Fabrication of Light Trapping Thin Film Structure for Efficient Si Solar Cell by Laser Treatment

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Abstract: ***Surface texturization became known as an important field of research with a broad range of applications in solar cells, electronics, and sensors. In this work, short-pulse Nd:YAG second harmonic nanosecond laser with different energies (600,700,800 and 900mJ) has been used to produce micro- and nano-scale surface textured patterns in a thin SiO_2 film formed on the (100) orientation of c-Si solar cell substrate of small areas (2×1 cm^2). The topography of laser textured surfaces were investigated depending on several test devices as FTIR, optical microscopy and AFM. The electrical parameters of manufactured solar cells were characterized by measurements of I-V parameters illuminated under standard AM 1.5 radiation. Results show a very good improvement of the efficiency of the solar cell textured by this method. This is achieved by (9.6%) efficiency compared with (3.34%) for the ordinary silicon solar cell when applying (900mJ) laser energy.***

Keywords: Textured Surface; Second Harmonic Laser; Light Trapping; Solar Cell

1. Introduction

Surface texturing plays a critical role in silicon solar cell performance, affecting both reflectance and light trapping [1]. Texturing causes reflected light to strike a second surface or more before it can escape, increasing the probability that the light will be absorbed [2].

The silicon substrate is the single most costly component in the solar cell.High efficiency crystalline solar cells must improve performance while replacing higher cost crystalline silicon with lower cost configuration. Thin film solar cells have several advantages compared with crystalline silicon based solar cells such as low material consumption, simple manufacturing processes, and the possibility to use flexible substrates [3]. In crystalline or amorphous silicon solar cells, light trapping is used to reduce the thickness of the cell without lowering the light absorption within the cell.

The new structure depends on passivated thin layer of silicon dioxide grown via dry thermal oxidation.A textured front surface with SiO_2 passivation layer has good light capture properties to allow the light to enter the cell[4]. A parameter called Fill Factor (*FF*) is defined as the ratio between the maximum power $P_{max}$and the $V_{oc}I_{sc}$product :

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

The fill factor has no units, indicating how far the product V_{OC} I_{SC} is from the power, and it determines the shape of the solar cell I-V characteristics. Also it is a useful parameter 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 multiplied by the cell area:

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

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* [5].

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:

$$V = V_m \text{ and } I = I_m \qquad [6].$$

In comparison with mechanical machining and chemical treatment, the laser offers perfect process control for silicon solar cells treatment, i.e., because it allows localized modifications with a large degree of control over the shape and size of the features that are formed. The dominating sources used for PV-related processes are solid state lasers. This is due to the demand of simultaneously delivering high power, top beam quality, and maximum repetition rates, all of which are needed to realize high processing speeds together with high resolution. Up to now, the laser equipment of research institutes as well as solar cell producers mainly consists of neodymium-doped rod made of YAG or Vanadate [7].

There are two important laser parameters may be the most affecting in the texture process which are the wavelength and the pulse duration (*tp*). Besides, choosing the lasers that are compatible with the passivated surface in this work. For radiation-silicon interaction, these parameters can be characterized by the optical penetration depth, *l*a, and the thermal diffusion length, *ld(t)*.

The thermal diffusion length, *ld(t),* can be approximated as:

$l_d(t) = 2\sqrt{K\,t}$ ………..(3)

In this equation, *K* is the thermal diffusivity and *t* is the diffusion time[52].

A wave number period :

Dk = 1 / 2nd ……..…(4)

Where *n* is the refractive index and *d* is the thickness of the sample (layer). If the refractive index is known thickness can be calculated and vice versa. For example, assuming n = 3.4 for silicon, the thickness works out to be 8.4mm[8].

2. Experimental Setup

All samples were formed on n-type region of a p-n junction silicon single crystal wafers of (100) orientation. The steps of preparation and process were performed as follows:

1) Before texturing process, the samples were sliced into pieces of (1×2 cm) , i.e. , of area (2 cm^2).
2) These samples should be cleaned for processing so they rinsed with ethanol to remove any dirt and left to dry.
3) The samples then exposured to air and because of moist, by the interaction with oxygen in air, and by the assistance of laser thermal energy according to equation :

$$2Si + O2 \xrightarrow{Laser} SiO2$$

The silicon dioxide (SiO_2) layer was formed, thus, considered as a thin dielectric filmdeposited onto Si wafer.

4) The green Nd:YAG laser radiation (λ = 532 nm , pulse width = 10 ns) was applied as pulses to each sample separately with different energies (600,700,800,and 900) mJs.
5) Multiple pulses were applied to each sample to cover as large area as possible with careful choice of their location that non-overlapped pulses may be utilized on the area of treatment as there is no X-Y table available to stand for every single pulse precisely.

Figure 1: Nd: YAG laser device

3. Measurements Categories

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

1) FTIR measurement
2) Electrical measurements: I-V Characteristics.
3) Surface Morphology : the following tests have been applied
   a) Optical microscopy (Image analyzer)
   b) AFM (atomic force microscope)

4. Result and Discussion

In Figure 2, the curve shows the i-v characteristics of samples determined when employing Nd:YAG laser with energy 900mJ ; and the results for treatment when employing different laser energies would be shown in table beneath this graph depending on equations (1) & (2) respectively.

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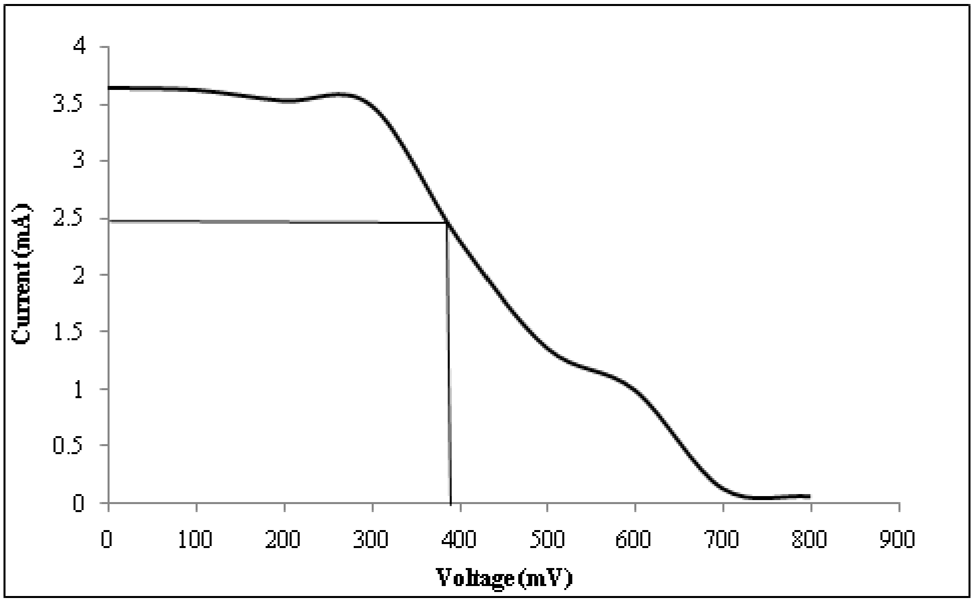

Figure 2: Current-Voltage characteristics of the solar cell textured surface produced under laser power density of 4.5×10^{12}mW/cm^2 (900 mJ).

Table 1: I-V measurements of solar cells of c- Si and that of texture layers formed on the n-type region with the assistance of different laser energies.

E(mJ)	V_m (mV)	I_m (mA)	Voc (mV)	Isc (mA)	FF	Efficiency%
Bulk silicon	292	6.03	370	6.04	0.79	3.34
600	350	2	500	3.164	0.44	6.96
700	350	2.2	500	3.394	0.45	7.63
800	350	2.3	500	3.564	0.45	8.01
900	390	2.5	600	3. 652	0.44	9.6

Figure 3: Shows spectroscopy image of this sample that treated by laser exhibit good indications of the laser pulse effects for retexturing the solar surface.

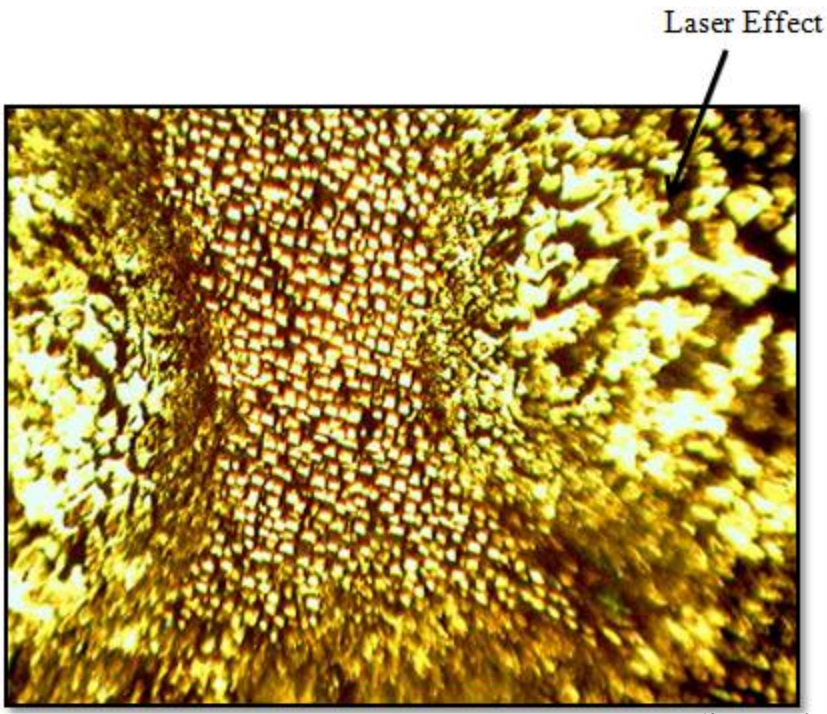

Figure 3: Image of optical microscope for laser power density of 4.5×10^{12}mW/cm^2 (900 mJ)

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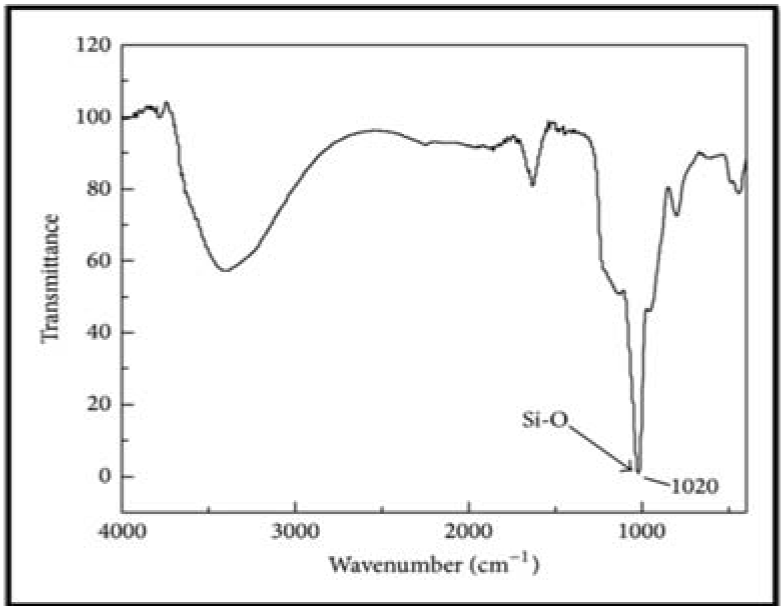

Figure 4: FTIR transmission spectrum of a silicon wafer covered by SiO_2 thin film

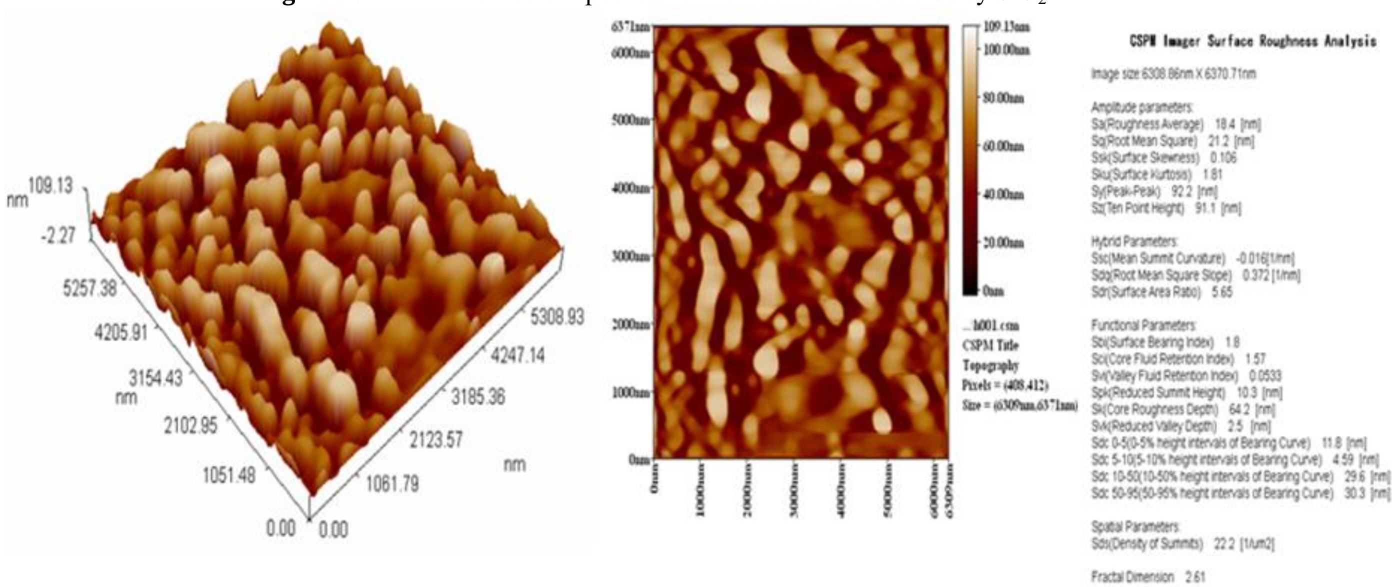

Figure 5: 3D and 2D AFM image of textured surface for laser power density of 4.5×10^{12}mW/cm^2 (900 mJ) and its Granularity Cumulation Distribution Report

Granularity Cumulation Distribution Report

Sample:900	**Code:**Sample Code
Line No.:lineno	**Grain No.:**547
Instrument:CSPM	**Date:**2016-04-10

Avg. Diameter:87.97 nm	<=10% Diameter:40.00 nm
<=50% Diameter:85.00 nm	<=90% Diameter:135.00 nm

Table 2: Texture surfaces roughness vs. different laser intensities applied

No.	Laser intensity mW/cm^2	Average surface roughness (nm)
1	3×10^{12}	2.94
2	3.5×10^{12}	1.62
3	4×10^{12}	2.08
4	4.5×10^{12}	18.4

This table shows the comparable values of surface roughness for the first three intensities applied and the jumped value as the laser intensity approached the fourth number which is the best value compared with the lower intensities.

Figure 5: Shows the proportionality of laser intensity applied for texturing and the efficiency concluded for each sample

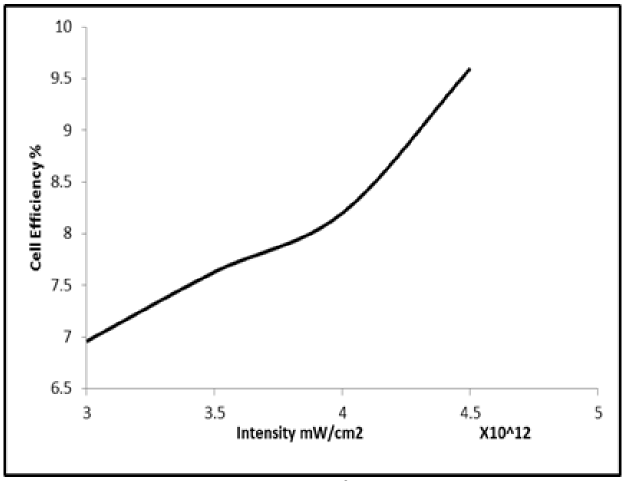

Figure 5: Laser intensity mW/cm^2 of the textured surface as a function of cell efficiency%

5. Conclusion

In this work, a surface texturization has been successfully formed on <100> n-region of the p-n junction solar cell (c-Si) wafer using the Nd: YAG second harmonic nanosecond laser pulses with different energies and accordingly an energy fluence exceeding the threshold of the SiO_2 thin film over the silicon substrate. The formed laser texture surface permits more absorption of light, hence, improving the efficiency of solar cell by good percentages. The main improvement in the performance of the c-Si solar cell is the peak conversion efficiency were obtained (~ 9.6%) compared with the ordinary solar cell (3.34%).

Structural and optical characteristics of the textured surface has been studied using several testing techniques of different accuracies as optical microscopy, AFM and FTIR measurements. These techniques reveal the nanostructures of the textured surface as well as the heights and the surface roughness formed. Using lasers with different wavelengths and powers has been approved to be one of the important parameters in the process. The dominancy of the second harmonic Nd:YAG laser (532nm) energy of 900 mJ over the other laser energies was very obvious for the cell efficiency .

6. Future Scope

It is recommended to apply other types of short and ultra-short lasers (different durations) to understand their effects on the cell surface andthe thin film. Besides, applying other dielectric materials as thin films might be essential to compare with SiO_2 thin film.

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