

**NUMERICAL SIMULATION OF HIGH-EFFICIENCY
SILICON SOLAR CELLS WITH DIFFERENT
ANTI-REFLECTIVE COATINGS**

IREEN ADRINA BINTI EDDIE ROS @ IDRUS

**BACHELOR OF SCIENCE (Hons.) PHYSICS
FACULTY OF APPLIED SCIENCES
UNIVERSITI TEKNOLOGI MARA**

FEBRUARY 2026

**NUMERICAL SIMULATION OF HIGH-EFFICIENCY SILICON SOLAR
CELLS WITH DIFFERENT ANTI-REFLECTIVE COATINGS**

IREEN ADRINA BINTI EDDIE ROS @ IDRUS

**Final Year Project Report Submitted in
Partial Fulfilment of the Requirements for the
Degree of Bachelor of Science (Hons.) Physics
in the Faculty of Applied Sciences
Universiti Teknologi MARA**

FEBRUARY 2026

ABSTRACT

NUMERICAL SIMULATION OF HIGH-EFFICIENCY SILICON SOLAR CELLS WITH DIFFERENT ANTI-REFLECTIVE COATINGS

Crystalline silicon solar cells remain the most widely adopted photovoltaic technology; however, their performance is constrained by optical reflection losses and non-optimized device parameters such as layer thickness, doping concentration, and anti-reflective coatings. This study aims to numerically optimize the performance of high-efficiency crystalline silicon solar cells by investigating the effects of absorber and window layer thicknesses, doping carrier concentrations, and single-layer anti-reflective coating (ARC) materials. Numerical simulations were carried out using the Personal Computer One-Dimensional (PC1D) simulation tool, employing a p-type silicon absorber and an n-type silicon window layer, where the absorber thickness was varied from 60 μm to 240 μm , the window layer thickness from 0.5 μm to 5.0 μm , the absorber doping concentration from 1×10^{14} to $1 \times 10^{19} \text{ cm}^{-3}$, and the window doping concentration from 1×10^{16} to $1 \times 10^{20} \text{ cm}^{-3}$. In addition, single-layer ARC materials including silicon nitride (Si_3N_4), titanium dioxide (TiO_2), zinc oxide (ZnO), silicon dioxide (SiO_2), and magnesium fluoride (MgF_2) were analysed with thicknesses ranging from 50 nm to 140 nm. The results show that under ideal anti-reflective conditions (zero reflectance), a maximum power conversion efficiency (PCE) of 25.35% was achieved, while a baseline efficiency of 16.85% was obtained without any ARC. Among the ARC materials studied, ZnO with an optimized thickness of 80 nm produced the highest efficiency of 23.41% at an absorber thickness of 240 μm and a window layer thickness of 0.5 μm , yielding a maximum open-circuit voltage (V_{oc}) of 0.7457 V and a short-circuit current (I_{sc}) of 4.054 A. These findings highlight that systematic optimization of structural parameters and ARC selection, particularly the use of ZnO, plays a critical role in minimizing optical losses and enhancing the overall efficiency of crystalline silicon solar cells.

TABLE OF CONTENTS

	Page
ABSTRACT	i
ABSTRAK	ii
ACKNOWLEDGEMENT	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	vi
LIST OF FIGURES	vii
LIST OF SYMBOLS	ix
LIST OF ABBREVIATIONS	x
CHAPTER 1 INRODUCTION	
1.1 Research Background	1
1.2 Problem Statements	5
1.3 Research Questions	6
1.4 Objectives	8
1.5 Significance of Study	9
CHAPTER 2 LITERATURE REVIEW	
2.1 Introduction	11
2.2 Silicon Solar Cells	12
2.3 Working Principle of Silicon Solar Cells	15
2.4 Photovoltaic Properties	18
2.5 PC1D Simulation	20
2.6 Different Parameters on The Efficiency of Silicon Solar Cells	23
2.6.1 The Thickness of Absorber and Window Layer	23
2.6.2 The Doping Carrier Concentration of Window and Absorber Layer	24
2.6.3 The Influence of Different ARCs Layers on Silicon Solar Cells	26
CHAPTER 3 METHODOLOGY	
3.1 Introduction	28
3.2 PC1D Simulation Framework	29
3.3 PC1D Basic Parameters	31
3.4 Different Parameters for PC1D Simulation	33
3.4.1 The Thickness of Absorber and Window Layer	33
3.4.2 The Doping Carrier Concentration of Absorber and Window Layer	36
3.4.3 Anti-Reflective Coating Layer	39
3.5 Experimental Design	42

CHAPTER 4 RESULT AND DISCUSSION	
4.1 Introduction	45
4.2 Basic Simulation of Silicon Solar Cells	46
4.3 Optimization of Window and Absorber Layer	49
4.4 Optimization of Doping Carrier Concentration of Window and Absorber Layer	56
4.5 Influence of ARC on Silicon Solar Cells	61
4.5.1 Simulation without ARC	61
4.5.2 Simulation with ARCs	62
4.6 Comparative Analysis of Different Parameter in Silicon Solar Cells	75
 CHAPTER 5 CONCLUSION AND RECOMMENDATION	
5.1 Introduction	76
5.2 Conclusion	77
5.3 Recommendations	78
 CITED REFERENCES	81
APPENDICES	87
<i>CURICULUM VITAE</i>	96