

Polarization Recycling LED Module for Pico Projector

Y. Chi, W.P. Tang, S.L. Chen, C.J. Tsai

Hong Kong Applied Science & Technology Research Institute Co. Ltd., Hong Kong

Abstract

Pico projector can display larger images based on handheld electronic devices including mobile phone, portable multimedia players (PMPs, or MP4), PDA, GPS, and mobile TVs. Nowadays LEDs are ideal light source for the pico projection optical engine. However the optical efficiency of common LEDs can not be used adequately in pico projectors due to the undesired polarization state is absorbed, scattered, and/or blocked. In this study, a polarization recycling LED module was developed, which could convert the undesired polarization state to the desired one. In order to simplify the projection optical design and shrink the size of the projection optical system, and further enhance the optical efficiency of the projection system, this LED module integrated light recycling system and thermal dissipation structure. The light recycling system includes a reflective polarizer and a quarter wave plate (QWP). The experimental results show that the light recycling can enhance the system optical efficiency and increase output brightness of the projector system by 11.14% and increase the LED module brightness by 22.67% respectively. This paper also analyzed how to improve the utilizing efficiency of recycled light further more.

Keywords: LED module, Polarization conversion, light recycling, pico projector

1 Instruction

The decreasing size of today's mobile devices, such as cell phones, PDA and digital cameras, coupled with the increasing requirement to offer a full graphic display and video playback capabilities, create the need of a portable multi-viewer display. The market challenge is to develop a display technology that combines a small form factor with a larger display size. Pico projection is a good solution to this problem, which could be as a standalone miniature projector system and as accessories of portable electronic product, and another is embedded into the portable electronic product. Then it could fulfill the needs of portability and also enlarge display size. At the 2009 International CES in Las Vegas, many

companies such as 3M, Optoma, Micovision, Toshiba, Samsung, LG, WowWee and etc. have published their pico projector prototypes. The total power consumption is in range of 1~5W.

Nowadays using LEDs as the lighting source is the current mainstream for Pico projectors, since the LEDs could meet the requirements of both size and power source for their characteristics of high efficiency, solid-state form and small étendue effect characteristics, quick switching time, more saturated colors, longer lifetime, and etc. Light emitted from the LED is projected onto a micro-display panel, such as a liquid crystal display (LCD), liquid crystal on silicon (LCoS). One challenge of the pico-projector technology is that the light is typically polarized in LCD or LCoS applications, and only the light with desired polarization state can be transmitted. However, most commercialized LEDs only emit unpolarized light, results that more than 50% light are wasted since undesired polarization state is absorbed, scattered, and/or blocked. In order to increase the efficiency of illumination, one would have to recycle the wasted light by converting the undesired polarization to the desired one. It is what is meant by polarization recycling.

Actually polarization recycling isn't a novel principle, which has been mentioned in many publications and patents [1-8]. Polarization recycling technology has been widely used in back light unit (BLU) for LCD display to improve the brightness. Kim [9] investigated the brightness enhancement of liquid crystal displays (LCD) through polarization recycling by placing a nano-wire grid polarizer (NWGP) between an LCD panel and a backlight unit. The results showed the brightness enhancement is up to 30%. Darmon [10] investigated a pico projection optical system with polarization recycling compounded a reflective reflector and a QWP. But the polarization recycling device is extended out of a LED package with four chips (RGGB). Sometimes, light recycling is combined with the collection function [11] or with the polarization conversion function [12]. Reported enhancement efficiency gained with such recycling systems ranges from 10%

to 30%.

In this study, a polarization recycling LED module was developed for pico projector. The developed LED compact a polarization system, a recycling system, a condenser system and a thermal management into one module. It is realized to output polarized light and furthermore convert the undesired polarization to the desired one, and the illumination efficiency was enhanced by larger than 20%. The output brightness of pico projection engine was enhanced by larger than 10%. Since the polarization recycling system was compacted into the LED module, it would be easy to assemble and have lower cost and small size compared with the separated polarization and recycling system.

2 Polarization Recycling LED Module

2.1 Structure

As shown in Fig.1, the LED module includes a reflective polarizer positioned in a light emission path of the LED, wherein the reflective polarizer is configured to polarize the LED light, and the reflective polarizer further transmits the p-polarization state light and reflects the s-polarization state light. A quarter wave plate (QWP) is stick below the reflective polarizer, which could covert the s-polarization state to the p-polarization state. So the reflective polarizer and the QWP composed of a polarization recycling system. The polarization recycling system is stuck on a LED package then a lens covers on the top of polarization recycling system for narrow the beam angle. In order to narrow the beam angle furthermore, an air gap is kept between the LED chip and the QWP.

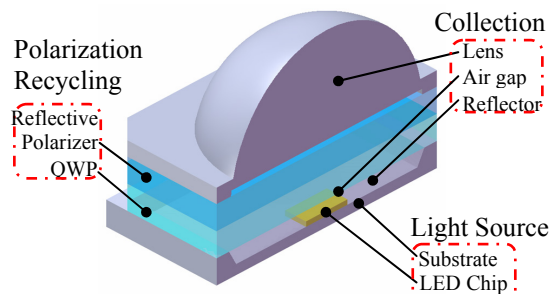


Fig.1 Polarization recycling LED module structure

2.2 Polarization Recycling

Fig.2 illustrates the polarization recycling principle. The LED chip emits light having both p-polarization and s-polarization. The reflective polarizer only allows p-polarized light to be emitted through but

reflects s-polarized light back towards the substrate. The reflected s-polarized light would pass through a quarter-wave plate, becoming circularly polarized light. Then it would be reflected by substrate and the chip so pass through the QWP again. After passing through the QWP twice, the s-polarized light would be converted into the p-polarized light. So the reflected light can pass through the PPL. The emission of the p-polarized light that is converted from s-polarized light increases the total light output and energy of the LED module.

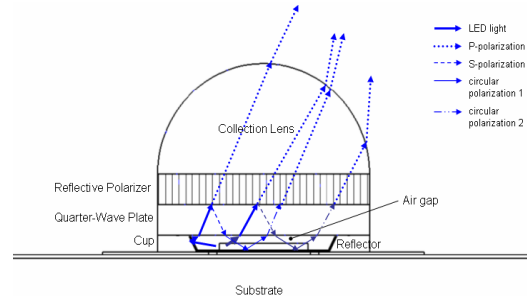


Fig.2 Schematic diagram of polarization recycling

2.3 LED Module Optical Design

FIG. 3 is a distribution plot showing the beam angle of the LED module. In order to match with the projection optical path, the beam angle is configured to 55° . For different projection optical engine, the beam angle of the LED module can be changed to match with the projection optical engine by modify the lens shape, the thickness of reflective polarizer, QWP and the air gap. Compared with typical beam angle of 120° configured by most commercialized LED, narrower beam angle would concentrate more energy and be advantage of the optical design on projection engine. Fig.4 shows a prototype photo of the polarization recycling LED module.

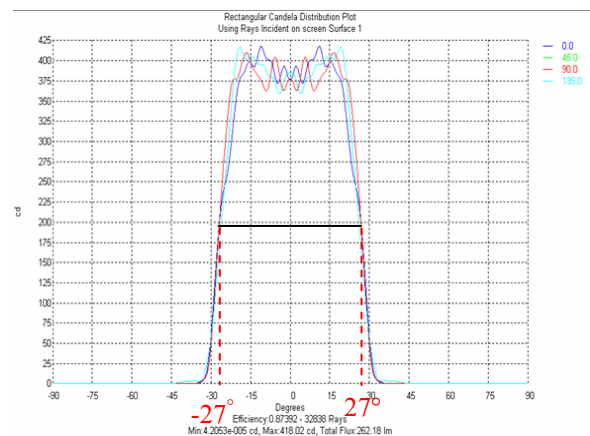


Fig.3 Luminous intensity distribution of LED module

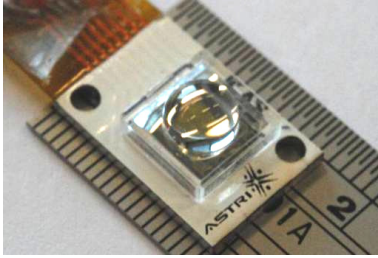


Fig.4 Polarization recycling LED module photo

3 Pico Projection Engine

3.1 Optical Design

Fig. 5 shows a side cross sectional view of a pico projection system including the polarization recycling LED module. The LED module is bonded to an MCPCB, and a heat sink is attached to the back side of the MCPCB so that the heat from the LED chip in the LED module can be dissipated. Then the LED module and the MCPCB are coupled to the mechanical housing. Several optical components may be positioned in the optical path and fixed by the housing and cover. An LCoS panel is attached to the housing opposite to the LED module. Some projection lenses may be positioned in a cylinder which can slide within the housing for adjusting the focus. The light rays emitted from LED module transmit through the optical components then reach the LCoS panel. After reflected by the LCoS panel and optical components, the light rays transmit through the projection lenses and then are projected out of the projection system. Due to polarization and light recycling, the LED module can increase the total light output and energy of the projection system compared with conventional projection systems.

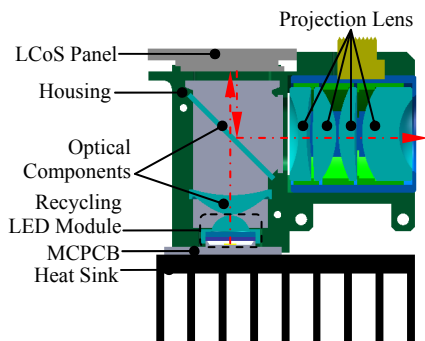


Fig.5 Pico projection engine structure

Optical simulation results show that these optical components unit can get a better uniformity and system efficiency. As shown in Fig. 6, the uniformity of this pico projection engine is +13.87%/-14.98%, and the system efficiency is 3.7%.

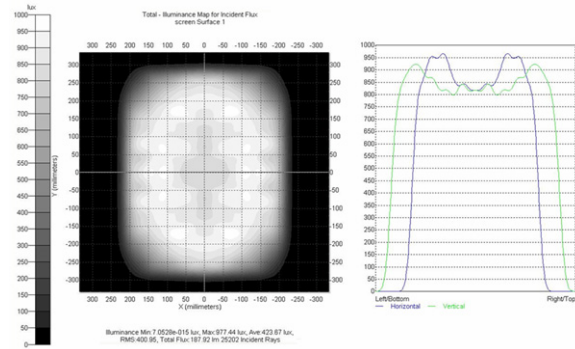


Fig.6 Simulated luminance flux on screen surface

Fig. 7 shows the prototype photo of the pico projection engine. The thickness is 10.8mm and the volume is 7.2cc when not including the heat sink.

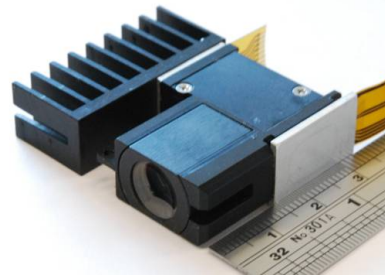


Fig.7 Pico projection engine photo

3.2 Thermal Solution

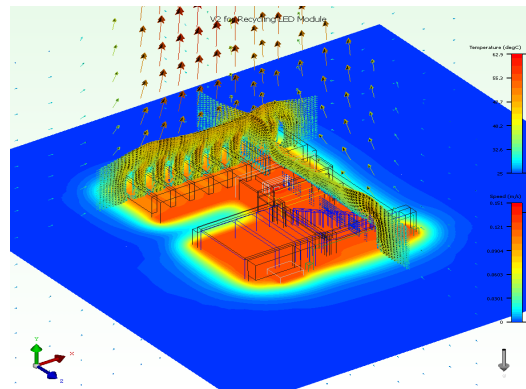


Fig.8 Simulated temperature and air flow distribution

In this application, the current of LED need be up to 600mA, so the power will be larger than 2W. Because the high power LED chip only has a surface area of 1mm², if approximately 75% electrical power transfers to heat, it will contribute a high heat flux of 150 W/cm² within the LED Chip, which will cause very high junction temperature (T_j). Therefore reducing the thermal resistance to keep the junction at a low temperature is very important for high power LED operating under high current condition. Because MCPCB can provide very good thermal conductive

base material for heat spreading, in this application, the LED directly mounted on a MCPCB and then attaches a heat sink for heat dissipation. Furthermore due to the metal housing, some heat can be dissipated into amber via housing outer surface simultaneously. The LED junction temperature is 62.9°C, and the surface maximum temperature of the projection engine is 56.1°C, as shown in Fig.8. It would be safe to operate for a long time.

4 Testing Results and Discussions

4.1 Polarization Effect Testing Method

As the LED module emits polarized light directly, in order to test the polarization degree, a polarizer was fixed on the inner of the integrating-sphere photometer. The LED module was stuck on a heat sink fixed on a support close to the integrating-sphere photometer. As shown in Fig.9, the polarizer can be rotated around its central axis, so this experimental device can measure the luminous output at different polarization degree. In operation, test the luminous output one time per rotating the polarizer by 30 degree. Through the following formula, we can get the degree position at the maximum brightness and calculate out the polarization degree.

$$\begin{cases} I = \frac{2}{3}[I(0^\circ) + I(60^\circ) + I(120^\circ)] \\ Q = \frac{2}{3}[2I(0^\circ) - I(60^\circ) - I(120^\circ)] \\ U = \frac{2}{\sqrt{3}}[I(60^\circ) - I(120^\circ)] \end{cases}$$

Then the polarization angle θ and the polarization degree P can be calculated:

$$\begin{cases} \theta = \frac{1}{2} \tan^{-1} \frac{U}{Q} \\ P = \frac{\sqrt{Q^2 + U^2}}{I} \end{cases}$$

Rotating the polarizer at the polarization angle, the maximum brightness can be measured.

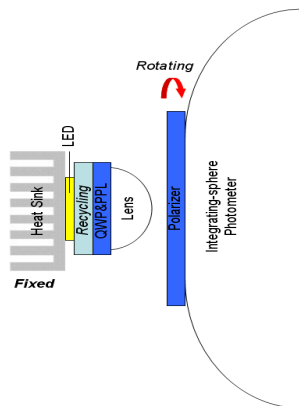


Fig.9 Polarization degree testing

4.2 Testing Results of Recycling LED Module

The polarization degree and luminous output testing results are shown in Table 1. In order to verify the brightness increment after adding the polarization recycling effect, three different LED modules are packaged for comparison testing. The first module is a common LED package, the second module is added a PPL between the LED and the lens, and the third one is further added a QWP between the LED and the PPL. From the testing result, by covering a PPL in front of the LED emitting surface, the whole LED package only emits one polarization state light, and the polarization degree is close to 90%. Compared with the first common LED module, the brightness of the second LED package was increased by 17.33%. When the second polarization state light reflected back by the PPL reaches to reflecting cup and the LED chip, it is reflected again and scattered resulting that some light is transited to the desired polarization state light. The desired polarization state light can transmit the PPL so the brightness increases. After adding a QWP between the LED and the PPL, the polarization conversion efficiency increases further more. The brightness increment reaches to 22.67% compared with the common LED package.

Table 1 Recycling LED module testing results

LED Module	LED + Lens	LED + PPL + Lens	LED + QWP + PPL + Lens
Structure			
Polarization degree	--	88.95%	89.60%
Luminous Flux (lm) (Max)	15.75	18.48	19.32
Brightness increment	--	+17.33%	+22.67%

4.3 Testing Results of Pico Projector Engine

Assemble above mentioned three different LED modules into the pico projection engine respectively to investigate the projection quality and system brightness increment by polarization recycling. Fig.10 shows the projection effect. From the projection image, we can see the projection quality is sharp and without distortion.

Table 2 shows the detailed data of pico projection engine testing results. Due to the assembly inaccuracy, the mean uniformity is +22.60%/-19.92% and contrast is 89.43. By using the second LED module with PPL but no QWP, the projection system brightness increases by 9.2% Comparing with use the

common LED module without polarization and light recycling. By adding a QWP to enhance the polarization conversion, the projection system brightness increment reaches up to 11.14%.



Fig.10 Projection image

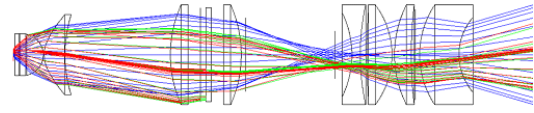
Table 2 Pico projection engine testing results

LED Module in projection engine	LED + Lens	LED + PPL + Lens	LED + QWP + PPL + Lens
Output brightness (lm)	2.316	2.529	2.574
Uniformity (9 P.)	+23.57%	+17.31%	+26.94%
	-16.89%	-17.31%	-25.56%
Contrast	90.98	84.00	93.13
Brightness increment	--	+9.20%	+1.78%
	--		+11.14%

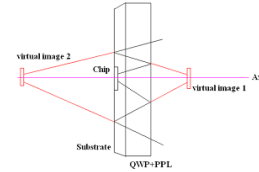
Comparing the brightness increment of LED module and the pico projection engine, the increment in LED module is 22.67% whereas in the pico projection engine the increment is down to 11.14%. Obviously only 50% recycled light from the LED module is utilized by the pico projection engine.

The optical design of projection engine is based on the LED chip size and position, most of the light can pass through the optical system, as shown in Fig.11 (a). The reflector on the substrate is flat in the prototype of polarization recycling LED module. The recycled light is reflected twice and the equivalence size and position is shown in Fig.11 (b). It results that only a few recycled light rays can pass through the system as shown in Fig.11 (c). If the recycled light path is not similar to the original light path, even the reflected light is recycled but it can not pass through the projection system because the projection optical design is based on the original LED chip position and size. If the size and position of visual image formed by reflected light rays are closer to the original LED chip by optimizing optical design, more recycled light rays can pass through the projection engine optical system, as shown in Fig.11 (d). So the

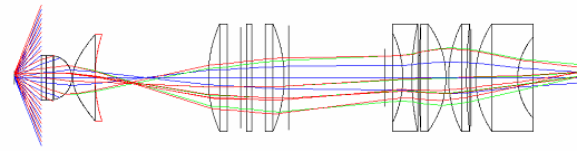
brightness enhancement of pico projection engine would be improved further more.



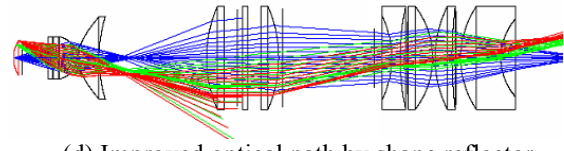
(a) Original LED chip optical path



(b) Virtual image of reflected light



(c) Optical path of recycled light



(d) Improved optical path by shape reflector

Fig.11 Optical path comparison between original light and recycled light

5 Conclusions

In this study, a polarization recycling LED module was developed for pico projector engine. The developed LED compact a polarizing system, a recycling system, a condenser system and a thermal management into one module. It is realized to output polarized light and furthermore convert the undesired polarization to the desired state. Testing results showed that the illumination efficiency was enhanced by 22.67%. By applying the polarization recycling LED module into the pico projection engine, the output brightness was enhanced by 11.14%. About 50% recycled light was utilized due to the emitting size and position difference between the original light and recycled light. This paper also analyzed how to improve the utilizing efficiency of recycled light further more.

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