Calculation of Ray Path in Liquid Crystal Modes

Byung-June Mun,[1] Sung-Ho Youn,[1] Joun Ho Lee,[2] Byeong Koo Kim,[2] Hyun Chul Choi,[2] Bongsoon Kang,[1] and Gi-Dong Lee[1,*]

1 Department of Electronics Engineering, Dong-A University, Busan 604-714, Korea
2 LG Display Co., Ltd., Gumi, Gyung-buk, 730-731, Korea

Various liquid crystal (LC) modes, such as twisted nematic (TN), vertical alignment (VA), in-plane switching (IPS), fringe-field switching (FFS), have been studied to improve the image quality of LCDs. Optical technologies regarding LC modes were focused on calculating the phase and transmittance of the light so far. However, current study for the LC technology is requiring the calculation of the ray path in LCD devices because current LC modes are becoming to use as ray controlling device such as tunable lens. Therefore, exact calculation of ray path of the ordinary (o) and extraordinary (e) waves of the light passing though several LC modes become more important. In order to calculate the ray path of the light in LC modes, at first, we need to check the characteristics of the arbitrary aligned LC modes. In general, LC modes consist of many birefringence layers whose orientations of LC directors are continuously changed between neighbouring LC directors in polar and azimuth direction between two isotropic substrates. Therefore, exact ray position of the light after passing through the LC mode should be obtained after important calculation; refraction and reflection at the interface between isotropic and uniaxial birefringence layer, between inhomogeneous uniaxial to uniaxial layer. Moreover, the ray path in LC modes may be more complicate because the o-ray and e-ray are liable to become bundle rays during pass through multi-dimensional aligned LC modes. Therefore, the calculation of the refraction property as a function of the difference of the director orientation between the neighbouring LC molecules is important for simple and exact calculation. Calculation of ray path has been proposed in the previous paper by using several methods such as Maxwell's equation [1], Huygen's principle [2] and phase matching condition [3]. However, methods gave the solution for the e-ray at only single interface without change of azimuth orientation of the optical axis. Therefore, these are not appropriate as calculation of the ray path in arbitrary aligned LC mode. A recent study had tried to solve the ray tracing in an arbitrary orientaional interface by using Hoygen's principle [4]. However, this study also handled only in single interface in *z*-direction. In this paper, we calculated the ray path of the light passing through LC modes by using the phase matching methods. We assumed LC modes as multiple stacked birefringence layers between two glass substrates. The phase matching in birefringence to birefringence interfaces was completed at *z*-axis and *y*-axis in each grid in the LC cell by calculating the wave vector **k** and the Poynting vector **S** of an o-ray and an e-ray. After calculation of the vectors of rays on the *z*-axis interface, we checked if the rays in the grid meet the *y*-axis interface on the grid. In the case of the ray met the *y*-axis interface, we could achieved the Poynting vectors of two rays by using dielectric tensor rotation method. From the optical approach, we calculated ray path of representative LC modes; TN, IPS, VA and ECB. We also traced the direction of the e-ray and o-ray when the orientation of LC directors in each mode is continuously changed as a function of the applied voltage state. As a result, we could confirm the exact paths of significant rays in several LC modes. This precise calculation for the ray path could be applied for analyzing optical performances of LCD devices. Our study can make the LC cell to become a more important optical component.

References:
[1] J.-P. Liu, H.-F. Yau, Z. Ye, C.-H. Kuo, and B. W. Ke, Optik **118**, 147-152 (2007).
[2] M. Avendano-Alejo, Opt. Express **13**, 2549-2555 (2005).
[3] Q.-T. Liang, Appl. Opt. **29**, 1008-1010 (1990).
[4] M. C. Simon, K. B. Bastida, and K. V. Gottschalk, Optik **116**, 586-594 (2005).

* presenting author; Byung-June Mun, E-mail: gdlee@dau.ac.kr