

LIQUID CRYSTAL ELECTROOPTICAL DEVICE

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The invention relates to a liquid crystal electrooptical element that uses a chiral nematic liquid crystal which has metastable states and more particularly to a liquid crystal electrooptical element capable of being multiplex driven by
10 using that bistability to perform switching.

Currently, the liquid crystal display devices being used as display devices for office equipment, etc., use a twisted nematic (TN) liquid crystal or a supertwisted nematic (STN)
15 liquid crystal. For example, these display systems, which are described by M. Schadt and W. Helfrich in *Appl. Phys. Lett.* 18 (1971) 127 or by T. J. Scheffer and J. Nehring in *Appl. Phys. Lett.* 45 (1984) 1021, do not have a memory effect, and therefore they are driven by a multiplex drive
20 method using voltage averaging or an active matrix drive method in which a transistor or other active element is provided at each picture element.

Other systems are being researched in addition to these,
25 though they have not reached the application stage. For example, high speed technologies for voltage averaging are disclosed in JP-A-59-219720 and JP-A-60-196728, and systems that utilize bistable switching are disclosed in JP-B-1-51818 and JP-B-3-26368.

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When a TN or STN type liquid crystal simple matrix is driven by the voltage averaging method, the ratio of the voltage V_{ON} for selecting the ON condition to the voltage V_{OFF} for selecting the OFF condition is given by the following equation,
35 where the number of scanning lines is N .

$$V_{ON}/V_{OFF} = ((N^{1/2} + 1)/(N^{1/2} - 1))^{1/2}$$

As can be seen from this equation, since V_{ON}/V_{OFF} approaches 1 as N becomes large, the contrast ratio also approaches 1. Considering both the electrooptical characteristic of current
5 liquid crystal and the delay in the voltage waveform, N is limited up to approximately 500. Therefore, it is impossible to use this system to realize display devices for workstations, etc., requiring high definition displays. Also, the display characteristic is greatly dependent on the viewing
10 angle, and the switching time is long.

The technology disclosed in the aforementioned JP-A-60-196728 is aimed at shortening the above switching time. By this means, the switching from ON to OFF can be speeded up by
15 using a configuration in which the pretilt angle θ_1 on the lower substrate (angle formed between the director vector of the liquid crystal molecules in contact with the liquid crystal alignment film on the substrate and the substrate surface) and the pretilt angle θ_2 on the upper substrate have
20 opposite signs. Also, the technology disclosed in the aforementioned JP-A-59-219720 is aimed at stabilizing the operating condition by adding a chiral substance to the liquid crystal material. However, even if these technologies are used bistability cannot be provided and the liquid crystal
25 element must be driven by means of a voltage averaging method. Therefore, even by using these technologies high definition liquid crystal displays cannot be realized.

A chiral nematic liquid crystal electrooptical element with
30 bistability is disclosed in JP-B-1-51818 (US-A-4,239,345). This liquid crystal electrooptical element has a 180° twist in its initial state, but after voltage is applied, it relaxes to two states different from its initial state, and those two states are extremely stable. The difference in twist
35 between the two states is approximately 360° , and bistable switching is performed between the two states. The two states can be optically distinguished by sandwiching the liquid

crystal electrooptical element between two polarizing plates. In this case, it is noted that a high contrast ratio can be achieved by configuring the element such that the result of dividing the product (R) of the birefringence Δn of the liquid crystal and the thickness d (μm) of the liquid crystal layer by the wavelength (λ) of the incident light (R/λ) is less than 2.

The technology disclosed in JP-B-3-26368 performs relatively rapid bistable switching by controlling the applied voltage. However, since it requires a rather high pretilt angle of 35° , the liquid crystal alignment film must be formed by oblique deposition, which is not practical.

Further, liquid crystal display devices requiring a high pretilt angle and liquid crystal display devices driven at a high duty ratio by a voltage-averaging method have a narrow effective viewing angle.

When a liquid crystal electrooptical element is used as a display element, normally a red, green and blue three-wavelength light source or white light source is used, and therefore the element must have a high contrast ratio and a high light transmittance in its ON state for light of those kinds of light sources. Therefore, it is necessary to know the conditions for obtaining a good display characteristic for those kinds of light sources.

Parameters that determine the display characteristic include the birefringence (Δn) of the liquid crystal material, the thickness (d) of the liquid crystal layer and the angles of the polarization axes of the two polarizing plates. The document JP-B-1-51818 states only that regarding R ($= d \cdot \Delta n$), a high contrast ratio can be achieved by making $R/\lambda \leq 2$ when a monochromatic light is used as the light source, and it does not make any reference to the conditions required to achieve a high ON light transmittance or to the angle of the

polarization axes. It does not discuss at all the conditions when white light is used. Though it is mentioned that a high contrast ratio can be achieved by making $R/\lambda \leq 2$, the R/λ of the cells in the embodiments is greater than 2 in each case, and there are no data on the light transmittance or the contrast ratio. In additional experiments in which we used white light, we were able to optically distinguish the two metastable states, but we did not obtain a display characteristic that would make the element useful as a display device.

As described below, in a liquid crystal display using two metastable states whose twist angles are $\Phi \pm 180^\circ$ setting the polarization axes, which are among the parameters that determine the display characteristic, to the optimum angle is not easy. In such a bistable liquid crystal display, the twist angle of which is 180° in its initial state, one of the two metastable states is a uniform state with a twist angle of 0° , and therefore the light transmittance when the two polarizing plates are each disposed at a certain angle can be sought relatively easily. However, the twist angle of the other metastable state is approximately 360° , and in order to speed up the response as much as possible, the liquid crystal layer must be made as thin as possible. When the twist angle is large and the liquid crystal layer is thin like this, the linearly polarized light (white light) incident on the liquid crystal layer is emitted as elliptically polarized light, thus making it difficult to seek the transmitted light spectrum in the 360° twisted state. At this point, it has not been established yet how to set the polarization axes to increase both the contrast ratio and the ON transmittance when R is a certain value.

The invention is intended to solve the above problems, and its first purpose is to offer a bistable liquid crystal electrooptical element that uses chiral nematic liquid crystal

having a sufficient display characteristic as a display element with a high contrast ratio and a high ON transmittance.

This first object is achieved with a liquid crystal electro-optical element as claimed in claim 1. Preferred embodiments of the invention are subject-matter of the dependent claims 2 to 15.

In the liquid crystal electrooptical element of the invention, the respective stabilities of the initial state and the two metastable states are dependent on the ratio (d/p_0) of the liquid crystal layer thickness (d) to the liquid crystal helical pitch p_0 . Where the twist angle in the initial state is Φr , the desired orientation state can be realized by satisfying the condition

$$0.5 \Phi r / 360^\circ \leq d/p_0 \leq 1.5 \Phi r / 360^\circ.$$

However, regarding the two metastable states obtained by applying a driving waveform, the metastable state in which the twist angle is roughly ($\Phi r + 180^\circ$) becomes more unstable than the other metastable state under the condition

$$d/p_0 \approx 0.5 \Phi r / 360^\circ$$

while under the condition

$$d/p_0 \approx 1.5 \Phi r / 360^\circ$$

the metastable state in which the twist angle is roughly ($\Phi r - 180^\circ$) becomes more unstable than the other metastable state. A liquid crystal display device having unbalanced stabilities of the two metastable states has the problem that greater energy is needed to select the unstable state, thus increasing the driving voltage or requiring that a pulse voltage be applied over a long period. Further, since the time required to relax from the selected unstable metastable state to the initial state (memory retention time) is short, relaxation may occur in the nonselection period when the display device has many scanning electrodes, thus degrading display quality.

The angle formed by the substrate interface and the director vector of the liquid crystal molecules (pretilt angle) also has an effect on the balance between the stabilities of the two metastable states. According to the results of experiments by the inventors, it was found that the stability of the metastable state of the twist angle which is $(\Phi_r + 180^\circ)$ dropped as the pretilt angle became larger. Such a display has the same problems as described above. In addition, a great pretilt angle will provide a narrow effective viewing angle.

Further, in a liquid crystal display with bistability or multi-stability, the orientation states used for display are often not sufficiently stable, and plural orientation states may occur at the same time due to local displacement in the surface condition or shape of the substrate, resulting in poor display quality.

In liquid crystal displays related to this invention, a shape effect occurs at the edge of the transparent electrodes, and particularly when the twist angle $(\Phi_r + 180^\circ)$ is selected as the metastable state by applying a driving waveform, a domain of the twist angle $(\Phi_r - 180^\circ)$ appears at the above edge, which lowers the contrast ratio. This tendency is most evident when the direction of rubbing is parallel to a selected side of the pixels.

In view of the above problems of the prior art, the second purpose of the invention is to offer a high definition liquid crystal display device with many scanning lines wherein the display characteristic of the bistable liquid crystal electrooptical element has little dependence on the viewing angle.

The second object is achieved with a liquid crystal display device as claimed in claim 16. Preferred embodiments are subject-matter of the dependent claims 17 to 21.

The chiral nematic liquid crystal of the invention has two metastable states as relaxation states which are different from its initial state; for example, assuming the initial
5 state has a twisted structure in which the twist angle is 180° , the chiral nematic liquid crystal has two metastable states in which the twist angle is 0° (uniform state) in one and 360° in the other when a pulse voltage is applied with an absolute value large enough to cause a Frederick's transi-
10 tion. The waveform and absolute value of the pulse voltage applied next determine whether the molecular orientation becomes the metastable state of a 0° twist angle or a 360° twist angle and both metastable states spontaneously relax to the initial state.

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The twist angle Φ_r in the initial state is not limited to 180° , and it can be set as desired. For example, assuming the twist angle Φ_r in the initial state is 90° , the two metastable states after Frederick's transition have twist
20 structures of $\Phi_r \pm 180^\circ$, i.e., -90° and 270° , and it was confirmed experimentally that switching between these metastable states was possible. The twist angles $\Phi_r \pm 180^\circ$ of the metastable states are not exact values but rather are roughly $\Phi_r \pm 180^\circ$.

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A cross section of the structure when the liquid crystal electrooptical element of the invention is applied to a liquid crystal display device is shown in FIG. 1. In the figure, 21 is the chiral nematic liquid crystal layer, 2 are
30 upper and lower alignment films, 3 are upper and lower SiO_2 insulating films, 4 are the upper and lower transparent electrodes, 5 are the upper and lower glass substrates, 6 is a seal member used as a spacer, 7 are the upper and lower polarizing plates, 19 is the rubbing direction on the lower
35 alignment film and 20 is the rubbing direction on the upper alignment film. In the figure, rubbing directions 19, 20 are oppositely parallel ($\Phi_r = 180^\circ$), and chiral nematic liquid

crystal 21 is infused between the two substrates 5 mated together with seal member 6 between them.

In the initial state, the angles formed by the director vectors in contact with the alignment films and the substrate surfaces are θ_1 and θ_2 , and they both have opposite signs. That is, assuming a twist angle of 180° in the initial state, the above two director vectors are roughly parallel to each other in opposing directions.

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Assuming the direction of rubbing on aforementioned lower substrate 5 is the x axis and the normal on the substrate is the z axis, in the measurement of angles using the x axis direction as a reference, the angles of the polarization axes of lower polarization plate 7 on lower substrate 5 and polarization plate 7 on upper substrate 5 are P and A, respectively, and if the direction of twist of the chiral nematic liquid crystal viewed in the z axis direction is clockwise, a positive angle of P indicates a clockwise rotation of the polarization axis and vice versa. FIG. 3 shows the condition in which the angle between rubbing direction x and the polarization axis indicated by the arrow is defined as P when the helical structure of the liquid crystal has a clockwise twist when viewed in the z axis direction. A similar measurement was performed for angle A formed by the polarization axis of the upper polarization plate and the x axis. $P \pm n\pi$ (n is an integer) and P are equivalent. The same is true for A.

The liquid crystal display device of the invention utilizes the switching between the two metastable states. The inventors confirmed experimentally that the time until the selected metastable state spontaneously relaxed to the initial state (memory retention time) was dependent on d/p_0 and discovered by statistical analysis of the results that a practical memory retention time for a display device could be achieved under the condition

$$0.8 \Phi_r/360^\circ \leq d/p_0 \leq 1.4 \Phi_r/360^\circ$$

A "practical retention time for a display device" as referred to here means the time equal to or longer than the time required for selection per line times the number of scanning lines and is essentially different from the bistability in the reference to a "lasting existence" JP-B-1-51818. Also, in the technology disclosed in the same publication, 25° to 45° is recommended for the pretilt angle, but in this invention, a practical retention time can be realized by applying the aforementioned condition formula in the 1° to 25° range; i.e., an angle range in which the pretilt angle can be achieved by the simple method of rubbing an organic film. Even when Φ_r is not 180° a practical retention time can be obtained by adjusting the helical pitch in a similar manner.

In a liquid crystal display with bistability or multi-stability, the orientation states used for display are often not sufficiently stable, and plural orientation states may occur at the same time due to a local displacement in the surface condition or shape of the substrate, resulting in poor display quality. This problem is solved when the condition

$$10^\circ \leq \Phi_0 \leq 80^\circ$$

where Φ_0 is the angle formed by a selected side of the pixel, is satisfied on each of the upper and lower substrates, in which case high definition display with many scanning lines is possible in a simple matrix system while maintaining a wide viewing angle and preventing the occurrence of undesirable domains in the pixels for a uniform displayed image.

The effective viewing angle can be widened when one or both of the angles formed by the rubbing directions and the vertical direction of the liquid crystal display as viewed by an observer is greater than or equal to 45°.

In a liquid crystal display with bistability or multi-stability as described above, particularly one in which switching is performed by applying an electric field, there are many cases in which orientation of a non-pixel area (between adja-

cent pixels) cannot be controlled because the electrodes are formed on only one substrate, resulting in light leaking and degrading the contrast ratio. As a countermeasure, the light transmittance in non-pixel areas should be made lower than
5 that in pixel areas, and this can be achieved by forming a layer of light masking material on non-pixels areas. Or the light transmittance in non-pixel areas can be made lower than that in pixel areas by adjusting the twist angle of the liquid crystal in the non-pixel areas as

10 $d_0/p_0 \geq 0.75$

where d_0 is the thickness of the liquid crystal layer in the non-pixel areas.

The invention enables multiplex drive of chiral nematic
15 liquid crystal having two metastable states by switching between the two metastable states. Where the twist angle Φ_r in the initial state and $R (= \Delta n \cdot d)$ are parameters, it was shown that the purpose of the invention was achieved by appropriately setting the angles P and A formed by the pola-
20 rization axes of the polarizing plates and one of the rubbing directions according to these parameters. The optimum values for the angles P and A are dependent on each other, and it was confirmed that their relationship was greatly influenced by Φ_r and R .

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The Mauguin condition is a condition for rotating the polarization axis of the propagated light so that the polarization axis follows the twist of the liquid crystal molecules when linearly polarized light is incident in the direction of the
30 helical axis of the chiral nematic liquid crystal. This is expressed by the equation

$$p' \cdot \Delta n \gg \lambda$$

where p' is the helical pitch of the liquid crystal when infused between two substrates that had undergone alignment
35 treatment, $\Delta n = n_e - n_o$, (n_e and n_o being the refractive indices of the liquid crystal for extraordinary light and

normal light, respectively), and λ is the wavelength of the light.

When linearly polarized light having a polarization axis
5 parallel (or perpendicular) to the alignment direction n_1 of
the liquid crystal molecules in contact with one substrate is
introduced in a liquid crystal cell in which the parameters
have been set so that the above Mauguin condition is satis-
fied, the axis of the polarized light is rotated to follow
10 the twist of the liquid crystal molecule alignment so that it
becomes linearly polarized light polarized parallel (or per-
pendicular) to the alignment direction n_2 of the liquid cry-
stal molecules in contact with the other substrate, and the
light is emitted. Also, when linearly polarized light having
15 a polarization axis in a direction other than parallel (or
perpendicular) to n_1 is introduced, the light becomes ellip-
tically polarized and is emitted. Widely used TN type liquid
crystal display devices perform switching between a homeotro-
pically aligned state and a twisted state that satisfy the
20 Mauguin condition. That twist angle is 90° , and the optimum
value for $p' \cdot \Delta n$ is approximately $1.88 \mu m$ ($p' \approx 20 \mu m$, $\Delta n \approx$
 0.094). By setting the two polarizing plates so that their
polarization axes are parallel (or perpendicular) to n_1 and
 n_2 , respectively, an extremely high contrast ratio and ON
25 transmittance can be achieved.

The above does not apply to the relationship between the dis-
play characteristic of the bistable liquid crystal display
device used in this invention and the Mauguin condition. In
30 this patent specification, where Φ_r is the twist angle in the
initial alignment state, switching is performed between two
twist states in which the twist angle is $\Phi_r + 180^\circ$ and $\Phi_r -$
 180° . The twist state of the twist angle whose absolute
value is the larger one is referred to as S^+ and the other is
35 referred to as S^- . Here, each of the parameters are set so
that both S^+ and S^- satisfy the Mauguin condition, and if the
two polarizing plates are disposed such that their respective

polarization axes are parallel (or perpendicular) to n_1 and n_2 , S^+ and S^- can hardly be distinguished optically. This is because, since n_1 and n_2 of S^+ match n_1 and n_2 of S^- , respectively, both the emitted light of S^+ and the emitted light of S^- become linearly polarized light polarized in the same direction. Also, when the two polarization plates are disposed such that their polarization axes are other than parallel (or perpendicular) to n_1 and n_2 , respectively, then S^+ and S^- can be optically distinguished but the display element does not have a display characteristic that is suited to practical application. This fact is irrespective of the value of Φ_r .

However, if S^+ , for example, should not satisfy the Mauguin condition, then the following can be considered. A case is explained in which Φ_r is roughly 180° , which is the angle at which the optimum display characteristic is expected to be achieved. Below, L is the helical pitch in S^+ .

(1) When $L \cdot (n_e - n_o)$ is sufficiently smaller than λ :

S^+ is optically isotropic, but it behaves as an optically active medium with several degrees of rotation power per $1 \mu\text{m}$ (de Gennes, P.G., *The Physics of Liquid Crystals*, p. 226, Oxford University Press (1974)). When an optical rotation angle of Φ_{rot} is assumed, it is clear that the light transmittance of S^+ reaches a minimum where the angle Φ_{12} formed by the polarization axes of the two polarizing plates is $90^\circ + \Phi_{\text{rot}}$.

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The twist angle of S^- , on the other hand, is 0° . However, since chiral nematic liquid crystal has an intrinsic twist, the twist angle of S^- is not strictly 0° even if $\Phi_r = 180^\circ$. However, if the twist angle is not very large, S^- may be considered to be a birefringent medium with no twist under the condition $\Phi_r \approx 180^\circ$. Therefore, if the angle (Φ_n) formed by the direction of the polarization axis of one polarizing

plate and the average alignment direction of the liquid crystal molecules in S^- is set to approximately 45° in order to raise the light transmittance of S^- under the condition $\Phi_{12} = 90^\circ + \Phi_{\text{rot}}$, it should be possible to obtain an extremely high contrast ratio and ON state brightness.

(2) When $L \cdot (n_e - n_o)$ is larger than λ but is not large enough to satisfy the Mauguin condition:

10 Even if $\Phi_n = 0^\circ$ in this case, the emitted light of S^+ becomes elliptically polarized light and the direction of the longer axis of the ellipse is not parallel to n_2 . Therefore, a high contrast ratio and ON state brightness can be expected assuming that, for example, $\Phi_n = 0^\circ$ and $\Phi_{12} = 90^\circ$.

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(3) When $L \cdot (n_e - n_o)$ is a value intermediate between (1) and (2) above:

In this case, a display characteristic intermediate between
20 (1) and (2) should be expected. It is not easy to imagine the display characteristic when Φ_r has shifted to a value larger than 180° . However, if the Mauguin condition is not satisfied, it should be possible to avoid the situation in which the polarization conditions of the emitted light in S^+
25 and S^- become nearly the same and cannot be optically distinguished.

In this invention the relaxed state is regarded as the metastable state because the memory retention time is not
30 infinite. It may be possible, however, that the stability of the metastable state extremely increases and that the memory retention time approaches infinite. Of course, this invention applies to the case of an infinite memory retention time. Though the term "optically isotropic medium" in general means
35 that Δn of the medium is zero, in the present patent specification the medium is regarded optically isotropic if the apparent Δn is much smaller than its intrinsic Δn .

Preferred embodiments of the invention will be described below in more detail with reference to the drawings, in which:

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FIG. 1 is a cross section of the liquid crystal electrooptical element of the invention,

FIG. 2 is a cross section of the liquid crystal electrooptical element of the invention,

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FIG. 3 is a graph defining the angles of the polarization axes,

15 FIG. 4 is a diagram showing the driving waveforms,

FIG. 5 is a diagram showing the optimum values for angles P and A of the polarization axes,

20 FIG. 6 is a diagram showing the driving waveforms,

FIG. 7 is a diagram for explaining the relationship between the electrodes and the alignment directions,

25 FIG. 8 is a block diagram of the driving circuit,

FIG. 9 is a diagram for explaining the relationship between the observer and the coordinate axes,

30 FIG. 10 is a diagram for explaining the relationship between the alignment directions and the polarization axes,

FIG. 11 is a diagram showing the driving waveforms,

35 FIG. 12 is a cross section showing the structure of the liquid crystal display element,

FIG. 13 is a diagram showing the driving waveforms, and

FIG. 14 is a cross section showing the structure of the liquid crystal display element, and

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FIG. 15 is a cross section showing the structure of a liquid crystal color display element.

A cross section of the liquid crystal electrooptical element used in this embodiment is shown in FIG. 1. A transparent electrode 4, an insulating SiO_2 film 3 and a liquid crystal alignment film 2 are formed on each of an upper substrate 5 and a lower substrate 5, after which they undergo rubbing. A polyimide is used as the liquid crystal alignment film.

15 Assuming an initial alignment state in which $\Phi_r = 180^\circ$, for example, the two substrates are mated together via a spacer 6 so that the rubbing directions are parallel to each other in opposing directions. Also, assuming $\Phi_r = 90^\circ$, the two substrates are mated together so that the angle formed by the two rubbing directions is 90° . The liquid crystal electrooptical element was fabricated by infusing a chiral nematic liquid crystal 21 between these two substrates and disposing the polarizing plates 7 on them. To use this liquid crystal electrooptical element as a reflective type, a reflective

25 plate need only be disposed on the outside of the upper polarizing plate or the lower polarizing plate. The liquid crystal material used included a nematic liquid crystal having a positive dielectric anisotropy ($\Delta\epsilon > 0$) available on the market and an optically active compound that induces a

30 helical structure added to the nematic liquid crystal to adjust the p_0 . In the first to the seventh embodiments, E. Merck's R-811 was used as the optically active compound, while in the eighth and later embodiments, E. Merck's S-811 was used.

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The Δn up until now referred to the apparent Δn , but in the following embodiments, the liquid crystal's intrinsic Δn was

used. This is because the pretilt angle is generally 1° to 5° , and therefore the apparent Δn in the non-twisted state and the intrinsic Δn of the liquid crystal can be considered to be nearly equal. However, when the pretilt angle is
5 large, the intrinsic Δn of the liquid crystal and the apparent Δn differ greatly and the apparent Δn must be used. Further, since the molecular alignment in a case in which display is performed in a memory state without applying voltage differs from that in a case in which display is
10 performed in a state in which voltage is applied, the values of the apparent Δn must be different. However, since the voltage is about 1 volt, the difference in the apparent Δn when a voltage is applied and when a voltage is not applied is very small and that difference may be ignored. Therefore,
15 it is natural that the average apparent Δn during display operation be used, but the intrinsic Δn of the liquid crystal is used in the following embodiments. As described above, when display is performed by applying a large voltage such that the alignment distribution deviates greatly or when the
20 pretilt angle is large the average apparent Δn during display operation must be used.

In order to set R to various values, several varieties of liquid crystal material with differing Δn were used and the
25 thickness of the liquid crystal layer was set between $1.7 \mu\text{m}$ and $25.0 \mu\text{m}$. The Δn of the liquid crystal materials and the number of the embodiment in which each liquid crystal material was used are shown in TABLE 1 below. Also, though the pretilt angle differed depending on the liquid crystal mate-
30 rial, the alignment film and the rubbing method, it was about 1° to 5° in the first to the seventh embodiments.

TABLE 1

5	Liquid crystal material	Δn	Embodiment
	ZLI-4119	0.06	1-1.
	ZLI-4262	0.10	1-2 to 9, 1-12, 1-15, 1-26 to 27, 2-1 and 2, 3-1 and 2, 4-1 and 2, 5-1 and 2, 6, 7
	ZLI-1370	0.14	1-10, 1-14, 2-4 and 5, 3-4 and 5, 4-4 and 5, 5-4 and 5
10	ZLI-2140-000	0.15	1-13
	ZLI-4454-000	0.159	1-16 to 19, 1-21 and 22, 2-3, 3-3, 4-3, 5-3
	ZLI-4155	0.186	1-11, 1-24
	ZLI-5049-000	0.208	1-20, 1-23, 1-25

15 We evaluated whether or not the liquid crystal element satisfies the Mauguin condition using the helical pitch L of the metastable state with the larger absolute value of the twist angle between the two metastable states, the Δn and the wavelength (380 to 780 nm) of the light. The twist angle Φ_r
20 in the initial state and L have the following relationship.

$$L = \{2\pi/(\Phi_r + 180^\circ)\} \cdot d$$

The left side ($L \cdot \Delta n$) of the inequality which describes the Mauguin condition and R have the following relationship.

$$L \cdot \Delta n = 2\pi \cdot R/(\Phi_r + 180^\circ)$$

25 Therefore, setting the direction of the polarization axis according to the value of $L \cdot \Delta n$ is nothing more than setting the direction of the polarization axis according to the value of R and Φ_r . Also, only when $\Phi_r = 180^\circ$ does $L \cdot \Delta n$ equal the retardation of S^- , because the relationship between Φ_r and L
30 shows that L is equal to d when $\Phi_r = 180^\circ$.

Rubbing direction 19 on lower substrate 5 is the x axis. In the first to the seventh embodiments, the helical structure observed in the direction normal to the substrate (z axis
35 direction) is a right handed twist (clockwise twist), and therefore the angle P of the polarization axis of lower polarization plate 7 is defined as shown in FIG. 3. Of course, P

and $P \pm n\pi$ (n is an integer) are equivalent. The same is true for A . A set of (P, A) and a set of $(P \pm n\pi/2, A \pm n\pi/2)$ are also equivalent. For example, $(P, A) = (160^\circ, 50^\circ)$ and $(P, A) = (70^\circ, 140^\circ)$ yield the same display
5 characteristic.

Switching between the two metastable states in which the twist angles of the liquid crystal are approximately 360° and 0° , respectively, is performed by applying a voltage waveform
10 such as that shown in FIG. 4. We also set P and A to various angles and measured the light transmittance in the 360° and 0° states to calculate the contrast ratio. We used a polarizing microscope, model BH-2, produced by Olympus and a white light source attached to it. However, the light transmit-
15 tance of the polarizing plate used was approximately 48%.

The display properties of a reflective type can be evaluated by using the display properties of a transmission type as shown below. In the transmission type liquid crystal display
20 device shown in Fig. 1, assume that it is used as a reflective type by placing a reflector plate under the lower polarizing plate. Assume that light of intensity I_0 is introduced to the upper polarizing plate and light of intensity I_d is reflected off. Assume that the intensity of
25 the incident light going into the liquid crystal layer after having passed through the upper polarizing plate is I_a , the intensity of the light transmitted through the lower polarizing plate is I_b , the intensity of the incident light going into the lower polarizing plate again after being
30 reflected off the reflection plate is also I_b , the intensity of the incident light going into the liquid crystal layer again after passing through the lower polarizing plate is I_c , and the intensity of the light (reflected light) transmitted through the upper polarizing plate is I_d . The ratio of I_d to
35 I_c is equal to the ratio of I_b to I_a , hence the following is true:

$$I_d = I_c \cdot I_b / I_a \quad (1)$$

Next, assume the light transmissivity of the polarizing plates for unpolarized light is x and the light
5 transmissivity of the polarizing plates for the linear polarized light which is polarized parallel to the light transmission axis of polarizing plate is y , then I_a and I_c can be expressed as follows:

$$10 \quad I_a = x \cdot I_o \quad (2)$$

$$I_c = y \cdot I_b \quad (3)$$

When the equations (2) and (3) are substituted into the
15 equation (1),

$$I_d = (I_b^2 / I_o) \cdot (y/x)$$

$$I_d / I_o = (I_b / I_o)^2 \cdot (y/x)$$

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can be obtained. Exactly speaking $y \neq 1$, however, it is close to $y = 1$. Further, we will distinguish light intensities in ON and OFF states by adding (ON) and (OFF), then the contrast ratio CR in a reflection type can be
25 expressed as follows:

$$\begin{aligned} CR &= I_{d(ON)} / I_{d(OFF)} \\ &= (I_{b(ON)} / I_{b(OFF)})^2 \end{aligned}$$

30 Thus, the reflectivity, I_d / I_o , and contrast ratio in a reflective type can be obtained from the transmissivity, I_b / I_o , and contrast ratio in transmission type.

35 First Embodiment: $\Phi_r = 180^\circ$

$$(1-1): R = 0.102$$

We adjusted p_o so that ϕ_r was nearly 180° by adding an appropriate amount of the optically active compound R-811 (E. Merck) to ZLI-4119 ($\Delta n = 0.060$) produced by E. Merck. The
5 thickness d of the liquid crystal layer was $1.7 \mu m$. $L = d = 1.7 \mu m$ and $d/p_o \approx 0.5$. The relationship between $L \cdot \Delta n$ and the wavelength is given by

$$L \cdot \Delta n = 0.102 < \lambda \text{ (0.38 to } 0.78 \mu m)$$

Therefore, the Mauguin condition is not satisfied.

10

The light transmittance I^+ in the 360° -twisted state, The transmittance I^- in the 0° twisted state and the contrast ratio CR in various combinations of P and A are shown in
TABLE 2 (second digit after the decimal point is rounded up
15 if the third digit is 5 or greater and rounded down if less than 5).

A light transmittance of 100 corresponds to an intensity of the transmitted light equal to that of the incident light.

20 Also, the values of $L \cdot \Delta n$, the wavelength (λ) and d and L are noted below the table. That is, combinations Nos. 1 to 13 are embodiments, and combinations 14 to 17 are comparison examples.

25 The meanings of T and R are as follows. The "o" in the T column indicates the combination is good enough to be used as a transmission type display element, and the "o" in the R column indicates that the combination is good enough to be used as a reflective type display element (Thus, R in this
30 and other tables should be distinguished from $R = \Delta n \cdot d$). An asterisk (*) in both the T and R columns indicates that the respective combination of P and A is given as comparison example. When $R = 0.102$, the combinations Nos. 1 to 6 can be used as both transmission type and reflective type elements.
35 Also, combinations Nos. 7 to 13 are not good enough to be used as transmission type elements. However, since greater emphasis is placed on the brightness in the bright state than

on the contrast ratio when used as a reflective type element, they can be used as reflective type elements. The contrast ratio in a reflective type element should be at least 1:2.

Therefore, if the contrast ratio when measured as a transmission type element is 1:1.4, it is good enough to be used as a reflective type element. Combinations Nos. 14 to 17 given as comparison examples can neither be used as transmission type nor as reflective type elements.

10 The results of visual evaluation by human eyes to determine whether or not an element can be used as a reflective type by actually disposing a reflective plate on it are depicted in FIG. 5. We found that if P and A were combined within the range indicated by shading, the element could be used as a
15 reflective type. The results for various R are shown below, and all tables are read the same.

(1-2): R = 0.16, the results are shown in TABLE 3
(1-3): R = 0.2, the results are shown in TABLE 4.
20 (1-4): R = 0.22, the results are shown in TABLE 5.
(1-5): R = 0.24, the results are shown in TABLE 6.
(1-6): R = 0.28, the results are shown in TABLE 7.
(1-7): R = 0.32, the results are shown in TABLE 8.
(1-8): R = 0.36, the results are shown in TABLE 9.
25 (1-9): R = 0.4, the results are shown in TABLE 10.
(1-10): R = 0.42, the results are shown in TABLE 11.
(1-11): R = 0.428, the results are shown in TABLE 12.
(1-12): R = 0.44, the results are shown in TABLE 13.
(1-13): R = 0.45, the results are shown in TABLE 14.
30 (1-14): R = 0.56, the results are shown in TABLE 15.
(1-15): R = 0.64, the results are shown in TABLE 16.
(1-16): R = 0.7, the results are shown in TABLE 17.
(1-17): R = 0.72, the results are shown in TABLE 18.
(1-18): R = 0.78, the results are shown in TABLE 19.
35 (1-19): R = 0.84, the results are shown in TABLE 20.
(1-20): R = 0.96, the results are shown in TABLE 21.
(1-21): R = 1.02, the results are shown in TABLE 22.

- (1-22): $R = 1.05$, the results are shown in TABLE 23.
(1-23): $R = 1.06$, the results are shown in TABLE 24.
(1-24): $R = 1.08$, the results are shown in TABLE 25.
(1-25): $R = 1.12$, the results are shown in TABLE 26.
5 (1-26): $R = 1.9$, the results are shown in TABLE 27.
(1-27): $R = 2.5$, the results are shown in TABLE 28.

(1-28) In the above embodiments, we confirmed that practical implementation of the liquid crystal electrooptical element
10 was possible if Φ_r was in the range $160^\circ \leq \Phi_r \leq 200^\circ$. The mutual settings for P and A differ in reflective type and transmission type elements because, as described above, the contrast ratio in reflective type elements differs from that in transmission type elements. Their relationship is tabula-
15 ted below.

(1) Reflective type element

- (1) When $0.102 \leq R \leq 0.4$ or $0.78 \leq R \leq 0.96$,
20 $[P + \alpha_1 \leq A \leq P + \alpha_2 \text{ and } -P + \beta_1 \leq A \leq -P + \beta_2]$ or
 $[P + \gamma_1 \leq A \leq P + \gamma_2 \text{ and } -P + \delta_1 \leq A \leq -P + \delta_2]$
(2) When $0.72 \leq R \leq 0.78$,
 $[P + \alpha_1 \leq A \leq P + \alpha_2 \text{ and } -P + \beta_1 \leq A \leq -P + \beta_2]$ or
 $[P + \gamma_1 \leq A \leq P + \gamma_2]$
25 (3) When $0.40 \leq R \leq 0.72$, $0.96 \leq R \leq 0.99$,
or $1.05 \leq R \leq 1.12$,
 $[P + \alpha_1 \leq A \leq P + \alpha_2]$ or
 $[P + \gamma_1 \leq A \leq P + \gamma_2]$
(4) When $0.99 \leq R \leq 1.02$,
30 $[P + \alpha_1 \leq A \leq P + \alpha_2]$
(5) When $1.02 \leq R \leq 1.05$,
 $[P + \gamma_1 \leq A \leq P + \gamma_2]$

Provided:

$\alpha_1 = -109.4 \cdot R - 133.1$	$(0.102 \leq R \leq 1.02)$
35 -225.0	$(1.05 \leq R \leq 1.12)$
$\alpha_2 = -45.0,$	$(0.102 \leq R \leq 0.32)$
$6696.4 \cdot R^3 - 8720.1 \cdot R^2 + 3354.7 \cdot R - 445.0$	$(0.32 \leq R \leq 0.64)$

	$1519.0 \cdot R^3 - 4175.2 \cdot R^2 + 3568.7 \cdot R - 1087.0$	$(0.64 \leq R \leq 1.02)$
	$-333.3 \cdot R + 175.0,$	$(1.05 \leq R \leq 1.12)$
	$\beta_1 = -9114.6 \cdot R^3 + 6666.7 \cdot R^2 - 1577.1 \cdot R + 74.0$	$(0.102 \leq R \leq 0.36)$
	-55.0	$(0.36 \leq R \leq 0.40)$
5	-75.0	$(0.72 \leq R \leq 0.96)$
	$\beta_2 = 9114.6 \cdot R^3 - 6666.7 \cdot R^2 + 1577.1 \cdot R - 74.0$	$(0.102 \leq R \leq 0.36)$
	55.0	$(0.36 \leq R \leq 0.40)$
	75.0	$(0.72 \leq R \leq 0.96)$
	$\gamma_1 = 312.5 \cdot R^2 - 187.5 \cdot R - 37.0$	$(0.102 \leq R \leq 0.32)$
10	$5208.3 \cdot R^3 - 7500.0 \cdot R^2 + 3341.6 \cdot R - 537.0$	$(0.32 \leq R \leq 0.64)$
	$1030.2 \cdot R^3 - 2722.0 \cdot R^2 + 2225.9 \cdot R - 684.0$	$(0.64 \leq R \leq 0.99)$
	$197575.9 \cdot R^3 - 626821.6 \cdot R^2 + 662332.3 \cdot R - 233217.9$	$(1.02 \leq R \leq 1.12)$
	$\gamma_2 = -625.0 \cdot R^2 + 225.0 \cdot R + 27.0$	$(0.102 \leq R \leq 0.32)$
	$7254.4 \cdot R^3 - 10245.5 \cdot R^2 + 4448.2 \cdot R - 577.0$	$(0.32 \leq R \leq 0.64)$
15	$-558.0 \cdot R^2 + 736.6 \cdot R - 267.9$	$(0.64 \leq R \leq 0.99)$
	$-5555.5 \cdot R^2 + 11500.0 \cdot R - 6024.9$	$(1.02 \leq R \leq 1.12)$
	$\delta_1 = -6746.0 \cdot R^3 + 5571.4 \cdot R^2 - 1504.0 \cdot R + 166.9$	$(0.102 \leq R \leq 0.40)$
	$-55.6 \cdot R + 68.4$	$(0.78 \leq R \leq 0.96)$
	$\delta_2 = 6746.0 \cdot R^3 - 5571.4 \cdot R^2 + 1504.0 \cdot R + 13.1$	$(0.102 \leq R \leq 0.40)$
20	$55.6 \cdot R + 111.6$	$(0.78 \leq R \leq 0.96)$

(2) Transmission type element

- (1) When $0.1 \leq R \leq 0.22$,
- 25 $A = P + \alpha$, where $\alpha = -82 \cdot R + \alpha_1$
- (2) When $0.22 < R \leq 0.42$,
- $A = P + \alpha$, where $\alpha = -82 \cdot R + \alpha_1$, or
- $A = -P + \beta_1$
- (3) When $0.42 < R \leq 0.44$,
- 30 $A = P + \alpha$, where $\alpha = -137.5 \cdot R + \alpha_2$, or
- $A = -P + \beta_1$
- (4) When $0.44 < R < 0.473$,
- $A = P + \gamma$, where $-137.5 \cdot R - 75 \leq \gamma \leq -60$
- (5) When $0.473 \leq R \leq 0.7$,
- 35 $A = P + \alpha$, where $\alpha = -137.5 \cdot R + \alpha_2$, or
- $A = P + \alpha_3$
- (6) When $0.7 < R \leq 1.06$,

$$A = -P + \beta_1$$

However,

$$\begin{array}{ll} -99^\circ \leq \alpha_1 \leq -58^\circ & -75^\circ \leq \alpha_2 \leq -35^\circ \\ -100^\circ \leq \alpha_3 \leq -60^\circ & 70^\circ \leq \beta_1 \leq 110^\circ \end{array}$$

5

(3) The conditions for achieving a contrast ratio greater than 10 and an ON transmittance of 10% in a transmission type element in which Φ_r is 180° are listed below.

10 (1) When $0.1 \leq R \leq 0.22$,

$$A = P + \alpha, \text{ where } \alpha = -82 \cdot R + \alpha_1$$

(2) When $0.22 < R \leq 0.42$,

$$A = P + \alpha, \text{ where } \alpha = -82 \cdot R + \alpha_1, \text{ or}$$

$$A = -P + \beta_1$$

15 (3) When $0.42 < R \leq 0.44$,

$$A = P + \alpha, \text{ where } \alpha = -137.5 \cdot R + \alpha_2, \text{ or}$$

$$A = -P + \beta_1$$

(4) When $0.44 < R \leq 0.7$,

$$A = P + \alpha, \text{ where } \alpha = -137.5 \cdot R + \alpha_2, \text{ or}$$

20 $A = P + \alpha_3$

(5) When $0.7 < R \leq 1.06$,

$$A = -P + \beta_1$$

However,

$$-94^\circ \leq \alpha_1 \leq -63^\circ \quad -70^\circ \leq \alpha_2 \leq -40^\circ$$

25 $-95^\circ \leq \alpha_3 \leq -65^\circ \quad 75^\circ \leq \beta_1 \leq 105^\circ$

Second Embodiment: $\Phi_r = 90^\circ$

In this embodiment, p_o was adjusted so that Φ_r was approximately 90° . For example, ZLI-4262 was used as the liquid crystal material and $d = 2.0 \mu\text{m}$ in embodiment 2-1. $L = 2.67 \mu\text{m}$ and $d/p_o \approx 0.3$.

Data related to various R are shown below and are read the same as in the first embodiment.

- (2-1): $R = 0.2$, the results are shown in Table 29.
(2-2): $R = 0.28$, the results are shown in Table 30.
(2-3): $R = 0.318$, the results are shown in Table 31.
(2-4): $R = 0.56$, the results are shown in Table 32.
5 (2-5): $R = 0.84$, the results are shown in Table 33.

Third Embodiment: $\Phi_r = 160^\circ$

In this embodiment, p_o was adjusted so that Φ_r was approxi-
10 mately 160° . For example, ZLI-4262 was used as the liquid
crystal material and $d = 2.0 \mu\text{m}$ in embodiment 3-1. $L = 2.12$
 μm and $d/p_o \approx 0.5$.

Data related to various R are shown below.

15

- (3-1): $R = 0.2$, the results are shown in Table 34.
(3-2): $R = 0.28$, the results are shown in Table 35.
(3-3): $R = 0.318$, the results are shown in Table 36.
(3-4): $R = 0.56$, the results are shown in Table 37.
20 (3-5): $R = 0.84$, the results are shown in Table 38.

Fourth Embodiment: $\Phi_r = 200^\circ$

In this embodiment, p_o was adjusted so that Φ_r was approxi-
25 mately 200° . For example, ZLI-4262 was used as the liquid
crystal material and $d = 2.0 \mu\text{m}$ in embodiment 4-1. $L = 1.89$
 μm and $d/p_o \approx 0.6$.

Data related to various R are shown below.

30

- (4-1): $R = 0.2$, the results are shown in Table 39.
(4-2): $R = 0.28$, the results are shown in Table 40.
(4-3): $R = 0.318$, the results are shown in Table 41.
(4-4): $R = 0.56$, the results are shown in Table 42.
35 (4-5): $R = 0.84$, the results are shown in Table 43.

Fifth Embodiment: $\Phi_r = 270^\circ$

In this embodiment, p_o was adjusted so that Φ_r was approximately 270° . For example, ZLI-4262 was used as the liquid crystal material and $d = 2.0 \mu\text{m}$ in embodiment 5-1. $L = 1.6 \mu\text{m}$ and $d/p_o \approx 0.8$.

Data related to various R are shown below.

- 10 (5-1): $R = 0.2$, the results are shown in Table 44.
(5-2): $R = 0.28$, the results are shown in Table 45.
(5-3): $R = 0.318$, the results are shown in Table 46.
(5-4): $R = 0.56$, the results are shown in Table 47.
(5-5): $R = 0.84$, the results are shown in Table 48.

15

Sixth Embodiment: $\Phi_r = 140^\circ$, $R = 0.28$

In this embodiment, p_o was adjusted by adding an appropriate amount of optically active compound to ZLI-4262 so that Φ_r was approximately 140° . $d = 2.8 \mu\text{m}$, $L = 3.15 \mu\text{m}$ and $d/p_o \approx 0.4$.

The data from these results are shown in TABLE 49.

25 Seventh Embodiment: $\Phi_r = 220^\circ$, $R = 0.28$

In this embodiment, p_o was adjusted by adding an appropriate amount of optically active compound to ZLI-4262 so that Φ_r was approximately 220° . $d = 2.8 \mu\text{m}$, $L = 2.52 \mu\text{m}$ and $d/p_o \approx 0.6$.

30

The data from these results are shown in TABLE 50.

The results shown here are for only one example. The inventors sought the conditions for achieving a contrast ratio of 1:2 or greater when $160^\circ \leq \Phi_r \leq 200^\circ$ by analyzing many measurement results. For example, the combinations of P and A

that satisfy such conditions when $R = 0.102$ are shown in FIG. 5. Combinations of P and A that can be used are in the shaded range. Considering the fact that the combinations of $(P \pm n\pi/2, A \pm n\pi/2)$ and (P, A) are equivalent, the range is established by 8 straight lines whose slope is 1 or -1. Further, the range is dependent on R . Relationships between P and A at particular values of R are shown below.

(1) Reflective type element

10

(1) When $0.102 \leq R \leq 0.4$ or $0.78 \leq R \leq 0.96$,

$$[P + \alpha_1 \leq A \leq P + \alpha_2 \text{ and } -P + \beta_1 \leq A \leq -P + \beta_2] \text{ or}$$

$$[P + \gamma_1 \leq A \leq P + \gamma_2 \text{ and } -P + \delta_1 \leq A \leq -P + \delta_2]$$

(2) When $0.72 \leq R \leq 0.78$,

15 $[P + \alpha_1 \leq A \leq P + \alpha_2 \text{ and } -P + \beta_1 \leq A \leq -P + \beta_2] \text{ or}$

$$[P + \gamma_1 \leq A \leq P + \gamma_2]$$

(3) When $0.40 \leq R \leq 0.72$, $0.96 \leq R \leq 0.99$,

$$\text{or } 1.05 \leq R \leq 1.12,$$

$$[P + \alpha_1 \leq A \leq P + \alpha_2] \text{ or}$$

20 $[P + \gamma_1 \leq A \leq P + \gamma_2]$

(4) When $0.99 \leq R \leq 1.02$,

$$[P + \alpha_1 \leq A \leq P + \alpha_2]$$

(5) When $1.02 \leq R \leq 1.05$,

$$[P + \gamma_1 \leq A \leq P + \gamma_2]$$

25 Provided:

$$\alpha_1 = -109.4 \cdot R - 133.1 \quad (0.102 \leq R \leq 1.02)$$

$$-225.0 \quad (1.05 \leq R \leq 1.12)$$

$$\alpha_2 = -45.0, \quad (0.102 \leq R \leq 0.32)$$

$$6696.4 \cdot R^3 - 8720.1 \cdot R^2 + 3354.7 \cdot R - 445.0 \quad (0.32 \leq R \leq 0.64)$$

30 $1519.0 \cdot R^3 - 4175.2 \cdot R^2 + 3568.7 \cdot R - 1087.0 \quad (0.64 \leq R \leq 1.02)$

$$-333.3 \cdot R + 175.0, \quad (1.05 \leq R \leq 1.12)$$

$$\beta_1 = -9114.6 \cdot R^3 + 6666.7 \cdot R^2 - 1577.1 \cdot R + 74.0 \quad (0.102 \leq R \leq 0.36)$$

$$-55.0 \quad (0.36 \leq R \leq 0.40)$$

$$-75.0 \quad (0.72 \leq R \leq 0.96)$$

35 $\beta_2 = 9114.6 \cdot R^3 - 6666.7 \cdot R^2 + 1577.1 \cdot R - 74.0 \quad (0.102 \leq R \leq 0.36)$

$$55.0 \quad (0.36 \leq R \leq 0.40)$$

$$75.0 \quad (0.72 \leq R \leq 0.96)$$

$$\begin{aligned}
 \gamma_1 &= 312.5 \cdot R^2 - 187.5 \cdot R - 37.0 & (0.102 \leq R \leq 0.32) \\
 &5208.3 \cdot R^3 - 7500.0 \cdot R^2 + 3341.6 \cdot R - 537.0 & (0.32 \leq R \leq 0.64) \\
 &1030.2 \cdot R^3 - 2722.0 \cdot R^2 + 2225.9 \cdot R - 684.0 & (0.64 \leq R \leq 0.99) \\
 &197575.9 \cdot R^3 - 626821.6 \cdot R^2 + 662332.3 \cdot R - 233217.9 & (1.02 \leq R \leq 1.12) \\
 5 \quad \gamma_2 &= -625.0 \cdot R^2 + 225.0 \cdot R + 27.0 & (0.102 \leq R \leq 0.32) \\
 &7254.4 \cdot R^3 - 10245.5 \cdot R^2 + 4448.2 \cdot R - 577.0 & (0.32 \leq R \leq 0.64) \\
 &-558.0 \cdot R^2 + 736.6 \cdot R - 267.9 & (0.64 \leq R \leq 0.99) \\
 &-5555.5 \cdot R^2 + 11500.0 \cdot R - 6024.9 & (1.02 \leq R \leq 1.12) \\
 \delta_1 &= -6746.0 \cdot R^3 + 5571.4 \cdot R^2 - 1504.0 \cdot R + 166.9 & (0.102 \leq R \leq 0.40) \\
 10 &-55.6 \cdot R + 68.4 & (0.78 \leq R \leq 0.96) \\
 \delta_2 &= 6746.0 \cdot R^3 - 5571.4 \cdot R^2 + 1504.0 \cdot R + 13.1 & (0.102 \leq R \leq 0.40) \\
 &55.6 \cdot R + 111.6 & (0.78 \leq R \leq 0.96)
 \end{aligned}$$

By satisfying these conditions, it is possible to offer
 15 display elements suited to practical implementation as
 reflective type elements. Some are also suited to implemen-
 tation as transmission type display elements.

Further, where $160^\circ \leq \Phi r \leq 200^\circ$, we sought the conditions for
 20 achieving a contrast ratio greater than 1:10 and an ON trans-
 mittance greater than approximately 10% to facilitate practi-
 cal implementation of the element as a transmission type dis-
 play element. The results are shown below.

- 25 (1) When $0.1 \leq R \leq 0.22$,
 $A = P + \alpha$, where $\alpha = -82 \cdot R + \alpha_1$
- (2) When $0.22 < R \leq 0.42$,
 $A = P + \alpha$, where $\alpha = -82 \cdot R + \alpha_1$, or
 $A = -P + \beta_1$
- 30 (3) When $0.42 < R \leq 0.44$,
 $A = P + \alpha$, where $\alpha = -137.5 \cdot R + \alpha_2$, or
 $A = -P + \beta_1$
- (4) When $0.44 < R < 0.473$,
 $A = P + \gamma$, where $-137.5 \cdot R - 75 \leq \gamma \leq -60$
- 35 (5) When $0.473 \leq R \leq 0.7$,
 $A = P + \alpha$, where $\alpha = -137.5 \cdot R + \alpha_2$, or
 $A = P + \alpha_3$

(6) When $0.7 < R \leq 1.06$,

$$A = -P + \beta_1$$

However,

$$\begin{array}{ll} -99^\circ \leq \alpha_1 \leq -58^\circ & -75^\circ \leq \alpha_2 \leq -35^\circ \\ 5 \quad -100^\circ \leq \alpha_3 \leq -60^\circ & 70^\circ \leq \beta_1 \leq 110^\circ \end{array}$$

When $\Phi_r = 180^\circ$, the conditions should be set as follows:

(1) When $0.1 \leq R \leq 0.22$,

10 $A = P + \alpha$, where $\alpha = -82 \cdot R + \alpha_1$

(2) When $0.22 < R \leq 0.42$,

$$A = P + \alpha, \text{ where } \alpha = -82 \cdot R + \alpha_1, \text{ or}$$

$$A = -P + \beta_1$$

(3) When $0.42 < R \leq 0.44$,

15 $A = P + \alpha$, where $\alpha = -137.5 \cdot R + \alpha_2$, or

$$A = -P + \beta_1$$

(4) When $0.44 < R \leq 0.7$,

$$A = P + \alpha, \text{ where } \alpha = -137.5 \cdot R + \alpha_2, \text{ or}$$

$$A = P + \alpha_3$$

20 (5) When $0.7 < R \leq 1.06$,

$$A = -P + \beta_1$$

However,

$$\begin{array}{ll} -94^\circ \leq \alpha_1 \leq -63^\circ & -70^\circ \leq \alpha_2 \leq -40^\circ \\ -95^\circ \leq \alpha_3 \leq -65^\circ & 75^\circ \leq \beta_1 \leq 105^\circ \end{array}$$

25

By setting the conditions as shown here, a display element can be offered that is suited to implementation as both a transmission type element and a reflective type element.

30 As R increases above $1.06 \mu\text{m}$, the value of $L \cdot \Delta n$ so increases that the Mauguin condition is satisfied and a display condition suitable for implementation as a transmission type element could not be achieved regardless of how the polarization axes were set. If R is made small, however, the S^+ becomes
35 an optically isotropic medium and the contrast ratio increases. However, if R is made too small, the ON transmittance becomes lower. Further, since the lower limit of the

birefringence of the liquid crystal material is about 0.06, it is difficult to make R less than 0.10 in production. Therefore, the desirable range of R is $0.10 \leq R \leq 1.06$.

- 5 Particularly in the range $0.18 \leq R \leq 0.30$, an extremely high contrast ratio and an extremely high ON transmittance can be achieved at the same time by setting P and A as described above.
- 10 By appropriately setting the polarization axes of the polarizing plates and Φ_r , a display characteristic can be achieved that makes the element suitable for implementation in both a transmission type display device and a reflective type display device as long as $0.10 \leq R \leq 1.06$, and if $R > 1.06$, a
- 15 display characteristic can be achieved that makes the element suitable for implementation in a reflective type display device.

In the above embodiments, only cases were discussed in which

20 the direction of the twist of the helical structure was clockwise when viewed in the Z axis direction, but if the twist is counterclockwise, then the angles of the polarization axes need only be measured in the counterclockwise direction.

25

Eighth Embodiment

Another embodiment is shown here in which $\Phi_r = 180^\circ$. A cell was fabricated as shown in FIG. 2 by forming an ITO transparent electrode pattern and applying a polyimide alignment

30 film on glass and disposing a substrate whose surface had undergone rubbing opposite this with a spacer between them to maintain the desired d . The differences from the first to the seventh embodiments are d/p_0 and the electrode configuration.

35

An optically active compound (E. Merck, S811) was added to a liquid crystal material (E. Merck, MJ90179, $\Delta n = 0.167$), which exhibits a nematic phase at room temperature, to adjust it to $p_0 = 2.9 \mu\text{m}$. S811 induces a helical structure with a
5 left handed twist. The cell was configured with polyimide alignment films (Nihon Gosei Gomu K.K., AL3046) disposed on the upper and lower substrates and which had undergone rubbing in opposing parallel directions, and $d = 1.7 \mu\text{m}$. When the above liquid crystal material was infused, the pretilt
10 angles on the upper and lower substrates became approximately 4° with opposing signs, and since $p_0/4 < d < 3p_0/4$, the initial alignment of the liquid crystal molecules was a 180° twisted state with a helical axis in the direction of the line normal to the substrate. This sample satisfies the con-
15 dition $0.8 \Phi r/360^\circ \leq d/p_0 \leq 1.4 \Phi r/360^\circ$ because $d/p_0 = 0.586$. The sample obtained as described above was sandwiched between two polarizing plates whose alignments were $P = 50^\circ$ and $A = -50^\circ$ and the voltage waveforms in FIG. 6 were applied to the electrodes. In FIG. 6, 201 is the scanning electrode
20 waveform, 202 is the signal electrode waveform, 203 is a composite waveform of 201 and 202, and 204 is the electrooptical response of the cell. A metastable state with roughly a 360° twist is selected in selection period t_{01} , a metastable state with a 0° twist (referred to as uniform state) is
25 selected in the next selection period t_{11} , and the first state is optically distinguished as a dark state. When driven with a waveform equivalent to a duty ratio of $1/400$ where $V_1 = 28.0 \text{ V}$, $V_2 = 1.5 \text{ V}$ and pulse duration $P_w = 350 \mu\text{s}$ ($t_{01} = t_{11} = 700 \mu\text{s}$, $t_0 = t_1 = 700 \mu\text{s} \cdot 400$), the light transmit-
30 tance level in the nonselection period ($t_{02} = t_{12}$) was stable, the contrast ratio was $1:77$, and the light transmittance in the bright state was approximately 60% (where the light transmittance in a similar optical system in which the two polarizing plates are disposed such that their polariza-
35 tion axes are parallel is 100%; same below).

Ninth Embodiment

In the eighth embodiment, an optically active compound was added to the liquid crystal composition (Chisso Sekiyu
5 Kagaku, K.K., SS-4103, $\Delta n = 0.154$) to adjust p_0 to $3.04 \mu\text{m}$. The cell was fabricated by rubbing polyimide alignment films (Nihon Gosei Gomu K.K., JALS-300) disposed on the upper and lower substrates in opposing parallel directions (180°) and making $d = 1.65 \mu\text{m}$. When the above liquid crystal material
10 was infused, the pretilt angles on the upper and lower substrates became approximately 6° with opposing signs, and since $p_0/4 < d < 3p_0/4$, the initial alignment of the liquid crystal molecules was a 180° twisted state. $d/p_0 = 0.543$. The sample obtained as described above was sandwiched between
15 two polarizing plates whose alignments were $P = 50^\circ$ and $A = -50^\circ$ and the voltage waveforms in FIG. 6 were applied to the electrodes. When driven with a waveform equivalent to a duty ratio of $1/400$ where $V_1 = 30.0 \text{ V}$, $V_2 = 1.8 \text{ V}$ and pulse duration $P_w = 300 \mu\text{s}$ in an optical arrangement similar to that in
20 the eighth embodiment, the light transmittance level in the nonselection period was stable as in the eighth embodiment, the contrast ratio was $1:112$, and the light transmittance in the bright state was approximately 70% .

25 Tenth Embodiment

As in the ninth embodiment, p_0 was adjusted to $2.36 \mu\text{m}$, $d = 1.65 \mu\text{m}$, $d/p_0 = 0.7$, $P = 50^\circ$, $A = -50^\circ$ and the voltage waveforms in Fig. 6 were applied to the electrodes. When
30 driven with a waveform equivalent to a duty ratio of $1/400$ where $V_1 = 30.0 \text{ V}$, $V_2 = 1.8 \text{ V}$ and pulse duration $P_w = 300 \mu\text{s}$ in an optical arrangement similar to that in the eighth embodiment, the light transmittance level in the nonselection period was stable as in the eighth embodiment, the contrast
35 ratio was $1:114$, and the light transmittance in the bright state was approximately 70% .

Eleventh Embodiment

As in the ninth embodiment, p_0 was adjusted to $4.13 \mu\text{m}$, $d = 1.65 \mu\text{m}$, $d/p_0 = 0.4$, $P = 50^\circ$, $A = -50^\circ$ and the voltage waveforms in Fig. 6 were applied to the electrodes. When driven with a waveform equivalent to a duty ratio of $1/400$ where $V_1 = 30.0 \text{ V}$, $V_2 = 1.8 \text{ V}$ and pulse duration $P_w = 300 \mu\text{s}$ in an optical arrangement similar to that in the eighth embodiment, the light transmittance level in the nonselection period was stable as in the eighth embodiment, the contrast ratio was $1:110$, and the light transmittance in the bright state was approximately 70%.

Comparison Example 1

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A sample was fabricated in which $d = 1.8 \mu\text{m}$ and $p_0 = 2.5 \mu\text{m}$ ($d/p_0 = 0.72$) and the other conditions were the same as in the eighth embodiment. Since $p_0/4 < d < 3p_0/4$, the initial alignment of the liquid crystal molecules was a 180° twisted state, and though the 360° twisted state was maintained when a voltage waveform was applied, the stability of the uniform state was extremely low and relaxation from the uniform state to the initial state was observed in the nonselection period.

Comparison Example 2

25 A sample was fabricated in which $d = 1.8 \mu\text{m}$ and $p_0 = 4.9 \mu\text{m}$ ($d/p_0 = 0.37$) and the other conditions were the same as in the eighth embodiment. Since $p_0/4 < d < 3p_0/4$, the initial alignment of the liquid crystal molecules was a 180° twisted state, and though the 0° uniform state was maintained when a voltage waveform was applied, the stability of the 360° twisted state was extremely low and relaxation from the 360° twisted state to the initial state was observed in the nonselection period.

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Comparison Example 3

A sample was fabricated in which the pretilt angle was made 26° by using an SiO oblique deposition film for the liquid crystal orientation layer. When the driving waveforms in FIG. 6 were applied to the cell in which $d = 1.7 \mu\text{m}$ and the same liquid crystal material as used in the eighth embodiment was infused, only the metastable state with uniform alignment appeared and could not be switched to a 360° twisted state.

10

By utilizing two metastable states which can be selected by applying voltage waveforms, a liquid crystal display device can be realized with a high contrast ratio and a wide effective viewing angle. Also, since the selected state in this device can be maintained over a sufficiently long period for practical application as a memory type display device, it can be applied to a simple matrix drive, high definition display with many scanning lines. This invention is not only applicable to direct view liquid crystal display devices, but it is also applicable to light valves, spatial light modulators, electrophotographic printer heads, etc.

Twelfth Embodiment

25 The cell was fabricated by disposing substrates, on which ITO transparent electrode patterns were formed and polyimide alignment films were applied to the glass surface and whose surfaces had undergone rubbing, opposite each other with the desired d via spacers. A generalized cross section is shown in FIG. 2.

30

Embodiment 12-1

An optically active compound was added to a liquid crystal composition (E. Merck, ZLI-1557, $\Delta n = 0.1147$), which exhibits a nematic phase at room temperature, to adjust the p_0 to 3.5 μm . The cell was fabricated by rubbing the polyimide align-

35

ment film (Nihon Gosei Gomu K.K., AL3046) in rubbing direction 33 as shown in FIG. 7 and with $d = 1.8 \mu\text{m}$. Rubbing was performed on one substrate at a 45° angle (θ_0 in FIG. 7 equals 45°) with respect to the sides of transparent electrodes 31, 32 and on the other substrate in a direction rotated 180° from this. When the above liquid crystal composition was infused, the pretilt angles on the upper and lower substrates became approximately 4° with opposing signs, and since $p_0/4 < d < 3p_0/4$, the initial alignment of the liquid crystal molecules was a 180° twisted state. The sample obtained as described above was sandwiched between two polarizing plates whose alignments were $P = 50^\circ$ and $A = -50^\circ$ and the voltage waveforms in FIG. 6 were applied to the electrodes as in the eighth embodiment. The circuit configuration was generally that shown in FIG. 8, wherein 11 is the liquid crystal panel, 12 is the backlight used as the illumination means, 13 is the driving circuit (shift register/logic circuit) for applying a voltage on the scanning electrode group of the liquid crystal panel, 14 is the driving circuit (shift register/latch/logic circuit) for applying voltage to the signal electrode group, 15 is the reference signal generator, and 16 is the line-sequential scanning circuit (ROM/controller). As a result, a light transmittance level that is stable during the nonselection period (t_{02} , t_{12}), a contrast ratio of 1:77 and a light transmittance in the bright state of 63% could be uniformly achieved over all of the pixels.

Embodiment 12-2

30

When θ_0 was made to equal 10° in embodiment 12-1, similar display characteristics were obtained.

Comparison Example 1

35

A cell was fabricated by making the rubbing direction on one substrate parallel to one side of the pixels ($\theta_0 = 0^\circ$ in FIG.

7) and leaving all the other conditions the same. Since $p_0/4 < d < 3p_0/4$, the initial alignment of the liquid crystal molecules was a 180° twisted state, but when the voltage waveform was applied to select the 360° twisted state, a domain of the uniform state appeared at the edge of the pixels.

Thirteenth Embodiment

10 Using an element (same as in twelfth embodiment except for p_0 being adjusted to $3.2 \mu\text{m}$) obtained by infusing the liquid crystal composition used in the twelfth embodiment, we disposed the rubbing directions and polarization axes of the polarizing plates as shown below. FIG. 9 shows the relationship
15 of the observer E to the liquid crystal display D and coordinate axes X, Y and Z used below. The liquid crystal display device D in the figure has its display surface in the x-y plane, and the observer E views the display surface along the line of sight L in the z axis direction. The vertical direc-
20 tion of the liquid crystal display device as viewed by the observer corresponds to the direction of the y axis in the figure. Using a similar coordinate system, FIG. 10 shows the disposition of the display surface, the rubbing directions and the polarizing axes. In the figure, 41 is the direction
25 of rubbing on the lower substrate (side toward illumination device or reflective layer), 42 is the direction of rubbing on the upper substrate (side toward observer), α_1 and α_2 are the respective angles formed by rubbing directions 41, 42 and the y axis, and 43 and 44 are the polarization axes of the
30 polarizing plates disposed on the lower substrate and the upper substrate, respectively, where polarization axis 43 forms angle β_1 with the y axis and polarization axis 44 forms angle β_2 with the y axis. By making
 $\alpha_1 = \alpha_2 = 0^\circ$
35 $\beta_1 = 45^\circ$
 $\beta_2 = 38^\circ$

in this embodiment, the metastable state in which the twist angle of the liquid crystal is roughly ($\Phi_r + 180^\circ = 360^\circ$) can be made the dark state and the state in which the twist angle is roughly ($\Phi_r - 180^\circ = 0^\circ$) can be made the bright state.

5

The voltage waveforms shown in FIG. 11 were applied to the electrodes of the element obtained as described above. In the same figure, 401 and 403 are composite waveforms of the scanning electrode waveform and the signal electrode
10 waveform, and 402 and 404 are the electrooptical responses of the same element. The 360° twisted metastable state is selected in selection periods T_1 and T_4 , and the 0° twisted metastable state is selected in T_2 and T_3 , where the former is the dark state. When driven with a waveform ($T_1 = T_2 = T_3$
15 $= T_4 = 600 \mu s$, $F_1 = F_2 = F_3 = F_4 = 600 \mu s \cdot 400$) equivalent to a duty ratio of 1/400 where pulse duration $P_w = 300 \mu s$, a contrast ratio of 1:77 and a light transmittance in the bright state of approximately 63% were obtained. Also, when we moved the observer E to vary the angle formed by the line
20 of sight L and the z axis using the arrangement in FIG. 9, we confirmed display with good readability in the area outside $\pm 60^\circ$ to the left and right (x axis direction) and $\pm 45^\circ$ up and down (y axis direction).

25 In this embodiment, a liquid crystal display device with a high contrast ratio and a wide effective viewing angle is realized by utilizing two metastable states. Also, since the selected state can be maintained over a sufficiently long period for practical application as a memory type display
30 device, it can be applied to a simple matrix drive, high definition display with many scanning lines. This invention is not only applicable to direct view liquid crystal display devices, but it is also applicable to light valves, spatial light modulators, etc.

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Fourteenth Embodiment

An example of a liquid crystal display device with a high contrast ratio and wide effective viewing angle is shown in which the light transmittance in the non-pixel area between adjacent picture elements is lower than the light transmittance in pixels when the liquid crystal electrooptical element of the invention is multiplex driven.

10 A photosensitive acrylic resin layer was formed on the glass substrate surface, and after exposure using a photomask, the resin was developed and baked to form a stripe pattern. An ITO transparent electrode was formed on the stripe pattern by a sputtering technique and then the alignment film was
15 applied and rubbed to complete one substrate. For the other substrate, an ITO transparent electrode pattern was formed on the glass, an SiO_2 insulating film was formed on top of that and then an alignment film was applied and rubbed. These two substrates were mated together with a spacer between them to
20 yield a cell with the structure shown in FIG. 12 (cross section). The numbers in the figure indicate the same members as in FIG. 2, and g is the resin layer, d is the thickness of the liquid crystal layer in the pixels, and d_0 is the thickness of the liquid crystal layer in the non-pixel area. The
25 drive circuit configuration was that shown in FIG. 8.

An optically active compound was added to a liquid crystal composition (E. Merck, ZLI-1557, $\Delta n = 0.1147$), which exhibits a nematic phase at room temperature, to adjust it to $p_0 = 3.2$
30 μm . Polyimide (Nihon Gosei Gomu K.K., JALS-300) was used for the alignment films. $d = 1.8 \mu\text{m}$ and $d_0 = 2.50 \mu\text{m}$. Rubbing was performed on one substrate in a direction that formed a 20° angle with the side of the pixels, and rubbing was performed on the other substrate in a direction rotated 180°
35 from this ($\phi_r = 180^\circ$). When the above liquid crystal composition was infused, the pretilt angles on the upper and lower substrates became approximately 14° with opposing signs, and

since $p_0/4 < d < 3p_0/4$, the initial alignment of the liquid crystal molecules in the pixels was a 180° twisted state. When $d/p_0 \geq 0.75$, the twist angle of the liquid crystal became

5 $\Phi r + 180n$ ($n = 1, 2, 3, \dots$)

and since $d_0/p_0 > 0.75$, the initial alignment in the non-pixel area was a 360° twisted state.

The voltage waveforms in FIG. 13 were applied to the electrodes of the element obtained as described above. In the figure, 301 is the scanning electrode waveform, 302 is the signal electrode waveform, and 303 is a composite waveform of 301 and 302 and is equivalent to the driving waveform applied to the liquid crystal layer. t_0 and t_1 are the frames in which the metastable states having twist angles of roughly $(\Phi r + 180^\circ)$ and $(\Phi r - 180^\circ)$ are selected, t_{01} and t_{11} are selection periods and t_{02} and t_{12} are nonselection periods. The optical response shown in FIG. 14 was obtained by disposing the polarizing plates such that $P = 50^\circ$ and $A = -50^\circ$, whereby $\Phi r + 180^\circ = 360^\circ$ was made the dark state and $\Phi r - 180^\circ = 0^\circ$ was made the bright state. Since the twist angle in the non-pixel area is 360° , light in the non-pixel area is masked in the same arrangement. In FIG. 11, 401 and 403 are composite waveforms of the scanning electrode waveform and signal electrode waveform, and 402 and 404 represent the electrooptical response of the same element. The metastable state with roughly a 360° twist is selected in selection periods T_1, T_4 , and the metastable state with roughly a 0° twist is selected in selection periods T_2, T_3 . When driven with a waveform ($T_1 = T_2 = T_3 = T_4 = 500 \mu s$, $F_1 = F_2 = F_3 = F_4 = 500 \mu s \cdot 400$) equivalent to a duty ratio of $1/400$ where $V_1 = 30 V$, $V_2 = 1.0 V$ and pulse duration $Pw = 250 \mu s$, a contrast ratio of $1:102$ and a light transmittance in the bright state of approximately 63% were obtained.

35

By making the twist state in the non-pixel area different from the twist state in pixels, the light transmittance in

the non-pixel areas can be suppressed and the contrast ratio increased.

Fifteenth Embodiment

5

Another example is shown here which is implemented for the same purpose as the fourteenth embodiment. A cross section of the configuration is shown in FIG. 14. The numbers in the figure indicate the same members as in FIG. 12, and 9 is a
10 light masking material.

A chrome (Cr) lattice pattern 9 is formed on lower glass substrate 5 in the figure as a light masking material, and then after acrylic resin layer 8 is formed for insulation and
15 smoothing, ITO transparent electrode 4 is formed in a stripe pattern and alignment layer 2 is laminated on top of this and undergoes rubbing to complete the lower substrate. The upper substrate is prepared by forming ITO transparent electrode pattern 4 on glass substrate 5, laminating SiO₂ insulating
20 layer 3 on this and then applying alignment film 2 and rubbing it. These two substrates are mated together with a spacer between them such that the ITO transparent electrodes oppose each other between the chrome lattice to form the picture elements.

25

A liquid crystal composition and an alignment film similar to those in the fourteenth embodiment were used, and $d = 1.8 \mu\text{m}$. Rubbing was performed on one substrate in a direction that formed a 60° angle with the side of the picture elements, and
30 rubbing was performed on the other substrate in a direction rotated 180° from this ($\Phi_r = 180^\circ$). When the above liquid crystal composition was infused, the pretilt angles on the upper and lower substrates became approximately 14° with opposing signs, and since $p_0/4 < d < 3p_0/4$, the initial
35 alignment of the liquid crystal molecules in the pixels was a 180° twisted state. In this embodiment, the non-pixel area was masked by a metal (Cr) lattice pattern. When measurement

was performed using the same polarizing plate arrangement and driving waveforms as in the fourteenth embodiment, a contrast ratio of 1:113 and a light transmittance in the bright state of 61% were obtained.

5

By disposing a light masking material in the non-pixel area as described above, the light transmittance in this area can be suppressed and the contrast ratio can be increased.

10 Sixteenth Embodiment

The structure of the liquid crystal display element of this embodiment, shown in Fig. 15, is similar to that of the preceding embodiment illustrated in Fig. 14. Where in Fig. 15
15 the same reference signs are used as in Fig. 14 they refer to the same components and will be no further described here. In this embodiment a color filter layer 10 is formed on the lower glass substrate 5. The color filter layer comprises a plurality of island or stripe shaped color filter portions
20 each of one of the primary colors R, G and B. The color filter portions are disposed in the pixel regions and between respective portions of the light masking material 9 (forming a so-called "black matrix") which are provided in the non-pixel regions.

25

A liquid crystal display device with the structure of Fig. 15, whose liquid crystal twist angle was $\Phi_r = 180^\circ$ and whose liquid crystal layer thickness was $d = 1.7 \mu\text{m}$ was formed using a liquid crystal composition and an alignment film
30 similar to those of the first embodiment. As a result, a color display having good display properties including a high contrast ratio was achieved.

The invention of this application solves the basic problems
35 of the above prior art, which was not knowing what effect the liquid crystal initial state, R and the angle formed by the polarization axes and the rubbing directions had on the

contrast ratio and ON transmittance when a chiral nematic liquid crystal having metastable states was used as the electrooptical element, and when the invention of this application is used as a display element by means of multiplexing drive, a sufficient display characteristic for practical application can be achieved.

Employed as a liquid crystal display device, the present invention can also be applied to portable display devices, game machines and liquid crystal TV and color TV displays.

Table 2

No.	P	A	I+	I-	CR	T	R
1	135	45	0.08	18.18	232.40	0	0
2	50	-40	0.08	17.62	223.53	0	0
3	35	-55	0.08	16.04	204.23	0	0
4	155	65	0.08	10.66	138.45	0	0
5	70	-30	0.86	11.33	13.18	0	0
6	30	-70	0.86	11.33	13.18	0	0
7	50	-60	4.34	20.62	4.75	*	0
8	70	-50	10.10	22.70	2.25	*	0
9	60	-70	17.42	28.86	1.66	*	0
10	60	20	28.95	17.64	1.64	*	0
11	40	40	46.18	28.68	1.61	*	0
12	45	55	44.19	27.71	1.59	*	0
13	35	65	33.15	21.25	1.56	*	0
14	20	20	46.17	38.62	1.20	*	*
15	30	10	41.94	35.72	1.17	*	*
16	60	80	39.67	35.35	1.12	*	*
17	80	-80	39.68	42.96	1.08	*	*

15 $d = 1.7\mu\text{m}$, $L = 1.7\mu\text{m}$, $L \cdot \Delta n = 0.102\mu\text{m}$, $\lambda = 0.38 \text{ to } 0.78 \mu\text{m}$

Table 3

No.	P	R	I+	I-	CR	T	R
1	45	-45	0.23	28.52	125.16	o	o
2	50	-40	0.23	27.66	121.40	o	o
3	40	-50	0.23	27.66	121.40	o	o
4	50	-50	0.53	28.83	54.02	o	o
5	50	50	45.91	18.80	2.44	*	o
6	55	55	45.91	21.28	2.16	*	o
7	30	20	45.60	29.29	1.56	*	o
8	60	70	43.48	28.94	1.50	*	o
9	60	-80	24.03	35.07	1.46	*	o
10	40	10	37.26	25.78	1.45	*	o
11	60	80	38.60	32.14	1.20	*	*
12	20	10	45.60	38.83	1.17	*	*
13	80	-80	38.60	44.03	1.14	*	*
14	80	80	45.92	43.24	1.06	*	*
15	0	20	38.59	40.35	1.05	*	*
16	0	0	45.90	46.22	1.01	*	*
17	90	80	45.63	45.46	1.00	*	*

$d = 1.6\mu\text{m}$, $L = 1.6\mu\text{m}$, $L \cdot \Delta n = 0.160\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 4

No.	P	R	I+	I-	CR	T	R
1	50	-50	0.24	37.80	160.17	o	o
2	45	-55	0.24	36.60	155.08	o	o
3	55	-45	0.24	36.60	155.08	o	o
4	40	-60	0.24	33.30	141.10	o	o
5	60	-40	0.24	33.30	141.10	o	o
6	65	-25	0.53	22.10	41.54	o	o
7	50	40	45.80	8.85	5.18	*	o
8	20	70	14.50	2.96	4.90	*	o
9	40	40	45.50	9.98	4.56	*	o
10	30	40	42.50	12.70	3.35	*	o
11	160	30	14.50	39.50	2.72	*	o
12	70	50	43.40	17.70	2.45	*	o
13	40	-20	16.10	36.20	2.25	*	o
14	50	-80	14.50	31.20	2.15	*	o
15	90	30	16.10	12.30	1.31	*	*
16	60	0	16.10	12.30	1.31	*	*
17	0	20	37.20	40.60	1.09	*	*

$d = 2.0\mu\text{m}$, $L = 2.00\mu\text{m}$, $L \cdot \Delta n = 0.200\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 5

No.	P	A	I+	I-	CR	T	R
1	50	-50	0.13	42.49	332.60	o	o
2	60	-40	0.13	37.51	293.87	o	o
3	40	-60	0.13	37.51	293.87	o	o
4	30	-70	0.13	24.91	195.49	o	o
5	80	-20	0.13	10.62	83.33	o	o
6	130	40	0.78	41.23	52.54	o	o
7	35	-75	2.34	25.18	10.76	o	o
8	50	40	47.91	5.67	8.45	*	o
9	50	50	47.22	6.89	6.85	*	o
10	160	40	7.25	38.32	5.28	*	o
11	30	40	43.85	10.09	4.35	*	o
12	40	-80	7.18	25.76	3.59	*	o
13	140	70	10.10	32.97	3.26	*	o
14	20	-50	10.19	33.01	3.24	*	o
15	0	20	38.11	42.01	1.10	*	*
16	20	0	45.87	42.94	1.07	*	*
17	90	80	47.75	46.72	1.02	*	*

$d = 2.2\mu\text{m}$, $L = 2.20\mu\text{m}$, $L \cdot \Delta n = 0.220\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 6

No.	P	A	I+	I-	CR	T	R
1	50	-50	0.06	42.66	658.13	o	o
2	45	-55	0.06	41.41	640.21	o	o
3	55	-45	0.06	41.41	640.21	o	o
4	40	-60	0.06	37.79	588.01	o	o
5	60	-40	0.06	37.79	588.01	o	o
6	30	-70	0.06	25.32	402.85	o	o
7	40	50	42.68	2.46	17.37	o	o
8	30	50	36.52	3.40	10.75	o	o
9	60	-60	6.28	42.92	6.84	*	o
10	40	-30	10.53	42.17	4.01	*	o
11	45	-25	10.53	38.55	3.66	*	o
12	60	-70	12.76	42.01	3.29	*	o
13	20	-40	18.01	39.01	2.17	*	o
14	80	80	46.59	40.37	1.15	*	*
15	20	0	45.52	40.53	1.12	*	*
16	0	20	36.49	39.84	1.09	*	*
17	90	80	47.62	44.07	1.08	*	*

$d = 2.4\mu\text{m}$, $L = 2.40\mu\text{m}$, $L \cdot \Delta n = 0.240\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 7

No.	P	A	I+	I-	CR	T	R
1	50	-50	0.10	46.10	443.27	o	o
2	40	-60	0.10	40.70	402.97	o	o
3	60	-40	0.10	40.70	402.97	o	o
4	25	-75	0.09	19.10	218.54	o	o
5	75	-25	0.09	19.10	218.54	o	o
6	60	30	41.40	0.50	83.13	o	o
7	50	40	46.00	0.62	74.55	o	o
8	80	20	20.40	1.66	12.29	o	o
9	160	30	10.50	44.90	4.28	*	o
10	60	-70	10.60	44.90	4.24	*	o
11	65	55	46.00	12.00	3.83	*	o
12	40	20	45.00	12.00	3.75	*	o
13	40	-30	12.70	44.80	3.53	*	o
14	140	-20	33.40	12.00	2.78	*	o
15	20	-10	41.40	45.00	1.09	*	*
16	10	10	44.20	41.10	1.08	*	*
17	90	80	46.00	45.00	1.02	*	*

$d = 2.8\mu\text{m}$, $L = 2.80\mu\text{m}$, $L \cdot \Delta n = 0.280\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 8

No.	P	A	I+	I-	CR	T	R
1	80	10	15.10	0.07	220.12	o	o
2	50	-50	0.49	43.90	89.78	o	o
3	60	-50	0.53	43.10	81.78	o	o
4	40	-60	0.48	38.90	81.38	o	o
5	160	-70	30.90	0.59	52.46	o	o
6	75	-25	0.44	18.50	42.53	o	o
7	70	10	23.00	1.53	15.03	o	o
8	120	40	8.34	38.20	4.58	*	o
9	85	-45	8.43	27.60	3.27	*	o
10	40	10	43.00	19.40	2.22	*	o
11	80	50	43.00	19.40	2.22	*	o
12	50	-20	15.20	32.40	2.13	*	o
13	0	10	38.00	45.20	1.19	*	*
14	20	0	45.70	40.30	1.13	*	*
15	90	-90	43.10	46.30	1.07	*	*
16	10	10	43.10	41.20	1.05	*	*
17	90	80	45.80	44.60	1.03	*	*

$d = 3.2\mu\text{m}$, $L = 3.20\mu\text{m}$, $L \cdot \Delta n = 0.320\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 9

No.	P	A	I+	I-	CR	T	R
1	55	-55	0.36	39.37	108.63	o	o
2	45	-65	0.33	35.06	104.81	o	o
3	65	-45	0.33	35.06	104.81	o	o
4	75	-35	0.26	24.18	91.59	o	o
5	75	15	25.88	1.02	25.45	o	o
6	70	10	25.88	2.11	12.26	o	o
7	80	20	25.89	2.12	12.20	o	o
8	40	-40	10.77	36.57	3.40	*	o
9	50	10	39.92	12.91	3.09	*	o
10	80	40	39.95	12.98	3.08	*	o
11	40	20	46.06	16.21	2.84	*	o
12	70	-80	20.44	44.51	2.18	*	o
13	40	-30	18.10	35.63	1.97	*	o
14	45	-25	18.09	32.46	1.79	*	o
15	10	0	45.26	43.68	1.04	*	*
16	80	80	41.58	41.92	1.01	*	*
17	20	-20	40.10	40.19	1.00	*	*

$d = 3.6\mu\text{m}$, $L = 3.60\mu\text{m}$, $L \cdot \Delta n = 0.360\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 10

No.	P	A	I+	I-	CR	T	R
1	85	5	13.14	0.02	709.01	o	o
2	55	-55	0.70	31.83	45.49	o	o
3	60	-60	1.51	34.68	22.90	o	o
4	80	-40	1.31	23.40	17.92	o	o
5	70	-70	10.76	40.68	3.78	*	o
6	75	-75	18.06	43.10	2.39	*	o
7	90	40	36.31	16.21	2.24	*	o
8	50	0	36.00	16.49	2.18	*	o
9	60	-90	17.92	36.37	2.03	*	o
10	90	-60	17.92	36.37	2.03	*	o
11	40	10	44.99	23.00	1.96	*	o
12	30	-50	13.53	24.52	1.81	*	o
13	60	60	39.66	24.83	1.60	*	o
14	0	0	39.62	47.33	1.19	*	*
15	10	-10	45.94	43.11	1.07	*	*

$d = 4.0\mu\text{m}$, $L = 4.00\mu\text{m}$, $L \cdot \Delta n = 0.400\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 11

No.	P	A	I+	I-	CR	T	R
1	175	-85	0.04	14.96	374.00	o	o
2	55	-65	31.59	1.35	23.40	o	o
3	170	-80	1.00	22.84	22.84	o	o
4	45	-75	26.55	1.19	22.31	o	o
5	90	-30	15.07	0.83	18.16	o	o
6	5	65	12.00	0.74	16.22	o	o
7	105	-15	10.00	0.64	15.63	o	o
8	70	-20	15.75	3.60	4.38	*	o
9	90	-50	31.02	9.22	3.36	*	o
10	150	-35	24.30	44.20	1.82	*	o

$d = 3.0\mu\text{m}$, $L = 3.00\mu\text{m}$, $L \cdot \Delta n = 0.420\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 12

No.	P	A	I+	I-	CR	T	R
1	175	-85	0.05	15.80	316.00	o	o
2	55	-65	30.51	1.34	22.77	o	o
3	50	-70	28.70	1.27	22.60	o	o
4	90	-30	15.48	0.73	21.21	o	o
5	105	-15	10.23	0.51	20.06	o	o
6	10	70	10.00	0.54	18.52	o	o
7	165	-85	1.80	23.79	13.22	o	o
8	90	-50	31.71	8.77	3.62	*	o
9	70	-20	13.50	5.20	2.60	*	o
10	155	-40	23.54	41.53	1.76	*	o

$d = 2.3\mu\text{m}$, $L = 2.30\mu\text{m}$, $L \cdot \Delta n = 0.428\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 13

No.	P	A	I+	I-	CR	T	R
1	85	5	16.64	0.05	315.58	o	o
2	105	-15	0.38	11.15	28.98	o	o
3	150	30	1.35	29.99	22.17	o	o
4	70	-50	1.25	27.30	21.90	o	o
5	55	-65	1.33	28.88	21.69	o	o
6	80	10	24.73	1.32	18.70	o	o
7	40	-70	1.48	20.25	13.65	o	o
8	100	30	25.20	8.97	2.81	*	o
9	75	-75	15.66	43.46	2.77	*	o
10	50	10	44.68	18.08	2.47	*	o
11	75	45	47.38	23.00	2.06	*	o
12	80	50	47.57	25.97	1.83	*	o
13	10	-30	45.19	30.00	1.51	*	o

$d = 4.4\mu\text{m}$, $L = 4.40\mu\text{m}$, $L \cdot \Delta n = 0.440\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 14

No.	P	A	I+	I-	CR	T	R
1	175	-85	0.05	16.64	332.80	o	o
2	100	-20	11.73	0.41	28.61	o	o
3	150	30	29.43	1.36	21.64	o	o
4	165	-85	1.89	24.74	13.09	o	o
5	90	-50	32.40	8.32	3.89	*	o
6	120	-90	32.69	47.52	1.45	*	o
7	100	50	22.40	31.05	1.39	*	o
8	10	10	44.96	39.00	1.15	*	*

$d = 3.0\mu\text{m}$, $L = 3.00\mu\text{m}$, $L \cdot \Delta n = 0.450\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 15

No.	P	A	I+	I-	CR	T	R
1	85	5	25.01	0.21	117.74	o	o
2	90	10	25.10	0.29	87.68	o	o
3	110	-20	0.41	22.48	55.13	o	o
4	75	-5	25.47	0.50	51.30	o	o
5	90	-40	1.94	23.53	12.11	o	o
6	70	-90	13.77	42.63	3.09	*	o
7	85	35	41.05	14.20	2.89	*	o
8	40	-10	43.19	15.35	2.81	*	o
9	135	85	42.26	15.04	2.81	*	o
10	100	50	42.85	15.45	2.77	*	o
11	20	-30	44.03	15.88	2.77	*	o
12	120	-50	17.62	42.85	2.43	*	o
13	140	-30	17.66	42.76	2.42	*	o
14	140	-50	30.99	39.52	1.28	*	*
15	120	-70	32.44	40.63	1.25	*	*
16	160	-30	32.61	40.44	1.24	*	*

$d = 4.0\mu\text{m}$, $L = 4.00\mu\text{m}$, $L \cdot \Delta n = 0.560\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 16

No.	P	A	I+	I-	CR	T	R
1	85	5	29.95	0.24	124.72	o	o
2	80	0	30.27	0.57	53.28	o	o
3	90	10	30.06	0.57	52.80	o	o
4	170	0	15.97	46.91	2.94	*	o
5	0	-50	41.86	16.07	2.60	*	o
6	40	40	15.37	35.56	2.31	*	o
7	100	50	42.88	19.46	2.20	*	o
8	175	-5	22.12	46.84	2.12	*	o
9	0	0	22.34	47.20	2.11	*	o
10	60	20	37.23	17.84	2.09	*	o
11	100	-80	21.11	43.84	2.08	*	o
12	80	80	21.11	43.84	2.08	*	o
13	120	70	44.29	21.85	2.03	*	o
14	40	0	41.63	24.18	1.72	*	o
15	20	-20	44.78	28.91	1.55	*	o
16	60	50	22.42	33.91	1.51	*	o

$d = 6.4\mu\text{m}$, $L = 6.40\mu\text{m}$, $L \cdot \Delta n = 0.640\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 17

No.	P	A	I+	I-	CR	T	R
1	175	-85	0.23	32.52	141.39	o	o
2	0	-90	0.22	27.42	124.64	o	o
3	170	-90	0.83	32.85	39.58	o	o
4	85	15	2.53	36.34	14.36	o	o
5	95	15	2.54	33.71	13.27	o	o
6	130	-20	25.35	1.99	12.74	o	o
7	20	60	19.46	1.91	10.19	o	o
8	90	-85	43.50	12.31	3.53	*	o
9	105	50	24.10	48.34	2.01	*	o
10	150	-50	23.75	23.71	1.00	*	*

$d = 4.4\mu\text{m}$, $L = 4.40\mu\text{m}$, $L \cdot \Delta n = 0.700\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 18

No.	P	A	I+	I-	CR	T	R
1	90	0	28.61	0.13	228.70	o	o
2	85	5	32.40	0.18	184.09	o	o
3	80	0	32.87	1.01	32.51	o	o
4	0	20	10.94	42.46	3.88	*	o
5	0	30	9.50	36.45	3.84	*	o
6	80	-80	12.26	44.05	3.59	*	o
7	175	5	14.19	47.01	3.31	*	o
8	70	-20	33.64	11.52	2.92	*	o
9	120	-60	9.61	25.40	2.64	*	o
10	175	-5	17.59	46.21	2.63	*	o
11	90	-90	17.73	45.23	2.55	*	o
12	20	-60	39.55	16.38	2.41	*	o
13	60	-20	39.55	16.38	2.41	*	o
14	100	40	40.17	19.46	2.06	*	o
15	80	40	30.99	16.30	1.90	*	o
16	30	-30	46.40	31.23	1.49	*	o
17	160	40	21.34	30.61	1.43	*	o

$d = 4.5\mu\text{m}$, $L = 4.50\mu\text{m}$, $L \cdot \Delta n = 0.720\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 19

No.	P	A	I+	I-	CR	T	R
1	90	0	30.34	0.06	516.13	0	0
2	85	5	31.83	0.11	289.63	0	0
3	95	-5	27.22	0.53	51.82	0	0
4	90	-80	15.90	46.79	2.94	*	0
5	85	-85	16.34	47.98	2.94	*	0
6	5	25	12.96	37.63	2.90	*	0
7	60	0	33.10	11.51	2.88	*	0
8	0	0	17.80	48.19	2.71	*	0
9	80	80	16.11	43.40	2.69	*	0
10	20	0	23.65	42.13	1.78	*	0
11	110	30	40.31	23.22	1.74	*	0
12	25	5	21.69	36.85	1.70	*	0
13	65	-65	27.25	43.64	1.60	*	0
14	100	40	37.90	24.78	1.53	*	0
15	40	-40	46.75	39.60	1.18	*	*
16	30	-30	44.25	41.19	1.07	*	*
17	50	-50	42.13	39.99	1.05	*	*

$d = 4.9\mu\text{m}$, $L = 4.90\mu\text{m}$, $L \cdot \Delta n = 0.78\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 20

No.	P	A	I+	I-	CR	T	R
1	85	5	27.05	0.05	534.38	0	0
2	90	0	27.91	0.08	359.67	0	0
3	80	10	24.74	0.33	75.31	0	0
4	95	-5	27.20	0.41	66.98	0	0
5	80	20	21.82	2.13	10.26	0	0
6	0	0	18.31	46.63	2.55	*	0
7	5	5	17.82	45.37	2.55	*	0
8	175	-5	17.82	45.37	2.55	*	0
9	5	-5	18.92	46.29	2.45	*	0
10	160	-30	9.41	21.84	2.32	*	0
11	90	30	25.56	11.24	2.28	*	0
12	60	0	25.04	11.21	2.23	*	0
13	120	0	25.98	12.12	2.14	*	0
14	20	0	19.11	40.80	2.14	*	0
15	40	-30	39.66	40.58	1.02	*	*
16	40	-40	42.34	41.57	1.02	*	*
17	50	-50	42.47	41.94	1.01	*	*

$d = 5.3\mu\text{m}$, $L = 5.30\mu\text{m}$, $L \cdot \Delta n = 0.84\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 21

No.	P	R	I+	I-	CR	T	R
1	175	-85	15.58	0.07	238.44	o	o
2	90	0	19.55	0.30	66.13	o	o
3	95	-5	22.94	1.67	13.75	o	o
4	105	15	23.56	7.01	3.36	*	o
5	40	10	9.82	23.41	2.38	*	o
6	30	20	13.36	28.60	2.14	*	o
7	0	-30	15.38	32.68	2.12	*	o
8	90	70	18.77	39.58	2.11	*	o
9	20	0	18.71	39.33	2.10	*	o
10	20	-10	19.04	38.84	2.04	*	o
11	20	-20	19.84	36.42	1.84	*	o
12	60	60	14.22	25.72	1.81	*	o
13	10	10	24.48	42.89	1.75	*	o
14	5	5	25.92	45.33	1.75	*	o
15	0	0	26.42	46.18	1.75	*	o

$d = 4.6\mu\text{m}$, $L = 4.60\mu\text{m}$, $L \cdot \Delta n = 0.96\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 22

No.	P	R	I+	I-	CR	T	R
1	85	5	10.32	0.12	84.47	o	o
2	90	0	14.79	0.42	35.60	o	o
3	85	-5	15.22	0.92	16.52	o	o
4	80	-30	29.77	13.19	2.26	*	o
5	60	-20	18.64	9.92	1.88	*	o
6	40	-60	32.00	17.29	1.85	*	o
7	70	-40	34.52	18.79	1.84	*	o
8	45	-55	33.22	18.73	1.77	*	o
9	40	-50	28.52	16.60	1.72	*	o
10	60	-50	37.62	22.45	1.68	*	o
11	40	-40	24.49	16.81	1.46	*	o
12	0	0	1.00	1.00	1.00	*	*
13	40	0	1.00	1.00	1.00	*	*
14	80	-60	1.00	1.00	1.00	*	*
15	60	-80	1.00	1.00	1.00	*	*
16	0	50	1.00	1.00	1.00	*	*

$d = 6.4\mu\text{m}$, $L = 6.40\mu\text{m}$, $L \cdot \Delta n = 1.02\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 23

No.	P	A	I+	I-	CR	T	R
1	90	0	11.93	0.45	26.78	o	o
2	85	-5	12.31	0.82	14.98	o	o
3	5	-85	12.31	0.82	14.98	o	o
4	20	-70	17.09	5.58	3.06	*	o
5	80	-30	26.97	12.17	2.22	*	o
6	60	-30	21.29	9.75	2.18	*	o
7	35	-75	29.13	14.32	2.03	*	o
8	60	-40	27.82	13.79	2.02	*	o
9	50	-50	29.27	15.24	1.92	*	o
10	60	-50	33.88	19.06	1.78	*	o
11	40	-40	20.23	12.55	1.61	*	o
12	40	-20	14.38	16.67	1.16	*	*
13	20	0	1.00	1.00	1.00	*	*
14	60	-80	1.00	1.00	1.00	*	*
15	80	-60	1.00	1.00	1.00	*	*
16	20	-20	1.00	1.00	1.00	*	*
17	60	60	1.00	1.00	1.00	*	*

$d = 6.6\mu\text{m}$, $L = 6.60\mu\text{m}$, $L \cdot \Delta n = 1.05\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 24

No.	P	A	I+	I-	CR	T	R
1	0	-90	0.45	11.93	26.51	o	o
2	85	-5	0.82	12.31	15.01	o	o
3	95	5	0.82	12.31	15.01	o	o
4	0	65	8.53	21.50	2.52	*	o
5	130	70	16.67	14.38	1.16	*	*
6	70	70	1.00	1.00	1.00	*	*

$d = 5.1\mu\text{m}$, $L = 5.10\mu\text{m}$, $L \cdot \Delta n = 1.06\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 25

No.	P	A	I+	I-	CR	T	R
1	85	-15	14.86	4.00	3.72	*	o
2	20	-80	16.31	5.24	3.11	*	o
3	80	-20	16.31	5.24	3.11	*	o
4	25	-85	21.47	9.60	2.24	*	o
5	85	-25	21.47	9.60	2.24	*	o
6	65	-35	21.78	9.95	2.19	*	o
7	30	-80	23.27	11.14	2.09	*	o
8	80	-30	23.27	11.14	2.09	*	o
9	40	-60	23.24	11.21	2.07	*	o
10	60	-40	23.24	11.21	2.07	*	o
11	45	-55	24.20	12.04	2.01	*	o
12	55	-45	24.20	12.04	2.01	*	o
13	40	-70	26.99	14.34	1.88	*	o
14	40	50	30.51	36.80	1.21	*	*
15	30	50	32.69	35.12	1.07	*	*
16	40	60	32.90	35.18	1.07	*	*
17	20	40	34.77	37.07	1.07	*	*

$d = 5.8\mu\text{m}$, $L = 5.80\mu\text{m}$, $L \cdot \Delta n = 1.08\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 26

No.	P	A	I+	I-	CR	T	R
1	70	-30	16.34	7.77	2.10	*	o
2	60	-40	19.00	10.20	1.86	*	o
3	60	-50	25.11	15.42	1.63	*	o
4	50	-60	25.11	15.42	1.63	*	o
5	50	20	17.07	25.88	1.52	*	o
6	50	-70	29.97	20.61	1.45	*	o
7	90	50	16.02	23.28	1.45	*	o
8	40	10	19.54	28.25	1.45	*	o
9	55	-65	30.76	21.34	1.44	*	o
10	60	-60	31.04	21.59	1.44	*	o
11	80	50	19.80	28.44	1.44	*	o
12	55	35	21.72	30.84	1.42	*	o
13	50	30	21.93	31.06	1.42	*	o
14	0	40	35.72	31.00	1.15	*	*
15	40	-30	11.39	10.08	1.13	*	*
16	30	60	34.00	31.96	1.06	*	*
17	40	60	35.35	36.32	1.03	*	*

$d = 5.4\mu\text{m}$, $L = 5.40\mu\text{m}$, $L \cdot \Delta n = 1.12\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 27

No.	P	A	I+	I-	CR	T	R
1	20	70	18.50	8.20	2.26	*	o
2	120	-30	27.60	14.90	1.85	*	o
3	140	-40	32.60	20.70	1.57	*	o
4	60	-40	16.00	25.10	1.57	*	o
5	40	-60	16.00	25.10	1.57	*	o
6	110	60	24.10	35.30	1.46	*	o
7	90	-90	43.60	48.00	1.10	*	*
8	110	-70	38.90	36.40	1.07	*	*
9	170	-80	5.80	2.30	2.52	*	*
10	80	-20	8.80	7.50	1.17	*	*

$d = 19.0\mu\text{m}$, $L = 19.00\mu\text{m}$, $L \cdot \Delta n = 1.900\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 28

No.	P	A	I+	I-	CR	T	R
1	110	-15	12.80	7.30	1.75	*	o
2	105	-20	12.70	7.30	1.74	*	o
3	20	70	14.60	9.00	1.62	*	o
4	115	-20	16.70	11.10	1.50	*	o
5	110	-25	16.60	11.10	1.50	*	o
6	120	-30	21.90	16.30	1.34	*	o
7	140	-40	26.90	22.50	1.20	*	*
8	110	60	29.00	34.20	1.18	*	*
9	60	-40	20.50	23.50	1.15	*	*
10	90	-90	43.80	47.90	1.09	*	*
11	130	-90	26.00	28.10	1.08	*	*
12	160	20	36.60	38.40	1.05	*	*
13	170	-30	33.20	34.30	1.03	*	*
14	90	-50	28.60	28.10	1.02	*	*
15	0	-90	3.90	0.00	975.00	*	*
16	170	-80	5.50	2.50	2.20	*	*
17	80	-20	9.40	7.10	1.32	*	o

$d = 25.0\mu\text{m}$, $L = 25.00\mu\text{m}$, $L \cdot \Delta n = 2.500\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 29

No.	P	A	I+	I-	CR	T	R
1	130	60	10.00	0.50	20.00	o	o
2	10	-90	2.50	22.10	8.84	*	o
3	100	0	2.50	21.90	8.76	*	o
4	110	-10	8.90	33.70	3.79	*	o
5	170	40	13.40	30.80	2.30	*	o
6	60	-70	12.90	28.00	2.17	*	o
7	80	0	6.70	13.60	2.03	*	o
8	90	-45	17.80	35.90	2.02	*	o
9	130	-80	40.40	20.50	1.97	*	o
10	160	-60	35.00	19.60	1.79	*	o
11	150	-20	42.60	40.80	1.04	*	*
12	120	-50	43.40	44.30	1.02	*	*
13	50	-40	0.90	5.50	6.11	*	*
14	50	-30	4.60	3.10	1.48	*	*

$d = 2.0\mu\text{m}$, $L = 2.67\mu\text{m}$, $L \cdot \Delta n = 0.267\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 30

No.	P	A	I+	I-	CR	T	R
1	50	-50	0.50	20.90	41.80	o	o
2	110	60	29.40	0.80	36.75	o	o
3	40	-60	1.00	22.50	22.50	o	o
4	100	-10	4.70	39.70	8.45	*	o
5	20	-40	22.50	3.30	6.82	*	o
6	20	70	11.70	46.80	4.00	*	o
7	90	0	7.50	28.70	3.83	*	o
8	90	-90	40.00	18.80	2.13	*	o
9	140	70	15.70	8.30	1.89	*	o
10	70	-10	11.30	19.80	1.75	*	o
11	160	-20	41.90	24.30	1.72	*	o
12	140	-40	44.40	31.70	1.40	*	o
13	100	-70	36.20	27.60	1.31	*	*
14	170	-80	19.00	18.50	1.03	*	*

$d = 2.8\mu\text{m}$, $L = 3.73\mu\text{m}$, $L \cdot \Delta n = 0.373\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 31

No.	P	A	I+	I-	CR	T	R
1	110	-10	6.40	45.90	7.17	*	o
2	60	-70	5.10	35.40	6.94	*	o
3	170	40	6.20	38.10	6.15	*	o
4	10	-90	6.40	39.00	6.09	*	o
5	100	0	6.50	38.90	5.98	*	o
6	130	-80	44.00	8.20	5.37	*	o
7	90	-45	10.20	40.60	3.98	*	o
8	160	-60	42.40	12.10	3.50	*	o
9	140	-50	46.20	20.20	2.29	*	o
10	110	-70	39.40	18.70	2.11	*	o
11	130	60	17.70	10.20	1.74	*	o
12	80	0	15.80	27.40	1.73	*	o
13	20	-50	18.90	12.90	1.47	*	o
14	150	-20	34.70	26.80	1.29	*	*

$d = 2.0\mu\text{m}$, $L = 2.67\mu\text{m}$, $L \cdot \Delta n = 0.424\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 32

No.	P	A	I+	I-	CR	T	R
1	90	-90	11.60	0.40	29.00	o	o
2	160	-20	13.60	2.00	6.80	*	o
3	120	-70	21.30	4.50	4.73	*	o
4	140	-40	16.30	4.20	3.88	*	o
5	80	-50	6.50	25.20	3.88	*	o
6	20	70	10.00	28.10	2.81	*	o
7	100	-10	22.30	41.50	1.86	*	o
8	160	-60	42.60	23.50	1.81	*	o
9	40	-60	25.10	42.10	1.68	*	o
10	110	60	41.40	27.30	1.52	*	o
11	90	0	36.30	47.40	1.31	*	*
12	70	-10	40.70	45.70	1.12	*	*
13	170	-80	45.70	43.40	1.05	*	*
14	140	70	42.10	40.40	1.04	*	*

$d = 4.0\mu\text{m}$, $L = 5.33\mu\text{m}$, $L \cdot \Delta n = 0.747\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 33

No.	P	A	I+	I-	CR	T	R
1	60	-60	36.70	4.30	8.53	*	o
2	140	-50	5.90	43.40	7.36	*	o
3	130	60	28.80	5.40	5.33	*	o
4	130	-80	6.80	27.00	3.97	*	o
5	160	-60	13.00	42.40	3.26	*	o
6	150	-20	10.80	27.00	2.50	*	o
7	170	40	35.20	14.20	2.48	*	o
8	20	-60	36.40	20.80	1.75	*	o
9	90	-45	33.40	24.10	1.39	*	o
10	50	-10	23.80	20.80	1.14	*	*
11	80	0	39.00	43.40	1.11	*	*
12	10	-90	45.50	43.20	1.05	*	*
13	100	0	45.60	43.40	1.05	*	*
14	110	-10	43.00	43.30	1.01	*	*

$d = 6.0\mu\text{m}$, $L = 8.00\mu\text{m}$, $L \cdot \Delta n = 1.120\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 34

No.	P	A	I+	I-	CR	T	R
1	100	0	0.20	11.10	55.50	o	o
2	20	-70	0.70	28.30	40.43	o	o
3	60	0	16.80	1.90	8.84	*	o
4	130	-80	40.10	10.00	4.01	*	o
5	60	-70	14.60	43.30	2.97	*	o
6	160	-60	33.10	12.80	2.59	*	o
7	110	-30	22.60	10.20	2.22	*	o
8	100	-45	26.80	12.30	2.18	*	o
9	170	40	14.60	22.50	1.54	*	o
10	150	-20	43.90	38.30	1.15	*	*
11	160	-90	9.50	0.20	47.50	*	o

$d = 2.0\mu\text{m}$, $L = 2.12\mu\text{m}$, $L \cdot \Delta n = 0.212\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 35

No.	P	A	I+	I-	CR	T	R
1	40	-60	0.20	47.30	236.50	o	o
2	20	-80	0.70	28.80	41.14	o	o
3	60	-40	0.70	28.80	41.14	o	o
4	170	-80	13.60	7.10	1.92	*	o
5	110	60	29.70	45.00	1.52	*	o
6	140	70	13.60	20.50	1.51	*	o
7	160	-20	45.30	40.10	1.13	*	*
8	90	-90	45.20	40.70	1.11	*	*

$d = 2.8\mu\text{m}$, $L = 2.96\mu\text{m}$, $L \cdot \Delta n = 0.296\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 36

No.	P	A	I+	I-	CR	T	R
1	40	-60	0.60	45.40	75.67	o	o
2	100	0	0.60	13.20	22.00	o	o
3	10	-90	0.60	13.20	22.00	o	o
4	130	-80	44.40	9.10	4.88	*	o
5	130	60	16.20	36.60	2.26	*	o
6	170	40	8.10	18.30	2.26	*	o
7	90	-45	11.30	8.20	1.38	*	o
8	150	-20	38.40	33.10	1.16	*	*
9	20	-20	39.40	42.00	1.07	*	*

$d = 2.0\mu\text{m}$, $L = 2.12\mu\text{m}$, $L \cdot \Delta n = 0.337\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 37

No.	P	A	I+	I-	CR	T	R
1	120	-60	24.80	40.00	1.61	*	o
2	140	-40	25.20	40.60	1.61	*	o
3	160	-20	26.50	42.10	1.59	*	o
4	90	-90	26.70	42.00	1.57	*	o
5	110	60	46.70	36.70	1.27	*	*
6	100	-10	7.30	0.30	24.33	*	*

$d = 4.0\mu\text{m}$, $L = 4.24\mu\text{m}$, $L \cdot \Delta n = 0.593\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 38

No.	P	A	I+	I-	CR	T	R
1	90	-10	28.90	1.60	18.06	o	o
2	80	0	28.90	2.70	10.70	o	o
3	150	-20	15.00	35.90	2.39	*	o
4	90	-45	18.50	8.90	2.08	*	o
5	170	40	24.70	18.40	1.34	*	o
6	130	60	38.50	34.30	1.12	*	*
7	20	-60	42.70	38.90	1.10	*	*
8	130	-80	10.90	10.10	1.08	*	*
9	60	-60	36.70	38.10	1.04	*	*

$d = 6.0\mu\text{m}$, $L = 6.35\mu\text{m}$, $L \cdot \Delta n = 0.889\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 39

No.	P	A	I+	I-	CR	T	R
1	50	-40	0.70	36.50	52.14	o	o
2	140	60	3.60	39.00	10.83	o	o
3	150	-50	44.60	12.00	3.72	*	o
4	150	-20	44.20	13.20	3.35	*	o
5	170	40	15.50	37.60	2.43	*	o
6	160	-90	8.80	19.00	2.16	*	o
7	110	-30	23.60	12.90	1.83	*	o
8	60	0	16.00	27.00	1.69	*	o
9	20	-10	39.40	45.60	1.16	*	*
10	100	-45	27.90	29.50	1.06	*	*
11	130	-80	39.50	38.20	1.03	*	*

$d = 2.0\mu\text{m}$, $L = 1.89\mu\text{m}$, $L \cdot \Delta n = 0.189\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 40

No.	P	A	I+	I-	CR	T	R
1	40	-60	0.40	28.60	71.50	o	o
2	60	-40	0.70	47.10	67.29	o	o
3	140	-40	45.30	2.10	21.57	o	o
4	160	-20	45.40	11.80	3.85	*	o
5	140	70	12.60	46.00	3.65	*	o
6	90	-60	27.90	44.70	1.60	*	o
7	110	60	28.20	35.80	1.27	*	*
8	90	-90	45.90	40.60	1.13	*	*

$d = 2.8\mu\text{m}$, $L = 2.65\mu\text{m}$, $L \cdot \Delta n = 0.265\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 41

No.	P	A	I+	I-	CR	T	R
1	40	-60	0.80	29.10	36.38	o	o
2	160	-60	37.00	1.70	21.76	o	o
3	150	-20	39.30	7.80	5.04	*	o
4	170	40	10.40	46.10	4.43	*	o
5	90	-45	13.70	40.10	2.93	*	o
6	130	60	14.90	43.10	2.89	*	o
7	130	-80	43.20	32.60	1.33	*	o
8	90	-80	40.20	44.50	1.11	*	*
9	10	-70	7.30	3.80	1.92	*	*

$d = 2.0\mu\text{m}$, $L = 1.89\mu\text{m}$, $L \cdot \Delta n = 0.301\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 42

No.	P	A	I+	I-	CR	T	R
1	170	-80	30.50	0.30	101.67	o	o
2	20	70	1.30	34.40	26.46	o	o
3	140	70	36.20	2.40	15.08	o	o
4	40	-30	36.20	2.40	15.08	o	o
5	100	-30	3.20	35.10	10.97	o	o
6	160	-70	39.90	5.60	7.13	*	o
7	110	60	44.20	7.20	6.14	*	o
8	100	-10	5.30	19.20	3.62	*	o
9	100	-60	17.40	47.50	2.73	*	o
10	140	-40	25.30	40.10	1.58	*	o
11	90	-90	31.10	42.10	1.35	*	o

$d = 4.0\mu\text{m}$, $L = 3.79\mu\text{m}$, $L \cdot \Delta n = 0.531\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 43

No.	P	A	I+	I-	CR	T	R
1	10	-70	31.20	1.60	19.50	o	o
2	100	0	31.40	2.70	11.63	o	o
3	30	-70	34.40	12.10	2.84	*	o
4	80	-80	17.80	43.20	2.43	*	o
5	150	-20	4.60	10.10	2.20	*	o
6	130	-80	20.00	34.50	1.73	*	o
7	90	-45	28.40	39.50	1.39	*	o
8	170	40	33.00	45.10	1.37	*	o
9	60	-40	44.70	44.20	1.01	*	*
10	130	60	41.50	41.60	1.00	*	*

$d = 6.0\mu\text{m}$, $L = 5.68\mu\text{m}$, $L \cdot \Delta n = 0.796\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 44

No.	P	A	I+	I-	CR	T	R
1	100	0	1.30	15.90	12.23	o	o
2	90	-10	1.30	15.90	12.23	o	o
3	10	-70	3.80	21.70	5.71	*	o
4	140	60	3.20	12.80	4.00	*	o
5	160	-90	9.20	29.40	3.20	*	o
6	170	40	15.60	5.80	2.69	*	o
7	60	0	16.00	32.90	2.06	*	o
8	100	-45	28.30	18.00	1.57	*	o
9	150	-20	44.40	31.00	1.43	*	o
10	110	-30	24.50	19.80	1.24	*	*
11	130	-80	39.10	41.80	1.07	*	*
12	140	-60	44.70	47.30	1.06	*	*
13	20	-20	31.35	31.40	1.00	*	*
14	30	-70	0.80	8.20	10.25	*	o

$d = 2.0\mu\text{m}$, $L = 1.60\mu\text{m}$, $L \cdot \Delta n = 0.160\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 45

No.	P	A	I+	I-	CR	T	R
1	40	-60	0.20	14.00	70.00	o	o
2	60	-40	0.20	14.00	70.00	o	o
3	10	-90	1.70	26.40	15.53	o	o
4	90	0	3.10	32.40	10.45	o	o
5	100	-10	3.30	21.80	6.61	*	o
6	70	-10	6.50	34.20	5.26	*	o
7	40	-40	5.20	23.30	4.48	*	o
8	170	-80	13.00	42.60	3.28	*	o
9	90	-90	44.40	15.10	2.94	*	o
10	140	70	11.60	31.60	2.72	*	o
11	140	-40	46.30	29.40	1.57	*	o
12	160	-60	35.80	46.50	1.30	*	*
13	110	60	26.60	33.00	1.24	*	*
14	20	70	13.30	15.40	1.16	*	*

$d = 2.8\mu\text{m}$, $L = 2.24\mu\text{m}$, $L \cdot \Delta n = 0.224\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 46

No.	P	A	I+	I-	CR	T	R
1	10	-90	2.20	31.40	14.27	o	o
2	100	0	2.30	31.40	13.65	o	o
3	100	-10	3.00	25.80	8.60	*	o
4	80	0	8.80	41.90	4.76	*	o
5	20	-60	7.50	35.10	4.68	*	o
6	150	-20	39.90	12.50	3.19	*	o
7	110	-10	6.30	20.00	3.17	*	o
8	130	60	13.10	33.70	2.57	*	o
9	120	-60	44.80	19.40	2.31	*	o
10	90	-45	14.20	8.30	1.71	*	o
11	170	40	10.20	6.80	1.50	*	o
12	130	-80	42.40	34.60	1.23	*	*
13	160	-60	37.70	43.60	1.16	*	*
14	20	-20	35.60	31.50	1.13	*	*

$d = 2.0\mu\text{m}$, $L = 1.60\mu\text{m}$, $L \cdot \Delta n = 0.254\mu\text{m}$, $\lambda = 0.38 \text{ to } 0.78\mu\text{m}$

Table 47

No.	P	A	I+	I-	CR	T	R
1	90	-90	27.30	1.40	19.50	o	o
2	100	-80	27.90	2.20	12.68	o	o
3	20	70	4.80	36.90	7.69	*	o
4	160	-20	29.20	4.20	6.95	*	o
5	100	-10	8.50	46.00	5.41	*	o
6	120	-60	30.60	6.40	4.78	*	o
7	60	-40	10.00	41.60	4.16	*	o
8	40	-60	10.00	41.50	4.15	*	o
9	140	-40	31.60	7.80	4.05	*	o
10	110	60	41.30	17.70	2.33	*	o
11	90	0	20.60	46.40	2.25	*	o
12	70	-10	26.90	41.40	1.54	*	o
13	170	-80	35.00	37.50	1.07	*	*
14	140	70	31.80	32.60	1.03	*	*

$d = 4.0\mu\text{m}$, $L = 3.20\mu\text{m}$, $L \cdot \Delta n = 0.448\mu\text{m}$, $\lambda = 0.38 \text{ to } 0.78\mu\text{m}$

Table 48

No.	P	A	I+	I-	CR	T	R
1	150	-20	1.90	24.70	13.00	o	o
2	130	60	44.20	10.00	4.42	*	o
3	160	-30	8.20	26.60	3.24	*	o
4	20	-60	45.30	23.30	1.94	*	o
5	60	-20	45.30	23.40	1.94	*	o
6	110	-10	26.10	39.70	1.52	*	o
7	90	-45	14.40	21.30	1.48	*	o
8	160	-60	29.70	43.50	1.46	*	o
9	170	40	17.80	12.40	1.44	*	o
10	130	-80	21.80	28.70	1.32	*	*
11	100	0	39.60	41.80	1.06	*	*
12	80	0	45.90	43.70	1.05	*	*
13	10	-90	39.60	41.50	1.05	*	*
14	90	-80	1.30	4.40	3.38	*	*

$d = 6.0\mu\text{m}$, $L = 4.80\mu\text{m}$, $L \cdot \Delta n = 0.672\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 49

No.	P	A	I+	I-	CR	T	R
1	40	-60	0.90	42.50	47.22	o	o
2	60	-40	0.40	18.20	45.50	o	o
3	100	-10	0.90	24.80	27.56	o	o
4	110	-70	44.10	3.00	14.70	o	o
5	90	0	2.90	23.60	8.14	*	o
6	20	70	9.50	24.10	2.54	*	o
7	140	-40	44.60	24.10	1.85	*	o
8	90	-90	44.40	24.40	1.82	*	o
9	140	70	14.50	9.70	1.49	*	o
10	170	-80	14.70	20.90	1.42	*	o
11	120	-30	24.80	21.60	1.15	*	*
12	110	60	30.80	31.20	1.01	*	*
13	80	-20	0.30	9.80	32.67	o	o
14	70	-10	7.60	7.80	1.03	*	*

$d = 2.8\mu\text{m}$, $L = 3.15\mu\text{m}$, $L \cdot \Delta n = 0.315\mu\text{m}$, $\lambda = 0.38$ to $0.78\mu\text{m}$

Table 50

No.	P	A	I+	I-	CR	T	R
1	40	-60	0.40	16.50	41.25	o	o
2	60	-40	1.20	40.80	34.00	o	o
3	90	0	1.90	23.90	12.58	o	o
4	100	-10	2.00	21.50	10.75	o	o
5	70	-10	6.50	42.50	6.54	*	o
6	140	-40	45.20	11.20	4.04	*	o
7	140	70	12.70	46.20	3.64	*	o
8	70	-60	12.70	31.70	2.50	*	o
9	170	-80	12.00	24.80	2.07	*	o
10	150	-60	41.20	21.30	1.93	*	o
11	90	-90	45.70	24.20	1.89	*	o
12	120	-40	35.60	23.30	1.53	*	o
13	20	70	12.20	18.50	1.52	*	o
14	110	60	27.50	23.80	1.16	*	*

$d = 2.8\mu\text{m}$, $L = 2.52\mu\text{m}$, $L \cdot \Delta n = 0.252\mu\text{m}$, $\lambda = 0.38 \text{ to } 0.78\mu\text{m}$



CLAIMS:

1. A liquid crystal electrooptical element comprising:
5 a pair of substrates (5) positioned between a pair of polarizing plates (7),
electrodes (4) and alignment films (2) disposed on the respective opposing inside surfaces of said substrates (5), the alignment films having undergone rubbing, and
10 a chiral nematic liquid crystal (21) sandwiched between said pair of substrates (5), wherein
the helical pitch of the chiral nematic liquid crystal is adjusted such that the twist angle in the initial state before applying a voltage is roughly equal to the angle Φ_r
15 which is formed by the respective rubbing directions on the alignment films (2),
the pretilt angles formed in said initial state by the director vector of the liquid crystal molecules in contact with each alignment film (2) and the substrate surfaces have
20 mutually opposing signs,
the chiral nematic liquid crystal (21) relaxes to one of two metastable states after applying a pulse voltage to said initial state, the twist angles in the metastable states being roughly $(\Phi_r + 180^\circ)$ and roughly $(\Phi_r - 180^\circ)$, respectively,
25 vely, and
the respective angles P, A formed by the polarization axis of each polarizing plate (7) and one of the rubbing directions are both set according to the values of the product R ($R = d \cdot \Delta n$) of the thickness d (μm) and the apparent Δn
30 of the chiral nematic liquid crystal layer and of Φ_r so that the contrast ratio between said metastable states is 2 or greater.
2. The element of claim 1 wherein the contrast ratio
35 is 2 or greater in a reflective type element.



3. The element of claim 1 wherein the contrast ratio is 10 or greater in a transmission type element.

4. The element of claim 1 wherein $90^\circ \leq \Phi r \leq 270^\circ$.

5. The element of claim 1 wherein $160^\circ \leq \Phi r \leq 200^\circ$.

6. The element of claim 1 wherein Φr is roughly 180° .

10 7. The element of claim 1 wherein the helical pitch p_0 and the thickness d of the liquid crystal layer satisfy the relation $0.8 \Phi r/360^\circ \leq d/p_0 \leq 1.4 \Phi r/360^\circ$.

8. The element of claim 5 wherein the absolute value
15 of the pretilt angle of the director of the liquid crystal molecules in contact with the liquid crystal alignment films is greater than or equal to 1° and less than or equal to 25° .

9. The element of claim 5 wherein the product R and
20 the angles P , A satisfy the following relationships:

(1) When $0.102 \leq R \leq 0.4$ or $0.78 \leq R \leq 0.96$,
[$P + \alpha_1 \leq A \leq P + \alpha_2$ and $-P + \beta_1 \leq A \leq -P + \beta_2$] or
[$P + \gamma_1 \leq A \leq P + \gamma_2$ and $-P + \delta_1 \leq A \leq -P + \delta_2$]

25 (2) When $0.72 \leq R \leq 0.78$,
[$P + \alpha_1 \leq A \leq P + \alpha_2$ and $-P + \beta_1 \leq A \leq -P + \beta_2$] or
[$P + \gamma_1 \leq A \leq P + \gamma_2$]

(3) When $0.40 \leq R \leq 0.72$, $0.96 \leq R \leq 0.99$,
or $1.05 \leq R \leq 1.12$,

30 [$P + \alpha_1 \leq A \leq P + \alpha_2$] or
[$P + \gamma_1 \leq A \leq P + \gamma_2$]

(4) When $0.99 \leq R \leq 1.02$,
[$P + \alpha_1 \leq A \leq P + \alpha_2$]

(5) When $1.02 \leq R \leq 1.05$,
35 [$P + \gamma_1 \leq A \leq P + \gamma_2$]

Provided:

$$\alpha_1 = -109.4 \cdot R - 133.1$$
$$-225.0$$

$$(0.102 \leq R \leq 1.02)$$

$$(1.05 \leq R \leq 1.12)$$



$$\begin{aligned}
 \alpha_2 &= -45.0, & (0.102 \leq R \leq 0.32) \\
 &6696.4 \cdot R^3 - 8720.1 \cdot R^2 + 3354.7 \cdot R - 445.0 & (0.32 \leq R \leq 0.64) \\
 &1519.0 \cdot R^3 - 4175.2 \cdot R^2 + 3568.7 \cdot R - 1087.0 & (0.64 \leq R \leq 1.02) \\
 &-333.3 \cdot R + 175.0, & (1.05 \leq R \leq 1.12) \\
 5 \quad \beta_1 &= -9114.6 \cdot R^3 + 6666.7 \cdot R^2 - 1577.1 \cdot R + 74.0 & (0.102 \leq R \leq 0.36) \\
 &-55.0 & (0.36 \leq R \leq 0.40) \\
 &-75.0 & (0.72 \leq R \leq 0.96) \\
 \beta_2 &= 9114.6 \cdot R^3 - 6666.7 \cdot R^2 + 1577.1 \cdot R - 74.0 & (0.102 \leq R \leq 0.36) \\
 &55.0 & (0.36 \leq R \leq 0.40) \\
 10 \quad &75.0 & (0.72 \leq R \leq 0.96) \\
 \gamma_1 &= 312.5 \cdot R^2 - 187.5 \cdot R - 37.0 & (0.102 \leq R \leq 0.32) \\
 &5208.3 \cdot R^3 - 7500.0 \cdot R^2 + 3341.6 \cdot R - 537.0 & (0.32 \leq R \leq 0.64) \\
 &1030.2 \cdot R^3 - 2722.0 \cdot R^2 + 2225.9 \cdot R - 684.0 & (0.64 \leq R \leq 0.99) \\
 15 \quad &0.99) \\
 &197575.9 \cdot R^3 - 626821.6 \cdot R^2 + 662332.3 \cdot R - 233217.9 & (1.02 \leq R \leq 1.12) \\
 \gamma_2 &= -625.0 \cdot R^2 + 225.0 \cdot R + 27.0 & (0.102 \leq R \leq 0.32) \\
 &7254.4 \cdot R^3 - 10245.5 \cdot R^2 + 4448.2 \cdot R - 577.0 & (0.32 \leq R \leq 0.64) \\
 20 \quad &0.64) \\
 &-558.0 \cdot R^2 + 736.6 \cdot R - 267.9 & (0.64 \leq R \leq 0.99) \\
 &-5555.5 \cdot R^2 + 11500.0 \cdot R - 6024.9 & (1.02 \leq R \leq 1.12) \\
 \delta_1 &= -6746.0 \cdot R^3 + 5571.4 \cdot R^2 - 1504.0 \cdot R + 166.9 & (0.102 \leq R \leq 0.40) \\
 &-55.6 \cdot R + 68.4 & (0.78 \leq R \leq 0.96) \\
 25 \quad \delta_2 &= 6746.0 \cdot R^3 - 5571.4 \cdot R^2 + 1504.0 \cdot R + 13.1 & (0.102 \leq R \leq 0.40) \\
 &55.6 \cdot R + 111.6 & (0.78 \leq R \leq 0.96)
 \end{aligned}$$

10. The element of claim 1 wherein at least one of the two metastable states of the liquid crystal does not satisfy the condition

$$|L| \cdot \Delta n \gg \lambda$$

where, $L = d \cdot 360^\circ / (\Phi r + 180^\circ)$ or $d \cdot 360^\circ / (\Phi r - 180^\circ)$ and λ is the wavelength of the light, and

the contrast ratio is 10 or greater.

35

11. The element of claim 10 wherein $L \cdot \Delta n$ is less than $1.88 \mu\text{m}$.



12. The element of claim 10 wherein at least one of the two metastable states is optically isotropic.

5 13. The element of claim 10, 11 or 12 wherein $90^\circ \leq \Phi_r \leq 270^\circ$.

14. The element of claim 10, 11 or 12 wherein $160^\circ \leq \Phi_r \leq 200^\circ$ and the product R and the angles P, A have
10 the following relationship:

(1) When $0.1 \leq R \leq 0.22$,

$$A = P + \alpha, \text{ where } \alpha = -82 \cdot R + \alpha_1$$

(2) When $0.22 < R \leq 0.42$,

$$A = P + \alpha, \text{ where } \alpha = -82 \cdot R + \alpha_1, \text{ or}$$

15 $A = -P + \beta_1$

(3) When $0.42 < R \leq 0.44$,

$$A = P + \alpha, \text{ where } \alpha = -137.5 \cdot R + \alpha_2, \text{ or}$$

$$A = -P + \beta_1$$

(4) When $0.44 < R < 0.473$,

20 $A = P + \gamma, \text{ where } -137.5 \cdot R - 75 \leq \gamma \leq -60$

(5) When $0.473 \leq R \leq 0.7$,

$$A = P + \alpha, \text{ where } \alpha = -137.5 \cdot R + \alpha_2, \text{ or}$$

$$A = P + \alpha_3$$

(6) When $0.7 < R \leq 1.06$,

25 $A = -P + \beta_1$

However,

$$-99^\circ \leq \alpha_1 \leq -58^\circ \quad -75^\circ \leq \alpha_2 \leq -35^\circ$$

$$-100^\circ \leq \alpha_3 \leq -60^\circ \quad 70^\circ \leq \beta_1 \leq 110^\circ$$

30 15. The element of claim 10, 11 or 12 wherein Φ_r is roughly 180° and the product R and the angles P, A have the following relationship:

(1) When $0.1 \leq R \leq 0.22$,

$$A = P + \alpha, \text{ where } \alpha = -82 \cdot R + \alpha_1$$

35 (2) When $0.22 < R \leq 0.42$,

$$A = P + \alpha, \text{ where } \alpha = -82 \cdot R + \alpha_1, \text{ or}$$

$$A = -P + \beta_1$$



(3) When $0.42 < R \leq 0.44$,

$A = P + \alpha$, where $\alpha = -137.5 \cdot R + \alpha_2$, or

$A = -P + \beta_1$

(4) When $0.44 < R \leq 0.7$,

5 $A = P + \alpha$, where $\alpha = -137.5 \cdot R + \alpha_2$, or

$A = P + \alpha_3$

(5) When $0.7 < R \leq 1.06$,

$A = -P + \beta_1$

However,

10 $-94^\circ \leq \alpha_1 \leq -63^\circ$ $-70^\circ \leq \alpha_2 \leq -40^\circ$

$-95^\circ \leq \alpha_3 \leq -65^\circ$ $75^\circ \leq \beta_1 \leq 105^\circ$

16. A liquid crystal display device wherein a matrix is disposed by forming each of the electrodes of the liquid crystal electrooptical element as defined in any one of the preceding claims into a scanning electrode group and a signal electrode group with pixels being formed by the intersection of the scanning electrode group and the signal electrode group.

17. The device of claim 16 wherein the angles formed by a selected side of the pixels and each of the rubbing directions are greater than or equal to 10° and less than or equal to 80° , respectively.

18. The device of claim 16 or 17 wherein one or both of the angles formed by the rubbing directions and the vertical direction of the display panel comprising said pixels is equal to or greater than -45° and less than or equal to 45° .

19. The device of any one of claims 16 to 18 wherein the light transmittance of a non-pixel area is lower than the light transmittance of pixels.

35 20. The device of claim 19 wherein a layer of light masking material is formed in the non-pixel area and in the edges of pixels.



21. The device of claim 19 wherein the thickness of the liquid crystal layer in the non-pixel area is made different from the thickness of the liquid crystal layer in the pixels in order to make the initial state in the non-pixel area different from that in the pixels.

Abstract of the Disclosure (Fig. 1):

5

LIQUID CRYSTAL ELECTROOPTICAL DEVICE

A liquid crystal electrooptical element comprises a pair of
10 substrates (5) positioned between a pair of polarizing plates
(7), electrodes (4) and alignment films (2) disposed on the
respective opposing inside surfaces of said substrates (5),
and a chiral nematic liquid crystal (21) sandwiched between
said pair of substrates (5). The liquid crystal is switched
15 between metastable states and the polarization axes of both
polarization plates (7) are set to specific angles according
to the initial state of the liquid crystal and the product of
the thickness and Δn of the liquid crystal layer, thereby to
achieve a display characteristic with a high contrast ratio
20 and a high transmittance.

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REPLACED

This Sheet Has Been Replaced



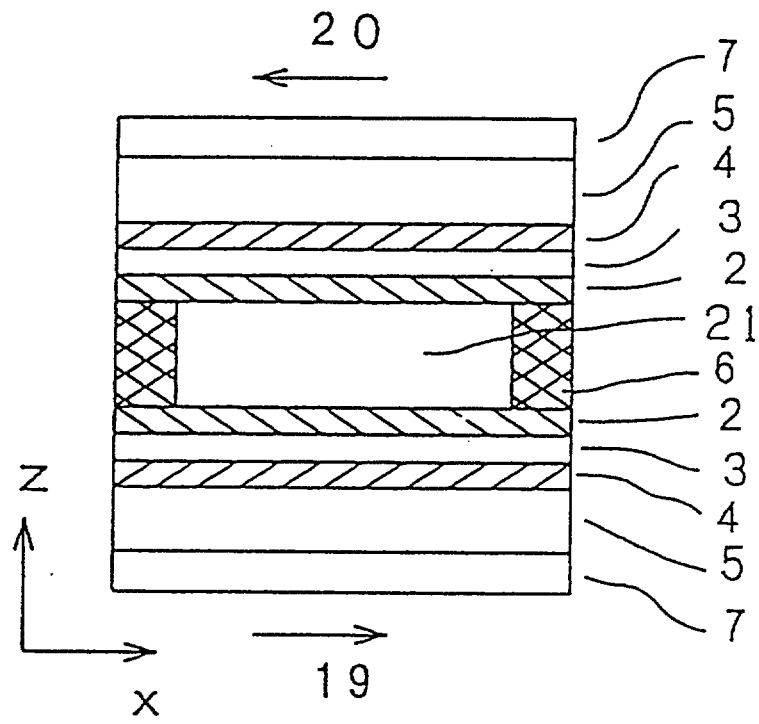


FIG. 1

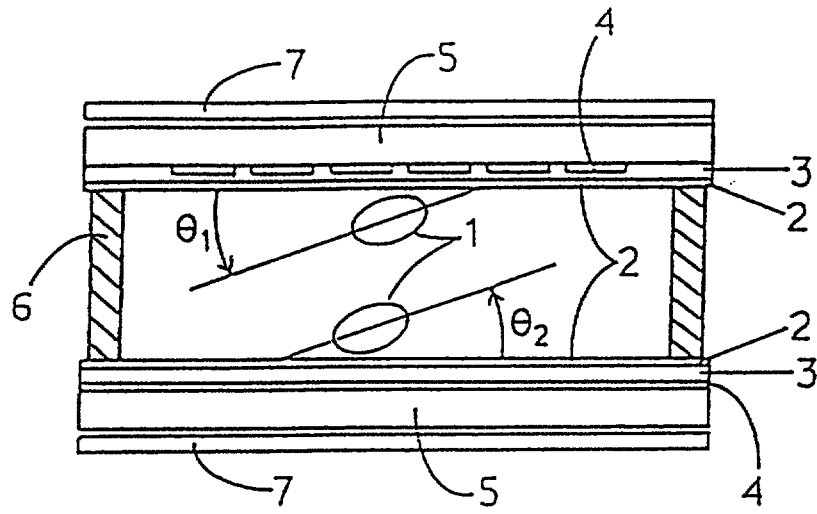


FIG. 2

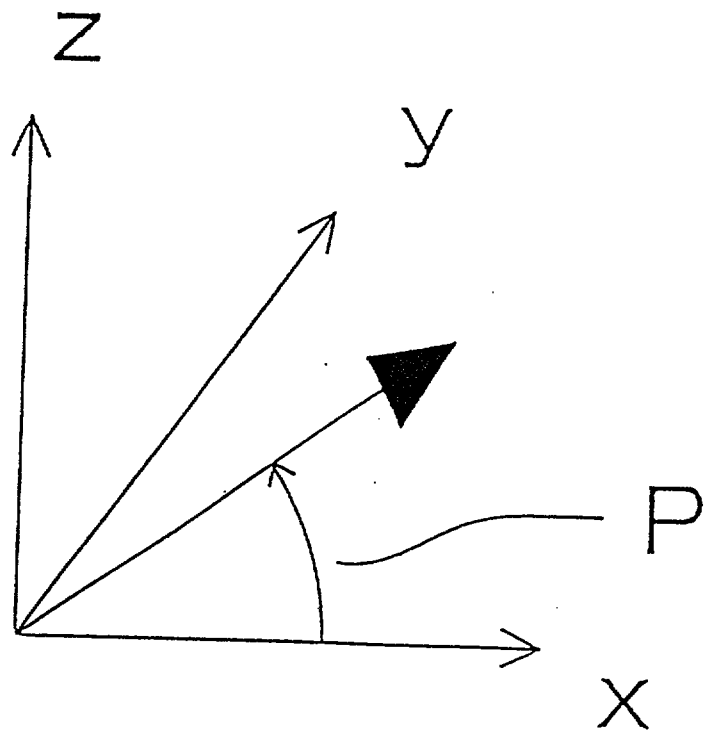


FIG. 3

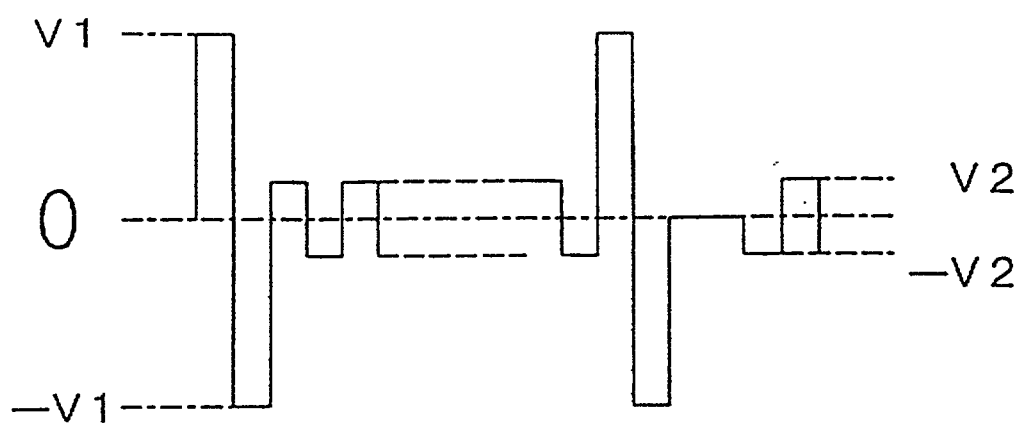


FIG. 4

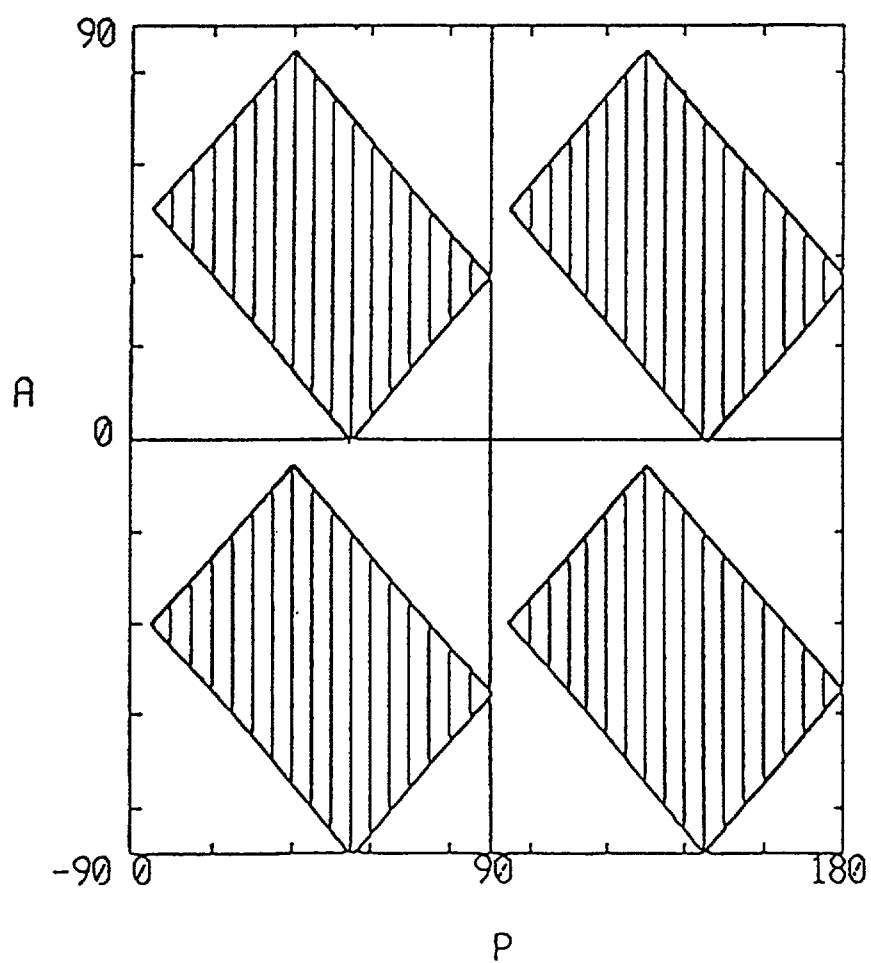


FIG. 5

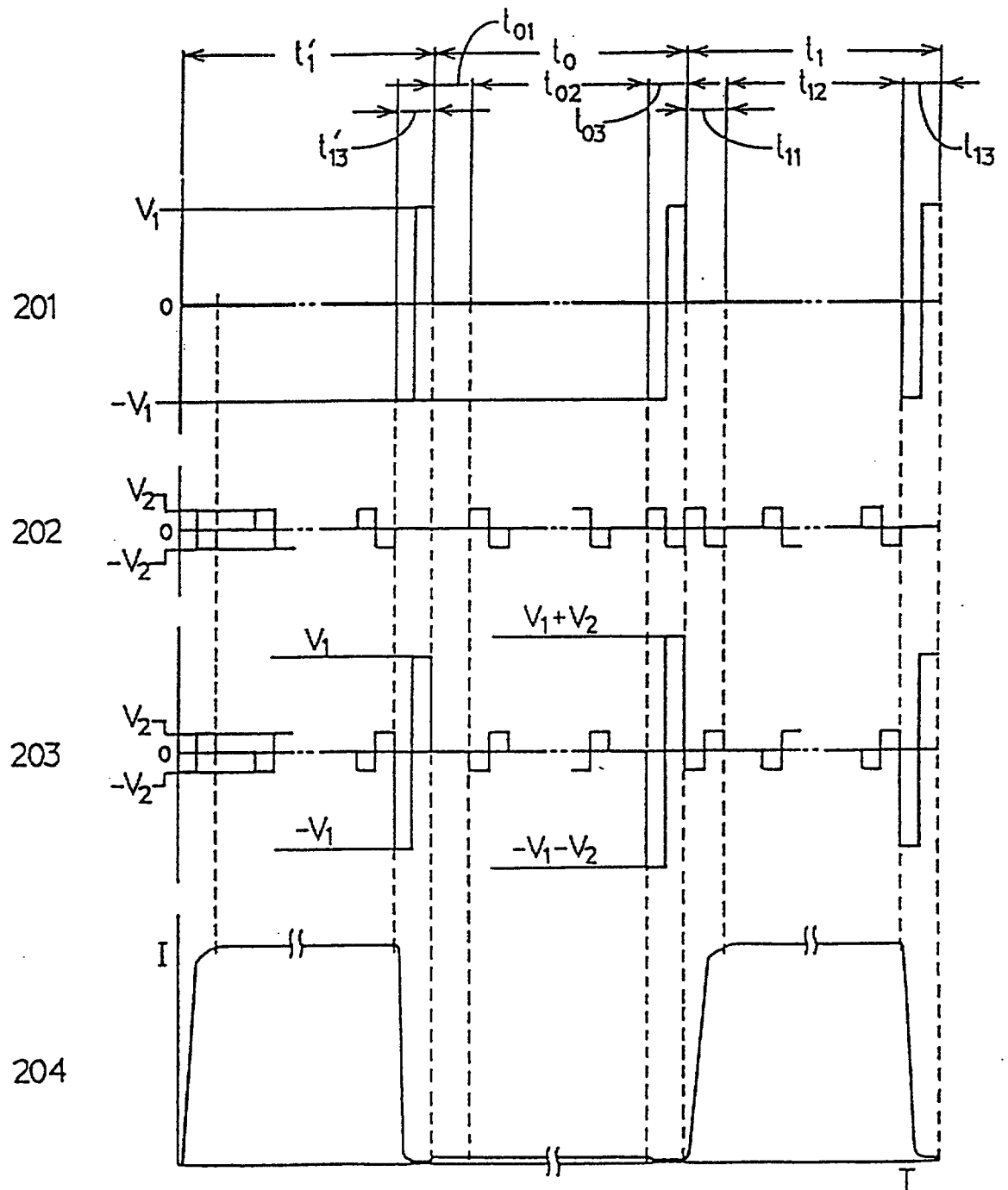


FIG. 6

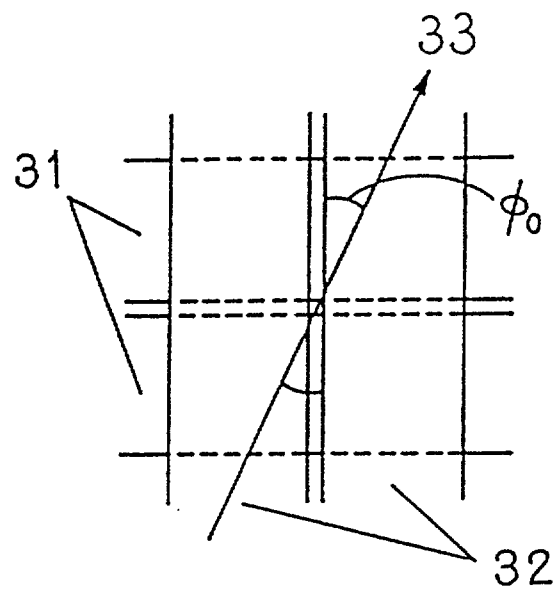


FIG. 7

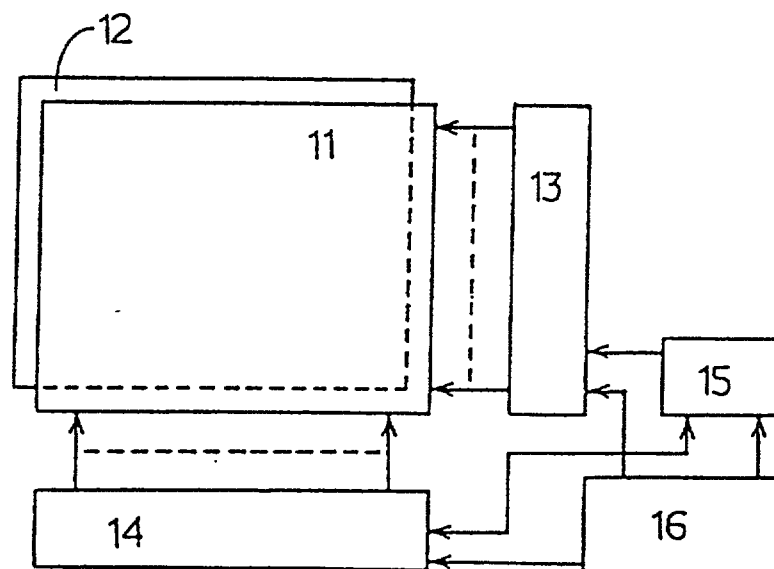


FIG. 8

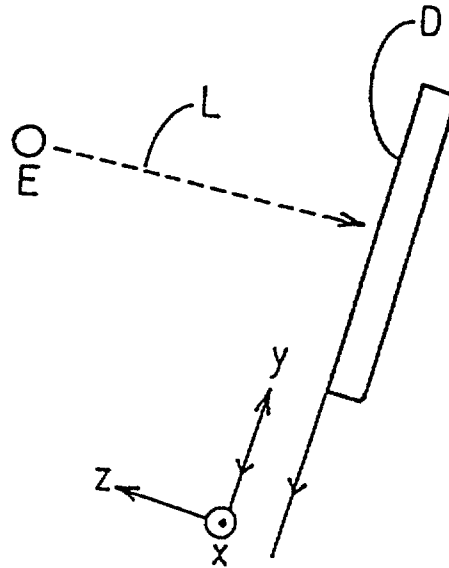


FIG. 9

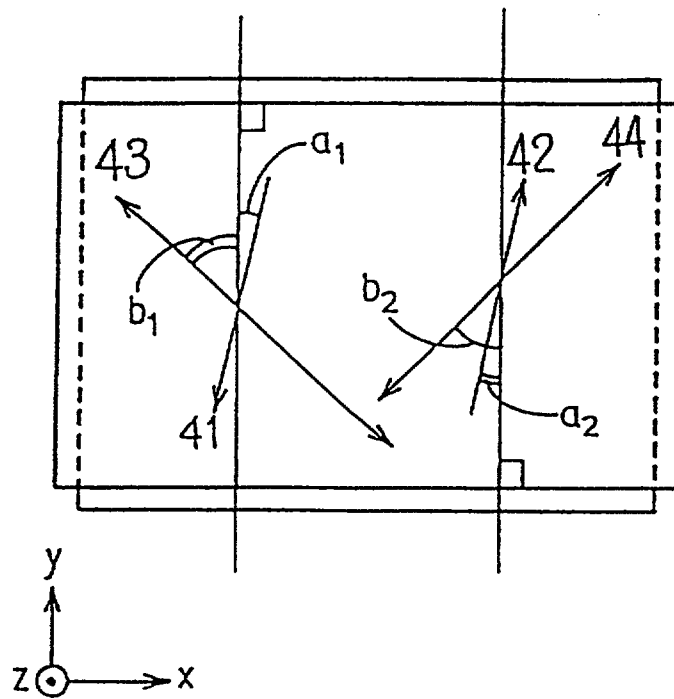


FIG. 10

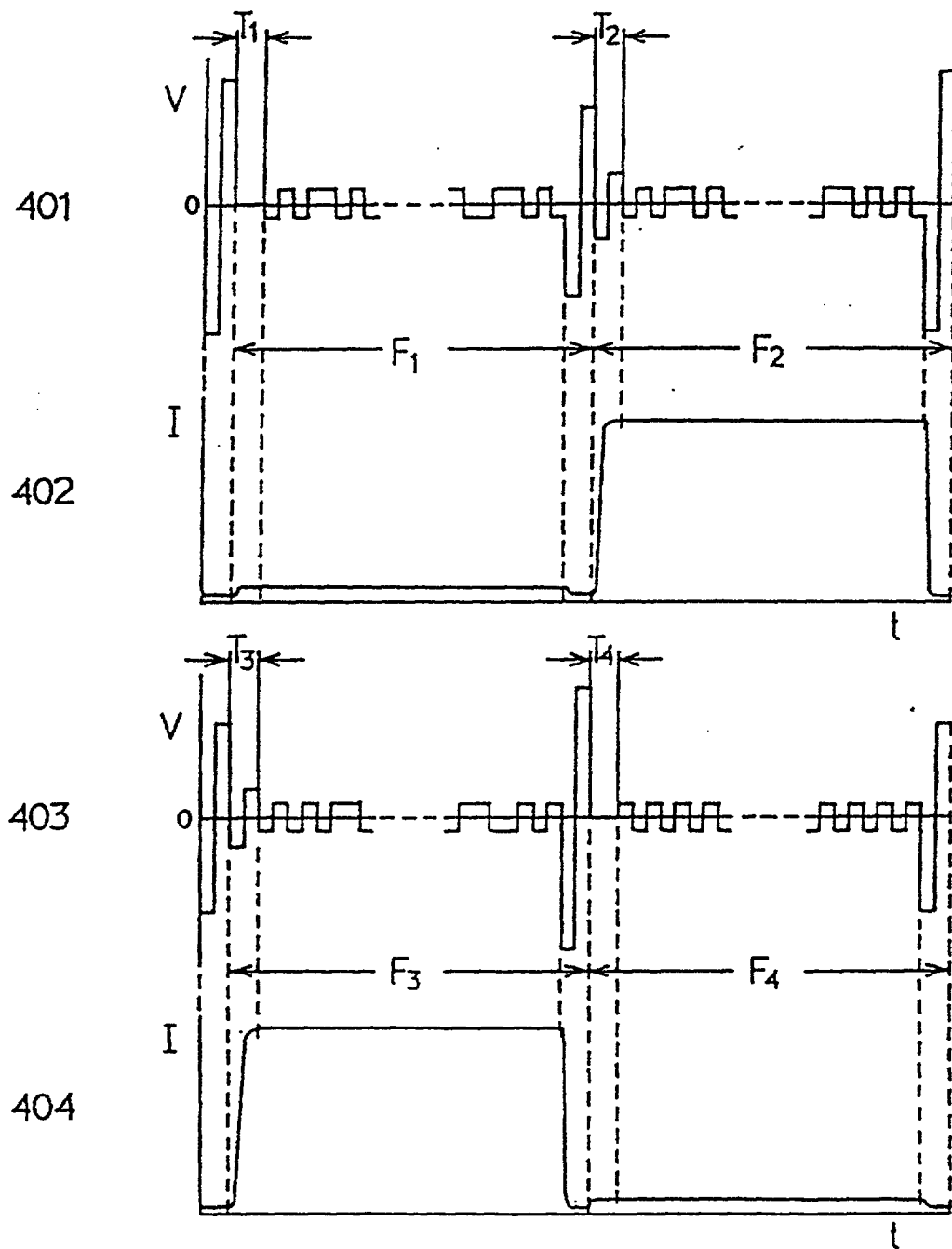


FIG. 11

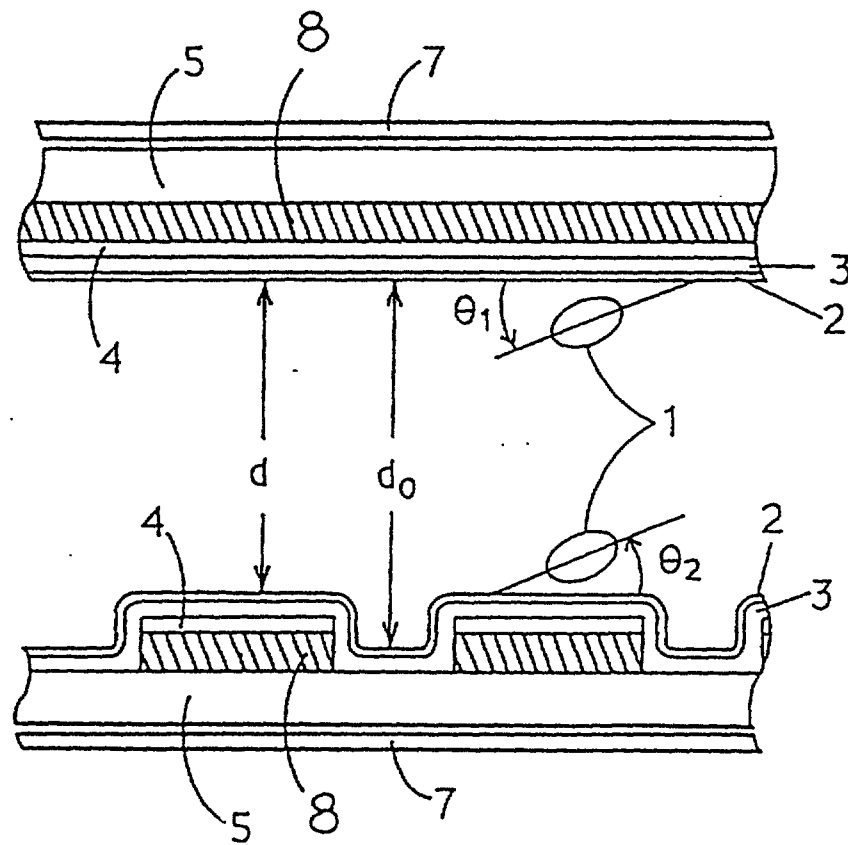


FIG. 12

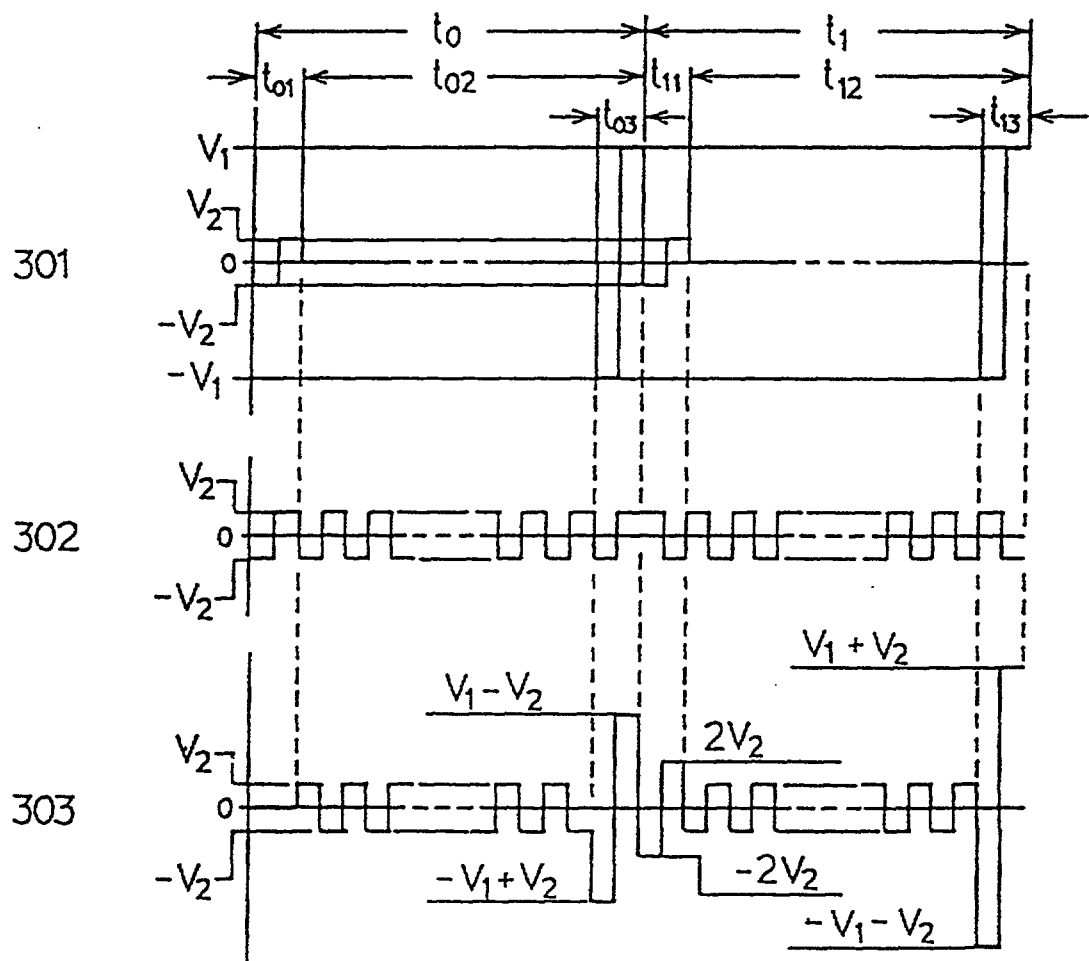


FIG. 13

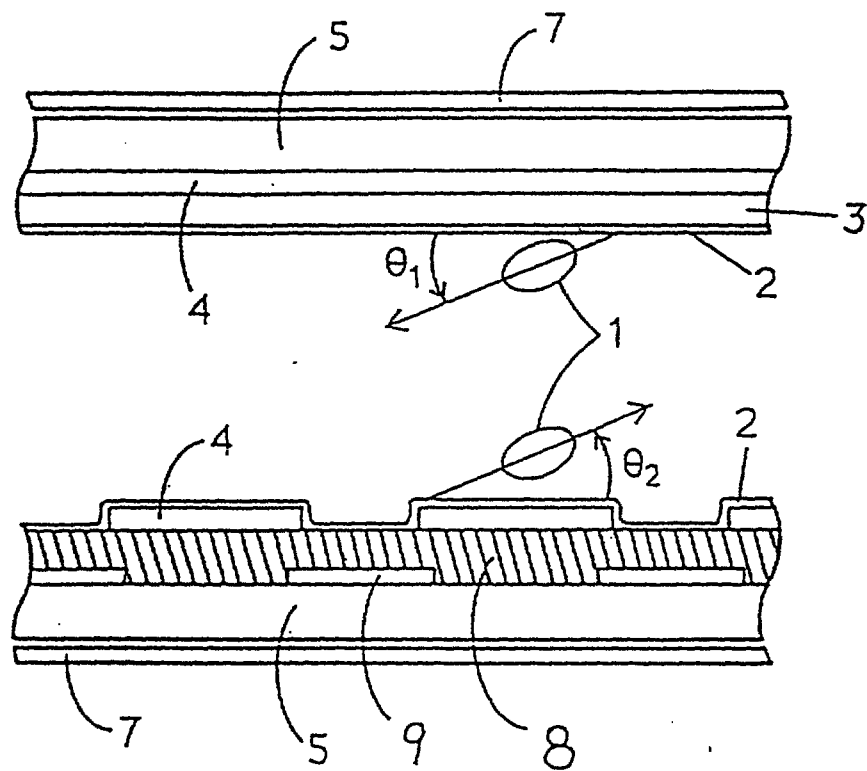


FIG. 14

Abstract of the Disclosure (Fig. 1):

5

LIQUID CRYSTAL ELECTROOPTICAL DEVICE

A liquid crystal electrooptical element comprises a pair of
10 substrates (5) positioned between a pair of polarizing plates
(7), electrodes (4) and alignment films (2) disposed on the
respective opposing inside surfaces of said substrates (5),
and a chiral nematic liquid crystal (21) sandwiched between
said pair of substrates (5). The liquid crystal is switched
15 between metastable states and the polarization axes of both
polarization plates (7) are set to specific angles according
to the initial state of the liquid crystal and the product of
the thickness and Δn of the liquid crystal layer, thereby to
achieve a display characteristic with a high contrast ratio
20 and a high transmittance.

Figure 1

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