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Micro surface texturing formation in polycrystalline-silicon solar cells by means of CO_2 laser

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Surface texturing of polycrystalline silicon solar cells using a CO_2 laser was achieved in the present study, with different line spacing and sizes in one dimension. The efficiency of the solar cell was calculated using the measurements of the short circuit current (ISC), the open circuit voltage (VOC), and the fill factor (FF). The SEM results showed the formation of micro-scale textures. Operational results showed that just 1.23% of the total surface area of the solar cell needs to be textured with a 0.5 mm line spacing in one dimension to enhance the efficiency of the solar cell up to 100%, while only 0.9% needs texturing with a 0.25 mm line spacing in one dimension.

Key words: CO_2 laser, laser interaction with matter, photovoltaic cell, polycrystalline Si-solar cells.

INTRODUCTION

Laser beam can be accurately and easily adjusted to achieve a desired response by delivering large amounts of energy into specific regions. Laser texturing for opaque materials is achieved by laser light interaction with the substrate surfaces, which leads to production of new crystal structure and modification of surface chemistry without harming the treated materials. By controlling the laser's spatial intensity profile, the energy can be delivered to a desired area on a material's surface, allowing for the modification of surface properties over multiple length scales and enhancing the material's performance for a specific purpose. The surface cosmetic and absorption process can also be controlled by changing the surface texture and chemical impurities in the surface (Brown and Arnold, 2010).

Some researchers have reported that the textured Silicon surface absorbs incident light more efficiently than the non-textured surface. Additionally, experimental evidence of the effect of nanostructure formation in Silicon photovoltaic cells on the spectral response has been reported (Taleb et al., 2011; Kais, 2011; Marouf et al., 2014). Lasers can induce various changes when exposed to materials; such as increasing hardness (Awadala et al., 2020a, b), inducing photoemission (Marouf and Khairallah, 2019), killing bacteria (Amna et al., 2018; Marouf et al., 2018), combusting wastes (Awad et al., 2023, 2020; Mustafa et al., 2023; Gawbah et al., 2018), preserving food (Mudawi and Marouf, 2022a, b), altering the properties of blood (Haimid et al., 2019a, b), and enhancing the performance of electrochemical cells (Ahmed et al., 2022). The paper presents results on the development of surface texturing of silicon solar cells

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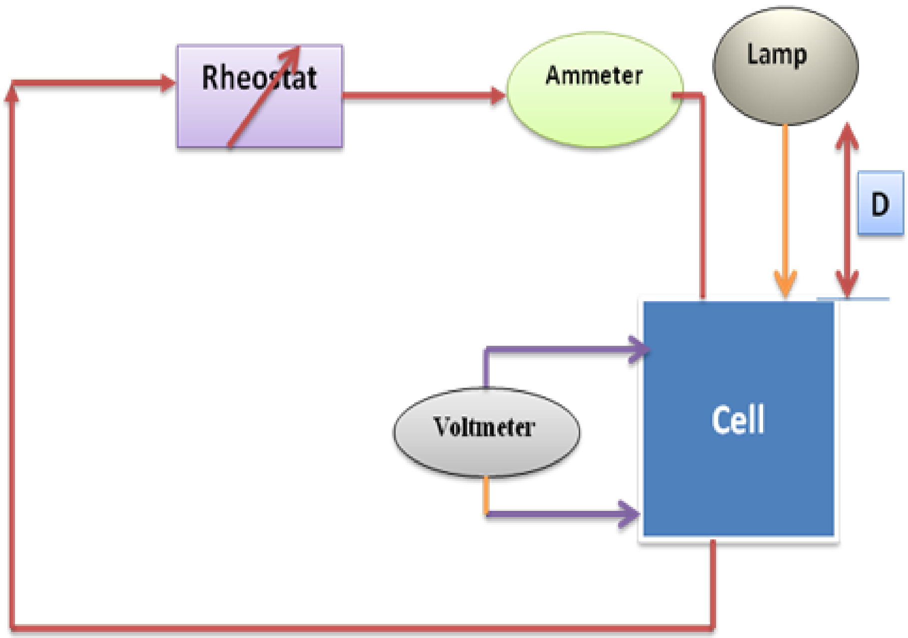

Figure 1. Schematic diagram of the experimental setup for Solar cell (with and without surface texture).
Source: Authors 2023

by means of laser processing and investigation of the effects of different line spacing and texturing areas on the operational properties of the photovoltaic cells in order to enhance the absorption efficiency and the fill factor.

EXPERIMENTAL

Sample preparation

The solar cells used in this work were assembled by the National Energy Research Center in Soba, Khartoum, Sudan. The sample size of the polycrystalline silicon used to fabricate the solar cells was 15.6 by 7.8 cm^2 (half cut). The texturing of the solar cells was performed using a CO_2 laser CNC machine manufactured by RISE Company in China. This machine had an output power of 150 W and 10.6 µm wavelength with a continuous mode. The laser beam was delivered to the working area through reflection silvered mirrors and lenses made from quartz with a focal length of 20 mm to focus the laser spot size. The parameters of laser treatment were adjusted and assumed to take the following values: Output power ($P = 30$ W), pulse duration = 200 µs, frequency (υ) = 5 kHz, texturing speed = 100 mm/s, and two textured area sizes (1 cm × 1 cm, 2 cm × 2 cm) with different line spacings (0.5 mm and 0.25 mm).

Measurements

SEM images

The SEM was used to study surface texture for the photovoltaic solar cells.

IV characteristics curve

The setup used to study the IV characterization curve of the modified solar cells is shown in Figure 1. The distance (D) from the lamp to the solar cell was kept constant at 40 cm during the measurement. The solar cell without laser texturing was used first and its voltage and current were measured using a rheostat. The fill factor and efficiency of the solar cell were then calculated. The same procedure was repeated for all solar cells. The effects of texturing parameters on the solar cell were studied and compared to the results of the IV characteristics curve of the solar cell without texturing and with texturing.

RESULTS AND DISCUSSION

SEM

The SEM results showed the formation of small-scale textured ripples in the micrometer range, which were created using laser energy that was absorbed near the surface and modified the morphology without altering the bulk structure Figure 2.

I -V characteristics

Table 1 shows the operational properties for the five cells before and after laser surface texturing. Table 2 shows the percentage increase of fill factor and efficiency. The percentage of the textured area 1 × 1 cm^2 and 2 × 2 cm^2

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

Type of solar cell		V_{oc} (mV)	I_{sc} (mA)	V_{max} (mV)	I_{max} (mA)	FF (%)	ŋ (%)
Un textured cell		0.51	0.26	0.40	0.21	63.6	13.9
Textured solar cell with 1×1 cm^2 laser surface texturing	Spacing 0.5 mm between grooves one dimension	0.51	0.26	0.405	0.218	66.5	14.6
	Spacing 0.25 mm between grooves one dimension	0.51	0.26	0.419	0.217	68.5	14.87
Textured solar cell with 2×2 cm^2 laser surface texturing	Spacing 0.5 mm between grooves one dimension	0.514	0.27	0.43	0.239	71.9	16.5
	Spacing 0.25 mm between grooves one dimension	0.52	0.28	0.44	0.24	72.5	17.5

Source: Authors 2023

Table 2. Percentage Increase of fill factor and efficiency.

Type of solar cell		Ŋ %	FF %
Textured solar cell with 0.0082% laser surface texturing	Spacing 0.5 mm between grooves one dimension	0.7	2.9
	Spacing 0.25 mm between grooves one dimension	0.97	4.9
Textured solar cell with 0.032% laser surface texturing	Spacing 0.5 mm between grooves one dimension	2.6	8.3
	Spacing 0.25 mm between grooves one dimension	3.6	8.9

Source: Authors 2023

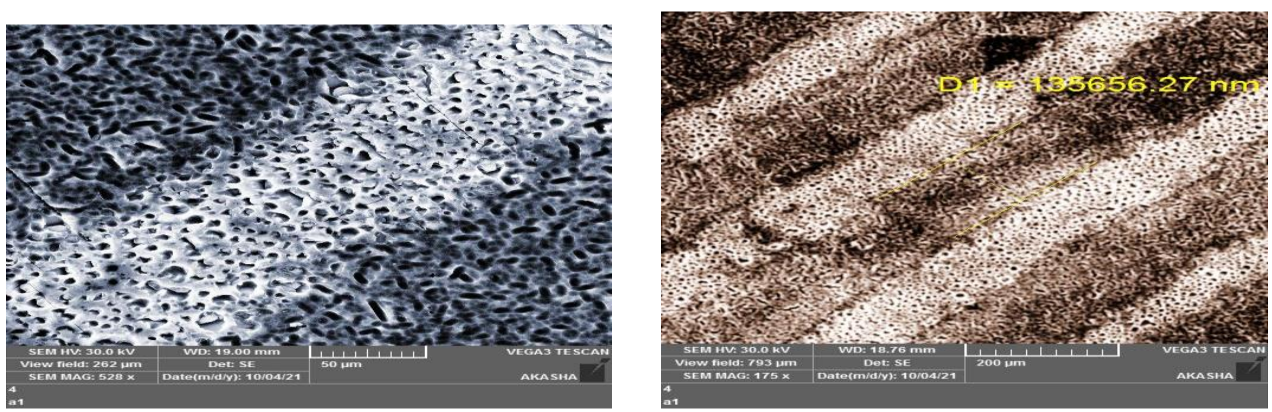

Figure 2. SEM image for one dimensional of the textured sample; (a) with magnification 50 µm, (b) with magnification 200 µm.
Source: Authors 2023

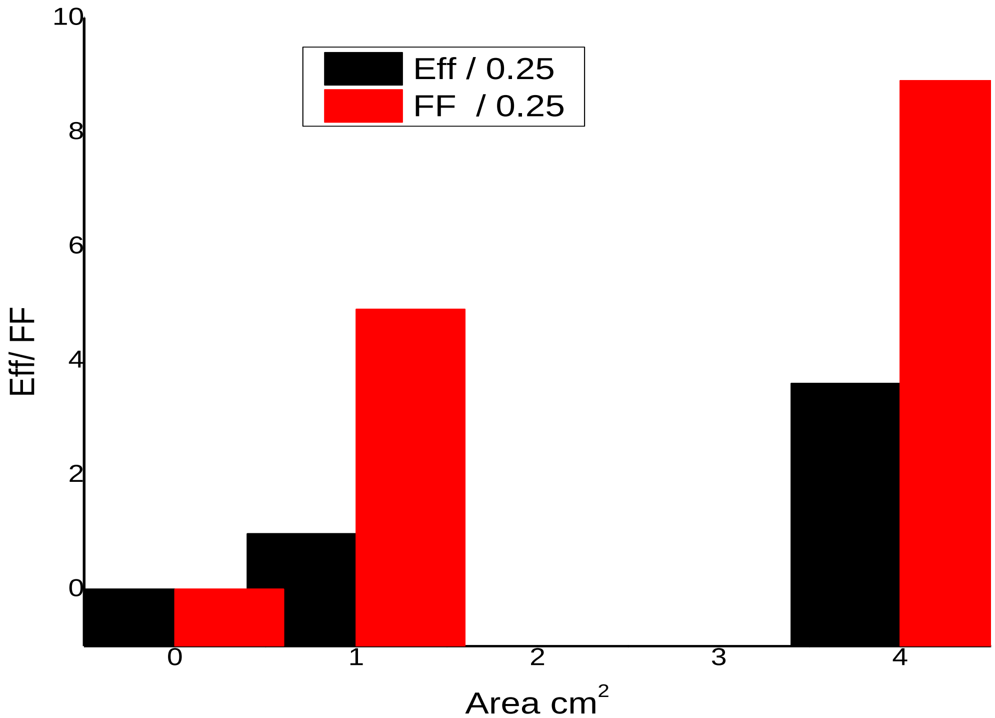

Figure 3. Eff and FF Vs the textured area in one dimension with 0.25 mm line spacing**.**
Source: Authors 2023

were calculated to be = 0.0082 and 0.032% respectively. Figure 3 depicted the values of the efficiency and fill factor versus the textured area in one dimension with 0.25 mm line spacing. Figures 4 depicted the increase in the efficiency and fill factor versus the percentages textured area in one dimension 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 one-dimension results in an increase of 0.97% in its efficiency and 4.9 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 one-dimension results in an increase of 3.6% in its efficiency and 8.9 in its fill factor. Based on these results, it's expected that to enhance the efficiency up to 100% needs to texture just about 0.9% from the total surface area of the solar cell by 0.25 mm line spacing in one dimension.

Figure 5 depicted the values of the efficiency and fill factor versus the textured area in one dimension with 0.5 mm line spacing. Figures 6 depicted the increasing in the efficiency and fill factor versus the percentages textured area in one dimension 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 one-dimension results in increasing of 0.7% in its efficiency and 2.9 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 one-dimension results in an increase of 2.6% in its efficiency and 8.3 in its fill factor. Based on these results, it's expected that to enhance the efficiency up to 100% needs to texture just about 1.23% from the total surface area of the solar cell by 0.5 mm line spacing in one dimension.

Figure 7 depicted the values of the efficiency and fill factor versus the line spacing in one dimension with 1 × 1 cm^2 area or 0.0082% from the total surface area of the solar cell. Figures 8 depicted the increasing in the efficiency and fill factor versus the line spacing in one dimension with 2 × 2 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.

Laser texturing increases light absorption from modified surface, so it enhances the efficiency and the fill factor of solar cell.

Conclusions

In conclusion, it was found that the use of laser texturing with a CO_2 laser is an effective method to increase the efficiency and fill factor of a solar cell by enhancing the absorption of light through the creation of micro-surfaces.

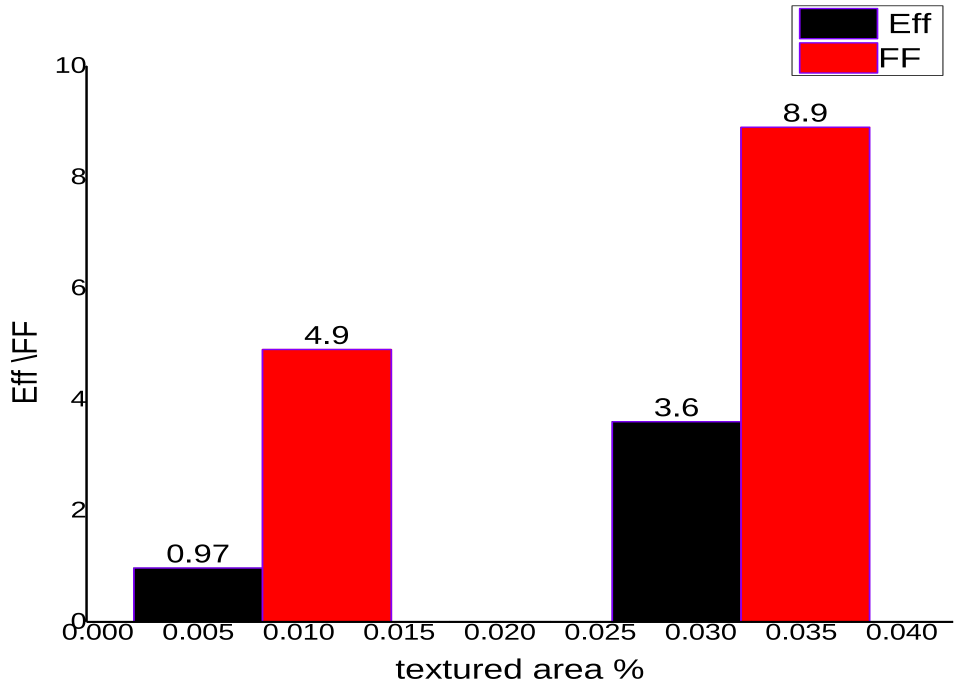

Figure 4. Eff and FF Vs the percentage textured area in one dimension with 0.25 mm line spacing.
Source: Authors 2023

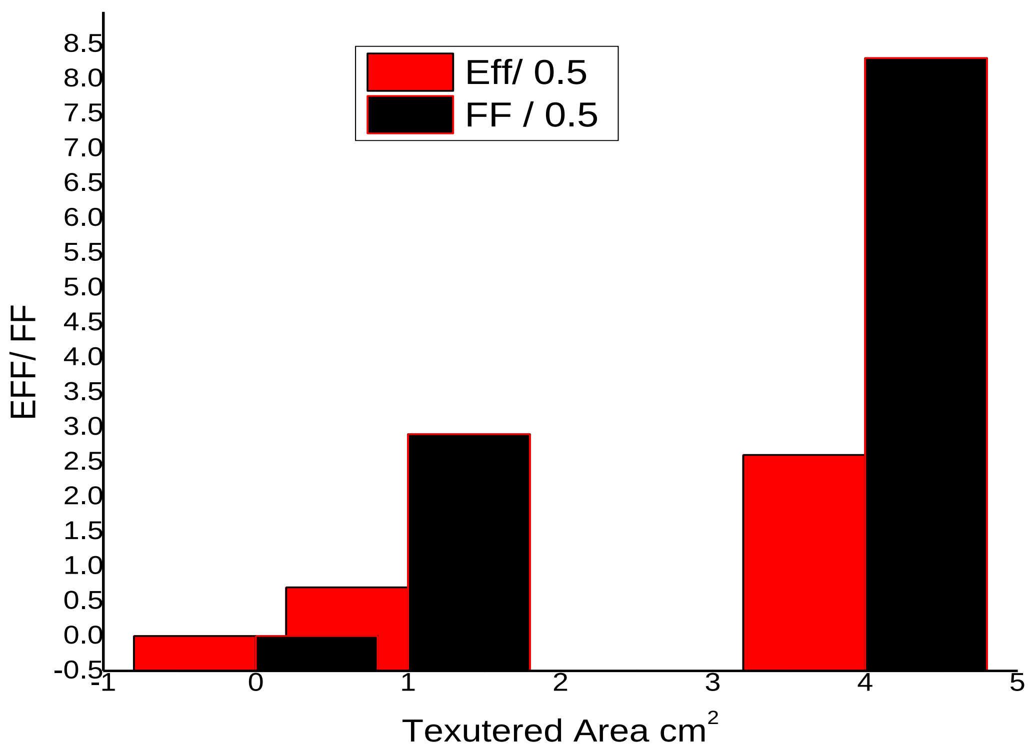

Figure 5. Eff and FF Vs the textured area in one dimension with 0.5 mm line spacing.
Source: Authors 2023

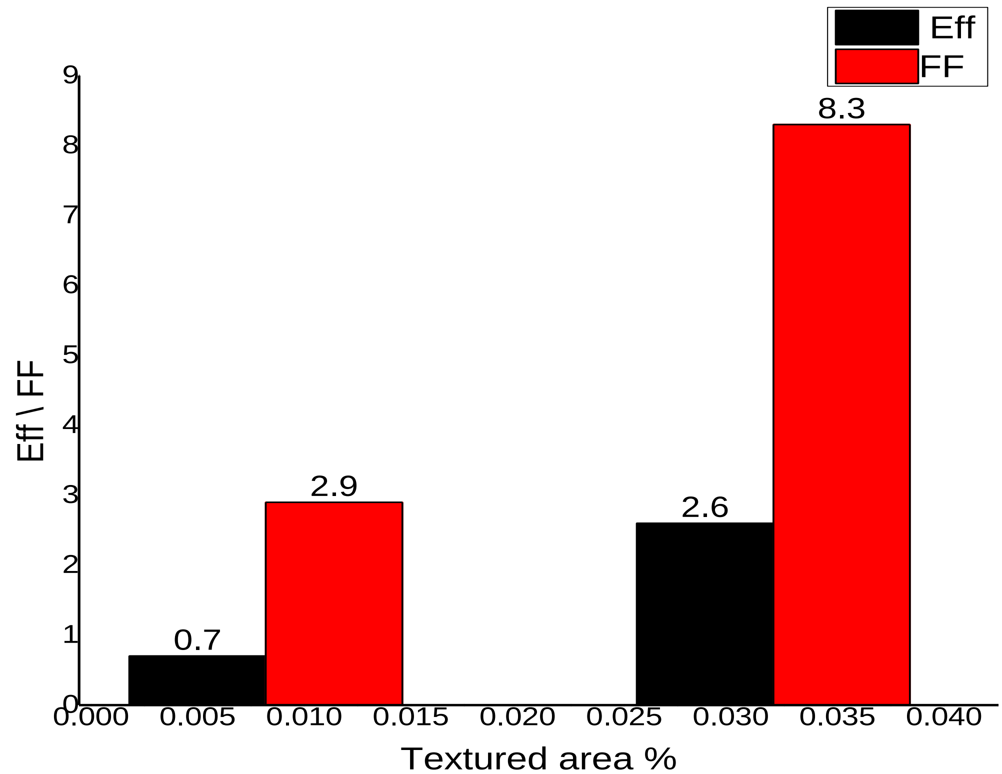

Figure 6. Eff and FF Vs the percentage textured area in one dimension with 0.5 mm line spacing. Source: Authors 2023

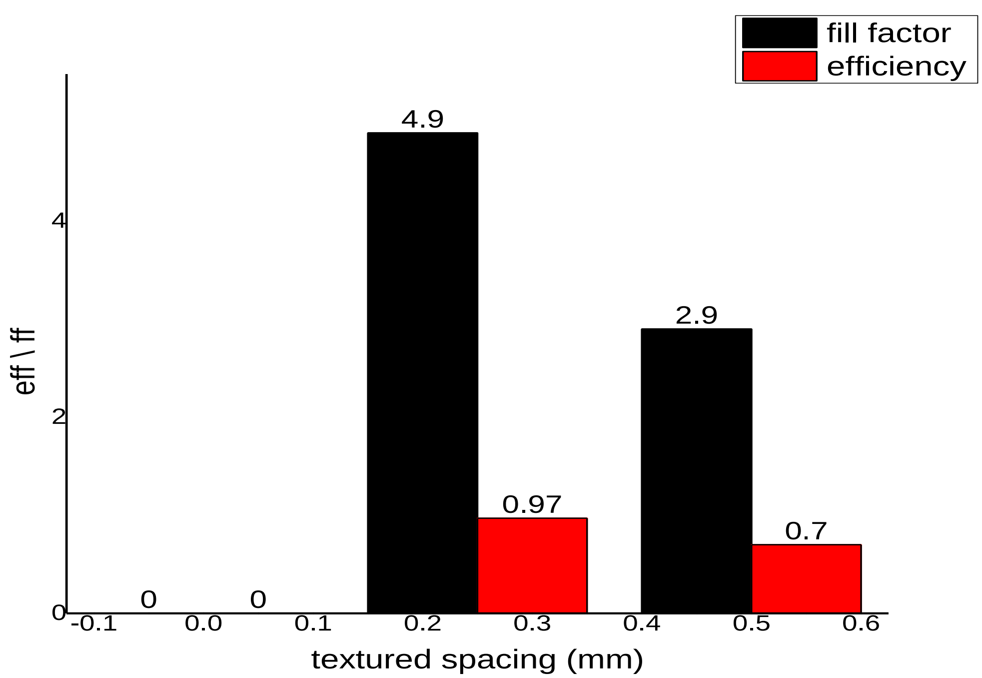

Figure 7. Eff and FF Vs the textured spacing in one dimension with 1×1 cm^2 area. Source: Authors 2023

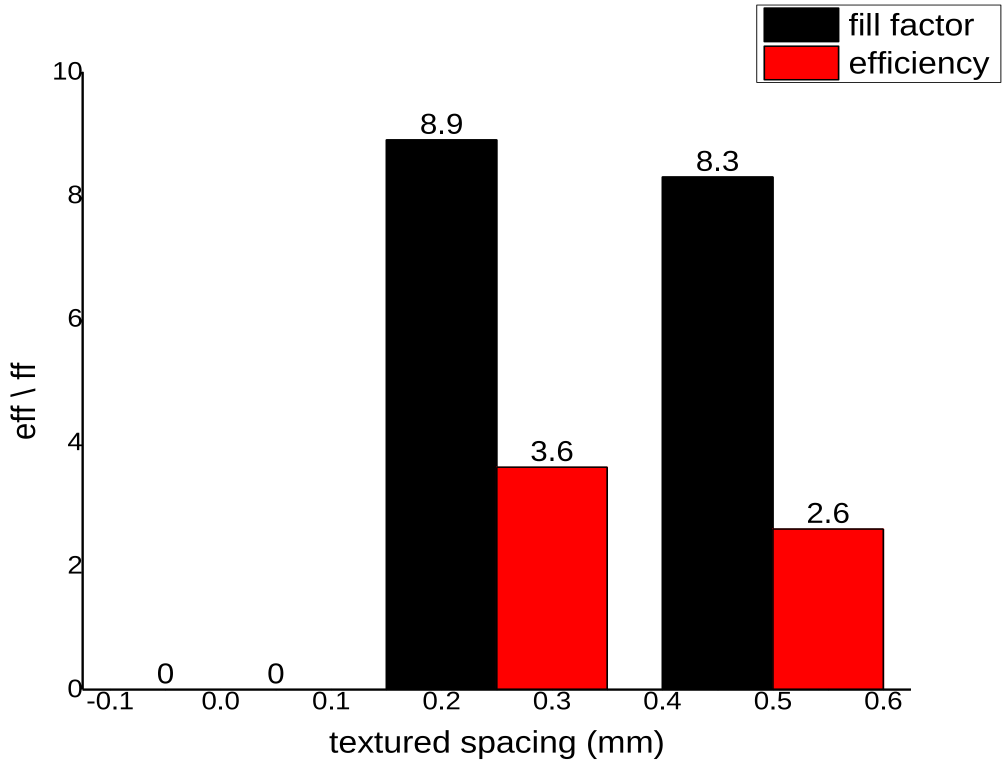

Figure 8. Eff and FF Vs the textured spacing in one dimension with 2 × 2 cm^2 area.
Source: Authors 2023

The results showed that solar cell efficiency increased as the textured area and number of grooves increased, providing the possibility of precise surface modification in less time than other conventional methods of texturing techniques.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Ahmed RSM, Alsabah YA, Marouf AAS (2022). Electrochemical Performance of Laser Modified Zinc Electrode. International Journal of Engineering and Applied Physics 2(3):544-548.

Amna OB Malik, Marouf AA (2018). Comparison of the Effects of Laser Pasteurization and Heat Pasteurization on The Cow's Milk Haya. The Saudi Journal of Life Sciences 3(1):46-50.

Awad AAG, Gawbah MAP, Orsod MU, Alsabah YA, Marouf AA (2020). Investigation of the Effects of Laser-Based Combustion on Sorghum Bran. Albaydha University Journal 2(2):52-59.

Awad FM, Alsabah YA, Marouf AA, Orsod MU (2023). An attempt to apply laser combustion to palm waste. Journal of the European Optical Society-Rapid Publications 19(1):5.

Awadala AS, Elfaky AE, Marouf AAS (2020a). Influence of high power Nd: YAG laser on hardness and surface properties of zirconium silicate. International Journal of Mathematics and Mathematical Sciences 2(3):39-44.

Awadala AS, Elfaky AE, Marouf AA (2020b). Investigation of the Effects of High-Power Nd: YAG Laser on Zirconium Silicate Surface Properties. International Journal of Latest Research in Science and Technology 9(4):6-10.

Brown MS, Arnold CB (2010). Fundamentals of laser-material interaction and application to multiscale surface modification In Laser precision micro fabrication. Springer Berlin Heidelberg, pp. 91-120.

Gawbah MAP, Elbadawi AA, Alsabah YA, Orsod MU, Marouf AA (2018). Characterization of the Crystal Structure of Sesame Seed Cake Burned by Nd: YAG Laser. Journal of Materials Science and Chemical Engineering 6(4):121.

Haimid MA, Marouf AA, Abdalla MD (2019a). In vitro UV-Visible and FTIR Spectroscopy Study of Low Power He-Ne Laser Irradiation on Human Blood. Asian Journal of Research and Reviews in Physics pp. 1-7.

Haimid MA, Marouf AA, Abdalla MD (2019b). Helium-Neon Laser Effects on Human Whole Blood by Spectroscopy In vitro Study. Asian Journal of Physical and Chemical Sciences 7:1-6.

Kais A AlNaimee. Nano/Micro Surface texturing and Enhahancing of Ph otovoltaic Cells Efficiency by using UV Femtosecond Laser Pulse (2011). Iraqi Journal of Applied Physics 7(2).

Marouf AA, Abdalah SF, Abdulrahman WS, AlNaimee K (2014). The Role of Photonic Processed Si Surface in Architecture Engineering. Study of Civil Engineering and Architecture 3:93-97.

Marouf AARS, Khairallah YA (2019). Photoemission Spectra of Sound Tooth and Those of Different Carious Stages. European Journal of Biophysics 7(1):23-26.

Marouf AAS, Esra OH Siddiq (2018). Evaluation of Laser Pasteurization on Production of Yogurt. International Journal of Advanced Research in Physical Science 5(4):15-23.

Mudawi AA, Marouf AA (2022a). Impact of Single Wavelength (532 nm)

Irradiation on the Physicochemical Properties of Sesame Oil. Journal of Materials Science and Chemical Engineering 10(4):1-15.

Mudawi AA, Marouf AA (2022b). Evaluation of Laser-Heating and Laser-Reheating of Sunflower (Helianthus annuus) Seed Oil Quality. Open Access Library Journal 9(6):1-10.

Mustafa HNH, Alzain AMT, Orsod MU, Marouf AA (2023). Recovery of High-Added Value Materials from Vinasse Using Laser-Based Combustion. Open Access Library Journal 10(2):1-8.

Taleb AM, Kais A AL-Naimee, Abdalah S, Riccardo Meucci, Arecchi FT. Nanostructure Formation in Silicon Photovoltaic Cells by Femtosecond Laser Pulses (2011). Materials Science Forum 670:118-121.