

# Long-pitch Supertwisted Nematic with Low Driving Voltage

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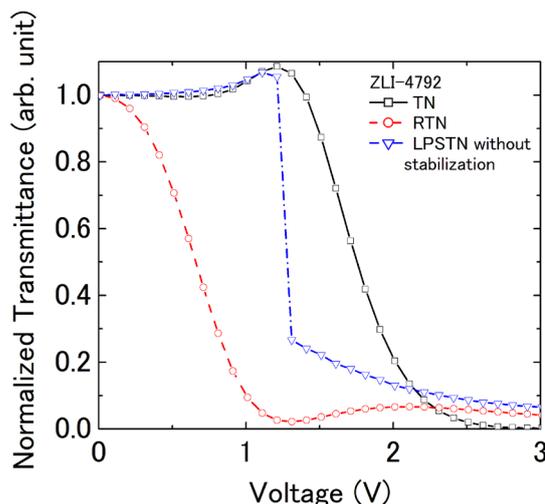
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## ABSTRACT

The stabilized long-pitch supertwisted nematic (LPSTN) structure could be formed during the stabilization process of the reverse twisted nematic (RTN) structure at a temperature near the clearing point. A notable feature of LPSTN liquid crystal devices is that a black state can be realized, unlike the normal supertwisted nematic (STN) mode under the crossed nicols condition.

## 1 Introduction

A reduction in the driving voltage of liquid crystal devices (LCDs) is desirable. Twisted nematic (TN) LCDs with low driving voltage have been achieved by the selection of LC materials that exhibit large dielectric anisotropy, a twisted hybrid aligned (THA) [1], hybrid twisted nematic (HTN) [2], quasi-twisted nematic (Q-TN) [3], or a reverse twisted nematic (RTN) [4]. An RTN with low driving properties is achieved by the addition of a chiral reagent opposite to the twist distortion determined by the rubbing directions. The RTN structure is formed by the application of voltage over Fredericks transition threshold voltage to the splay twisted (ST) structure and is maintained with application of a specific voltage. This voltage is referred to as the sustain voltage. This structure was metastable and relaxed to the ST structure after the voltage was turned off. The ST structure changes to the RTN structure because the director near the center of the LC cell is rotated oppositely as the Gibbs free energy increases with the voltage. This phenomenon can be explained by assuming that the stress of the LC structure generated by the splayed structure with an electric voltage can be released because the reversely twisted structure (no splay deformation) is more stable than the splayed structure [4–6]. The RTN structure that includes reactive mesogens (RMs) was stabilized by the formation of a polymer matrix with UV irradiation under application of a voltage from 1.25 to 1.5 V [7]. The driving voltage for the RTN-LCD is reduced compared to that with the TN-LCD (Fig. 1). The RTN structure appears when the chiral pitch to cell thickness ( $p/d$ ) ratio is more than 3. When the  $p/d$  ratio was 2.14, a supertwisted nematic (STN) structure appeared [8], of which the twist direction is opposite to the one for the expected RTN structure. Application of a voltage higher than the threshold voltage to the ST structure increases the energy of the ST structure to obtain the STN structure without splay structure twisting in the direction of the chiral LC material. The STN has an increased twist angle of from



**Fig. 1.** Dependence of transmittance on the applied voltage for TN-LCDs (black open squares, cell thickness = 5.0  $\mu\text{m}$ ), RTN-LCDs (red open circles, chiral pitch = 15.0  $\mu\text{m}$ , cell thickness = 5.0  $\mu\text{m}$ , RM) [4], and LPSTN-LCD (blue open reversed triangles, chiral pitch = 15.0  $\mu\text{m}$ , cell thickness = 7.0  $\mu\text{m}$ ) [8].

180° up to 270° [9–11], which is known to increase the steepness of the transmittance-voltage curve, as shown in Fig. 1 [8]. When the  $p/d$  ratio is 2.14, the RTN structure appears by application of a high voltage to the STN structure, while the ordinary STN ( $p/d$  ratio = 1.5) does not change to the RTN. Our group refers to this non-ordinary STN ( $p/d$  ratio > 1.5) as a long-pitch STN (LPSTN).

In this study, we focus on the effect of thermal energy on the Gibbs free energy and attempt to cause the transformation by heat rather than voltage to maintain the structure by application of a low voltage. At a temperature slightly below the nematic isotropic point, the ST state changed to the RTN state with the application of 1.0 V. When this RTN structure was irradiated with UV, the LPSTN structure was maintained. Furthermore, the electro optical properties and Gibbs free energy were calculated for each structure and compared with the measurement results.

## 2 Experiment

The LC material (MLC-2173 (US048), Merck Co.) had a left-handed pitch of 15.0  $\mu\text{m}$  and 1% RM. The cell thicknesses were set at 5.4  $\mu\text{m}$  using silica bead spacers.

The rubbing directions were set to form a right-handed twist of the LC material without a chiral reagent from the upper to the lower substrate. The polyimide material for the alignment layers was produced by mixing PIA-X768-01X and PIA-X359-01X (Chisso Petrochemical Co.) in a 15:85 ratio. The pretilt angle of the alignment layer was confirmed to be 6° with a pretilt analysis system (PAS-301, ELSICON Co.). The temperature was controlled with a high-precision temperature controller (mK1000, Instec Inc.) and UV light was irradiated to cure the RM with a UV lamp (LUV-6, AS ONE Co.). The electro optical properties (applied voltage dependence of the transmittance and response time) were measured using an OPTIPRO-standard (Shintech Inc.). The dielectric anisotropy  $\Delta\epsilon$ , and the elastic constants  $K_{11}$  and  $K_{33}$  were measured with an LC elastic constant measurement system (EC-1, Toyo Co.). The optical axis of one polarizer was set parallel to one of the rubbing directions in a crossed nicols setting. Simulations of the electro optical properties and Gibbs free energy were performed using the LCD Master (Shintech Inc.) software under various conditions, such as pretilt angle, cell thickness, and chiral pitch. The LCDs were driven by a square wave.

### 3 Results and Discussion

The transition from ST to RTN was confirmed by polarized optical microscopy (POM) measurements under a crossed nicols condition. The clearing point for this LC is 353 K (Merck & Co., Inc.). Figure 2 shows the lowest sustain voltage as a function of temperature. These voltages started to decrease near 343 K. Transition to the isotropic phase occurred with application of 1.0 V at 356.5 K for 5.4  $\mu\text{m}$ . At a high temperature near the clearing point, the chiral pitch extended up to 16.8  $\mu\text{m}$ , and  $\Delta\epsilon$  and  $K_{11}$ ,  $K_{22}$ , and  $K_{33}$  decreased to 1/4.  $K_{22}$  is represented by

$$K_{22} = \frac{1}{4} \left( 4K_{11} + K_{33} - \frac{\epsilon_0 \Delta\epsilon}{\pi^2} V_{th}^2 \right) \quad (1)$$

where  $V_{th}$  is the threshold voltage of TN-LCD. The RTN structure appears easily because  $p/d$  becomes larger and the elastic constants get smaller at high temperatures.

A decrease of the voltage under 0.5 V resulted in a transition of the RTN structure to the ST structure via the STN state (Fig. 3(b)), while the RTN structure relaxed to the ST structure directly at room temperature (Fig. 3(1)). An increase of the voltage to 1.0 V before relaxing to the ST structure resulted in a transition of the STN structure to the RTN structure, while the ST structure was maintained. It was necessary to apply 1.2 V to transform the ST structure into the RTN structure, while 1.0 V is required for a transition from the STN to the RTN structure. Therefore, there is a higher potential barrier between ST and RTN than between STN and RTN.

These RTN-LCDs were irradiated with UV light for 1 h, while 1.0 V was applied at 356 K, after confirmation of the RTN structure with POM observations. The RTN structure was maintained at high temperature; however, the LPSTN structure was formed at room temperature. Figure 4

(green solid triangles) shows voltage-transmittance (V-T) curves for the LPSTN. The RTN structure relaxed to the ST structure at room temperature when the cell thickness was under 5.3  $\mu\text{m}$ . The driving voltage increased in the order of RTN-LCD (red open circles) < LPSTN-LCD (green solids triangles) < TN-LCD (black solid pentagons ( $d = 5.4 \mu\text{m}$ ) and black open squares ( $d = 5.0 \mu\text{m}$ )). When the V-T curves were calculated (LCD Master) for cell thicknesses of 5.0-6.2  $\mu\text{m}$  with a chiral pitch of 15  $\mu\text{m}$ , a pretilt of 6° and a twist angle of 270°, the driving voltage was the lowest for a cell thickness of 5.0  $\mu\text{m}$  (Fig. 5). However, the structure of 5.0  $\mu\text{m}$

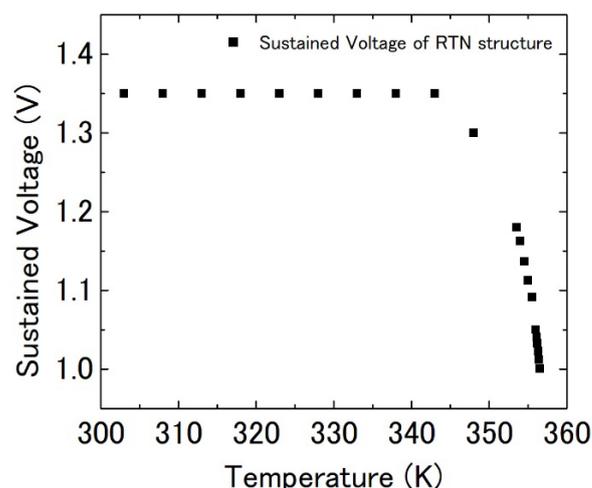


Fig. 2. Dependence of the sustain voltage of the RTN structure on the temperature.

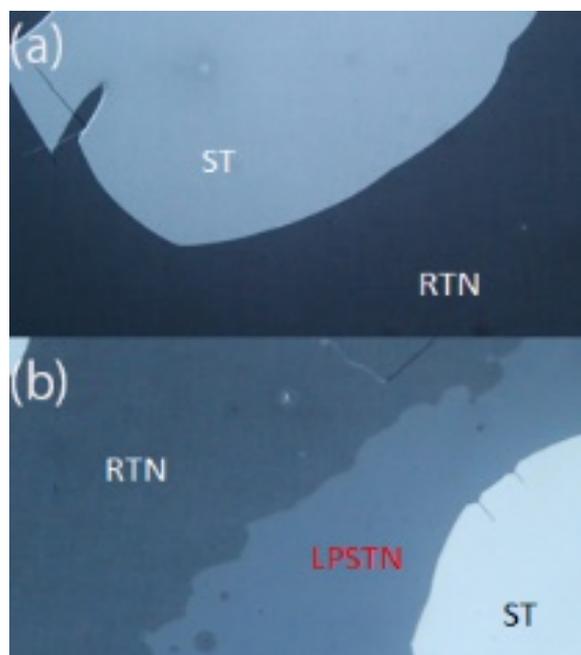
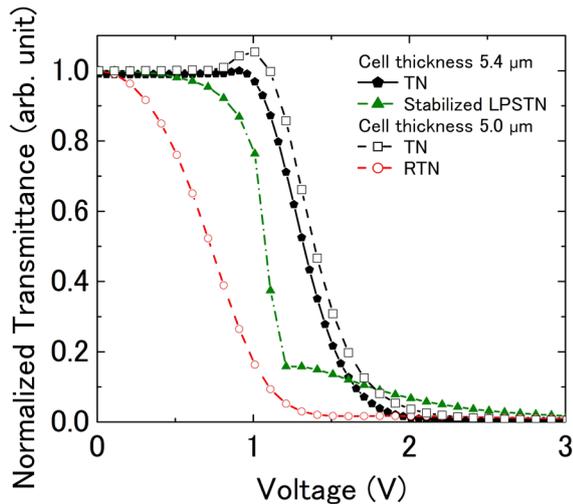
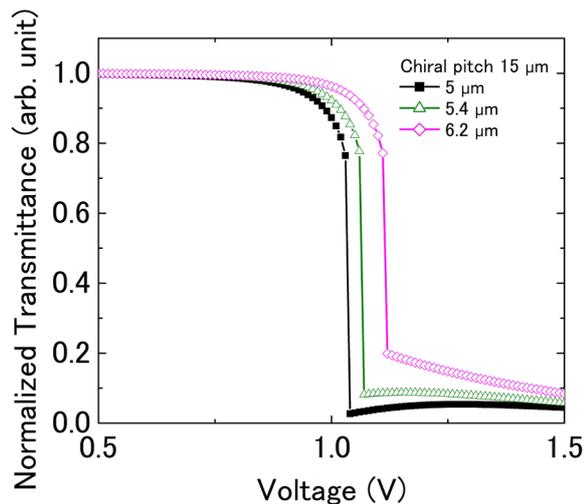


Fig. 3. POM images of LC structures when the voltage was decreased from 1.0 V to 0.5 V at (a) room temperature and (b) 356K.



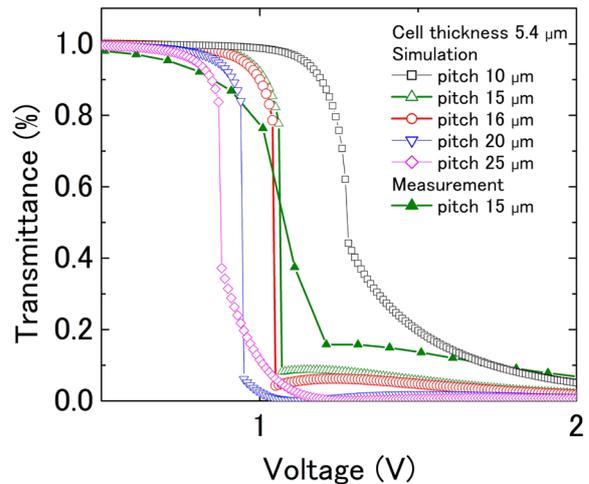
**Fig. 4.** Dependence of transmittance on the applied voltage for the LPSTN-LCD (green solids triangles), RTN-LCD (red open circles), and TN-LCD (black solid pentagons ( $d = 5.4 \mu\text{m}$ ) and black open squares ( $d = 5.0 \mu\text{m}$ )).



**Fig. 5.** Dependence of transmittance on the applied voltage for cell thicknesses of 5.0, 5.4, and 6.2  $\mu\text{m}$ .

returned to the ST structure even if RMs were polymerized when the structure was RTN with application of the sustain voltage at high temperature.

Figure 6 shows V-T curves for LPSTNs calculated for various chiral pitches of 10–25  $\mu\text{m}$  and a cell thickness of 5.4  $\mu\text{m}$ . A longer chiral pitch resulted in a lower driving voltage; however, if the pitch was too long, then the transmittance was slowly decreased as a function of the voltage. However, the structure returned to the ST structure experimentally when the  $p/d$  ratio was over 2.78 in the case of the chiral pitch of 15  $\mu\text{m}$ . The dependence of the transmittance and the change of the azimuth angle on the voltage were calculated for LPSTN using LCD Master for a cell thickness of 5.4  $\mu\text{m}$  and a chiral pitch of 15  $\mu\text{m}$ . The transmittance decreased similar to that for STN LCDs



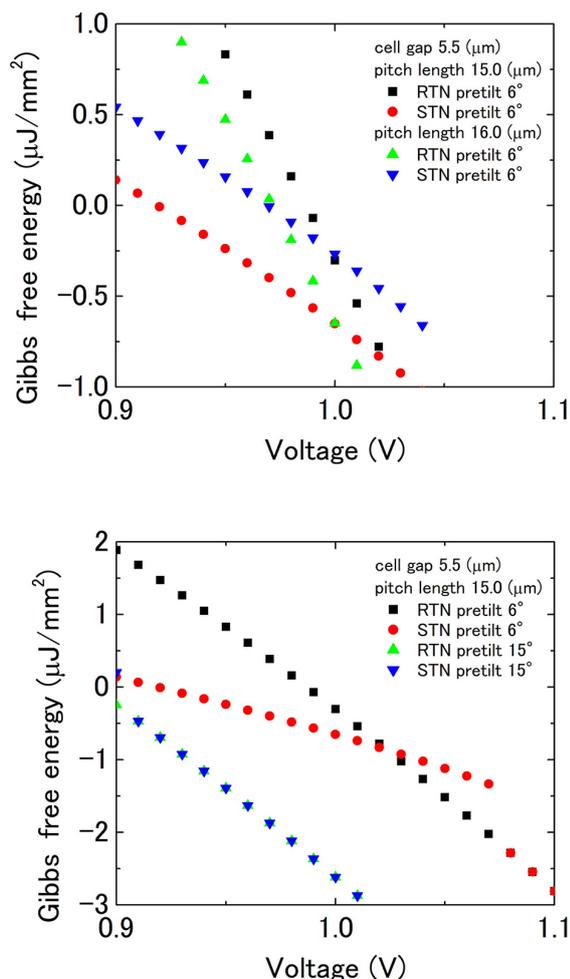
**Fig. 6.** Dependence of transmittance on the applied voltage of LPSTNs for chiral pitches of 10, 15, 16, 20, and 25  $\mu\text{m}$  by simulation and a chiral pitch of 15  $\mu\text{m}$  by measurement.

until 1.06 V and then dropped slowly from 1.07 V. The twist of the azimuth angle was  $270^\circ$  up to 1.06 V, which then changed to  $90^\circ$ , not simple rotation. The LC molecules near the alignment layer twist left-handed. This phenomenon is an intrinsic twist for the RTN structure. Consequently, the LPSTN structure changed into an RTN structure with application over a certain voltage.

The Gibbs free energy for the RTN and STN was calculated for chiral pitch lengths of 15.0 and 16.0  $\mu\text{m}$ , and pretilt angles of  $6.0^\circ$  and  $15.0^\circ$  (Fig. 7) because the pitch length of MLC-2173 (US048) was 16.8  $\mu\text{m}$  at 351 K and the tilt angle in the vicinity of the alignment layer could be higher because the RMs were polymerized by UV irradiation when the sustain voltage was applied. The energy of the RTN and STN structures decreased when the pretilt angle increased. The transition from the STN to RTN structure occurred at over 0.9 V. The energy of the STN is lower than that of the RTN at 1.0 V when the pretilt angle was low. On the other hand, the energy of the RTN structure decreased and that of the STN structure increased when the pitch length was increased. The RTN structure (green triangles in Fig. 7) was stable for a chiral pitch of 16.0  $\mu\text{m}$  under application of 1.0 V at high temperature; however, after UV irradiation, the STN structure was stable because the pitch length returned to 15  $\mu\text{m}$  at room temperature.

#### 4 Conclusions

The LPSTN-LCD, but not the RTN-LCD, was successfully stabilized with UV irradiation under application of 1.0 V near the clearing point. It is considered that the LPSTN was stabilized because the sustain voltage was low compared with that for



**Fig. 7. Gibbs free energy for the RTN and the STN structures with various (upper) chiral pitches and (lower) pretilt angles with a cell thickness of 5.5  $\mu\text{m}$ .**

stabilization of the RTN [7] and then the pretilt angle was low. The notable points of the LPSTN-LCD are a low driving voltage and a black display when a high voltage is applied under the crossed nicols condition. A black state can be realized due to the change from STN structure to TN structure, unlike the normal STN mode under the crossed nicols condition. The upper limit of the  $p/d$  ratio for the LPSTN was 2.14 [8]; however, that was improved to 2.78 using this method. The lowest driving voltage was calculated when the chiral pitch was 15 or 20  $\mu\text{m}$  with cell thicknesses of 5.0 or 5.4  $\mu\text{m}$  ( $p/d$  ratios of 3.0 or 3.7). The structure returned to the ST structure under the former condition. If the  $p/d$  ratio is dominant, then the structure will return under the latter condition. Further consideration will be required to determine the conditions for LPSTN stabilization, such as the elastic constant at high temperature.

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