SEM, PL and AFM tests. The obtained solar cell efficiency was in the range of 11% compared to the typical solar cell efficiency which was (3.34%).

Keywords: Nanostructured Porous Silicon; Blue laser; Photo-Electrochemical Etching; Solar cell

Introduction

PSi consists of a network of nanoscale sized silicon wires and voids which formed when crystalline silicon wafers are etched electrochemically or photoelectrochemically in hydrofluoric acid (HF) based electrolyte solution under constant anodization conditions and current densities below those used for electropolishing [1,2]. The history of solar cell started in the late 19th century. In 1954 at Bell Labs, the three American researchers, Gerald Pearson, Calvin Fuller and Daryl Chapin have designed a silicon solar cell capable for energy conversion efficiency with direct sunlight but produced less than a watt of power. The precise control of porosity and thickness allows the tailoring of optical properties of porous silicon and has opened the door to a multitude of applications in optoelectronics technology. Such structures consist of silicon

particles in several nanometer size separated by voids. Hence, porous silicon layers are regarded as nanomaterials [3].

The output power of a solar cell is the product of the output current delivered to the electric load and the voltage across the cell. The value of the power at the short circuit point is zero, because the voltage is zero, and also the power is zero at the open circuit point where the current is zero. However, there is a positive power generated by the solar cell between these two points. It also happens that there is a maximum of the power generated by a solar cell somewhere in between. This happens at a point called the maximum power point (MPP) with the coordinates:

$V = V_m$ and $I = I_m$.

The Fill Factor parameter (FF) is introduced as an important parameter defined as the ratio between the maximum power $P_{\max}$ and the $V_{oc} I_{sc}$ product:

$$FF = \frac{P_{max}}{V_{OC} I_{SC}} \quad \text{.... (1)}$$

The fill factor has no units, indicating how far the product $V_{OC} I_{SC}$ is from the power,

Resistance result in to higher fill factor and thereby to larger efficiency delivered by the solar cell. In other words, the fill factor defines the portion of electrical power produced in solar cell in load [4,5,6,7].

The fill factor determines the shape of the solar cell I-V characteristics. Its value is higher than 0.7 for good cells. The fill factor is useful parameters for quality control test.

The power conversion efficiency η is defined as the ratio between the solar cell output power and the solar power impinging the solar cell surface (*Pin*). This input power equals the irradiance G multiplied by the cell area:

$$\eta = \frac{P_m(V_m I_m)}{P_{in}} = FF\frac{V_{oc}I_{oc}}{P_{in}} \quad \frac{V_{oc}I_{oc}}{G \times Area} \quad \text{….. (2)}$$

As can be seen the power conversion efficiency of a solar cell is proportional to the value of the three main photovoltaic parameters: short circuit current density, open circuit voltage and fill factor, for a given irradiance *G*.

the series and shunt resistance of solar cell influence on the fill factor. Increase of shunt resistance and decrease of series

The PSi pore diameter can be calculated from the following equation [42]:

$$E_{gPSI} = E_{gSi} + \frac{h^2}{8d^2}\left[\frac{1}{m_e^*} + \frac{1}{m_h^*}\right] \quad \text{….. (3)}$$

where E_{PSi} is the energy band gap of the PSi layer calculated from the PL peak graphs , E_{gSi} is the energy band gap of bulk c-Si, h is Planck's constant equal to (4.13×10-15 eV·s), m_e^* and m_h^* are the electron and hole effective masses, respectively. At 300 K, (m_e^* = 0.19 m_o, m_h^* = 0.16 m_o, and m_o=9.109x10^{-31} kg).

This parameter shows how much thickness observed during the process i.e., how much etching from the c-silicon during a certain time as illustrated in the following equation [27].

$$Etching\ Rate = \frac{d}{t} \quad \text{….. (4)}$$

Experimental Setup

All samples were formed on n-type region of a p-n junction silicon single crystal wafers of 420 µm thickness, (100) orientation and 1-10 Ω.cm resistivity. The steps of preparation and process were performed as follows:

1. Before etching process, the samples were sliced into pieces of (1×1.5 cm) ,i.e., of area (1.5 cm^2) which is suitable for the area of the 0-ring in the Teflon cell (0.5 cm diameter). Thus the anodized area would be 0.1963 cm^2 which was illuminated by the laser light simultaneously.
2. These samples then rinsed with ethanol to remove any dirt hence immersed in diluted (10%) Hydrofluoric acid (HF) for 10 min to remove any native oxide layer . This is followed by rinsing with ethanol again and left for a few minutes in the ambient atmosphere to dry, thus maintaining these samples immersed and stored in a plastic containers filled with methanol to prevent the formation of oxide layer once again at their surfaces.
3. The samples placed one by one in the bottom of cylindrical Teflon cell and fixed by stst plate as a backing material which are considered as the Anode. A platinum mesh rod, as a cathode, was placed perpendicular to the Si surface at a distance of 1 cm. The resulting samples were obtained by varying the current density at a constant etching time or vice versa in a solution of concentrations 48% HF, 99.90% ethanol and deionized water ($HF:C_2H_5OH: H_2O$) at a volumetric ratio of 2:3:3 respectively.

This solution mixture was approached after several experimental work trials to explore the most suitable ratio for the purpose of this work.

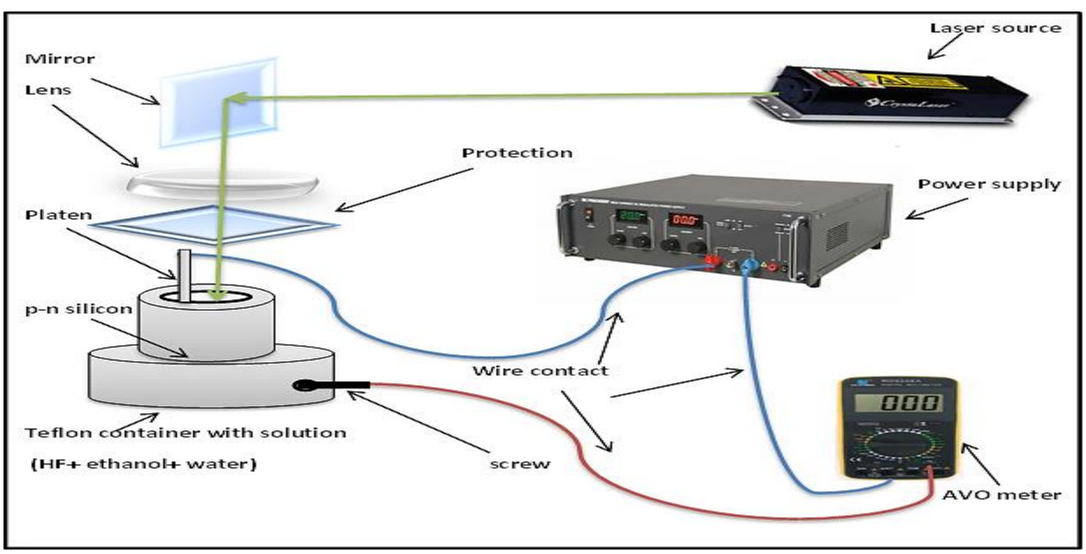


Figure 1: The PEC system (schematic diagram)

Measurements Categories

For the purpose of this work, measurements can be categorized into three main divisions:

i. Electrical Measurements: as I-V Characteristics, current density Measurements.

ii. Surface Morphology: the following tests have been applied :
   a. SEM (Scanning Electron Microscopy).
   b. AFM (Atomic Force Microscopy)

Result and Discussion

In Figure 2, the curve shows the i-v characteristics of samples determined when employing different laser diodes available; the results for treatment would be shown in table beneath this graph depending on equations (1) & (2) respectively

.

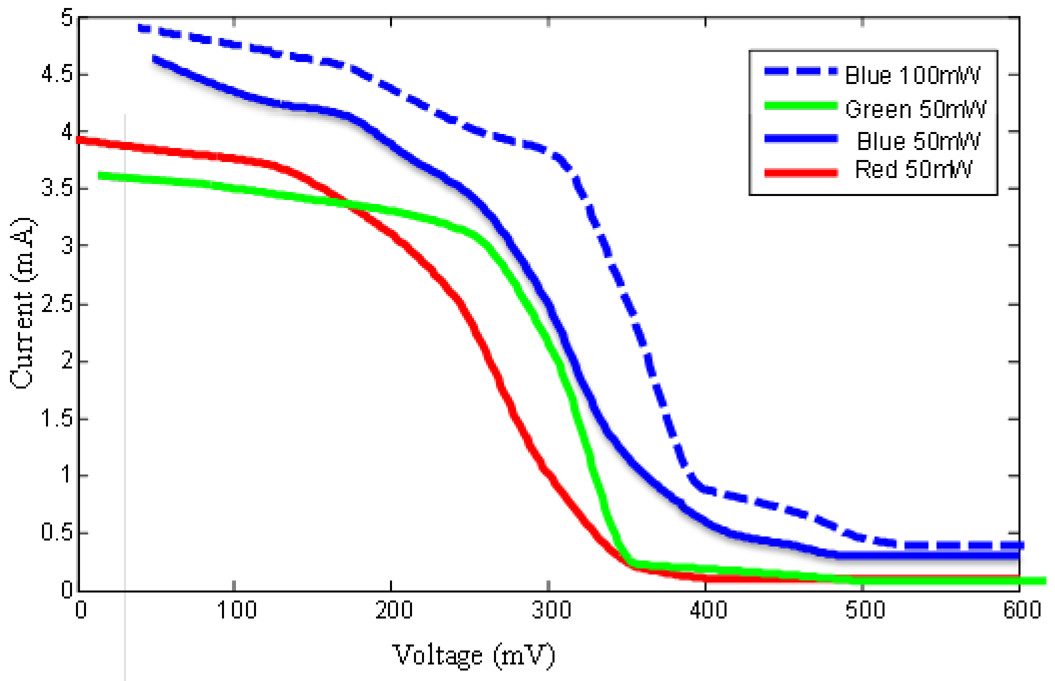
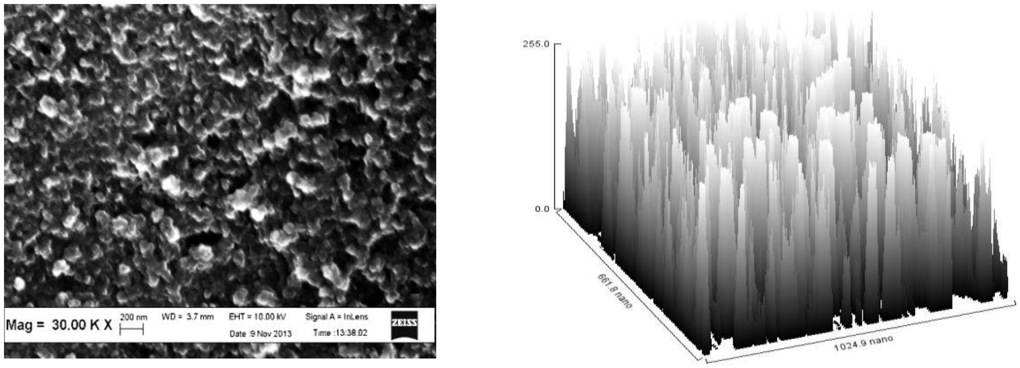


Figure 2: Electrical characteristics of the nanostructured solar cells produced at different wavelengths (473,532 & 671) nm at {50&100mW} powers.

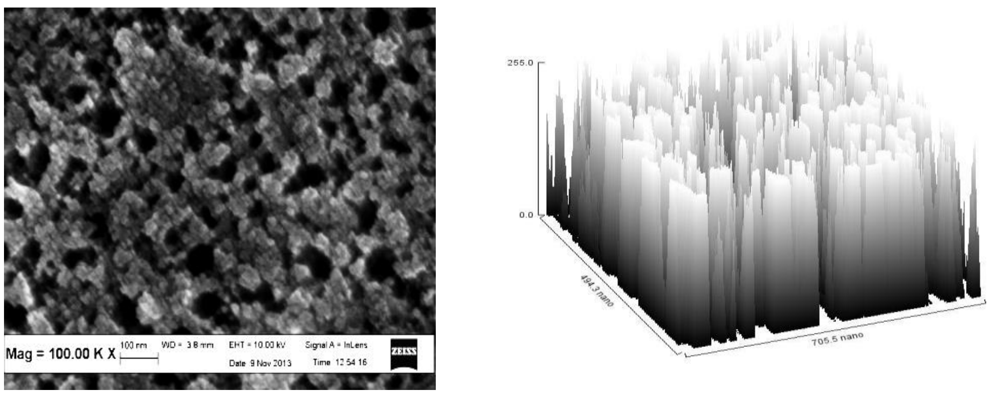
Table 1 : I-V measurements of solar cells of c- Si and that of PSi layer formed on the n-type region with the assistance of different laser wavelengths and powers.

Sample	Type of laser	V_m (mV)	I_m (mA)	V_{oc} (mV)	I_{sc} (mA)	FF	Efficiency(η)%
Bulk Silicon	/	292	6.03	370	6.04	0.79	3.34%
PSi	Red	225.6	2.935	305.9	3.701	0.58	6.6213
PSi	Green (50mW)	266.9	3.147	347.2	3.76	0.643	8.39
PSi	Blue (50mW)	241.1	3.491	351.2	4.327	0.553	8.416
Psi	Blue (100mW)	297.3	3.832	400.3	4.718	0.603	11.3925



(a) (b)

Figure 3: (a) SEM images (top-view) of (nPSi) layers prepared with blue laser (50mW) at etching time(15 min). (b) The surface plot of the of the nanostructured solar cell



(a) **(b)**

Figure 4: (a) SEM images (top-view) of (nPSi) layers prepared with Green laser (50mW) at etching time(25 min). (b)) The surface plot of the of the nanostructured solar cell

The AFM images show good relative homogeneities of PSi pores after using the assisting lasers so that to give an idea about the PSi surface roughness that shows a precise picture of the surface formation.

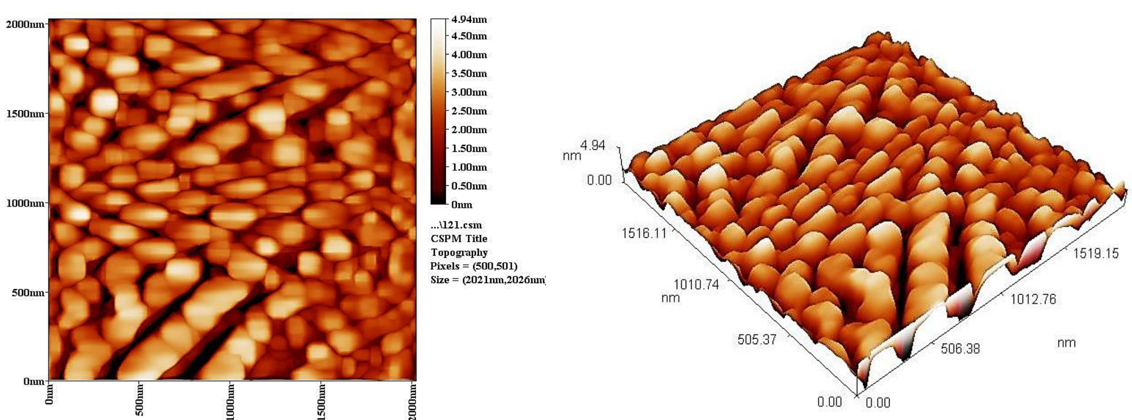


Figure 5: AFM image of porous silicon monolayer prepared at J=15 mA/cm^2etched under 15 min and blue laser=50mW

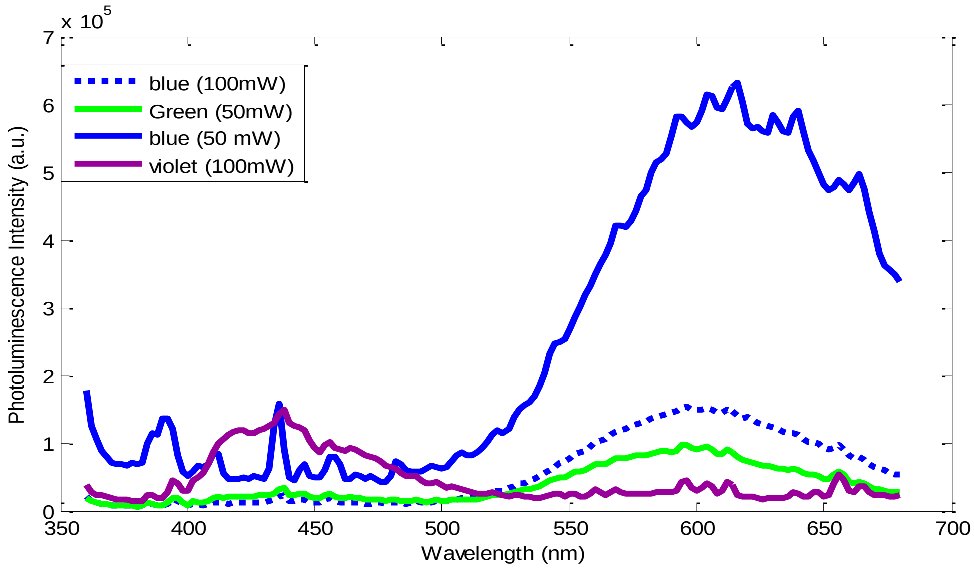
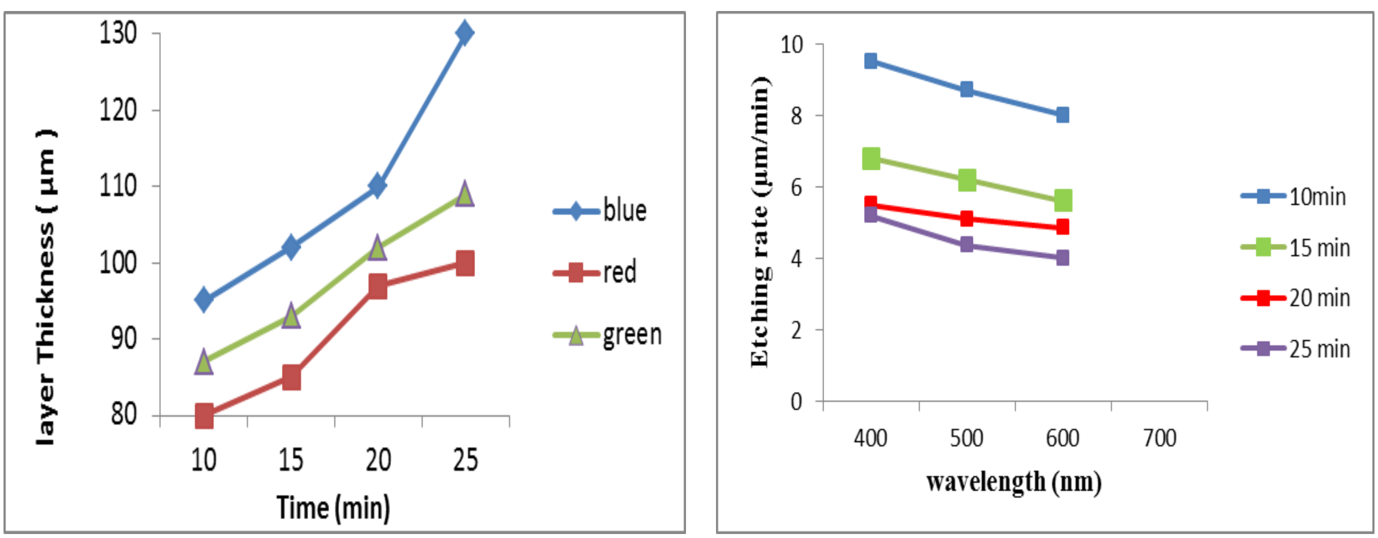


Figure 6: Photoluminescence spectrum of the p-n junction porous sample prepared by different lasers (Blue, Green ,Violet) at 15min.

Table 2: Results of PL tests illustrating the band–gaps and the pore diameters of the PSi layer of different wavelengths applied under the PL intensity peak values at 15 min iodization time**.**

No	Wavelength (nm)	λ at peak intensity(*nm*)	$Eg_{ps\,i}$(eV)	Pore diameter (*nm*)
1	405 (100mW)	438	2.829	3.97
2	473 (50mW)	596	2.079	5.3009
3	473 (100mW)	596	2.079	5.300
4	532 (50mW)	596	2.079	5.3009



(a) **(b)**

Figure 7: (a) The PSi layer thickness as a function of etching time with different laser wavelengths at (50mW), **(b)** The etching rate as a function of wavelengths at different times (10, 15, 20& 25)min. The data obtained from the SEM and the surface plot program**.**

Figure (7- a&b) shows the proportionality of the layer thickness with time and the inverse proportionality of etching rate with different laser wavelengths and different times. Obviously, Figure (7-a) gives an assurance of the dominancy of the blue laser among the other wavelengths to produce higher PSi thicknesses at the exact giving times.
On the other hand, Figure (7-b) gives rise to the interesting idea that there must be a limit for the laser wavelengths used to assist the PSi formation which needs more studies.

Conclusion

In this work a porous silicon (PSi) layer has been successfully formed on the n-region of the p-n junction solar cell (c-Si) wafer using a photo-electrochemical etching method with the assistance of different laser wavelengths and power densities. The new junction formed exhibits electrical and optical properties similar to those of semiconductors with a direct energy band gap. The main improvement in the performance of the PSi is the layer thickness, pore diameter and the peak efficiency obtained (11.4%) compared with the ordinary solar cell (3.34%).
Structural and optical characteristics of the PSi layer have been studied using several testing techniques of different accuracies as, SEM, PL and AFM. These techniques reveal the micro and nano structures of the PSi layer as well as the pore sizes and the surface roughness formed. They reveals the homogeneity of PSi surface for the blue laser particularly. Using lasers with different wavelengths and powers has been approved to be one of the important parameters in the process. The dominancy of the blue laser(473nm) over the other laser applied wavelengths was very obvious for the cell efficiency and the monolayer thickness.

References

[1] Magentharau Adin Naraina , " **Preparation Of Porous Silicon By Electrochemical Etching In The Fabrication Of A Solar Cell**", Thesis Submitted To The School Of Graduate Studies, University Putra Malaysia, Dec. (2003).
[2] P. Panek, M. Lipinski & H. Czternastek, "**Psi Layer As Anti-Reflection Coating In Solar Cells**", Optoelectronics Review, 8(1), 57-59, (2000).
[3] K. Salman & Z. Hassan, **"Effect Of Silicon Porosity On Solar Cell Efficiency",** Int. J. Electrochem. Sci., 7, P376 - 386, (2012).
[4] Tom Markvart, **"Solar Cells: Materials, Manufacture And Operation"**, Elsevier Ltd.,(2006)
[5] Y. Zaidan Dawood, **"Preparation of porous silicon and it's application in solar cell",**PhD thesis,University of Technology,(2009).
[6] Tayyar Dzhafarov, "**Silicon Solar Cells With Nanoporous Silicon Layer**", Department Of Solar And Hydrogen Cells, Institute Of Physics, Azerbaijan National Academy Of Sciences, Azerbaijan, (2012).
[7] O. Bisi, S. Ossicini & L. Pavesi, **"Porous Silicon: A Quantum Sponge Structure For Silicon Based Optoelectronics",** Elsevier, Surface Science Reports 38, (2000).

التحقق من الخصائص الكهروضوئية للسلكون المسامي

سعد عبد العزيز محمد
جامعة النهرين / كلية الهندسة
قسم هندسة اليزر والاتصالات

ميامين سلمان كاظم
جامعة النهرين / كلية الهندسة
قسم هندسة اليزر والاتصالات

الخلاصة :

هدف هذه الدراسة تحضير طبقة السلكون المسامي على الوجه (n) من مفرق (p-n) المكون للخلية الشمسية الذي تكون الاضاءة من متطلبات التفاعل عنده ثم التحقق من امواصفات الجديدة للخلية الشمسية بعدة وسائل مختلفة مثل : SEM و PL و AFM. استعمل في التحضير خليط من حامض الهيدروفلوريك والايثانول اضافة الى الماء بنسبة (2:3:3) وضوء الليزر باطوال موجية و قدرات مختلفة في خلية مصنعة محليا من التفلون فيما يسمى طريقة التنميش الضوئي- الكهروكيميائي وضع السلكون فيها كقطب الانود اما الكاثود فكان من البلاتينيوم. هنالك عوامل متعددة تؤثر في هذا التفاعل اخترنا اهمها وهو زمن التنميش (25,20,15,10) دقيقة في حين ثبتنا بقية الاعلومات. برز الليزر الازرق (473nm) كافضل انواع الليزرات المستعملة التي اعطت افضل النتائج العملية من ناحية الكفاءة و سعة الفجوات ومعدل التنميش. كانت النتائج مشجعة اذ كانت كفاءة الخلية الشمسية الجديدة اكثر من (11%) مقارنة بالخلية السلكونية الاصلية التي كانت (3.34%).