Technical Report on the Anti-Reflection Coating for Solar Cell

An analysis using the Transverse Matrix Method

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# Overview

Abstract

This report studies the design of an anti-reflective coating for solar cells, which enhances the transmitted power to solar cells. By employing the Transfer Matrix Method (TMM), this study looks into a double layer coating by outlining the theoretical basis for the system and computationally solving for optimal indices of refraction (IOR) choices to maximise the transmittivity. The main optimization strategy involves minimizing the reflectivity at a center wavelength to increase the transmittivity near that wavelength. The design of a 3-layer system will also be examined to show that the underlying methodology used to design the 2 layers system is generalizable. All of the implemented code is found [here](https://github.com/JDazogbo/Anti-Reflection-Coating).

Introduction

In recent years, global warming has become and increasingly worrying topic to an ever-increasing number of individuals. As time progresses and no drastic solutions to the global CO2 emission problem is found, smaller, more concrete solutions are developed to slow down the progression of this crisis.

One area of research that is growing because of this is renewable energy sources. Making more efficient and less costly renewable energy sources could make them more attractive compared to fossil fuels which are still the reasons why the power sources have yet to reach widespread adoption.

Solar panels in particular aren’t seeing much use despite the numerous benefits they offer since their cost of installation and development do not justify their low power output. Making a more efficient solar panel system could prove to be useful from both a financial, for economical profit, and an ecological standpoint.

This report analyses the potential design of a solar power cell coating capable of decreasing the total system reflectance, which would increase the total power that a single meter squared (m2) of solar cell material. This system will be assessed using the Transfer Matrix Method (TMM) which allows to predict the output reflectivity, transmittivity and transmitted power of a layer system computationally.

# Body of the Report

The Double Layer Coating

## General Theory

The Double Layer Anti-Reflective coating was designed to behave like a set of 4 different materials, each having its own index of refraction (η0, η1, η2 and ηcell). The incident waves from one layer will propagate through the medium where part of this wave will be reflected at the boundary, and some will transmit to the other layer. This should theoretically increase the amount of power that will be absorbed by the last medium as part of the reflected waves from layers 1 and 2 will reflect to a previous boundary and be absorbed at a future time.



Figure 1: Diagram for the Double Layer Coating System

## No Layer System

For a system with no anti-reflective layers, the system can be simplified into a single boundary between 2 mediums (in this case, Air and Silicon).



Figure 2: Diagram for the no Layer setup

The reflectance of a system like this is simply:

For the case of air and silicon:

The total power absorbed by the system would then be:

## Two Layer Coating

To compute the reflectance and power of a system with a larger number of layers, consideration for the reflections of the reflections is needed. As this process happens an infinite amount of time, analytical computations using the usual formulas can get tedious. The Transverse Matrix Method allows us to look at the limit of these reflections and as such simplifies the math. A Python implementation of this algorithm was developed to avoid any manual computations.



Figure 3: UML Class Diagram of the TMM Application

The system would define a Layer class that would contain the main parameters relevant to a layer (index of refraction, center wavelength) as object attributes and will have 2 methods that would compute the dynamical and propagation matrices. This method of design will allow us to create a multitude of instances of layers that we can chain together using the previousLayer field. No scaling issues will arise when upgrading to the Triple Layer Coating.

To validate the results of the TMM implementation in Python, the TMM algorithm was performed manually to determine reflectivity of the double layer coating as a function of refractive indices. The TM for this system would be:

The reflectance at the center wavelength will then be:

where:

To minimize the total reflectance at the center wavelength (i.e when the numerator of the reflectance is 0), the indices of refractions of this system must respect this relationship:

For our choices of η0, η1 and η3, it follows that η2 must equal 2.62

Using the Python implementation of the TMM, we can graph the reflectance of the system at various incident wavelengths:

A graph of a function of a power production

Description automatically generated

Figure 4: Screenshot of the Reflecticity of the System as Computed by the designed Algorithm from λ1 = 400 nm to λ2 = 1400 nm

A graph of a function of light

Description automatically generated

Figure 5: Reflecticity for ranges of wavelengths from λ1 = 200 nm to λ2 = 2200 nm

## Potential Optimization

The approach used to optimize the multilayer system as done for the 2 layers (and the same that will be used for the 3 layer coating) is to minimize the reflectivity at a certain wavelength. This approach gives us a very good Transmittivity to Reflectivity ratio. By searching for a better reflectivity spectrum by calculating the total power for random values of a n1 and n2, we can find various pairs of indices of refraction that give better general reflectivity. Using a step of 0.1, we find that if n1 is 1.5 and n2 is 2.4, the transmitted power from 200nm to 2200nm is of 941.20. This is its resulting reflectivity-power spectrum:

A graph with a blue line

Description automatically generated

We notice from this spectrum that the power is close to 0 for a more significant portion of the incident wavelengths since it 0 close to 250nm, 500nm and 850 nm. This result shows that the approach of optimizing for a specific wavelength might not be the ideal methodology for designing an effective anti-reflection coating for the solar cell.

The Triple Layer Coating

## General Theory

The Triple Layer Anti-Reflective coating behaves very similarly to the Double Layer coating except that instead of having 4 medias, a 5th one is introduced to further minimize the reflectance. Once again, this system was modeled using the Python algorithm developed and the analytical approach was used to confirm these results



Figure 6: Diagram of the 3 Layer system

The transfer matrix of this system would then be :

and the total reflectance would be :

To minimize the total transmitted power, the indices of refractions must follow this relationship :

which for our system η2 is 2.48

By comparision, the Python algorithm outputs this as a function of total transmitted power

A graph of a curve

Description automatically generated

Figure 7: Transmitted power graph

From this graph, we can see that the peak power for the transmitted power is closer to 2.15. This might be a result of the numerical integration that has a limit on the number of iterations that can be achieved.

# Conclusion

## Summary

In summary, the design of an anti-reflection coating for solar cells was successful in increasing the total transmitted power that the solar cell received. By looking at the transmitted power for a 2 layer and 3 layer system with a specific constraint of layer thicknesses, we were able to optimize our design for a single center wavelength and show that this “obvious” methodology wasn’t the best approach at increasing the total transmitted power.

## Additional Observations and Recomendations

In doing the analysis of the system, one interesting trend seems to emerge for the minimization of the total reflectance of the system. It seems that the steeper the difference between layers that are adjacent, the higher the resulting reflection coefficient. This is simply restating a fact that is buried in this equation.

Taking this reasoning to the limit, the “best possible” coating might be a coating with a continuous index of refraction ranging from the initial IOR of air (1.0) to the IOR of the solar cell (≈3.5).

This is not feasible in the practical world as it would imply that materials of all possible IOR ranges exist and can be easily usable to manufacture the coatings. Even though this theoretical limit is unfeasible, this knowledge can be used to determine a rough estimation of very good layer IORs by simply gradually increasing the IORs until we arrive at the last boundary with the cell.