

SPECIFICATION

Liquid crystal display element

5 The invention relates to a liquid crystal display element.

Nematic or nematic-cholesteric liquid-crystalline materials have the property of significantly varying their optical properties, such as light transparency, light scattering, bi-refringence, reflectivity or colour, under the influence of electric fields and are utilised for liquid crystal display elements. Display elements of this type function on the phenomena of dynamic scattering, the deformation of aligned phases or the Schadt-Helfrich effect in the case of a twisted nematic cell.

10 Amongst these conventional types of liquid crystal display elements, it is twisted nematic display elements which have recently gained particular importance since they can be operated at relatively low control voltages which are readily available using small batteries. Moreover, these display elements have hitherto proved the most suitable for the construction of matrix display elements which permit presentation of a high density of information without an intolerably large number of triggering leads, input leads and output leads.

In use in practice, however, considerable difficulties still persist in the case of the twisted nematic cell, especially when in the form of matrix display elements. In particular, there is a marked dependence of the display contrast on the angle of observation. The display contrast is good as long as the direction of observation is at least approximately perpendicular to the plane of the liquid crystal layer. If, however, the display element is observed obliquely, for example, the angle of observation deviates by more than 15 to 20 degrees from the perpendicular, the display contrast decreases strongly until finally - depending on the position of the polariser facing the observer - the display is no longer perceptible. Additionally, interference colours frequently occur, that is to say display elements for black-and-white displays additionally show iridescent colours which, depending on irregularities in the layer of the electrode surface which faces the liquid crystal dielectric, cause a play of colours over the entire spectrum of visible light to appear.

From work by Mauguin (Bull.Soc.franc.Min., Volume 34, year 1911, pages 71 - 117) relating to the behaviour of liquid crystals between polarisers, it has been deduced that at least the occurrence of interference phenomena can be prevented if, in the liquid crystal cell, the product of the layer thickness and the optical anisotropy of the liquid crystal material is substantially greater than the wavelength of the light used. The optical anisotropy of liquid crystal material is here defined as the difference between the extraordinary index of refraction and the ordinary index of refraction. In practice, it is accepted as a rule of thumb that the value of the product of the layer thickness and the optical anisotropy must not be less than 1,400 nm; the product specifications of known electronics manufacturers prescribe values of more than 2,000 nm for this product. Raising this value by increasing the layer thickness of the liquid-crystalline dielectric is, however, limited by the fact that the switching time of the liquid crystal material increases with the square of the layer thickness. With layer thicknesses of 10 to 12 μ usual nowadays, liquid-crystalline dielectrics are therefore demanded which have an optical anisotropy of at least 0.14 and preferably more than 0.18.

40 Although in this way the difficulties due to the generation of interference colours can largely be eliminated in a twisted nematic display element, the dependence of the contrast on the angle of view is hardly improved. Moreover, the fact that each reduction of the layer thickness possibly causes a disturbance due to interference colours, blocks this route to the development of liquid crystal display elements which switch more rapidly, such as are required, for example, for use as a television screen.

45 We have now found that, surprisingly, liquid crystal display elements based on the twisted nematic cell, which are also free from interference colours, are obtained when the product of the layer thickness and the optical anisotropy of the liquid-crystalline dielectric has a value between 150 and 600 nm, in particular between 200 and 500 nm. Moreover, the display contrast of these display elements, contradicting the hitherto accepted opinion, is almost independent of the angle of observation over a wide range, that is to say these display elements with their reproduced information can almost always be read with the same ease from the most diverse directions.

The invention thus provides a twisted nematic liquid crystal having a liquid-crystalline dielectric layer the product of the thickness and the optical anisotropy of which has a value between 150 and 600 nm.

The construction of a preferred liquid crystal display element according to the invention from polarisers, electrode baseplates and electrodes, the surface of which has been treated in such a way that the preferential orientation of the particular liquid crystal molecules adjacent thereto is in most cases twisted relative to one another by 90° from one electrode to the other, corresponds to the construction conventional for display elements of this type. The term conventional construction is here taken in a wide sense and also comprises all the variations and modifications of a twisted nematic cell, known from the literature, in particular also matrix display elements and the display elements such as are disclosed in German Offenlegungsschrift 2,748,738, which additionally contain magnets. A difference between the preferred form of the display element according to the invention and the hitherto customary display elements based on the twisted nematic cell is, however, constituted by the thickness of the liquid crystal layer: whilst the layer thickness in the customary display elements is not less than 8 μ , preferably at least 10 μ and as a rule 12 to 20 μ , the layer thickness in the preferred form of the display element according to the invention is at most 10 μ , preferably 5

- 8 μ , and particularly 6 - 7 μ for industrial use. Provided the manufacturing tolerances of the electrodes and spacer means permit this, it is also possible to manufacture display elements with a thickness of the liquid crystal layer of only 3 μ . Like the cells having a layer thickness within the range of 5 - 8 μ , these exhibit a contrast which unexpectedly depends only to a small extent on the angle of view and are free from interference colours if the optical anisotropy of the liquid-crystalline dielectric is sufficiently great for the product of the latter and of the layer thickness to have a value within the range of 150 to 600 nm, preferably 200 to 500 nm. Optimum properties were observed on those display elements in which this product has a value of around 400 nm, that is to say within the range between 350 and 450 nm.

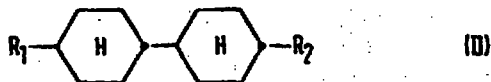
Liquid-crystalline dielectrics having values of the optical anisotropy within the range of 0.03 to 0.12, preferably 0.05 to 0.10, are used for the preferred forms of display elements according to the invention. In the case of extremely thin cells having a liquid crystal layer of, for example, only 3 μ thickness, the effect of freedom from interference colours is still obtained even with a liquid-crystalline dielectric having an optical anisotropy of more than 0.12; systems of this type, however, are not preferred since - apart from the industrial difficulties in the manufacture of such thin cells on a large scale - their angular contrast depends on the angle of view to a greater extent than those elements in which the value of the optical anisotropy of the liquid-crystalline dielectric lies at or below 0.12.

Liquid-crystalline dielectrics having an optical anisotropy Δn below 0.12, preferably 0.05 to 0.10, can be prepared from conventional liquid-crystalline base materials. A large number of materials of this type are known from the literature. Advantageously, the dielectrics used for preferred forms of display elements according to the invention contain at least 50 per cent by weight of at least one compound, forming a liquid-crystalline mesophase, of the formula

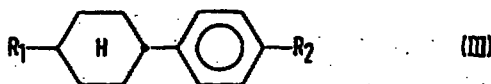


In this formula (I), the groups (A) and (B) represent rings or ring systems which are generally conventional in liquid-crystalline base material. In the embodiments to be described, at least one of these groups is a non-aromatic or only partially aromatic cyclic structural element, preferably a trans-1,4-disubstituted cyclohexane ring. Further structural elements which can be used for this purpose are the 1,4-disubstituted bicyclo[2.2.2] octane ring, the trans-2, 5-disubstituted 1,3-dioxane ring, the 2,6-disubstituted 1,2,3,4-tetrahydronaphthalene system or the 4-(trans-4-alkylcyclohexyl)-phenyl ring. The same structural elements can also be present in the other of the groups (A) and (B) but, furthermore, other homoaromatic or heteroaromatic structural elements, which are usual in liquid-crystalline substances for electro-optical purposes, such as, in particular, the 1,4-disubstituted benzene ring which additionally can also contain one or more fluorine atoms in the other positions, the 4,4'-disubstituted biphenyl system, the 2,6-disubstituted naphthalene system, the 2,5-disubstituted pyrimidine ring or the 3,6-disubstituted s-tetrazine ring, can also be used. The group X preferably represents a carboxyl group or a direct single C-C bond; additionally, it can represent, for example, a thioester group, a methyleneoxy group, a methylenethio group or an ethylene group. The wing groups R_1 and R_2 in the compounds of the formula (I) are alkyl, alkoxy or alkanoyloxy groups having up to 12 C atoms; one wing group can also be cyano, nitro, halogen or trifluoromethyl.

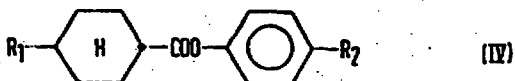
Preferred components of liquid-crystalline dielectrics having a low optical anisotropy are cyclohexylcyclohexanes having a formula (II),



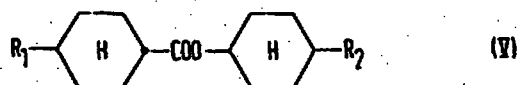
phenylcyclohexanes having a formula (III),



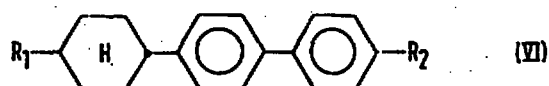
cyclohexanecarboxylic acid phenyl esters having a formula (IV),



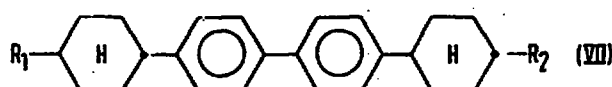
cyclohexanecarboxylic acid cyclohexyl esters having a formula (V),



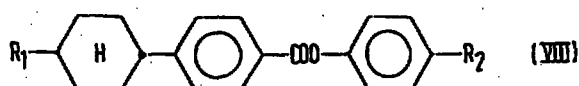
biphenylcyclohexanes having a formula (VI),



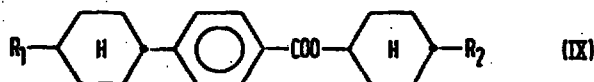
4,4'-dicyclohexylbiphenyls having a formula (VII),



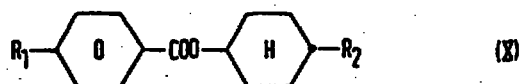
cyclohexylbenzoic acid phenyl esters having a formula (VIII),



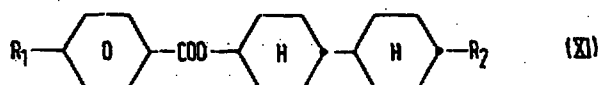
cyclohexylbenzoic acid cyclohexyl esters having a formula (IX),



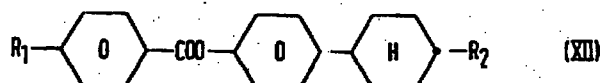
benzoic acid cyclohexyl esters having a formula (X)



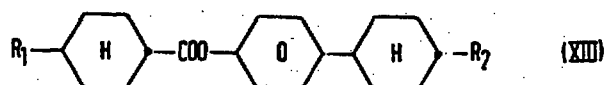
benzoic acid bicyclohexyl esters having a formula (XI),



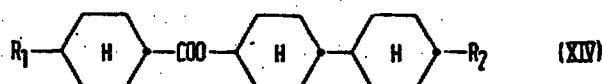
benzoic acid cyclohexylphenyl esters having a formula (XII),



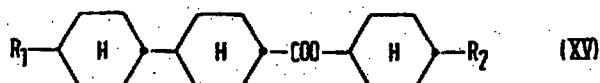
cyclohexanecarboxylic acid cyclohexylphenyl esters having a formula (XIII),



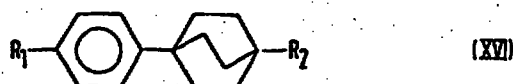
cyclohexanecarboxylic acid bicyclohexyl esters having a formula (XIV),



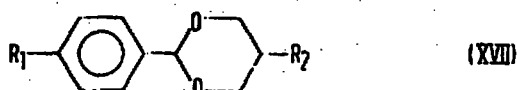
cyclohexylcyclohexanecarboxylic acid cyclohexyl esters having a formula (XV),



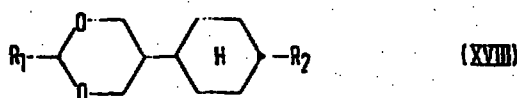
phenylbicyclo[2.2.2]octanes having a formula (XVI),



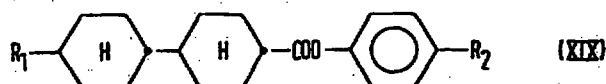
phenyl-1,3-dioxanes, having a formula (XVII),



cyclohexyl-1,3-dioxanes having a formula (XVIII),



and cyclohexylcyclohexanecarboxylic acid phenyl esters having a formula (XIX).



In the compounds of the formulae (II) to (XIX), the wing groups R_1 and R_2 have the meaning indicated with reference to formula (I). A wing group bonded to a cyclohexane ring or 1,3-dioxane ring here is preferably alkyl or alkanoyloxy having up to 12 C atoms, in particular having up to 8 C atoms, or in some cases a cyano group.

The liquid-crystalline dielectrics for the display elements contain at least 50 per cent by weight of one or more compounds of the formula (I), preferably of the formulae (II) to (XIX). As a rule, dielectrics of this type are mixtures containing two or more of these compounds; the composition of such mixtures, even with further components, can be varied within wide limits, as long as the optical anisotropy does not exceed the value of 0.12. Preferred dielectrics for the liquid crystal display elements contain at least 60 to 85 per cent by weight of at least one compound of the formulae (II) to (XIX); dielectrics can also be composed exclusively of liquid-crystalline base materials from these groups. Dielectrics of this type can, however, additionally contain conventional amounts of dyestuffs or doping substances, if thereby the optical anisotropy is not increased to beyond 0.12.

In order that the present invention be readily understood embodiments thereof will now be described by way of example with reference to the accompanying drawings, in which:-

Figure 1 is a diagrammatic representation of a liquid crystal display element;

Figure 2 is a graph of absorption versus operating voltage for two different viewing angles of a conventional liquid crystal display element;

Figure 3 is a lobe diagram of a conventional liquid crystal display element;

Figure 4 is a graph of absorption versus operating voltage for two different viewing angles of an embodiment of the present invention; and

Figure 5 is a lobe diagram of an embodiment of the present invention.

Figure 1 is a diagrammatic representation of a liquid crystal cell, for the purpose of defining the angles of observation (or viewing) θ and ϕ .

Figure 2 shows the dependence of the absorption of a conventional twisted nematic display element having a layer thickness of 9μ and an optical anisotropy of $\Delta n = 0.18$ ($d \times \Delta n = 1,720 \text{ nm}$) on the operating voltage for two different angles of observation θ . Whilst the absorption, in the case of observation from the direction of the perpendicular ($\theta = 0^\circ$; $\phi = 0^\circ$), reaches 90% of the maximum value at an operating voltage of about 3.7 V and then, with increasing voltage, tends slowly but steadily to the limiting value of the maximum absorption, in the case of observation at an angle of $\theta = 40^\circ$ and $\phi = 0^\circ$ the absorption reaches a maximum of about 95% at a voltage of about 2.7 V. At an only slightly increased voltage, the absorption falls steeply and the value of 90%, which is regarded as satisfactory for normal operation, is reached again only at a voltage of about 6 V. The characteristics for other angles of observation (not in the figure) show a qualitatively similar course, except that the initial maximum of the absorption lies at different operating voltages. With such a

liquid crystal display element, an absorption of at least 90%, independent of the angle, is reached only at an operating voltage of 6 V; this value is too high for most types of application in practice, where display elements of this type are operated with a battery as the voltage source, so that expensive voltage-multiplier circuits, which consume additional energy, become necessary.

Figure 3 is a lobe diagram of the same liquid crystal cell as that whose characteristics are shown in Figure 2, wherein the absorption at a constant angle of observation of $\theta = 40^\circ$ is plotted as a function of the angle of observation ϕ . The operating voltage was here kept constant at twice the threshold voltage, that is to say at about 4.5 V. Under these conditions, an absorption of at least 90% is reached only in the range of the angle ϕ from about 38° to 52° , and an absorption of at least 60% is reached only from $\phi = 5^\circ$ to 90° , that is to say over a range of about 85° .

Figure 4 is similar to Figure 2 but shows the dependence of the absorption on the operating voltage for a preferred embodiment of a liquid crystal display element according to the invention, having a layer thickness of 6.5μ and an optical anisotropy of the dielectric of $\Delta n = 0.06$ ($d \times \Delta n = 390 \text{ nm}$). In the case of observation in the direction of the perpendicular, the characteristic corresponds to that of a conventional display element according to Figure 2; an absorption of 90% being reached at an operating voltage of 3.7 V. In the case of an angle of observation θ of 40° , an absorption of 90% is reached again at 2.7 V. With increasing voltage, however, the absorption still rises a little and then also falls again a little, but not to less than 90%. The characteristics for other angles of observation θ have an analogous appearance. An absorption of at least 90%, which is virtually independent of the angle of observation, is thus reached by the preferred form of liquid crystal display element according to the invention at an operating voltage of 3.7 V.

Figure 5 shows the lobe diagram of a preferred form of liquid crystal display element according to the invention, having a layer thickness of 9μ and an optical anisotropy of the dielectric of $\Delta n = 0.06$ ($d \times \Delta n = 540 \text{ nm}$). In this diagram, the absorption is again plotted as a function of the angle of observation ϕ , at a constant angle of observation of $\theta = 40^\circ$ and at a constant operating voltage of twice the threshold voltage. An absorption of at least 90% is reached here in the range of ϕ from about 31° to 58° , but the absorption is more than 80% from -90° (270°) to $+172^\circ$, that is to say over a range of about 262° ; this is more than three times the range of the liquid crystal cell of conventional construction.

The examples which follow relate to liquid-crystalline dielectrics having a low optical anisotropy, for use in display elements according to the invention.

Example 1

A liquid-crystalline dielectric is composed of
 25% of 4-(trans-4-n-propylcyclohexyl)-benzonitrile;
 18% of 4-(trans-4-n-propylcyclohexyl)-phenetol;
 20% of trans-trans-4-n-butylcyclohexyl-cyclohexane-4'-carbonitrile;
 20% of trans-trans-4-ethylcyclohexyl-cyclohexane-4'-carbonitrile;
 10% of trans-4-n-pentylcyclohexanecarboxylic acid 4-(trans-4-n-propylcyclohexyl)-phenyl ester; and
 7% of trans-trans-4-n-propylcyclohexylcyclohexane-4'-carboxylic acid trans-4-n-propylcyclohexyl ester. The dielectric has a melting point of -7°C , a clear point of $+60^\circ$, a viscosity of $26 \times 10^{-3} \text{ Pa.s}$ at 20°C , a dielectric anisotropy of $\Delta\epsilon = +6.03$ and an optical anisotropy of $\Delta n = 0.08$. When used in a twisted nematic cell in a layer thickness of 6.5μ , the measured threshold voltage at 20°C is 1.85 V. The temperature dependence of the threshold voltage is $9.5 \text{ mV}/^\circ\text{C}$; the dielectric is thus outstandingly suitable for liquid display elements which are triggered in multiplex operation.

Example 2

A liquid-crystalline dielectric is composed of
 29% of trans-trans-4-ethylcyclohexyl-cyclohexane-4'-carbonitrile;
 29% of trans-trans-4-n-butylcyclohexyl-cyclohexane-4'-carbonitrile;
 28% of 4-(trans-4-n-propylcyclohexyl)-phenetol;
 9% of trans-trans-4-n-propylcyclohexyl-cyclohexane-4'-carboxylic acid trans-4-n-propylcyclohexyl ester; and
 5% of 4-(trans-4-n-pentylcyclohexyl)-4'-n-propylcyclohexyl-biphenyl.
 The dielectric has a nematic mesophase within the temperature range from -6°C to $+63^\circ\text{C}$, a viscosity of $28 \times 10^{-3} \text{ Pa.s}$ at 20°C , a dielectric anisotropy of $\Delta\epsilon = +3.55$ and an optical anisotropy of $\Delta n = 0.07$. The threshold voltage measured at 20°C is 2.16 V and the temperature dependence of the threshold voltage is $13.5 \text{ mV}/^\circ\text{C}$. This dielectric is well suited for liquid crystal display elements in multiplex operation.

CLAIMS

1. A twisted nematic liquid crystal display element having a liquid-crystalline dielectric layer the product of the thickness and the optical anisotropy of which has a value between 150 and 600 nm.
2. A display element according to claim 1, wherein the thickness of the liquid-crystalline dielectric layer is 3 to 10μ .
3. A display element according to claim 1 or 2, wherein the optical anisotropy of the liquid-crystalline dielectric layer is in the range 0.03 to 0.12.



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liquid crystal display element, an absorption of at least 90%, independent of the angle, is reached only at an operating voltage of 6 V; this value is too high for most types of application in practice, where display elements of this type are operated with a battery as the voltage source, so that expensive voltage-multiplier circuits, which consume additional energy, become necessary.

Figure 3 is a lobe diagram of the same liquid crystal cell as that whose characteristics are shown in Figure 2, wherein the absorption at a constant angle of observation of $\theta = 40^\circ$ is plotted as a function of the angle of observation ϕ . The operating voltage was here kept constant at twice the threshold voltage, that is to say at about 4.5 V. Under these conditions, an absorption of at least 90% is reached only in the range of the angle ϕ from about 38° to 52° , and an absorption of at least 60% is reached only from $\phi = 5^\circ$ to 90° , that is to say over a range of about 85° .

Figure 4 is similar to Figure 2 but shows the dependence of the absorption on the operating voltage for a preferred embodiment of a liquid crystal display element according to the invention, having a layer thickness of 6.5μ and an optical anisotropy of the dielectric of $\Delta n = 0.06$ ($d \times \Delta n = 390 \text{ nm}$). In the case of observation in the direction of the perpendicular, the characteristic corresponds to that of a conventional display element according to Figure 2; an absorption of 90% being reached at an operating voltage of 3.7 V. In the case of an angle of observation θ of 40° , an absorption of 90% is reached again at 2.7 V. With increasing voltage, however, the absorption still rises a little and then also falls again a little, but not to less than 90%. The characteristics for other angles of observation θ have an analogous appearance. An absorption of at least 90%, which is virtually independent of the angle of observation, is thus reached by the preferred form of liquid crystal display element according to the invention at an operating voltage of 3.7 V.

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and
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3. A display element according to claim 1 or 2, wherein the optical anisotropy of the liquid-crystalline dielectric layer is in the range 0.03 to 0.12.



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4. A display element according to claim 1 or 2, wherein the liquid-crystalline dielectric contains at least 50 per cent by weight of one or more of cyclohexylcyclohexanes, benzoic acid cyclohexyl, bicyclohexyl or cyclohexylphenyl esters, cyclohexane-carboxylic acid phenyl, cyclohexylphenyl, bicyclohexyl or cyclohexyl esters, phenylcyclohexanes, cyclohexylbiphenyls, 4,4'-dicyclohexylbiphenyls, cyclohexylbenzoic acid
- 5 phenyl or cyclohexyl esters, cyclohexylcyclohexane-carboxylic acid phenyl or cyclohexyl esters, phenyl- or cyclohexyl-1,3-dioxanes and phenylbicyclo[2.2.2] octanes.
5. A liquid crystal display element according to claim 1, wherein the liquid-crystalline dielectric is in accordance with Example 1 or Example 2.
6. A liquid crystal display element substantially as hereinbefore described with reference to Figure 4 or 5 of the accompanying drawings.

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