ISSN 1674-1056
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Citation: Chin. Phys. B . 2019, 28(12): 124208 . **doi:** 10.1088/1674-1056/ab53d1
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Wide color gamut switchable autostereoscopic 3D display based on directional quantum-dot backlight*

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(Received 13 July 2019; revised manuscript received 8 October 2019; published online 29 November 2019)

A switchable autostereoscopic 3-dimensional (3D) display device with wide color gamut is introduced in this paper. In conjunction with a novel directional quantum-dot (QD) backlight, the precise scanning control strategy, and the eye-tracking system, this spatial-sequential solution enables our autostereoscopic display to combine all the advantages of full resolution, wide color gamut, low crosstalk, and switchable 2D/3D. And also, we fabricated an autostereoscopic display prototype and demonstrated its performances effectively. The results indicate that our system can both break the limitation of viewing position and provide high-quality 3D images. We present two working modes in this system. In the spatial-sequential mode, the crosstalk is about 6%. In the time-multiplexed mode, the viewer should wear auxiliary and the crosstalk is about 1%, just next to that of a commercial 3D display (BENQ XL2707-B and View Sonic VX2268WM). Additionally, our system is also completely compatible with active shutter glasses and its 3D resolution is same as its 2D resolution. Because of the excellent properties of the QD material, the color gamut can be widely extended to 77.98% according to the ITU-R recommendation BT.2020 (Rec.2020).

Keywords: three-dimensional (3D) display, directional and scanning quantum-dot backlight, color gamut, full resolution

PACS: 42.79.Kr, 07.07.Hj, 42.15.Eq **DOI:** 10.1088/1674-1056/ab53d1

1. Introduction

The 3-dimensional (3D) display has drawn wide attention in scientific research and commercial applications. Also, it is generally accepted that the viewing experience can be enhanced by the 3D equipment, compared with traditional displays.[1] Additionally, 3D displays, as the new generation consumer products, have come into the commercial market. The stereoscopic displays with auxiliary glasses, such as the active shutter glasses or polarizing glasses, become more popular. The active shutter glasses are composed of two switching lenses which are fabricated by liquid crystal.[2] The active shutter glasses, backlight, and liquid crystal display (LCD) panel could work together. The active shutter glasses and backlight are controlled by the vertical synchronization signal sent by the display card. High frequency responding displays, such as the LCD panels and projectors,[3] are essential to show the different perspective images in the time-multiplexed solution. The polarized glasses are widely used in cinemas and the projection screens can maintain the polarization of the light from the projectors. However, the inconvenience caused by the auxiliary glasses limits its development and this solution will be replaced by the autostereoscopic display. Spatial-multiplexed displays are those autostereoscopic displays most frequently encountered by the public. Two examples are parallax barrier displays[4–6] and lenticular lens displays.[7–10] In these solutions, the trade-off between view number and perceived resolution, the diffraction and light efficiency must be taken into consideration carefully. However, the resolution loss, narrow viewing angle, crosstalk, and incompatible data format will hinder the development of the spatially multiplexed displays which use parallax and lenticular barrier. The crosstalk and resolution loss degrade the 3D image quality severely. Redesigning the subpixel shape[11] can solve these problems to some extent. The directional backlight solution,[12–15] which can alternately project the left and right images to the location of user's corresponding eyes, has overcome the issues related to the resolution loss and crosstalk. The crosstalk can be reduced to an unprecedented low level which is close to that of the stereoscopic display system with auxiliary glasses. This improvement increases the possibility of applying the backlight illumination scheme to practical applications. In conjunction with the head-tracking system, the viewer will see perspective images in different positions. Directional backlight solution enables the autostereoscopic display to maintain the original physical resolution by using the spatial-sequential-multiplexed technology. This solution will reduce the interaction between the lens array and the LCD panel.[16] However, the performance will be limited by the narrow viewing angle. Display qualities, such as resolution, crosstalk, and brightness, are the main research emphases. The

*Project supported by the National Key R&D Program of China (Grant No. 2016YFB0401503) and the R&D Plan of Jiangsu Science and Technology Department, China (Grant No. BE2016173).

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color gamut defines a more specific range of colors from the range of colors identifiable by the human eye. In this paper, we use the Rec.2020[17] to evaluate the color gamut performance of our prototype. A wide color gamut is useful to enhance the image quality. The wide color gamut enables a display device to represent the real object accurately. So, the color gamut is also an important aspect that should be systematically studied and examined before the wide application of the autostereoscopic display.

Here, an autostereoscopic system belonging to the category of binocular eye-tracking display is proposed. Two parallax images (left image for the left eye and right image for the right eye) are used to produce exit pupils within the viewing scope. Different from those traditional ways using the lenticular lens or parallax barriers, we introduce a system based on temporal multiplexing theory. The display device comprises a directional optical module, a dynamic blue scanning backlight, and a 120 Hz LCD panel. The directional optical module includes the lenticular lens, the parallax barrier, and the quantum-dot-polymer (QDP) film. The light from blue LEDs in a specific group passes through the directional optical module and will be directed to the viewing zone. The dynamic blue scanning backlight comprises 80R (row) and 992C (column) blue LEDs. These LEDs are mounted regularly and driven by the constant current driver circuit. All the blue LEDs are controlled by the vertical synchronization signal sent from the display card and scan in pace with the refreshing of the LCD from top to bottom. The blue light can excite the QDP film to produce white light. The QD materials have been widely used to enhance the ability to restore the true color in the field of flat panel display. These materials can be excited by blue light. The emitted light has the advantage in narrow bandwidth. Its full width at half maximum (FWHM) is about 20–40 nm.[18,19] The domain wavelength is tunable by changing the size of the materials. Compared with the backlight using traditional phosphor white LEDs, the color gamut and display brightness will be improved if the QD materials could be implied.[20,21]

We present two working modes of this system. In the spatial-sequential mode, the crosstalk is about 6%. In the time-multiplexed mode, the viewer should wear auxiliary and the crosstalk is about 1%, just next to that of a commercial 3D display. Additionally, our system is also completely compatible with the active shutter glasses and its 3D resolution is the same as its 2D resolution. Due to the excellent properties of the QD material, the color gamut can be widely extended to 77.98% according to Rec.2020.

The main improvements and contributions of this study are as follows. (i) Reconstruction strategy of 3D images is improved, reducing the crosstalk. (ii) Based on the implementation of the QD material, the color gamut is widely extended and the ability to express the color is greatly enhanced. (iii) Real-time motion parallax is improved, allowing the viewer to see different perspectives of the 3D content. (iv) A dynamic scanning blue backlight has been used to reduce the crosstalk. Also, our prototype is completely compatible with the active shutter glasses.

2. System configuration and operation principle

The overall configuration of the proposed autostereoscopic 3D display device is based on a dynamic blue scanning backlight, a directional optical module, and a 120 Hz high refreshing rate LCD panel. The directional optical module comprises of the lenticular lens, the parallax barrier, and the QDP film. The proposed device operates by refreshing the left and right images alternately on a single direct-view display screen (LCD). The switching of the dynamic blue scanning backlight must be in synchronization with the refreshing of the LCD panel. The eye-tracking system controls the directional blue backlight. Separating and then projecting the left and right images are the main function of the directional backlight. Exit pupils are formed at where either a left or a right image is seen among the complete area of the screen, for the sake of removing the special glasses. Each pair of the exit pupils which are formed in pairs will follow the eye position of the viewer. When the backlight works in high switching speed, the viewer can perceive the 3D images on the LCD panel without the auxiliary glasses. In this case, the images are directed to the corresponding eyes of the viewer by the backlight, instead of being selected by the special glasses, such as the active shutter glasses.

2.1. System description

In order to explain the working principle more accurately, only 8R and 16C blue LEDs are shown in the schematic figure. The color of the LEDs indicates the switching state (yellow-OFF, blue-ON). As shown in Fig. 1(a), when the vertical synchronization signal of the left image is sent from the display card, the left image begins to fill out the screen. After a very short time, which is determined by the hold-type characteristic of the LCD panel, the LEDs behind the left image are turned on. Only the area which is steadily displaying the left image is highlighted. For example, the particular LEDs in the first two rows are turned on in the array. The blue light goes through the directional optical module and will be directed to form the exit pupil. The blue light can excite the QDP film to produce white light. The formation of the right exit pupil is similar to that of the left exit pupil. The difference lies in the position where the LEDs are turned on.

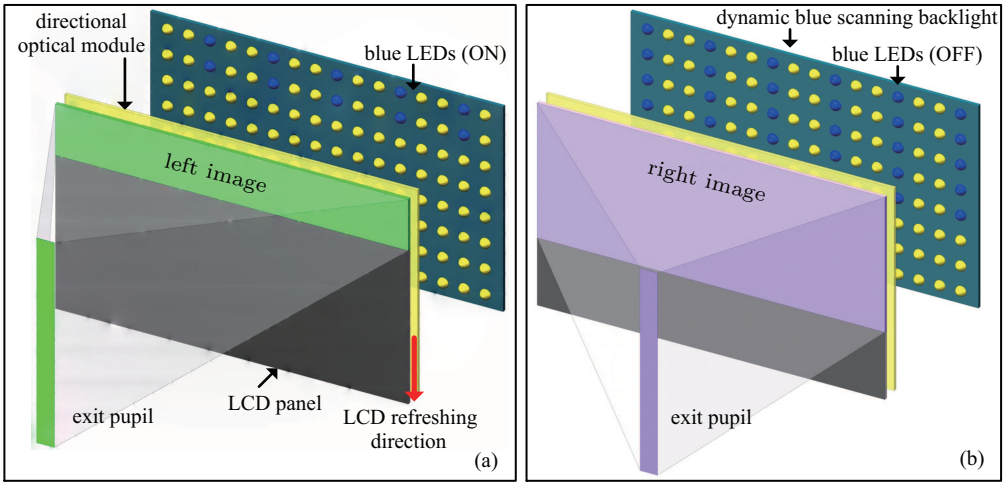


Fig. 1. Schematic of the time-multiplexed 3D display system in conjunction with the directional backlight. (a) The formation of the exit pupil for the left image. (b) The formation of the exit pupil for the right image.

All the LEDs used in the system emit blue light and the domain wavelength is 450 nm. In order to obtain the high horizontal resolution of the exit pupils, the small package LEDs are mounted accurately. The distance between adjacent LEDs is quite small, as shown in Fig. 2(a). The LEDs are numbered in *R*-*C*-*G*, where *R* is the index of the row, *C* is the index of the column, and *G* is the index of the group. The LEDs belonging to the same group (index *G*) are controlled in a special order according to the vertical synchronization signal. As shown in Fig. 2(b), the directional optical module is composed of the lenticular lens 1, the lenticular lens 2, the QDP film, and the parallax barrier. The blue light emitted from the blue LEDs goes through these components, and will be turned into white light.

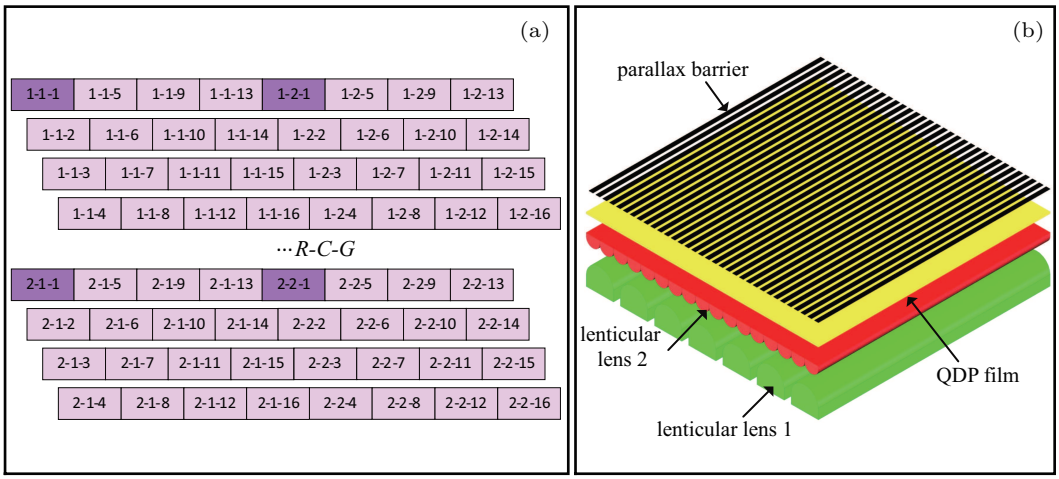


Fig. 2. Schematic of the components. (a) The arrangement of the blue LEDs. (b) Structural sketch of the directional optical module.

The sequential 3D content is displayed alternately by a high-resolution LCD panel. The left and right images are projected to the viewer by the directional backlight. Two converging light beams, which are carrying the left and right images, are sequentially formed at the eye position of the viewer. When the LCD panel is displaying the images, the scanning backlight works at high speed.

2.2. Principle of directional view method

Two lenticular lenses (lenticular lens 1 and lenticular lens 2) with different focal lengths are mounted face-to-face. They play an important role in the directional backlight, as shown in Fig. 3. The blue LEDs array is fixed on the back surface of lenticular lens 1. All LEDs are spaced evenly and horizontally, numbered as 1, 2, …, *N*. In Fig. 3, the relationship between parameters *Q* and *P* can be given as

$$\frac{Q}{P} = \frac{f_Q}{f_P}. \tag{1}$$

The width of the slit is p and the width of the exit pupil is w. $\beta = w/p - 1$ is introduced as the 3D projection ratio factor. The relationship between parameters L and d can be given as

$$L = d \times \beta. \tag{2}$$

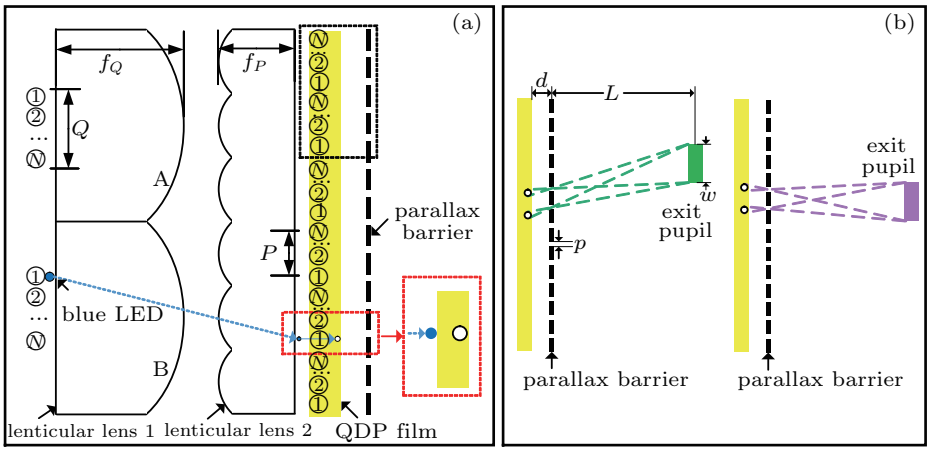


Fig. 3. Schematic of directional backlight system. (a) The components of the backlight system. (b) The formation of the exit pupil.

2.3. Principle of 2D/3D switching

In 3D mode, the blue LEDs in a particular position will be turned on. Consequently, the slit light source will be formed periodically. In 2D mode, all blue LEDs are turned on simultaneously and the periodicity of the slit light source is destroyed. The beams cannot form independent display regions, so the system will work as a traditional 2D display device. As long as we change the working mode of the blue LEDs, the display mode will be changed accordingly, as illustrated in Fig. 4.

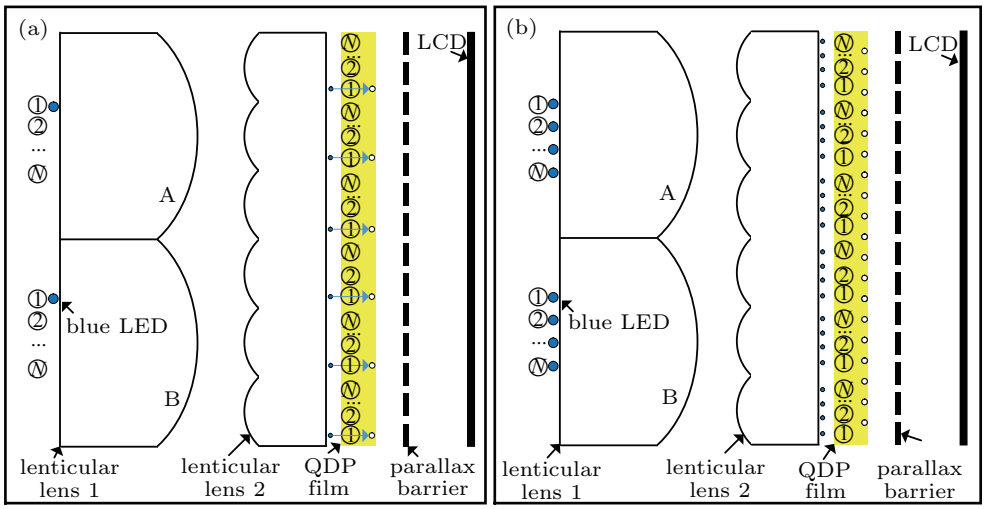


Fig. 4. The principle of switchable LED array: (a) 3D mode, (b) 2D mode.

2.4. Synchronization between backlight and 3D images

It is crucial to reduce the crosstalk in the time-multiplexed 3D display because each eye of the viewer should only see the left or right image intended for it. The operation of the backlight must be in synchronization with the refreshing of the left and right images.

Figure 5 shows the sketch map of the backlight control circuit, which consists of the blue LED array, the field programmable gate array (FPGA), the constant current driver, and the display card. The display card is used for two functions: transmitting the sequential 3D images continuously to the LCD panel alternately via a HD multimedia interface (HDMI); transmitting the vertical synchronization signal to the FPGA through a universal bus port. The FPGA plays an important role in synchronizing the blue LEDs backlight with the 3D video streams. The display card sends the 3D video sequence and the vertical synchronization signal simultaneously. In fact, due to the hold-type characteristic of the liquid crystal, there will be a certain time delay between the image display and image data transmission. When the FPGA detects the vertical synchronization signal, a certain temporal delay is inserted between the vertical synchronization signal and the backlight control signals. LEDs in the different group are turned on and the light from them is directed to the eye position of the viewer. When the backlight operates in 3D mode, the LEDs for the left and right images are alternatively turned on and off in the same frequency with the 3D frame rate. The backlight control signal is carefully modulated in order to effectively reduce the crosstalk.

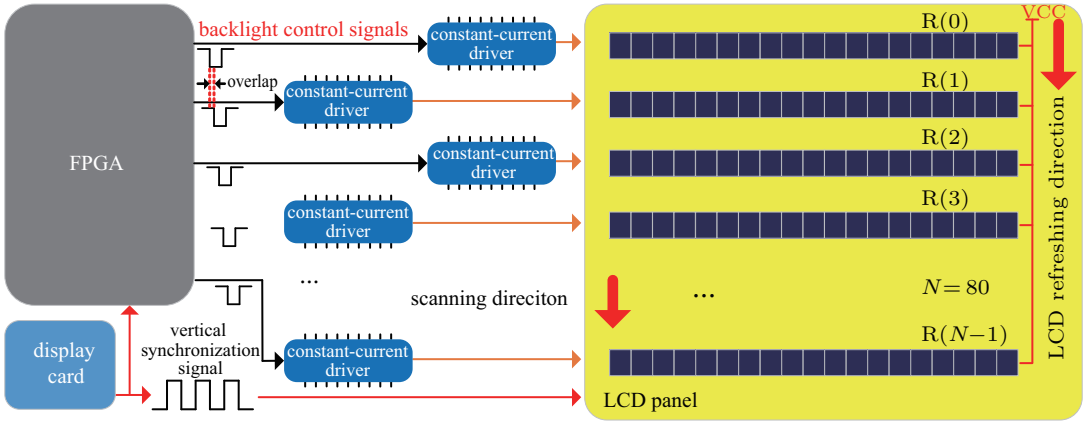


Fig. 5. The sketch map of the backlight control circuit.

3. Prototype and results

To verify the feasibility of the proposed idea, a prototype is fabricated and related experiments are carried out.

3.1. Prototype setup

The characteristic summary of the LCD panel used in this prototype is recorded in Table 1.

Table 1. Display characteristics.

Item	Value
Screen diagonal	685.65 mm (27.0″)
Active area	597.6 mm (H)×336.15 mm (V)
Response time	5 ms (Typ. on/off)
Pixel H×V	1920(×3)×1080
Frame rate	120 Hz
Display mode	TN mode, normally white

Figure 6(a) shows the layout of the lenticular lens, the parallax barrier, and the QDP film. The blue LEDs which belong to the same group are turned on, as shown in Fig. 6(b). The distance between the left and right exit pupils is 60 mm, which is close to the distance of human eyes. The backlight has 16 operating modes. 80×62 blue LEDs will be turned on and off in each mode. The focal lengths of the lenticular lens 1 and the lenticular lens 2 are 32.8 mm and 0.6 mm, respectively. The sandwich structure formed by the lenticular lens 2, the QDP film, and the parallax barrier is shown in Fig. 6(d). The thickness of the middle layer is 150 μm. The arrangement width (Q) of the blue LEDs in the same group is 3.8 mm and parameter P is set as 0.09129 mm. The pitch of lenticular lens 1 is 10.0 mm. The best viewing distance is 800 mm and the viewing angle is $\pm 30^\circ$. The frame rate of the camera is 60 Hz and the resolution is 640×480. The detection algorithm takes less than 1/60 s to process each frame. The eye position data is sent to the FPGA by the cluster communication port (COM). The baud rate is set as 115200 bps.

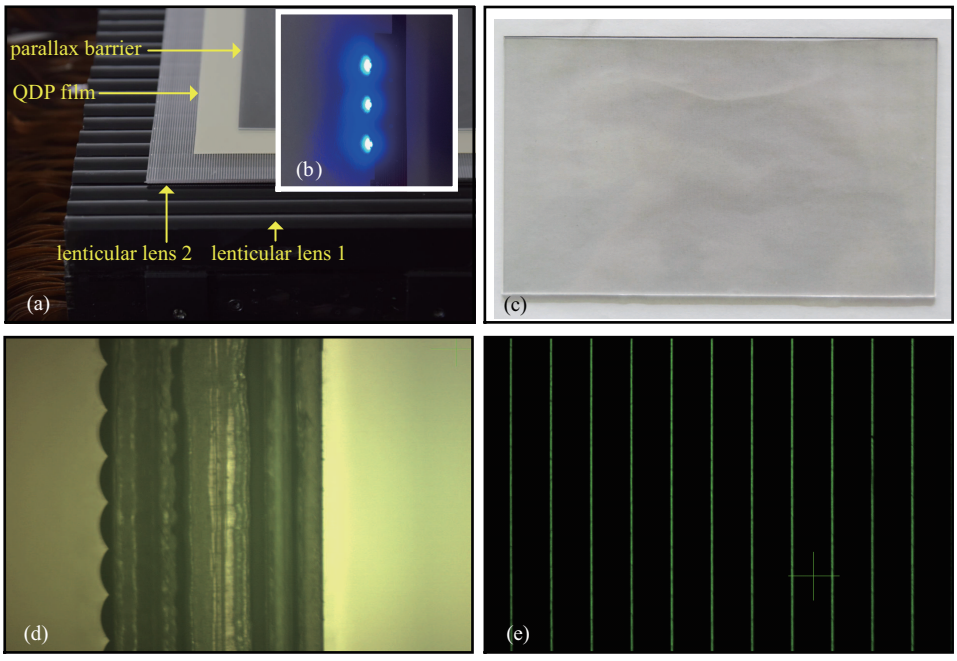


Fig. 6. Components used in this prototype. (a) The directional optical module. (b) The blue LED which is turned on. (c) The lenticular lens 1. (d) The lenticular lens 2. (e) The parallax barrier.

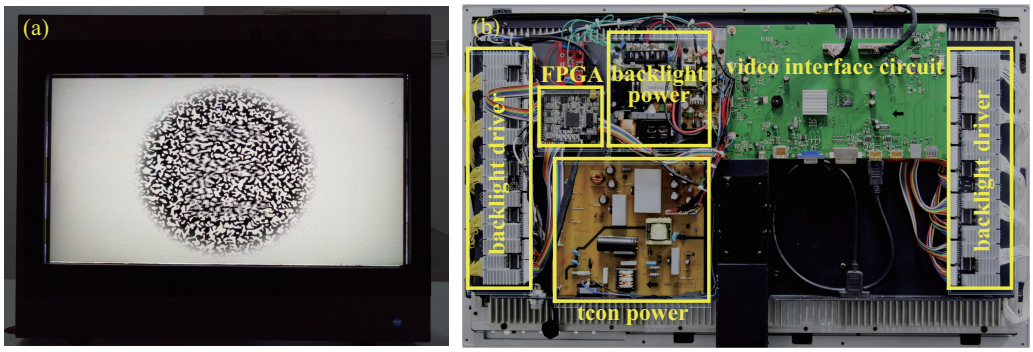


Fig. 7. The front and rear pictures of the device. (a) The assembled display. (b) The internal circuit diagram of the device.

Figure 7(a) shows the front picture of the prototype which is working in 2D mode. Figure 7(b) shows the internal circuits used in the prototype. In order to drive so many LEDs, two backlight driver circuits are applied in this device. The integrated circuit driver chip used in this system is a 16-bit constant-current sink driver. The output current can be adjusted from 5 mA to 120 mA by an external resistor. The aluminum radiators are fixed on the circuits to dissipate heat.

3.2. Results and discussion

3.2.1. The crosstalk in spatial-sequential mode

The viewing experience of 3D displays is influenced by the crosstalk. Generally, the ratio from the unexpected rays can be used to quantify the 3D image quality, and the crosstalk ratio (CR) of the n-th view zone in N viewing zones case is defined as[16]

$$\mathrm{CR}_n = \frac{\sum_{j=1, j\neq n}^{N} \text{light intensity}_{(j)}}{\sum_{j=1}^{N} \text{light intensity}_{(j)}}. \tag{3}$$

As shown in Fig. 8, when the LCD panel shows the left image (frame N), the left exit pupil is formed by the directional backlight. When the LCD panel shows the right image (frame $N+1$), the right exit pupil is formed. It is not accurate to measure only one point at the exit pupil. Hence, the display color analyzer (CA-310: manufactured by KONIC MINOLTA) is applied to measure the light distribution of the exit pupil at the viewing distance.

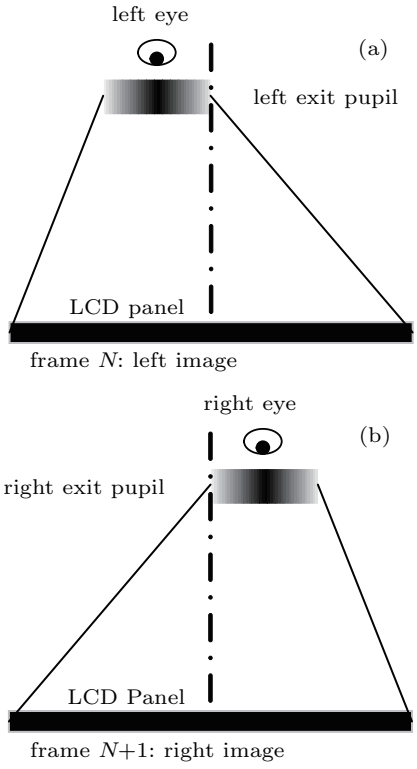


Fig. 8. The formation of (a) the left exit pupil and (b) the right exit pupil.

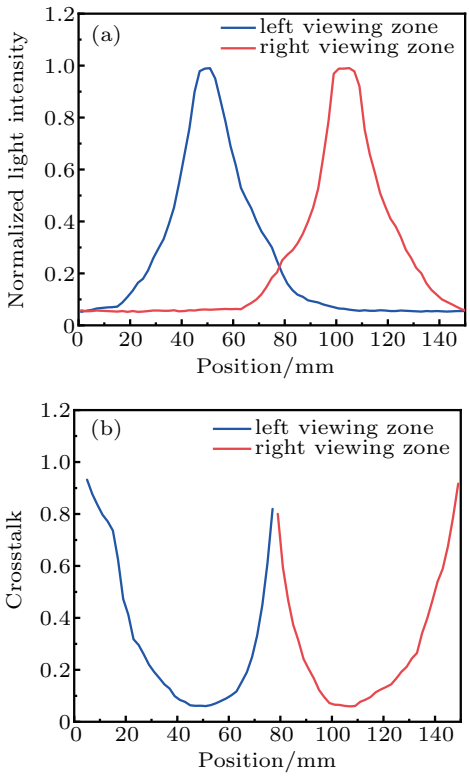


Fig. 9. (a) Normalized light intensity in the viewing zones. (b) The crosstalk in spatial-sequential mode.

The normalized light intensity is shown in Fig. 9(a). The left viewing zone is represented by the blue line and the right viewing zone is represented by the red line. The distance between the left viewing zone and the right viewing zone is about 60 mm, which is equivalent to the distance between human eyes. According to Eq. (3), the crosstalk is calculated, as shown in Fig. 9(b). The minimal crosstalk is about 6%.

3.2.2. The crosstalk in time-multiplexed mode

Figure 10 is used to explain the crosstalk in time-multiplexed mode. As shown in Fig. 10(a), the left image is pure white and the right image is pure black. As an example, the light leakage from the left image to the right eye increases the crosstalk.

The crosstalk of our prototype in time-multiplexed mode can be defined as follows:[17–20]

$$\text{left eyes} : (BW - BB)/(WB - BB), \tag{4}$$

$$\text{right eyes} : (WB - BB)/(BW - BB). \tag{5}$$

Here WB represents that the pure white image (255, 255, 255) for viewer's left eye and pure black image (0, 0, 0) for the viewer's right eye are displayed alternately on the screen. BW represents that the pure black image for viewer's left eye and pure white image for the viewer's right eye are displayed alternately on the screen. BB represents that the images displayed on the screen for the left and right eyes are both pure black.

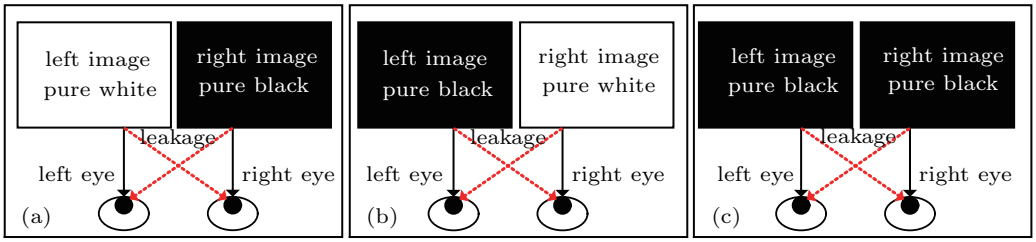


Fig. 10. (a) The light leakage when the left image is pure white and the right image is pure black. (b) The light leakage when the left image is pure black and the right image is pure white. (c) The light leakage when both images are pure black.

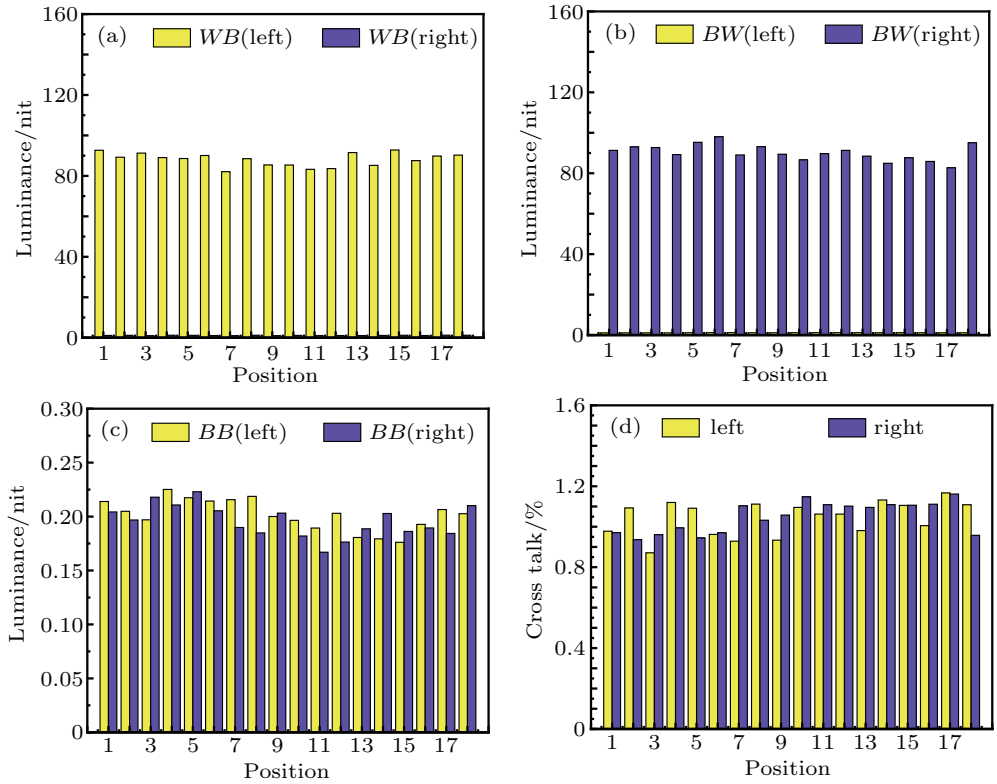


Fig. 11. Brightness through the left and right switching lenses of the active shutter glasses recorded when the panel displays (a) WB, (b) BW, and (c) BB. (d) The crosstalk of our time-multiplexed stereoscopic display.

Because of the dynamic scanning backlight, the spatial-sequential device can also be used in the time-multiplexed mode. We set up 18 equal interval measurement points from top to bottom on the LCD panel. When the LCD displays WB or BW, the brightness through the left switching lens (or right switching lens) of the active shutter glasses is about 80.00 nit, as shown in Figs. 11(a) and 11(b). When the LCD displays BB, the brightness through the left switching lens (or right switch-

ing lens) is about 0.2 nit, as shown in Fig. 11(c). According to Eqs. (4) and (5), the crosstalk can be calculated and shown in Fig. 11(d). In addition, the crosstalk of commercial displays (BENQ XL2707-B and View Sonic VX2268WM) is measured under the same condition. The crosstalk of the commercial displays is 1% (BENQ XL2707-B) and 1.4% (View Sonic VX2268WM). The brightness through the switching lens is about 50 nit when the LCD displays the WB or BW.

3.2.3. Measurement of 3D images

The schematic diagram of the measuring device is shown in Fig. 12. Perspectives observed at different positions are recorded by a camera (Nikon D3300, exposure parameter: f/2.2, ISO-160, 1/33 s), as shown in Figs. 13(a)–13(l). The enlarged pictures in Figs. 12(f) and 12(g) indicate that the left and right images have little parallax. When the left eye is in the viewing zone shown in Fig. 12(f) and the right eye is in the viewing zone shown in Fig. 12(g), the viewer will enjoy good 3D experience.

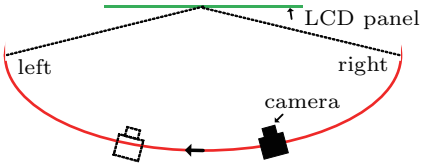


Fig. 12. Schematic diagram of the measuring device.



Fig. 13. (a)–(l) Perspectives observed from right to left.

3.2.4. Measurement of signal synchronization

Both the FPGA and the LCD panel receive the vertical synchronization signal simultaneously from the display card. As shown in Fig. 14(a), the duty cycle of the vertical synchronization signal is 50% and the period (t_p) is 1/60 s. When the vertical synchronization signal is sent out, the LCD panel starts to refresh the pixels on the top of the panel. For example, when the pixels on the top of the panel complete the transition from the last frame to a new frame, a low pulse (t_d) is sent from the FPGA and the blue LEDs in the corresponding area are turned on. The blue LEDs in the first row are turned on at t_0 and blue LEDs in the second row are turned on at t_1. The time delay between two adjacent LED rows is very short. To observe the time delay more obviously, the backlight control signal 0 and backlight control signal 12 are measured, as shown in Fig. 14(b).

The scanning backlight, LCD panel, and active shutter glasses could work interactively and be controlled by the vertical synchronization signal transmitted from the display card. The vertical synchronization signal and the active shutter glasses control signal can be seen in Fig. 14(a). When the internal control circuit of the shutter glasses receives the vertical synchronization signal, the shutter glasses control signal is generated to drive the switching lens (8.3 ms low pulse). To avoid the polarization of the liquid crystal, the control signal of the switching lens changes periodically around the reference value.

3.2.5. Measurement of the color gamut

In our prototype, the traditional white LEDs backlight module is replaced by the QD backlight which utilizes blue LEDs and QDP film. CA310 is used to measure the color coordinates of nine measuring points. The distribution of the nine measuring points is shown in Fig. 16(e). The color coordinates of the commercial 3D displays (BENQ XL2707-B and View Sonic VX2268WM) are also measured as the control group. The results are listed in Table 2.

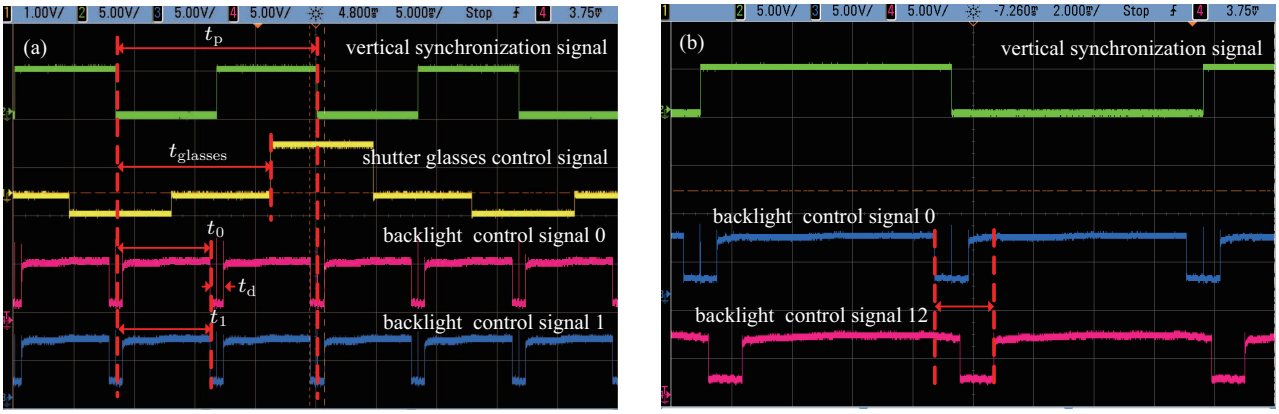


Fig. 14. The vertical synchronization signal, backlight control signals, and shutter glasses control signal. (a) The vertical synchronization signal, backlight control signal 0, backlight control signal 1, and shutter glasses control signal. (b) The backlight control signal 0 and backlight control signal 12.

Table 2. Display characteristics.

	Our prototype						BENQ XL2707-B						View Sonic VX2268WM					
	R_x	R_y	G_x	G_y	B_x	B_y	R_x	R_y	G_x	G_y	B_x	B_y	R_x	R_y	G_x	G_y	B_x	B_y
1	0.6776	0.2981	0.2137	0.6995	0.1439	0.0445	0.6375	0.3472	0.3172	0.6314	0.1439	0.0482	0.6440	0.3392	0.2809	0.6034	0.1433	0.0677
2	0.6762	0.2984	0.2153	0.7019	0.1431	0.0423	0.6383	0.3471	0.3163	0.6312	0.1438	0.0483	0.6435	0.3390	0.2809	0.6025	0.1436	0.0677
3	0.6779	0.2997	0.2180	0.7016	0.1432	0.0437	0.6374	0.3462	0.3154	0.6299	0.1435	0.0478	0.6448	0.3398	0.2829	0.6049	0.1434	0.0696
4	0.6765	0.2980	0.2149	0.6983	0.1438	0.0456	0.6389	0.3477	0.3177	0.6301	0.1441	0.0482	0.6451	0.3396	0.2822	0.6051	0.1434	0.0693
5	0.6758	0.2985	0.2164	0.7017	0.1436	0.0442	0.6383	0.3479	0.3172	0.6289	0.1438	0.0474	0.6437	0.3400	0.2823	0.6031	0.1438	0.0691
6	0.6764	0.2992	0.2182	0.7009	0.1434	0.0456	0.6369	0.3471	0.3167	0.6299	0.1436	0.0472	0.6457	0.3402	0.2841	0.6067	0.1438	0.0722
7	0.6744	0.2982	0.2120	0.6977	0.1439	0.0426	0.6379	0.347	0.3162	0.6301	0.1442	0.049	0.6437	0.3404	0.2821	0.6043	0.1432	0.0685
8	0.6768	0.2989	0.2168	0.7002	0.1434	0.0424	0.6385	0.3471	0.3158	0.6312	0.1438	0.0481	0.6431	0.3401	0.2825	0.6037	0.1435	0.0686
9	0.6758	0.2988	0.2189	0.6998	0.1438	0.0439	0.6389	0.3476	0.3168	0.6291	0.1429	0.0479	0.6445	0.3402	0.2836	0.6053	0.1434	0.0709

Various methods are used to express (diagram) the color gamut, but the common method used for display products is the *x*–*y* chromaticity diagram of the *XYZ* color system established by the International Commission on Illumination (CIE). In an *x*–*y* chromaticity diagram, the colors of the visible range are represented using numerical figures and graphed as color coordinates. The area shaped like an upside-down "U" surrounded by dotted lines indicates the range of colors visible to human beings with the naked eye. Various standards have been proposed to regulate how a display could reproduce colors, such as Rec.2020, sRGB, Adobe RGB, and NTSC. The color gamut defined by each standard is depicted as a triangle on the *x*–*y* chromaticity diagram. These triangles show the peak RGB coordinates connected by straight lines. A larger area inside a triangle is regarded to represent a standard capable of displaying more colors. As shown in Fig. 15, the color gamut of our time-multiplexed stereoscopic display is 77.98%. The color gamut of BENQ XL2707-B and View Sonic VX2268WM is 55.69% and 54.37%, respectively. The chromaticity coordinates of the reference white (D65) are (0.3127, 0.3290). The white coordinates of our prototype are (0.2612, 0.2497). The white coordinates of BENQ XL2707-B and View Sonic VX2268WM are (0.3077, 0.3215) and (0.3336, 0.3511), respectively. Due to the excellent optical properties of the QDP, the color gamut of our display is wider than the commercial displays.

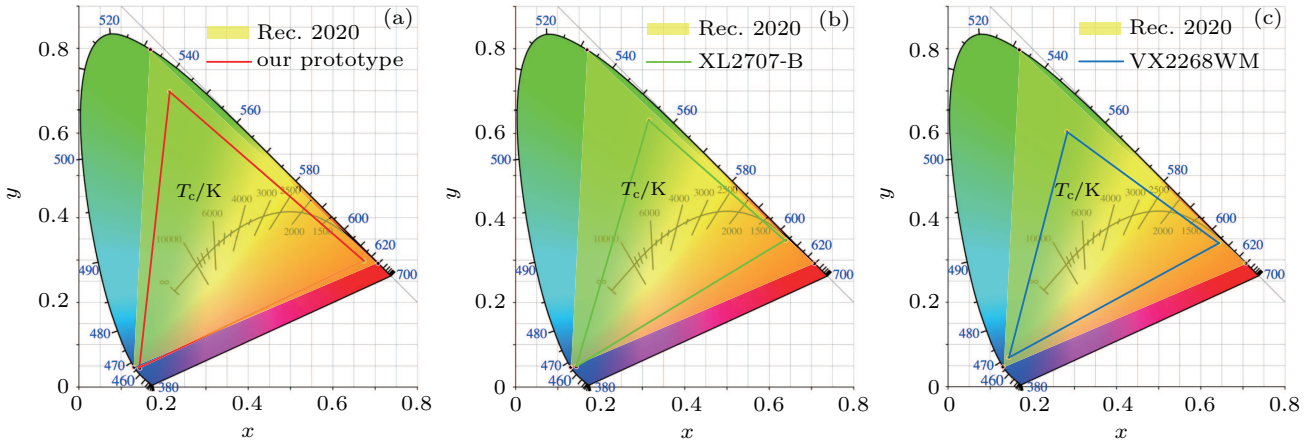


Fig. 15. The color gamut of (a) our prototype, (b) BENQ XL2707-B, and (c) View Sonic VX2268WM.

In our prototype, the traditional white LEDs backlight module is replaced by the QD backlight which utilizes blue LEDs and QDP film. The test images used in this experiment are shown in Figs. 16(a)–16(d). The detailed RGB information is also presented.

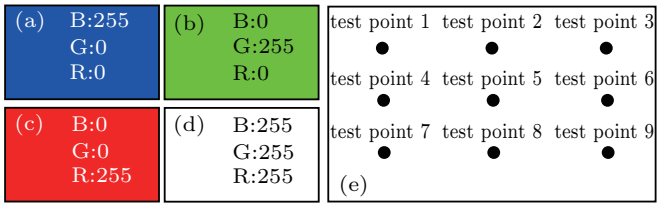


Fig. 16. (a) The pure blue image, (b) pure green image, (c) pure red image, and (d) pure white image for the test. (e) Nine measuring points.

When the different test images are displayed on the panel, the photos are recorded by the camera (Nikon D3300) with the same exposure parameter (f/5.6, ISO-100, 1/60 s). As shown in Fig. 17, limited by the performance of the camera, the recorded pictures do not represent the difference very well.

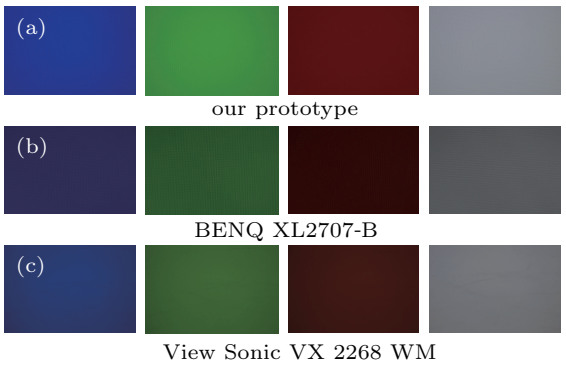


Fig. 17. The recorded photos when the different test images are displayed by (a) our prototype, (b) BENQ XL2707-B, and (c) View Sonic VX2268WM.

The QDP down-conversion efficiency, i.e., absolute photoluminescence quantum efficiency, of the QD-polymer films is measured to be 80% with a Horiba PTI Quanta Master 400 steady-state fluorescence system with an integrated sphere. The concentration ratio between the red and green QDs is about 1 : 4. The spectrums of the prototype are shown in Fig. 18.

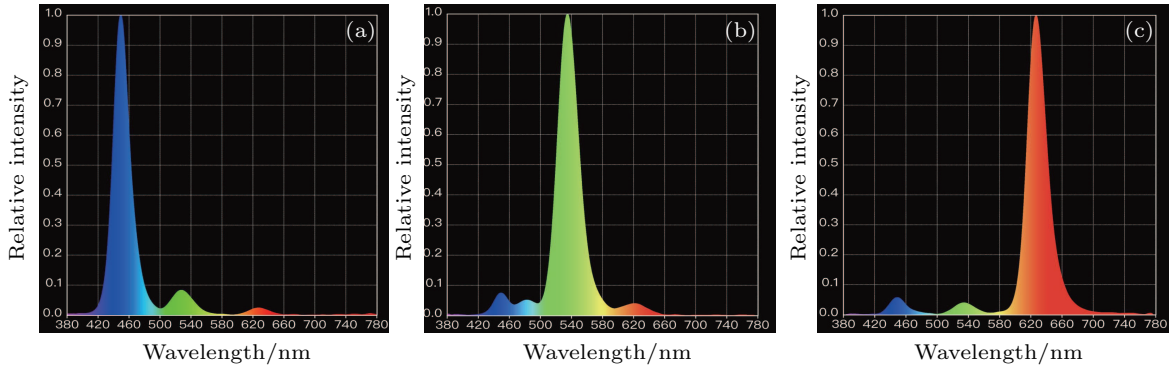


Fig. 18. Spectrums of the prototype when LCD is displaying (a) the pure blue image, (b) the pure green image, and (c) the pure red image.

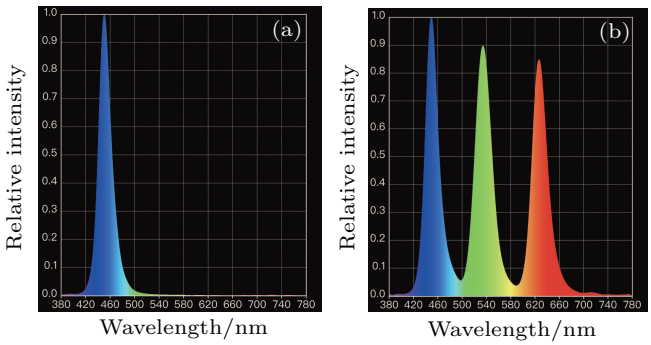


Fig. 19. (a) The spectrum of the blue LEDs used in the system. (b) The spectrum of the backlight.

4. Conclusion

A switchable autostereoscopic 3D display device with wide color gamut is introduced. A prototype is fabricated and some experiments are carried out to evalue the performances. Our prototype has advantages in resolution, crosstalk, color gamut, and switchable 2D/3D. In conjunction with a novel directional QD backlight and eye-tracking system, the viewer can enjoy the 3D experience with motion parallax. The system has two working modes. In the spatial-sequential mode, the crosstalk is about 6%. In the time-multiplexed mode, the viewer should wear active shutter glasses and the crosstalk is about 1%. Our system is completely compatible with the traditional active shutter glasses due to the dynamic scanning backlight. Compared with the commercial displays, our prototype also has the advantage in expressing colors.

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