Optical Engine for Liquid Crystal Projection Using Continuous Grain Silicon TFT

Keisuke Mitani*1 Tamotsu Takatsuka*2 Akira Takushima*3
Toshifumi Kurobe*1 Masaharu Hara*1

*1 A1207 (B) Project Team *2 Engineering Department NO.3, LCD System Division, Audio-Visual Systems Group
*3 Precision Technology Development Center, Production Technology Development Group

Abstract

A new optical engine for LCD rear projection HDTV has been developed using three 2.6 inch CG-Silicon(Continuous Grain Silicon) TFT LCD panels. The optical engine realizes the brightness of 1000cd/m^2 and CCR(center-corner ratio) of 80% with 60 inch condition.
This optical engine uses two UHP(Ultra High Power) lamps to fulfil enough brightness and long life. Closed cooling system has been developed to keep out the dust, and original lens has been designed by own company to get high quality image.

Introduction

Recently, LCD projectors have achieved higher resolutions and higher luminance in for use in data display applications. Even in the area of high-end AV monitors, such as high resolution HDTV, LCD rear projection TV has an advantage of a clearer image at the screen edge, and lower production cost compared with CRT. We have decided to commercialize ultra high resolution LCD rear projection systems that utilizing the CG- Silicon TFT LCD panels, in which a high speed LCD driver is implied. By utilizing the CG-Silicon technology the mobility of electrons in the semiconductor is boosted and realizes high speed driving of the LCD from an ultra micro high resolution display to large screen super ultra high resolution display.
Quite a few problems to be solved to achieve an high efficient illumination system for such a high-resolution LCD projector. The problems were optimization of a projection lens which is suitable for high resolution, reduction of dust adhered on the LCD panels which causes problems with the projected image; extension of the life of the lamp as to be comparable to that of existing AV monitors and so on. Details of the technology used to solve these problems are described in following technical explanation.

1. Illumination system

Fig 1 is the outline scheme of the newly developed optical engine. In this optical engine the fly eye lens system is introduced in order to uniform the illuminance and the color coordination in the screen. The fly eye lens produces uniform illumination by securing an adequate number of fly eye cells; in this development we divided the fly eye cells into 144 pieces. To separate light into each primary color, R, G and B, dichroic mirrors are introduced. With regard to the blue optical path, which is longer than the other two paths, relay lenses are introduced to make the illuminance distribution the same as the other colors. In addition to these, a color prism is used for combining the R, G and B light. This prism diminishes the deterioration of resolution caused at the color combiner and makes the back working distance of the projection lens shorter than that of a one-mirror system. The shorter back working distance make it easy to miniaturize projection lens itself and improve the performance of projection lens.
Long life lamp is required for AV television use. However, it has been difficult to achieve long life with high brightness, since generally long life lamps consume low electric power and irradiate relatively low luminous flux. Therefore, in this system two long life lamps are used to satisfy the requirements of long life and high brightness.
However, using two lamps in one illumination system decreases the efficiency of light integration will decreases, since an integration area of the light irradiance will become larger compared to a one-lamp system. Therefore, even

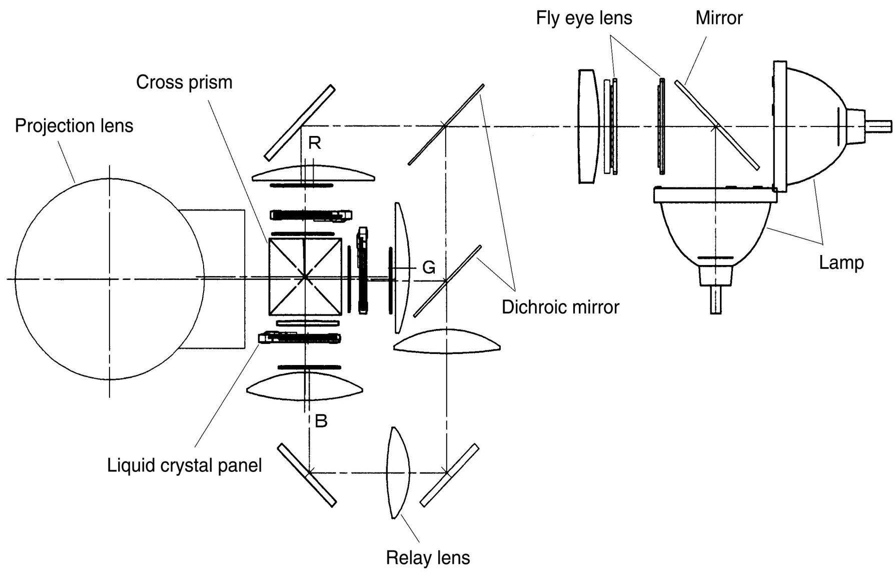

Fig. 1 CGS TFT LCD projection optical engine.

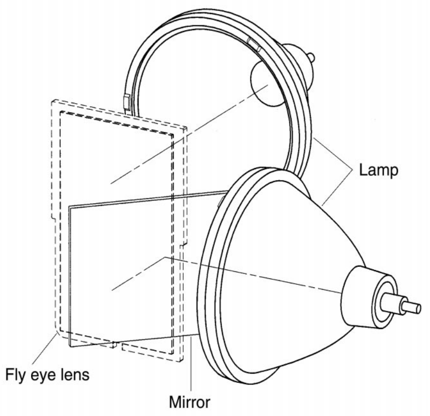

Fig. 2 Lamp system of optical engine.

in a system, that has two lamps, the integration area of light irradiance should be as small as possible. In this optical system, lamps are aligned vertically as shown in **Fig.2**. The light from one lamp is reflected by a mirror and the light from the other lamp irradiate straight without a mirror. Thanks to this architecture, the areas of light irradiance from two lamps can be adjacent to each other, and the entire area of light integration decreases. Thus, light integration efficiency of this illumination system have been improved.

2. Closed cooling system

As the temperature of the LCD panels increase, the heat from the LCDs cause deterioration of the polarizers which results in a decrease display performance. Thus, in order to control the rise of temperature of the LCD panels, a cooling system is used while operating the projector. The intake of external air is the usual way to cooling the LCD panels. However, this method has the problem of dust in air easily adhering onto the LCD panels, and this will cause the unacceptable effect on the image. Therefore, we have adopted a closed cooling system that isolates LCD panels from external air.

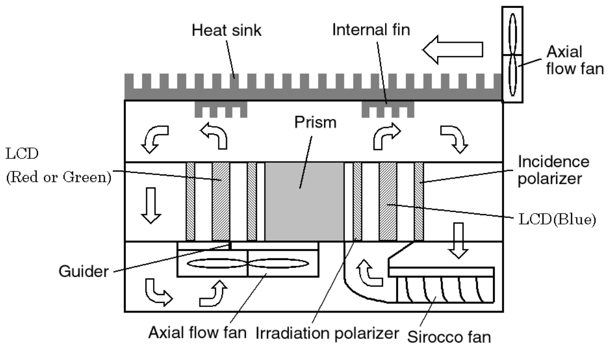

Fig. 3 Closed cooling system.

2.1 Composition of the closed cooling system

Closed cooling system has a sealed room that consists of optical components and heat sinks for heat radiation, etc. in which the LCD panel, the polarizers, and the cooling fan are arranged. Architecture of the closed cooling system is shown in **Fig. 3**.

2.2 Air flow for cooling

The ratio of the heat irradiation between the red, green and blue LCD panels is 1:1:1.5. This ratio means that more airflow is needed for the cooling the blue LCD than the other two LCDs. In order to make the situation simple, we assume that the heat conductive rate on the LCD panel surface and the polarizer surface are proportional to the inverted square of airflow velocity. On this assumption the blue LCD panel requires 2.2 times as much airflow as the red/green LCD panels for sufficient cooling. As shown in **Fig. 3**, the closed cooling system is designed to provide airflow between the input side polarizer and the LCD panel, and between the LCD panel and the output side polarizer. It is considered that when the air flows into a passage like this, the pressure loss is proportional to the velocity of airflow, and 2.2 times more pressure loss will occur at the blue LCD than at the red/green LCDs. Considering the heat irradiance from each LCD panels, we introduce an axial flow fan and high static pressure sirocco fan into the green/red LCD and the blue LCD respectively. The air that blows from the axial flow fan is separated by an air guide installed between the LCD panel and axial flow fan, allowing a sufficient amount of air to flow to the red/green LCD panel. The air absorbs heat from the LCD panels and the polarizers, and then collides with the heat sink on top of the closed cooling system. The temperature of the air decrease as it passes the heat sink. It then continues through a duct that consists of optical components, and returns to the axial flow fan after circulating in the closed cooling system. On the other hand, the air that flows from the sirocco fan will be led to the blue LCD panel by implemented guide. This air carries the heat from the panel to the heat sink, and finally returns to the sirocco fan after circulating within the closed cooling system. In order not to mix the circulating air from the axial flow fan with the air from the sirocco fan, the inhalation position of one fan is kept apart from the other. In addition, the air guide is designed so that the air is led to the parts of the LCD panels and polarizers that have the highest temperature.

2.3 Heat radiation

Heat within the sealed room is radiated from the wall of the closed system and is forced to be exhausted by the heat sink. The heat sink composes the wall of the closed system. Various flat cables ---such as those from the LCD panels---penetrate the heat sink. Above the blue LCD panel, where the temperature is high, a fin shaped fan is attached to the heat sink as an internal fin in order to boost the efficiency of exchanging the heat though the heat sink. A pushed out fin with a thick base has been adopted to decrease the temperature distribution at the base surface of the heat sink. The axial flow fan is used to expedite the heat radiation from the heat sink and is arranged so that the amount of heat radiation is maximized.

3. Projection lens

3.1 The optimization of the illumination system and image formation systems.

Fig. 4 shows the ray figure of the custom designed projection lens, (the focal length is f = 44 mm, and effective F2.5) which is introduced to the optical system. The optimization of the projection lens including the illumination system has been managed in order to match the illumination system to the image formation system. This optimization has been done by taking into consideration of the following two points.

(1) Integrating the light efficiently into the pupil of the projection lens.
(2) Two lamps are appropriately arranged.

The purpose of (1) is to reduce the loss of light through the projection lens. The image of the light source at the fly eye lens and the image of the light source at the pupil of projection lens are related to the object and the image respectively. In this case, because the image formation is done by all the lenses between the fly eye lens and the pupil of the projection lens, the optimization has been done by combining the lenses just after the fly eye lens of

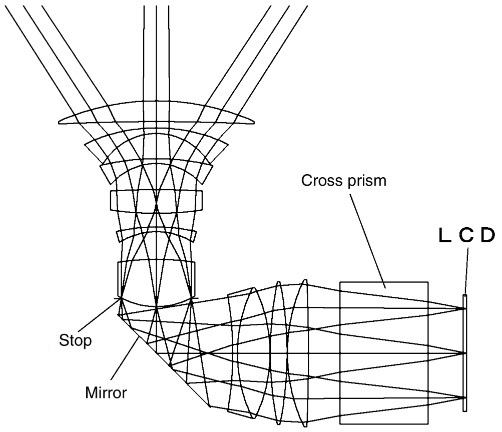

Fig. 4 Optical path of projection lens.

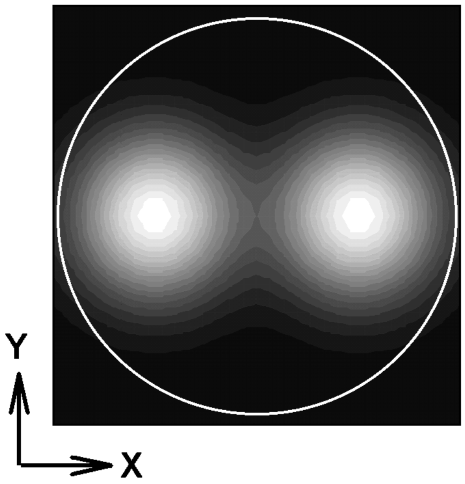

Fig. 5 Intensity distribution of the light source image in the pupil.

the illumination system with the one just before the pupil of the projection lens. With regard to the design, especially light integration at the marginal of the pupil of the projection lens is taken into consideration. Thanks to this effort, the loss of light is minimized.
The reason why (2) is considered is that the light distribution at the pupil of the projection lens greatly influences the evaluation of the projection lens. The diagram of the image at projection lens pupil, which indicates the case of a 2-lamp optical system, is shown in **Fig. 5**. The system has distribution at the pupil of the projection lens as shown in **Fig. 5**, and the resolution of the X direction is generally inferior to that of Y direction. When the image is defocused a little, the focus depth becomes very shallow and the image splits into two. While the pixel pitch of the LCD panel is 45µm and 32µm to the H direction and V direction, respectively, these values are comparable to a spatial frequency of 11Lpm and 16Lpm, respectively. According to these figures, the resolution across the H direction will not require as much resolution as the V direction. Therefore, in this optical mechanism, the lamps are arranged so that the X direction of lamp is set in the H direction and vice versa.

3.2 Feature of self design projection lens

When the arrangement of the lamp is decided, the image formation performance of projection lens itself defines the final image quality. To obtain a fine image, it is required to suppress the blur of the point image as much as possible. In order to satisfy the requirements above, it is necessary to obtain a smooth image throughout the entire screen, in which the best focus position should be independent of image height. Taking into the shallowness of focus depth across the H direction as explained before, the variation of blur of the point image and of the image quality within the image, which are caused by manufacturing errors, must be tightly controlled. Furthermore, in case of the wide-angle lens such as this, it is difficult to correct the screen distortion and the wave length dependent variation of the magnification (chromatic aberration of magnification). To solve these issues, we adopt a projection lens that consists of a nine-group, ten-piece spherical lens as shown in **Fig. 4**. Because there is a limitation to the depth direction of the internal space in the product, the projection distance is short. Therefore, the light path is bent to 90 deg. at the middle of the projection lens by a mirror. In addition, an outstanding technology is implemented to obtain an even brightness from corner to corner of the screen. Because various aberrations are excellently corrected throughout the entire the screen, this lens produces an excellent resolution in spite of its wide angle and non-vignetting. Furthermore, the relatively small values of the aberration, which is yielded by each individual lens, eliminate manufacturing error and increase productivity. In addition, we attain low cost by introducing the least expensive BK7 glass material into five of the ten lenses, and by using comparatively less expensive glass material for the remaining five lenses. In general, the resolution of the projection lens is evaluated by MTF (Modulation Transfer Function). MTF is an amount, which indicates how accurately the contrast of the object is reproduced in the image through the lens. The closer value is to 100%, the better the reproducibility becomes. The performance of the projection lens used for high class TV such as HDTV requires that at the specified spatial frequency, which corresponds to the LCD panel pixel pitch (11Lpm and 16Lpm are for the H direction and the V direction, respectively, in this case), an MTF of over 70% to be sufficient. When MTF is calculated by taking into consideration of the distribution on the pupil of the

Table 1 Specification of 60" LCD rear projection HDTV.

Item	Specifications
Screen size	60 inches
Number of pixels (horizontal x vertical)	1280 x 1024 (1,310,000 pixels)
Brightness	1000cd/m^2
Outside dimensions (width x height x depth)	1429 x 1469 x 597(mm)
Lamp	Two 100W UHP lamps
Center corner ratio	80%

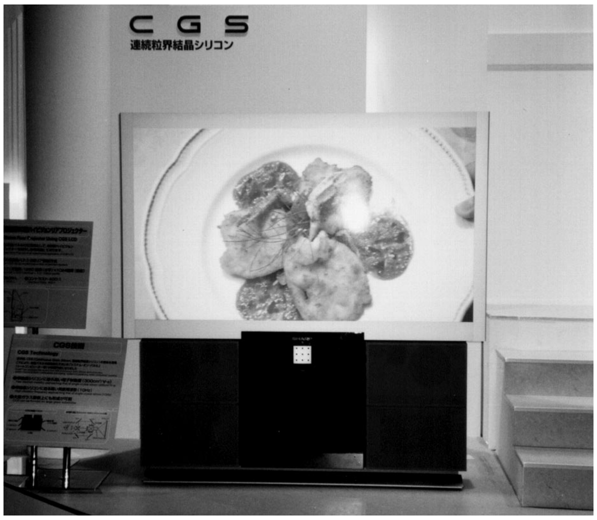

Photo 1 60" LCD rear projection HDTV.

projection lens, this lens gives an MTF of 70% or more at each space frequency in the whole area of the screen. Moreover, the TV distortion is suppressed to 0.8% or less.

4. Liquid crystal panel

CG-Silicon technology has been developed in collaboration with Semiconductor Energy Laboratory Co. Ltd. Thanks to a new method of solid phase growth formed on a glass substrate, a continuous grain field silicon (CG-Silicon : Continuous Groin Silicon) semiconductor whose property is so good that it is comparable to the single crystal silicon has been realized. This method has succeeded in obtaining such characteristics by giving the atomic level continuousness at the silicon grain boundary at the atomic level and high electron mobility approximately 600 times and 4 times as high as that of amorphous (non-crystal) silicon and ordinary low temperature poly-silicon TFT, respectively.

By utilizing this technology, we have succeeded in developing a 2.6-inch super ultra high resolution CG-Silicon TFT LCD panel with a built-in high speed driver (13.8MHz, 4 times as fast as a conventional one) and a pixel count of 1,310,000 (1280 x 1024)—the highest level in the industry. This panel enables the development a suitable LCD projection TV for the coming digital television age.

Conclusion

An optical engine for a 60-inch liquid crystal rear projection screen for use in HDTV has been developed. The specifications are shown in **Table 1** and the appearance is shown in **photo 1**. As for the performance, a screen luminance of 1000 (cd/m^2) and an illumination ratio of 80% have been obtained, plus 2 long-life lamps have been adapted in order to satisfy the requirements of long life and high brightness. Thanks to closed cooling system, the LCD panels are protected from dust. Moreover, by improving the projection lens and the other components, a sharp and fine image throughout the entire screen has been achieved. The inherent characteristics of LCD projectors, such as the wide dynamic range of color reproducibility, high purity of color and effect-less terrestrial magnetism, have been realized. The system surpassed CRT projection in the picture quality. A new market is expected to be formed in the approaching digital broadcasting age by our further efforts to improve the brightness and resolution.

Acknowledgment

This product was the first to apply CG-Silicon technology jointly developed by Semiconductor Energy Research Center Co., Ltd. and our company. As an exclusive engine for mounting on the 60" type rear projector for HDTV, it was developed to enable CG-Silicon TFT liquid crystal panels to manifest their functions fully. The author wishes to thank those concerned at Semiconductor Energy Research Center Co., Ltd. for their great cooperation in the development of CG-Silicon technology and the development of the 2.6" type CG-Silicon TFT liquid crystal panel incorporated in the engine.

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