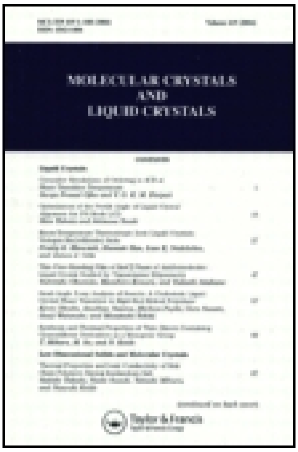

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

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Version of record first published: 24 Sep 2006.

Mol. Cryst. Liq. Cryst., 1993, Vol. 225, pp. 81–88
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Printed in the United States of America

A Novel Liquid Crystal Display: A Randomly-Oriented Nematic Liquid Crystal Display (RON-LCD)

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(Received March 9, 1992; in final form May 1, 1992)

A novel liquid crystal display: a Randomly-Oriented Nematic Liquid Crystal Display (RON-LCD) is demonstrated and the electro-optical properties are discussed compared with those of a Polymer Network Liquid Crystal Display (PN-LCD). The Homeotropic-RON-LCD with an 8 μm network layer and a 2 μm no-network layer has sufficient opaqueness at off-state and can be driven by lower voltage than the d = 10 μm PN-LCD. The resistivity of RON-LCD is improved by using a liquid crystal PN-011.

Keywords: light scattering, alignment

1. INTRODUCTION

Liquid crystal displays (LCDs) which utilize the electro-optical effects of nematic/polymer films dispersed micron-sized droplets of nematic liquid crystals in a polymer matrix have been reported.[1-4] They are known as NCAP or PDLC films in which a nematic droplet is perfectly surrounded by a polymer matrix and isolated from each other. We presented[5-8] Polymer Network Liquid Crystal Displays (PN-LCDs) which contain a three-dimensional polymer network in liquid crystal (PNLC). The PNLC can be driven at lower voltage than NCAP or PDLC. The Guest-Host PNLC, however, is difficult to achieve because the PNLC is prepared by polymerization-induced-phase separation with UV light. Moreover, the preparation conditions should be optimized for each PNLC material and the resistivity of the PNLC is reduced during UV irradiation.

We are interested in using a substrate, which can orient the nematic liquid crystals randomly, for a light-scattering liquid crystal display. Based on the PNLC technology, we have now achieved a novel liquid crystal display: a Randomly-Oriented Nematic Liquid Crystal Display (RON-LCD). A RON-LCD includes a substrate with a polymer network which orients the nematic liquid crystal randomly and another substrate with or without an alignment layer. We discuss the electro-optical properties of several kinds of RON-LCDs compared with those of PN-LCDs.

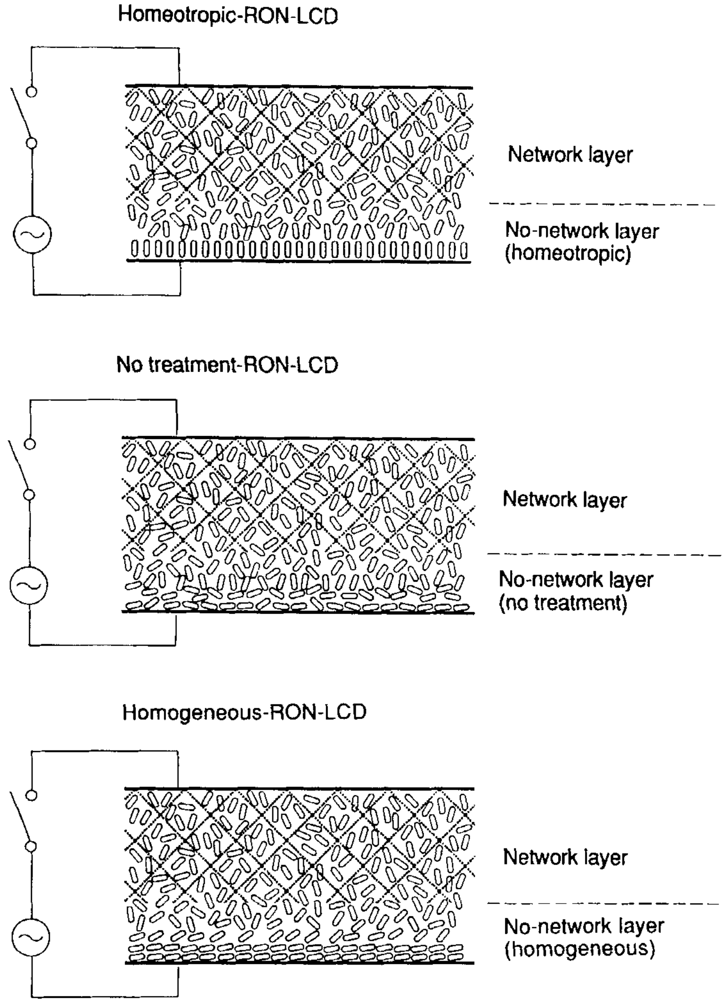

FIGURE 1 Off-state configuration of RON-LCDs.

2. STRUCTURE AND OPERATING PRINCIPLE

Figure 1 shows the off-state configurations of the RON-LCDs. The nematic molecules in the network layer are aligned parallel to the surface of the polymer network, which is randomly oriented. As a result the nematic molecules are oriented randomly. A Homeotropic-RON-LCD and a Homogenous-RON-LCD include substrates with an alignment layer, and the nematic molecules are aligned perpendicular and parallel to the respective substrates. A "No-treatment-RON-LCD" includes no alignment layer and the directors of the nematic molecules are randomly oriented.

The randomly-oriented nematic liquid crystal causes light scattering at off-state and the display is opaque. By applying an electric field, the nematic molecules are

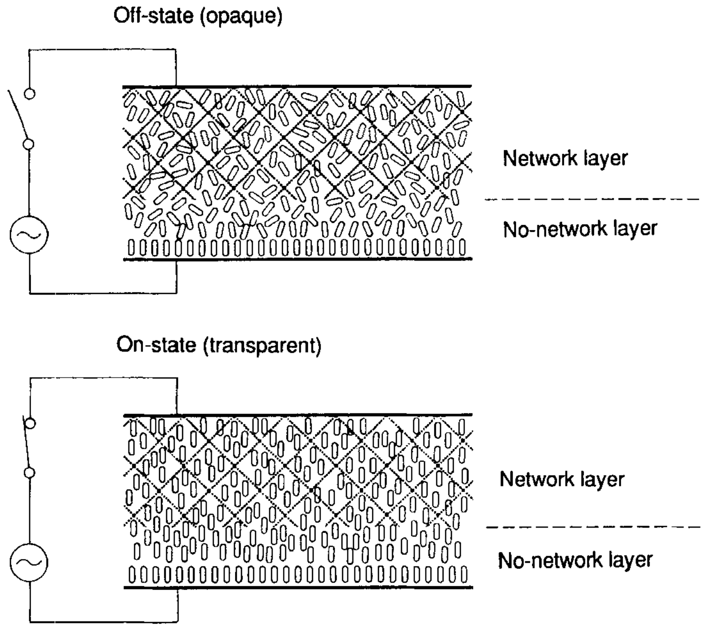

FIGURE 2 Operating principle for a RON-LCD.

TABLE I

Properties of nematic liquid crystals PN-001, PN-005 and PN-011

	PN-001	PN-005	PN-011
T_{N-I}	68.5	72.1	66.3
n_e	1.787	1.759	1.708
n_o	1.533	1.525	1.512
Δn	0.254	0.234	0.196
$\Delta \varepsilon$	26.9	27.8	13.8
$\eta_{20^\circ C}$ (c.p)	59.1	83.6	48.5
K_{11} ($\times 10^{-12}$N)	6.5	7.0	8.8
K_{33} ($\times 10^{-12}$N)	17.1	18.8	14.2

aligned parallel to the field as shown in Figure 2. No light scattering occurs and the display becomes transparent.

3. PREPARATION

The diacrylate oligomer and the photoinitiator are solved in the liquid crystal PN-001, consisting of the 2-(4-cyanophenyl)-5-alkyl-pyridines and the 2-(4-cyano-phenyl)-5-(4-alkylphenyl)pyridines. The solution is sandwiched with a thickness of a network layer 6~10 μm controlled by glass fiber spacers between a glass substrate with a transparent conductive electrode and a polycarbonate substrate. After poly-

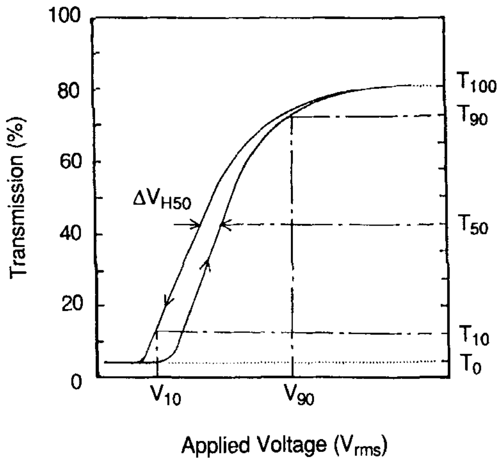

FIGURE 3 Definition of electro-optical properties V_0, V_{10}, T_0, T_{100} and ΔV_{H50} for transmission-voltage characteristic.

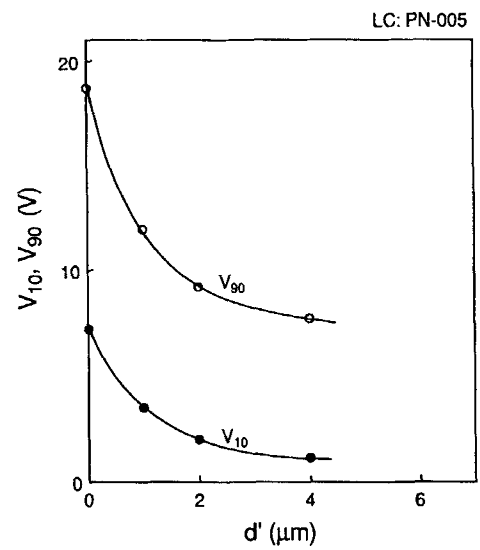

FIGURE 4 Influence of thickness of no-network layer (d') in $d = 10$ μm Homeotropic-RON-LCD cell on the threshold voltage V_{10} and the saturation voltage V_{90}.

merization with UV light, the polycarbonate substrate is stripped off and the liquid crystal is removed by a solvent. The substrate with a polymer network is completed by drying. After the vacant cell is fabricated by a normal method using the substrate with a polymer network and another substrate with or without an alignment layer on a conductive electrode, the cell is filled with a proper liquid crystal. We have now filled the RON-LCDs with nematic liquid crystal PN-005 or PN-011. The properties of PN-001, PN-005 and PN-011, which can be supplied by Rodic Co., are shown in Table I.

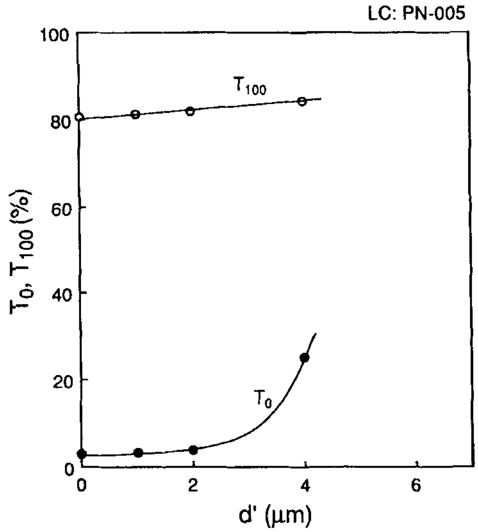

FIGURE 5 Influence of thickness of no-network layer (d') in d = 10 μm Homeotropic-RON-LCD cell on the T_0 and the T_{100}.

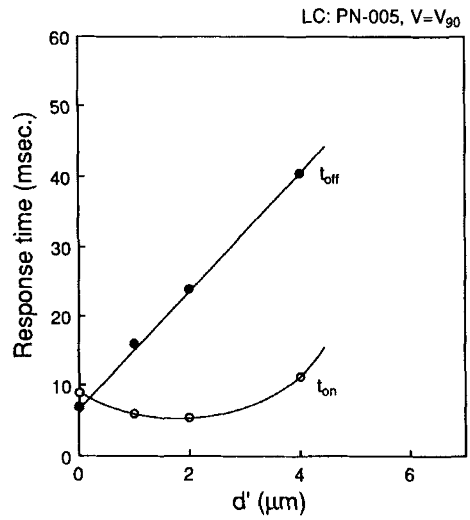

FIGURE 6 Influence of thickness of no-network layer (d') in d = 10 μm Homeotropic-RON-LCD cell on the response times t_{on} and t_{off}.

4. ELECTRO-OPTICAL PROPERTIES

The transmission-voltage characteristics were measured, detecting the light beam passed through the sample and the aperture by a photomultiplier. The off-state transmission T_0, the transmission at the 100% saturated voltage T_{100}, the threshold voltage V_{10}, the saturation voltage V_{90} and the hysteresis width ΔV_{H50} are defined in Figure 3. The response times measured at the driving voltage which is equal to

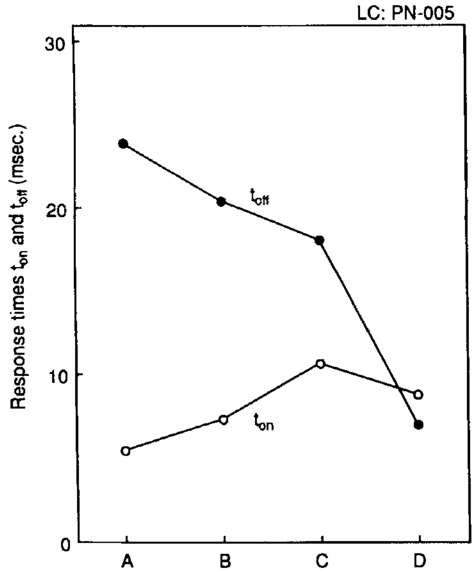

FIGURE 7 Comparison of response times t_{on} and t_{off} for d = 10 μm, d' = 2 μm RON-LCD and d = 10 μm PN-LCD cells.

TABLE II

Comparison of hysteresis width ΔV_{H50} for d = 10 μm, d' = 2 μm RON-LCD and d = 10 μm PN-LCD cells filled with PN-005

	Cell	d (μm)	d' (μm)	Hysteresis width ΔV_{H50} (V)
A	Homeotropic-RON-LCD	10	2	0.4
B	No-treatment-RON-LCD	10	2	0.4
C	Homogenious-RON-LCD	10	2	0.6
D	PN-LCD	10	-	1.2

the saturation voltage V_{90} correspond to the transmission changes t_{on} (0%→90%) and t_{off} (100%→10%).

Figure 4 shows the influence of the thickness of a no-network layer (d') in the Homeotropic-RON-LCD cell, filled with a nematic liquid crystal PN-005, on the threshold voltage V_{10} and the saturation voltage V_{90}. The thickness of the RON-LCD cell (d) is 10 μm. We use the data of a PN-LCD cell when d' equals zero. The appearance of a no-network layer decreases the threshold and the saturation voltages drastically. The V_{10} and the V_{90} decrease with the increase of the thickness of a no-network layer. The Homeotropic-RON-LCD with a 2 μm no-network layer can be driven at almost half the driving voltage for a PN-LCD.

The transmission at off-state T_0 relates to the opaqueness caused by the light scattering, that is, a strong light scattering gives a small value of T_0 which leads to good contrast. The liquid crystal display with a value of $T_0 > 10\%$ does not give

TABLE III

Electro-optical properties of $d = 10\ \mu m$, $d' = 2\ \mu m$ Homeotropic-RON-LCD filled with PN-011

V_{10}	2.6 V
V_{90}	11.8 V
T_0	5.8 %
T_{100}	83.1%
t_{on}	4.3 msec
t_{off}	14.0 msec
ΔV_{H50}	0.4 V
Resistivity	$1.3 \times 10^{11}\ \Omega cm$

a sufficient contrast. Figure 5 shows the influence of the thickness of a no-network layer (d') on the T_0 and T_{100}. The T_0 increases rapidly where the thickness of a no-network layer is between 2 μm and 4 μm. The Homeotropic-RON-LCD with a 4 μm no-network layer has 25% T_0 and cannot be used for a display. The Homeotropic-RON-LCD with a 2 μm no-network layer exhibits almost the same strength of light scattering as the PN-LCD in which the polymer network occupies the whole area in the 10 μm cell, and exhibits stronger light scattering than the $d = 8\ \mu m$ PN-LCD. This shows that the directors of the liquid crystal molecules in the 2 μm of a no-network layer are random by the influence of the 8 μm of a network layer and the randomness contributes to the light scattering.

Figure 6 shows the influence of thickness of a no-network layer (d') in a Homeotropic-RON-LCD cell on the response times t_{on} and t_{off}. The Homeotropic-RON-LCD cell with a 2 μm no-network layer has a quicker turn-on time t_{on} than the 10 μm PN-LCD. The t_{on}, however, increases with the increase of the d' in the range of $d' > 2\ \mu m$. The turn-off time t_{off} increases with the increase of the d'. Figure 7 shows the response times t_{on} and t_{off} for $d = 10\ \mu m$, $d' = 2\ \mu m$ RON-LCD cells with or without an alignment layer, and for $d = 10\ \mu m$ PN-LCD cell. From Figure 7 it follows that the homeotropic alignment layer makes the t_{on} quicker and the t_{off} slower, and the homogeneous alignment layer makes the t_{on} slower and the t_{off} quicker than a no-treatment substrate. By the comparison with the result for PN-LCD, it is clear that the no-network layer makes the t_{off} slow in every RON-LCD.

Table II shows the hysteresis width ΔV_{H50} for $d = 10\ \mu m$, $d' = 2\ \mu m$ RON-LCD and $d = 10\ \mu m$ PN-LCD cells filled with PN-005. It is stated [4] that the shape of the nematic droplet influences the hysteresis for NCAP or PDLC. The structure of the polymer network also probably influences the hysteresis. The hysteresis width of each RON-LCD becomes drastically narrower than that of PN-LCD, whereas the structure of the network layer in each RON-LCD should be almost the same as that of PN-LCD. It follows that the no-network layer in RON-LCD reduces the hysteresis width; alternatively the interface between the liquid crystal and the polymer network, which is cleaned by a solvent, reduces the hysteresis width. Moreover, it is interesting that the alignment layer can also influence the hysteresis width for a RON-LCD; the homogeneous alignment increases the hysteresis width.

The low viscosity of the liquid crystal leads to a quick response and the use of a small concentration of strongly polar liquid crystal components enable to fabricate a highly-resistive liquid crystal display, which is important for the active addressing. Considering these, we prepared a liquid crystal PN-011, which is less viscous and includes less concentration of the polar liquid crystal components than PN-005. Table III shows the electro-optical properties of d = 10 μm, d' = 2 μm Homeotropic-RON-LCD filled with PN-011. The t_{off} is reduced to 14.0 msec. by the lower viscosity of PN-011 than that of PN-005. The specific resistivity of the RON-LCD is improved to 1.3×10^{11} Ω cm.

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