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Amorphous twisted nematic liquid crystal displays: The characteristics and the theoretical considerations

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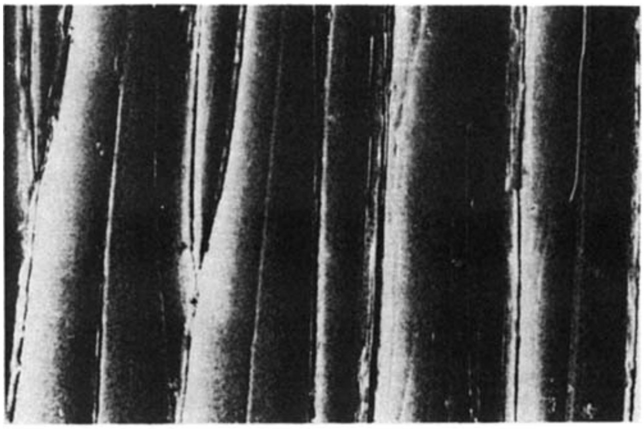
Amorphous twisted nematic liquid crystal display cells have been prepared without rubbing. The textures consisted of twisted nematic multi-domains. Theoretical calculations of the optical properties of such cells have been carried out by the 4 × 4 matrix method. The optical anisotropy of the liquid crystal is optimized to suppress/optimize the background colour. The electro-optical characteristics of the a-TN have been measured. It is shown that the a-TN devices exhibit wide and uniform viewing angle characteristics and possess good gray scale capability. Viewing angles of − 47° to + 45° (up-down) and − 51° to + 46° (left-right) have been achieved. A rise time of 36·5 ms and decay time of 35·5 ms have been measured in an a-TN sample.

1. Introduction

The first liquid crystal display (LCD) device used the dynamic scattering mode [1] and the substrate surfaces were unrubbed. However, since the twisted nematic (TN) LCD was invented by Schadt and Helfrich [2], the rubbing technique has been widely used for the alignment of liquid crystal molecules in LCD manufacturing processes, including TN-LCD, super twist nematic (STN) LCD, and ferroelectric liquid crystal display devices (FLCD).

Recently, Kobayashi and his co-workers [3] proposed a new method of preparing TN LCDs: the non-rubbing technique in which the cells are made without rubbing. The liquid crystals are injected in the isotropic phase and then cooled down into the nematic phase. Randomly distributed micro-TN domains were formed during the cooling process. The mode is called the amorphous twisted nematic (a-TN) liquid crystal display. Analytical simulations for the a-TN are also given by this group [4]. The non-rubbing technique can eliminate defects caused by the electrostatic charge and avoids destruction of the thin film transistor (TFT) of the active matrix. Unlike traditional TN-LCDs, an a-TN LCD can provide neutral and wide viewing angles (VA). Therefore the a-TN appears very useful for large size active matrix driven LCDs.

In the previous paper [5], we reported some experimental results on non-rubbed LCDs. In this paper, the characteristics of the a-TNs are further investigated. Optical parameters of the liquid crystal are calculated and optimized by the 4 × 4 matrix method [6]. Experimental results and the theoretical calculations are presented.


(*a*)

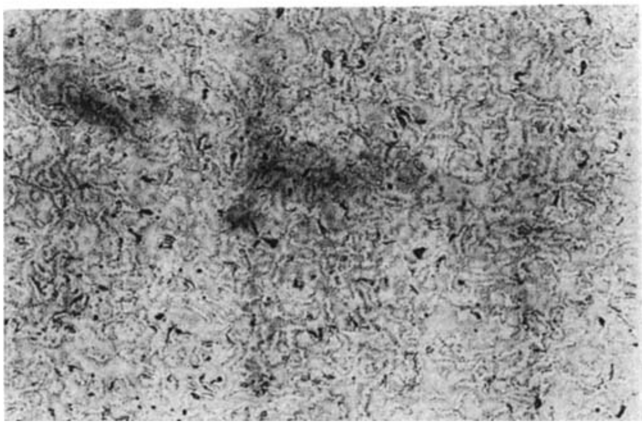

(*b*)

Figure 1. (*a*) Photographs of the texture in an a-TN cell: (*a*) the flow-pattern, and (*b*) the randomly distributed multi-domain structures.

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* Author for correspondence.

2. Experimental

We prepare the a-TN cells with indium–tin oxide (ITO) glass plates coated with a polyimide (PI) film which are unrubbed. These PI films align the nematic liquid crystal molecules parallel to the surfaces of the substrates. The nematic liquid crystal is injected into the cells in the isotropic phase. The cooling process is found to be critical because the cooling rate strongly affects the final amorphous nematic textures, the size of the domains and the electro-optical characteristics. The typical cooling rate is about 100°C per minute. If the liquid crystal is injected in the nematic phase, an undesirable kind of flow-pattern will appear, as shown in figure 1 (*a*). The texture of the a-TN cell is identical to the Schlieren texture [7]. Figure 1 (*b*) shows the textures of the micro-domains. Once the a-TN texture is formed, it always keeps this pattern which results from memory effects of the surface molecular anchoring [8].

The macroscopic characteristics of the a-TN cell do not change when turning the cell between crossed polarizers, which suggests that the micro-domains of the texture are distributed randomly. Samples are prepared near the first and the second minima of the Gooch–Tarry condition [9]. The value of Δnd for the samples **1** and **2** is 0·44 and 1·05, respectively.

The measurement of electro-optical (E-O) characteristics of the a-TN is performed on an Otruka Electronics MCPD-1000 system. The light source is calibrated to be an E-source. The electric signal is supplied by a Philips PM5191 function generator. The luminance contrast ratio contours and the switching characteristics are obtained by Melchers Display Measuring System (DMS).

3. Results and discussions

To suppress/optimize the back ground colour, calculations are carried out by the 4 × 4 matrix method and based on a randomly distributed micro-TN domains model [5]. The aligning angle is defined as an angle between the director of the liquid crystal molecules on the top boundary of a micro-domain and the polarization axis of the top polarizer. The transmittance spectrum of the a-TN is calculated as the average for different micro-domains. The calculated and the measured spectra for sample **1** is given in figure 2 as solid and dotted lines, respectively, and for sample 2, in figure 3.

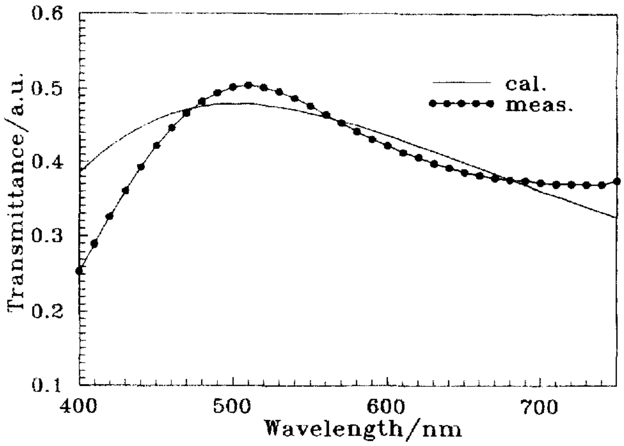


Figure 2. Comparison of the measured spectrum (dotted line) with the calculated spectrum (solid line) for sample 1.

Comparison with the theoretical data, the discrepancies are probably caused by the following reasons: (i) the molecule domain configurations near the domain boundaries are very complex and are not taken into account; (ii) the polarization efficiency and the transmittance of the polarizers are supposed to be 99 per cent

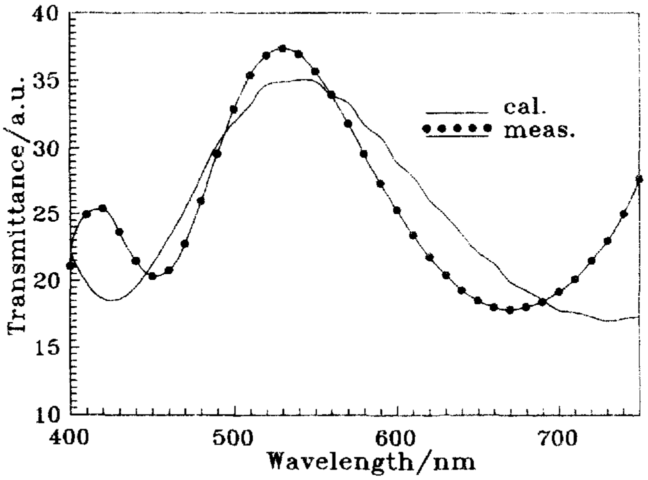


Figure 3. Comparison of the measured spectrum (dotted line) with the calculated spectrum (solid line) for sample 2.

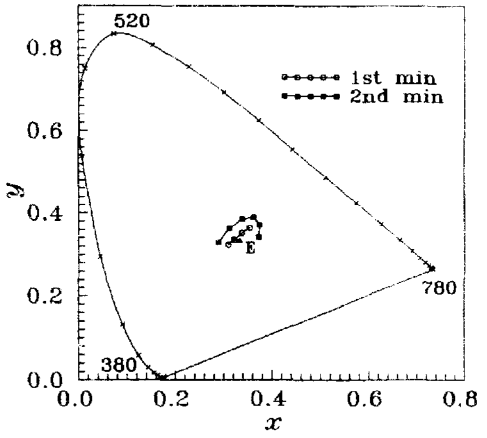


Figure 4. Colorimetric coordinates of the background colour of the a-TN cell around the first minimum (from left, $\Delta nd = 0{\cdot}40$, 0·44, 0·48 and 0·52); around the second minimum (from left, $\Delta nd = 0{\cdot}95$, 1·00, 1·05, 1·10, 1·15 and 1·20); and the E-source.

and 49 per cent in the calculations, while in the experiment, the polarization efficiency of the polarizers are not constant decreasing rapidly as the wavelength increases, especially in the region of 650–780 nm.

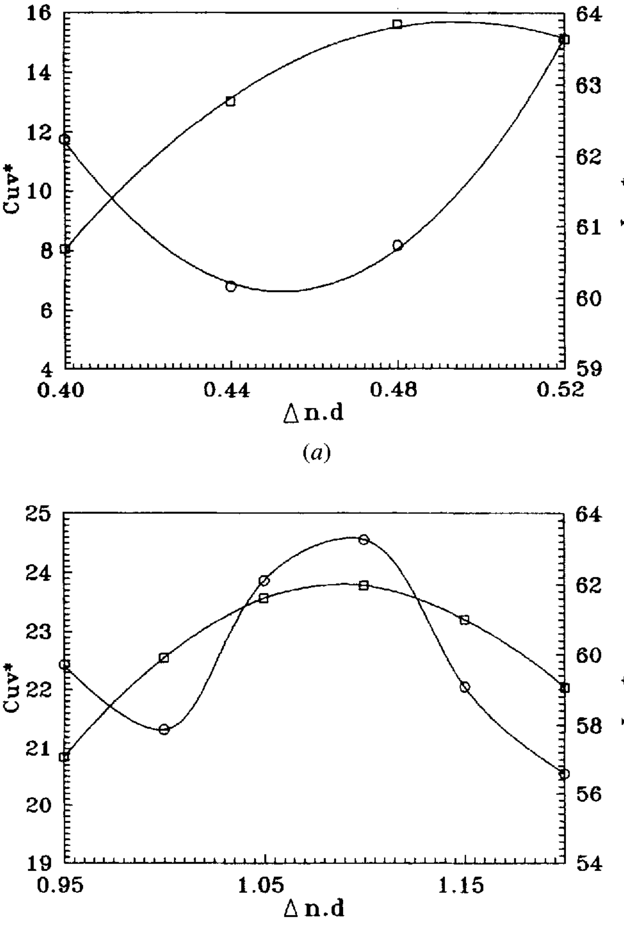
The calculation indicates that the background colour of an a-TN cell depends on the optical anisotropy, Δ*nd*. Figure 4 shows the colorimetric coordinates (in the CIE 1931 system [10]) of the background colour versus Δ*nd* around the first and the second minima.

The optical anisotropy, Δ*nd*, of an a-TN cell is optimized with the multi-domain model. The calculated chroma (*Cuv**) and the lightness (*L**) in the CIE 1976 $L^*u^*v^*$ system [10], versus Δ*nd* around the first minimum are given in figure 5 (*a*), while for those around the second minimum are given in figure 5 (*b*). According to the figures, one can suppress the background colour by adjusting Δ*nd* of the cell to 0·44–0·46 for the 1st minimum. Referring also to figure 4, one can get a background colour of greenish yellow when choosing the Δ*nd* between 0·95 and 1·10.

The E-O curves for different incident angles of an a-TN are given in figure 6 (*a*), with the identical E-O curve of the TN cells, in figure 6 (*b*), for comparison. There is no effect of threshold voltage shift in an a-TN cell.

The a-TN cells exhibit excellent viewing angle characteristics; the contrast ratio contour of an a-TN cell is shown in figure 7 (*a*). The neutral and uniform viewing angle is preferrable to the tilted ones of TNs (see figure 7 (*b*)), especially in large area AM-LCDs.

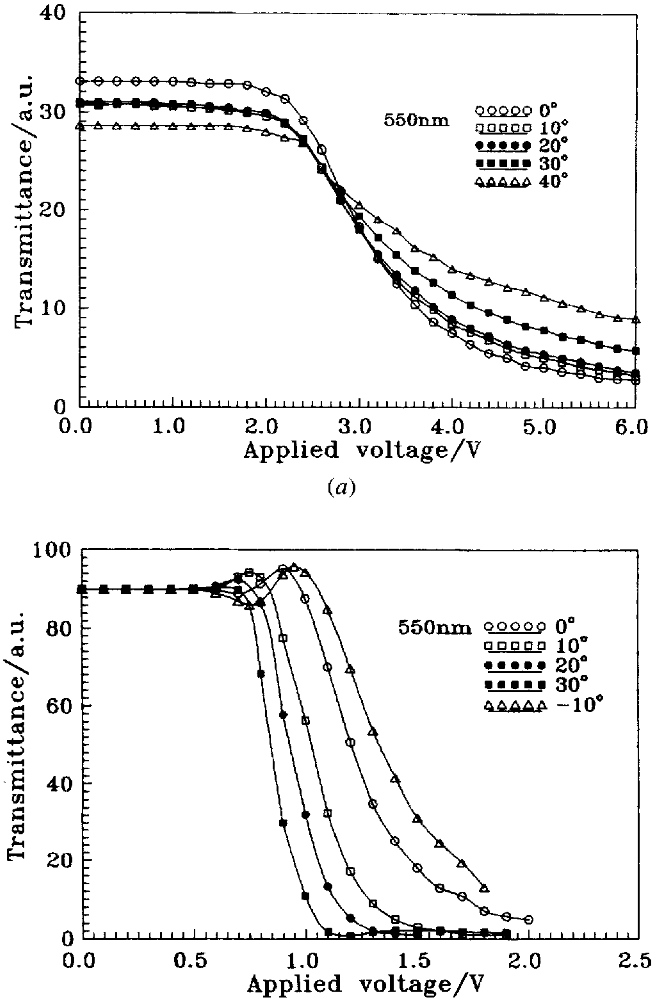
In the transmission mode, for a contrast ratio larger than 3·0, the viewing angles of the a-TN sample are −47° to +45° (up-down) and −51° to +46° (left-right), respectively. However, when operated in the reflective mode, the contrast ratio of the device can be further improved.



(*a*)

(*b*)

Figure 5. The optimization of Δ*nd* in CIE 1976 $L^*u^*v^*$ system by the chroma (*Cuv**) and the lightness (*L**), (*a*) around the first minimum and (*b*) around the second minimum.



(*a*)

(*b*)

Figure 6. The electro-optical performance at different incident angles for (*a*) the a-TN cell, and (*b*) the TN cell. The measurements are carried out at the wavelength of 550 nm.

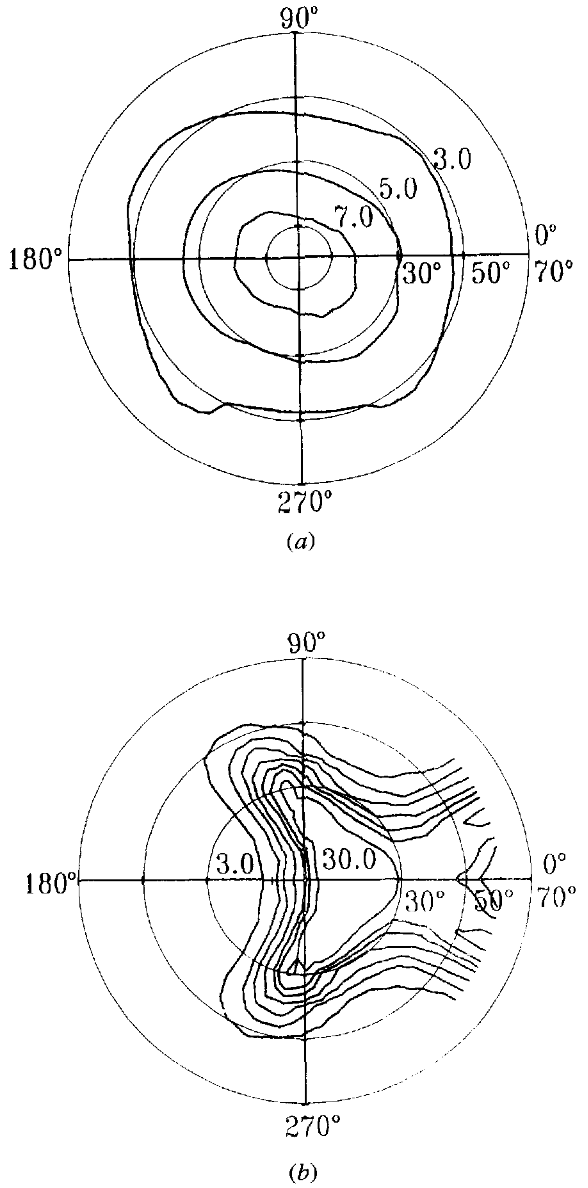


Figure 7. Viewing angle characteristics of (*a*) the a-TN cell, and (*b*) the TN cell, the curves stand for $C_r = 3{\cdot}0$, 5·0, 7·0, 10·0, 15·0, 20·0, and 30·0, respectively.

The response times, T_r and T_d, of sample **1** are measured to be 36·5 ms and 35·5 ms, respectively. The switching characteristics of the a-TNs are similar to conventional TNs.

4. Conclusions

We have prepared a-TN cells with uniform micro domains and excellent viewing angle characteristics. The background colour of the a-TN cell depends on the optical anisotropy of the liquid crystal. Normally white a-TN devices can be achieved by adjusting the Δn of the LC material. The a-TN may be utilized in static driven LCDs and active matrix driven LCDs.

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