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Research Paper

Impact of Texturisation and Anti-Reflective Coatings on Light Absorption Efficiency in Solar Panels

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ABSTRACT

The global shift from non-renewable energy sources to clean energy systems has put the existing renewable infrastructure to test. Solar power, the most promising resource for future, faces the barrier of lower efficiency rates than the conventional sources of energy, and thus increasing efficiency of each step involved can ensure its reliability.

This study aimed to address the light absorption efficiency of solar cells through experimentation on texturisation and Anti-Reflective Coatings through the online simulator 'Wafer Ray Tracer'. For the experiment, 3 different materials (Silicon Dioxide, Titanium Oxide, and Silicon Nitride) with texturized and planar surface were used and ray tracing was performed.

The results of the experiment showed that all the 3 materials had significantly higher efficiency rates than control (bare silicon wafer) and texturisation of the surface also reduced optical losses to a great extent. Moreover, Texturized Silicon Nitride and Titanium Oxide recorded mean light absorption efficiency close to 98%, compared to 63% of planar Silicon Wafer.

Key words: solar panels, light absorption, texturization, anti-reflective coating

INTRODUCTION

With more than 80% of global primary energy coming from fossil fuels, the world faces an impending threat to energy security in near future. [1] The focus, thus, has now shifted to the sphere of clean energy sources that, unlike conventional sources of energy, provide for a much more reliable and stable energy supply chain. Among all the available renewable sources like wind energy, solar power, hydropower, geothermal and tidal energy etc., Solar power stands out as being the most affordable, practical, and scalable resource for the future. But there are 2 main barriers to the widespread utilisation of solar resource: high fluctuations in supply owing to atmospheric conditions, and lesser efficiency than conventional sources of energy. [2-4]

In solar panels, the efficiency of the device is the product of the efficiencies of various sub-processes that occur prior to the generation of electricity, namely light absorption, charge excitation, charge drift, charge separation, and charge collection. [5]

The light absorption efficiency of bare silicon wafer stands at less than 65% according to our initial experimentation. In order to make solar panels more commercially viable, it is necessary to improve their efficiency by minimizing losses at all the steps of PV systems. The use of Anti-reflective coatings and texturisation helps in reducing the optical losses of solar panels.

Anti-reflective coatings (ARCs) are few nanometers thick coatings of dielectric material on the surface of Silicon cells that use the phenomenon of destructive interference to minimize reflection from the surface of the panels. [6-9] The thickness of the coatings is determined in such a way that the light reflected from the ARC is out of phase with the light reflected from the semiconductor, thus resulting in zero net reflectivity. Texturisation is another proven technique of reducing optical losses, wherein the principle used is that any irregularity in the surface increases the chances of light bouncing back into the material, thereby increasing the light absorption efficiency of the material. [10-13]

Addressing the problem of lower efficiency rates of Photovoltaics systems, this study aims at comparing the light absorption efficiency of solar panels with different experimental subjects. For the experiment, 3 different materials, which are commonly applied on the surface to minimise reflectivity, have been used as ARCs for the experiment. The materials (Silicon Dioxide, Titanium Oxide, and Silicon Nitride) offer various important properties like optimal refractive indices, high durability and stability, mechanical resistance, high transmittance, and comparatively lower cost. [14-17] The experiment has been carried out with the help of the online ray-tracing simulator 'Wafer Ray Tracer', offered by PV Lighthouse. [18]

The uniqueness of this study is that in contrast to the previous studies in the field of Photovoltaics, this study not only quantitatively measures the efficiency of strategies developed to combat optical losses, but also explores digital means of conducting experiments by using an online simulator for Ray Tracing. Thus, this study aims at comparing the light absorption efficiency in solar panels with texturized and planar Anti- reflective coatings of Silicon Dioxide, Titanium Oxide, and Silver Nitride, and testing it against control (planar bare Silicon Wafer).

MATERIALS AND METHODS

Method of Experimentation

I. An investigation into the properties of the materials was carried out, and the refractive indices were determined. The data obtained is as depicted in table 1.

Table 1: ARC Materials with their refractive indices

Material	Refractive Index	
Silicon Dioxide	1.4694	Gao et al. 2013 [19]: Thin film; n,k 0.252–1.25 µm
Titanium Oxide	2.1466	Sarkar et al. 2019 [20]: Thin film; n,k 0.30–1.69 µm
Silicon Nitride	2.0458	Luke et al. 2015 [21]: n 0.310–5.504 µm

II. Using the refractive indices of the materials, the optimum thickness of the ARC was determined with the formula.

$d_1 = \lambda_0/4\eta_1$

In the formula,

d_1 is the thickness of the ARC, λ_0 is the wavelength of incident light, and n_1 is the refractive index of the material. The wavelength of incident light was taken as 550 nm (near the peak of solar spectrum).

The thicknesses of the ARCs are as shown in table 2.

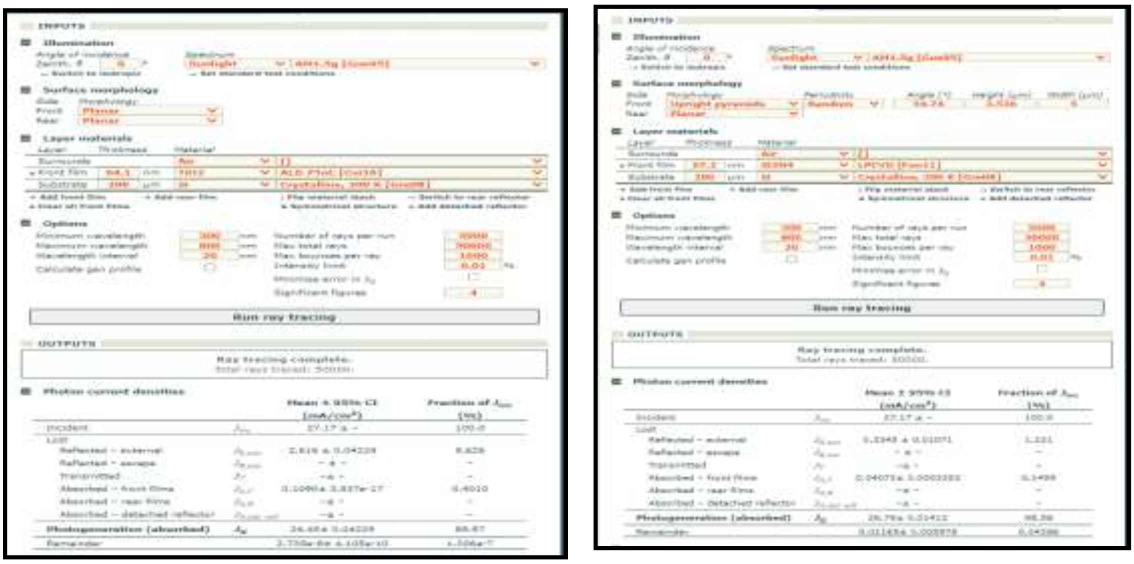
Table 2: ARC **Materials with their calculated optimal thickness**

Material	Thickness (in nm)
Silicon Dioxide	93.9
Titanium Oxide	64.1
Silicon Nitride	67.2

III. The experiment has been carried out with the help of the online ray-tracing simulator 'Wafer Ray Tracer', offered by PV Lighthouse. It determines the photo generated current density in a solar cell or test structure under a chosen illumination spectrum by combining Monte Carlo ray tracing with thin film optics.

The link to the simulator is Wafer ray tracer (pvlighthouse.com.au) [18]

Figure 1: Screenshots of the simulator 'Wafer Ray Tracer'. A: Planar-TiO2 B: Texturised-Si3N4



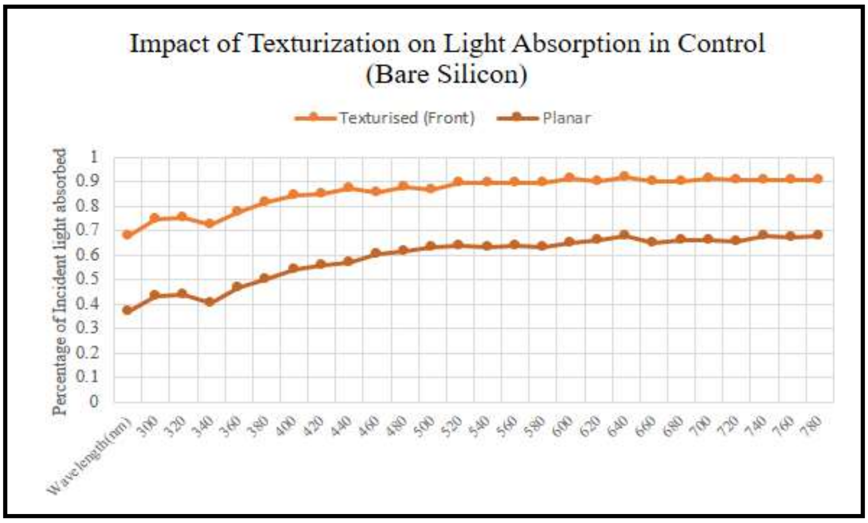
For the experiment, a few parameters were kept constant. The angle of incidence was taken to 0 degree, and the spectrum chosen was Sunlight. The substrate chosen was 200 µm Silicon film,and the ray tracing was done at 20 nm intervals from 300 to 800 nm in order to include the complete visible region of the spectrum. Moreover, the treatment/texture applied on all the substances was random upright pyramids with angle 54.74 degrees.

Ray tracing was performed a total of 8 times: 4 times for planar ARCs + control, and 4 times for texturized ARCs + control. The data obtained from the simulator was collected and analysed: inference was drawn with the help of summary statistics.

RESULTS AND DISCUSSION

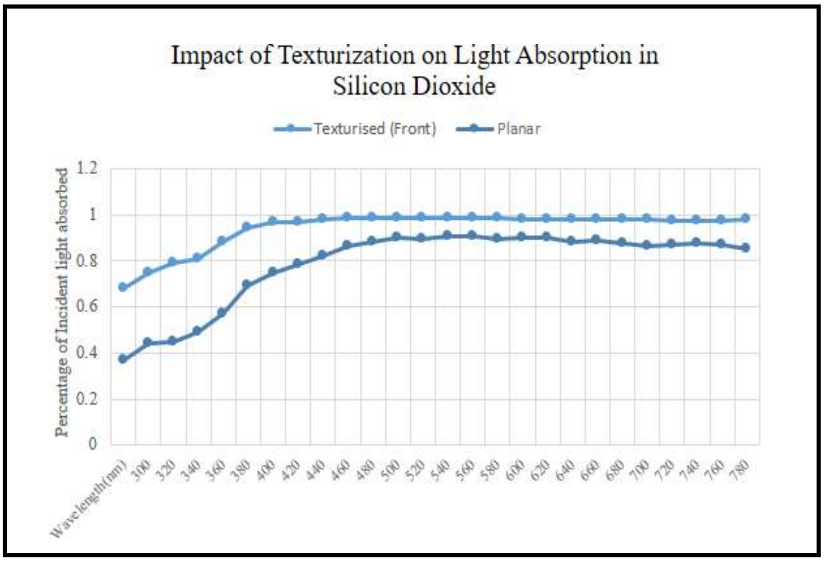
Of the 27.17 mA/cm^2 incident light, about 17.06 mA/cm^2 was absorbed by the control (Bare Silicon wafer without texture). This resulted in mean light absorption efficiency of 62.77%, with standard deviation of 9.59%. On the other hand, around 24.07 mA/cm^2 of incident light was absorbed on texturing the surface, increasing the mean light absorption efficiency to 88.59%. The graph comparing the proportion of light absorbed for Planar and Texturized Silicon surface is plotted for the 26 values obtained from Ray Tracing. **(Figure 2)**

Figure 2: Illustration of impact of texturization on light absorption (Bare Silicon wafer with and without texture)



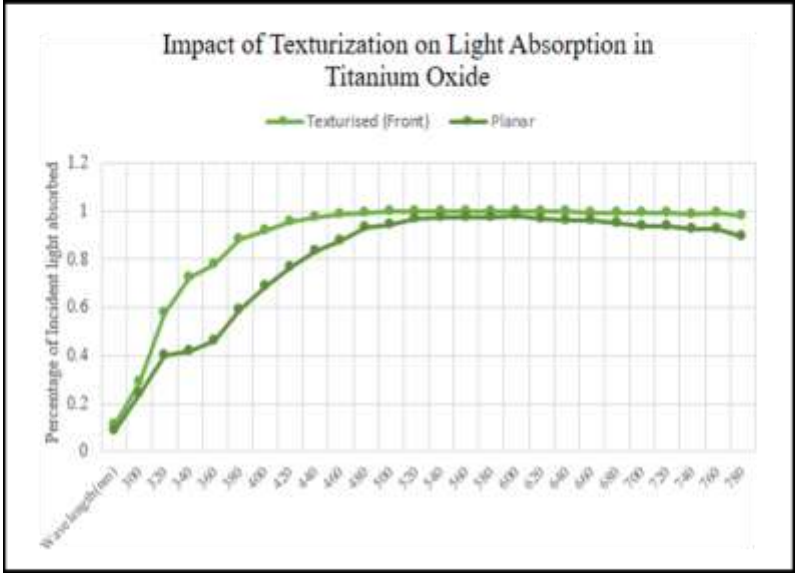
The mean percent of light absorbed with planar ARC of Silicon Dioxide (93.9 nm) was found to be 85.52%, while the value increased to 97.34% on texturizing the surface. The graph shows that both the planar and texturized surfaces followed a similar trend, with a modest crest around the region of yellow colour spectrum (570-590 nm). **(Figure 3)**

Figure 3: Illustration of impact of texturization on light absorption (Silicon dioxide wafer with and without texture)



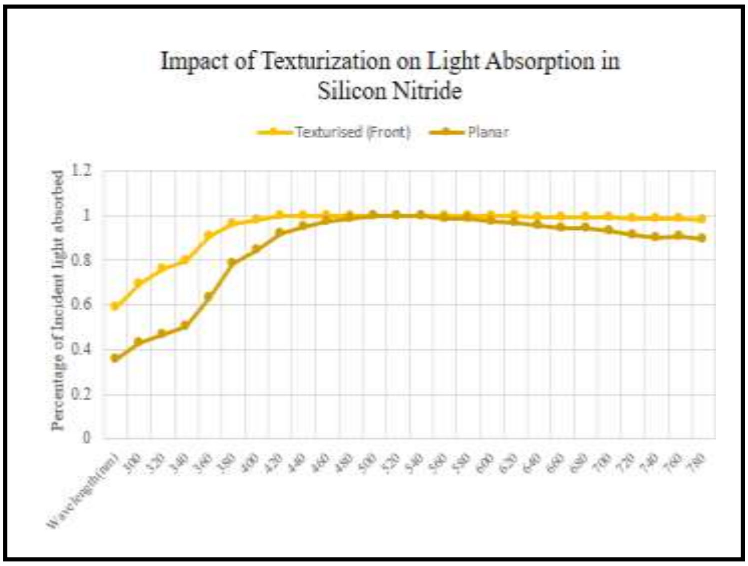
Planar ARC of Titanium Oxide had mean light absorption efficiency close to 90%, and texturisation increased the value to 97.4%. Interestingly, the efficiency increased steeply from 300 to 450nm, jumping from less than 10% to more than 95% for the texturized ARC. Moreover, the absorption efficiency on texturisation was more than 99.5% in the 500-700 nm range.

Figure 4: Illustration of impact of texturization on light absorption (Titanium Oxide wafer with and without texture)



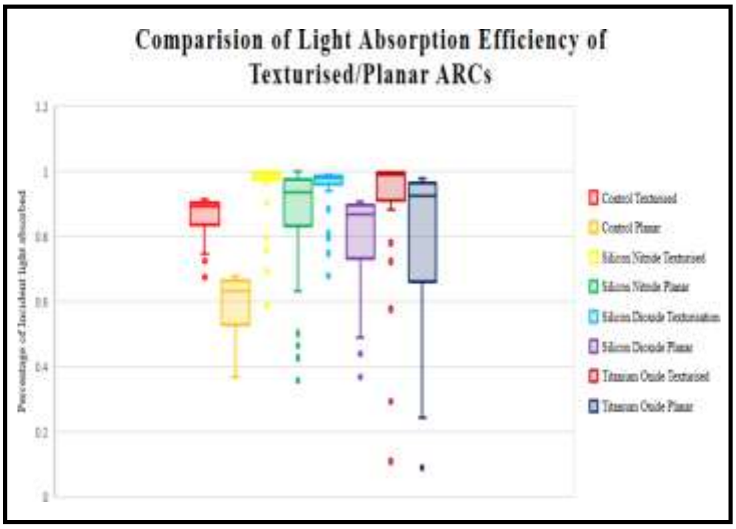
Silicon Nitride recorded the highest mean light absorption efficiency for both the groups, with the value being 93.10% and 98.58% before and after texturisation respectively. The effect of texturisation was not significant around the peak of solar spectrum though.

Figure 5: Illustration of impact of texturization on light absorption (Silicon Nitride wafer with and without texture)



Since the distributions of the subjects were skewed in the range of 300-400 nm, boxplot analysis was done for all the planar and texturized ARCs, and it was found that the median light absorption efficiency for texturized ARCs was significantly greater than that of planar ARCs, and their Inter Quartile Range was also significantly less than that of planar ARCs. Among the ARCs, it was found that the Q3 value and the median value of Titanium Oxide were about the same as that of Silicon Nitride (Planar). Silicon Dioxide also followed closely, with the median absorption efficiencies of all the 3 materials being significantly greater than the control. **(Figure 6)**

Figure 6: Boxplot analysis of effect of planar and texturized ARCs on light absorption efficiency



Photovoltaics systems, the most promising alternative energy resource, have lower efficiency in comparison to the conventional sources of energy. The present work addressed this problem and studied light absorption efficiency of solar cells through experimentation on texturisation and Anti-Reflective Coatings through the online simulator 'Wafer Ray Tracer'. All the three different materials used (Silicon Dioxide, Titanium Oxide, and Silicon Nitride had significantly higher efficiency rates than control (bare silicon wafer). In addition, texturisation of the surface also reduced optical losses to a great extent. Texturized Silicon Nitride and Titanium Oxide recorded mean light absorption efficiency close to 98%, compared to 63% of planar Silicon Wafer.

Future research can expand on the results of this experiment to include and exclude Infrared and Ultraviolet regions, such that a more comprehensive analysis can be done for reducing optical losses.

CONCLUSION

Light absorption efficiency of solar cells with texturisation and Anti-Reflective Coatings revealed much higher efficiency rates. All the 3 ARCs have significantly greater light absorption efficiency rates than that of bare Silicon, with Silicon Nitride and Titanium Oxide having the efficiencies >99% much of the spectrum. Moreover, texturisation was also found to increase the absorption efficiency in all the materials significantly.

Declaration by Authors: Shashvat Rastogi (Ideation, Data Analysis, and manuscript preparation); Vivasvat Rastogi (Experimentation, Data Collection, manuscript review)

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