78.1: Ultra Compact Polarization Recycling System for White Light LED based Pico-Projection System

Li Tan [1], Ho-Chi Huang [2], Hoi-Sing Kwok [1]

[1.] Center for Display Research, Department of Electronic and Computer Engineering
Hong Kong University of Science and Technology
Clear Water Bay, Hong Kong
[2.] Himax Display Incorporated, Tree Valley Park, Sinshih, Tainan County 744-45, Taiwan

Abstract

An ultra compact polarization recycling system, for white light LED based projectors, is proposed. White light LED is applied as the light source, which is composed of blue LED die and yellow phosphor. By optimizing the illumination optics and properly placing a reflective type polarization film, the light with non-useable polarization state will be reflected back and concentrated right on to the phosphor surface. The yellow phosphor will be re-excited by the blue spectrum component of the reflected light. More light energy will be recycled by attaching a piece of quarter wave plate before the reflective type polarization film. Experimental results show more than 30% light efficiency improvement.

1. Introduction

Pico-projectors are attractive because of the ability of displaying high resolution, large projected image, good brightness, over small power consumption, compact size and low cost [1-4]. Liquid-crystal-on-silicon (LCOS) and digital light processing (DLP) are the two mainstream technologies for realizing such projection display. LCOS has the advantages of combining matured LCD technology together with the best semiconductor technology in silicon. Color-Filter (CF) type LCOS [5] projector, which integrates color filters on silicon for achieving colors, illuminated by white light LED, is the most promising configuration to be embedded into mobile phones, because of its compact size and low cost.

Polarization conversion system design is an important topic for improving the efficiency of LCOS projection system, since only light with one certain polarization state could be utilized by the LCOS panel. A polarization state (PS) converter is generally used in traditional large projectors [6]. Lense arrays are used for concentrating light beams onto the PS converter. This kind of PS converter needs to be precisely aligned with the lens array. Otherwise light efficiency will be greatly reduced. At the same time, with the increasing demanding of compressing system size, the width of the PS converter is reduced. This will greatly increase the fabrication difficulty and the cost. Other polarization conversion designs were proposed, such as Dual Paraboloid Reflector System [7]. However it is only applicable to UHP lamps.

LEDs have the advantages of high power efficiency, small emitting surface, long life time, good chromatic performance, high reliability and green product compliant. It has been regarded as the most promising solid-state light source. White light LEDs, which are made by blue chip covered with yellow phosphors, have efficacy as high as 140lm/W [8], which is larger than most light sources.

In this paper, we propose an ultra compact polarization recycling system for white light LED based projection system. By optimizing the illumination optics and properly placing a reflective type polarization film, the light with non-useable polarization state can be reflected back on to the phosphor surface. The yellow phosphor will be re-excited by the blue spectrum component of the reflected light. Part of the scattered re-excited white light would also be collimated by the condensers and collected on the imager. Experimental results also show that more light energy will be recycled by attaching a piece of quarter wave plate (QWP) before the reflective type polarization film. It is because that the scattered light is with partial polarization state. As a result, more than 30% light efficiency improvement is obtained

2. CF type LCOS projector configuration

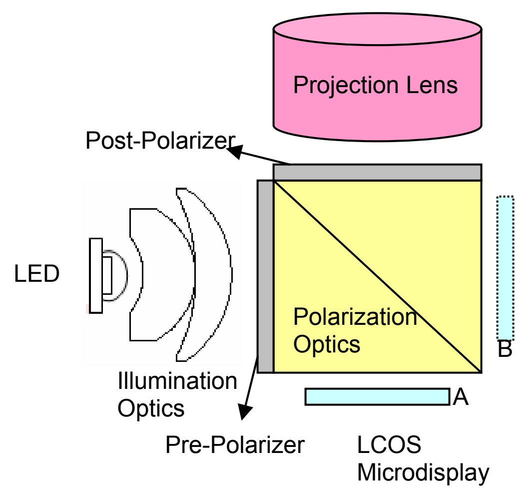


Figure 1. A Schematic diagram of Single LED CF-LCOS Projection System

The Schematic diagram of a single white light LED CF-LCOS projection system is shown in Figure 1. Light comes out from LED emitting surface, usually with very large emitting cone angle. Illumination optics is designed to re-direct the light ray onto LCOS microdisplay with a certain F/#. This light energy within certain F/# will be projected onto screen through projection lens placed after polarization optics. Polarization optics is a must component for LCOS type projector, because only certain polarization light state is useful and will be modulated by the LCOS.

There are three main types of components that could be applied as polarization optics component. Common glass type polarization beam splitter (PBS), based on multilayer dielectric coatings, provides an extinction ratio of as high as 1000:1 in transmission, while only about 40:1 in reflection. And, the light leakage is increased with increasing incident angle. Reflective type polarization films, made of hundreds of layers of highly birefringent polymer films, developed by 3M Innovative Properties Company, have better angular performance than multilayer dielectric coatings PBS, and have the advantage of low cost. Wire grid polarizer [9-10] also shows as good angular performance as 3M reflective type polarization films. Moreover the contrast ratio in transmission light path is better.

The LCOS imager could be placed either at A or B position, depending on the property of polarization optics components applied. Besides, a pre- or a post- polarizer should be placed accordingly for improving the system contrast.

3. Optimization

Four main factors, which will determine the overall system efficiency and final energy output are power efficiency of LED, Collection efficiency of illumination optics, polarization optics including polarization recycling method, and of course the reflection of imager.

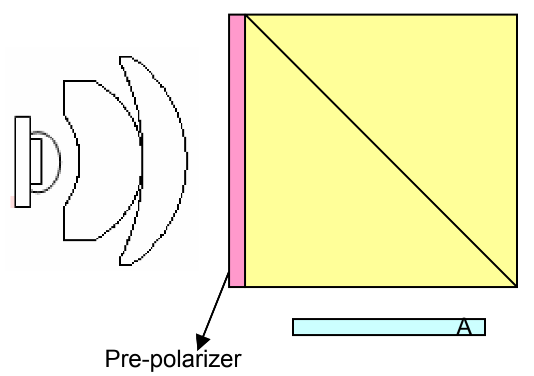


Figure 2. polarization recycling by reflecting the non-usable polarization state and re-exciting the yellow phosphor

Conventionally, optical components like lens array and light pipe are widely used in the illumination optics design, for obtaining uniform light distribution. While, these kinds of structures have the disadvantages of large size and are not suitable for pico-projector module, which is designed to be embedded in to mobile phone.

Simple illumination optics, which includes only 2 pieces of condensers, is optimized. The optimization target is not only for uniform illumination on imager with small F/# and high efficiency, but also that light with un-usable polarization state should be reflected back on the LED light emitting surface.

So, the polarization recycling could be realized by placing a piece of reflective type thin film polarizer at a proper position, reflecting the light with un-usable polarization state. The white light will be concentrated back on the emitting surface, which are covered yellow phosphors. Because of the property of yellow phosphor, light with corresponding exciting wavelength will re-excite the phosphor and gain more white light energy. This re-excited light will also be scattered out and re-direct by the condenser.

As shown in Figure 2, if glass PBS is applied as the beam splitter, a pre-polarizer is require for compensating the system contrast.

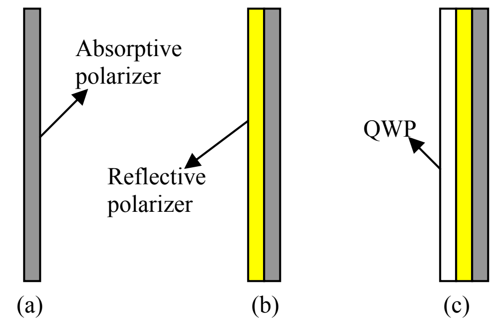


Figure 3. Three kinds of pre-polarizer configuration combination: (a). absorption type polarizer only; (b). reflective type added in front; (c). one piece of QWP attached.

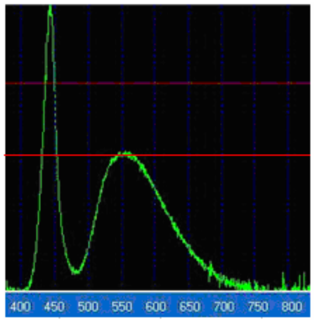
Conventionally, a single absorptive type polarizer is attached, , as shown in Figure 3(a), because of its good extinction ratio. In our case, the reflective thin film polarizer is inserted before absorptive polarizer, acting as not only pre-polarizer, but also polarization recycling component, as shown in Figure 3(b). Moreover, an extra piece of QWP attached, as shown in Figure 3(c), is also helpful for efficiency improvement. Because the polarization state of reflected light is transformed from linear to circular. Part of the reflected light could maintain its polarization state, and converted to usable polarization state after passing through QWP again.

4. Results

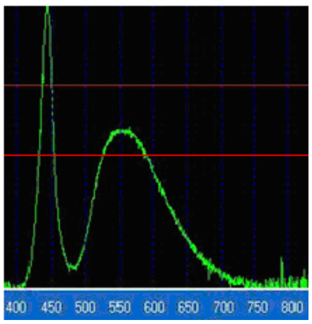
We made several real samples of above described optimization, utilizing XR-E LED from CREE. Three different types of pre-polarizer combinations are applied. And the light output after the different types of pre-polarizer was measured respectively. The Light output was measured by integrating sphere of 0.5m diameter.

The measured results are show in Table 1. It is observed that only 43% of the light with desired polarization could be obtained by conventional absorption type thin polarizer. If adding 1pcs of reflective type polarizer before the pre-absorption type polarizer, the transmission efficiency will be increased from 43% to 48%. 1 more piece of QWP helps further increasing the efficiency to 56%. More than 30% improvement is obtained without increasing system dimension. Totally, about 540K color temperature drops, because relative more energy excited at the yellow spectrum range.

The spectrum comparison of with and without polarization recycling is recorded and show in Figure 4. More yellow light could be observed through the normalized spectrum distribution.



(a)



(b)

Figure 4: Measured spectrum at position A of applying (a) absorption type polarizer only (b) adding 1pcs of QWP and 1pcs of reflective type polarizer.

Table 1: Transmission efficiency and color temperature of three different pre-polarizer combination structures

Configuration	lm	Eefficiency	Color Temperature
W/O Polarizer	154.5	-	6286.3K
Absorptive Polarizer Only	66.2	42.8%	6001.4K
Reflective+ Absorptive Polarizer	73.8	47.8%	5552.5K
QWP+ Reflective+ Absorptive Polarizer	86.9	56.2%	5465.5K

5. Conclusion

We have reported a compact polarization recycling system, optimized especially for white light LED based LCOS projection display. The recycling is realized by reflecting light with non-usable polarization state, and optimizing the illumination optics, so that the reflected light could be concentrated back to the LED phosphor surface. The phosphor will be further excited by the reflected light blue spectrum. Experimental result shows a more than 30% light efficiency improvement without increasing the system dimension and at very low cost. Moreover, this method does not have the alignment issue. It is very suitable for mobile phone pico-projector, in which compact size and low cost are most emphasized.

6. References

[1] Refer to www.himaxdisplay.com/en/product/info.asp for Himax Display projectors.

[2] Refer to www.dlp.com for DLP projectors.

[3] Refer to www.microvision.com for Microvision laser projectors.

[4] Refer to www.displaytech.com for Displaytech FLCOS projectors.

[5] H. C. Huang, B. L. Zhang, H. S. Kwok, P. W. Cheng, and Y. C. Chen SID'05, p.880, (2005).

[6] Kuo-Yuin Li, US Patent 2004/0075787 (2004).

[7] Seiji Inatsugu, Kenneth Li, SID'05, p.874, (2005).

[8] Refer to http://www.cree.com/ for high power LEDs.

[9] Douglas Hansen, Eric Gardner, Raymond Perkins, Michael Lines, Arthur Robbins, SID'02, p.720, (2002).

[10] Raymond Perkins, Douglas Hansen, Eric Gardner, Thorne James M, Robbins Arthur A, US Patent 6122103 (2000).