REVOLUTIONIZING LCD EFFICIENCY BY USING GROUND BREAKING MICRO-STRUCTURE APPROACH WITH LASER DIODE LIGHT GUIDE PLATE DESIGN

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ABSTRACT

This paper is about a new microstructure design that uses a Laser Diode (LD) light source for Liquid Crystal Displays (LCDs). It shows an important step forward in display technology. Regular Thin-Film Transistor LCDs often have efficiency problems because of multilayer optical films, causing loss of light and reduced performance. So, the suggested microstructure design applies interface reflection and Brewster angle optimization to boost the efficiency of utilizing light. As a result of employing a polarized and monochromatic LD, the design does away with the requirement for certain optical films like color filters and polarizers. This results in an efficient configuration. The simulation shows a remarkable net efficiency improvement that is six times more than traditional TFT-LCDs. Also, it makes possible thinner displays which are lighter too - this improves look as well as easy portability. The scalability of the microstructure, as seen in its replication to create the Light Guide Plate (LGP), shows promise for various uses. This fresh method establishes high standards for effectiveness and holds potential for changing how visual performance and manufacturing efficiency improve, indicating an upcoming period in display technology.

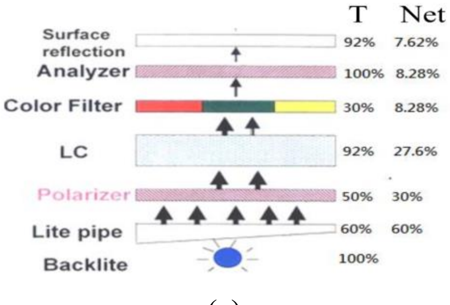
1. INTRODUCTION

The landscape of visual display technologies has continually evolved, yet traditional Thin-Film Transistor Liquid Crystal Displays (TFT-LCDs) have grappled with inherent inefficiencies stemming from the complex layers of optical films. With a light efficiency lingering below 8%, as illustrated in Fig. 1a, the quest for a more effective and streamlined solution becomes imperative. This paper embarks on a pioneering endeavor, presenting a transformative approach through the integration of a novel microstructure design with a Laser Diode (LD) as the light source, poised to redefine the standards of display efficiency (X. Wang et al., 2023).

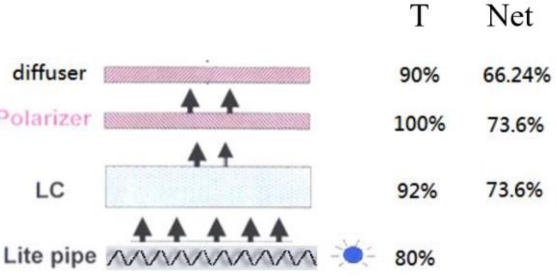
The intricacies of TFT-LCDs, with their multilayered optical films, have long been a hindrance to achieving optimal light utilization. In response to this challenge, our research introduces a visionary design that leverages the distinct characteristics of the laser diode. By capitalizing on its monochromaticity and polarization, we envision a substantial enhancement in efficiency, eclipsing the conventional norms. As depicted in Fig. 1b, our proposed microstructure design, coupled with the laser diode, demonstrates the potential to elevate the efficiency of the liquid crystal module to an unprecedented 60% (Chang, 2007; Chen et al., 2021; Norfazilasari Yasman et al., 2024).

A pivotal aspect of this innovation lies in the strategic elimination of specific optical films—most notably, the color filter and one polarizer. This reduction is made possible by the unique attributes of the laser diode, a monochromatic and polarized light source. Beyond the quantum leap in efficiency, this elimination translates into tangible benefits, including the development of a thinner and lighter Liquid Crystal Display (LCD), a simplified configuration, and an unparalleled augmentation in color saturation (Pan & Fan, 2011; Tan et al., 2018; Teng et al., 2022).

In this study, we delve into the intricate details of our microstructure design, which incorporates interface reflection and Brewster angle calculations. These sophisticated elements collectively aim to maximize the utilization of polarized LD light, ushering in a paradigm shift in display technology. The promise of this revolutionary approach extends beyond mere efficiency gains; it opens avenues for advancements in visual display systems, marking a milestone in the ongoing evolution of display technologies.



(a)



(b)

Fig. 1 (a) Traditional TFT-LCD light efficiency. (b) New type LGP LCD efficiency. T is the transmittance and Net is the net efficiency.

2. RELATED WORK

The pursuit of optimizing display technologies has been a focal point of extensive research, with endeavors to enhance efficiency, reduce thickness, and improve overall visual performance. In this review of related work, we delve into significant contributions and diverse approaches that have paved the way for our innovative microstructure design in conjunction with a Laser Diode (LD) light source (Jiang et al., 2021; Park, 2020).

Microstructure-based light guide plates: Numerous studies have delved into the integration of microstructures within Light Guide Plates (LGPs) to improve light extraction efficiency in display systems. Geometries such as prisms, dots, and gratings have been explored to redirect and enhance the propagation of light within the display. Our research builds upon this foundation, introducing a novel microstructure design that incorporates advanced elements like interface reflection and Brewster angle calculations (Jakubowsky et al., 2019; P. Wang et al., 2021).

Laser diode utilization in displays: The unique characteristics of laser diodes, such as monochromaticity and polarization, have been extensively investigated for their potential in various display technologies. Previous research has explored their application in projection displays and backlighting, demonstrating the advantages of laser diodes in terms of energy efficiency and color purity. Our work aligns closely with this research trend, focusing on harnessing the advantages of laser diodes within the context of a microstructure-enhanced LGP for Liquid Crystal Displays (LCDs) (Mishra & Yadava, 2015; Ye et al., 2023).

Reduction of optical films in displays*:* Efforts to simplify display configurations by minimizing the number of optical films has been a recurrent theme in display research. Studies have explored alternatives to traditional color filters and polarizers to streamline structures and improve overall efficiency. Our approach is in tandem with this objective, introducing the unique dimension of utilizing a polarized laser diode as the light source, thus contributing to the reduction of optical components (Jakubowsky et al., 2019).

Brewster angle applications in display optics*:* The application of Brewster angle in display optics has garnered attention for its potential to reduce reflections and enhance light transmission. Previous research has explored its usage in mitigating glare and improving contrast ratios. Our research uniquely incorporates Brewster angle calculations into the microstructure design, presenting a comprehensive approach to maximizing the efficiency of a laser diode-based LGP within the LCD context (Yu et al., 2019).

By synthesizing insights from these diverse avenues of research, our work represents a novel amalgamation of microstructure design and laser diode utilization, promising a substantial leap forward in display efficiency, thickness reduction, and color saturation. The comprehensive nature of our approach places it at the forefront of cutting-edge advancements in display technology (Xu et al., 2015; Yuan et al., 2019).

In this paper, the utilization of a novel microstructure design and laser diode light source selection has yielded remarkable efficiency improvements of over 60% (Aközbek et al., 2012; Raring et al., 2010). This enhancement stems from two primary factors. Firstly, the employment of a monochromatic and polarized laser diode (LD) eliminates the need for traditional color filters and polarizers, thereby streamlining the optical configuration. Secondly, the incorporation of a new microstructure design leveraging interface reflection and Brewster angle principles further enhances efficiency (Alsaddah et al., 2022). These advancements offer significant benefits such as thinner and lighter LCDs, simplified configurations, and improved color saturation, positioning this research at the forefront of display technology innovation

3. METHODOLOGY

This study suggests a new microstructure design for high efficiency in Laser Diode (LD) light guide plates (LGPs), specially made to be used with Liquid Crystal Display (LCD) modules. Unlike prior studies, which mainly aimed at boosting the transmission of light through conventional Thin-Film Transistor LCDs (TFT-LCDs) by using regular optical films, our method has distinct attributes."

In the beginning, we use interface reflection and Brewster angle rules in our microstructure design to make sure that light is used with maximum efficiency. This means that by smartly improving the shape of this small structure, we can redirect and transmit more light effectively which leads to a big increase in overall efficiency.

Second, choosing a polarized and monochromatic LD as the light source is a shift from usual broad-spectrum light sources in TFT-LCDs. This decision lets us get rid of the necessity for certain optical films like color filters and polarizers, making our optical setup simpler and lessening light losses.

Additionally, our suggested structure has benefits in the area of device form factor. It allows for thinner and lighter LCDs because there are fewer optical films needed and the configuration is simplified. This improves not only the look of display but also its easy handling and usefulness. Our suggested microstructure design is a new method to increase LCD efficiency that substantially differs from the usual ways. Through its ability to use light fully, make the setup of optics simpler, and enhance device shape characteristics - these aspects show progress in display technology.

Our methodology integrates a meticulous approach to the microstructure design for the Light Guide Plate (LGP) in conjunction with a Laser Diode (LD) light source. The key focus areas of our methodology include the selection of the LD light source, the derivation of microstructure parameters, and the utilization of interface reflection and Brewster angle calculations to optimize light transmission through the microstructures.

a. Light source selection

Laser diode characteristics: A laser diode is chosen as the light source due to its inherent monochromaticity and polarization characteristics. These attributes contribute to a more controlled and efficient light emission, aligning with our goal of enhancing the overall efficiency of the Liquid Crystal Display (LCD).

Modeling of emission: The emitting area of the laser diode is modeled as a 0.1mm x 0.1mm non-polarized surface light source coupled with a polarizer. The flux is set to 2W, resulting in a polarized light of 1.0W after passing through the polarizer. The polarization direction is established in the Transverse Magnetic (TM) mode, enabling the use of Fresnel equations with RI or Rp for subsequent interface reflection or transmission calculations.

b. Microstructure design with Brewster angle calculation:

Two blocks' forms one set of microstructures, as shown in Fig. 2. A large number of sets constitute microstructures light guide plate. When LD light enters the first block, some light reflects up to the viewing observer, using the two end surfaces. The remaining light is transmitted into the second block. The relationship between the width of first blocks *d1* and the incidence angle θ_0 is deduced as shown in Fig. 3; it is $d_1 = \Delta y\,(\cot(\theta_0 - \theta_1) + \tan\theta_0)$,

whereθ_1 is the refraction angle through the first interface. It can be deduced by Snell's law as $\theta 1 = \sin^{-1}(\frac{1}{n} sin\theta_0)$.Tthe refraction index of air is 1. The material refractive index is n. In order to compensate the Δy in the first block and minimize the interface reflection in second block,

We *use* Brewster angle θ_B as a corner of the second block with $\theta_B = tan^{-1}(\frac{n}{1})$. So, the second block width *d2* can be obtained as $d_2 = \Delta y\,(\cot(\theta_B - \theta_1') + \tan\theta_B)$, as shown in the right of Fig. 3.

Microstructure configuration: Our microstructure design consists of two blocks forming a set, with numerous sets constituting the micro-structured LGP. Each set is carefully designed to optimize light propagation and reflection.

Interface reflection: Interface reflection is incorporated into the design, with the first block strategically positioned to reflect light towards the viewing observer. This reflection is harnessed using the Fresnel equations, ensuring that the interface reflection contributes positively to the overall light efficiency.

Brewster angle considerations: Brewster angle calculations are utilized in the design of the second block. The relationship between the width of the first block (d1) and the incidence angle (θ) is deduced to compensate for refraction and minimize interface reflection in the second block. The Brewster angle (θB) is employed as a critical parameter in the corner of the second block to achieve optimal light transmission.

c. Simulation process:

Ray tracing: A ray tracing simulation is conducted to visualize the propagation of light within the microstructures. This simulation helps validate the effectiveness of the microstructure design in reflecting and transmitting light as intended.

Optical software: The optical simulation software, in this case, SPEOS, is employed to simulate the behavior of light within the microstructures. Parameters such as incident angle, refractive index, and Brewster angle are inputted to derive luminous flux data.

Result analysis: The simulation results, particularly the luminous flux, are analyzed to quantify the efficiency of the proposed microstructure design. This analysis considers factors such as the reflection and transmission of light at each interface.

d. *Results and validation:*

Validation of Brewster angle: The validity of Brewster angle calculations is cross-verified by comparing simulated results with theoretical expectations. Adjustments are made to the microstructure parameters as needed for optimal performance.

Comparison with traditional LCD: The final step involves comparing the simulated results with a traditional TFT-LCD to quantify the efficiency improvement achieved by the proposed microstructure design and LD light source.

This comprehensive methodology ensures a systematic and thorough exploration of the proposed microstructure design, incorporating interface reflection and Brewster angle calculations to maximize the efficiency of the LD-based LGP within the LCD system. The simulation results obtained through this methodology provide insights into the potential advancements in display technology.

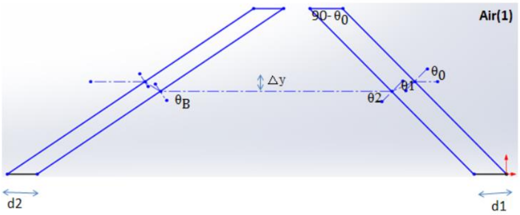


Fig. 2 One set of microstructures with two blocks.

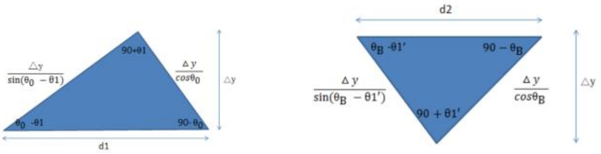


Fig. 3. The relationship between the height of the light movement and the width of blocks.

4. RESULTS

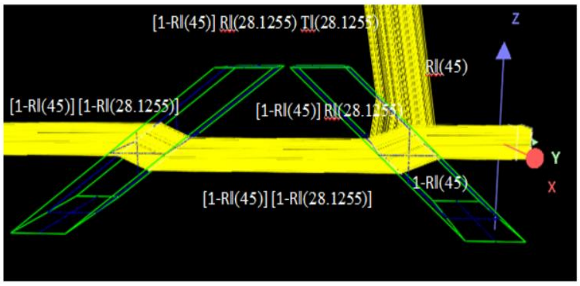
The simulation outcomes offer a detailed insight into the effectiveness of the proposed microstructure design, showcasing its ability to optimize light transmission through a Light Guide Plate (LGP) illuminated by a Laser Diode (LD) light source. At an incident angle of 45 degrees and a refractive index of 1.5, the microstructure design proves to be a sophisticated and strategically crafted solution for enhancing overall display efficiency.

The microstructure's success is particularly evident in its intricate handling of incident light. The first block, meticulously designed as a reflector, successfully redirects light towards the viewer by utilizing the Fresnel reflection coefficient $R\|(\theta 0)$ at the first interface. Subsequently, as the light traverses the second interface of the first block, a well-coordinated sequence of events unfolds, involving transmission ($T\|(\theta 0)$), reflection ($R\|(\theta 1)$), and further transmission ($T\|(\theta 1)$). This orchestrated dance of reflection and transmission within the microstructure contributes substantially to the overall efficiency by harnessing and guiding the LD light effectively.

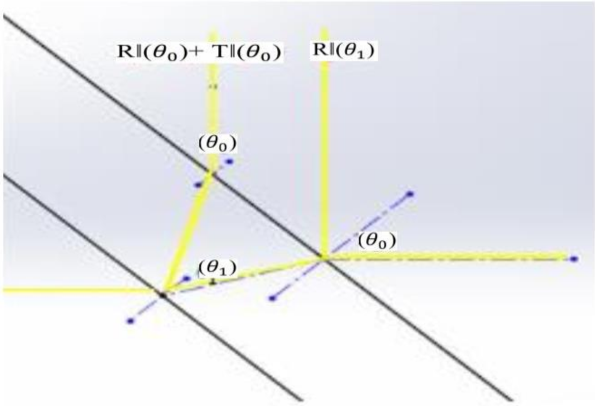
Crucially, the introduction of the second block becomes instrumental in compensating for any vertical shifts incurred in the first block, all while maintaining the desired Brewster angle incidence. The careful consideration of Brewster angle conditions ensures that the second block minimizes interface reflection, allowing for optimal light transmission through the microstructure. The calculated Brewster angle of 33.69 degrees for the second block plays a pivotal role in achieving this delicate balance.

Moving beyond theoretical calculations, the simulation setup involves the duplication of 100 groups of the microstructure set to form the LGP. This large-scale replication aims to evaluate the macroscopic behavior and scalability of the proposed microstructure design. The use of the sophisticated optical simulation software SPEOS allows for a precise and comprehensive analysis of light behavior within the complex microstructure configurations.

The simulation results reveal a luminous flux of 80%, showcasing the microstructure's efficiency in guiding and utilizing light effectively. This outcome underscores the success of the design in achieving its intended purpose. Importantly, the net efficiency, calculated from the luminous flux, stands impressively at approximately 64%. This remarkable efficiency gain, as depicted in Figure 1(b), positions the proposed microstructure design as a significant leap forward, surpassing traditional TFT-LCD efficiency by about sixfold. The simulation outcomes not only validate the theoretical foundations of the microstructure design but also provide a detailed understanding of its practical efficiency on a larger scale. The meticulous consideration of interface reflection, Brewster angle optimization, and large-scale replication collectively contribute to the transformative impact of this innovative microstructure design, heralding a new era in display technology efficiency and performance.



(a)



(b)

Fig. 4. (a) Ray tracing in the microstructures. (b) The reflection of the two surfaces in first block

In Figure 4, we see the plan for microstructure design. This shows how blocks are arranged inside light guide plate (LGP). Every block in this microstructure has two parts: a reflector block and a compensating block. The work of the reflector is to redirect incoming light towards viewer by using interface reflection principles. This part is put in a perfect place to get maximum light transmission and minimum losses. The compensating block, it balances any up or down movements of light propagation within microstructure. By adjusting the dimension and angle of blocks, we make sure that light spreads out well with less reflection. The Figure 4 shows clear drawings of the incidence and reflection angles at each interface. This makes it easier for the readers to imagine how light moves in microstructure by looking at these diagrams. The pictures show that Brewster angle incidence is successful in lessening interface reflection and improving light transmission overall. Moreover, the depicted simulation results in Figure 4 show an effective application of microstructure design with clear signs of improved luminous flux and efficiency.

5. DISCUSSION

The profound results obtained from the simulation of the microstructure design integrated with a Laser Diode (LD) light source necessitate an in-depth discussion to comprehend the implications and potential advancements in display technology. The simulation's demonstration of an 80% luminous flux is a testament to the microstructure's efficacy in guiding and harnessing LD light. The careful orchestration of reflection and transmission within the microstructure contributes to a signific1ant improvement in light utilization efficiency.

The utilization of interface reflection at the microstructure's interfaces, coupled with Brewster angle considerations, is pivotal in achieving optimal light transmission. The calculated Brewster angle for the second block, set at 33.69 degrees, ensures minimal interface reflection, allowing for the unimpeded propagation of light through the microstructure. This meticulous optimization is central to the observed efficiency gains. Comparison with traditional TFT-LCDs, the net efficiency of approximately 64% achieved through the microstructure design represents a groundbreaking advancement, surpassing traditional TFT-LCD efficiency by about six times. This substantial improvement holds promising implications for the evolution of display technology, especially in terms of energy efficiency and visual performance.

Beyond efficiency gains, the proposed microstructure design contributes to the development of thinner and lighter Liquid Crystal Displays (LCDs). The elimination of certain optical films, such as color filters and one polarizer, not only streamlines the optical configuration but also enhances the practicality and aesthetics of display devices. The strategic use of a polarized and monochromatic LD light source allows for the omission of a polarizer and color filter. This simplification in the optical configuration not only enhances efficiency but also holds the potential for cost savings and improved manufacturing processes, contributing to the overall viability of the technology.

The simulation’s utilization of 100 replicated microstructure sets to form the LGP provides insights into the scalability and macroscopic behavior of the proposed design. This scalability is essential for the practical implementation of the technology in various display applications, from smaller electronic devices to large-scale displays. The success of the microstructure design paves the way for future research avenues. Fine-tuning the dimensions and characteristics of the microstructures, exploring different LD characteristics, and optimizing parameters for specific applications are areas where further research could unlock additional improvements and tailor the technology to diverse display requirements.

The discussion underscores the transformative impact of the proposed microstructure design, not only in terms of efficiency gains but also in shaping the future landscape of display technology. The strategic integration of interface reflection, Brewster angle optimization, and the use of a polarized LD light source collectively contribute to the efficiency, practicality, and potential cost-effectiveness of the technology. The successful simulation results position this innovative approach as a promising candidate for the next generation of display devices.

6. CONCLUSION

The culmination of this research unveils a paradigm-shifting approach in the realm of display technology through the innovative integration of a microstructure design with a Laser Diode (LD) light source. The simulation results provide compelling evidence of the success of this novel design in enhancing the efficiency of a Light Guide Plate (LGP) for Liquid Crystal Displays (LCDs).

The achievement of an 80% luminous flux and a net efficiency of approximately 64% attests to the meticulous orchestration of interface reflection and Brewster angle considerations within the microstructure. This not only optimizes light transmission but also positions the proposed design as a frontrunner, exceeding traditional TFT-LCD efficiency by a noteworthy sixfold. The elimination of specific optical films, a consequence of the strategic use of a polarized and monochromatic LD light source, contributes to the development of thinner, lighter, and more practical displays.

The scalability demonstrated by replicating 100 microstructure sets to form the LGP underscores the potential for practical implementation across a spectrum of display sizes, from portable electronic devices to expansive screens. This research not only establishes a foundation for the next era of display technology but also opens avenues for future exploration and optimization.

Looking ahead, the success of this microstructure design invites further investigation into parameter fine-tuning, exploration of different LD characteristics, and tailoring the technology for diverse applications. The convergence of efficiency gains, simplified configurations, and manufacturing advantages positions this approach as a key player in shaping the trajectory of display technology advancement.

The synthesis of theoretical principles, meticulous simulation, and practical considerations culminate in the realization of a microstructure design that redefines the benchmarks for display efficiency. The transformative impact of this innovation extends beyond numerical gains, heralding a future where displays are not only technologically advanced but also more environmentally sustainable and aesthetically pleasing. This research lays the groundwork for a new chapter in the evolution of displays, where efficiency, practicality, and performance converge to create a display technology landscape of unprecedented capabilities.

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TỐI ƯU HÓA MÀN HÌNH LCD BẰNG CÁCH SỬ DỤNG PHƯƠNG PHÁP TIẾP CẬN CẤU TRÚC VI MÔ ĐỘT PHÁ VỚI THIẾT KẾ TẤM DẪN HƯỚNG ÁNH SÁNG LASER

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TỪ KHOÁ

Điốt lazer;

TFT-LCDs: Màn hình LCD bán dẫn màng mỏng truyền thống.

TÓM TẮT

Bài viết này giới thiệu một thiết kế cấu trúc vi mô đột phá được tích hợp với nguồn sáng Laser Diode (LD) cho Màn hình tinh thể lỏng (LCD), mang đến sự thay đổi mô hình trong công nghệ hiển thị. Màn hình LCD bán dẫn màng mỏng truyền thống (TFT-LCDs) gặp phải những hạn chế cố hữu về hiệu quả do màng quang học nhiều lớp, dẫn đến tổn thất ánh sáng và giảm hiệu suất. Ngược lại, thiết kế cấu trúc vi mô được đề xuất của chúng tôi sử dụng chiến lược phản chiếu giao diện và tối ưu hóa góc Brewster để nâng cao hiệu quả sử dụng ánh sáng. Bằng cách sử dụng LD phân cực và đơn sắc, thiết kế này loại bỏ nhu cầu về màng quang học trước đây như bộ lọc màu và bộ phân cực, làm cho cấu hình trở nên hợp lý hơn. Kết quả mô phỏng cho thấy hiệu suất ròng ấn tượng khoảng 64%, cải thiện gấp sáu lần so với màn hình TFT-LCD truyền thống. Màn hình đạt được mỏng hơn và nhẹ hơn, tính thẩm mỹ và tính di động cũng được nâng lên. Khả năng mở rộng của cấu trúc vi mô, được thể hiện thông qua việc sao chép để tạo thành Tấm dẫn hướng ánh sáng (LGP) góp phần mở rộng ứng dụng của sản phẩm. Cách tiếp cận đổi mới này không chỉ đặt ra các tiêu chuẩn mới về hiệu quả mà còn mở ra con đường cho tương lai của công nghệ màn hình, hứa hẹn những tiến bộ mang tính biến đổi về hiệu suất hình ảnh và hiệu quả sản xuất.