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E-BOOK OF EXTENDED ABSTRACTS

SMART SURFACE DESIGN: IMPACT OF TEXTURING ON SILICON SOLAR CELL OUTPUT

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ABSTRACT

This research studies the influence of surface texturing on the electrical properties of silicon solar cells to enhance solar cells' efficiency. The objectives of this study are to analyse the electrical properties of textured surfaces and identify optimal angle texture for highest efficiency. The methodology involves using PC1D software to simulate electrical behaviour. The key parameters used in this study are 200 μm thickness of silicon substrate, a $3\mu m$ pyramid height, and varied angles (0°-80°), surface area of 100 cm^2, a respective doping concentration with 1×10^{18} cm^{-3} for the n-type, and $1 \times 10^{17}$$cm^{-}$ for the p-type. Along this study, the textured surfaces are expected to increase light absorption, as well as reduce reflection losses and enhance crucial parameters such as short-circuit current and open–circuit voltage. Among all angles, solar cell surface with the angle 53° is the most optimal angle that balance both properties with the photogeneration density, J_{max} = 37.13 mA/cm^2 and reached a 45.04% enhancement as well as the short current circuit, I_{sc} = 3.907A, open circuit voltage, V_{oc} = 0.7342V. The final design's efficiency is 24.49%. These findings demonstrate higher angle pyramid textures enhance light absorption and current generation but must take consideration about surface recombination which may affect value of V_{oc}.

Keywords: Silicon, Solar Cells, Surface Angle, Surface Texturing, PC1D

INTRODUCTION

The sustainable and renewable energy sources have never been pressing for the worldwide but somehow the renewable energy technologies became one of need and more well-known as competitive replacements for traditional fossil fuels due to concern towards the growth of climate changes. In addition, Solar energy became a concern that brought one unique renewable energy source because of its benefits and functionality for the environment. For decades, silicon (Si) solar cells have ruled the photovoltaic industry which converts the sunlight into electrical energy (Xiao & Xu, 2013). However, there are issues with solar energy slowly increasing and limiting the Solar's availability to users (PV Case Team, 2024). According to Andreani et al. (2018), The most promising renewable energy source is solar energy which can be converted into usable power by photovoltaic (PV) conversion in solar cells. For instance, in the European Union, solar power accounts for roughly 4% of the average grid electricity, but in nations like Germany and Italy, it accounts for over 7%. The most widely used material in solar is the best solar modules of crystalline silicon which currently transform more than 22% of sunlight to electric power and can be low-cost and long-lasting (New World Record for CIGS Solar Cells, 2024). However, enhancing the efficiency of silicon solar cells is a key of research.

The photovoltaic (PV) market remains dominated by crystalline silicon solar cells due to their stability, abundant material supply, and reasonable efficiency. In 2020, the c-Si modules have been installed over 125 GW, in 95% of the total photovoltaic (PV) market, and the cumulatively installed is over 700 GW. There is strong evidence that predicts in 2040-2050, the crystalline silicon (c-Si) photovoltaic would become the most significant world electricity source (Ballif et al., 2022). However, one of the obstacles faced is the inherent reflection of sunlight on flat surfaces, which limits the amount of light absorbed and decreasing conversion efficiency. One of effective technique is by adding surface texturing. Surface texturing has come out as a important technique to electrical properties by decreasing reflection and increasing light trapping within the cell. By optimising the surface texture such as adding upright structures, the interaction incident light and efficiency can increase. This study aims to investigate the effects of surface texturing on the electrical and optical properties of silicon solar cells, eventually determining the most effective texture arrangement for performance enhancement.

RESULTS AND DISCUSSION

Table 1 shows the value of parameter that becomes basic parameter to be use in this study. This fundamental parameter has been obtained from (Belarbi et al., 2014). Only a few parameters, such as surface texturing, angle, and thickness on the n- and p-regions will be manipulated in this study.

Table 1: The value of basic parameter for simulation of silicon solar cell.

Parameter	Value
Device area	100 cm^2
Surface texturing	Upright pyramidal
Varied angle	0^o-80^o
Dielectric constant	11.9
Band gap	1.124 eV
n-layer thickness	10 µm
n-doping concentration	1 x 10^{18} cm^{-3}
p-layer thickness	190 µm
p-doping concentration	1 x 10^{17} cm^{-3}
Excitation	One-sun

Figure 1 below shows the schematic diagram of pyramidal surface Si solar cell schemes and a p-n layer. The angle of upright pyramidal will be varied between 0-80, in increments that include small (10°-39°), medium (40°-59°), and large (60°-80°) angles, The same procedure was applied for 10µm thickness of n-type and 190µm thickness of p-type respectively. The results for short-circuit current density (Isc), open circuit voltage (V_{oc}) and maximum power output, and efficiency were tabulated.

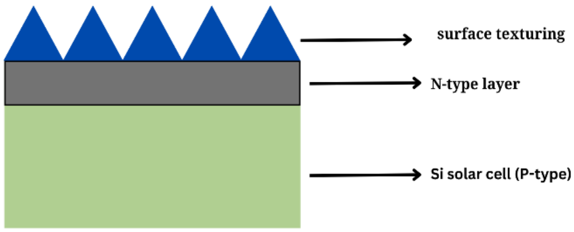

Figure 1: Schematic diagram of pyramidal surface Si solar cell.

The maximum current produced by the solar cell when the external load is shorted is known as the short circuit current (I_{sc}). It is directly influenced by the amount of light that is absorbed and converted into electron-hole pairs, and it indicates the photogeneration rate of charge carriers in the device. Short current circuit (I_{sc}) rises steadily with angle in Figure 2, from 3.867 A at planar surface to 3.938 A at 70°. This is because the influence of increasing photon absorption from multiple internal reflections in higher angle pyramidal textures which lead to greater photogeneration of charge carriers. The most notable enhancement in current occurred in the medium angle (50° and 53°) and large angle (65°-70°) categories.

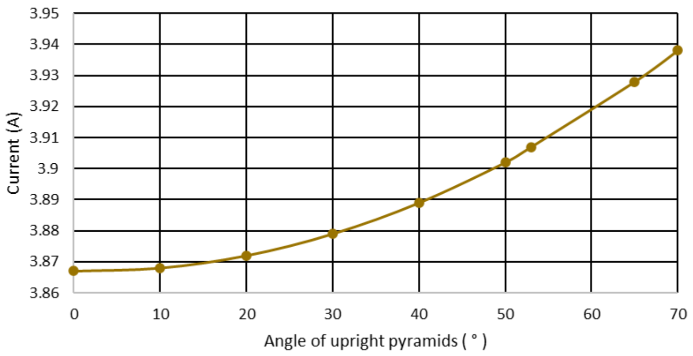

Figure 2: Current characteristic for the upright angle pyramids.

Open circuit voltage (V_{oc}) is a crucial parameter in determining solar cell performance, as it shows the maximum potential difference that a cell can produce when there is no current flow. In contrast to short circuit current, which is influenced by the amount of light absorbed, V_{oc} is strongly impacted by surface recombination and the carrier lifetime. As in Figure 3 shows the voltage characteristic for the upright angle pyramids. V_{oc} showed a slight decrease with increasing pyramid angle from 0.7345 V at planar surface to 0.7333 V at 70°. At 50° and 53°, V_{oc} decreases slightly to 0.7342 V and continues to reduce to 0.7337 V at 65° and 0.7333 V at 70°. A larger textured surface area leads to increased surface recombination, which is an important explaining physical effect that is caused in this drop. According to Ju et al. (2016), greater surface recombination velocity is caused by steeper pyramid textures on crystalline silicon, which decreases carrier lifetime and open-circuit voltage

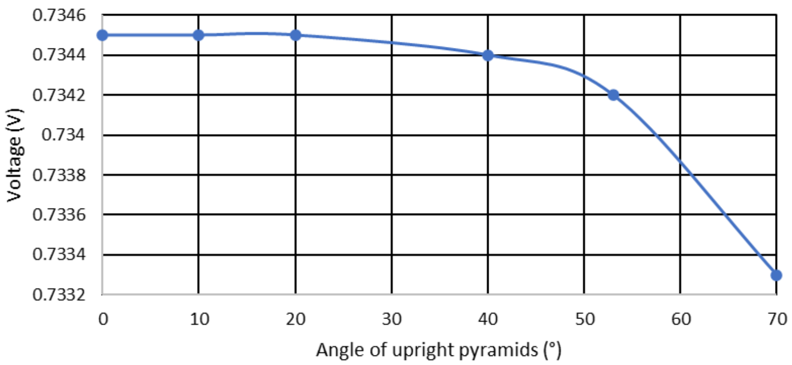

Figure 3: Voltage characteristic for the upright angle pyramids.

CONCLUSION

The electrical properties of silicon solar cells can be significantly improved by optimising surface texture angle. The highest overall efficiency of 24.62% was obtained at angle of 70°. However, the 53° pyramid angle is found to be the suitable configuration, and was identified as optimal angle, achieving a short circuit current of 3.907 A, an open circuit voltage of 0.7342 V, and a correspond power conversion efficiency of 24.49%. This angle offering a well-balanced trade-off between enhancing current generation and stable voltage performance.

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