Impact of Broadband Antireflection Coating Design on Solar Power Production

ELG 3106

Professor Henry Schriemer

Akram Atassi

Student Number: 300273147

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# Introduction

Solar cells have emerged as a reliable and economically viable source of renewable energy, playing a pivotal role in the global shift toward cleaner energy solutions. The ongoing improvement of solar cell efficiency, crucial for converting sunlight into electricity, has significantly contributed to the economic viability of solar energy. One effective strategy in this pursuit is the application of anti-reflective coating, a technology designed to minimize light reflection and optimize light transmission to solar cells.

This design studies the parameters for minimized light reflection, with a specific focus on solar cells featuring either two or three layers of anti-reflection coating. The design methodology encompasses the determination of layers, refractive indices, and thicknesses. It takes into account the idealized solar spectral irradiance to derive the wavelength distribution of incident sunlight on the solar cells.

The primary objective of this study is to evaluate the full optimization of solar cell power generation, even when employing seemingly straightforward approaches to anti-reflection coating design. Power calculations in this endeavor involve the numerical integration of a provided equation, leveraging wavelength-dependent transmissivity obtained through the Transfer Matrix Method (TMM) implemented in a MATLAB script. The design focuses on both double and triple-layer anti-reflection coatings, simulating solar radiation on the solar cell system using uniform plane waves.

Furthermore, the design ambitiously formulates a multilayer anti-reflection coating with the highest attainable transmissivity across an extensive wavelength range. This ambitious pursuit results in a reflectivity versus wavelength curve characterized by both depth and width, symbolizing the broadest possible bandwidth and, consequently, the most optimal power generation.

In essence, this study sheds light on the intricate dynamics of solar cell design. By dissecting the influence of various design parameters, it aims to contribute valuable insights into the challenges that present themselves in the quest for higher solar cell efficiency. As solar energy continues to be a cornerstone of sustainable energy solutions, this design exploration sets the stage for further advancements in solar cell technology, driving the evolution toward cleaner and more efficient energy production.

# Theory

where nm and .

## Transfer Matrix Method

Where

Is the dynamic matrix, which is defined by the reflection and transmission coefficients

and

where the propagation matrix () is defined as:

.

And is the phase thickness of the *mth* layer, whose physical thickness is *dm*. Here is the wavelength in free-space (air).

Where T is the system transform matrix

Assume

For a lossless non-magnetic medium

# Part 1

## A)

Let

## B)

For a two-layer anti-reflective coating, we can use the following formula:

Using the reflections and transmission coefficients for the double layer, the dynamical matrices Q can be calculated:

The phase thickness () is defined as

Where dm is the thickness of each layer of the anti-reflective coating, and it is assumed to be  
 , where is the center wavelength. At , we get . The two propagation matrices can be calculated by

Algorithm Plan:

Given and :

1. find
2. find

Given :

1. Find and

Solve .

Get and solve for and

## C)

By assuming the design condition to have , we can solve for as follows:

Solving for and (skipping,, and ignoring the coefficient of the matrix product):

## D)

The minimum reflectivity we can get is , which occurs when . Doing so, we get the following equation:

For ,, and , we get

# Part 2

## A)

A screen shot of a graph

Description automatically generated

Figure

## B)

A screen shot of a graph

Description automatically generated

Figure : Wavelength between 440nm and 1400nm

A screen shot of a graph

Description automatically generated

Figure : Wavelength between 200nm and 2200nm

## C)

A screen shot of a graph

Description automatically generated

Figure

In an effort to find maximum power transmission, we determine if modifications to the refractive index and/or layer thickness could result in heightened power output. We create a graph depicting the total power output over a range of refractive indices for n2. After performing calculations for 200 indices, it emerged that a refractive index of around 2.3 yielded the most favorable power output at around 940 W/m^2.

# Part 3

Where:

Similar to part 1, if we want to find the least reflectivity (), we set it to 0, which means that .

Plugging in these into :

# Part 4

## A)

A screen shot of a graph with Arch bridge in the background

Description automatically generated

Figure

In the analysis represented in Graph 6, a significant observation emerges, highlighting the optimal performance associated with a specific refractive index, denoted as n2 = 2.17. This particular refractive index has been identified as the most advantageous for maximizing the transmission of power to the solar cell.

What stands out in this observation is the distinct emphasis on the role of n2 in facilitating optimal power transmission, overshadowing the conventional focus on the refractive index at the center wavelength. Unlike the typical center wavelength consideration, it becomes evident that, in this specific context, the refractive index of n2 = 2.17 plays a crucial role in achieving maximum power transmission efficiency to the solar cell. This nuanced understanding underscores the importance of looking beyond conventional parameters and tailoring specific refractive indices to achieve optimal outcomes in the context of solar cell performance. The implications of this finding extend to the potential refinement of coating strategies and design considerations to enhance solar cell efficiency under varying optical conditions.

## B)

## C)

A screen shot of a graph

Description automatically generated

Figure

In contrast to traditional expectations focused on minimizing reflectivity at the central wavelength, the analysis of total power for a refractive index of n2=2.17 challenges the norm by indicating superior power transmission compared to n2=2.36. This assertion finds support in the graph above, a visual representation of the power transmission characteristics associated with these refractive indices. Further exploration in section D.2 scrutinizes this phenomenon, elucidating that n2=2.17 outperforms the center wavelength in power transmission.

# Conclusion

Without an anti-reflective coating, optical analysis simplifies to a basic interface between air and the semiconductor, involving reflection and transmission. The power transmitted to the semiconductor depends on incident light intensity and transmissivity, with around 30% of light expected to reflect without the coating. This simplified analysis validates theoretical expectations.

Examining dual-layer coating using the Transfer Matrix Method in MATLAB reveals a systematic approach to evaluating its impact on optical properties. Similarly, for the triple-layer coating, a systematic MATLAB approach employing the Transfer Matrix Method demonstrates the influence of refractive index values on optical performance. Despite slight variations between analytically derived and MATLAB-implemented refractive indices, the visual representation of reflectivity against wavelength provides insights into coating performance under different optical conditions.