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Impact of laser surface modification on polycrystalline silicon photovoltaic cell by means of CO_2 laser

Abstract

In this research, we investigate the effect of laser texturing on the photo-electrical properties of the polycrystalline silicon solar cell. Laser surface texturing technique was used to achieve the texturing results, which based on the interaction between pulsed CO_2 laser (10.6μm) and polycrystalline silicon used for solar cells. Four of photovoltaic solar cells have been textured in two dimensions in different ranges (1 cm x 1cm and 2 cm x 2 cm) with different line spacing. Solar cells with laser-modified surface were characterized by SEM as well as photo-electrically before and after texturing process. The obtained results showed that laser surface texturing with small grooves spacing, results in increasing of the melted silicon surface area which enhance the silicon electrical properties. Furthermore, it increases the optical path length inside the solar cell which enhances light trapping.

Keywords: CNC machine, laser direct writing, laser processing, photovoltaic, poly Si - solar cells

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Introduction

Renewable resources such as solar energy are clean, safe and give much lower environmental impact than conventional energy sources. Solar cells are made of semiconductor materials such silicon and it's the main material in photovoltaic devices. Mono-crystalline silicon solar cells are more expensive than poly crystalline silicon because of its best electrical properties. While, poly silicon solar cells consists of small grains of a single crystal so it's cheaper and easier to manufacture than mono-crystalline cells because of the lower purity of the raw material, but it is less efficient so to decrease the manufacturing cost. Therefore, intense research is being performed to polycrystalline silicon and looking for how to increase the efficiency of polycrystalline silicon photovoltaic.[1]

The main factor effect on solar cell efficiency are light wavelength, light density, optical path and surface modify. Surface modification either with chemical coating or by surface texturing can used to reduce reflection. Laser surface texturing has many benefits due to non contact process. Moreover, it can used without any additional coating, Surface texture increase the chance of incident light to meets the solar cell surface and thus considerably penetration of light into the solar cell increased, and optical path length inside the solar cell increased too. In 2013 Antanas VINČIŪNAS et al.,[2] utilized novel Laser Beam Interference Ablation techniques to produce surface textures in poly-Silicon solar cells surface. They reported that the reflection from the textured surface was minimized to 14%.[2] Marouf et al.,[3] demonstrated that used UV femtosecond laser pulses in texturing silicon cell surface had excellent effect on the spectral response and electrical properties of solar cell.[3]

Laser texturing utilized for different purposes such as enhancing of the performance of the electrochemical cells.[4] Because of lasers have high-power and with low divergence, and enough power density it produce heating spot at a constant temperature in a fixed position. Therefore, laser material irradiation could produce new crystal structure in the material.[5–10]

In this work, we have investigated the impact of laser melting on the polycrystalline silicon solar cell efficiency improvement as well as the groove spacing and the textured area by texturing of its surface using CO_2 laser.

Experimental

Sample preparation

The silicon solar cells samples were a collected from National Energy Research Center, Soba, Khartoum, Sudan (NERC-SOBA SOLAR). With specific size (15.6×7.8) cm^2, Thickness (Si) 240 μm ±40 μm. Solar cells were texturized by means of CO_2 laser with output power 30W, pulse duration 200μs, pulse frequency (υ) 5 KH, and textured speed 100mm/s. Irradiation process was done using CO_2 laser CNC machine manufactured in China by RISE Company. CO_2 beam delivered by using optical elements (reflection mirrors, quartz lenses have focal length 15mm to focus laser spot size. The lines of irradiations were separated with 0.5 mm & 0.25 mm, in two dimensions in two different ranges namely 1 cm x 1cm and 2 cm x 2 cm. The procedures above were repeated with each solar cell.

Measurements

SEM Imaging

The SEM was used to study surface morphology of the textured photovoltaic solar cells. It was conducted by means of SEM manufactured by JEOL Ltd. Tokyo, Japan.

Photo-electrical measurements

To study the electrical properties of the solar cell, the setup below used to carry out the IV characteristics curve of the texturized solar cell. Tungsten light source was fixed over the solar with distance (D) equal to 40 cm and the electrical circuit shown in Figure 1 was connected to study the electrical properties of each solar cell,

Results and discussion

Results of SEM

Figure 2 show the high-precision removal of layers with thickness in the range from sub -μm to mm. It also showed that the irradiation process leads to the formation of Micro- Nano structure on substrates. Moreover, it depicted that the CO_2 laser energy is absorbed near the surface and modified the polycrystalline silicon into melted silicon by the laser thermal effect. This melted silicon might be crystalline silicon with best electrical properties, so we could not ignore the impact of the thermal interaction of the laser on the crystal structure of the polycrystalline silicon; which can contribute in the enhancement of the cell performance.

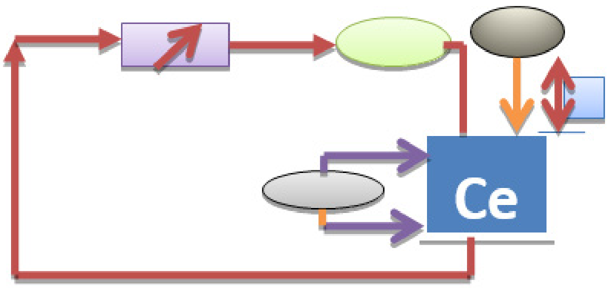

Figure 1 Schematic diagram of the experimental setup of solar cell (with & without surface texture) IV curve measurements.

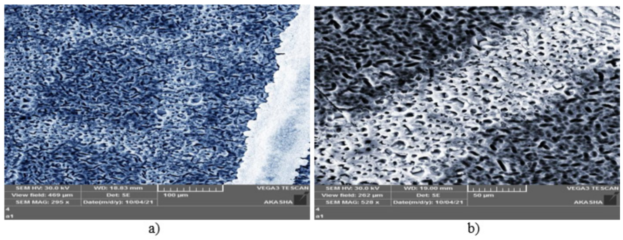

Figure 2 SEM images of two dimensions texturized sample a) 100 μm, b) 50 μm.

Results of I-V characteristics

The obtained results of IV characteristics curve of the solar cells without texturing and with texturing were compared. The effect of the laser texturing on solar cell parameters were also studied and compared.

Table 1 shows the operational properties for the five cells before and after laser surface texturing. Table 2 shows the Percentage increase in the cells' fill factor and efficiency. The percentage of the textured area 1x1 cm2 and 2x2 cm^2 were calculated to be = 0.0082% and 0.032%, respectively.

Table 1 Operational properties for the five cells before and after laser surface texturing

Type of solar cell		Voc (mV)	Isc (mA)	V_{max} (mV)	I_{max} (mA)	FF	ŋ
Un textured cell		0.51	0.26	0.4	0.21	63.60%	13.90%
Textured solar cell with 1×1 cm2 laser surface texturing	With 0.5 mm spacing between grooves two dimension	0.51	0.26	0.422	0.222	70.60%	15.60%
	With 0.25 spacing mm between grooves two dimension	0.52	0.26	0.43	0.23	73.10%	16.40%
Textured solar cell with 2×2 cm2 laser surface texturing	With 0.5 spacing mm between grooves two dimension	0.51	0.26	0.43	0.23	74.50%	16.65%
	With 0.25 spacing mm between grooves two dimension	0.52	0.26	0.44	0.25	81.36%	18.30%

Table 2 Percentage of the increase in fill factor and efficiency

Type of solar cell		ŋ %	FF %
Textured solar cell with 0.0082% laser surface texturing	With 0.5 mm spacing between grooves two dimension	1.7	7
	With 0.25 spacing mm between grooves two dimension	2.5	9.5
Textured solar cell with 0.032% laser surface texturing	With 0.5 spacing mm between grooves two dimension	2.75	10.9
	With 0.25 spacing mm between grooves two dimension	4.4	18.03

Figure 3 depicted the values of the efficiency and fill factor versus the textured area in two dimensions with 0.25 mm line spacing. Figure 4 depicted the increasing in the efficiency and fill factor versus the percentages textured area in two dimensions with 0.25 mm line spacing. The obtained results showed that the texturing of 0.0082% from the total surface area of the solar cell by 0.25 mm line spacing in two dimension results in increasing of 2.5% in its efficiency and 9.5 in its fill factor. While, the texturing of 0.032% from the total surface area of the solar cell by 0.25 mm line spacing in two dimension results in increasing of 4.4% in its efficiency and 18.03 in its fill factor.

Figure 5 depicted the values of the efficiency and fill factor versus the textured area in two dimensions with 0.5 mm line spacing. Figures 6 depicted the increasing in the efficiency and fill factor versus the percentages textured area in two dimensions with 0.5 mm line spacing. The obtained results showed that the texturing of 0.0082% from the total surface area of the solar cell by 0.5 mm line spacing in two dimension results in increasing of 1.7% in its efficiency and 7 in its fill factor. While, the texturing of 0.032% from the total surface area of the solar cell by 0.5 mm line spacing in two dimension results in increasing of 2.79% in its efficiency and 10.9 in its fill factor.

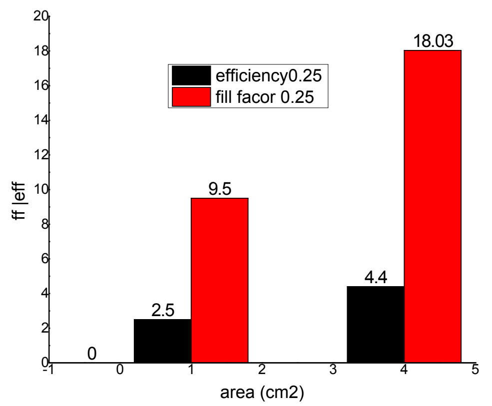

Figure 3 Eff and FF Vs the textured area in two dimensions with 0.25 mm line spacing.

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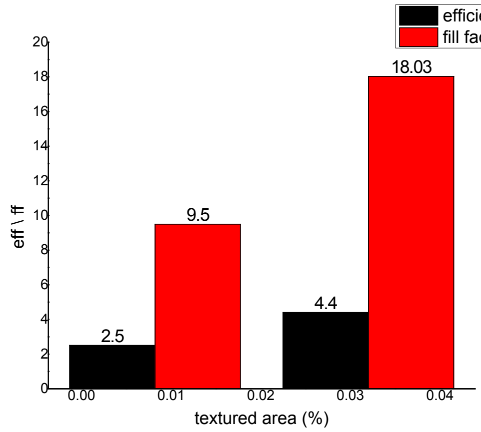

Figure 4 Eff and FF Vs the percentage textured area in two dimensions with 0.25 mm line spacing.

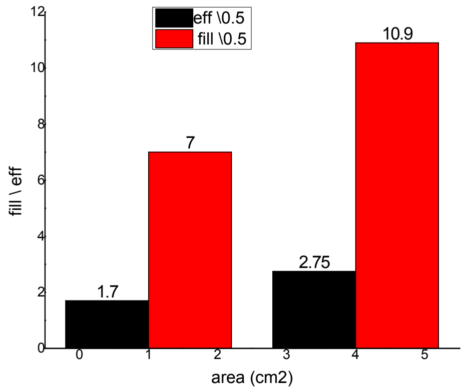

Figure 5 Eff and FF Vs the textured area in two dimensions with 0.5 mm line spacing.

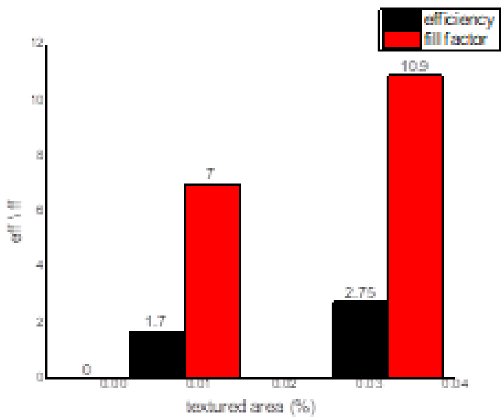

Figure 6 Eff and FF Vs the percentage textured area in two dimensions with 0.5 mm line spacing.

Figure 7 depicted the values of the efficiency and fill factor versus the line spacing in two dimensions with 1x1 cm^2 area or .0082% from the total surface area of the solar cell. Figure 8 depicted the increasing in the efficiency and fill factor versus the line spacing in two dimensions with 2x2 cm^2 area or .032% from the total surface area of the solar cell. The obtained results showed that decreasing in the texturing line spacing increases the efficiency and the fill factor of the solar cell.

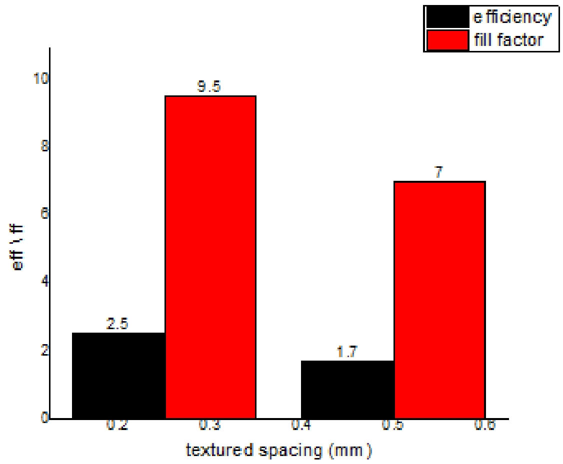

Figure 7 Eff and FF Vs the textured spacing in two dimensions with 1x1 cm2 area.

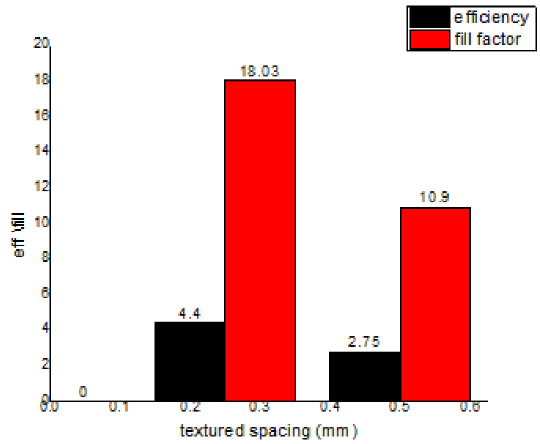

Figure 8 Eff and FF Vs the textured spacing in two dimension with 2x2 cm2 area.

Laser surface texturing with small grooves spacing, results in increasing of the melted silicon surface area which enhance the silicon electrical properties and increases the optical path length inside the solar cell which enhance light trapping. This leads to the possibility of generating electron hole in the adjacent region pairs which lead to increase the number of pregnant minority and reduce the losses and thus will increase the efficiency of cell.

Conclusion

The paper presents the impact of the surface texturizing by means of CO_2 laser on the polycrystalline silicon solar cell. It revealed an improvement in the solar cell and efficiency of its performance. The improvement is proportional to the number of the groves and surface texture area. Surface texturing by means of CO_2 laser; allow trapping more light inside it, in addition to the contribution of the silicon melting in enhancing the electrical properties of the solar cell.

Acknowledgments

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Conflicts of interest

There are no conflicts of interest.

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