Study on the Efficiency of the LCOS Optical Engine Based on the LED Light Source

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Abstract

LCOS technology is a core technology independently developed in China of large screen projection. In this paper, after theoretically analyzing the influence of the various optical elements on the whole system efficiency, the model of the LCOS optical engine based on the LED light source is established with the beam expansion theory, the light transmission theory, and the polarization transformation theory. With the analysis of the factors influencing the efficiency of the optical engine, an evaluation system is established for that efficiency. Finally, a method is proposed to improve the efficiency of polarization conversion for recycling polarized light.

Keywords

Liquid Crystal on Silicon (LCOS); Light Emitting Diode (LED); Optical Engine; Polarization Conversion

1. INTRODUCTION

In recent years, various micro-display systems are more and more widely applied to many fields. The light source plays a very important role in projection equipment. The design of light source directly affects the performance of equipment. UHP and UHE discharge high brightness bulbs are generally used in common projectors. Their advantages are high luminous efficiency and high light density, while their disadvantages are large calorific value, relatively short life, and difficulties to make the structure compact. Miniaturization and long life of micro-display projection system are the development direction of projection technology [1].

The LED devices with high brightness provide new possibilities for the long life and miniaturization of micro-display projection systems [2, 3]. LED has the characteristics of high luminous efficiency, no infrared radiation, small device, low power consumption and long life, and monochrome LED has good monochrome, narrow bandwidth. Specially white LED has wide gamut, adjustable white spot, and high dimming rate, and therefore it has flexible selectivity. It has the advantages that traditional light sources cannot reach in the application of projection display system. However, due to the different shape and luminous characteristics of the LED and the traditional projector source, the existing lighting system is not suitable for LED, and cannot meet the requirements of miniaturization of the projection system. Therefore, it is very necessary and meaningful to study the small projection lighting system for LED [4].

LCOS technology is a core technology of large screen projection developed independently in China without relying on foreign countries. There are two reasons for its slow development nowadays: one is that the rate of good products is too low; the other is that its working principle is similar to LCD which needs polarized light, so its optical engine efficiency is not high enough, and therefore the brightness of the screen is hard to meet the requirements. In this paper, based on the structure of LCOS optical engine of LED light source [5], the optical efficiency of each optical element in the optical engine is analyzed according to the optical transmission theory. Then the efficiency evaluation system is established, and the method of improving the efficiency of the optical engine is studied [6-8].

2. OPTICAL TRANSMISSION THEORY MODEL OF OPTICAL ENGINE

The LCOS optical engine of LED light source is mainly composed of five parts: light source, switching light path, polarization conversion, LCOS micro display and projection lens. Optical engine's optical transmission should satisfy three theories: beam expansion theory [9], light energy transmission theory [10], and polarization conversion theory [11].

Beam expansion theory: In the transmission of light in the lighting system, the beam spread keeps constant or increases, but does not decrease, which is similar to the concept of entropy in the second law of thermodynamics, and is an irreversible process. In the process of light transmission, the size of LED light source and LCOS micro-display and the number of projection objective F should satisfy the theory of beam expansion. With the important beam expansion theory, the lighting system can be designed by calculation to make full use of light energy. When the size and lens of LCOS micro display are determined, the matching LED light source can be selected quickly. Then, the parameters can be confirmed after compromise adjustment in the design process.

Light energy transmission theory: when light is transmitted in an optical engine, it will cause the loss of light energy. There are three main causes: the reflection loss of the transmission surface, the absorption loss of the reflecting surface coated with metal and the absorption loss of the optical material. When light transmits from one medium to another, there must be reflection loss at the polishing interface, and its transmittance is less than 1 ($\tau < 1$). The reflecting surface of the metal coating can not reflect all the incident light energy, but absorb a small part of it, and its reflection coefficient is less than 1 ($\rho < 1$). Optical materials can not be completely transparent. When a beam passes through, some light can be absorbed by the material. In addition, impurities and bubbles in the material will scatter the light, so when light passes through the optical material, it will be accompanied by absorption and scattering losses. The absorption loss of light in optical materials depends not only on the properties of the materials themselves, but also on the total thickness of the optical parts (generally referred to as the central thickness). Denote the absorption rate per unit length as α . The transfer optical path and projection objective in the optical engine should satisfy the light energy transmission theory. Assuming that there are k_1 transmission surfaces, k_2 metal reflective surfaces and the central thickness of optical material is $\sum d$, the efficiency of the transfer optical path and projection objective is $\eta = \tau^{k_1} \rho^{k_2} (1-\alpha)^{\sum d}$.

Polarization conversion theory: Like LCD, each pixel point on LCOS micro-display is composed of liquid crystal. The liquid crystal filters the passing light by twisting, so it needs polarized light to be incident on the LCOS micro-display to make it work. Because the LCOS panel is based on CMOS chip, it can't let light pass through directly. Its polarization conversion device uses polarization splitting prism (PBS) to separate the incident beam from the reflected one. When incident light is incident on PBS, because the prism is coated with polarization film, the senkrecht light will be totally reflected on the prism, and the parallel light will be transmitted (as shown in Fig.1). If the voltage is used to control the phase change of the senkrecht light in LCOS panel, the parallel light is reflected from LCOS. As long as a detector is

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used to detect the emission of the parallel light, it can detect the added signal voltage, thus realizing the readout function of the signal.

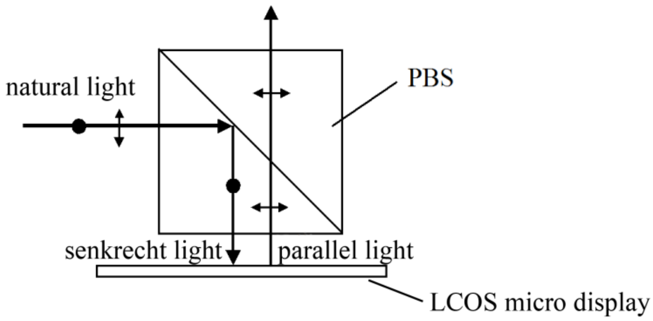

Figure 1. Principle diagram of PBS

3. EVALUATION SYSTEM OF OPTICAL ENGINE EFFICIENCY

The efficiency of the optical engine refers to the ratio of the final output luminous flux of the system to the total luminous flux of the three-color LED light source. The formula for calculating the efficiency of an optical engine is shown in Formula (1).

$$\eta = \eta_C \cdot \eta_I \cdot \eta_P \cdot \eta_{\mu D} \cdot \eta_{CR} \cdot \eta_L \quad (1)$$

The meaning of each parameter in the Formula (1) is as follows.

η_C : The LED light collection efficiency. After selecting the LED light source, according to the beam expansion, the collector angle of the LED can be calculated, and the efficiency of the LED light source can be calculated according to the collector angle. The formulas for calculating the beam expansion of LED and imaging system are shown in Formula (2) (3), where A represents the area and F is the F number of projection lens.

$$E_{LED} = \pi A_{LED} \sin^2 \theta \quad (2)$$

$$E_{system} = \pi A_{LCOS} / (4F)^2 \quad (3)$$

η_I : The imaging spot efficiency of the illumination system. The illumination system needs to image the LED surface light source on the micro-display, and is slightly larger than it, so as to facilitate the light path adjustment of the illumination system. With the optical system design software, the imaging spot size of the illumination system can be simulated. The ratio of the area of the micro-display to the area of the imaging spot is the efficiency.

η_P : The polarization conversion efficiency. When the natural light from LED passes through the polarization converter, the influence of beam expansion should be considered.

$\eta_{\mu D}$: The LCOS micro-display efficiency, commonly known as the opening rate. Because LCOS transistors and driving circuits are made in silicon substrates, which are located under the reflecting surface and do not occupy the surface area, only the pixel gap occupies the open area, which can now reach about 70%.

η_{CR} : The efficiency of transfer system mainly refers to the optical efficiency of lighting system and combining system. It should be calculated according to the light energy transmission theory.

η_{L} : The efficiency of projection objective should also be calculated according to the light energy transmission theory.

4. IMPROVEMENT OF POLARIZATION CONVERSION EFFICIENCY BY RECYCLING REFLECTED LIGHT

LED light source emits natural light using PBS to produce polarized light, then only the senkrecht light (or the parallel light) light can be used and the parallel light (or the senkrecht light) light is completely lost, and hence light efficiency is less than 50%. Therefore, improving the efficiency of polarization conversion has become a research hot-spot. The common scheme is to use half-wave plate to convert waste paralle light into available senkrecht light, as shown in Figure 2. However, this scheme doubles the area of the beam and doubles the beam expansion. Affected by the optical expansion, only half of the light can enter the subsequent optical system, so this scheme is not suitable for the optical engine based on LED light source.

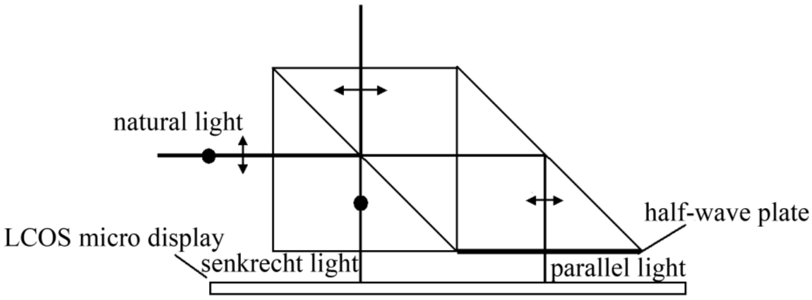

Figure 2. Improving Polarization Conversion Efficiency with Half-wave Plates

Affected by the beam expansion, the polarization conversion efficiency is generally less than 50% in the optical engine which needs polarized light to work. Half of the light energy is wasted when polarization is started. We can consider recycling the wasted light to improve the efficiency of polarization conversion. Two schemes are proposed here.

One scheme uses reflective polarizers to improve efficiency by recycling reflected light, as shown in Figure 3. After the orthogonal polarized light is polarized by the reflective polarizer, half of the energy of the linear polarized light passes through, and the other half of the reflected light is reflected on the glass cover of the LED. Then it is reflected by the LED to form recycling and improve the polarization conversion efficiency. In theory, light will continue to bounce back and forth until all light is polarized properly and passes through the whole system. In fact, the preparation of reflective polarizers with good extinction ratio is difficult. Reflective polarizers are usually composed of multi-layer polymer films with different reflective properties. A certain amount of orthogonal polarized light can also pass through reflective polarizers. It is necessary to add an absorption polarizer in the optical path to improve the contrast of the system. The polarization direction of the output light is determined by the absorption polarizer. The efficiency of optical recycling is mainly determined by the extinction ratio of the reflective polarizer and the reflectivity of the LED glass cover.

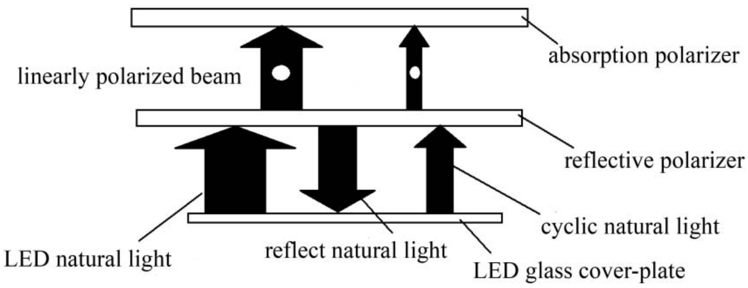

Figure 3. The scheme of recycling reflected light with the reflective polarizer

Another scheme is to use PBS to polarize the transmitted parallel light and reflect it back to the original optical system through a planar mirror, as shown in Figure 4. A quarter wave plate is placed in front of the PBS. The reflected parallel light passes through the quarter wave plate twice and becomes the senkrecht light. In this scheme, the beam spread will not change. In theory, light will continue to reflect and circulate until all the light changes to a suitable polarization state and passes through the whole system. However, light loses in the transmission process. The efficiency of optical recycling is mainly affected by the reflectance of the reflector and the absorption loss of the optical system.

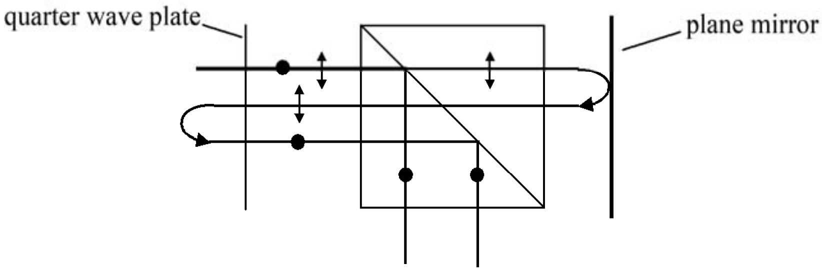

Figure 4. The scheme to polarize the transmitted parallel light and reflect it back to the original optical system

5. SUMMARY

Based on the structure of LCOS optical engine of LED light source, the optical efficiency of each optical element in the optical engine is analyzed according to three optical transmission theories: beam expansion theory, light energy transmission theory and polarization conversion theory. The evaluation system of the efficiency of the entire optical engine is established, and the method of improving the efficiency of the optical engine by utilizing the reflected light cycle is proposed. The application of LED light source with miniaturized LCOS optical engine provides a theoretical basis. The next step is to test and improve the technology according to the factors affecting the efficiency of the optical engine, so as to make the LCOS optical engine of LED light source develop toward the direction of further miniaturization and energy saving.

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