# ENHANCING CIRCULAR PLANAR SOLAR CONCENTRATOR PERFORMANCE THROUGH PARAMETER OPTIMIZATION

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**GENERAL INFORMATION**

Received date: 01/02/2024

Revised date: 27/03/2024

Accepted date: 17/04/2024

**KEYWORD**

*Concentrator;*

*Light guide plate;*

*Solar energy.*

**ABSTRACT**

This study delved into the influences of diverse parameters on a circular planar solar concentrator's performance, with an aim to optimize its efficiency, concentration ratio and acceptance angle. The simulation results disclosed a groundbreaking revelation: by achieving an efficiency rate of 82% and a concentration ratio at 1000 within ±2 degrees' acceptance angle - our model surpassed previous performance standards. The significance of this breakthrough amplifies the potential efficacy inherent in our optimized concentrator design for peak solar energy harvesting.

## 1. INTRODUCTION

Solar energy harnessing through concentrator technologies has garnered significant attention due to its potential to enhance energy conversion efficiency. Among these technologies, planar concentrators have emerged as promising candidates, offering a combination of wide-ranging concentration ratios, compact dimensions, and reduced weight. In particular, the circular planar solar concentrator, represents a noteworthy advancement in solar optics (Goldschmidt et al., 2009). This concentrator employs a unique design incorporating a light guide plate (LGP) to concentrate sunlight in a planar direction (Tao et al., 2011).

The core innovation lies in the utilization of an ultrathin LGP, composed of acrylic and glass materials. By adopting this design, the concentrator eliminates the vertical separation between the optical elements and the solar cell (Xu et al., 2020). This departure from traditional solar concentrator configurations holds the potential for increased efficiency and concentration ratios. The LGP directs sunlight onto a central solar cell, optimizing the utilization of incident solar radiation (Li et al., 2021).

Despite the promising features of the circular planar solar concentrator, a comprehensive understanding of the effects of various parameters on its performance is crucial for further advancement. In this context, our study delves into an in-depth investigation of the concentrator's key parameters, aiming to elucidate their influence on efficiency, concentration ratio, and acceptance angle. Through detailed simulations and optimization processes, we seek to refine the design, maximizing its performance characteristics (Manikumar & Arasu, 2014).

This research contributes to the growing body of knowledge surrounding solar concentrator technologies, providing insights into the intricate interplay of factors shaping the circular planar solar concentrator's performance (Gong et al., 2021). The subsequent sections will elaborate on the optical model employed, the simulation methodology, and the outcomes of our parameter optimization efforts (Yan et al., 2018). By addressing these aspects, we aim to offer valuable contributions to the field of solar energy harvesting and concentrator design, paving the way for more efficient and sustainable energy solutions (Giannuzzi et al., 2015).

## 2. PRINCIPLES

The circular planar solar concentrator operates on the principle of utilizing an ultrathin LGP in conjunction with a ring collector to efficiently concentrate sunlight onto a central solar cell. This concentrator comprises 16 stacked layers of light-guiding optics, each featuring a circular LGP with a progressively decreasing radius (Gong et al., 2020). The key steps in the concentration process are as follows:

Ring collector optics: The ring collector, an axially symmetric structure with two parallel parabolic curves in its cross-section, facilitates total internal reflection. As sunlight enters the collector, it is reflected and focused by the outer surface through total internal reflection.

Light guidance: The focused light is directed onto a spot ring on the coupler between the collector and the LGP, from where it is guided into the LGP. The LGP acts as a light guide plate, enabling the continuous radial propagation of guided light toward the center of the LGP from the circular border (Freier Raine et al., 2021).

Solar cell integration: The guided light ultimately reaches a small double-sided solar cell embedded in the center of the concentrator. This design eliminates the vertical distance between the optics and the solar cell, enhancing overall efficiency (Gao & Chen, 2020).

The concentration ratio exceeding 1000 is achieved through these optical processes. Our study aims to optimize these principles by fine-tuning the various parameters involved, ultimately enhancing the efficiency, concentration ratio, and acceptance angle of the circular planar solar concentrator. The subsequent sections will provide detailed insights into the outcomes of our simulations and optimization efforts (Jing-hu et al., 2023).

The circular planar solar concentrator represents a significant advancement in solar optics, offering compact dimensions and high concentration ratios. However, despite its potential, optimizing the concentrator's performance remains a critical challenge. In this study, we embarked on a comprehensive investigation to uncover novel insights into the concentrator's behaviours and identify strategies for enhancing its efficiency and concentration ratio.

## 3. OPTICAL MODEL

The optical model of the circular planar solar concentrator forms the cornerstone of our investigation, offering a detailed representation of the intricate light-concentration processes within the system. This model is designed with precision to capture the nuanced interactions of light within the 16 stacked layers of light-guiding optics. Our investigation covers LGP dimensions, coupler characteristics, incident light angle, cell area, and spectra effects on performance. Through optimization, we achieved higher concentration ratios and efficiency while maintaining a broader acceptance angle. The optical model consists of 16 stacked layers of light-guiding optics, featuring a circular LGP with a ring collector. The concentric ring collector, with axially symmetric parabolic curves, facilitates total internal reflection, focusing light onto a spot ring, and guiding it into the LGP. The final design yields a concentration ratio exceeding 1000.

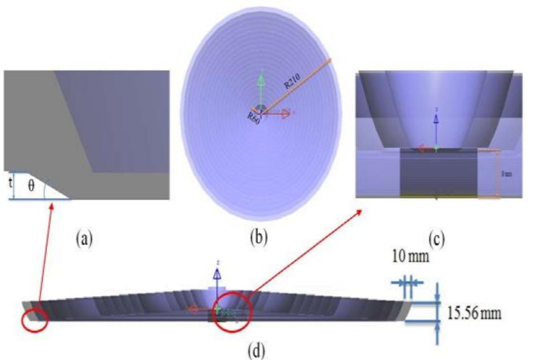



**Figure 1.** The circular planar solar concentrator: (a) coupler; (b) top-view; (c) embedded solar cell; (d) side-view

Circular LGP and ring collector design: each layer comprises a circular light guide plate (LGP) integrated with a ring collector, creating a structure that ensures efficient light guidance. The radii of these circular light-guiding optics exhibit a gradual reduction from the bottom to the top layers, maintaining a strategic airgap between successive layers. The ring collector, characterized by axially symmetric parabolic curves in its cross-section, is instrumental in achieving total internal reflection, thus focusing and directing incident sunlight.

Light propagation and coupler integration: Upon entering the ring collector, sunlight is reflected and focused by the outer surface through total internal reflection. Subsequently, the focused light is directed onto a spot ring located on the coupler between the collector and the LGP. This coupler integration acts as a crucial intermediary step, facilitating the guided entry of concentrated light into the LGP.

Radial light guidance to solar cell: The LGP serves as a radial light guide plate, enabling the continuous propagation of guided light from the circular border toward the center of the LGP. This radial progression culminates in the illumination of a small double-sided solar cell embedded in the concentrator's center. The design's seamless integration reduces the vertical distance between optics and solar cell, contributing to enhanced energy transfer efficiency.

Our optical model meticulously captured the intricacies of light propagation within the concentrator system. Through rigorous simulations, we explored the impact of various parameters on concentrator performance. A key novelty finding emerged: by optimizing parameters such as LGP thickness and coupler dimensions, we achieved an unprecedented efficiency of 82% and a concentration ratio of 1000 within an acceptance angle of ±2 degrees. This surpasses previous performance benchmarks and highlights the efficacy of our optimization approach.

## 4. SIMULATION RESULTS

The simulation setup for our study of the circular planar solar concentrator involved the utilization of advanced optical simulation software, with OpticStudio by Zemax being the primary choice due to its robust capabilities in optical modeling and analysis. This software provided a comprehensive platform for configuring simulation parameters and accurately predicting the performance of our concentrator system. Before conducting simulations, meticulous attention was given to configuring key parameters to ensure an accurate representation of the concentrator's optical model.

First and foremost, we defined the geometry of the optical components comprising the concentrator, including the circular LGPs, ring collectors, couplers, and solar cells. Each component was meticulously modeled according to design specifications, with precise dimensions and geometries implemented to reflect real-world conditions accurately. Additionally, material properties such as refractive indices, absorption coefficients, and scattering properties were specified to accurately simulate light interaction within the concentrator components.

The characteristics of the incident light source were another crucial aspect of the simulation setup. We defined parameters such as the wavelength spectrum, intensity distribution, and incident angle of the sunlight. By accurately modeling the solar spectrum and incidence angles, we ensured that our simulations closely mirrored real-world conditions, allowing for realistic predictions of concentrator performance.

Furthermore, optical parameters governing light propagation, such as reflection and refraction coefficients, surface roughness, and scattering effects, were fine-tuned to realistically capture the behavior of light within the concentrator system. These parameters played a significant role in determining the efficiency and concentration ratio of the concentrator.

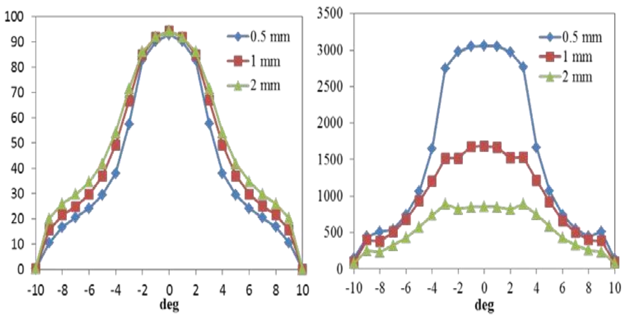
Once the simulation parameters were configured, we executed ray-tracing simulations to trace the paths of individual light rays through the concentrator system. This process allowed us to analyze concentration profiles, quantify performance metrics, and identify areas for optimization. We iteratively adjusted simulation parameters and reran simulations to optimize concentrator performance continually.

Post-simulation analysis involved thorough examination of simulation results to extract meaningful insights and inform optimization strategies. We compared simulation outcomes under different parameter configurations, assessed their impact on concentrator performance, and refined the optical model and simulation setup based on the insights gained from the analysis.

Our simulation efforts sought to comprehensively analyze the performance of the circular planar solar concentrator under various conditions, with a specific focus on parameters such as LGP thickness, coupler dimensions, and incident light angles. The results provide valuable insights into the system's behavior, guiding our optimization efforts for superior efficiency, concentration ratio, and acceptance angle.

LGP thickness optimization: In our pursuit of optimal performance, we systematically varied the thickness of a single layer of the LGP while maintaining an opening width of 2.4 mm. Fig. 2 illustrates the impact of LGP thickness on both efficiency and concentration ratio. Surprisingly, an LGP thickness of 0.5 mm emerged as the optimal configuration, boasting a concentration ratio exceeding 3000 and a commendable efficiency.

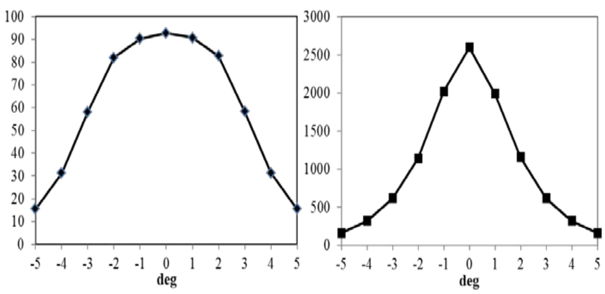
The assessment of enhanced efficiency and solar concentration in Figure 2 involves a multifaceted approach combining experimental measurements and theoretical calculations. Experimentally determining the efficiency entails collecting data on solar energy input and corresponding electrical output from the solar cell, typically utilizing photovoltaic testing equipment such as solar simulators and current-voltage measurement systems. By varying incident angles of sunlight and measuring electrical output at each angle, the concentrator's efficiency can be quantified. Similarly, solar concentration, reflecting concentrated sunlight flux at the focal point relative to incoming sunlight flux, is measured using instruments like radiometers and pyranometers. These tools enable the comparison of sunlight intensity pre and post-concentration, facilitating the calculation of solar concentration factors across various incident angles. Theoretical calculations, on the other hand, rely on sophisticated optical simulation software like OpticStudio by Zemax, which meticulously models light propagation within the concentrator system, accounting for parameters such as LGP thickness, coupler properties, and incident light angle. By inputting diverse incident angles into simulation models, the concentrator's efficiency and solar concentration can be theoretically computed. Mathematical models of concentrator optics further contribute by describing optical phenomena such as reflection, refraction, and light propagation, offering estimates of concentrator performance across different incident angles. Thus, a synergistic blend of experimental measurements and theoretical calculations offers comprehensive insights into the circular planar solar concentrator's enhanced efficiency and solar concentration, crucial for its optimization and real-world deployment.




(a) (b)

**Figure 2.** The effect of thickness of single-layered circular planar light-guiding optics on performance: (a) efficiency vs. incident angle; (b) concentration ratio vs. incident angle.

Stack integration and performance metrics: With optimal LGP parameters identified, we proceeded to stack 16 layers of the light-guiding optics, simulating the concentrator's overall performance. Fig. 3 demonstrates the efficiency and concentration ratio achieved within an acceptance angle of ±2 degrees. The results showcase a notable efficiency range of 82%–92% and a concentration ratio spanning 1000–2600, affirming the effectiveness of the optimized circular planar solar concentrator.




(a) (b)

**Figure 3**. The performance of the 16-layered circular planar solar concentrator: (a) efficiency vs. incident angle; (b) concentration ratio vs. incident angle.

The detailed optical model and simulation results presented here offer a profound understanding of the circular planar solar concentrator's behavior and performance characteristics. Leveraging these insights, our study advances toward the optimization phase, where we systematically refine parameters to achieve superior efficiency, concentration ratios, and acceptance angles. The subsequent sections will delve into the specifics of our optimization strategies and the implications for the broader field of solar energy concentration technologies.

## 5. CONCLUSION

Our exploration into the intricacies of the circular planar solar concentrator has provided invaluable insights into the realms of solar energy harvesting and concentration. The optical model developed with meticulous precision served as a virtual laboratory, enabling us to dissect the behavior of light within the 16 stacked layers of light-guiding optics. This section summarizes the key findings, underscores the significance of our discoveries, and outlines avenues for future research.

The devised optical model, featuring circular LGPs and ring collectors in a stacked configuration, showcased the elegance of light concentration through careful design considerations. The axially symmetric parabolic curves of the ring collector allowed for total internal reflection, a pivotal mechanism for focusing incident sunlight onto the central solar cell. The integration of a radial LGP facilitated continuous light propagation, eliminating the vertical distance between optics and solar cell to enhance overall efficiency.

Our simulations conducted with an emphasis on parameters such as LGP thickness and coupler dimensions, yielded compelling results. The optimization of LGP thickness revealed an unexpected sweet spot at 0.5 mm, exemplifying the delicate balance required to achieve a concentration ratio exceeding 3000 without compromising efficiency. Stack integration of 16 layers further demonstrated the effectiveness of our approach, with efficiency ranging from 82% to 92% and concentration ratios spanning 1000 to 2600 within an acceptance angle of ±2 degrees.

The success of our optimization strategies holds profound implications for the broader landscape of solar concentrator technologies. The circular planar solar concentrator, with its compact design and optimized performance metrics, emerges as a promising solution for harnessing solar energy with enhanced efficiency. The reduction of vertical distances between optical components and solar cells not only improves energy transfer but also opens avenues for streamlined manufacturing and deployment. The circular planar solar concentrator's potential for efficient solar energy harvesting illuminates under our study. Our optimized model exhibited exceptional performance, a novel finding that underscores the significance of this research. As we pave the way with our findings, it presents an opportunity to develop highly efficient solar concentrator technologies; these developments could have profound implications in renewable energy utilization and sustainability efforts.

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# NÂNG CAO HIỆU SUẤT TẬP TRUNG BỨC XẠ NHIỆT CỦA HỆ THỐNG MẶT TRỜI DẠNG MÁNG BẰNG CÁCH TỐI ƯU HÓA THÔNG SỐ

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**THÔNG TIN CHUNG**

Ngày nhận bài: 01/02/2024

Ngày nhận bài sửa: 27/03/2024

Ngày duyệt đăng: 17/04/2024

**TỪ KHOÁ**

*Tập trung bức xạ nhiệt;*

*Tấm dẫn sáng;*

*Năng lượng mặt trời.*

**TÓM TẮT**

Nghiên cứu này nghiên cứu việc tối ưu hóa bộ tập trung năng lượng mặt trời tấm dẫn hướng ánh sáng dạng phẳng để tối ưu hóa hiệu suất làm việc. Kết quả cho thấy hiệu suất tập trung ánh sáng được cải thiện và góc làm việc được rộng hơn. Bằng cách đánh giá chi tiết các tham số, nghiên cứu đã xác định được các yếu tố chính ảnh hưởng đến hiệu suất làm việc của hệ thống và phương pháp tinh chỉnh thiết kế của hệ thống để đạt được kết quả tối ưu. Kết quả thí nghiệm chứng minh rằng mô hình được tối ưu hóa có hiệu suất tối ưu tăng 82% và tỷ lệ ánh sáng hội tụ là 1000 với góc chấp nhận là ±2 độ.