Fabrication of Field-Sequential Color Display Using Predesigned Ferroelectric Liquid Crystals

Chun-Yen Liu*[1], Yan-Song Zhang[2], Jui-Hsiang Liu*[2]

[1]School of Optometry and Vision Science Program, UC Berkeley, Berkeley, CA 94720, USA
[2]National Cheng Kung University, Tainan, Taiwan

ABSTRACT

A series of low transition temperature and fast response chiral smectic C (SmC*) liquid crystals was designed and synthesized. Phase transition behaviors and electro-optical properties of the synthesized compounds were investigated and compared. Ferroelectric phase of the liquid crystals are characterized by means of DSC, POM, X-ray diffraction and electro-optical measurements. The synthesized materials revealed low melting points (< 0℃) and wide chiral Smectic C phase ranges (~80℃). The wide SmC* phase was achieved via the induction of achiral trisiloxane and chiral methyl side chain into terminal of molecules. A response time of 100 μs at the electric field of 10V/μm gives an opportunity to use the synthesized materials for the field sequential color liquid crystal display. The color frame frequency more than 200 Hz was applied by RGB LED on this FSCD.

Keywords: liquid crystals, field sequencial color display, ferroelectric, smectic

1 INTRODUCTION

Color filter is the main component of ordinary liquid crystal display (LCD) to generate color image. However, it is energy wasting. In addition, the tranmittance of color film is always low. This brings the problem of power insufficient to all mobile devices which contain LCD. Field sequential color (FSC) LCD is a new technology that can solve these energy and brightness problem because it can generate full color display without the present of color filter. Colors are generated by making use of the persistence of vision. When red, green and blue lights are displayed sequentially in high frequency, a resulting color is generated in human's brain.

Ferroelectric liquid crystals are chiral smectic liquid crystals that have a layered order. Within the layer the liquid crystal molecules (called mesogenes) are tilted away from the layer normal (90°), forming a so-called smectic C liquid crystal. Chiral behavior is introduced by inserting asymmetric carbon atom into the mesogenic molecule, termed now smectic C* (the asterix denotes the chirality). The chirality causes a smectic layer to exhibit a permanent spontaneous polarization at right angle to the tilt plane, giving rise to the term ferroelectric. In an unconstrained system a helical twist in the structure lowers the energy of the structure, i.e. the tilt direction changes from layer to layer by some degree. In other words, the azimuthal direction in which the molecules tilt away from the layer normal will differ slightly from one layer to the next. Therefore, the overall polarization of an unconstrained smectic C* phase will be zero.

In this study, a series of predesigned liquid crystals were synthesized. Theromal and optical properties of the synthesized liquid crystals were studied. A practical field sequencial color display was fabricated showing stable colorful disply properties.

2 EXPERIMENTAL

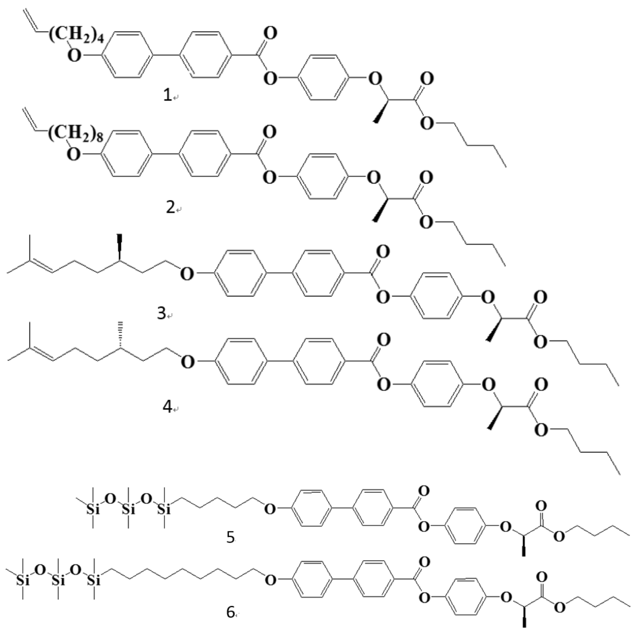
2.1 Analytical Apparatus

Chemicals used in this investigation were characterized using ^{1}H-NMR and FT-IR. 500 MHz ^{1}H NMR spectra were obtained on a Bruker 500 MHz FT-NMR. All spectra were run in $CDCl_3$ or DMSO-d_6 solutions. Fourier transform infrared spectroscopy crystal phase behavior of the different materials was identified using polarizing optical microscopy (POM), differential scanning calorimetry (DSC), wide angle X-ray scattering (WAXS) and electro-optical measurements. Polarizing optical microscopy was performed using a Mettler FP82HT hot stage, a Mettler FP80 central processor and a high-speed TUCSEN TrueChrome II charge-coupled device (CCD) with a microscope (Nikon labophot- pol). DSC measurements were conducted with a Perking Elmer DSC 6000 differential scanning calorimeter. Wide-angle X-ray scattering was recorded using a NANOSTAR U SYSTEM (Bruker AXS Gmbh).

2.2 Materials and Synthesis

Materials and reagents were of commercial grade quality and used without further purification unless otherwise noted. The structures of the synthesized compounds 1 to 6 were shown in Scheme 1. All the structures were identified using ^{1}H-NMR, and the data agreed with the structures in all cases. To prepare the deformed helix ferroelectric liquid crystal cell, two inner surfaces of ITO glass plates were washed with acetone twice and coated with a 0.5% polyvinyl alcohol aqueous solution (Mw= 80,000–110,000). After drying, the two ITO glass plates were rubbed in an antiparallel direction then separated by 3.2 µm spacers and sealed with epoxy resin on two sides of the cell.

3 RESULTS AND DISCUSSION



Scheme 1: Structures of the synthesized compounds.

Scheme 1 shows the structures of the synthesized liquid crystal compounds. The synthtic process was described in the published literature [1]. The molecules were confirmed using FTIR, NMR and elemental analysis.

Compound	Transition temperature
1	Cr 72^{o} S_{m}C* 83^{o} S_{m}A* 128^{o} I
2	Cr 40^{o} S_{m}C* 112^{o} I
3	Cr -27^{o} S_{m}C* 30^{o} TGBA* 43^{o} N* 51^{o} I
4	Cr -7^{o} S_{m}C* 18^{o} TGBA* 33^{o} N* 40^{o} I
5	Cr 32^{o} S_{m}C* 59^{o} S_{m}A* 66^{o} I
6	Cr -3^{o} S_{m}C* 76^{o} TGBA* 82^{o} TGBA* 90^{o} I

Table 1: Phase transition temperatures of the synthesized compounds.

To investigate the thermal properties of the compounds, DSC was used for the measurung of the phase transition. The results are summarized in Table 1. The phase transition points were confirmed using DSC analysis and polarized optical scopy (POM). Color textures show the apperance of asisotropic liquid crystals. From comparison of the textures with published data, the LC phases were identified.

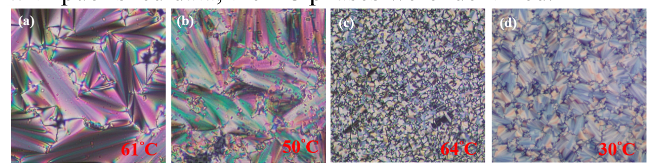


Figure 1: POM texture of compound 5, (a) SmA* phase at 61°C ×400 magnification, (b) SmC* phase at 50°C ×400 magnification, (c) SmA* phase at 64°C ×100 magnification, (d) SmC* phase at 30°C ×400 magnification. (Cooling rate is 5°C)

Figure 1 shows the POM textures of compound 5 at various temperatures. S_{m}A* and S_{m}C* were confirmed. The phases were confirmed using a program controlled heating plate with heating and cooling rate 5^{o}C per second.

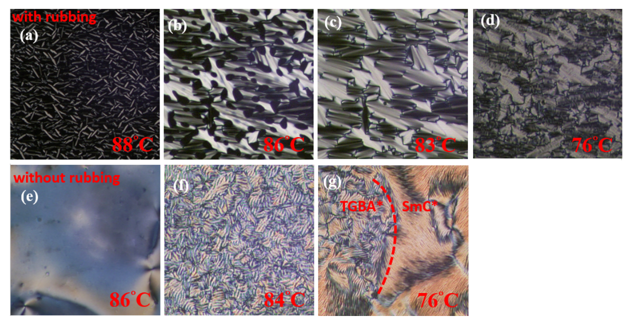


Figure 2: POM texture of compound 6, (a)-(c) growth of SmA* phase from 88°C to 83°C, (d) SmC* phase at 76°C, (e) and (f) growth of TGBA* phase from 86°C to 76°C, (g) SmC* phase at 76°C. (Cooling rate is 5°C, ×400 magnification)

Figure 2 shows POM textures of compound 6 at various temperatures. The phase transition points were confirmed using DSC. POM analyzer was equiped with a program controlled heating plate and a camera. S_{m}A*, S_{m}C* and TGBA phases were confirmed. The substrates were rubbed in parallel direction. Both rubbed and without rubbing LC cells were fabricated. The difference in Figure 2 is mainly due to the effect from alligning layers.

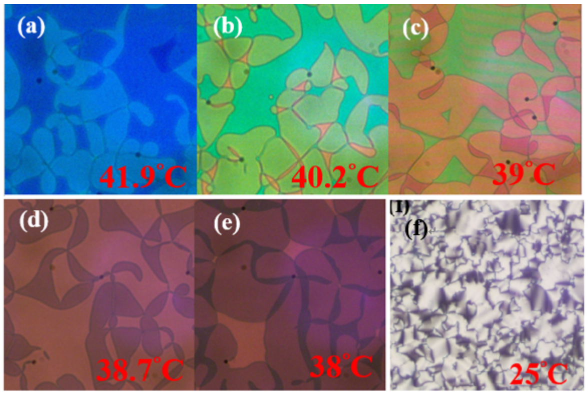


Figure 3: POM texture of compound 3, (a)-(e) TGBA* phase from 41.9°C to 38°C, (f) SmC* phase at 25°C. (Cooling rate is 5°C, ×400 magnification)

Figure 3 shows POM texture of compound 3 at various temperatures. S_mC^* and TGBA* phases were observed. The phase transition temperatures were confirmed with DSC data shown in Table 1. The observed textures were compared with tghose textures in literatures.

To study the application of the synthesized compounds on field sequencial color display (FSCD), a liquid crystal cell was fabricated. The driving schematics for the field-sequential color display with a deformed helix ferroelectric liquid crystal (DHFLC) cell are illustrated in Figure 4. As shown in Figure 4, color symbole of national cheng kung university were observed via the fabricated liquid crystal cell. Besides pure R,G,B color, color image between RGB were also observed.

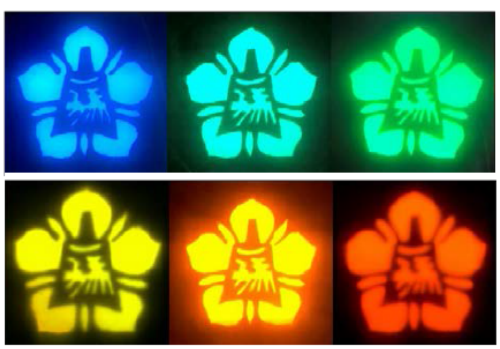


Figure 4: The driving of DHFLC: a) the top three waveforms are the applied signal to the sequential RGB LED, and the bottom waveform is the combined appearance of the DHFLC cell with compound 3. b) Top: target colorful image, middle: deformed-helix ferroelectric liquid crystal cell, bottom: one frame consists of three R-G-B sub-images. c) Photographs of the developed Field-Sequential Color Liquid Crystal Display operated at a color frequency of 500 Hz (i.e., a frame frequency of 166 Hz) of SmC* 3. The device size is 2 cm × 4 cm, and the effective electrode area is 1 cm × 1 cm.

Field sequencial color display is based on the persistence of vision. Figure 5 shows the formation of images via such phenomena. Figure 5(a) shows the voltage biassed on the liquid crystal cell. By controlling the biassed psriod of voltage, various colors were observed. Figure 5(b) shows the formation of color image via a fast sequencial RGB voltage biass. Due to the persistence of vision, color images were observed. In one fram, three images were sequencially shown with a fast frequency.

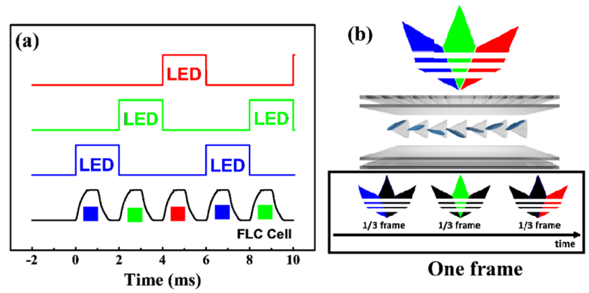


Figure 5: The driving of DHFLC: (a) the top three waveforms are the applied signal to the sequential RGB LED, and the bottom waveform is the combined appearance of the DHFLC cell with the synthesized SmC*s. (b) Top: target colorful image, middle: deformed-helix ferroelectric liquid crystal cell, bottom: one frame consists of three R-G-B sub-images.

3 CONCLUSION

A series of predesigned chiral ferroelectric liquid crystals were synthesized and characterized. Terminal achiral trisiloxane and chiral methyl-lateral substituents gave the synthesized liquid crystalline compounds great phase transition properties. The SmC* phase was found to exist across a wide range near room temperature and had a high spontaneous polarization and a large tilt angle. The observed fast response time of 0.3 ms is sufficient to drive the FLC cell with a high frequency. At high driving frequencies of up to 2 kHz, approximately 70% light transmittance was observed.

Acknowledgements

The authors would like to thank the Ministry of Science and Technology (MOST) of the Republic of China (Taiwan) for financially supporting this research under Contract No. NSC 104-2923-E-006-004-MY3.
*Jun-Yen Liu, e-mail: chunyenliu@berkeley.edu, jimmyliu4017@gmail.com; JH Liu, jhliu@mail.ncku.edu.tw.

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