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Preface

The Scientific Project Colloquium offers a platform for publishing Diploma Science final year projects (FYP). The objective is to effectively distribute research findings throughout all scientific disciplines. The primary objective of including final year projects into the course curriculum is to encourage students to put their theoretical knowledge into practical applications.

We would like to express our gratitude to our primary establishment, the Faculty of Applied Sciences and Universiti Teknologi MARA, Perak Branch, for their invaluable assistance.

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SIMULATION STUDY OF DOUBLE LAYER ANTI- REFLECTIVE COATING (ARC) IN SILICON SOLAR CELL BY RAY TRACER

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Abstract: The aim of this work is to investigate the effect of anti-reflection coating to improve the performance of silicon solar cells and to study double-layer ARC of various thicknesses on silicon solar cells. Four Light schemes with a double layer of ZnO/MgF_2 with various thicknesses on 100 µm thin crystalline silicon (c-Si) were investigated. These parameters were manipulated by using wafer ray tracer in the PV Lighthouse simulator to study the efficiency of solar cells. The reflection, absorption, and transmission curve within the 300 - 1200 nm wavelength region were analyzed and the maximum potential photocurrent density (J_{max}) for each light trapping (LT) scheme was calculated. It was found that with the addition of ARC into the c-Si, the J_{max} increased to 34.06 mA/cm^2 and obtained a 36.95% enhancement compared to the J_{max} of the c-Si references (without ARC). Hence, it was observed that the double layer of ZnO/MgF_2 ARC is significant to enhance the optimum broadband of light absorption.

Keywords: *Solar cell, Anti-Reflective Coating (ARC), Single-layer, Double-layer, Efficiency*

INTRODUCTION

Due to the world becoming more developed, many technologies are being built to generate electricity. Sunlight is also one of the electricity generators known as solar cells. The solar cell, also called a photovoltaic cell, is any device that directly converts the energy of light into electrical energy through the photovoltaic effect. The overwhelming majority of solar cells are fabricated from silicon with increasing efficiency and lowering cost as the materials range from non-crystalline to polycrystalline to crystalline silicon form (Amalathas et al., 2019). Solar cells do not utilize chemical reactions or require fuel to produce electric power unlike batteries or fuel cells and they do not have any moving parts, unlike electrical generators. However, like other technologies, photovoltaic cells also have many challenges and issues that need to be addressed in order to be able to supply affordable electricity to users (Jamaluddin et al., 2022). One of the important issues of modern photovoltaic science is the optical losses in solar cells. In general, optical losses account for about 7% efficiency loss in crystalline solar cells. So, the reduction in optical loss can have a huge positive impact on the conversion efficiency of silicon solar cells. To reduce the optical loss, ARC plays a pivotal role in reducing reflection, thus increasing the conversion efficiency of solar cells (Pakhuruddin, 2020a).

ARC is one of the commonly used ways to prevent sunlight from being reflected from the surface of the solar cell. ARC is a technical means to reduce reflection and increase light absorption of solar cells and thus increase their performance (Pakhuruddin, 2020b). They consist of a thin layer of dielectric material, with a specially chosen thickness so that interference effects in the coating cause the wave reflected from the anti-reflection coating top surface to be out of phase with the wave reflected from the semiconductor surfaces.

Recent advancements have explored various types of ARCs, including single-layer, bilayer, and multilayer designs. Single-layer ARCs, while simpler, face limitations such as narrow bandwidth and lack of Omni directionality. This is primarily due to the absence of suitable inorganic materials with a sufficiently low refractive index. In contrast, bilayer and multilayer ARCs can meet performance requirements more effectively across a broader range of wavelengths and angles of incidence. Among the most commonly used bilayer ARCs are combinations of materials like TiO_2-SnO_2, TiO_2-SiO_2, and ZnO_2-SiO_2 (Sharma, 2017). These materials are selected based on their optical properties and compatibility with various applications. For this study, we investigate the use of ZnO/MgF_2 as a bilayer ARC to improve light trapping in silicon solar cells. The effectiveness of this bilayer ARC will be analyzed using wafer ray tracing simulations to evaluate its impact on enhancing solar cell performance.

METHODOLOGY

For this work, a wafer ray tracer by PV Lighthouse was used to determine the photo-generated current density in a solar cell and test structure under a chosen illumination spectrum. It also generates curves for reflection, transmission, and absorption based on the entered data (Salleh, 2022). In this research, the double layers of ARC used were magnesium fluoride, MgF_2, and Zinc Oxide, ZnO. The thickness for ZnO is fixed which is at 75 nm while the thickness for MgF_2 is varied which are 70 nm, 90 nm, 110 nm, and 130 nm. The substrate of a single layer is fixed to 100 µm while the structure of the surface is fixed to a planar structure. Sunlight with the air mass (AM) 1.5 g spectrum was employed, which stands for Air Mass 1.5 spectra, and was intended for flat- panel displays with integrated powers 1000 W/m^2 or 100 mW/cm^2 at zero angles of incidence. The maximum number of rays utilized for ray tracing is 50 000, and the number of rays used in each run is 5000. Each ray is allowed a maximum of 1000 bounces and a maximum intensity of 0.01%. In order to study the optical properties of silicon solar cells, a range of wavelengths is used, ranging from a minimum wavelength of 300 nm to a maximum wavelength of 1200 nm with a wavelength interval of 20 nm. The result of reflection, transmission and absorption can be found in the graph that has been plotted by the simulation. In addition, we can calculate the efficiency of the materials solar cell using the Jmax formula.

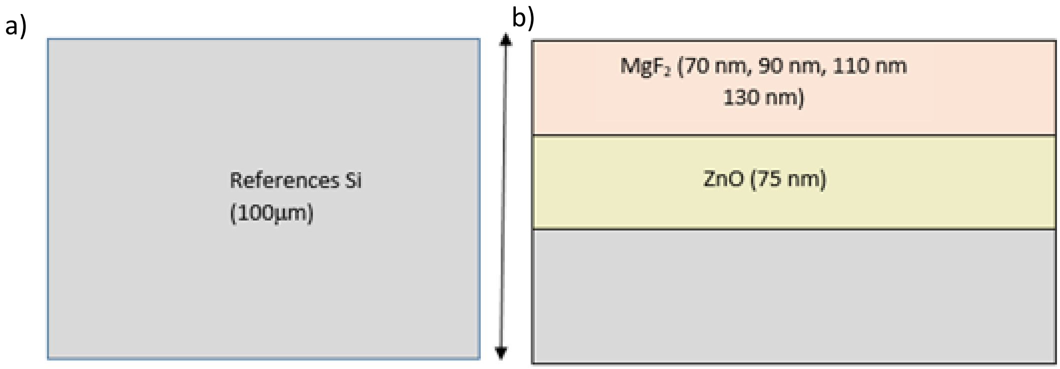

Figure 1: Schematic diagrams of a) reference c-Si (with thickness 100 µm) without ARC and b) MgF_2 ARC for Si solar cell with thickness of 70 nm, 90 nm, 110 nm and 130 nm)

FINDINGS

From the study, we observed the effect of ARC parameters on Reflection, Absorption, and Transmission curves. In order to make a comparison, the reference c-Si curves are obtained at wavelength in the range of 300-1200 nm. In figure 2(a), at wavelength of 600 nm, the reflection of the references was about 35%. This might be because the refractive index of incoming light changes rapidly as it travels and strikes the c-Si reference body from air n=1.0. In figure 2(b), the reference c-Si has lower broadband of absorption compared to another scheme where the maximum absorption reference can be reached is 69% at 780 nm since it does not cooperate with any ARC schemes. Hence, c-Si solar cells need ARC coating in order to increase their efficiency. By adjusting the thickness for both layers of ARC coating, a high value of absorption was achieved. In figure 2(c), the transmission curve for reference wavelength 920 nm and above was lower compared to other schemes. From this situation, long wavelength light cannot be absorbed due to the narrow inability of c-Si.

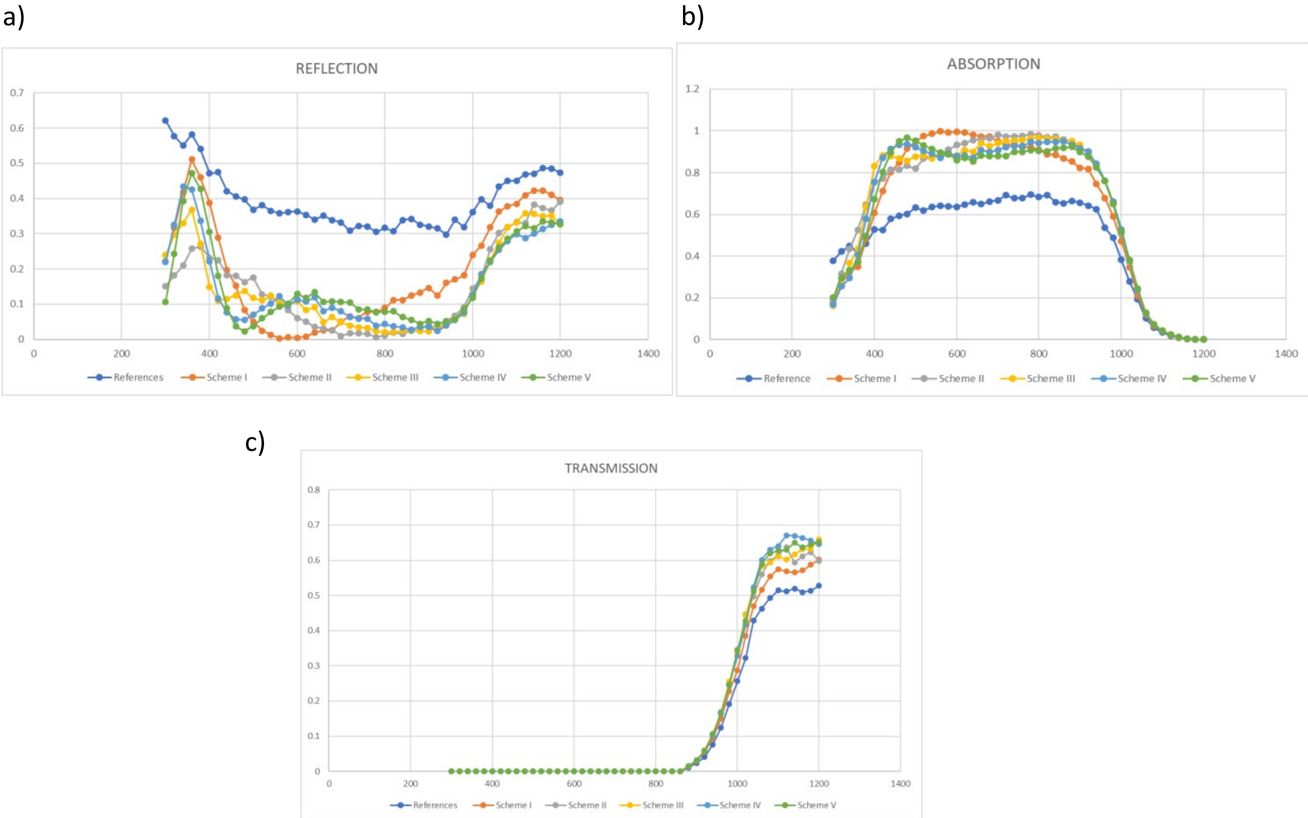

Fig. 2. a) Reflection b) Absorption c) Transmission curves for silicon solar cells with different thickness of 70 nm, 90 nm, 110 nm, and 130 nm. Reference curve of silicon solar cells included for comparison.

In this study, the first layer of ARC ZnO was kept constant at 75 nm thickness and for the second layer, MgF_2 was changed at 70 nm, 90 nm, 110 nm, and 130 nm. From the simulation, different efficiencies were observed at different thicknesses where narrowing the second layer thickness will reduce the reflection and hence enhance the absorption and transmission. For scheme I, (ZnO = 75 nm, MgF_2 = 70 nm) the reflection is 2% when the wavelength reaches 680 nm and this value is maintained until 880 nm as shown figure 2 (a). This resulted from enhanced light scattering at the planar-air interface (Pakhuruddin, 2020b). For absorption, more than 90% was achieved at wavelength 600 nm until 920 nm as shown in figure 2 (b). As for the Scheme II (ZnO = 75 nm, MgF_2 = 90 nm), reflection increased to 3% from 720 until 940 nm. The absorption curve achieved 90% above at wavelength 660 until 900 nm. In figure 2 (c), the transmission reaches 65% at wavelength 1200 nm. Reflection for Scheme III (ZnO = 75 nm, MgF_2 = 110 nm) was increased to 6% from 720 until 960 nm. Furthermore, the absorption reached 90% above from 700 to 900 nm. For the transmission, the maximum value that was obtained is 67% at 1120 nm wavelength. For the Scheme IV (ZnO = 75 nm, MgF_2 = 130 nm), the reflection curve increased to 8% from 740 until 980 nm.

The J_{max} measured value of the thin c-Si (100 μm thickness) using incremental LT schemes is shown in Table 1. The percentage of J_{max} enhancement was then computed by normalizing the J_{max} for each LT scheme in online simulation and comparing it to the J_{max} of the reference c-Si that did not have an LT scheme. J_{max} enhancement was calculated as shown in equation below:

$$J_{max} = [(J_{max}\ \text{LT scheme} - J_{max}\ \text{ref})/J_{max}\ \text{ref}] \times 100$$

From Scheme I (70 nm), in comparison with the reference of c-Si where J_{max} equals 24.87 mA/cm^2. J_{max} raised to 35.07 mA/cm^2 which signifies a 41.01% of enhancement. Apart from that, because of the increased light coupling via the ARC, light absorption within the thin c-Si starts to boost at some stage in the complete wavelength place using Scheme II (90 nm). J_{max} increased to 34.91 mA/cm^2 which showed a 40.37% improvement. Once Scheme III (110 nm) was employed, high optical light absorption in the thin c-Si increased. The J_{max} tends to increase for about 38.96 % enhancement at 34.56 mA/cm^2. Finally, for Scheme IV (130 nm), the high optical wavelength for absorption of light finally gained about 34.06 mA/cm^2 with 36.95% enhancement.

Table 1: Summary of Jmax of thin c-Si (with 100 µm thickness) with incremental LT schemes. J_{max} reference c-Si is included for comparison.

LT SCHEME	J_{max} (mA/cm^2)	J_{max} Enhancement (%)
c-Si	24.87	-
Scheme I: ZnO/MgF_2 ARC (ZnO = 75 nm, MgF_2 = 70 nm)	35.07	41.01
Scheme II: ZnO/MgF_2 ARC (ZnO = 75 nm, MgF_2 = 90 nm)	34.91	40.37
Scheme III: ZnO/MgF_2 ARC (ZnO = 75 nm, MgF_2 = 110 nm)	34.56	38.96
Scheme IV: ZnO/MgF_2 ARC (ZnO = 75 nm, MgF_2 = 130 nm)	34.06	36.95

CONCLUSIONS

In this study, ray tracing of LT schemes in thin c-Si of solar cells with 100 µm thickness has been investigated. The effect of anti-reflective coating improves the performance of silicon solar cells has been investigated. ZnO/MgF_2 was applied for double-layer anti-reflective coating (ARC). The four light trapping techniques, which are formed from multiples of the MgF_2 thickness values of 70 nm, 90 nm, 110 nm, and 130 nm, were examined. This simulation shows that double-layer ARC with a 70 nm thickness of MgF_2 (Scheme I) is much more effective among LT schemes. Enhancement of 41.01% results from increasing Jmax to 35.07 mA/cm^2 in comparison to the references scheme. This indicates that the photo-generated current, which has a significant impact on the efficiency of the solar cell, was somehow improved along with the absorption of light photons. Even though MgF_2's performance as an ARC is not very remarkable, it is still a considerable improvement over a surface that is not coated since MgF_2 has a wide transmission range that can aid in the Si solar cells' improved absorption

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