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Effects of Carbon Nanotube Length on Electro-Optical Characteristics in Liquid Crystal Cell Driven by Fringe Field Switching

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We have fabricated carbon nanotubes (CNTs) doped homogeneously aligned nematic liquid crystal cells driven by fringe-field switching and their electro-optic characteristics were investigated. The CNTs doped liquid crystal cell shows lower transmittance, higher driving voltage but faster response time than those in the pure liquid crystal cell. In addition, CNTs-doped liquid crystal cells as a function of the CNT length were investigated. This paper gives an explanation on difference in electro-optic characteristics of pure and CNT-doped LC in the FFS mode.

Keywords Carbon nanotube; electro-optic characteristics; fringe-field switching

Introduction

Nowadays, liquid crystal displays (LCDs) was required to show excellent moving picture performance and more superb image quality. To improve this moving picture performance, various methods such as backlight scanning technology [1,2], increase in frame rates from 60 Hz to 120 or 240 Hz [3,4], and physical property improvement of liquid crystal (LC) mixture [5,6] were proposed and studied. Since LCD-television starts adopting high frame rates, the development of LC mixture which exhibits faster response time becomes more important. Recently many researchers are trying to improve electro-optic performance of LCDs by doping a foreign particle like MgO

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[7], BaTiO3 [8], Sn2P2S6 [9] and CNTs [10–12]. We also reported the effect of CNTs in the twisted nematic (TN) mode [13,14] and in-plane switching (IPS) mode [15]. The reported CNTs-doped TN cells have characteristic that voltage-transmittance curves did not show a significant difference as compared with pure LC cell. Furthermore response time and voltage holding ratio (VHR) were improved in the TN mode. However, CNT-doped IPS cell exhibited increase in the driving voltage and decrease in the decay time as compared with pure LC cell. These results have reported only about effect of CNTs on the electro-optic performance of LCDs, however, investigation on effect of length of CNT has not been done.

In this report, we doped thin multi-wall CNTs (t-MWCNTs) with different lengths into LC mixtures and the electro-optic characteristics in the LC cell driven by fringe field switching were investigated.

Experimental

The t-MWCNTs were synthesized by the chemical vapor deposition using FeMoMgO catalysts. The outer diameter of pristine t-MWCNTs ranged from 3 to 6 nm with typical lengths of several μm. The short t-MWNT powders were prepared by milling or grinding method as it is reported previously [16,17]. These short t-MWNT powders were dispersed in dichloroethane (DCE) by sonication and the CNT lengths in the supernatant were measured using dynamic light scattering method after centrifugation. Two different average lengths, 290 nm and 177 nm t-MWCNTs were prepared by increasing grinding time as shown in the Figure 1. The dispersed t-MWCNTs in the DCE were poured into LC mixture with positive dielectric anisotropy ($\Delta\varepsilon = 15.4$), birefringence ($\Delta n = 0.1034$ at $\lambda = 589$ nm), and rotational viscosity ($\gamma_1 = 139$ mPa.s) and then solvent was evaporated. Clearing point was measured in order to confirm complete solvent evaporation and same clearing temperature like in the pure LC mixture was obtained. Finally t-MWCNT-dispersed LC mixture was thoroughly sonicated before injection into FFS cell.

Figure 2 presents the cell structure of the CNT-doped FFS cell. Ideally, both LCs and CNTs are homogenously aligned at an initial state, as shown in Figure 2(a). Here, the electrode width (w) and a distance (l') between electrodes was made to be 4 μm and 5 μm, respectively. Because of this electrode structure, a fringe-electric field which has both horizontal (E_y) and vertical (E_z) components is

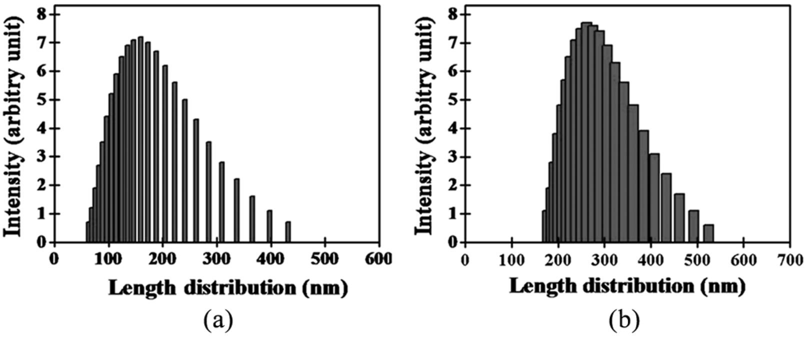


Figure 1. Measured size distribution data of t-MWCNT with dynamic light scattering method: (a) average length 177 nm and (b) average length 290 nm.

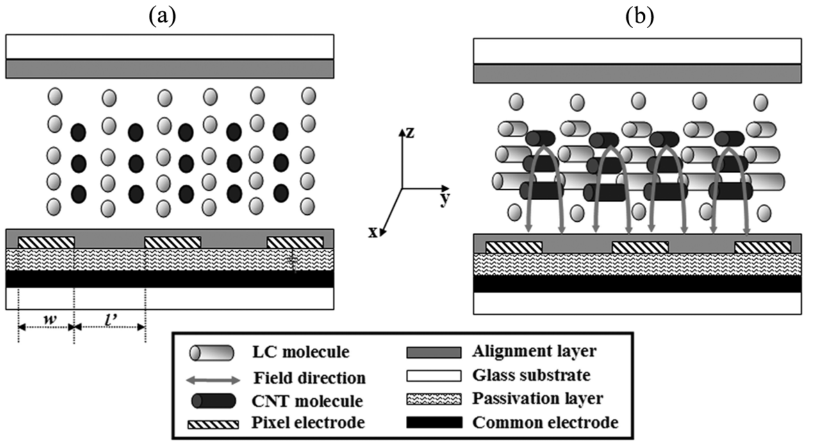


Figure 2. Schematic of the cell structure of the t-MWCNT doped FFS cell in (a) off and (b) on states.

generated and the field rotates LC and possibly CNTs over whole electrode surface, as shown in Figure 2(b). One noticeable thing is that the intensity of E_y is periodically changing along electrode positions, i.e., it is highest and lowest at the edge and center of electrodes near bottom substrate, respectively [18,19]. For an alignment layer, a homogeneous alignment layer (AL16139 from Japan Synthetic Rubber Co.) was spin coated on the patterned electrode at bottom and top glass substrates with a thickness of 800 Å. The rubbing process on both substrates was performed in the antiparallel direction to align the nematic LC with an angle of 83° with respect to E_y. The cell was then assembled to give a cell gap $d = 3.2\,\mu m$, where the plastic balls were used to keep d. Finally, the LC mixture with 1×10^{-3} wt% of t-MWCNTs was filled at room temperature by capillary action. An undoped (C-1), 290 nm t-MWCNT-doped (C-2) and 177 nm t-MWCNT-doped (C-3) cells were fabricated for the comparison of the electro optic characteristics.

Results and Discussion

We first observed the pure and CNT-doped LC cell under the polarizing optical microscopy before and after applying voltage. As indicated in Figure 3(a), 3(c), and 3(e), the C-1, C-2, and C-3 cells in all exhibit complete dark state without showing leakage of light by any defects and CNT clusters except near ball spacers. In the on state, the uniform transmittance was generated and there was no distinct difference between pure and doped cells and among two doped-cells as shown in Figure 3(b), 3(d) and 3(f). This implies that CNTs are also homogenously aligned along LC director and then rotates along the field direction [20]. Voltage-dependent transmittance (V-T) curves after applying a square wave voltage of 60 Hz with an increasing step of 0.01 V were measured using a halogen lamp, as shown in Figure 4. The maximum transmittance (4.17% for C-2, 4.14% for C-3) of CNT doped cell was slightly lower than that (4.25% for C-1) of pure cell. The operating voltages (3.24 V for C-2, 3.24 V for C-3) of CNT-doped cell were slightly higher than that of C-1 (3.19 V). This result is similar to previous one in IPS cell [15] and it can be explained by increase of twist elastic constant (K_{22}) from strong interaction between

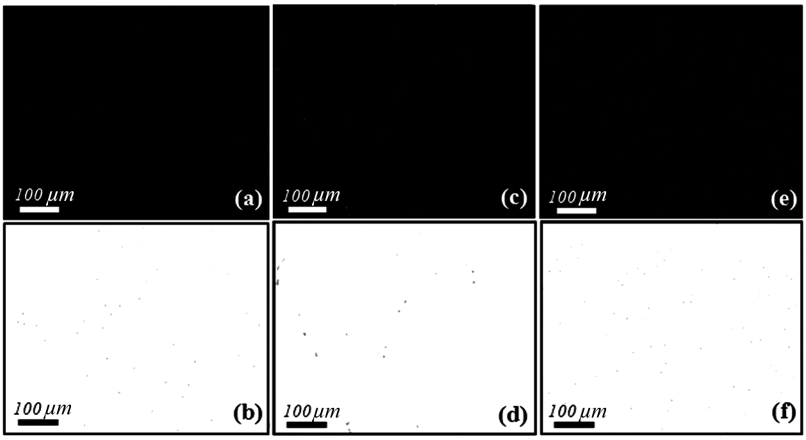


Figure 3. Polarization microphotographs of the pure and t-MWCNT doped cells: (a) off and (b) on state for pure cells, (c) off and (d) on state for 290 nm t-MWCNT, (e) off and (f) on state for 177 nm t-MWCNT.

CNTs and LC molecules. However, effect of different average lengths was not observed. Finally, we measured response time of the pure LC and t-MWCNT-doped LC cells to confirm the effect on response time of t-MWCNT-doped LC cell. Figure 5 presents the measured rising time and decaying time of the FFS cell in eight gray levels by applying a 60 Hz square wave AC voltage. Here, the applied voltages for each gray scale were identical for all cells. In the case of the rising time, no big difference was observed among cells. However, C-2 and C-3 cells showed faster decaying time than C-1. When we compare effect from different average lengths, shorter CNT doped C-3 cell showed faster than C-2 cell. The decaying time is in general proportional to γ_1/K_{22}, so these improvements of CNT doped cells can be explained by

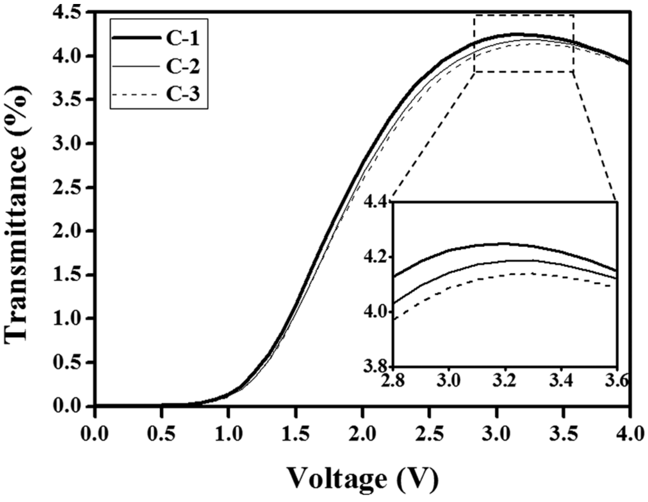
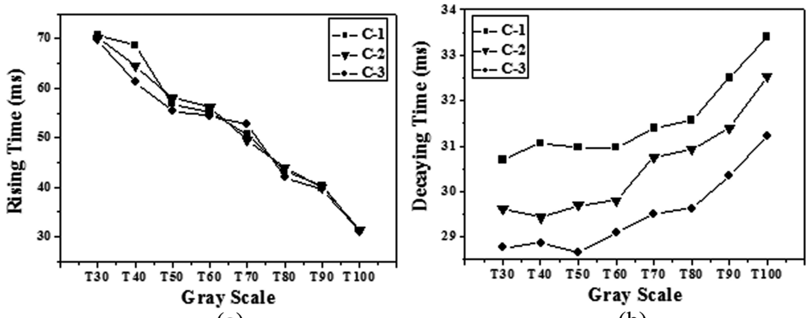


Figure 4. Measured voltage-dependent transmittance curves of the pure and t-MWCNT doped LC cells.



(a) (b)

Figure 5. Measured (a) rising and (b) decaying response times of the pure LC and t-MWCNT doped LC cells. The numbers in the label of the row axis show the relative transmittance with respect to the maximum transmittance at the normal direction.

the decrease of rotational viscosity or increase of elastic constants as it is reported in IPS case [15]. However, it's still unclear at present why shorter CNT improve decaying time more effectively.

Conclusions

We have examined effects of CNTs with different average lengths on the electro-optic characteristics of the FFS cells. The operation voltage was increased slightly and decaying time was decreased after doping CNTs into pure LC mixtures. The shorter CNTs were more effective for the improvement of decaying time. Further study of the optimization of length distribution will result in the possible application of the CNT-doped LC to the FFS LCD to improve the response time.

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