Improvement of alignment quality for FLC with mixing liquid crystal polymer

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Abstract — Ferroelectric liquid crystal (FLC) with I-N*-C* phase sequence is most attractive due to its continuous grey level and fast response; however, the alignment problem of two-domains defect restricted its application. In this work, one kind of one terminal polymerizable nematic liquid crystal (NLC) mesogen was mixed to FLC to improve its alignment quality. Experimental results showed that mono-domain uniform alignment of FLC can be obtained with mixing NLC polymer. With optimized concentration, the FLC devices could offer half-V-shaped electric-optical characteristic of driving contrast of 182:1 and fast response of 300 µs even after polymerization. This work can provide one simple and effective method for fabricating stable I-N*-C* FLC devices.

1   Introduction

Nematic liquid crystal (NLC) device brings one great technical revolution in flat display industry. Nowadays, NLC is the dominant technology, because of its advantages such as low cost, easy manufacture, and so on.[1] However, with the demanding requirement of high speed display,[2,3] devices based on ferroelectric liquid crystal (FLC) have drawn much more attention because it can switch up to 100 times faster than standard nematic LC.[4,5] Surface-stabilized ferroelectric liquid crystal display (SS-FLCD) exhibiting bistability was first developed by Clark and Lagerwall.[6] It has attracted a great deal of researcher's interest for its characteristics such as fast response, wide viewing angle, and suitability for a high-resolution display. However, it is very difficult to control continuous gray scale because of its bistability mechanism and zigzag alignment problem. Hence, with the rapid development in the research of FLCDs, several new FLC materials with continuous gray scale have been provided by different groups.[7–9] And among them FLC with I-N*-C* phase sequence, without smectic A phase, is well known for its half-V shaped electro-optical (EO) performance.[10] One typical FLC is commercial R2301 (Clariant, Japan), which has been reported by many researchers. FLC with I-N*-C* phase sequence is most attractive mainly because of its continuous gray levels and fast response,[10–12] which are suitable for active devices such as thin film transistors (TFTs). However, one key obstacle for its practical application is to realize high quality alignment.[13] Some researchers utilized direct current electric field during the phase transition process of FLC devices.[14,15] These methods are not only complicated but also impracticable with modern manufacturer procedure. Some others provided hybrid alignment technique to achieve uniform alignment using photoalignment[16,17] or photoaligning–rubbing hybrid alignment[18,19] or only rubbed polyimide film.[20] These methods could achieve uniform alignment without applied voltage during fabrication process; however, its thermal stability or anti-shocking stability was still needed to improve for practical application. Hence, some researchers utilized polymer network to stabilize alignment performance[21–24]; but the most fatal disadvantage is to sacrifice its fast response, which shows no great superiority compared with NLC devices.

In order to improve the thermal stability and the resisting performance against shock for FLC devices, we doped one terminal polymerizable liquid crystal mesogen into FLC material, which existed similar structure to FLC molecule before its polymerization reaction. Then the mixture was exposed with UV light within SmC* phase of FLC. After exposure, main chains of doped liquid crystal polymer were mainly distributed between the FLC molecular layers and the mosogens were mostly distributed parallel to FLC molecules within its layer structure. As a result, this method not only maintained the uniform alignment but also greatly enhanced the ability against annealing or shock. Finally, the stability problem of FLC uniform alignment was resolved. Comparing with common polymer network stabilized method, FLC devices fabricated with one terminal liquid crystal polymer shows fast response, high driving contrast, and no light leakage. Finally, alignment performance of FLC with I ↔ N* ↔ SmC* phase sequence was improved with mixed liquid crystal polymer and the real effect was confirmed with experiments in this work.

2 Process

In this work, FLC material R2301 (AZ Electronic Material, Branchburg, NJ, USA) is used here. Its phase sequence is I (Isotropic phase) (86.8–84.8 °C) N* (64.7 °C) SmC* (−4 °C) Cr (crystal). The liquid crystal photosensitive monomer was synthesized by our group named as LCA1. LCA1 was mixed into FLC material R2301 with different concentrations: 0 wt %, 2.5 wt%, 5 wt%, and 10 wt%. And then this FLC mixture was stirred for 24 h at 90 °C. RN 1199 (Nissan Chemical Industries, Ltd, Japan) of 3% solution was spin-coated onto ITO glass substrates and used as alignment film, which was prebaked at 80 °C for 10 min and then hard baked at 250 °C for 60 min. After one directional rubbing treatment, antiparallel aligned FLC cells were fabricated as sandwich-type cells between two substrates coated by RN1199 rubbed films and the thickness was about 2 μm. Then, the FLC cell was heated to 90 degree, and FLC mixture with different LCA1 concentration was filled into cell under capillary action and cooled down to room temperature with a rate of 0.1 °C/min. For polymerization, 365 nm UV light with intensity of 0.4 mW/cm^2 was used as light source.

3 Measurement

Alignment performance of tested FLC cell was investigated under polarized microscope (BX-P Olympus Corporation). Static contrast ratio (CR) was defined as CR = Imax/Imin of FLC cell without applied voltage, which was rotated on the object stage under polarized microscope and its transmittance was recorded with photoelectric detector. Large CR value is corresponding to a good alignment performance of the FLC. EO performance was measured on LCD parameter tester LCT-5016C. The EO property and alignment texture was measured after attacking with 2-g steel ball falling down from 0.5-m height. So does the annealing test, which was repeated for 3 cycles with such procedure: heating FLC sample to 90 °C

for 5 min and cooling down to room temperature with cooling rate of 10 °C/min.

4 Results and discussions

The typical alignment defect for FLC with I → N* → SmC* sequence is the two-domain coexistence during temperature decreasing process as shown in Fig. 1(a). Such "double domains" were easily generated during cooling process or phase transition from nematic phase to chiral smectic C* phase, and both domains were with same stability and appeared at the same probability. This disadvantage greatly increased difficulty for fabrication of FLC devices; hence, it badly restricted industrial application of FLC. To resolve this alignment defect, in this work, we proposed to mix polymerized liquid crystal monomer into FLC materials. Because the mesogenic group of LCA is with similar molecular length with FLC molecules, it is easy to dissolve in FLC and also easily align same direction with FLC. And then UV exposure was used to polymerize the LCA monomer into polymer. The conception of this work is to firstly align the mesogenic groups of LCA together with FLC molecules within its molecular layers. And because there is only one terminal polymerization group in LCA molecular structure, hence, the most probability of distribution for polymerized side chain is in the space between different FLC layers as shown in Fig. 1(b). After UV exposure, the network of polymer is designed to keep all FLC molecules in almost one direction and hence to avoid the coexistence of two-domains.

In order to obtain optimal mixing concentration of LCAl, different concentration of 0 wt%, 2.5 wt%, 5 wt%, and 10 wt % was used as FLC mixture. After fabrication of antiparallel FLC cells on rubbed polyimide film, these FLC mixtures were injected into cells for a test. From the photos taken under crossed polarized microscope as shown in Fig. 2, it is seen that with increase of LCA1 mixing concentration, the defect of two-domain was depressed gradually. Compared with 0% doping sample, we can already see some degradation of two-

(a)   (b)
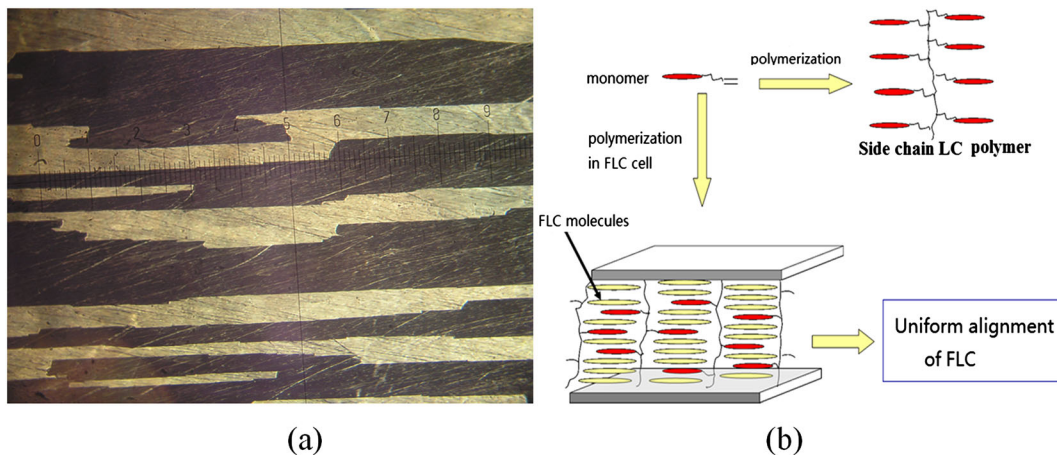
FIGURE 1 — Alignment defect of ferroelectric liquid crystal (FLC) with I → N* → SmC* phase sequence (a) and the schematic structure of LCA1 and its effect of stabilizing FLC (b).
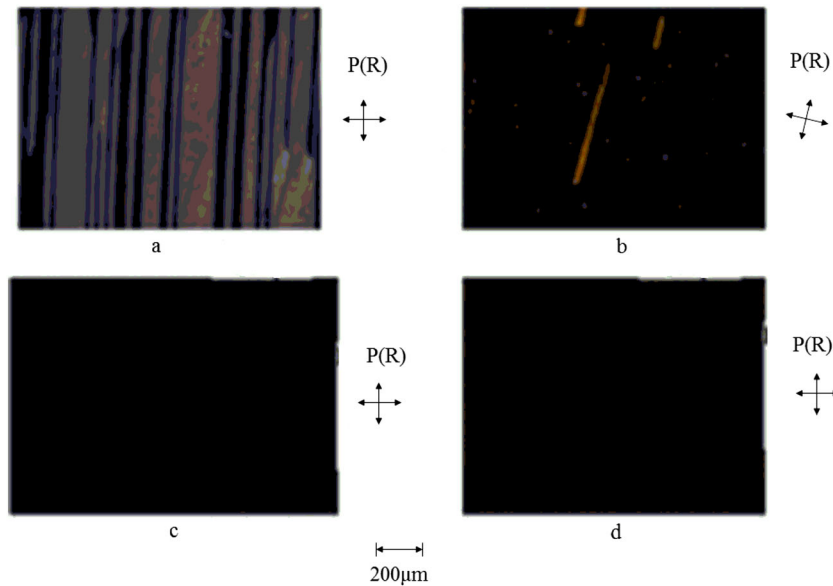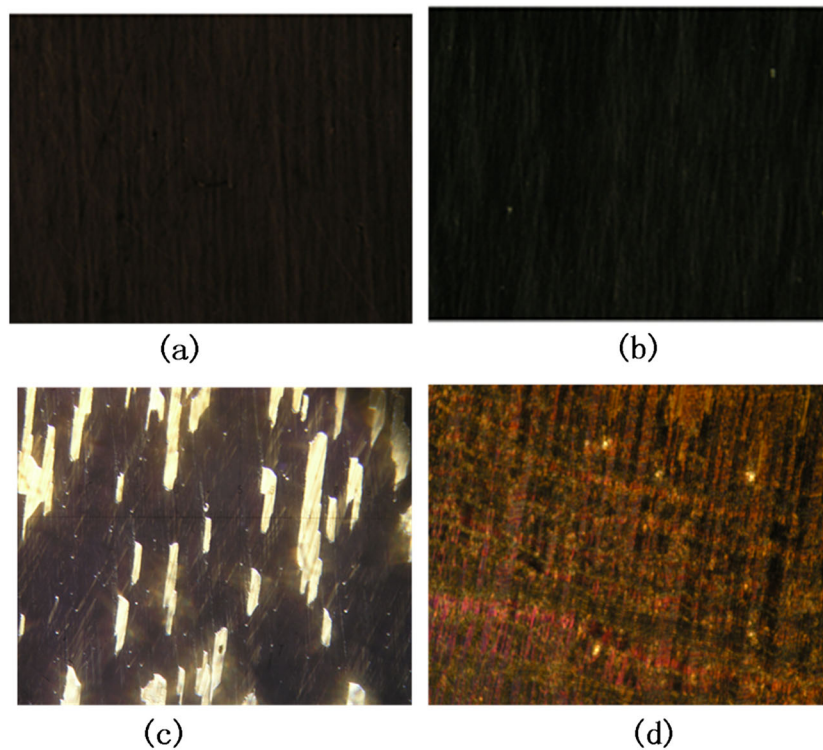
FIGURE 2 — Photos of ferroelectric liquid crystal cells under crossed polarized microscope with different mixing concentration without UV exposure: (a) 0 wt% (b) 2.5 wt% (c) 5 wt% (d) 10 wt%.

domain defect of alignment even in small mixing concentration of 2.5%. While when the mixing concentration is 5%, the static CR of FLC cell is 280:1; and when the concentration is increased to 10%, the static CR goes up to 330:1. All these photos confirmed that the mixing of LCA1 to FLC material indeed improved the alignment performance and the improvement was gradually enhanced with increased mixing concentration of LCA1.

To test its stability, then we did some anti-shocking test for FLC samples with 5% and 10% LCA1. As shown in Fig. 3, it

FIGURE 3 — Photos of ferroelectric liquid crystal cells under crossed polarized microscope without UV exposure: (a) 5 wt% mixing, before anti-shocking test; (b) 10 wt% mixing, before anti-shocking test; (c) 5 wt% mixing, after anti-shocking test; and (d) 10 wt% mixing, after anti-shocking test.

seems that before test, both cells give fine alignment performance without defect. However after anti-shocking test, there were obvious defects in both cells. The tests show that although the mixing of LCA1 could depress two-domain defects of FLC alignment, the stability of anti-shock were very weak for both samples with 5% and 10% when the mixed LCA1 was not polymerized. In order to confirm the real effect of polymerization process on alignment stability improvement, alignment texture was investigated for contrast before and after anti-shocking and annealing test with samples of 5% mixed LCA1. Hence, after injection of FLC mixture to cells, UV exposure of 365 nm of 0.4 mW/cm² was performed for fabricated cells with same exposed condition as reported in Ref. 25. And then, the samples were performed with anti-shocking and annealing tests as shown in Fig. 4. Without polymerization process, cells with 5% LCA1 gave fine alignment effect as shown in Fig. 4(a); but after test, it exist many unrecovered defects as shown in Fig. 4(b) and (c), which means the alignment effect was degraded by shocking or annealing treatment. However, compared with the samples after polymerization, as shown in Fig. 4(e) and (f), it kept fine alignment texture as good as that of before test shown in Fig. 4 (d). From the microscope photos in Fig. 4(e) and (f), we could not see any obvious defect as seen in Fig. 4(b) and (c). The change of static CR after test was within 5% of that before test, which means the stability against shock and annealing was greatly enhanced after polymerization process of LCA1. For further investigation, the EO property was investigated for samples with 5% and 10% LCA1 after UV polymerization process. The EO property was checked on LCT 5016C as shown in Fig. 5. However, the result was completely contrary to that with LCA1 mixing concentration test: with larger concentration results in worse alignment. The mechanism is most probably because without polymerization test, for larger concentration of 10% LCA1, static CR goes larger than that of 5% sample. This means more LCA1 monomer would cause stronger induced effect for FLC molecules to align in one
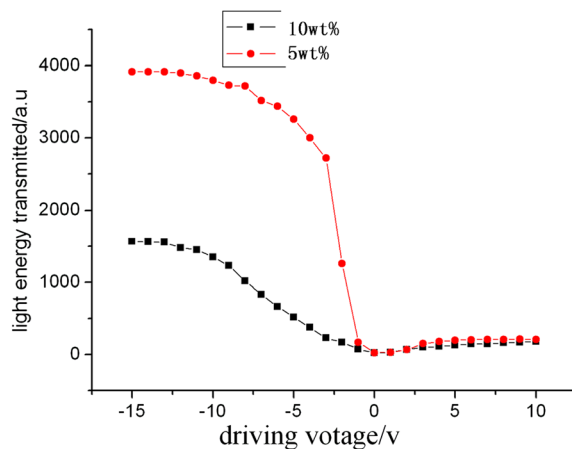

FIGURE 5 — Electro-optical test curves for samples with 5% and 10% LCA1.

direction; hence, we obtained better degree of aligned order and larger static CR. But for driving CR test, it will cause adverse effect; with more LCA1 molecules, the driving voltage become higher and the maximum transmittance went lower, almost 50% of that with 5% concentration sample. It is measured that the driving CR of 5% sample was 180:1 and the value of 10% sample was only 70:1. These phenomena stated that with more mixed LCA1, the network restriction for FLC molecules became stronger and hence FLC molecules were not easy to rotate freely, which results in small rotation range and lower transmittance. So, based on the results in Fig. 4 and EO test in Fig. 5, they show that 5% mixing was the optimized concentration both for alignment stability improvement and fine EO retaining.

For further investigation, the EO curve of 5% LCA1 sample was tested against shocking and annealing effect. As shown in Fig. 6, it shows that the EO curves after test was almost the same as that the before test. With data calculation, the change of driven transmittance was effectively maintained
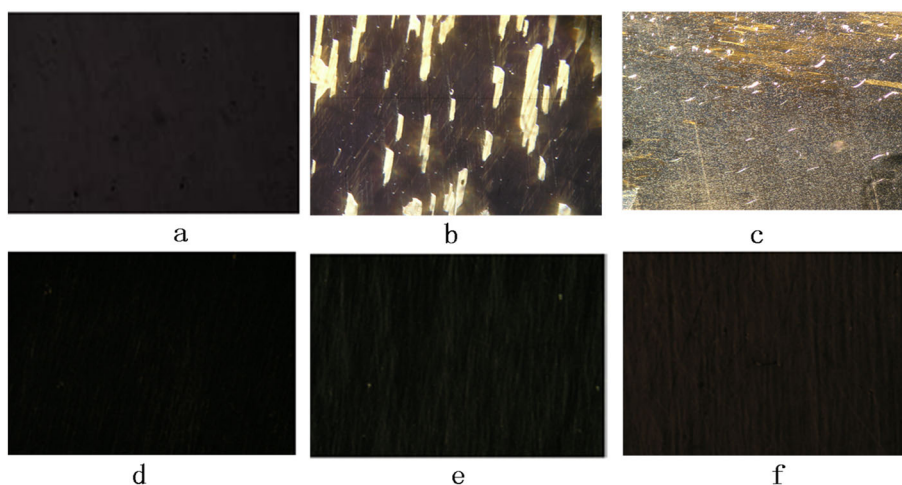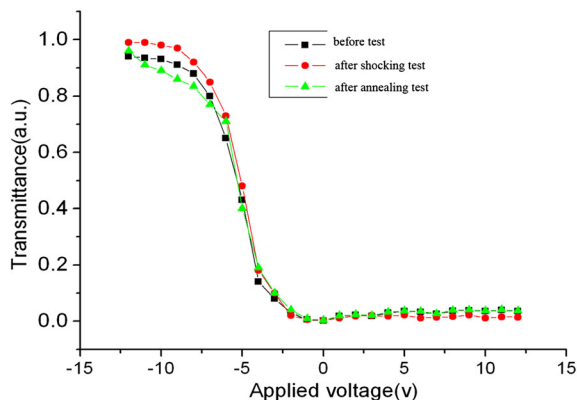

FIGURE 4 — Photos of ferroelectric liquid crystal cell with 5% LCA1 under crossed polarized microscope without UV exposure: (a) before test ; (b) after anti-shocking test; (c) after annealing test, with UV exposure; (d) before test; (e) after anti-shocking test; and (f) after annealing test.

FIGURE 6 — Electro-optical test curves of samples with 5% before and after shocking or annealing tests.

within 5%, which is the same as static CR change after shocking or annealing tests. Besides the EO curve, the response was another important parameter for FLC devices. Hence, the response of 5% LCA1 sample was tested; the response on/off time under 10 V voltage was 300 μs and 270 μs, respectively, which was one time faster than the result in the work of Tang using common polymer network method.

5   Conclusions

The alignment performance of FLC with I-N*-C* phase sequence was indeed improved with mixing LCA1, which shows similar molecular structure with FLC molecules when it is in monomer state before polymerization. When mixed, larger concentration resulted in better alignment effect. However, its stability against heating or shocking was still poor no matter how much you mixed LCA1 into FLC materials. The stability of FLC was greatly enhanced only after polymerization of LCA1; but the result was not simply dependent on mixing concentration of LCA1. More LCA1 would give better alignment induction action; however, it will also give more restriction of FLC molecules rotation, resulting worse response performance. Finally, with optimized concentration, the FLC devices could offer half-V-shaped EO characteristic of driving contrast of 182:1 and fast response of 300 μs with fine stability against heating or shocking. All the results were just based on mixing one terminal NLC polymer with one-step UV exposure without applied voltage or any precise alignment control. This method is simple and effective, which shows high potential for future application of I-N*-C* FLC devices.

Acknowledgment

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