Abstract

We proposed vertical alignment liquid crystal devices (VA-LCDs) in which the vertically aligned LC is surrounded by polymer wall, named locked-super homeotropic (LSH) device. Although the device has advantages of wide-viewing angle, spacer-free and simple fabrication, it exhibited relatively slow rising response time due to undefined azimuthal tilting direction with bias voltage. To resolve the problem, we fixed pretilt angle of VA using the polymerization of reactive mesogen (RM) with bias voltage. Conclusively, dynamic stability of LC directors is improved, exhibiting a fast response time.

1. Introduction

Recently, several wide-viewing-angle technologies are competing with each other. Among them, the VA modes have advantages in rubbing-free and fast decaying time due to bend deformation. Nevertheless, to realize high image quality comparable to the fringe-field switching (FFS) [1] and in-plane switching [2], 4 or 8-domain VA, that is, tilting direction downward should be in four or eight directions when a voltage is applied. Conventional approach to form multi-domain is to pattern electrodes called patterned VA (PVA) [3] or form protrusions called multi-domain VA (MVA) [4]. This causes collisions between LCs, generating defect point and disclination lines, giving rise to slow rising response time and low transmittance. In addition, the fabrication process to form 8-domains is rather complicated and expensive so that it is required to develop the low cost VA device with high performances. Some other report tried to improve this problem by polymerization of acrylic monomer in the fine pattern VA cell [5].

We have proposed the VA device in which the vertically aligned LC is locked by a polymer wall called LSH mode [6]. Unlike conventional VA modes, in the LSH device, the polymer wall plays the role of both the spacer and the locking of the LCs in a confined area. The device shows a dark state since the vertically aligned LCs exist under crossed polarizers at an initial state and with applied vertical electric field, the LC mid-directors tilt down symmetrically around a center in each domain, exhibiting a wide viewing. However, time-resolution study of the LC texture shows that the LC directors are not stable enough during an instantaneous LC reorientation when a voltage is applied, which gives rise to slow rising time. To solve this, we proposed the LSH cell with patterned ITO on top substrate [7]. However, this approach is not enough to achieve a fast rising time. Therefore, we studied a process for the vertically aligned LC to have defined azimuthal tilting direction through polymerization of RM monomer in the LSH mode. Figure 1 displays cell structures of conventional LSH and the LSH with the patterned ITO on top substrate.

2. Experimental Conditions

Conventional structures have no equipment of guiding the LCs in response to the electric field. To complement this handicap, the multi-pretilt angle technology, which is networked RM monomer, is applied to LSH mode. For experiment, samples were prepared by mixing chiral-doped LC with negative dielectric anisotropy ($\Delta\varepsilon = -4.7$, $\Delta n = 0.11$ at $\lambda = 589\text{nm}$, chiral pitch (p) = 16µm, Merck), reactive nematic monomer, and photo initiator Irgacure.
After mixing LC, RM monomer, and photo initiator, the mixture was heated to the isotropic temperature of the LC for a short time, and then the mixture was cooled to room temperature and filled into bottom substrate of conventional LSH cell by one dropping method [8]. The bottom substrate which consists of patterned polymer wall as a pixel matrix is made of negative photo resist and the height of the wall is 4µm. After dropping the LC, an ITO-coated top substrate with a homeotropic alignment layer was attached to the bottom substrate. In the completing cell, the chiral-doped LC is filled with RM monomer. Initially, the LC and RM are vertically aligned and then the some voltage is applied to the cell so that the RM monomer as well as LC reorients with a slight tilt angle from vertical alignment in response to electric field. At this state, UV light is exposed to the LSH cell, So, RM monomers are polymerized with constant angle tilted, as described in Fig. 2. In our experiment, the polymerization of RM monomer displays untidy texture as point defects when the strong UV light is exposed to the cell for an instant, that is, polymerized RM monomer is not enough to pile up surface of substrate.

**Figure 2. Control of liquid crystal director through multi-pretit angle.**

3. Results and Discussion

Actually, reoriented LCs exhibit many collisions each other before reaching final stable state due to undefined direction while twisting by additive chiral dopant and tilting in limited space (LCs is surrounded by polymer wall) when the voltage is applied. Collisions repeat and decrease until the LCs have pure radial configuration, as shown Fig. 3. The dark and white 4-brushes indicate indirectly that the mid-layer of LCs in the cell is pure radial configuration.

**Figure 3. Top view of reoriented LCs in response to the vertical electric field with crossed polarizers.**

Figure 4 shows multi-pretit angle LC layer on the surface of bottom substrate dependent on the polymerization of the RM monomer without electric field. Because the LCs have multi-pretit angle on the surface of both substrates, the reorientation of entire LCs in the cell is guided to minimize the collision of LCs in response to electric field. Additionally, such a multi-pretit angle LC layer hardly affects the dark state of the cell, since the tilting of LCs is very slight on the surface.

**Figure 4. Multi-pretit angle LC layer on the surface of bottom substrate dependent on the polymerization of the RM monomer.**

To observe this effect on electro-optic characteristics of the LSH cell, we observed time-resolved texture by applying an operation voltage in a cylindrical shape of polymer wall-hole with a size of 60µm. Figure 5(a) is time-resolved LC textures of conventional LSH. The LC texture shows that the conventional LSH cell is very unstable, taking 25ms to reach 90% of maximum transmittance. Furthermore, it takes about 60ms to complete LC texture variation, i.e., reorientation of LCs. To improve this, we patterned electrode on top substrate of the LSH cell so that the patterned electrode helps LC molecules tilt down in more defined way. In this case, although the dynamic behavior is improved compared to the conventional LSH
cell, it takes still long time till the texture (fig. 5(b)) becomes stable. In other hands, texture of LSH cell through multi-pretilt angle shows very stable dynamics, that is, the LC texture is almost fixed, meaning that the rising time becomes very fast. Figure 5(c) show the time-resolved texture of the LSH with multi-pretilt angle, and the LCs in the cell reoriented fast under 16.7ms.

Conclusively speaking, the dynamic stability of the LSH cell by controlling the LC through multi-pretilt angle is greatly improved, which overcomes demerit of the conventional VA mode.

4. Summary

We report for the first time the LSH cell by applying the multi-pre-tilt angle on the alignment layer of substrate through polymerization of the RM monomer. This improves the dynamic stability, which decreases an instantaneous collision due to fixed reorientation of LCs when a voltage is applied. This approach has a great impact on the VA mode.

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6. References