

ELECTRO-OPTICAL DEVICE

The present invention relates to an electro-optical device, such as a super twisted nematic liquid crystal display.

In a prior super twisted nematic liquid crystal display as described in Japanese Published Patent No. 50511/1985, the twist angle of the liquid crystal molecules is in excess of 180° , and the product of the optical anisotropy n and the thickness d of the liquid crystal layer is from 0.7 to 1.1 micro-metres.

This liquid crystal display becomes coloured as a result of birefringence when it is driven by a dynamic drive technique involving the selective application of a plurality of different voltages. When a non-selecting voltage is applied to the display, it appears yellow. When a selecting voltage is applied, the display turns blue. When intermediate voltages are applied, the colour of the display goes from yellow to blue through a somewhat blue-green colour, as shown in the CIE chromaticity diagram of Figure 18. Thus, the display can only produce a limited range of colours, which is not sufficiently large for practical use.

Some known electro-optical devices having colour filters can display multiple colours. However, devices of this kind require three kinds of pixel arranged respectively to display the three primary colours, red, green and blue, and, therefore, these devices are very difficult to fabricate.

According to the present invention there is provided an electro-optical device comprising a liquid crystal cell having a pair of

electrode plates disposed opposite to each other and a layer of a twisted nematic liquid crystal material sandwiched between the electrode plates, a pair of polarisers disposed on opposite sides of the liquid crystal cell, and means for applying a selectively variable voltage between the electrode plates of the liquid crystal cell, the twist angle of the nematic liquid crystal material lying in the range from 180° to 360° , and the product of the optical anisotropy n of the nematic liquid crystal material and the thickness d (in micro-metres) of the liquid crystal layer being in excess of 1.1 micro-metres.

As described below, the means for applying a selectively variable voltage between the electrode plates of the liquid crystal cell are arranged such that the voltage may selectively assume three or more values. Multiple colours with appropriate contrast can be displayed by the application of these several different voltages with a low duty ratio of, for example, less than 1/100.

The invention will be described further, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a schematic cross sectional view of a liquid crystal display constituting a first embodiment of electro-optical device according to the invention;

Figure 2 is a diagram illustrating the relation between the absorption axes of polarisers of the liquid crystal display shown in Figure 1 and directions of rubbing of electrode plates of the liquid crystal

display;

Figures 3, 4, 5, 6, 7 and 8 are chromaticity diagrams showing the colours which may be created by specific examples of the liquid crystal display shown in Figure 1;

Figure 9 is a schematic cross sectional view of another liquid crystal display constituting a second embodiment of electro-optical device according to the invention;

Figure 10 is a diagram illustrating the relation between the absorption axes of polarisers of the liquid crystal display shown in Figure 9 and directions of rubbing of electrode plates of the liquid crystal display;

Figures 11, 12, 13, 14 and 15 are chromaticity diagrams showing the colours which may be created by specific examples of the liquid crystal display shown in Figure 9;

Figures 16 and 17 are chromaticity diagrams showing the colours which may be created by specific examples of a variation on the liquid crystal display shown in Figure 9; and

Figure 18 is a chromaticity diagram showing the colours which can be created by the prior liquid crystal display.

A first liquid crystal display is shown schematically in Figure 1, and comprises a lower polariser 1, and upper polariser 2 and a liquid crystal cell 10 sandwiched between the polarisers 1 and 2.

The liquid crystal cell 10 comprises a lower electrode plate 11, an upper electrode plate 12, and a layer 13 of a nematic liquid crystal material sandwiched between the two electrode plates. The lower electrode plate 11 has electrodes 11a on its upper

surface, and the upper electrode plate 12 has electrodes 12a on its lower surface. The surfaces of the electrode plates 11 and 12 which are in contact with the nematic liquid crystal layer 13 are rubbed or otherwise processed to twist the molecular packing. Spacers 14 are mounted between the electrode plates 11 and 12 at the edges of these plates. The spacers 14 hold the nematic liquid crystal material between the electrode plates 11 and 12 and maintain a constant spacing between the plates 11 and 12 so that the thickness of the liquid crystal layer 13 is rendered uniform. Spacer means, such as glass fibre or glass balls may also be provided throughout the region between the plates 11 and 12.

A drive circuit 3 for driving the liquid crystal cell 10 is connected to the electrodes 11a and 12a. In the present example, the drive circuit 3 utilises a dynamic drive technique in that it applies respective ones of a selecting voltage, a non-selecting voltage, and one or more intermediate voltages at different times between the electrode plates 11 and 12 in order to generate multiple colours.

Figure 2 illustrates the relationship between the axes of the liquid crystal molecules close to the electrode plates 11 and 12 of the liquid crystal display shown in Figure 1 and the absorption axes of the polarisers 1 and 2. Although the means for orienting the liquid crystal molecules is not limited to rubbing, in this example the direction of orientation of the long axis of each of the liquid crystal molecules close to the electrode plates is considered to be equal to the direction in which the associated electrode plate is rubbed, for convenience of explanation. This assumption is also applied to the embodiments described below.

Referring to Figure 2, the lower electrode plate 11 and the upper electrode plate 12 of the liquid crystal cell 10 are rubbed in directions indicated by R11 and R12, respectively. The liquid crystal molecules inside the liquid crystal cell 10 are twisted downwardly as viewed in Figure 1. The direction and the angle of the twist are indicated by T. The directions of the absorption axes, or polarisation axes, of the lower polariser 1 and the upper polariser 2 are denoted by P1 and P2, respectively. The direction P1 of the absorption axis of the lower polariser 1 forms an angle θ_1 with the direction of rubbing R11 of the lower electrode plate 11. The direction P2 of the absorption axis of the upper polariser 2 forms an angle θ_2 with the direction of rubbing R12 of the upper electrode plate 12.

In the above structure, the upper and lower electrode plates 11 and 12 are arranged in such a way that the twist angle T of the liquid crystal molecules lies in the range from 180° to 360° . In this case, the direction and the angle T of the twist of the liquid crystal molecules are determined by the rubbing directions R11, R12, and the nature and amount of the optically active substance added to the nematic liquid crystal layer 13. Preferably, the angles θ_1 and θ_2 that the directions of rubbing form with the absorption axes of the polarisers each lie in the range from 15° to 75° . The product of the optical anisotropy Δn and the thickness d (in micro-metres) of the liquid crystal layer 13 is made larger than 1.1 micro-metres.

The voltage applied between the electrode plates 11 and 12 is varied to reduce the retardation of the liquid crystal layer 13. This changes the colour of the transmitted light. The colour change can be

increased by increasing the change in the retardation. For this purpose, it is necessary to increase the initial value of the product $\Delta n \cdot d$. It has been found that multiple colours can easily be displayed under the condition that the initial value of the product $\Delta n \cdot d$ is in excess of 1.1 micro-metres. This facilitates the display of a variety of colours by selectively varying the applied voltage between several values. No limitations are imposed on the upper limit of the product $\Delta n \cdot d$. Multiple colours can be displayed however great the value of the product is. At present, however, the optical anisotropy Δn can be increased only up to about 0.2. Considering the response speed, the product $\Delta n \cdot d$ is preferably less than 2.0 micro-metres.

In order to increase the number of colours displayed, the liquid crystal cell 10 is advantageously activated by the dynamic drive technique mentioned above. Sufficient contrast can be obtained even if the liquid crystal cell 10 is driven at a low duty ratio of, for example, less 1/100.

The present invention actively makes use of the birefringence of the liquid crystal material and requires that the directions of orientation of the liquid crystal molecules differ from the absorption, or polarisation, axes of the polarisers. In particular, when the angles θ_1 and θ_2 that the directions of orientation form with the absorption axes are set to be within the range from 15° to 75° , colours can be displayed with high contrast and high colour purity.

Some specific examples of the display shown in Figure 1 are given below.

EXAMPLE 1

The nematic liquid crystal layer 13 was made from a PCH liquid crystal. The optical anisotropy Δn was 0.13. The thickness d of the liquid crystal layer 13 was 10 micro-metres. Hence, the product $\Delta n \cdot d$ was 1.3 micro-metres. The twist angle T of the liquid crystal molecules was 180° . The angles θ_1 and θ_2 that the directions of rubbing formed with the absorption axes of the polarisers 1 and 2 were 30° and 60° , respectively. The liquid crystal cell 10 was driven by the drive circuit 3 by the dynamic drive technique on the basis of four different voltages at a duty ratio of 1/100. When an effective non-selecting voltage of 2.10 V was applied to the cell 10, it turned blue-green. When an effective selecting voltage of 2.32 V was applied to it, it turned red. When effective intermediate voltages of 2.17 V and 2.25 V were applied to the cell 10, it turned blue and purple, respectively. However, the response time was as slow as 600 ms or greater.

EXAMPLE 2

Instead of using the liquid crystal of Example 1, a liquid crystal layer 13 made from tolan was employed. The optical anisotropy Δn was 0.18. The thickness d of the liquid crystal layer 13 was 8 micro-metres. This example was similar to Example 1 otherwise, and the liquid crystal cell produced four colours in the same way as in Example 1. However, the response time was improved to 300 ms.

EXAMPLE 3

The liquid crystal material of Example 2 was used. The present example was similar to Example 2 except in that: the twist angle T of the liquid crystal molecules was 220° . The angles θ_1 and θ_2 that the directions of rubbing formed with the absorption axes of the polarisers were both 45° . The liquid crystal cell 10 was driven by the drive circuit 3 with four different voltages at a duty ratio of 1/100. The liquid crystal display exhibited four colours as shown in the chromaticity diagram of Figure 3.

EXAMPLE 4

This Example was similar to Example 3 except that the twist angle T of the liquid crystal molecules was changed to 230° . The cell 10 was driven by the drive circuit 3 with four different voltages at a duty ratio of 1/100. The colours obtained by this Examples are shown in Figure 4. The liquid crystal display showed yellow in addition to the three primary colours, i.e. green, blue and red.

EXAMPLE 5

The liquid crystal display of Example 4 was driven by the drive circuit 3 with eight different voltages at a duty ratio of 1/200. When an effective non-selecting voltage of 2.24 V was applied to the liquid crystal cell 10, the display turned green. When an effective selecting voltage of 2.4 V was applied to the liquid crystal cell 10, the display turned yellow. When effective intermediate voltages of 2.26 V, 2.29 V,

2.31 V, 2.33 V, 2.35 V and 2.38 V were applied, the display turned blue-green, blue, purple, red, orange and yellowish-orange respectively. The colours obtained are shown in Figure 5 and, as can be seen from this diagram, the application of a different voltage created a different colour for each of the eight voltages. The response time was 400 ms.

EXAMPLE 6

In Example 5, the thickness d of the liquid crystal layer 13 of tolan whose optical anisotropy Δn was 0.21 was changed to 5.5 micro-metres. The response time was improved to 250 ms.

EXAMPLE 7

The twist angle T of the liquid crystal molecules of Example 6 was set to 260° . The angles θ_1 and θ_2 that the directions of rubbing formed with the absorption axes of the polarisers 1 and 2 were both set to 10° . The liquid crystal cell 10 was driven by the drive circuit 3 with eight different voltages at a duty ratio of 1/200. When an effective non-selecting voltage of 2.28 V was applied to the liquid crystal cell 10, the display turned red. When an effective selecting voltage of 2.44 V was applied to the liquid crystal cell 10, the display turned orange. When intermediate voltages were applied, blue-green, yellow and other colours were produced. The colours displayed are shown in Figure 6. The angle formed between the absorption axes of the polarisers 1 and 2 were set to 80° . Eight colours complementary to the above described colours were produced. These complementary colours are located

at diametrically opposite positions of the white point 0 from the colours indicated by the points in Figure 6.

EXAMPLE 8

5 In Example 7, the twist angle T of the liquid crystal molecules was increased to 330° , for example. To orient the liquid crystal molecules, the liquid crystal material was subjected to oblique evaporation instead of rubbing the surfaces of the electrode plates. 10 As a result, a wider angle of visibility was obtained than in Example 7. A similar advantage may be derived from Examples 1 to 6 by increasing the twist angle T .

EXAMPLE 9

15 In this Example, the liquid crystal layer 13 included tolan added to the aforementioned PCH. The optical anisotropy Δn was 0.18. The thickness d of the liquid crystal layer 13 was 9 micro-metres. The product 20 $\Delta n \cdot d$ was 1.62 micro-metres. The twist angle T of the liquid crystal molecules was 180° . The angles θ_1 and θ_2 that the directions of rubbing formed with the absorption axes of the polarisers 1 and 2 were 30° and 25 60° , respectively. The liquid crystal cell 10 was driven by the drive circuit 3 with four different voltages at a duty ratio of 1/100. The liquid crystal display exhibited four colours, i.e. green, blue, red and yellow. However, the response time was 1000 ms, 30 which is relatively slow.

EXAMPLE 10

In Example 9, the proportion of the tolan in the

liquid crystal layer 13 was increased. The optical anisotropy Δn was set to 0.22. The thickness d was set to 7 micro-metres. The liquid crystal cell 10 was driven in the same manner as in Example 9. The liquid crystal display exhibited four colours in the same way as in Example 9. However, the response time was improved to 400 ms.

EXAMPLE 11

The liquid crystal material of Example 10 was used. The thickness of the liquid crystal layer 13 was set to 9 micro-metres. The twist angle T of the liquid crystal molecules was 240° . The angles θ_1 and θ_2 that the directions of rubbing formed with the absorption angles of the polarisers 1 and 2 were both set to be 45° . The liquid crystal cell 10 was driven by the drive circuit 3 with eight different voltages at a duty ratio of 1/200. The colours obtained are shown in the chromaticity diagram of Figure 7. The liquid crystal display exhibited eight colours including thin green, green, blue, red and yellow.

EXAMPLE 12

A liquid crystal material similar to the liquid crystal material of Example 11 was employed, except that the twist angle T was altered to 260° , and the liquid crystal cell 10 was driven in the same manner. The colours obtained are shown in the chromaticity diagram of Figure 8, where points A and B are both yellow but point A has a higher colour purity than point B. That is, two kinds of yellow having different colour purities were produced.

EXAMPLE 13

5 In the preceding Example, the twist angle T of the liquid crystal molecules was further increased, for example to 330° . The liquid crystal molecules were oriented by oblique evaporation instead of by rubbing the surfaces of the electrode plates. A wider angle of visibility was obtained than in Example 12. Similar advantages could be obtained by increasing the twist angle T of the liquid crystal molecules of each of Examples 9 to 11.

15 One example of the drive circuit 3 for causing the liquid crystal display to display several colours as described above is a pulse generating circuit that is arranged to control the pulse duration determining the selecting period. Another example is a circuit that is arranged to control the selected number of frames within each cycle of a plural number of frames. In Examples 1 to 13 described above, the latter drive circuit was used. However, the former drive circuit can also be employed with similar effect.

25 In the first embodiment described above, a single liquid crystal cell 10 is placed between the two polarisers 1 and 2. In a further embodiment, two or more liquid crystal cells are placed between the polarisers 1 and 2.

30 Figure 9 is a schematic cross section of a second liquid crystal display, in which two liquid crystal cells are placed between the two polarisers. The liquid crystal display includes a lower polariser 1, an upper polariser 2 and a liquid crystal cell 10 (hereinafter referred to as the first cell) placed between the polarisers, in the same manner as the display shown in

Figure 1.

A second liquid crystal cell 20 is placed between the first cell 10 and the upper polariser 2. The second cell 20 comprises a lower electrode plate 21, an upper electrode plate 22, and a layer 23 of a nematic liquid crystal material sandwiched between the electrode plates 21 and 22. The electrode plates 21 and 22 have electrodes 21a and 22a on their upper and lower surfaces, respectively. The molecules of the liquid crystal layer 23 are twisted by rubbing the surfaces of the electrode plates 21 and 22 or by otherwise treating the liquid crystal material. Spacers 24 are placed between the electrode plates 21 and 22. A drive circuit 4 for driving the second cell 20 is connected to the electrodes 21a and 22a. In the present example, the drive circuit 4 is a static drive circuit arranged to apply any arbitrary voltage between the electrodes 21a and 22a.

Figure 10 is a diagram illustrating the relationship between the directions of the rubbing of the electrode plates of the liquid crystal display shown in Figure 9, i.e. the directions of the axes of the liquid crystal molecules close to the electrode plates, and the absorption axes of the polarisers 1 and 2.

Referring to Figure 10, the lower electrode plate 11 of the first cell 10 is rubbed in a direction indicated by R11. The upper electrode plate 12 is rubbed in a direction indicated by R12. The direction of rubbing R12 of the upper electrode plate 12 of the first cell 10 forms an angle θ with the direction of rubbing R21 of the lower electrode plate 21 of the second cell 20. The liquid crystal molecules of the first cell 10 are twisted downwardly as viewed in Figure 9. The direction and the angle of the twist are

indicated by T1. The direction and the angle of the twist of the liquid crystal molecules in the second cell 20 are indicated by T2. The absorption axes of the lower polariser 1 and the upper polariser 2 are indicated by P1 and P2, respectively. The absorption axis P1 of the lower polariser 1 forms an angle θ_1 with the direction of rubbing R11 of the lower electrode plate 1 of the first cell 10. The absorption axis P2 of the upper polariser 2 forms an angle θ_2 with the direction of rubbing R22 of the upper electrode plate 22 of the second cell 20.

In the above structure, the angle T1 of the twist given to the liquid crystal molecules of the first cell 10 is set to a value from 180° to 360° , depending on the nature and amount of the optically active substance added to the nematic liquid crystal layer 13 and also on the directions of rubbing R11, R12, in the same way as in the first embodiment described above. The product of the optical anisotropy Δn of the liquid crystal material of the first cell 10 and the thickness d (in micro-metres) of the liquid crystal layer 13 is set to be larger than 1.1 micro-metres.

The liquid crystal display having the first cell 10 placed between the polarisers 1 and 2 is thus further provided with the second cell 20 independent of the first cell 10. The colours displayed by the liquid crystal display can be changed by electric signals. Also, a black and white display for a personal computer or the like can be realised by switching the electric signal applied to the second cell 20 between two values.

Preferably, the twist angle T2 of the nematic liquid crystal molecules of the second cell 20 is set to be $90^\circ \times n \pm 40^\circ$, where n is 0 or an integer, to provide a black and white display with high contrast.

Also, it is preferable to set the angle θ to 90° . The direction of the twist given to the liquid crystal molecules of the second cell 20 is preferably the reverse of the direction of the twist given to the liquid crystal molecules of the first cell 10.

Some specific examples of the display shown in Figure 9 are given below.

EXAMPLE 14

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The liquid crystal layer 13 of the first cell 10 of the liquid crystal display shown in Figure 9 was made from PCH to which tolan was added. The optical anisotropy Δn and the thickness d of the liquid crystal layer 13 were set to 0.18 and 8 micro-metres, respectively. The product $\Delta n \cdot d$ was 1.44. The liquid crystal molecules of the first cell 10 were twisted to the left through 220° ($T_1 = 220^\circ$). The liquid crystal molecules of the second cell were twisted to the right through 90° ($T_2 = 90^\circ$). The angles θ_1 and θ_2 were set to 45° . The angle θ was set to 90° . An effective voltage of 10 volts was applied to the second cell 20 by the static drive circuit 4. The first cell 10 was driven by the drive circuit 3 by the dynamic drive technique mentioned above at a duty ratio of 1/100 with four different voltages. Four colours, i.e. blue-green, violet, red and yellow, were displayed as shown in the chromaticity diagram of Figure 11. The drive circuit 4 for the second cell 20 was then turned off. As shown in Figure 12, when an effective non-selecting voltage of 2.24 V was applied, bluish-black was displayed as shown at point A. When an effective selecting voltage of 2.4 V was applied, yellowish-white was displayed as shown at point B. Thus, a

substantially black and white display was provided. The contrast ratio was 1:10.

EXAMPLE 15

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This Example was similar to Example 14 except in that the liquid crystal molecules of the first cell 10 were twisted to the left through 230° ($T_1 = 230^\circ$) and the liquid crystal molecules of the second cell 20 were twisted to the right through 270° ($T_2 = 270^\circ$). The drive circuit 4 applied an effective voltage of 10 V to the second cell 20. The drive circuit 3 drove the first cell 10 with eight different voltages at a duty ratio of 1/200. The colours obtained are shown in Figure 13. As can be seen from this diagram, the application of each different voltage created a different colour. The drive circuit 4 for the second cell 20 was then turned off. When an effective non-selecting voltage of 2.28 V was then applied to the first cell 10, bluish-black was displayed as shown at point A. When an effective selecting voltage of 2.44 V was applied to the first cell 10, yellowish-white was displayed as shown at point B. As a result, a substantially black and white display was provided. The contrast ratio was 1:15.

EXAMPLE 16

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In Example 15, the electrode pattern on one of the electrode plates of the second cell 20 was made equivalent to the electrode pattern on one of the electrode plates of the first cell 10. A static voltage was applied to the second cell 20. The display mode could be switched at will between a colour display and a

black and white display for each line by switching the voltage applied to the second cell 20 between 10 V and 0 V. Both kinds of display can be provided simultaneously on the same screen.

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EXAMPLE 17

In Example 15, the effective voltage applied to the second cell 20 by the drive circuit 4 was varied from 10 V to 0 V. As a result, the green (x, y) = (0.197, 0.386) shown in Figure 13 turned blue, red and black as shown in Figure 15. Also, the other colours shown in Figure 13 could be changed by varying the effective voltage applied to the second cell 20 by the drive circuit 4 from 10 V to 0 V.

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EXAMPLE 18

In Example 15, the liquid crystal molecules of the first cell 10 were twisted to the left through 330° ($T_1 = 330^\circ$). The liquid crystal molecules of the second cell 20 were twisted to the right through 450° ($T_2 = 450^\circ$). In the same way as in Example 15, the drive circuit 4 applied an effective voltage of 10 V to the second cell 20. The drive circuit 3 drove the first cell 10 with eight different voltages at a duty ratio of 1/200. A wider angle of visibility was obtained than in Example 15. When the drive circuit 4 for the second cell 20 was turned off, a black and white display was provided. The contrast ratio was improved to 1:52.

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In Examples 14 to 18, the liquid crystal molecules of the second cell 20 were twisted to the

right, while the liquid crystal molecules of the first cell 10 were twisted to the left. Similar results may be obtained with these directions reversed. When the liquid crystal molecules of the first and second cells were twisted in the same direction, a similar but unsatisfactory effect arose in that a little colour is generated and a monochrome effect cannot be obtained.

In the second liquid crystal display, the drive circuit 4 for driving the second cell 20 is a static drive circuit. Any circuit generating an AC waveform may be used. For example, this circuit may alternatively apply a sinusoidal wave voltage or a triangular wave voltage to the electrodes 21a and 22a, or it may drive the second cell 20 by a dynamic drive technique.

In a variation of the liquid crystal display shown in Figure 9, the molecules of the second cell 20 are changed from twisted orientation to vertical orientation. The vertical orientation is realised by the use of an orientation agent made from titanium. The relationship between the directions of rubbing of the surfaces of the electrode plates of the first cell 10 and the absorption axes of the polarisers is as shown in Figure 2.

EXAMPLE 19

In this variation, the liquid crystal layer 13 of the first cell 10 was made from PCH to which tolan was added. The optical anisotropy Δn and the thickness d of the liquid crystal layer 13 was set to 0.18 and 8 micro-metres, respectively. The liquid crystal molecules of the first cell 10 were twisted to the left through 220° ($T_1 = 220^\circ$). The angles θ_1 and θ_2 were

set to 45° . The liquid crystal layer 23 of the second cell 20 showed negative dielectric anisotropy. The first cell 10 was driven by the drive circuit 3 by the dynamic drive technique with four voltages at a duty ratio of 1/100 and four colours, namely blue-green, violet, red and yellow, were displayed as shown in the chromaticity diagram of Figure 16. When an effective voltage of 10 V was applied to the second cell 20 by the drive circuit 4 and an effective non-selecting voltage of 2.24 V was applied to the first cell 10, bluish-black appeared as shown at point A in Figure 17. When an effective selecting voltage of 2.4 V was applied to the first cell 10, yellowish-white was displayed as shown at point B. Thus, a substantially black and white display was provided. The contrast ratio was 1:8.

As described, multiple colours can easily be displayed in accordance with the invention by applying several different voltages. When the or a respective liquid crystal cell is driven by the dynamic drive technique mentioned above, multiple colours can be displayed with high contrast even at a low duty ratio, which is less than 1/100. In this way, an inexpensive electro-optical device can be produced which is capable of displaying multiple colours easily by comparison with the prior art using colour filters.

C L A I M S

1. An electro-optical device comprising a liquid crystal cell having a pair of electrode plates disposed opposite to each other and a layer of a twisted nematic liquid crystal material sandwiched between the electrode plates, a pair of polarisers disposed on opposite sides of the liquid crystal cell, and means for applying a selectively variable voltage between the electrode plates of the liquid crystal cell, the twist angle of the nematic liquid crystal material lying in the range from 180° to 360° , and the product of the optical anisotropy Δn of the nematic liquid crystal material and the thickness d (in micro-metres) of the liquid crystal layer being in excess of 1.1 micro-metres.

2. An electro-optical device according to claim 1 wherein the means for applying a selectively variable voltage comprises a drive circuit for selectively applying between the electrode plates a selecting voltage having a first value, a non-selecting voltage having a second value and at least one further voltage having an intermediate value between the first and second values.

3. An electro-optical device according to claim 1 or 2 wherein the absorption axes of the polarisers respectively form angles of 15° to 75° with the directions of orientation of the liquid crystal molecules at the adjacent sides of the liquid crystal cell.

4. An electro-optical device according to any preceding claim further comprising a second liquid crystal cell having a second pair of electrode plates disposed opposite to each other and a layer of a nematic liquid crystal material sandwiched between the second



pair of electrode plates.

5. An electro-optical device according to claim 4 wherein the liquid crystal molecules of the nematic liquid crystal material of the second liquid crystal cell are twisted through $90^\circ \times n \pm 40^\circ$, where n is either 0 or an integer.
