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E-BOOK OF EXTENDED ABSTRACTS

THICKER OR THINNER? UNVEILING THE BEST SILICON FOR SOLAR EFFICIENCY

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ABSTRACT

This thesis uses simulation methods to study how substrate thickness affects silicon (Si) solar cells' electrical and optical performance. The study simulates optical behavior using PV Lighthouse and analyses electrical factors using PC1D software. Substrate thicknesses ranging from 30µm to 190µm were examined, as well as surface texturing (upright pyramids) to improve light trapping. The PC1D results indicated that increasing thickness typically enhanced overall efficiency, power output (Pmax), and short-circuit current (Isc). The highest efficiency was recorded at 190µm (24.50%). However, open-circuit voltage (Voc) remained reasonably consistent, suggesting that voltage is less sensitive to thickness than current generation. Improved light absorption and decreased reflection with increased thickness were shown by optical simulation using PV Lighthouse, especially in the visible range (300–600nm). In comparison to a flat reference cell, the simulated photocurrent density (Jg) was further increased by using textured surfaces, increasing by 50.62%. These results imply that adding useful surface texturing and optimising substrate thickness, particularly between 160 and 190µm, greatly increase solar cell efficiency while using less material. Through design optimisation, the study advances the creation of high-performance, reasonably priced silicon-based solar systems.

Keywords: Silicon, Solar Cell, Subtrate Thickness, PC1D, Efficiency

INTRODUCTION

The increase demand for renewable energy sources has fueled research into enhancing the efficiency of photovoltaic (PV) technologies, notably silicon (Si)-based solar panels. Silicon is the most commonly utilised material in photovoltaic applications due to its abundance, stability, and high efficiency. However, as the world's energy needs grow, more efficient silicon solar cells are required to make solar energy more economically viable and sustainable. In order to tackle problems like shortages of food, and worldwide climate change, renewable energy technologies have the potential to significantly contribute to global sustainable development by providing clean energy (Izam et al., 2022).The thickness of the silicon substrate is a crucial element in the performance of silicon solar cells. Substrate thickness influences both optical and electrical qualities, which together determine power conversion efficiency. This research aims to investigate the impacts of substrate thickness on the efficiency of silicon solar cells, with an emphasis on how thickness changes affect critical optical and electrical properties, eventually reducing power conversion efficiency.

Existing research emphasises the importance of substrate thickness in silicon solar cell design. Thinner silicon substrates have been demonstrated to lower material costs and improve light-trapping capabilities, resulting in increased photon absorption. By using a lot less material, increasing optical absorption also makes it possible to reduce the thickness of the active absorber layer, which lowers production costs (Amalathas & Alkaisi, 2019). However, the use of very thin substrates brings additional issues, such as increased surface recombination losses and probable mechanical instability, both of which can reduce total efficiency. These problems highlight the importance of carefully balancing substrate thickness to optimise performance without losing structural integrity. An in-depth study of these thickness properties could bring new insights into better silicon solar cell design.

This study is expected to make a significant addition to the area of solar energy by improving our understanding of substrate thickness, a critical parameter in silicon solar cell performance. This work will help to refine design recommendations for high-efficiency, low-cost silicon solar cells by investigating how altering thickness affects power conversion efficiency. According to the findings of recent techno-economic research on thin silicon, wafers that are 50µm thick have the potential to lower manufacturing capital expenditure (capex) by 48%, module costs by 28%, and the levelised cost of electricity (LCOE) by 24% (Augusto et al., 2020). The findings may have important consequences for industrial applications, as optimising substrate thickness might lower production costs while preserving or even increasing cell efficiency. Finally, our research intends to promote the widespread use and economic viability of silicon-based solar technology, in line with global sustainability goals and contributing to the development of dependable renewable energy sources.

METHODOLOGY

The impact of substrate thickness on the electrical and optical performance of silicon solar cells was examined in this study using a simulation-based methodology. PC1D was utilised to evaluate electrical parameters, and PV Lighthouse Wafer Ray Tracer was used to analyse optical behaviour. Two solar cell designs were developed for simulation purposes. The first was a reference crystalline silicon (c-Si) solar cell with a flat surface, as illustrated in Figure 1 (a). The second was a pyramid-textured structure with front surface features slanted at 54.74°, which was intended to improve light trapping and reduce reflection, as shown in Figure 1 (b). The substrate thickness varied from 30µm to 190µm, while the emitter thickness remained constant at 10µm. Table 1 shows the details of basic parameter for the simulation of silicon solar cell.

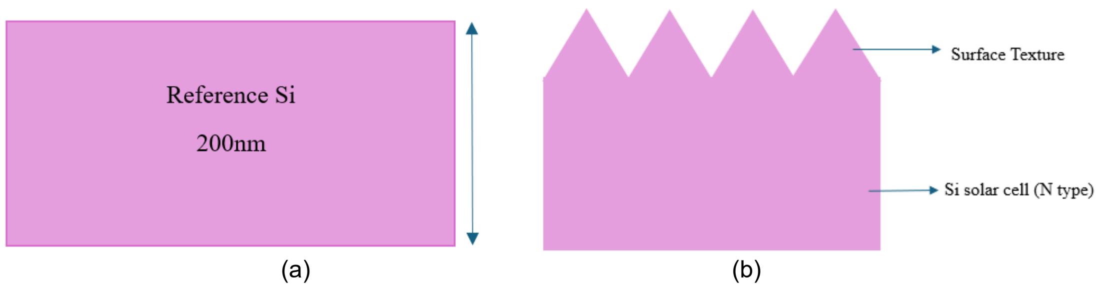

Figure 1: (a) Reference c-Si solar cell (b) Pyramid surface Si solar cell.

Table 1: The value of basic parameter for PC1D simulation of silicon solar cell.

Parameter	Value
Device area	100 cm^3
Front surface texture depth	3 µm
Dielectric constant	11.9
Band gap	1.124 eV
Intrinsic concentration at 300K	1×10^{10} cm^{-3}
Background doping	1×10^{19} cm^{-3}
Bulk recombination	1000 µs

RESULTS AND DISCUSSION

Simulation results using PC1D showed that raising the substrate thickness from 30µm to 190µm significantly improved the solar cell's electrical output. The short-circuit current (I_{sc}) rapidly grew as thicker substrates allowed more photons to absorb and convert into charge carriers. At the same time, the open-circuit voltage (V_{oc}) remained largely constant across all thicknesses, demonstrating that voltage is less affected by structural changes. Table 2 shows that the maximum power conversion efficiency (PCE) of 24.50% was obtained at 190µm. This confirms that thicker substrates enhance overall device performance, although the benefits reduce after around 160µm. As highlighted by (Du et al., 2020) the performance of solar cells is greatly influenced by the device's thickness and light intensity. This is because bulk recombination becomes more likely when the produced carriers travel longer distances to reach the junction, increasing the likelihood of recombination before contributing to current. Furthermore, above a certain depth, light absorption is limited, so increasing thickness has no effect on the generation of further electron-hole pairs. The output power continues to increase with thickness, although at a slower rate, and efficiency eventually plateaus. The ideal range between 160µm and 190µm balances performance and material utilization.

Table 2: PC1D results for different subtrate thickness.

Surface texture	Thickness substrate (µm)	Isc (Amps)	Voc (Volts)	Power (Watts)	Efficiency (%)
None (reference)	200	3.867	0.7345	2.427	24.27
Upright pyramid	40	3.533	0.7440	2.239	22.39
	70	3.696	0.7421	2.326	23.26
	100	3.781	0.7401	2.393	23.93
	130	3.835	0.7382	2.422	24.22
	160	3.874	0.7363	2.438	23.38
	190	3.902	0.7347	2.448	24.48
	200	3.909	0.7341	2.450	24.50

The PV Lighthouse simulations concentrated on the optical characteristics of silicon solar cells with pyramidal surface patterns. Adding a textured front surface dramatically enhanced light absorption, particularly in the visible wavelength region (300-600nm). The photocurrent density (J_g) rose with thickness, settling at 38.71 mA/cm² for a 200µm thick textured substrate, representing a 50.62% enhancement over a flat reference cell. Figure 2 shows that the increase decreases beyond 160µm, indicating an appropriate range for maximum absorption while limiting material utilisation. This pattern suggests that although thicker substrates absorb more light overall, the majority of the J_g enhancement happens between 40 and 160µm, and additional thickness increases only yield slight improvements. Because of deeper light trapping within the textured structure, reflectance also reduced with increasing thickness, especially in the visible range of 300–600nm. (Kowalczewski & Andreani, 2015) claimed that reducing the thickness below about 40 µm is useless because it drastically lowers the maximum efficacy that may be achieved. However, due to silicon's increased transparency in the near-infrared spectrum, reflection patterns started to converge across all thicknesses at longer wavelengths above 1000nm. These results demonstrate how surface texturing and a moderate substrate thickness can be combined to greatly improve optical performance without using large amounts of material.

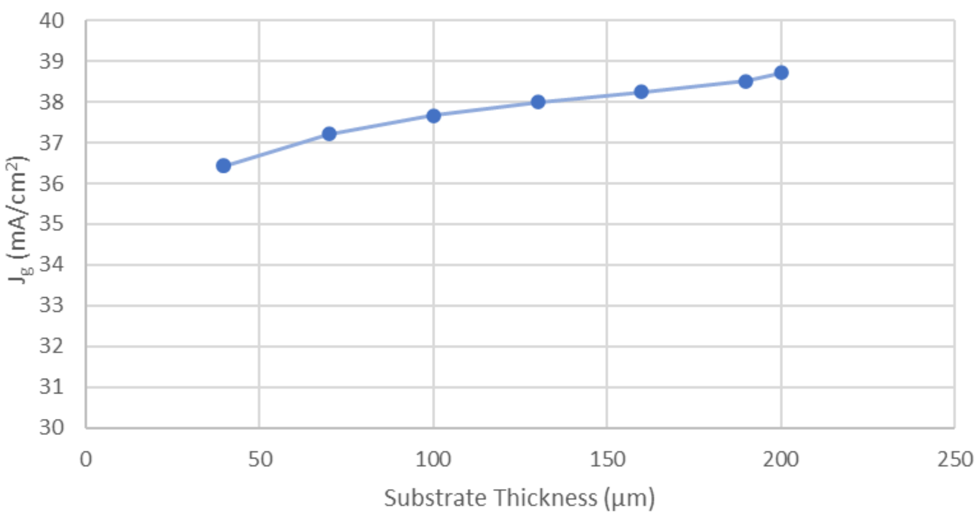

Figure 2: Photogenerations with substrate thickness for textured silicon solar cell.

CONCLUSION

This study investigated how a silicon solar cell's thickness impacts its ability to generate power and absorb light. According to the simulations, efficiency can be increased with thicker substrates, particularly between 160 and 190 µm. However, thickness increases only little beyond that point. Even for thinner cells, the use of pyramid textures on the surface significantly improved light trapping. Finding the ideal balance between thickness and surface design ultimately yields the highest performance, assisting in the development of solar cells that are both economical and efficient.

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