

Optimizing Electrically Suppressed Helix Ferroelectric Liquid Crystals for Commercial Applications

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Abstract

We present our development of ESHFLC materials characterized by a fast response time of 17 μs at 10 V, a low temperature dependence at a tilt angle of 22.5°, and a broad SmC temperature range from -30.7 to 66.7 °C. These findings highlight the potential of ESHFLCs to advance display and photonic applications while addressing related challenges to material optimization for commercialization.

Author Keywords

Electrically suppressed helix, Ferroelectric Liquid crystal, fast response, efficient displays

1. Introduction

Since the discovery of ferroelectricity in tilted chiral smectic LCs, the largest efforts were concentrated on the development of FLC materials exploiting surface stabilized FLC (SSFLC) [1-3], where the helix pitch (p_0) of FLC materials should be essentially larger than the FLC cell gap (d). However, SSFLC displays did not become commercially profitable products because of the several fundamental problems [2] including alignment issues resulted in unsatisfactory low contrast. The Electrically Suppressed Helix (ESH) FLC [3,4] is a promising alternative to SSFLC.

In many aspects the ESH mode resembles SSFLC, except for the helix pitch (p_0) appearance in an electrooptical (EOP) cell. In SSFLC the helix is completely unwound by surfaces, whereas in the ESHFLC the surfaces unwound it only partially, thus, the helix is always present in absence of electric field. The d/p ratio for ESHFLC suggest that there should be a delicate balance between the surface anchoring energy and helical elastic energy of the FLC molecules [3], such a balance will help in suppressing inherent defects that are associated with SSFLC such as zig zag defects due to chevron structure, C1 and C2 defects and defect arising due to the ferroelectric domains [5]. Therefore, the optical quality of ESHFLC is far superior to the SSFLC and the CR can reach up to 10000:1 and exhibit good mechanical stability.

These key differences between SSFLC and ESH FLC define the requirements to the helix pitch values in a material for each of the mode. For the SSFLC, the helix pitch measured in a bulk should be much longer than EOP cell gap (d) the ratio $d/p \ll 1$, whereas for the ESH FLC, the value of p_0 should be comparable with d or less, i.e. for the typically used cell thickness of 1.5-3 μm the p_0 preferably is in the range of 0.4-1 μm.

Although, ESHFLC showed excellent performance compared to SSFLC, there is still a lot of room for material optimization for commercialization of this technology. Optimizing FLC properties is tricky in general because of the number of parameters involved in the optimization and since it is a multiparameter optimization a single change should not alter the other property. Below we provide a short discussion on parameters involved for optimization, early ESHFLC materials and their shortcomings; followed by explaining the current work.

The first FLC mixture where ESHFLC was discovered [4], is FLC-595. Using FLC-595, the potential of ESHFLC was revealed in 2015 [6] by a full color display covering up to 130% of NTSC requirements based on field sequential mode, which requires no color filter thus boasting efficiency.

A higher T_c , as far as possible of working range, also favors lowering the tilt temperature dependence ($\Delta\theta$). Besides, the chiral component FOTDA of high twisting power [7] can also be exchanged with simpler and easier available LUCH [8], because ESH material does not require very tight pitch.

In this work, we present recently developed ESHFLC materials that approaching simultaneously to the optimal parameter values (response time, viscosity, tilt angle, spontaneous polarization and contrast ratio). The best of our ESH material shows an SmC region from -30.7 to 66.7 °C, temperature tilt dependence as low as 3° from 25 to 55 °C and a response time of 33 μs at 5 V, for room temperature, making it a strong candidate for commercial display applications.

2. Experiment

The experiment was carried out in an optical system shown in Fig.1 containing a laser ($\lambda = 633$ nm), Glan-Thompson based cross-polarizers, heating stage and photodetector. The ESHFLC aligned planar fashion to the cell surface using the alignment layer, 0.5 % Nylon 6 dissolved in 2,2,2-trichloroethanol.

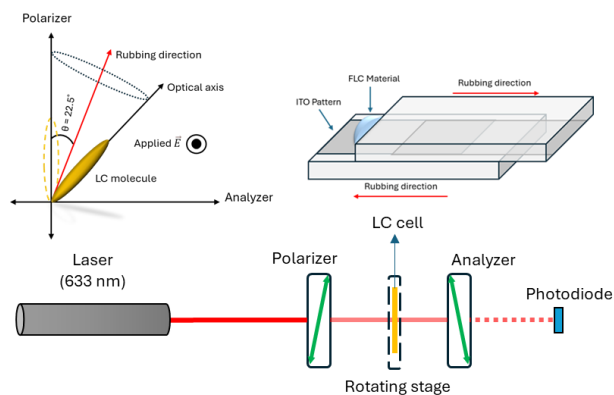


Fig.1 Electro Optics measurement setup
{inset: LC alignment(left),LC cell assembly(right)}

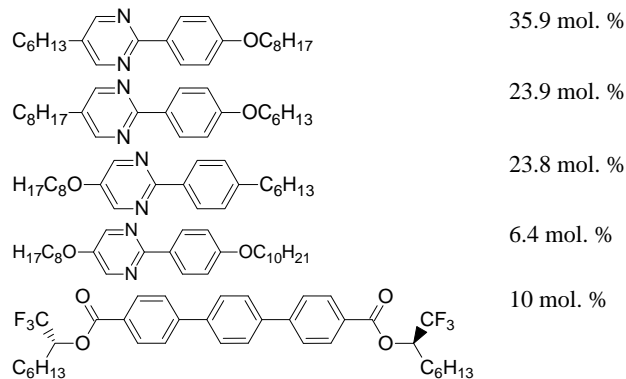
The substrates consist of a conductive Indium-tin-oxide (ITO) layer coating with a specific etched out pattern. The cell dimensions were fixed as (15×20) mm. The patterned ITO substrates were thoroughly washed and put in UV-Ozone chamber for 20 minutes for surface activation.

The substrates were then spin-coated with the nylon 6 solution, to obtain a thin film of alignment layer on the substrates. The coated substrates were then soft baked at 100°C for 10 mins, followed by hard baking at 180°C for 50 mins for removal of the solvent. Thereafter, the substrates were rubbed 7 times with a soft velvet cloth. The rubbed substrates are finally assembled by placing the active region (overlapped ITO region) on the rubbed faces of the substrates facing each other such that the rubbing direction is anti-parallel to each other, as shown in Fig.1(inset: right)

The FLC material is placed at the entrance of one of the openings and filled under a value (250 millibar) vacuum at ~10 °C above the isotropic transition temperature. The molecules under electric field would align their optical axis with 22.5° on either polarity, as shown in Fig.1(inset: left). In such situation, for one polarity where the optical axis is parallel to polarizer will result in a dark state, whereas the other polarity will make an angle of 45°, giving maximum transmittance/bright state.

3. Results and Discussion

The initial candidate for ESH was FLC-595 mixture:



As we already mentioned, due to very low transition temperature $T_{SmC^*} \rightarrow T_{SmA}$ of 42.9 °C, the tilt angle is optimal in only very narrow range (see Fig 3). Besides, the chiral component is also desirable to replace with more available one.

The first generation of improved ESH is VVV-11-165 mixture. It exhibits an ideal tilt value of 22.5°, $V_C \sim 0.7$ V, $P_S = 50$ nC/cm², $p_0 = 515$ nm and a response time of 17 μs at 10 V for 25 °C. However, this material was poor in its tilt temperature dependence, having $\Delta\theta$ (change in tilt from 25 to 55 °C within the SmC* phase) of 5.5°, as well Δn should also be reduced to provide half-wave plate optical condition with larger cell gap suitable for industry.

Eventually, we developed ESHFLC material deploying phenacylic SmC components [9] to reduce Δn keeping high T_c , which shows promising results. The ESH-FLC VVV-12-104 has the following phase transitions (in °C): Cr -30.77° SmC 66.2° SmA 86.4 Iso; and $p_0 = 517$ nm, $P_S = 37$ nC/cm², tilt = 23.05 ° measured at 25 °C.

A comparison of tilt angles, as shown in Fig 2, clearly shows the temperature dependence of these materials. For the mixture FLC 595, since the transition temperature lies below 55°C range, the tilt temperature dependence $\Delta\theta$ is not applicable or incomparable.

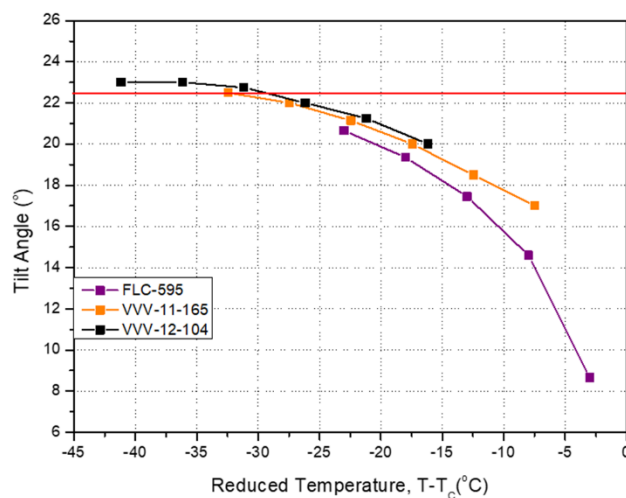


Fig. 2 Tilt angle comparison. {Red line: ideal tilt angle 22.5°}

The response time of the ESHFLC's as a function of electric field was measured at a frequency of 90 Hz at 25°C(Fig.3). FLC-595 has the critical field of helix unwinding (V_c) at ~0.4V [6], at which the helix is completely unwound. Similarly for 11-165 and 12-104, the V_c is 0.72 V and 0.56 V respectively. In terms of driving voltage, it depends on the driving scheme for the panel. Typically, a driving voltage of 5 V, is sufficient to achieve completely saturated response from any ESHFLC material.

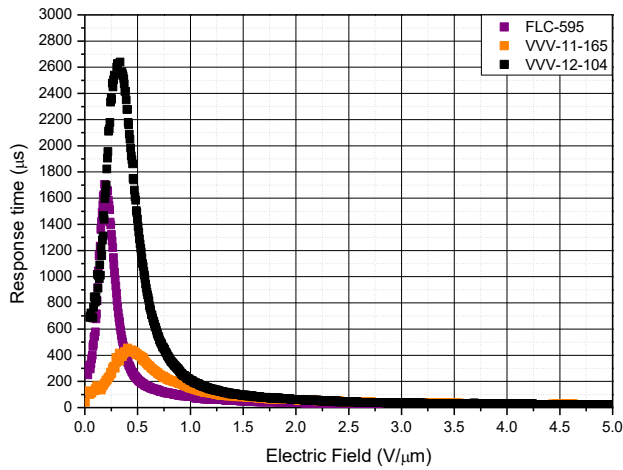


Fig. 3 Response time/On time (in μs)

Both 11-165 and 12-104 have a response time of 33 μs at 5V. For measuring the response time, a square wave of $\pm 5\text{V}$ has been applied to the LC cell (Fig.4).

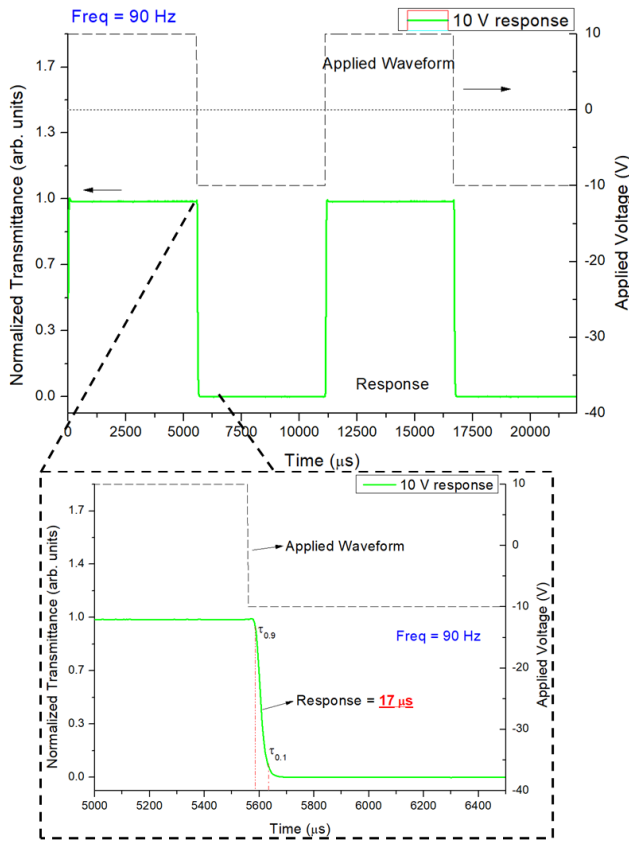


Fig. 4 Response curve of the ESHFLC. Green curve is the optical response curve; dotted black curve is the applied waveform.

When the cell is set at $\beta = 0^\circ$, the molecules will change their optical axis from $+22.5^\circ$ to -22.5° at $V > V_c$. The transmittance versus voltage curve shows the transmittance saturates for voltages $> 1.5\text{V}$. The cell shows excellent alignment quality at these voltages, as shown in Fig.6.

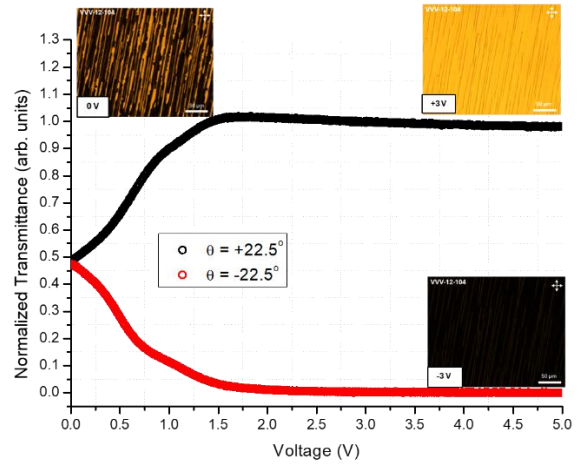


Fig. 5 Transmittance versus Voltage

Table 1. lists out the ideal and acceptable parameters for an ESHFLC material to deploy into real world applications. VVV-12-104 has a broader SmC region, ranging from -30.77°C to 66.17°C . With a slight increase in tilt at 23.05° compared to VVV-11-165, 12-104 still shows a better temperature dependence of 3° in the SmC region.

Table 1 Key parameters of ESHFLC

Parameter	ESHFLC		FLC595	VVV-11-165	VVV-12-104
	Ideal	Accept.			
Crystallization temperature, $^\circ\text{C}$	< -30	< -10	-28.8°	-24.3°	-30.8°
T_c , $^\circ\text{C}$	$> 80^\circ$	$> 60^\circ$	43.0°	57.5°	66.2°
Tilt angle, θ	22.5°	$22.5^\circ \pm 0.2$	20°	22.5°	23.05°
Temperature dependence of θ ,	0°	2°	N/A	5.5°	3.0°
Helical pitch, μm	0.5-0.6	0.5-0.6	0.495	0.517	0.532
Birefringence	0.10	0.10 ± 0.03	0.16	0.15	0.14
Driving Voltage, V	$\pm 5\text{ V}$	$\pm 5\text{ V}$	$\pm 5\text{ V}$	$\pm 5\text{ V}$	$\pm 5\text{ V}$
Response time, μs	< 10	< 50	22	33	32
Viscosity	< 0.010	< 0.030	0.022	0.0277	0.0205

Another fact to consider is that the higher the transition temperature T_c , better would be the tilt temperature dependence near room temperature. In other words, tilt would be stable for the operating region. This is evident for the 2 materials in study. With the response time for both, 11-165 and 12-104, being the nearly of the same order, either of these materials would prove effective for fast switching requirements in any modern display field sequential color display. There is still some room for improvement in the temperature dependence of tilt, which can be further modified by increasing the transition temperature, T_c . The response time could

also be improved by slightly lowering the viscosity of the material. However, even within these limitations, these materials have a lot of potential in the field of LCD displays, and even beyond display such as in photonic components such as FLC grating, Fresnel lens, circular damman grating etc.

4. Conclusions

We here report on the development of ESHFLC material, where all key parameters are achieved simultaneously in terms of operating range, tilt temperature dependence, viscosity, response time, etc., which are all vital parameters to consider for competing in the current market for display and photonic applications. Our lab has synthesized an ESHFLC exhibiting an impressive SmC region of 95.4°, temperature tilt dependence as low as 3°, and a response time of 33 μ s at 5 V for room temperature. This is substantial growth in the field of ESHFLC that will open wide possibilities and offer efficient quality of display in terms of response, temperature stability, and contrast etc.

5. Acknowledgements

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