# High Performance Azimuthally Continuous Nematic Domain Mode for TFT-LCD application

*Kwang-Soo Bae*[1]*, Jin Seog Gwag*[2]*, In-Young Han*[3]*, You-Jin Lee*[1]*, Min Young Jin*[2]*, and Jae-Hoon Kim*[1,2,3]
[1]Department of Information Display Engineering, Hanyang University, Seoul 133-791, Korea
[2]Research Institute of Information Display, Hanyang University, Seoul 133-791, Korea
[3]Department of Electronics and Computer Engineering, Hanyang University, Seoul 133-791, Korea
*TEL:82-2-2220-0343, e-mail: jhoon@hanyang.ac.kr.*

**Keywords : liquid crystal display, vertically aligned modes, high transmittance, wide viewing angle, color shift**

## Abstract

*We proposed azimuthally continuous nematic domain mode characterized by a cone field induced from patterned electrode structure with a circular slit. This mode has good optical performances such as higher transmittance and wider viewing angle through decreasing the demerits caused by domain walls. We could confirm to these optical characteristics by the manufactured sample.*

## 1. Introduction

Recently, in company with rapid increment of the market of displays including mobile phone, computer system, televisions, etc., demand of consumers for displays with higher performances has been increased. Among display devices, TFT-LCDs have been settled as the main players satisfying consumer's demands due to their excellent performances. However, TFT-LCDs should overcome shortcomings to maintain the supreme authority in the display market. The biggest obstacles to disturb the plan to the most valuable device were their narrow and non-uniform viewing angle characteristics [1]. To solve the issues, several technologies have been developed and introduced, such as patterned vertical aligned (PVA) nematic mode with multi-domain structure by patterned electrodes, advanced super view (ASV) mode, and multi-domain vertical alignment (MVA) mode [2-7]. PVA and MVA modes with the chevron electrodes which are induced a multi-domain boundaries adapt the compensation film for a practical wide viewing angle. But, the chevron electrode structure has singular points of the LC's behavior at domain boundaries reducing the transmittance. ASV mode hasn't the optical defect due to azimuthally continuous LC domain by the continuous pinwheel alignment, but it should use a chiral compound which may be an impurity into a LC.

In this work, we propose ACD (azimuthally continuous nematic domain) mode rotating LC molecules by a cone-like-field induced by patterned electrodes with slits like a circle and a donut, respectively. Without using any chiral dopant and extending domain boundaries, our proposed LC mode can be formed through the simple and cost-effective process and has the high optical performances.

## 2. Structure and Operation of ACD mode

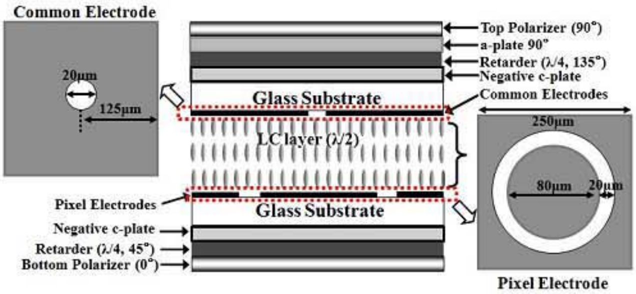


**Figure 1. The schematic of ACD mode: cross-sectional structure and the electrode configuration**

The schematic diagram of the cross-sectional structure of the proposed ACD mode is shown in Fig. 1. The optical structure of this mode consists of the top polarizer and a λ/4 retardation film with optical axis of 135° with respect to optic axis of polarizer, on the top substrate and a λ/4 retardation film with optical axis of 45° and the bottom polarizer, under the bottom substrate. Moreover, A-plate and positive or negative C-plates are added to compensate optical mismatch at side view. The transparent electrodes were made of ITO (indium-tin-oxide). Between the common electrode with the 20 μm aperture of the circular type and the pixel electrode with 20 μm slit formed like a donut shape, LC layer is vertically aligned initially and produces λ/2 by electric field for the maximum transmittance.

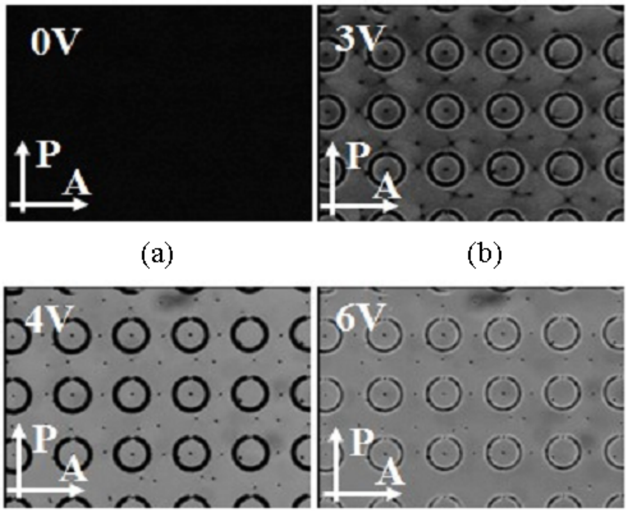
We can express the optical polarization states in each light path of the proposed mode. In initial state with vertical aligned LCs, the linearly polarized light to 0° direction by bottom polarizer become the left-handed circular polarization state after passing through the λ/4 retardation film with optical axis of 45° as shown in Fig. 1. In next step passing through LC layer, the polarization of the light is not changed due to homeotropic LC layer without optical phase retardation, so the light maintains the circular polarization state. In final step passing through the λ/4 retardation film with optical axis of 135°, the polarization state of the light returns to the original state, 0° polarization. Therefore, we can obtain the darkness at vertically aligned initial LC state. We obtained the bright state by inducing the cone like field. When the voltage was applied into the LC cell, the left-handed circular polarized light after passing through the λ/4 retardation film with optical axis of 45° become the right handed circular polarized state after passing through LC layer with optical phase ratardation of λ/2. Finally, after passing through the λ/4 retardation film with optical axis of 135°, the light become the linear polarization state to 90° direction. So, we can get the maximum brightness under electric field that produces the effective retardation of λ/2 at LC layer. On basis of this optical principle, we obtain various optical states that can express gray levels as a preferred display.

## 3. Experiment

We manufactured a real test cell to confirm its high optical characteristics. The ACD mode test cell was made using two patterned indium tin oxide (ITO) glass substrate. Pixel electrode of our test cell has the slits like a donut. The width of the slit is 20 μm. On the counter substrate, common electrode has the circular slit with a diameter of 20 μm. The electrode structure with the slits was made by etching the ITO uncovered with PR patterned by photolithography. To control homeotropically the direction of LC layer, we coated ALIH659 polyimide (JSR, Japan) on the substrates with patterned ITO electrodes and cured it at 210℃ for 1h. The cell gap was maintained 3.4 μm by using glass spacers. The used LC was MLC6610 (from Merck), which was injected into the cell by capillary action at room temperature. After manufacturing the LC cell with simple structure, we attached the optical retardation film to the outer sides of the LC cell to optically compensate.

## 4. Results and Discussion

Figure 2 shows the polarizing microscopic textures of our ACD mode at gradually increased voltages from 0V to 6V ((a) 0V, (b) 3V, (c) 4V, (d) 6V). In the field-off state, LC molecules are oriented perpendicularly by vertical alignment layer. When the voltage applied to our LC cell, LC molecules are rearranged along the field direction by the electrode structure of our LC mode. Our real cell with ACD mode starts to be reoriented LC molecules by the electric field in the sate of about 2.5V and has the driving voltage of about 5.5V.



(a) (b)

(c) (d)

**Figure 2. The microscope image of ACD mode test cell under applied voltage ((a) 0V, (b) 3V, (c) 4V, (d) 6V).**

When the voltages over 5.5V are applied to inner cell, all of pixels area has the high bright state except the small slit area. As shown in Fig. 3, we measured the EO characteristic of our test cell to confirm the optical properties. The measured threshold voltage and driving voltage were 2.5V and 5.5V, respectively. Our ACD mode has the real black in the dark state which is the merit of general VA modes and the high brightness in the bright states by elimination the optical defects through the special electrode structure. Accordingly, we obtained LC mode with a good contrast ratio. Figure 4 shows the measured EO response times of ACD mode test cell. The rising times of 18 ms and falling times of 12 ms were measured. The slow response time might be due to the low dielectric anisotropy ($\Delta\varepsilon$= -3.1) and the exterior electrode area to the slit of pixel electrode like a ring. This problem can be optimized easily by using black matrix between pixels. We also confirmed the simulated viewing angle characteristics of ACD mode in polar coordinate. In the optical simulation, we obtained a contrast ratio greater than 10:1 from almost all viewing areas in the contours having polar angle limits of 80˚.

## 5. Conclusion

We proposed azimuthally continuous nematic domain (ACD) mode with a unique electrode structure. LC molecules orientation of our proposed mode is determined by the field direction by the electrode structure with special slits. Because of decreasing the domain walls through the new electrode structure, our proposed mode has higher transmittance. We could fabricate also a real ACD mode cell by a simple and cost-effective process. Therefore we expect that the proposed mode will be applied to LCD industry.

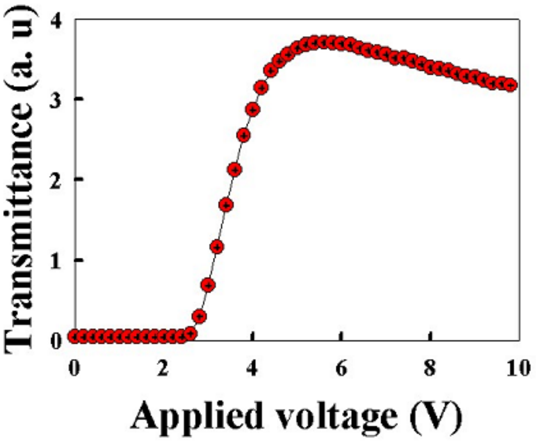


**Figure 3. Measured V-T curve of ACD mode.**

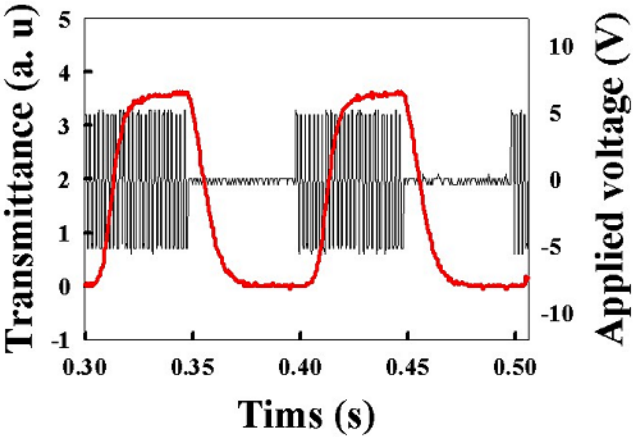


**Figure 4. Measured EO response time of our ACD mode.**

## 6. Acknowledgements

This research was supported in part by the Korea Research Foundation Grant funded by the Korean Government

## 7. References

1. K.-H. Kim, S.-B. Park, J.-U. Shim, J.-H. Souk, and J. Chen, *SID'08 Technical Digest*, Vol. **29**, p1085 (1998).
2. J.O. Kwang, K.C. Shin, J.S. Kim, S. G. Kim, and S. S. Kim, *SID'02 Technical Digest*, Vol. **33**, p256 (2002).
3. H.L. Ong, N. Cheong, J. Lo, M. Metras, and O. Woodard, *SID'03 Technical Digest*, Vol. **34**, p680 (2003).
4. A. Takeda, S. Kataoka, T. Sasaki, H. Chida, H. Tsuda, K. Ohmuro, T. Sasabayashi, Y. Koike, and K. Okamoto, *SID'98 Technical Digest*, Vol. **29**, p1077 (1998).
5. Y. Ishii, S. Mizushima, and M. Hijikigawa, *SID'02 Technical Digest*, Vol. **33**, p1090 (2002).
6. V.A. Konovalov, A.A. Muravski, C.N. Timofeev, and S.Y. Yakovenko, *SID'98 Technical Digest*, Vol. **29**, p90 (1998).
7. H.H Shin, H.-C. Lee, J.-J. Park, and S.-B. Kwon, *SID'98 Technical Digest*, Vol. **29**, p718 (1998).

8. Y.-J. Lee, T.-H. Lee, J.-W. Jung, H.-R. Kim, Y. Choi, S.-G. Kang, Y.-C. Yang, S. Shin, and J.-H. Kim, Jpn. *J. Appl. Phys.*, Vol. **45**, p7827 (2006).
9. S.-T. Wu, and D.-K. Yang, *Reflective Liquid Crystal Displays,* John Willy & Sons LTD., (2001).