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STN-gels in fast passive matrix displays

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STN-gels in fast passive matrix displays

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Liquid crystalline physical gels have been prepared in a super twisted nematic configuration. These gels show a remarkable increase in switching speed from the in field to out of field relaxation. We explore whether these gels might be used in fast passive matrix displays.

1. Introduction

Liquid crystal displays are increasingly used for showing animations or even video content. Therefore increasing the response speed in liquid crystal displays is an important topic. The switching dynamics of a display can be manipulated in several ways. The response of the liquid crystal to an externally applied electric field is faster at higher field strength. This is used in so-called overdrive schemes [1]. The response speed upon decreasing the electric field on the other hand is determined by the material parameters of the liquid crystal and the cell thickness. The dependence on the cell thickness is related to the fact that the change in liquid crystal orientation upon decreasing the electric field propagates from the cell walls [2, 3].

The introduction of polymer networks into liquid crystals has also been shown to increase their speed of response [4, 5]. In this case the network promotes the orientation of the liquid crystal, such that propagation does not necessarily have to propagate from the walls [6–8]. It has been shown that by varying the electrical field during polymerization, the structure of the polymer network can be manipulated and the response speed changed [4]. One disadvantage of polymerization inside the liquid crystal is that residual traces of initiator often adversely affect the liquid crystal properties. Recently it has been shown that networks formed by hydrogen bonding can have a similar effect in twisted nematic displays [9–11]. These displays exhibit a rather weak dependence of transmission on the electric field, and are therefore only suitable for active matrix addressing. In this paper we report on similar liquid crystal gels in a super twisted nematic (STN) configuration. We explore whether these may be used for fast addressing in passive matrix displays.

2. Experimental

2.1. *Samples*

Cells were made in two configurations, a 240°- and a 260°-twist configuration. The liquid crystal mixtures were custom made for commercial STN displays and obtained from Dainippon Ink (Japan). The concentration of chiral dopant was chosen in such a way that no orientation artefacts occurred upon switching of the samples without a gelling agent. For the 240°-twist sample the dopant concentration was 0.9 wt %. For the 260°-twist configuration samples were initially made with the same concentration of dopant, but no homogeneous gel could be achieved. Therefore fresh samples were made with a dopant concentration of

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1.1 wt%, from which homogeneous gels could be produced. Liquid crystal alignment was accomplished with a spincoated polyimide layer, CRD 8650 from Sumitomo Chemical. The gelling agent, Lys18 has been described previously [11, 12]. Seven samples were evaluated:

1. Reference cell, standard 240°-twist STN with 0.9 wt% dopant;
2. as (1), with the addition of 0.3 wt% gelling agent;
3. as (1), with the addition of 0.5 wt% gelling agent;
4. as (1), with the addition of 1.0 wt% gelling agent;
5. 260°-twisted cell with 0.9 wt% dopant;
6. 260°-twisted cell with 1.1 wt% dopant;
7. as (6), with the addition of 0.3 wt% gelling agent to the liquid crystal mixture.

Samples (1–3) were evaluated after the cells were filled. For samples (4) and (6) the liquid crystal and gel alignment did not appear to be correct initially (wrong colour between polarizers). In this case a correct alignment was obtained after applying 30 V to the cells at 60°C, then removing the voltage and cooling to room temperature.

2.2. *Electro-optical measurements*

Measurements of the transmission as a function of applied voltage and/or relaxation time were made on a display measurement system, DMS 803 from Autronic (Germany). The applied pulses were a.c. block-pulses of 100 Hz. The twist was determined using a retardation meter RETS 6000 from Otsuka electronics (Japan).

3. Results

3.1. *Switching voltage and optics*

As can be seen in figure 1, the switching voltages increase quite drastically with the introduction of the gel. In table 1 the applied voltages at 90 and 10% of the maximum luminance are shown. The maximum number of lines ($N_{\max}$) which can theoretically be addressed are calculated by using V_{10} as V_{on} and V_{90} as V_{off} using the Alt and Plesko law [13]. The maximum transmission is only slightly decreased by the introduction of the gel. This decrease is probably related to the slight scattering that can be observed on visual inspection. The transmission in the black state is also only slightly affected, except for the sample with 0.5% gelling agent. It must be remarked however that this might well be related to the exact position of the measurement spot. Apart from this effect, the contrast is reduced from 5.4 for the pure LC to 4.2 for the sample with 1% gel.

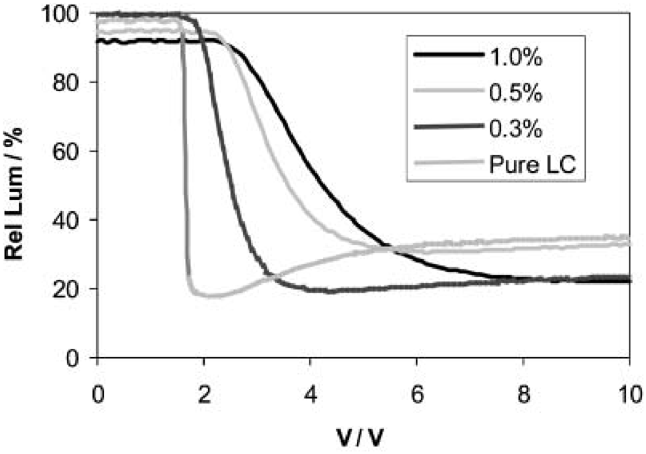

Figure 1. Transmission as a function of the applied voltage for the 240°-twist samples.

Table 1. Switching voltages and maximum multiplex ratio.

Sample	V_{10}	V_{90}	$N_{\max}$
240° twist, 0.9% dopant			
1.0%	6.0	2.8	2.4
0.5%	4.7	2.7	3.9
0.3%	2.6	2.2	36.5
Pure LC	1.69	1.62	559
260° twist, 0.9% dopant			
Pure LC	1.715	1.693	6000
260° twist, 1.1% dopant			
0.3%	5.2	7.0	11.7
Pure LC	1.772	2.023	57.7

As expected, the 260°-twist sample, with the standard 0.9 wt% dopant concentration, had a very steep transmission to voltage dependence. Consequently a high maximum number of lines could be addressed. Unfortunately, a gel made of this sample was inhomogeneous, showing a high concentration of holes in which there was no gelling agent. On using a dopant concentration of 1.1 wt%, however, a homogeneous gel could be made, in a 260°-twist configuration, sample (7). However in this case the maximum number of addressable lines was lower than for the 240°-twist sample, and the introduction of the gel reduced the contrast.

3.2. *Switching speed*

The switching curves are shown in figure 2. In the experiment to obtain these curves a voltage of 10 V was applied to the cell and the transmission of the cell was measured for a certain time. Subsequently, the voltage

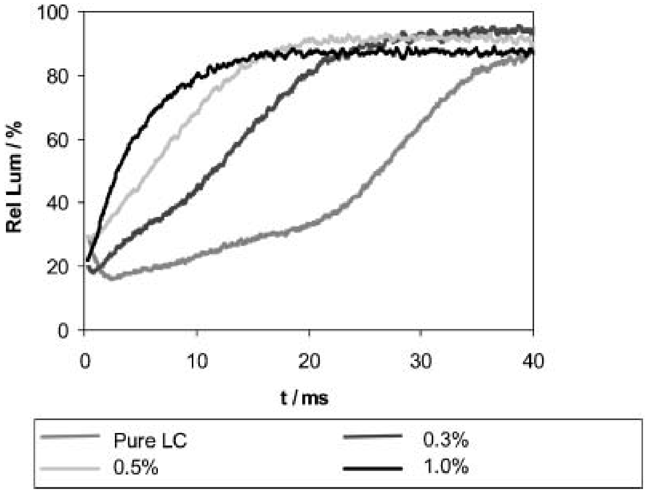

Figure 2. Response in transmission of the 240°-twist samples after removing the electric field.

Table 2. Switching speed: addressing by 10 V.

	Sample	$T_{50\mathrm{s}\rightarrow\mathrm{ns}}$/ms	$T_{50\mathrm{ns}\rightarrow\mathrm{s}}$/ms
(1)	240°-twist, 1.0%	4.0	1.7
(2)	240°-twist, 0.5%	7.1	1.1
(3)	240°-twist, 0.3%	22.6	1.1
(4)	240°-twist, pure LC	29.0	0.8
(5)	260°-twist, 0.3%	9.1	1.1
(6)	260°-twist, pure LC	21.6	0.6

was removed and the transmission of the cell measured again. The switching times are shown in table 2. T_{50} denotes the time in which 50% of the change in relative luminance has been accomplished. Very clearly, the time by which the liquid crystal switches from the select to the non-select state is dramatically decreased by the introduction of the gel. The time by which the liquid crystal switches from the non-select to the select state, on the other hand, is slightly increased by the introduction of the gel.

3.3. *Photomicrographs and twist determination*

Sample (4) with a relatively high gel content exhibited a rather special behaviour. In this case the colour of the cell between crossed polarizers was significantly different from that of the reference cell without gelling agent. A correct alignment was obtained after applying 30 V to a cell at 60°C, then taking off the voltage and cooling the sample to room temperature. This cell was analysed with a retardation meter to determine the twist. Outside the matrix area (i.e. the regions of the cell where no voltage can be applied), the twist was much lower than expected. The twist values correspond well with the expected values for a 'reduced twist' configuration, i.e. 60° instead of 240°.

Photomicrographs were made of all samples at the interface between a pixel and its direct proximity. These have been made at several voltages, and a selection is shown in figure 3. The reference sample with no gel looks very similar at voltages between 3 and 10 V. This is not the case for the samples with gelling agent. In this case the pixel switches in an inhomogeneous fashion. Some parts switch at 3 V, while other parts switch only when the voltage is close to 10 V. The region of the pixel which switches gradually increases with the applied voltage, in correspondence with the gradual change in the transmission curves (figure 1). The length scale of these inhomogeneities is in the order of tens of microns. In figure 4 it can be seen that for the sample with the highest gel concentration (1%), some holes appear in the gel. This was not the case for the other samples. In this sample the rubbing directions are also clearly visible (as indicated by the arrows).

3.4. *Stability*

When the 240°-twist samples with the gel were addressed for the first time the transmission voltage curve showed hysteresis, i.e. the curve obtained by increasing the voltage is not the same as the curve obtained after decreasing the voltage. This is not the case after several addressing cycles. Also, in the first addressing cycles the threshold drifts somewhat.

4. Discussion

In most samples introduction of the gel leaves the STN structure intact. This is not the case for the 240°-twist sample with 1% of gelling agent. In this case the liquid crystal is initially in the reduced twist configuration. Pinning of this configuration can be prevented by putting a relatively high voltage on the cell while cooling. The gel increases the threshold voltage. For a liquid crystal with no gelling agent, the threshold depends on the twist elastic constant, K_{22} [2]:

$$V_{\mathrm{th}}=\frac{d}{2P}(4\pi K_{22}\varepsilon)^{\frac{1}{2}}$$

where d denotes the cell thickness, P the pitch of periodicity of the liquid crystal orientation and ε the dielectric anisotropy of the liquid crystal. The switching speed also depend on the twist elastic constant [2]:

$$\tau_{\mathrm{s}\rightarrow\mathrm{ns}}=\eta/K_{22}(P/\pi)^2$$
$$\tau_{\mathrm{ns}\rightarrow\mathrm{s}}=\eta/\left[\varepsilon V^2/4\pi d^2-K_{22}(P/\pi)^2\right].$$

A number of theories have been proposed to deal with the influence of networks [6–8]. All predict an

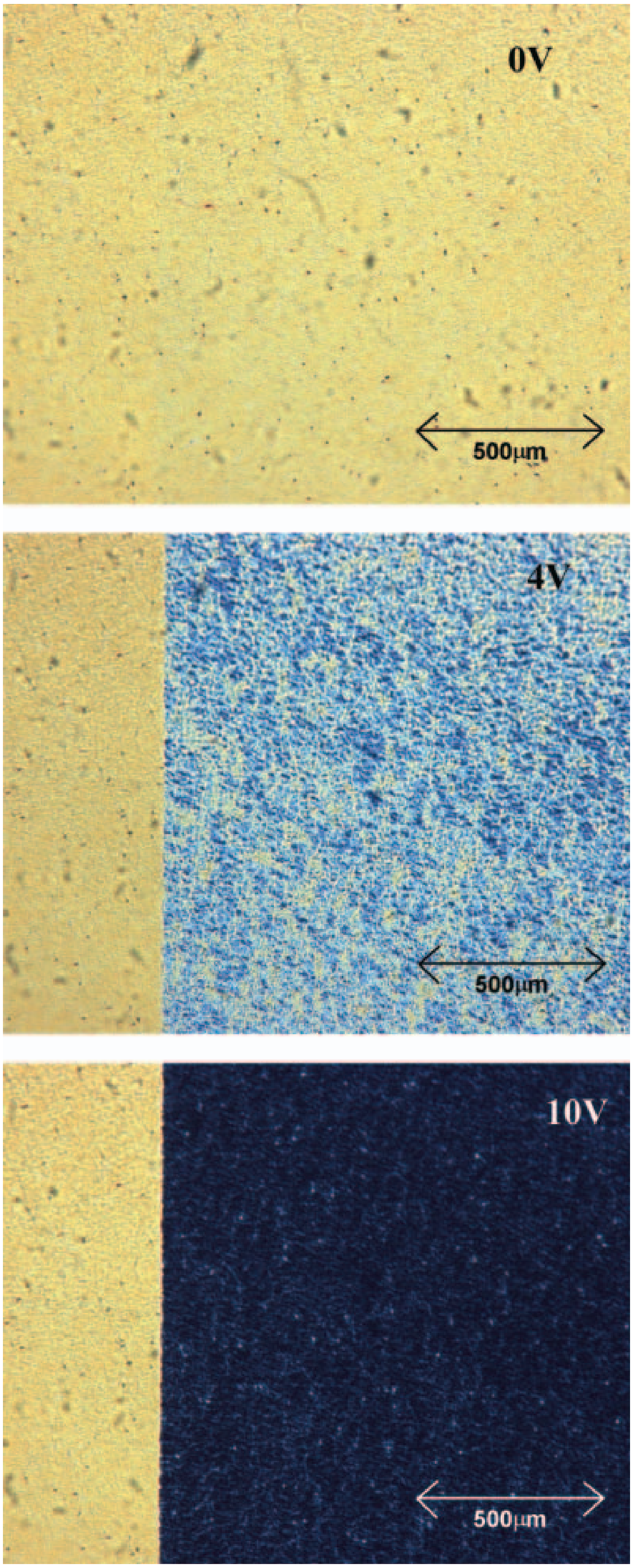

Figure 3. Photomicrographs of the voltage dependent switching of the sample with 0.5% gel and 240° twist.

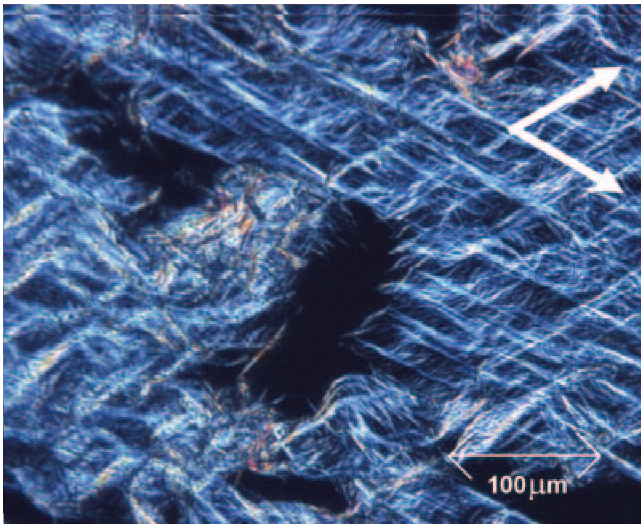

Figure 4. Photomicrographs of the sample with 1% gel and 240° twist. Note the hole in the gel and rubbing directions (indicated by the arrows).

increase in the threshold voltage and a decrease in switching speed after reducing the electric field, related to an extra term in the propagation of the director profile from the network rather than the cell walls. The assumptions and quantitative outcome of these theories are, however, quite different. In [7] network deformation plays a major role. This theory is not valid in the case of the small cell-gap used here. In [6] two types of networks are considered: type 1 is an irregular mesh of fine fibrils, in type 2 the liquid crystal is confined in domains separated by polymer walls. Although in figure 4 clearly fibrilic structures can be observed, these fibrilic structures are not irregular. By contrast, the fibrils in this case are oriented along the rubbing directions. It is therefore not surprising that the transmission voltage curve and switching curves are rather different.

The theoretical treatment by Kossyrev *et al.* [8] seems to describe the situation in our gel most closely. In this case the network orientation and order depend on the liquid crystal. Their results are also quite similar to ours, although the magnitude of the effects they find on the threshold voltage and relaxation time are considerably smaller than ours. Within their theory this could be explained by a very strong anchoring between the network and the liquid crystal. In none of the theories is a highly twisted structure considerd. This could also partly explain the relatively strong increase in the threshold voltage, and switching time from the select to the non-select state.

The steepness of the transmission–voltage curve is clearly decreased by the introduction of the gelling agent. This appears to be related to the fact that the structure of the gel is inhomogeneous and that some parts switch at lower voltages than others. The length scale of the inhomogeneities is similar to the average distance between fibrous aggregates, which have been observed by AFM [11]. Moreover the rubbing directions are clearly visible in the sample with 1% of gelling agent. This confirms that the gel forms fibrous aggregates, which orient at the cell surfaces, rather than a more random structure as was observed for some other systems [10]. The fact that the rubbing directions are so clearly visible seems to indicate a relatively high concentration of fibres near the cell surfaces.

For the next generation of displays, which will be used for displaying video content, the increase in switching speed, might be beneficial. For application in passive matrix displays the decrease in steepness of the transmission–voltage curve, on the other hand, has severe consequences for the multiplex ratio (number of lines which can be addressed, table 1). This limits the application area of the display. Nevertheless the formulation with 0.3% gel still has considerable multiplex possibilities, slightly better than conventional TN displays. Moreover, the multiplex ratio might be improved by, for example, using a liquid crystal mixture with higher ratio of bend and splay elastic constants. It can also be improved by increasing the twist.

One of the disadvantages of a high twist is that it can lead to instabilities and orientational artefacts. It has been reported however that polymer networks might suppress these instabilities [4]. That is why we prepared cells with a twist of 260°. With the same amount of dopant in the liquid crystal this indeed results in an increase of the multiplex ratio. However, in this case no homogeneous gel could be prepared. If the dopant concentration is increased a stable gel can be made, but no increase in the multiplex ratio was observed. It should be further explored as to whether there is an optimum dopant concentration for which the multiplex ratio is increased and; yet a stable gel can be made.

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