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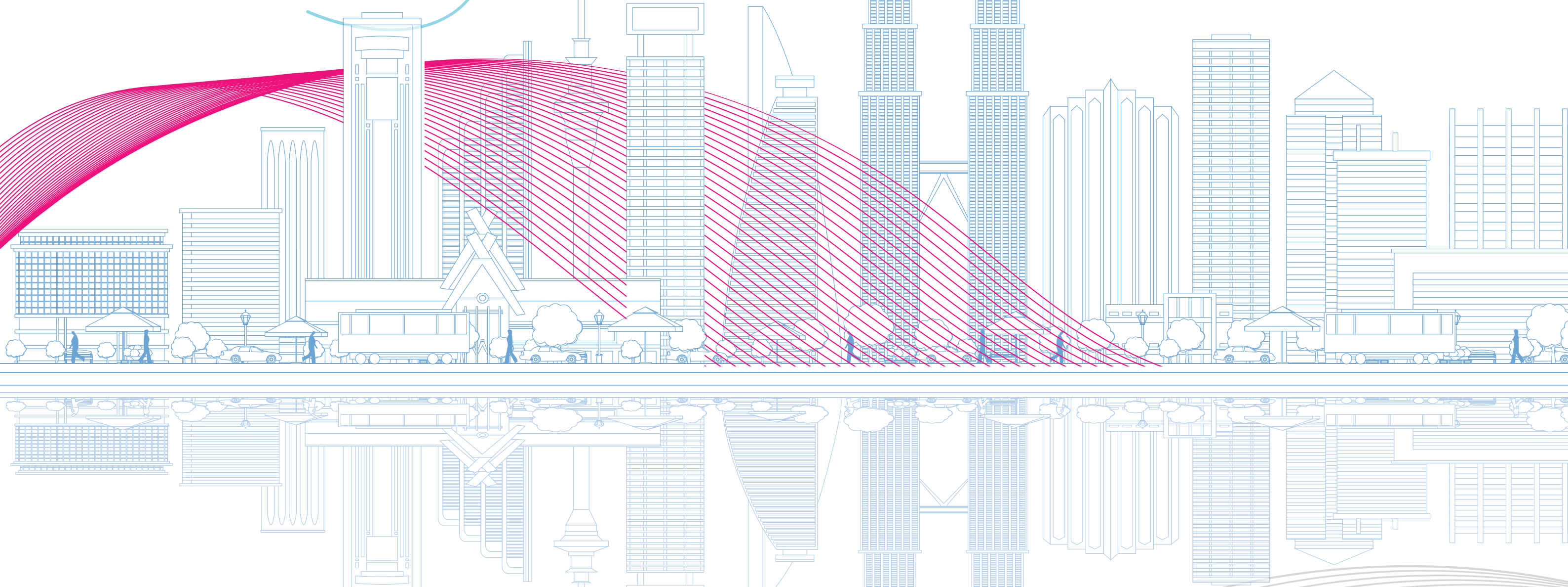
"Undergraduates' Digital Engagement Towards Global Ingenuity"

2nd Edition



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NUMERICAL MODELLING OF HIGH-EFFICIENCY Si SOLAR CELL USING VARIOUS DLARCs

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Abstract
Solar cells, also known as photovoltaic cells, convert sunlight into electricity, reducing human reliance on fossil fuels. Understanding historical advancements, principles, and various types of solar cells is crucial for optimising this sustainable energy alternative and advancing the use of clean and renewable energy sources. This study investigates the impact of double-layer antireflection coating (DLARC) materials on silicon solar cells, focusing on their role in reducing reflectance across various wavelengths. There are five material pairing schemes intended for DLARC. The current-voltage and power-voltage electrical characteristics of solar cells will be analysed further. Among the five schemes, the pairing from MgF_2 and Si_2N_3 has yielded the highest efficiency, which is 20.94%. It is proven that DLARC can improve the solar cell's ability to absorb sunlight and will further increase the power conversion efficiency.

Keywords: *silicon, solar cells, PC1D simulation, solar cell efficiency, double layer anti-reflection coatings*

1. INTRODUCTION

Solar cells, also referred to as photovoltaic cells, directly convert sunlight into electricity. Their significance lies in their pivotal role in harnessing clean and renewable energy sources, thereby effectively reducing our reliance on fossil fuels. To advance and optimise this sustainable energy alternative, a thorough understanding of the historical advancements, underlying principles, and various types of solar cells is imperative. The field of solar cell research has its roots in the 19th century when scientist Alexandre-Edmond Becquerel made the groundbreaking discovery of the photovoltaic effect. This phenomenon involves certain materials generating an electric current upon exposure to light. Becquerel's discovery paved the way for further investigations and studies in this area. However, it was not until the 1950s that practical applications of solar cells began to emerge, giving credit to the innovative work carried out at Bell Laboratories (Fraas, 2014). In 1954, an efficiency rate of approximately 6% was carried out by Daryl Chapin, Calvin Fuller, and Gerald Pearson, who invented the first silicon solar cell.

Solar panels composed of silicon currently offer a blend of optimal effectiveness, affordable pricing, and extended longevity. These modules can retain over 20% of their initial energy output even after this extensive period of use. Silicon is a nontoxic material. Thus, it poses no harm to the ecosystem. In contemporary photovoltaic technology, every cell comprises two different layers of semiconducting materials: the p-type material acts as the emitter, while the n-type material serves as the base. In the presence of light at the p-n junction, the photons of light effortlessly penetrate the junction by passing through the thin p-type. The current top-performing solar panels have an efficiency rating of approximately 18% to 20% (Saleem et al., 2019). Although this might not appear significant, today's solar panels are significantly more powerful compared to those developed over 60 years ago. Additionally, researchers at the National Renewable Energy Laboratory have achieved a breakthrough in solar cell efficiency, setting a record of 39.2% efficiency with a silicon solar cell. This leads to optimising for a substantial improvement in the efficiency of solar panels soon.

2. MATERIALS AND METHODS

The refractive index is one of the most important properties to consider, as it describes how the material affects the speed of light travelling through it. A good pairing of DLARCs will help the Si solar cell absorb incident sunlight effectively. Using PC1D simulation software, five pairings of DLARCs are designed on top of Si solar cells (with a 100 µm thickness), and the thickness of each ARC layer is set to 75 nm. This is the optimum thickness of ARC, as the value of the current density will decrease if the thickness of ARC is set higher (Jamaluddin et al., 2022). The details of the five schemes with the refractive index of each partnering material are displayed in Table 1. A constant parameter has been used for the basic setting in PC1D for simplification purposes. The following constant parameters are shown in Table 2.

Table 1. Parameters of each appliance used in PC1D setting.

Parameter	Value
Device area	200 cm^2
Substrate material	Silicon
Thickness of substrate	100 µm
Number of time steps	16
Temperature	25 ^oC
Excitation mode	One-Sun.exe
Thickness of ARC layers	75 nm

Table 2. The refractive index of DLARCs on Si solar cells.

Scheme	Top layer ARC	n_1	Bottom layer ARC	n_2
Scheme I	MgF_2	1.38	ZnS	2.36
Scheme II	SiO_2	1.45	ZnS	2.36
Scheme III	Al_2O_3	1.60	ZnS	2.36
Scheme IV	TiO_2	1.798	ZnS	2.36
Scheme V	MgF_2	1.38	Si_2N_3	2.30

3. RESULTS AND DISCUSSION

The process of destructive interference is essential for increasing light cell absorption. The thickness and refractive index of DLARC layers may be precisely adjusted to control the interference effects (Abdellatif et al., 2018). The phenomenon of destructive interference combined with anti-reflective coatings that minimise reflection contributes to improved solar cell performance. The results of applying several kinds of anti-reflective coating to silicon solar cells are further discussed in this section. While maintaining the 100 µm silicon cell constant as the reference cell, the coating is composed of five distinct pairs of DLARC, namely (MgF_2/ZnS), (SiO_2/ZnS), (Al_2O_3/ZnS), (TiO_2/ZnS), and (MgF_2/Si_2N_3). Table 3 shows the data collected during the simulation.

Table 3. Summary of the results for Si solar cells based on the five designs (reference is included as a comparison)

Scheme	I_{SC} (A)	P_{max} (W)	V_{OC} (V)	η (%)
Reference	4.827	2.825	0.7005	14.1237
Scheme I	7.006	4.171	0.7105	20.8543
Scheme II	7.021	4.180	0.7106	20.8994
Scheme III	6.974	4.152	0.7104	20.7611
Scheme IV	6.753	4.027	0.7095	20.1352
Scheme V	7.034	4.188	0.7106	20.9406

Current-voltage and power-voltage characterisation are crucial to understand as they help to optimise solar cell performance in power conversion efficiency. Figure 1 shows the current-voltage characteristic curve for each intended scheme.

The reference scheme shows very poor performance compared to others as it is set without any ARC to enhance the absorption of light. Thus, the I_{sc} produced is only at 4.827 A and 0.7005 for V_{oc}. Compared to other schemes, Scheme V displays the highest values of I_{sc} and V_{oc}. This is because, Silicon Nitrate (Si_2N_3) is used as the high-index material in this double-layer antireflective coating strategy, while Magnesium (II) Floride (MgF_2) is the low-index material.

Having a significant refractive index difference makes this scheme the ideal combination when compared to others. It is more than a 45% increment in current (45.72%)-voltage (48.25%) values compared to the reference. Meanwhile, P_{max} for MgF_2/Si_2N_3 (Scheme V) is achieved at 4.188 W with an enhancement of 48.25% (Figure 2). Destructive interference in Scheme V effectively cancels out the reflections compared to other schemes. This phenomenon increases photon absorption in the silicon layer in solar cells. This result is further strengthened by the previous study by Sharma (2021). The study has proven that the combination of MgF_2 and Si_2N_3 is capable of producing a high efficiency of over 20%.

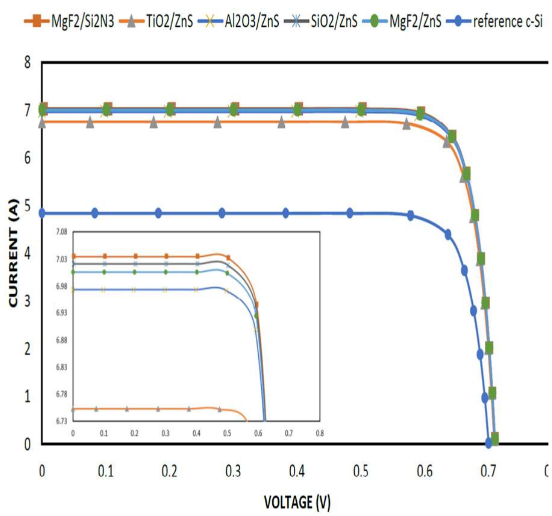

Figure 1. I-V curve of Si solar cells for different DLARC schemes.

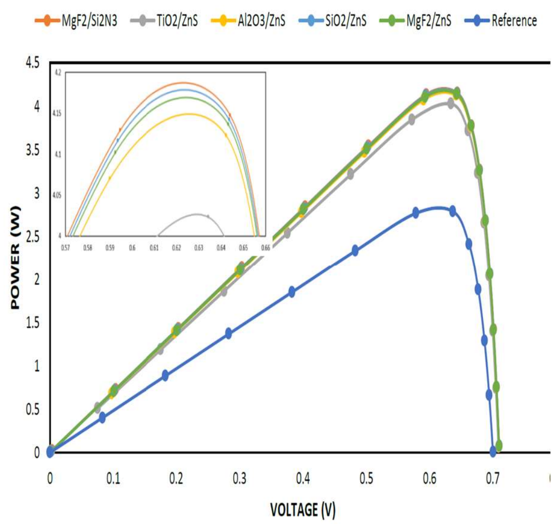

Figure 2. P-V curve of Si solar cells for different DLARC schemes.

4. CONCLUSION

One of the key factors in improving a PV module's efficiency is ARC. The need for more efficient solar panels is driving researchers to investigate how to increase light traction. Owing to their capacity to enhance solar panel efficiency, these coatings have proliferated in the marketplace. Therefore, the same strategy is adopted in this thesis to boost efficiency for ARC, focusing on DLARC. It works effectively with a glass substrate and silicon solar cell to minimise reflection. By increasing power and current, DLARC has a major impact on the solar cell industry. Higher power output is more efficient and economically feasible. Therefore, Scheme V: MgF_2/Si_2N_3 generates the highest amount of power, with a value of 4.188W. With a value of 48.25%, Scheme V demonstrates the highest P_{max} enhancement. This result suggests that DLARC might be applied to improve solar cell applications' performance more successfully. The MgF_2 and Si_2N_3 of DLARC described in this study may potentially be used and modified as a helpful part of raising solar cell efficiency by decreasing optical loss. Thus, the results of the simulation and the findings show that the goal of the study has been achieved.

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