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Optical Design Impact on PERC Solar Cell Efficiency: Upright Pyramids vs Inverted Pyramids Textured Surfaces

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Abstract: Aims: Textured surfaces morphology on solar cell are benefited to minimize the reflection. Many configurations are used for solar cell manufacturing. The ray's simulators are used in this work. The gains (photogeneration) and losses (reflection, transmission, parasitic absorption) are recorded for each ray. The global gains and losses are determined by averaging many rays. With a sufficiently large number of rays, the Monte Carlo simulation converges to the physical model. The Monte-Carlo algorithm employed by the Wafer Optics Calculator necessarily results in output uncertainties. These uncertainties are calculated by dividing the user-requested number of rays into several sub-simulations, then applying statistical analysis to the set of sub-simulations to arrive at a mean value and 95% confidence interval (about two standard deviations). The calculators weight the magnitudes by the photon flux in the user-defined spectrum, then integrates over the wavelength, to calculate photon current density. The photogenerated current JG in a wafer equates to the short circuit current that could be extracted from a perfect solar cell made from the wafer. This work focuses on two textured surfaces morphology such that, upright pyramids, and inverted pyramids. To show their impact in solar cell efficiency. Which involve evaluating the external reflection for both surface morphology. Also compare the photogeneration JG absorbed by the substrate.

Keywords: Optic, Perc, Upright, Inverted Pyramids, Solar Cell

1. Introduction

Today photovoltaic [1] is a rapidly growing and increasingly important renewable alternative to conventional fossil [2] fuel electricity generation, but compared to other electricity generating technologies, it is a relative newcomer, with the first practical photovoltaic devices demonstrated in the 1950s. The most fundamental of solar cell characterization techniques is the measurement of cell efficiency., Standardized testing allows the comparison of devices manufactured at different companies and laboratories with different technologies to be compared. Although more than half of the manufactured modules used multicrystalline silicon for many years, starting in 2018, monocrystalline silicon began to dominate and by 2020 and 2021 it became difficult to buy multicyrstalline silicon cells. The reasons for the change were complex, but were aligned with a transition from using aluminum-back-surface-field cell designs to using passivated-emitter rear contact (PERC) structures. Although high efficiencies were achieved with PERC cells as early as 1990, these did not become commercially viable before about 2015. The PERC structure enables higher efficiencies for monocrystalline cells but does not give much performance boost for multicrystalline cells. For multicrystalline wafers, only a small fraction of the surface will have the required orientation of <100> and consequently these techniques are less effective on multicrystalline wafers. However, multicrystalline wafers can be textured using a photolithographic technique [3] as well as mechanically sculpting the front surface using dicing saws [4] or lasers [5] to cut the surface into an appropriate shape. Surface texturing can be accomplished in several ways. A single crystalline substrate can be textured by etching along the faces of the crystal planes. The crystalline structure of silicon results in a surface made up of pyramids if the surface is appropriately aligned with respect to the internal atoms. This type of texturing is called "random pyramid" texture [6], and is commonly used in industry for single crystalline wafers. Another type of surface texturing used is known as "inverted pyramid" texturing [7, 8]. Using this texturing scheme, the pyramids are etched down into the silicon surface rather than etched pointing upwards from the surface.

The aim of this work is to measure the impact of textured surface [9] on the perc solar cell. Here upright pyramids [10] and inverted surfaces [11] morphology are considered. Consider the illumination is isotropic and the light is tripping. The standard test conditions are used. The bifacial passivated emitter and rear cell (PERC) [12] is applied with two films SiNx and SiOx on the front contact and the rear contact of the solar cell [13].

2. Materials and Methods

The figure below the inverted pyramids and upright pyramids surface morphology.

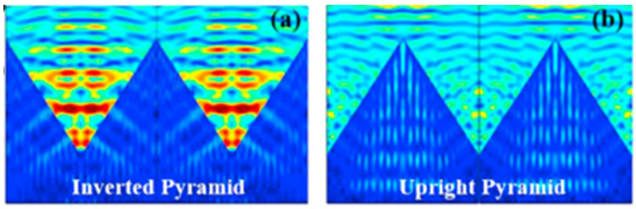

Figure 1. *Inverted pyramids and Upright pyramids surface morphology of solar cell.*

The conditions applied on the test are:

1) Air mass 1.5 spectrum (AM1.5) [14]
2) Intensity of 100 mW/cm^2 (1 kW/m^2, also known as one-sun of illumination)
3) Cell temperature of 25°C (not 300 K)

The bifacial passivated emitter and rear cell is given by the following figure.

Surface morphology pyramids

Table 1 and table 2 show respectively the upright and inverted pyramids morphology surfaces

Table 1. *Parameter of the upright pyramids surface.*

Side	Morphology	periodicity	Angle (°)	Height (um)	Width (um)
Front	Upright pyramids	Regular	54.74	3.536	5
Rear	Upright pyramids	Regular	54.74	3.536	5

Table 2. *Parameter of the inverted pyramids surface.*

Side	Morphology	periodicity	Angle (°)	Height (um)	Width (um)
Front	Inverted pyramids	Regular	54.74	3.536	5
Rear	Inverted pyramids	Regular	54.74	3.536	5

3. Results and Discussion

The model implemented in the powerful calculation running in the Monte Carlo algorithm [15] show the following results. 50000 rays are applied in this simulation.

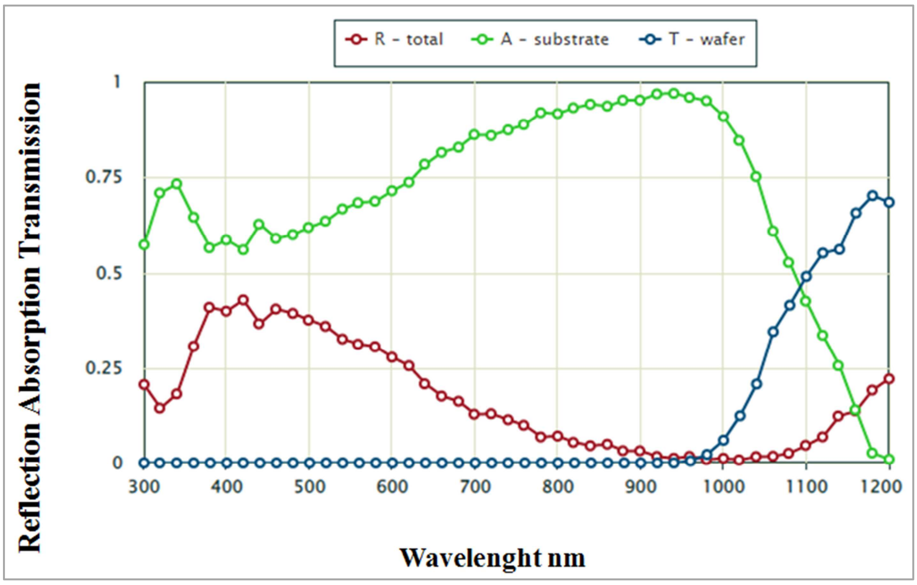

Figure 2. *Main optical loss depending on wavelength.*

Figure 2 shows the main optical loss on the substrate, the wafer and the total loss for a PERC solar cell [16]. The surface morphology is upright pyramids. The solar cell is coating with two films SiO2 and SiNx for both surfaces front and rear.

The optical loss is important on the substrate over the range 300nm-950nm wavelength. For more than 1000nm the optical loss [17] decreases and approaches to zero at 1200nm. Compared to the substrate, the reflection, absorption, and the transmission are very week over the range 300nm-1000nm. The total optical loss is important over the range 350nm - 450nm.

The table below shows the optical loss in different regions of the solar cell.

Table 3. *Optical loss on upright pyramids morphology surface.*

	Mean ± 95% CI (mA/cm^2)	Fraction of J_{in} %
Incident J_{inc}	23.08± 0.01035	100
Reflected-external $J_{inc-ext}$	3.562±0.09017	15.43
Reflected-escape $J_{inc-esc}$	0.2136±0.01756	0.9256
Transmitted J_T	1.675±0.03057	7.259
Absorbed-front films J_{A-F}	0.2987± 0.002327	1.294
Absorbed-rear films J_{A-R}	0.06197±0.002025	0.2685
Photogeneration (Absorbed)	17.22±0.1623	74.62
Remainder J_G	0.04576±006662	0.1983

The absorption on both surfaces fronts and rear [18] are very weak compared to the photogeneration (absorbed) 17.22 mA/cm^2. And then the external reflection [19] is 15% compared to the 74% of photogeneration absorbed. That means the textured surface plays an important role in optical loss and improve the solar cell efficiency.

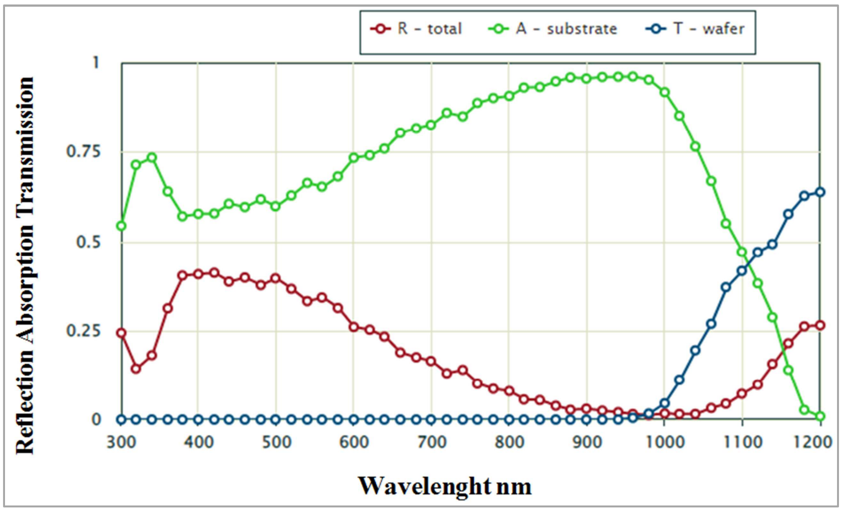

Figure 3. *Main optical loss depending on wavelength.*

The figure 3 shows ass well the main optical on inverted pyramids surface morphology solar cell. There is a small difference between the upright pyramids surface. The main optical loss on the substrate is very significant over the range 300nm-1000nm. Nevertheless the change occurs over the range 400nm-450nm.

Table 4. *Optical loss on inverted pyramids morphology surface.*

	Mean ± 95% CI (mA/cm^2)	Fraction of J_{in} %
Incident J_{inc}	23.00± 0.09143	100.0
Reflected-external $J_{inc-ext}$	3.720±0.08130	16.17
Reflected-escape $J_{inc-esc}$	0.3073±0.01933	1.336
Transmitted J_T	1.439±0.03761	6.255
Absorbed-front films J_{A-F}	0.2969± 0.002407	1.294
Absorbed-rear films J_{A-R}	0.05903±0.001701	0.2566
Photogeneration (Absorbed)	17.14±0.1448	74.50
Remainder J_G	0.04401±0.003272	0.1913

The absorption on both surfaces front and rear are very weak compared to the photogeneration (absorbed) 17.14 mA/cm^2. And then the external reflection is 15% compared to the 74.50% of photogeneration absorbed. That means the textured surface plays an important in optical loss and improve the solar cell efficiency [20]. And then the optical loss on the wafer (transmission does not exist over range 300nm -900nm [21]. The solar cell efficiency for both textured surfaces inverted pyramids and upright pyramids are approximatively similar. Textured surface is benefited to reduce the external reflection.

4. Conclusion

Textured surfaces reduce the reflection at surface of the material according to the results obtained in this work.

The amount of photogeneration (absorbed) approximatively for both surfaces upright pyramids and the inverted pyramids are then same. Also, the External reflections change a little bit but does not show a major difference between the upright pyramids textured surface and the inverted pyramids surface. This work could be enlarged by studying the effect of films thickness on the substrate.

References

[1] Azem Hysa Modeling and Simulation of the Photovoltaic Cells for Different Values of Physical and Environmental Parameters Emerging Science Journal, Vol 3, No 6, December 2019.

[2] N. Abas, A. Kalair, N. Khan, Review of fossil fuels and future energy technologies, Elsevier journal, future 69 (2015) pp 31-49.

[3] J. Zhao, A., W., Dai, X., Green, M. A., and Wenham, S. R., "Improvements in Silicon Solar Cell Performance", *22nd IEEE PV Specialists Conference*. pp. 399-402, 1991.

[4] S. R. Wenham and Green, M. A., "Buried contact solar cell". 1988.

[5] J. C. Zolper, Narayanan, S., Wenham, S. R., and Green, M. A., "16.7% efficient, laser textured, buried contact polycrystalline silicon solar cell", *Applied Physics Letters*, vol. 55, p. 2363, 1989.

[6] W. L. Bailey, Coleman, M. G., Harris, C. B., and Lesk, I. A., "United States Patent: 4137123 - Texture etching of silicon: method". 1979.

[7] P. Campbell and Green, M. A., "Light trapping properties of pyramidally textured surfaces", Journal of Applied Physics, vol. 62, no. 1, p. 243, 1987.

[8] P. Campbell and Green, M. A., "High performance light trapping textures for monocrystalline silicon solar cells", Solar Energy Materials and Solar Cells, vol. 65, no. 1-4, pp. 369 - 375, 2001.

[9] Min su Kim, Jue Heon Lee. Moon Kyu Kwak, Review: Surface Texturing Methods for solar cell efficiency Enhancment, International journal of precision engineering and Manufacturing (2020) 21: 1389-1398.

[10] Keith R. McIntosh and Simeon C. Baker-Finch, OPAL 2: Rapid Optical Simulation of Silicon Solar Cells, Accepted version of the paper presented at the 38th IEEE Photovoltaic Specialists Conference, Austin, 2012. Copyright, IEEE.

[11] Hanbo Tang, Yaoping Liu, Quansheng Chen, Yan Wang, Wei Chen, Juntao Wu, Yan Zhao and Xiaolong Du, Optical Design of Inverted Pyramid Textured PERC Solar Cells, Applied electronics material, 2019, 1, 2684-2691.

[12] Martin A. Green, The Passivated Emitter and Rear Cell (PERC): From conception to mass production, Solar Energy Materials & Solar Cells 143 (2015) 190–197.

[13] Shruti Sharma, Kamlesh Kumar Jain, Ashutosh Sharma, Solar Cells: In Research and Applications—A Review, Materials Sciences and Applications, 2015, 6, 1145-1155.

[14] Mohamed Amara, Fabien Mandorlo, Romain Couderc, Félix Gérenton, and Mustapha Lemiti, Temperature and color management of silicon solar cells for building integrated photovoltaic, EPJ Photovoltaics 9, 1 (2018).

[15] M. D. Abbott, K. R. McIntosh, B. Sudbury; Optical Loss Analysis of PV Modules; 32nd European Photovoltaic Solar Energy Conference and Exhibition; pp 976 – 979; ISBN. 3-936338-41-8.

[16] Andrew Blakers Development of the PERC Solar Cell; IEEE journal of photovoltaics, Vol. 9, No. 3, May 2019.

[17] Jo Gjessinga, Erik S. Marstein; Optical performance of solar modules; Elsivier; Energy Procedia 38 (2013) 348 – 354 1876-6102 © 2013 The Authors. Published by Elsevier Ltd. Selection and/or peer-review under responsibility of the scientifi c committee of the Silicon PV 2013 conferencedoi: 10.1016/j.egypro.2013.07.288 Silicon PV: March 25-27, 2013.

[18] P. J. Verlinden, Swanson, R. M., and Crane, R. A., "7000 High Efficiency Cells for a Dream", Progress in Photovoltaics: Research and Applications, vol. 2, pp. 143 - 152, 1994.

[19] Alassane Diaw, Papa Touty Traore, Awa Dieye; Comparative Studies on Reflection Defect between Textured and Planar Surface Based on TCO Materials; Science research publishing, Energy and Power Engineering, 2022, 14, 550-557.

[20] Alassane Diaw, Awa Dieye, Ousmane Ngom, Moulaye Diagne, Nacire Mbengue, Oumar Absatou Niasse, Bassirou Ba; Optimization of Antireflective Layers of Silicon Solar Cells: Comparative Studies of the Efficiency Between Single and Double Layer at the Reference Wavelength; American Journal of Physics and Applications 2021; 9 (6): 133-138.

[21] Awa Dieye, Alassane Diawa, Modou Pilora, Oumar A. Nissea, El Hadji Abdoulaye Niassa, Nacire Mbenguea, Moulaye Diagnea, Bassirou Baa; The Equations and Optical Parameters of Antireflective Multilayers: A Literature Review; IRA-International Journal of Applied Sciences ISSN 2455-4499; Vol. 17, Issue 02 (Q. 2 2022) Pg. no. 17-23.