A Novel Technology to Achieve 3D Polarized Stereoscopic Display Utilizing Glass Patterned Retarder

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Abstract
A novel technology named glass patterned retarder (GPR) to achieve 3D polarized stereoscopic display was proposed. A polymer liquid crystal (PLC) served as PR was generated in glass occupied with mark which can match the mark in 2D panel to ensure the position accuracy. A unique optical alignment (OA) technology of BOE was used to provide the ±45 ° UV polarized light needed for polyimide (PI) to control the alignment angle of PLC close to ±45 ° in odd and even rows. Therefore, a small 3D crosstalk has been achieved nearly 0.7%. Furthermore, BM was allowed to generate on glass and the wide of BM is adjustable. And a wide 3D vertical view angle of ±13 °and horizontal view angle of ±85 ° has achieved in 86 inch GPR, which is superior to glasses-free 3D. This new GPR 3D technology has received high recognition from customers.

Author Keywords
Glass patterned retarder (GPR); 3D stereoscopic display; 3D wide view angle; 3D crosstalk

1. Introduction
Nowadays, three-dimensional (3D) stereoscopic displays are expected to become more widespread attributing to provide a feeling of presence over traditional two-dimensional (2D) displays [1-3]. 3D display technologies, including binocular disparity, volumetric displays, holography, and light field displays, have been extensively researched for their ability to provide a real-world-like experience [4]. A crucial turning point for 3D movies was the successful release of the movie "Avatar" in 2009, leading to the commercialization of 3D movies at home through polarized glasses type (with patterned retarder, PR) or shutter glasses (SG) 3D TV products. PR 3D is widely applied in middle and high-end displays with the merit of slim glasses and flicker-free compared with SG [5-7].

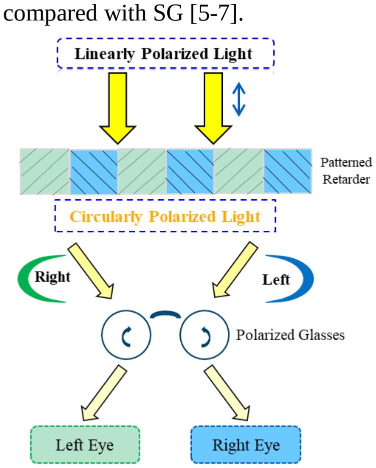

Figure 1. The principle of polarized 3D display.

Polarized glasses type 3D utilizes binocular disparity to achieve stereoscopic display, in which a patterned retarder (PR) is necessary. Fig. 1 illustrates the principle of polarized 3D display. The principle of polarized stereoscopic display is the display with PR which has different light polarization along vertical direction and transform linearly polarized light into left-handed and right-handed circularly polarized light to shows left and right images respectively. Patterned glasses help observer separate "left" and "right" images into left and right eyes and generate binocular disparity to obtain a 3D display in human brain.

3D crosstalk, defined as the image should be observed in left eye but be observed in both left and right eyes, as shown in Fig 2, is a key factor for quality evaluation of polarized stereoscopic image. 3D vertical view angle, another important indicator, will affect the 3D viewing experience directly. Traditional PR was generated in a film named FPR. 3D display can be enjoy by affix the FPR on a normal 2D display. However, it's hard to optimize the 3D vertical view angle of FPR, and the cost, service life and 3D display effect of FPR, especially the 3D crosstalk resulting from the alignment shift, shrinkage and position accuracy of film, were worrying.

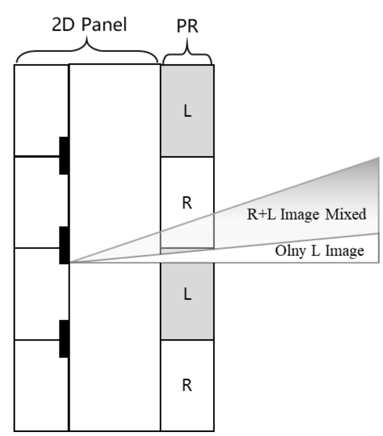

Figure 2. The scheme of 3D crosstalk

In this study, a new technology that the PR was generated in glass (GPR) to achieve 3D polarized stereoscopic display was proposed. PR was fix on glass by a unique process of optical alignment technology. We tested various methods to enhance the 3D view angle and reduce the 3D crosstalk. This new GPR 3D technology with a wide 3D view angle and small 3D crosstalk has received high recognition from customers.

2. Experiment
The function of GPR to transform the linearly polarized light into

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circularly polarized light need the help of a retarder with different alignment angles of ±45 °in odd and even rows on the surface of glass. Generally, liquid crystal (LC) can serve as a retarder. What we need to consider is how to fix the alignment angles of LC in ±45 °.

2.1 Polyimide

Fortunately, we found a polyimide (PI) which can complete the ±45 ° alignment under the UV polarized light with ±45 °. As shown in Fig 3, PI will fix the polymer liquid crystal (PLC) alignment in the direction perpendicular to UV polarized light. What we need to do next is to protect this alignment of PLC by UV curing.

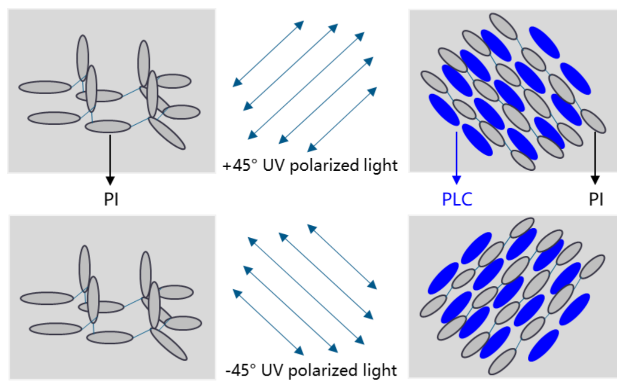

Figure 3. The scheme of PI alignment.

2.2 Optical alignment

Double rotation exposure method, a unique optical alignment (OA) process of BOE, was used to provide the ±45 °UV polarized light needed for PI. As shown in Fig 4, the wire grid polarizer (WGP) with ±45 °can change the natural light into ±45 ° UV polarized light, which align the PI in 45 °(blue line) and -45 °(red line). Besides, asahikasei photosensitive resin (APR) with pattern A (open) and pattern B (close) is needed to control the UV polarized light illuminate uniformly in a fixed area of the glass. Last but not least, black matrix (BM) will be pre coated onto the glass substrate to guide the UV polarized light move in a right direction.

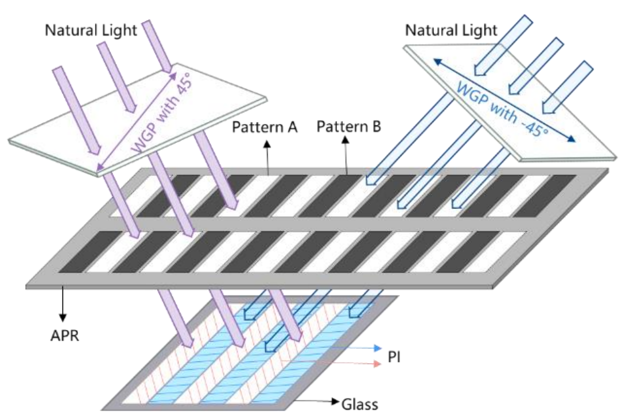

Figure 4. The scheme of double rotation exposure method.

2.3 Process flow

In addition to the BM, PI, OA, PLC and UV curing mentioned above, the production of GPR also requires an ITO layer to prevent electrostatic discharge and an OC protective layer. The process flowchart and sections chart of GPR are shown in Fig 5.

The summary of process flow was performed as follows:

(1) BM was generated on bare glass with a BM mask;

(2) ITO layer was coating on total area of the glass with BM;

(3) PI layer was coating on ITO and aligned using WGP by UV OA after baked;

(4) PLC layer was coating on PI, and was baked and cured by UV;

(5) OC protective layer was coating on PLC.

Then the GPR production was finished.

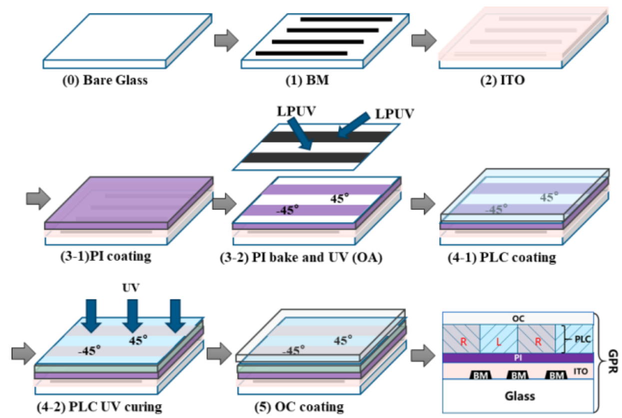

Figure 5. Process flowchart for GPR production.

3. Results and discussion

3.1 3D crosstalk optimize

It is easy for 3D crosstalk to be influenced by the position accuracy between the 2D panel and PR and the alignment accuracy of PR. Therefore, a new technology named glass patterned retarder (GPR) is proposed to overcoming these issues mentioned above.

First, an advantage of the GPR is the PR was generated in a glass occupied with mark which can match the mark in 2D panel to ensure the position accuracy between the 2D panel and GPR. As shown in Fig 6, the GPR mark (yellow cross) can be enclose in 2D panel mark (white cross), which can increase the position accuracy between the 2D panel and GPR significantly and reduce the 3D crosstalk. For example, the position accuracy of 86 and 31.5 inch GPR can be control in ±50um and ±30um respectively.

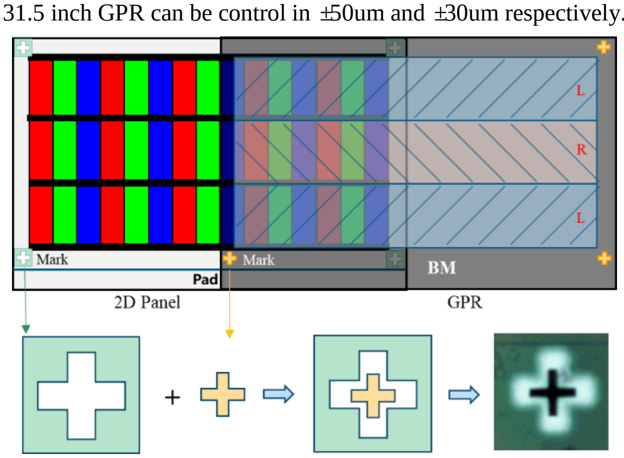

Figure 6. The scheme of mark in 2D panel and GPR.

Besides, we use optical alignment to ensure the alignment angle of PLC. Before the working for alignment accuracy, we chose three different retardation of PLC, low retardation (L-R) of 124nm, middle retardation (M-R) of 132nm and high retardation (H-R) of 141nm, to verify the compatibility between GPR and commercialized polarized glasses. As shown in Fig 7, the 3D crosstalk was reduced significantly in L-R group compared to H-R group, but there is little difference between L-R and M-R group. Therefore, 124nm retardation of PLC was used in next experiment.

As is known to all, the closer the alignment angle of PLC is to 45 °, the smaller the 3D crosstalk. However, we have to attempt several times to control the alignment angle of PLC due to the WGP is close to its service life. What we can see in Table 1 is the 3D crosstalk has reduced to 1.0% when the alignment angle of PLC is ±44 °. Furthermore, the standard linearly polarized light also attributes to reduce the 3D crosstalk. We found the phase difference of POL, used in 2D panel to generate linearly polarized light, affect the compatibility between linearly polarized light and GPR. Therefore, we change the high phase difference of PET POL into no phase difference of PMMA POL, which reduces the 3D crosstalk to 0.7%. After the new WGP used in GPR production, the alignment angle of PLC can be more nearly to 45 °, and we can definitely reduce the 3D crosstalk to a new lower level.

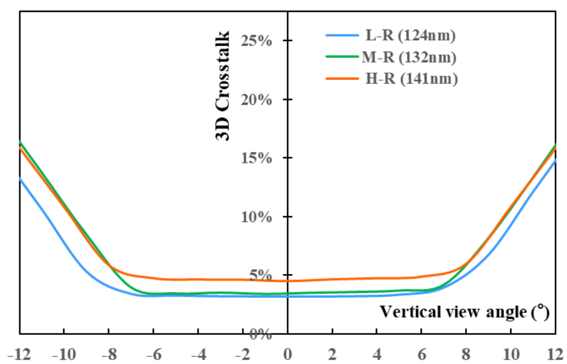

Figure 7. The 3D crosstalk with different thickness of PLC.

Table 1. 3D crosstalk in front view angle

PLC alignment angle	±37 °	±42 °	±44 °	±44 °
POL	PET	PET	PET	PMMA
3D Crosstalk	3.2%	2.0%	1.0%	**0.7%**

3.2 View angle design

3D vertical view angle, defined as the view angle when the 3D crosstalk is below 10%, is a key factor for quality evaluation of 3D polarized stereoscopic image. Many factors affecting 3D crosstalk have been reported, such as the wide of BM in 2D panel, the thickness and refraction index of glass substrate [8]. And the estimation method of 3D crosstalk has been proposed as well.

In this study, GPR was pasted on 2D panel by OCA glue as shown in Fig 8. What we can see else is the 3D crosstalk is limited to the wide of BM in both 2D Panel (H) and GPR (h) and the total thickness (T), including the thickness of glass substrate, POL, OCA and PR layer in GPR. Thus, we adopt a simple method to calculate the 3D vertical view angle with 0% 3D crosstalk as follow.

$$\theta = tan^{-1}\frac{H+h}{2T}$$

Thus, the wide of BM and the total thickness will perform an important role.

The optimization of 3D vertical view angle and the optimization of crosstalk are carried out synchronously. Another advantage of GPR is the BM was allowed to generate on glass and the wide of BM is adjustable. At first, the wide of BM in GPR was 20um and the 3D vertical view angle was ±9.5 °. To optimize the 3D vertical view angle, the wide of BM in GPR was increased to 70um and the 3D vertical view angle was increased to ±12 ° as shown in Fig 9. Besides, 2D panel used in this study are mass product and purchase from Fuzhou BOE. What we can optimize is the thickness and substrate of POL. As mentioned above, the PET POL was replaced by PMMA POL with no phase difference and lower thickness of 123um. The 3D vertical view angle has been promoted to ±13 °.

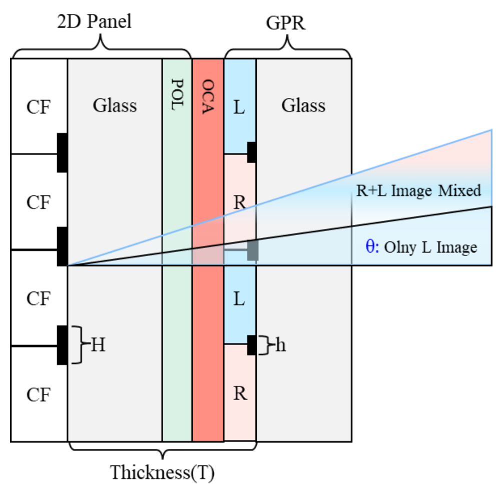

Figure 8. The 3D crosstalk scheme between 2D Panel and GPR.

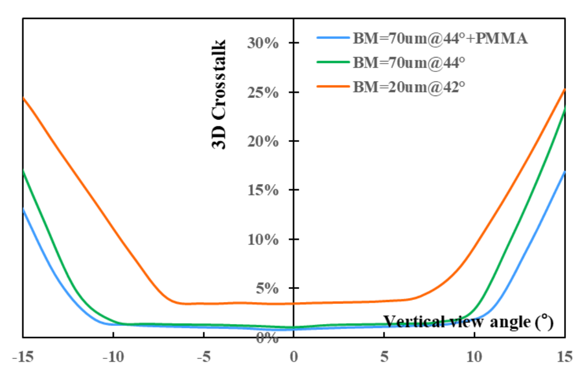

Figure 9. The 3D vertical view angle in different condition.

The 3D horizontal view angle has been promoted synchronously. A wide 3D horizontal view angle over ±85 ° has achieved if using the same definition of 3D vertical view angle, which convenient for many audiences, such as families or students, enjoy the 3D display at the same time.

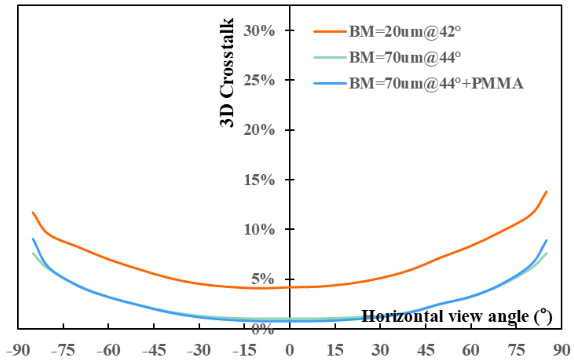

Figure 10. The 3D horizontal view angle in different condition.

At last but not lease, GPR can maintain the performance of 2D panel and won't affect the 2D display. As shown in Table 2, there is only a little lost in normal optical parameters, including transmittance (Tr.), contrast ratio (C.R.) and color gamut (C.G.).

Table 2. Normal 2D optical parameters

ITEM	2D Panel		2D Panel + GPR	
	1#	2#	1#	2#
White (nit)	890.4	884.9	888.8	882.9
Black (nit)	0.5343	0.5273	0.5650	0.5548
C.R.	1667	1678	1573	1591
Tr.	5.59%	5.56%	5.58%	5.55%
C. G. (DCI)	95.00%	94.90%	94.8%	94.60%

4. Conclusion

In this study, a new technology named GPR to realize 3D display was proposed. As shown in Fig 11, a small 3D crosstalk of 0.7% has achieved by control the phase difference of POL, the retardation and alignment angle of PLC, and the position accuracy between GPR and 2D panel. What's more, a wide 3D vertical view angle of ±13° and horizontal view angle of ±85° has achieved in 86 inch GPR by increasing the wide of BM in GPR, which is significantly superior to glasses-free 3D. This new GPR 3D technology has received high recognition from customers and will contribute to promote the application and popularization of 3D stereoscopic display.

Figure 11. The 3D display utilizing GPR.

5. References

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