A New Electrode Structure for Color-shift Reduction in PVA LCD

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Abstract

We introduce a new electrode structure for the patterned vertical alignment (PVA) mode, which has a lower color-shift at large viewing angle than the one-domain VA mode. By manipulating the period of electrode structure, we can make more multi-domains and use the existing fabrication processes without having to use additional materials.

Keywords : liquid crystal, PVA, color-shift

1. Introduction

Nowadays, there are higher demands for liquid crystal display (LCD) TVs including high resolution, light weight, slim size, and low power consumption. There have been, reports of problems in LCDs such as viewing angle and color shift at off-normal directions. To resolve these problems, several LC modes have been proposed including horizontal switching mode and film-compensated vertical aligned mode. Horizontal switching modes such as in-plane switching (IPS) and fringe-field switching (FFS) modes show wide viewing angle characteristics [1, 2]. They use a chevron-type electrode structure to enhance color-shift performance by making more domains [3,4]. Although horizontal switching modes show wide-viewing angle characteristics, they still have problems in realizing good dark state. On the other hand, film-compensated vertical aligned modes can not only demonstrate wide-viewing angle characteristics but also good dark state, which brings about high contrast ratio. To improve color-shift characteristics, several attempts have been made to make multi-domains in a pixel, such as multi-domain VA (MVA) mode and patterned VA (PVA) mode [5,6]. Recently, super-patterned vertical alignment (S-PVA) mode, where a pixel is divided into sub-pixels to make more multi-domains, has been developed to overcome the color-shift [7,8]. However, S-PVA mode requires additional materials and fabrication processes to induce different voltages to each sub-pixel: to control the tilt angle of each sub-pixel's LC directors. It needs more cost and complicated processes than the conventional PVA mode.

At the middle gray levels, a single-domain structure shows different light-transmission from viewing directions, resulting into color-shift problems. So, multi-domain structure was proposed to overcome this problem as shown in Fig. 1. In this paper, we suggest a new electrode structure for PVA mode which not only has more multi-domain effect than the conventional PVA mode but also uses the conventional fabrication processes and cost. By manipulating the period of the electrode in a pixel, we make more multi-domains in PVA electrode structure than the conventional one, resulting in effective reduction of color-shift problems in off-normal directions.

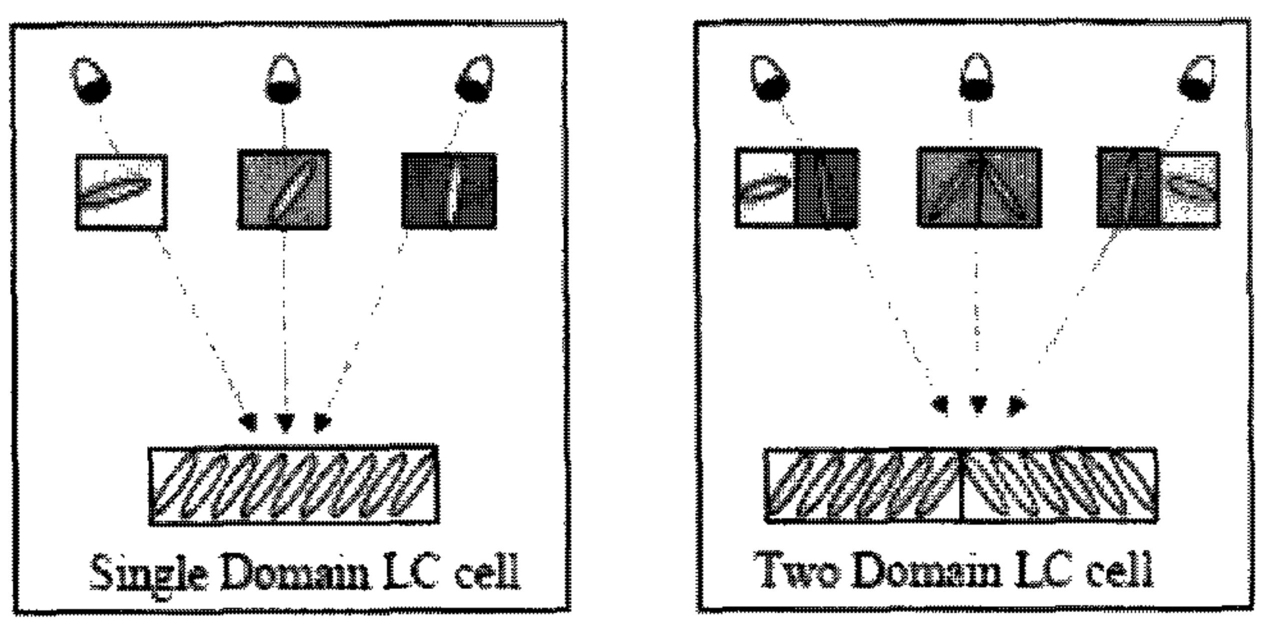

Fig. 1. Multi-domain effects in LCDs.

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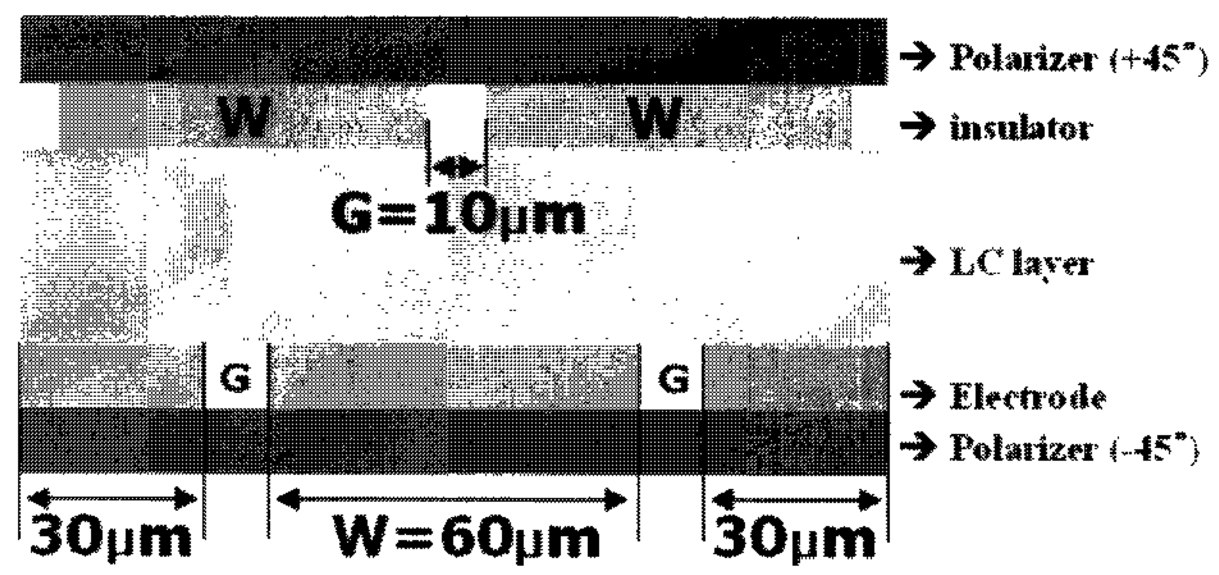
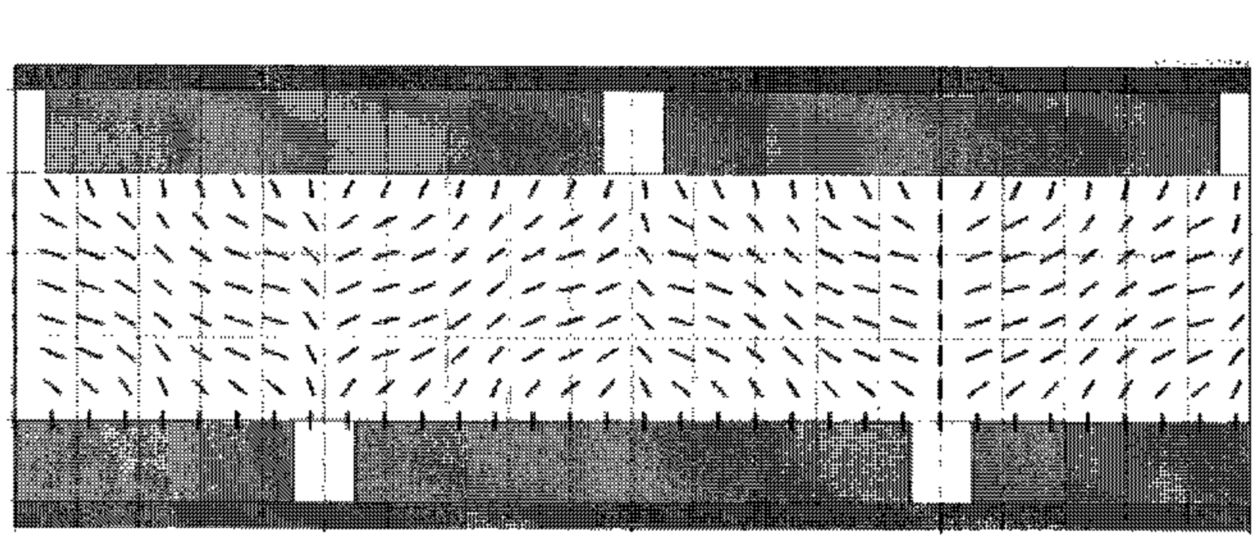
2. Configuration

PVA mode uses fringe field effect between up and down patterned electrodes, when applying voltage signals. The transmission axes of polarizers (TA) are made to cross each other, and LC (MDA-2306, Δn: 0.1204, Δε: -5, Merck Ltd.) layer is aligned vertically at the initial state between crossed polarizers. The cell gap is set by 3.4 μm. And, commercially available software, LCD MASTER, was used for numerical calculation. The overall structure is shown in Fig. 2(a) and the electrode width (W) and gap (G) of reference electrode structure is 60 μm and 10 μm, respectively. At the middle gray level, director profile of LC show a periodic and symmetric deformation due to the electric field of patterned electrodes as shown in Fig. 2(b). Yet, they still show color-shift problems in low gray levels. In order to make more domains, we suggest an electrode structure whose upper insulator width (G') and electrode width (W') of suggested structure is 20 μm and 55 μm as shown in Fig. 3, while holding bottom electrode width (W) and gap (G), same as those of the reference. The difference of the proposed electrode structure is expected to manipulate the period of multi-domains which come from changing electric fields between point Ⓐ and Ⓑ in Fig. 4.



(a)



(b)

Fig. 2. Electrode structure of PVA mode (a) electrode structure of the conventional PVA mode (b) multi-domains in PVA mode.

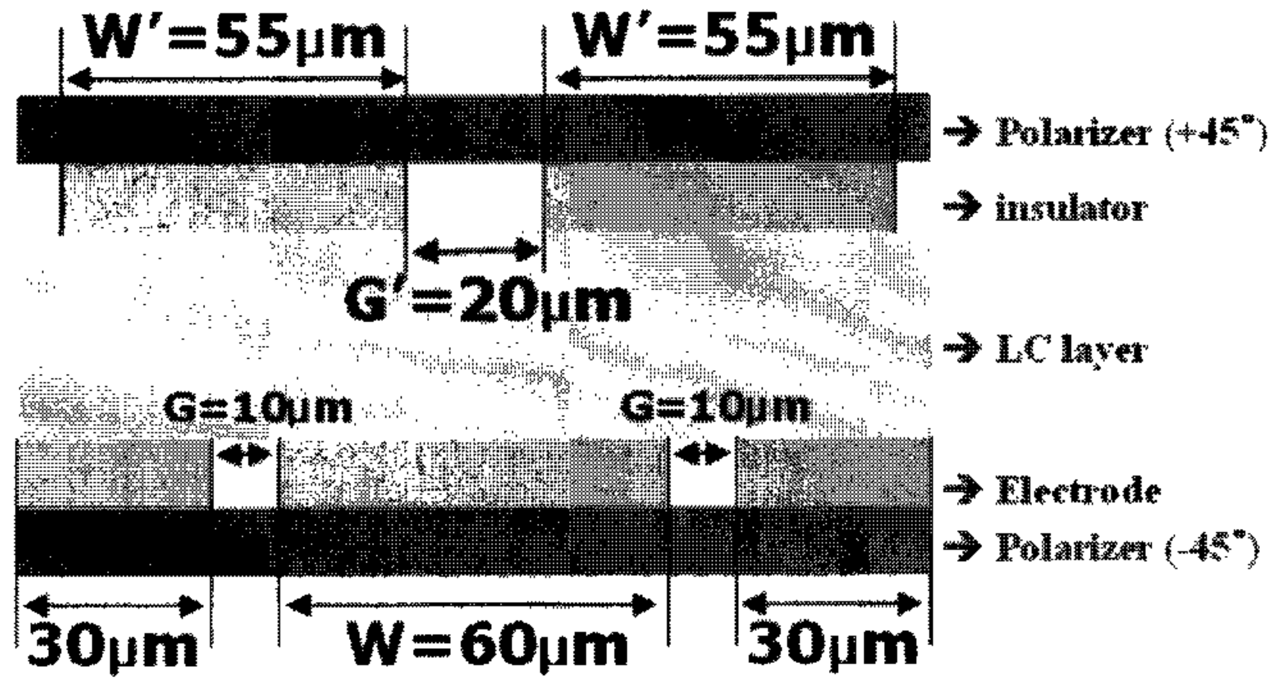


Fig. 3. Electrode structure of color-shift reduced PVA mode.

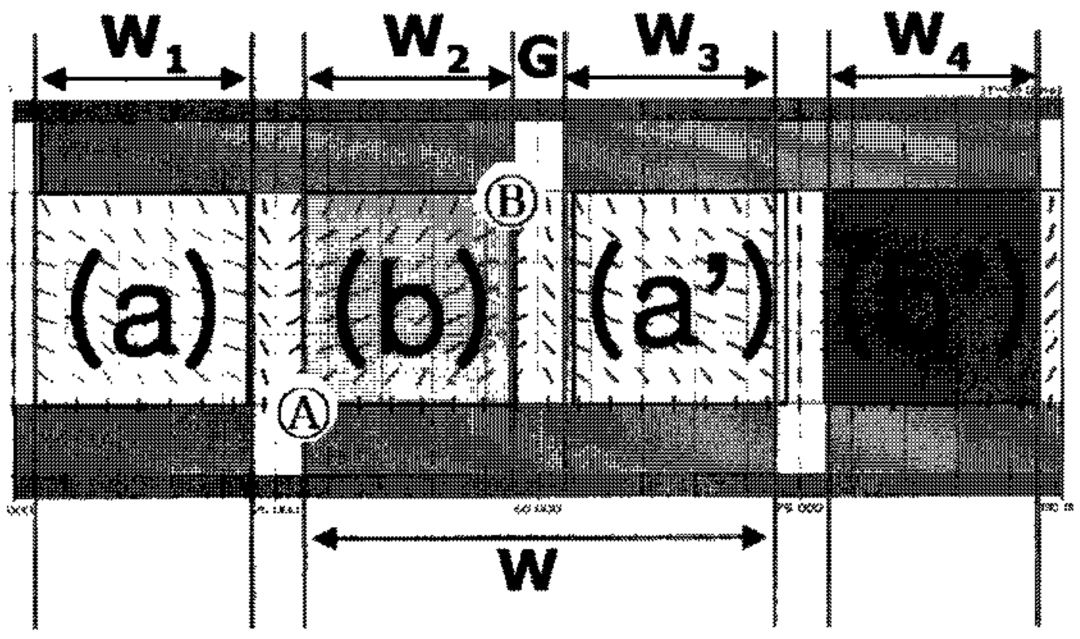


Fig. 4. Principle of making multi-domains in PVA mode.

Fig. 4 shows a principle of making more multi-domains in PVA mode. W_1, W_2, W_3, and W_4 represent the overlap region of up and down electrode. W_1 and W_2 has the same width as 25 μm in reference structure, whereas W_1 and W_2 in the proposed structure is 20 μm and 25 μm, respectively. Those different overlap widths of the proposed structure are attributed to the upper electrode gap (G) which is changed from 10 μm to 20 μm. So, the electric field between points Ⓐ and Ⓑ become different, and then the LC director has a different deformation tilt angle in regions (b) and (a') form those in regions (a) and (b') as shown in Fig. 4. Thus, the proposed structure can make more multi-domains than the reference one by manipulating the period of the electrode. Finally, the tilt angle of LC directors in the regions (a) and (a'), (b) and (b') has a different value, and then there are more domain effects at the proposed electrode structure than the reference one.

3. Results and discussion

We can see that there is less changes in the suggested electrode structure than the reference structure as shown in

Fig. 5, which is the color difference of the two electrode structures at 10% gray level. These results show that the color-shift of the suggested structure is reduced more than the reference one, because there are more multi-domains by changing upper electrode gap (G'). However, transmittance of these two electrode structures is quite different as shown in Fig. 6. Maximum transmittance of the reference and suggested electrode structure is 24.5% and 22.3%, respectively. In order to make more multi-domains, we increase the width of gaps between electrodes. Then, the z component of electric field becomes weak between the electrodes, so that LC directors can not move. This effect results in the decrease of maximum transmittance in the proposed structure.

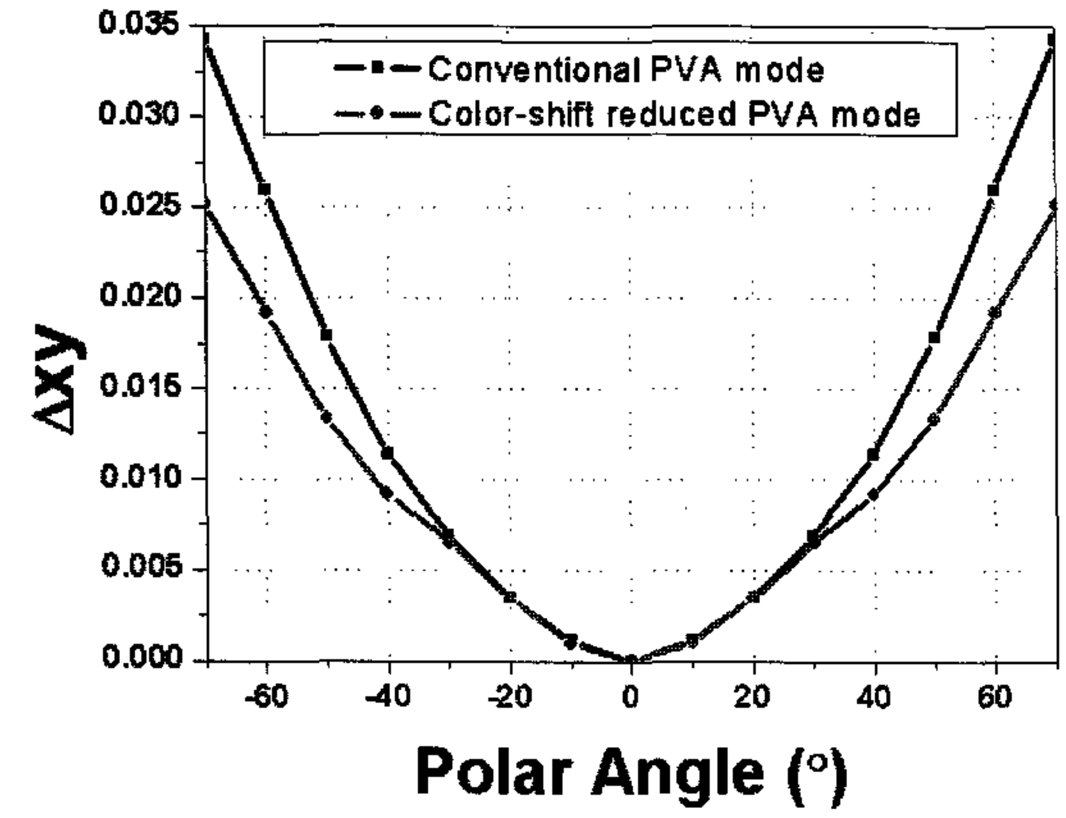


Fig. 5. Color difference of the conventional and color-shift reduced electrode structure at the 10% gray level.(Φ= 0°, θ= sweep). This graph shows that the color-shift of the proposed electrode structure is more reduced than the conventional one.

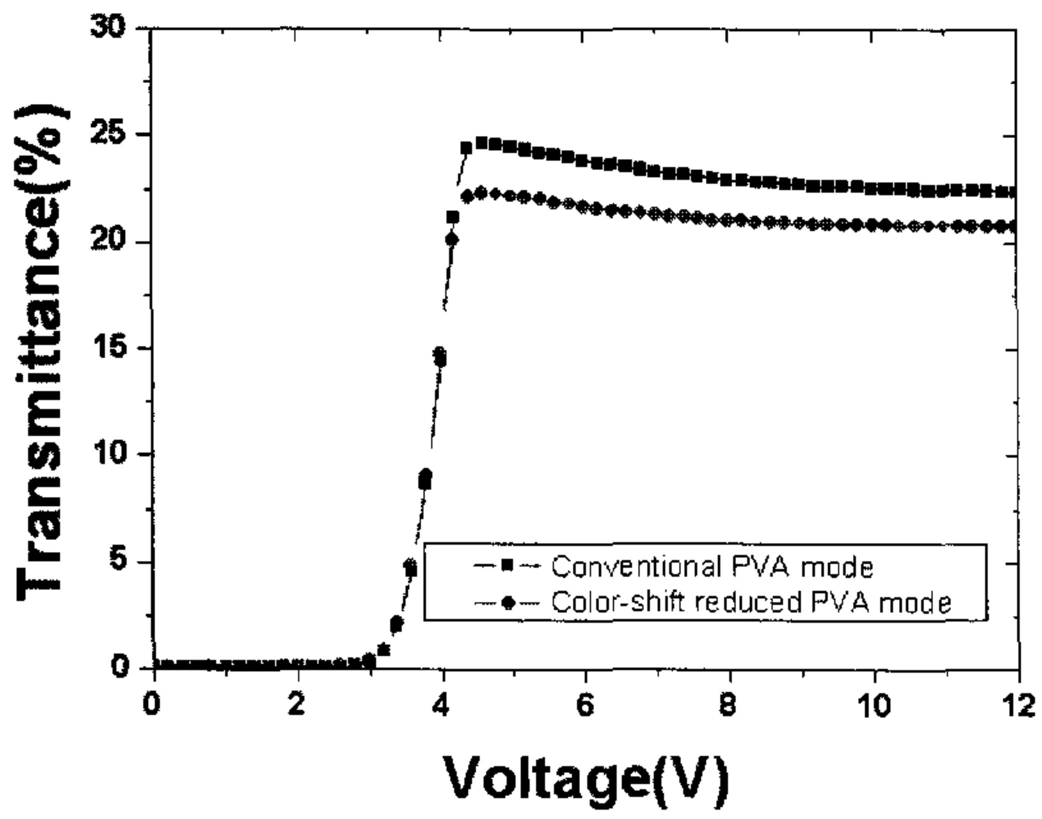


Fig. 6. Voltage-dependent light transmission of the conventional and color-shift reduced electrode structure. Due to the increasing width of gaps between electrodes, proposed electrode structure's transmittance is lower than the conventional one.

To overcome this problem, we propose another electrode structure to conserve the maximum transmittance and reduce the color-shift by using more domain effects. As shown in Fig. 7, the newly proposed structure has an upper additional electrode K (10 μm) which is intended to apply the vertical electric field to LC directors to enhance the transmittance. The transmittance of the newly suggested structure is shown in Fig. 8 and the maximum transmittance is 24.7%. Also, the color difference of the two electrode structures in Fig. 9 shows the color-shift reduction at the 10% gray level, viewed at the azimuth angle of 45° with respect to polarizer. That means the newly suggested electrode structure can make more multi-domains than the reference electrode structure, without reducing the light transmittance.

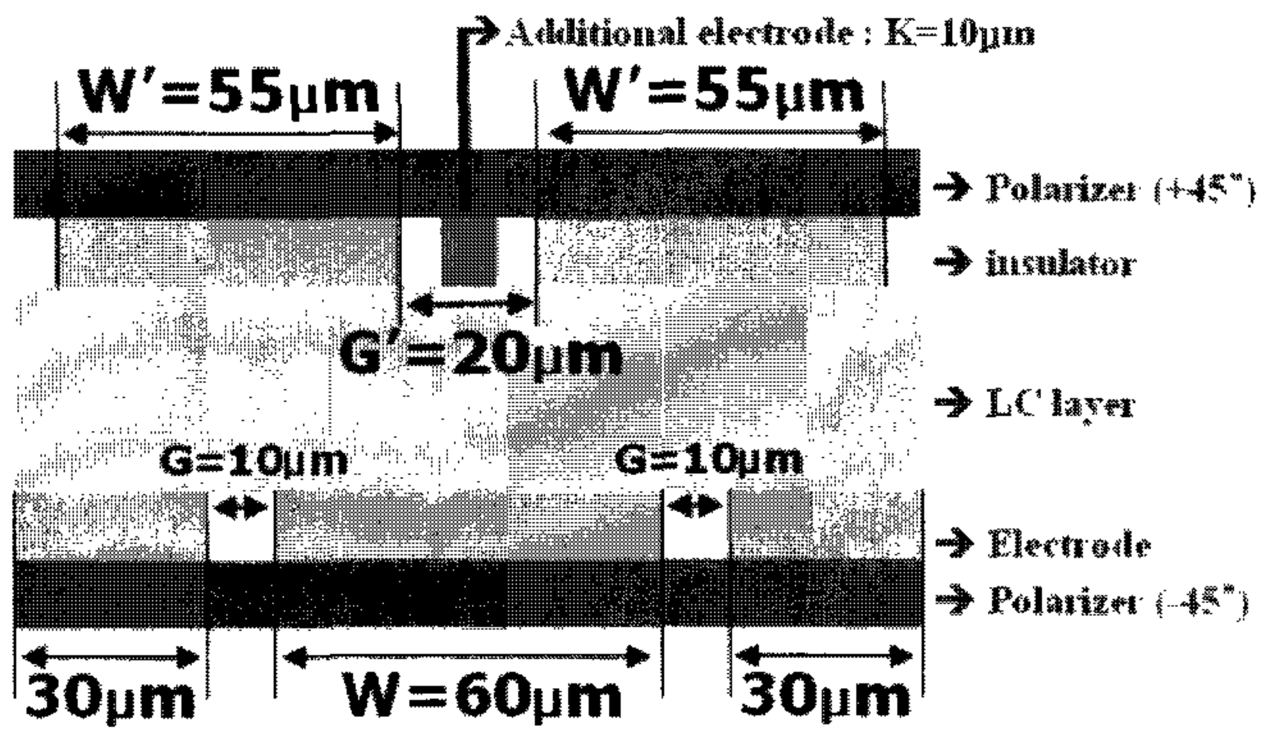


Fig. 7. Electrode structure of color-shift reduced PVA mode with an additional electrode.

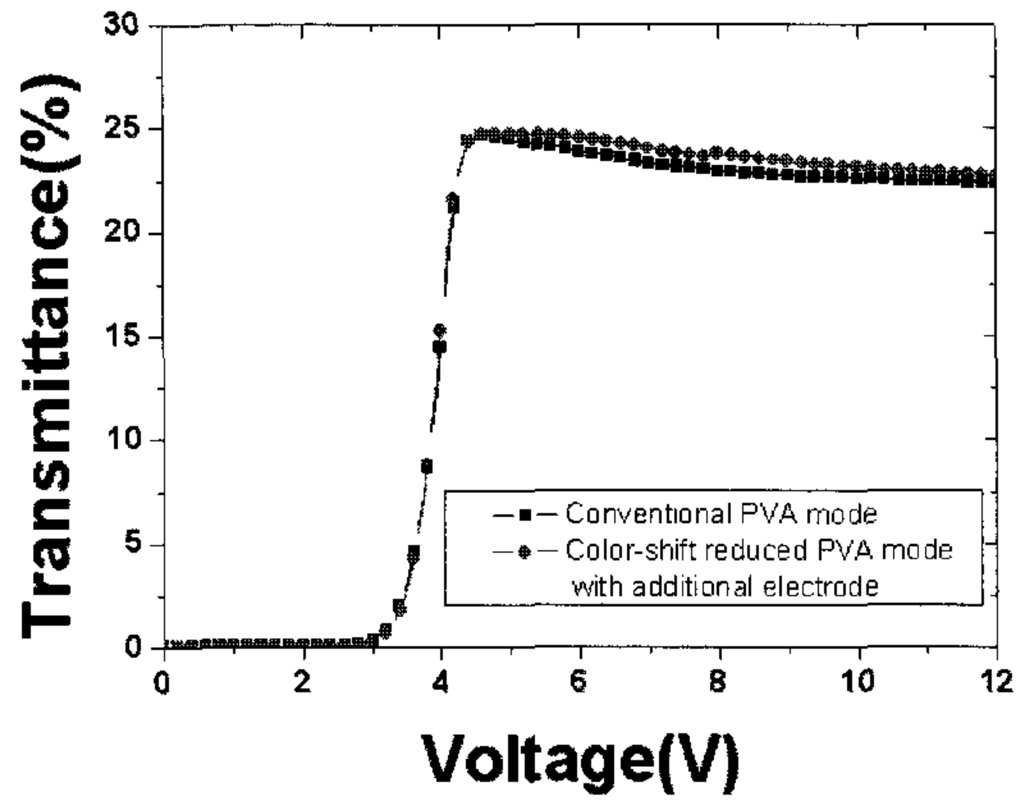


Fig. 8. Voltage-dependent light transmission of the conventional and color-shift reduced with additional electrode structure. Maximum transmittance of newly proposed structure with additional electrode is almost same compare with conventional one.

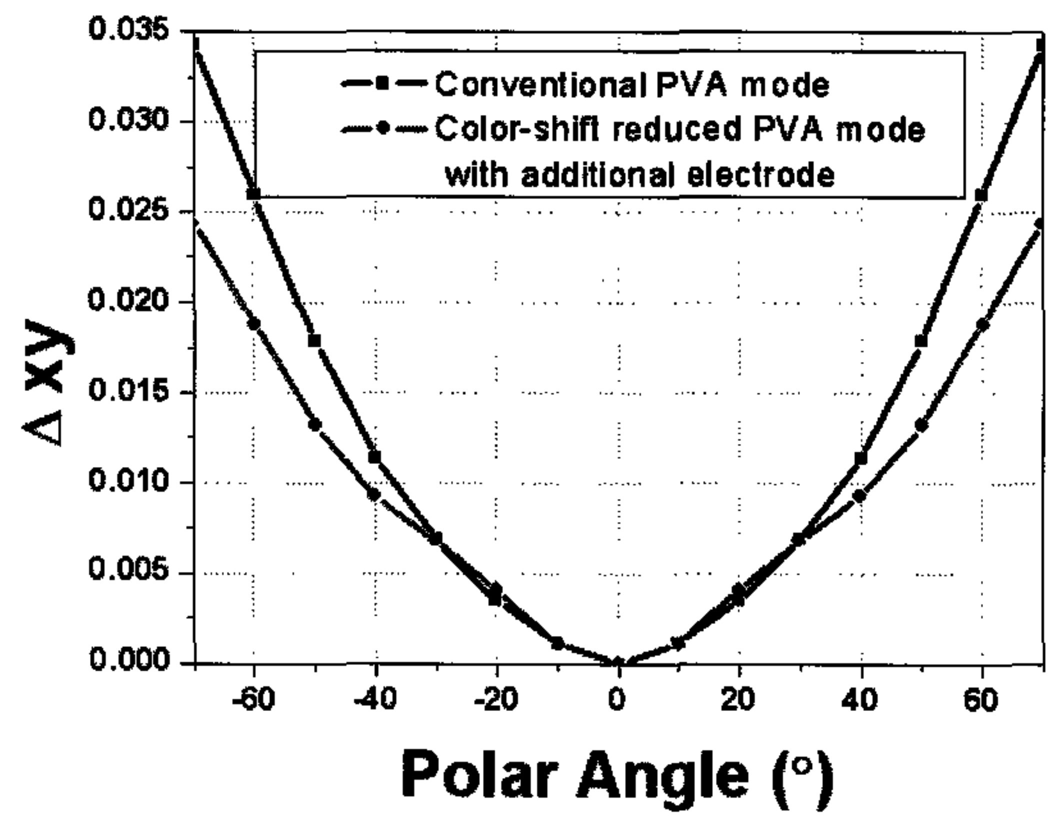


Fig. 9. Color difference of the conventional and color-shift reduced with additional electrode structure at the 10% gray level. (Φ= 0°, θ= sweep) This graph shows that the color-shift of the newly proposed structure with additional electrode is more reduced than the conventional one.

In order to confirm the result in the chevron electrode structure, we used 3-dimension software, Techwiz LCD. The reference and newly proposed electrodes have the same electrode width and gap described above, and we know that the color filter transmits about 25~30% of the incident light. So, the maximum transmittance of the reference and the newly proposed electrode structure is 4.86% and 5.09%, respectively, as shown in Fig. 10. Now, we look over the color-shift at the 10% gray level, as shown in Fig. 11. The color-shift result of reference structure shows over 0.03 value at the 70° polar angle. However, the result of newly suggested electrode structure shows less than 0.02 value overall polar angle limits in the Δu'v' coordinate system.

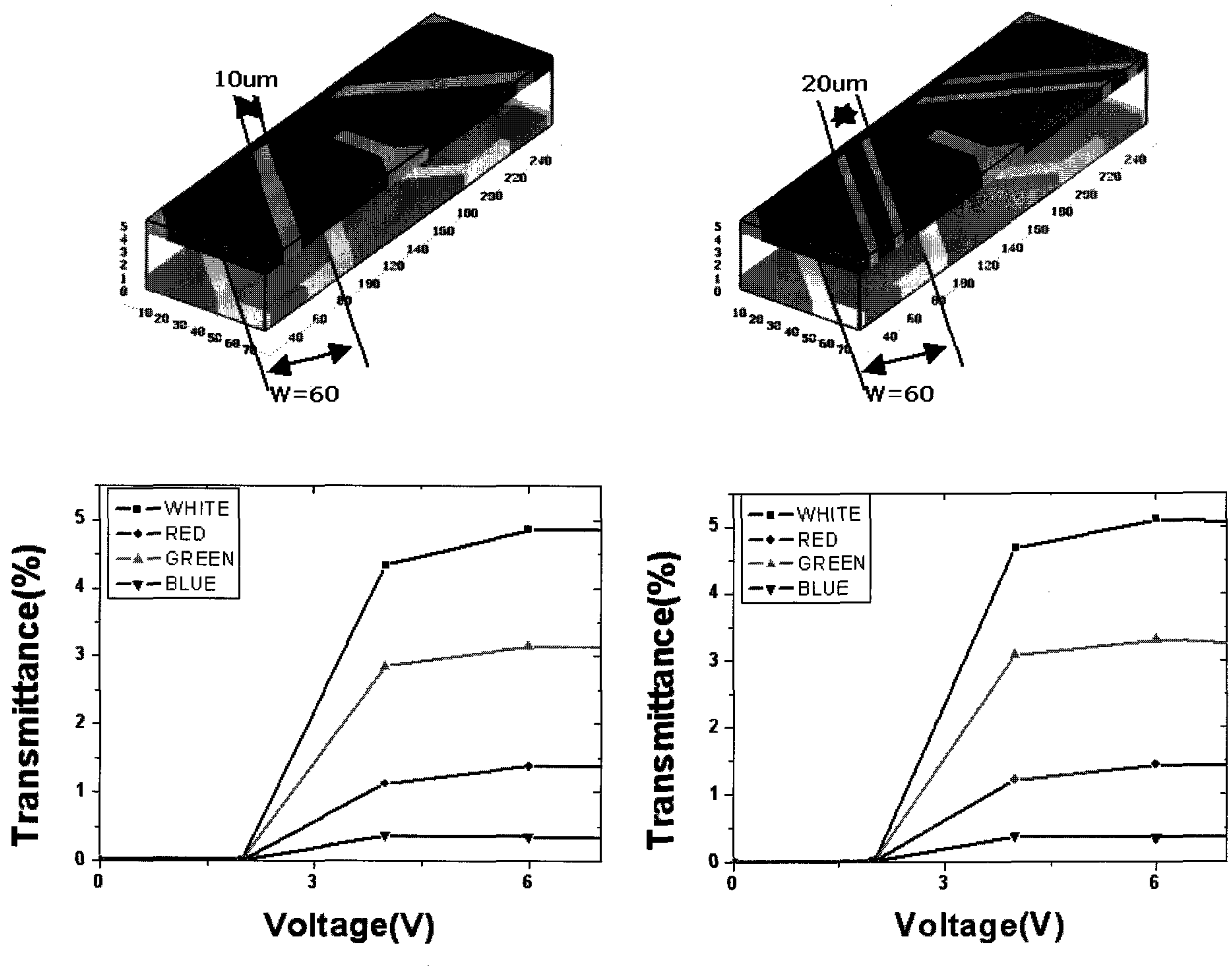
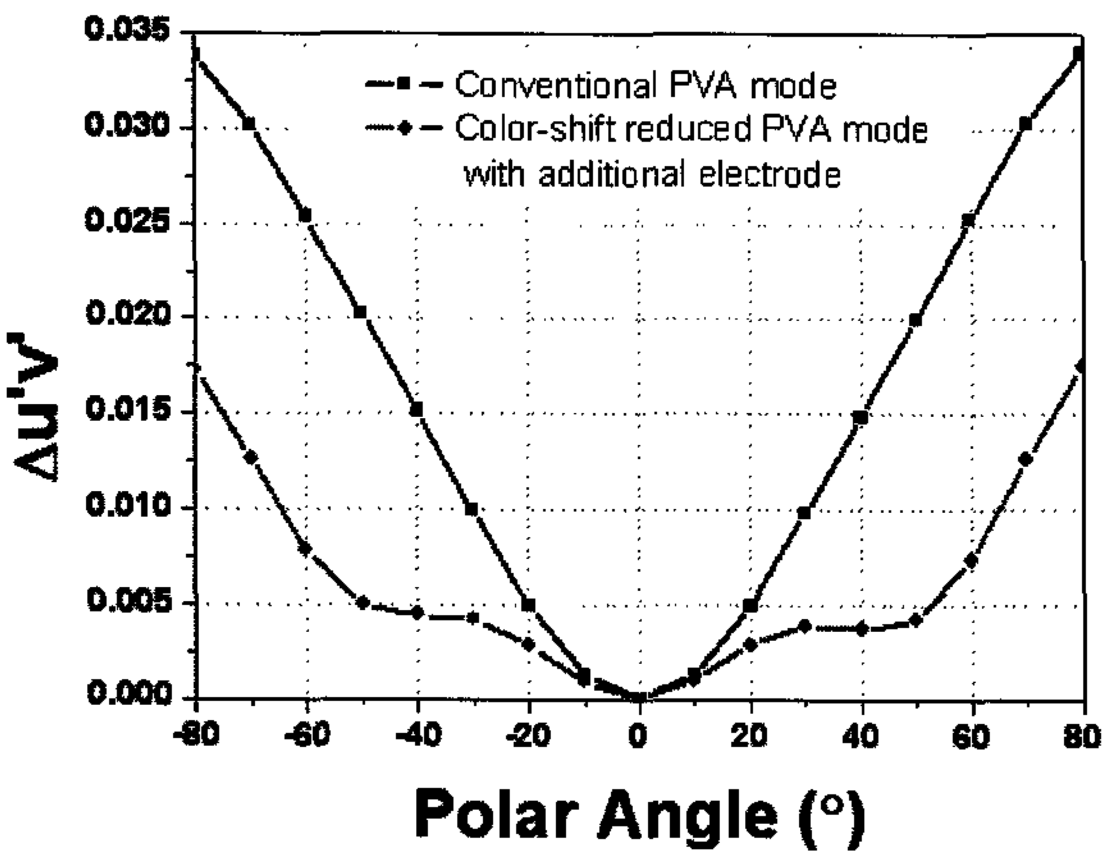
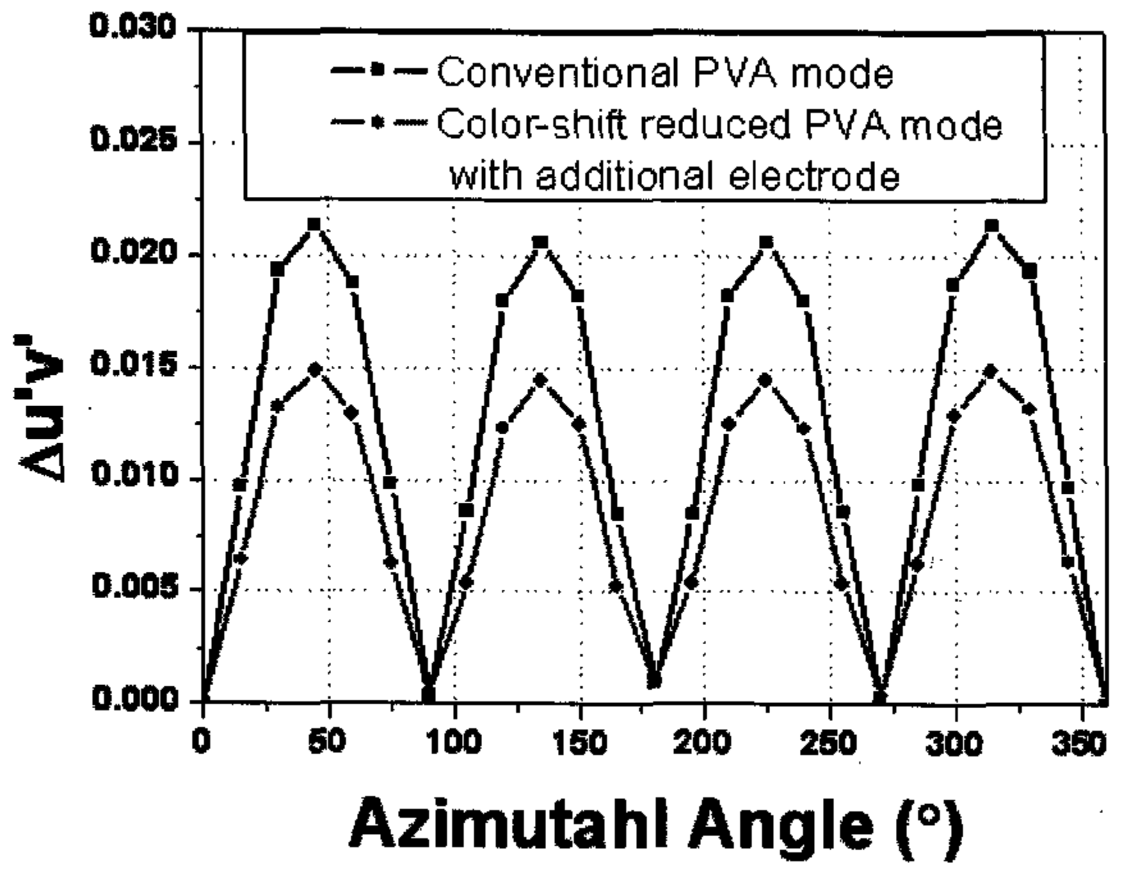


Fig. 10. Voltage-dependent light transmission of PVA modes (a) the conventional PVA (b) the color-shift reduced PVA mode with additional electrode.



(a)



(b)

Fig. 11. Color difference of the conventional and color-shift reduced with additional electrode structure at the 10% gray level (a) dependence on the polar angle (b) dependence on the azimuth angle. The 3-dimension results of newly proposed structure with additional electrode show that color-shift is more reduced than the conventional one overall polar and azimuthal angle.

4. Conclusions

We propose an electrode structure to reduce the color-shift problems in PVA LCD. By manipulating the period of electrode structure, we can make multi-domains in the proposed electrode structure. We can maintain the maximum transmittance and reduce the color-shift in PVA mode. Thus, we were able to use the existing fabrication processes without having to use additional materials.

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