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Film compensation of twisted nematic liquid crystal display using a rod-like reactive mesogen

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ABSTRACT

A hybrid aligned nematic liquid crystal compensation film using UV curable rod-like mesogen has been made to compensate the residual birefringence of a twisted nematic (TN) device at oblique viewing directions in the dark state. Effective retardation value of the fabricated film was characterized by experiment and calculation using simulation. The results showed that the film has a hybrid alignment with a tilt angle variation from 3° to 19°. The optical compensation effects are evaluated in terms of light leakage in the dark state and contrast ratio (CR). The measured results showed that the light leakage is greatly suppressed with the compensation film and the viewing angle characteristics of TN device are greatly improved, most particularly in the up direction.

1. Introduction

Twisted nematic liquid crystal displays (TN-LCDs) [1] which were proposed several decades ago are still popular in small portable displays because of the characteristics of low power consumption, high light efficiency and low cost caused by high process margin in spite of their narrow viewing angle characteristics.

The residual birefringence effect is the cause of limited viewing angles in TN-LCDs, since when light passes through the medium, the strong light leakage occurs at oblique viewing directions in the dark state, which decreases the contrast ratio (CR) and is the basic reason of gray scale inversion in the displayed image. To eliminate the residual birefringence effect of the LCDs in dark state is the serious issue and has a great attention of current research.

In order to overcome the narrow viewing angle problems, several wide viewing angle liquid crystal (LC) devices such as in-plane switching (IPS) [2], multi-domain vertical alignment (MVA) [3], patterned vertical alignment (PVA) [4], and fringe-field switching (FFS) [5–7] have been developed and commercialized. Nevertheless, TN-LCDs with adoption of film compensation are emerging as an important area in the method for wide viewing angle due to relatively low production cost and easy fabrication. The compensation films such as a polymerized discotic LC film called as wide-view (WV) film [8–10] and hybrid aligned LC film [11,12] using a rod-like liquid crystalline polymer were developed and showed wide viewing angle characteristic compared with conventional TN-LCD. However, WV film with discotic LC has high production cost and gray scale inversion still persists.

In this paper, we have developed a compensation film using a rod-like reactive mesogen (RM) based on thiol-ene polymerization as an alternative to acrylate photopolymerizations [13]. In this system, step-growth free-radical polymerization between diene-type RMs and dithiol compounds, initiated by photoinitiator, proceeds rapidly under an ambient environment as compared to the conventional acrylate-type RMs of which polymerization has to be performed under nitrogen atmosphere to avoid an inhibition by oxygen [14]. In addition, the photosensitive resin formulated from the novel RM gave a uniformly aligned polymeric film having a hybrid LC alignment after photocuring, which enabled us to explore a new type of nematic liquid crystal compensation film. Since the new compensation film is based on a rod-like RM, it is cheaper than those obtained from discotic LC, and is very useful to remove viewing angle dependent light leakage in the dark state of conventional TN-LCD. Through the experiment, simulation and analysis of results, we confirm the configuration and tilt angle of

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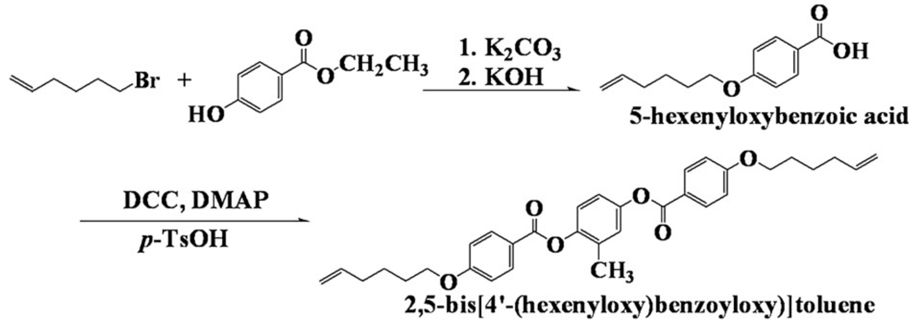

Fig. 1. Synthetic route and chemical structure of UV curable RM.

RM on substrate and compensation effect on TN cell where the viewing angle and CR are important perspectives.

2. Film fabrication and analysis

Firstly, a diene-type reactive mesogen (DERM), 2,5-bis[4′-(hexenyloxy)benzoyloxy]toluene, was synthesized as shown in Fig. 1 by condensation reaction between methyl hydroquinone and 4′-(5-hexenyloxy)benzoic acid [13], and mixed with 1 eq 1,6-hexanedithiol and 2 wt% of diphenyl(2,4,6-trimethylbenzonyl)-phosphineoxide (TPO, Ciba Darocure™) in xylene to obtain a photo-curable RM resin. Then, homogeneous alignment layer (Polyimide, AL 16157) was coated on the glass substrate and rubbed to be aligned in one direction. After rubbing, the synthesized photo-curable RM resin was spin-coated, solvent was removed, and UV light (365 nm, 90 mW/cm^2) was irradiated for 120 s to give a uniformly aligned polymeric film by step-growth free-radical polymerization between DERM and dithiol.

Fig. 2 shows retardation value depending on viewing angle and microscopic images of hybrid film in the left, front, and right directions. The difference in the effective phase retardation values according to viewing angle is clear from Fig. 2(a). The retardation value in the front direction was 138 nm, smaller than the retardation value of 149 nm in the left direction but larger than that of 103 nm in the right direction at polar angles of −40° and 40° respectively, at an incident light of 589 nm. Fig. 2(b) shows that the left direction image of the film is brighter than the front one, however the right direction image of film is darker, comparatively. These results indicate that the effective phase retardation value according to viewing angle of fabricated film gradually decreases from left to light, which is responsible for the darker and darker images in the same direction. The optical properties of the hybrid compensation film were measured by using REMS-150 in Sesim Photonics Technology.

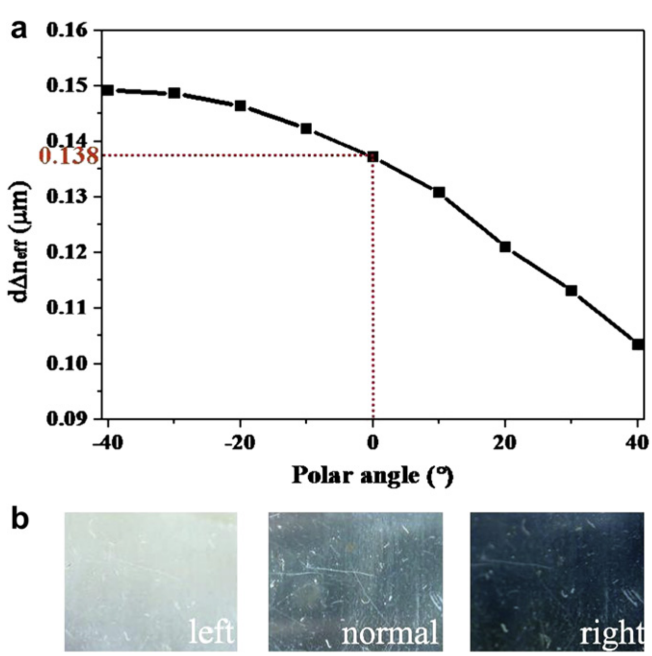

Fig. 2. (a) Retardation values depending on viewing angle and (b) microscopic images of fabricated film according to the left, normal, and right viewing direction.

Fig. 3(a) shows a simple modeling of the tilt and distribution of RM from bottom to top direction on the fabricated film, as based on the results we expected here that fabricated film has hybrid alignment. At the bottom, the RM is aligned homogeneously due to the interfacial interaction between RM molecules and homogeneous alignment layer rubbed. However, to minimize the surface tension difference between the RM and the surface in contact with air, RM at the surface should be aligned homeotropically, so the RM is aligned from horizontally to perpendicularly on the substrate from the bottom to top. The angle formed by the RM on the top is a maximum tilt angle, whereas the angle of RM on the substrate is minimum tilt angle, as shown in Fig. 3(a). From the scanning electron microscopic (SEM) image of fabricated film, we confirmed that photo-curable resin formed polymer layer of a thickness of 815.5 nm, which can be seen in Fig. 3(b).

3. Principle of film compensation

Although molecules of the both TN cell and fabricated film have rod-like shape and positive birefringence ($n_x = n_y < n_z$), compensation effects in the dark state of the TN cell can be improved effectively as the rubbing direction of TN cell is perpendicular against rubbing direction of hybrid aligned film as shown in Fig. 4 (a). In the TN mode, effective birefringence (Δn_{eff}) is not zero at off-normal axes in the dark state because mid-director of LC molecules tilts up close to 90°, whereas LC molecules in the vicinity of surfaces are hard to tilt up due to surface anchoring energy, which causes the tilt angle distribution of LC into a symmetric LC orientation from the middle to either top or bottom surfaces of the TN cell. In addition, the tilt angle variations have hybrid alignment from the surfaces to middle of the TN cell along the z-axis. To compensate the residual birefringence generated by hybrid configuration of TN cell in the dark state, the molecules pattern of the compensation film should also be in hybrid structure similar to half of the dark state in TN cell. The normalized transmittance (T) of TN cell under the crossed polarizer is given as follows:

$$T \propto \sin^2(\delta(\theta, \Phi, \lambda)/2),$$